

7. During the inspection if parts or components are found to be missing the ALFA 4 will be notified. The WCS will generate a 2-Kilo using the proper APL and order the missing items.

Cycle to the fullest extent possible to prevent deterioration. Re-preserve as required

1.6.0 Final Inspection

As Final Inspector you will perform a final inspection on all CESE leaving the mechanic shops. First, perform the prestart inspection. Before operating, make a visual inspection to ensure that all repairs were made properly, parts installed and tightened, and fluids put back in. You do not want to start up a piece of equipment or vehicle with parts or fluids missing. Then the operator operates the equipment, including attachments for at least for 15 minutes after normal temperature has been reached, to ensure the unit is dependable and safe to put back into service. If the unit is checked out, return it to Dispatch along with the Hard Card, and obtain the Dispatcher's signature and date on the 4790/2K. As Final Inspector, you also signs and dates the 4790/2K. Then enter the total time for the final inspection on the 4790/2K, and forwards the package to Cost Control if the equipment passes inspection, or to the shop supervisor if the equipment fails inspection.

Occasionally a piece of equipment or vehicle will be returned to the shop for re-work, which may be an indication of how well you are doing your job. If you do not feel the quality of work coming out of the individual shops, light, heavy, 5000, etc., is satisfactory, return the 4790/2K to the Shop Supervisor and inform the Maintenance Supervisor of the situation.

As the Final Inspector, you work directly for the Maintenance Supervisor. You are essentially his or her eyes and ears out in the shops. You should be aware how work is being performed since you see every piece of CESE that goes through the shops. You may notice an existing pattern that the Maintenance Supervisor may need to be aware of so it can be corrected. The Maintenance Supervisor should evaluate any problems preventing work from being performed satisfactorily. Maybe someone needs additional training in an area in order to correct a deficiency. So keeping the Maintenance Supervisor informed of any shortcomings within the mechanic shops is necessary to ensure the shops are operating efficiently.

2.0.0 CRANE INSPECTOR

The Crane Inspector should be the most knowledgeable and conscientious mechanic available within the unit. In addition to the regular CESE inspection requirements, the weight-handling equipment inspection will place primary emphasis on the safety of all load-bearing, load-controlling parts and safety devices for safe and sound working conditions.

2.1.0 NCF Weight Handling Equipment (WHE) Program

The Crane Inspector, although an integral component, is not the only individual responsible for the safe operation of the Weight Handling Equipment (WHE). The Crane Inspector is a member of a team of knowledgeable and skillful operators and mechanics that cooperatively ensure all procedures are followed in support of the weight handling equipment program. The weight handling program within the Navy is taken very seriously and carries a #1 priority status. Everyone within the program must be proficient and competent. *Figure 3-4* shows the weight handling program organization.

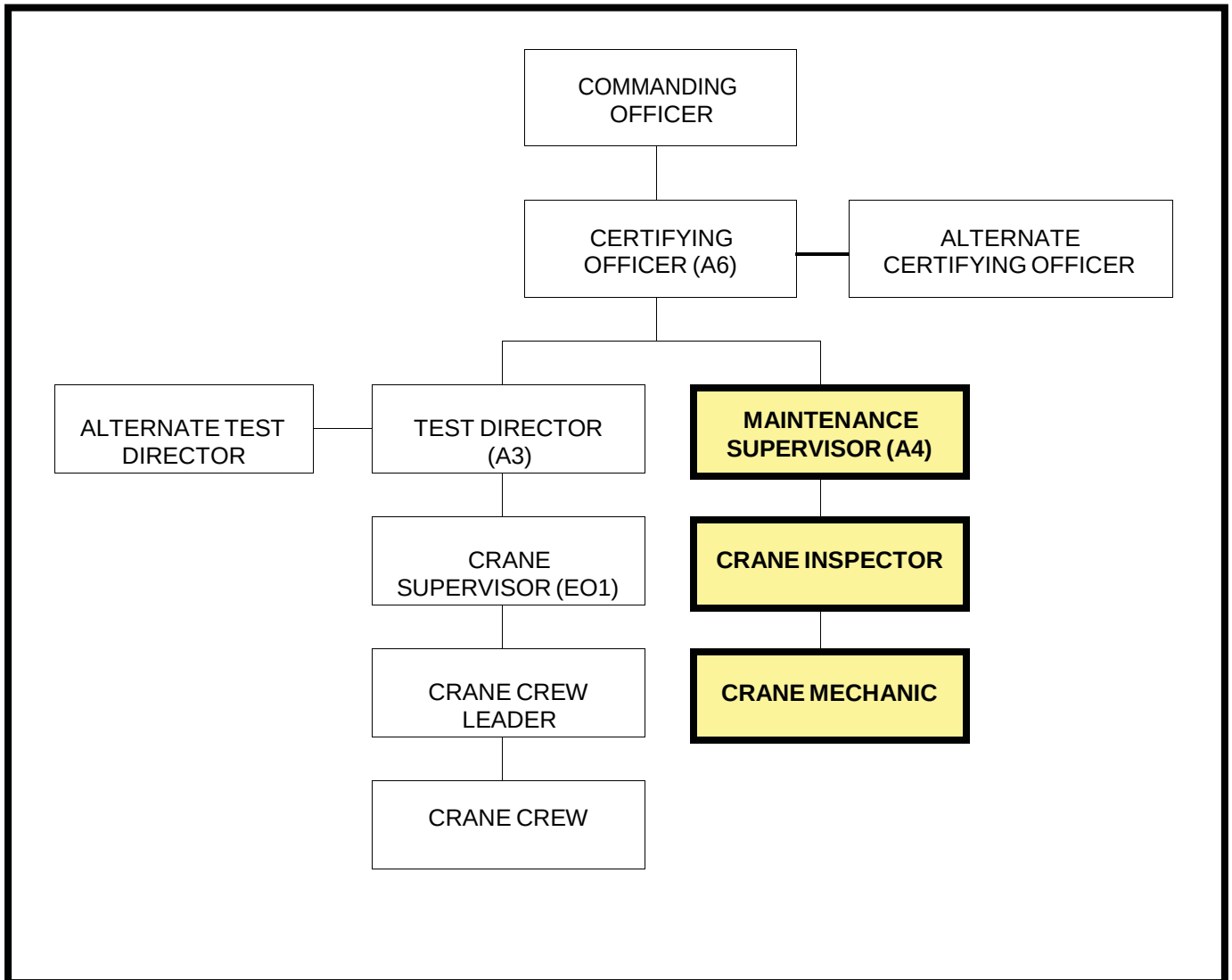


Figure 3-4 - Weight Handling Program organization.

2.1.1 Commanding Officer

The Commanding Officer will designate in writing the Certifying Officer and alternates, who normally are the ALFA Company Commander and the ALFA Company Chief respectively. The CO will also designate in writing the official and organization responsible for the management and administration of the program for instructing, testing, and licensing of operators.

2.1.2 Certifying Officer (A6)

The Certifying Officer will appoint in writing the Test Director (normally the ALFA Company Operations Chief [A3]), the Crane Crew Supervisor (to control and manage the unit's WHE Program), the **Crane Inspector** and mechanic(s), the Crane Performance Test Examiner, instructors, and all alternates for the WHE Program, along with performing the following duties:

- Ensure all WHE is maintained, serviced, tested, and certified by cognizant authority per applicable directives and that all safety and operating procedures outlined in all applicable directives are strictly enforced.
- Serve as the chairperson for all WHE Mishap Investigation Boards and appoint, in writing, other members or advisors as required.
- Sign WHE certification documents after successful completion of condition inspections, stability tests, load tests, other appropriate proof tests, and review the certification signatures of the test director, inspector, and test personnel. Withhold certification, pending correction of all deficiencies existing after inspections, load tests, or other appropriate proof tests which, in his or her judgment, could cause unsafe conditions.
- In an emergency or contingency condition, request concurrence from the Commanding Officer to extend the certification period of a crane. The P-307, Section 1 provides an "exception rule" for units of the NCF and SOU from compliance which will preclude the execution of their wartime tasking in strictly military unique operation.
- Authorize the extension or adjustment of a prescribed maintenance inspection, lubrication, or service. All authorizations for extension or adjustment must be in writing and placed in the equipment history file.
- Approve all crane operations and maintenance SOPs for the Battalion's WHE program. It is important to review any existing SOPs to ensure all items still apply.
- Exhaust all efforts to retain the primary crane crew personnel as their primary assignment throughout the Battalion's homeport/deployment cycle and preferably 24 consecutive months during a full tour of duty.
- Ensure hands-on training is properly documented into each crane crewmember's license record. Selection to the crane crew should be accomplished a minimum of seven months prior to the upcoming deployment.

2.1.3 Equipment Maintenance Supervisor (A4)

The Equipment Maintenance Supervisor will be responsible for overseeing all WHE condition inspections, and documenting the results on inspection reports, equipment repair orders, and other pertinent documents, and perform the following duties:

- Ensure all discrepancies and repair actions are fully documented, obtaining all signatures required to complete a given action.
- Request from the WHE organization any and all approvals required for alterations/modifications to weight handling equipment. Provide information as required to the appropriate member(s) for preparation of alteration/modification. Provide information package to WHE organization for all alteration/modification packages.

- Maintain specification data sheets and brake specification data sheets.
- Maintain cranes by calendar month as outlined in the NAVFAC P-307 for type A, B, and C inspections.

2.1.4 Crane Test Director (A3)

The Crane Test Director is normally the ALFA Company Operations Chief (A3) who will ensure only fully qualified and properly licensed personnel operate WHE and only fully qualified personnel rig all loads to be lifted or moved by the crane and rigging crews along with performing the following duties:

- Serve as primary member of the WHE Mishap Investigation Board.
- Perform inspections and test procedures, and establish test criteria for all WHE.
- Be responsible for Navy Crane Center liaison, long-shoring certificates, and planned or scheduled modifications.

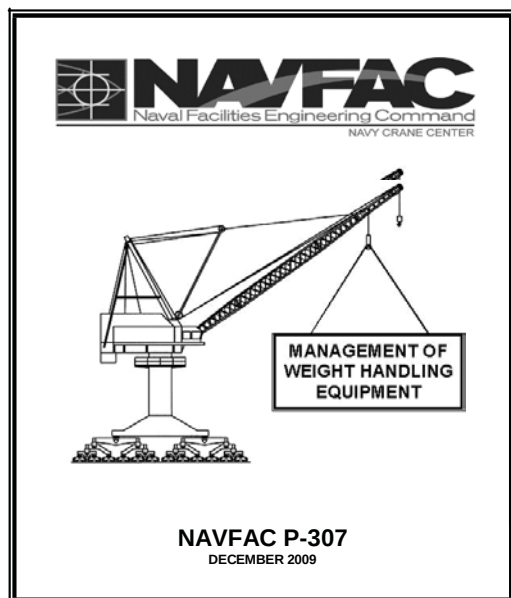
2.1.5 Crane Crew Supervisor

The Crane Crew Supervisor, who is normally an EO1, is responsible for the overall safe operation of cranes, and schedules all work, taking into consideration the availability of equipment, operators, riggers, workload, and safe operating practices. This supervisor also has the following responsibilities:

- Stop crane operations immediately if unsafe acts or conditions are observed. Suspend all operations at the request of the crane operators until conditions can be checked, improved, or corrected.
- Conduct a pre-job briefing for all special or critical lifts with specific attention to safety, equipment required, and procedures.
- Ensure all required daily services and inspections are conducted and documented.
- Conduct and/or arrange for all proficiency and competency training for the crane crews.
- Immediately notify the Safety Office and the WHE Chain of Command of all mishaps.
- Periodically inspect cranes for good housekeeping and sanitation practices.
- Review SOP(s) prior to authorizing any complex lifts. If such a lift is authorized, he or she should be present throughout the duration of the lift.
- Be thoroughly familiar with and ensure compliance with all requirements of all instructions, manuals, and applicable regulations.
- Ensure that immediate action is taken to correct safety deficiencies noted during daily inspections. When deficiencies cannot be corrected immediately, the crane should be removed from service until corrections have been accomplished before the equipment is returned to service (re-certified if required).
- Ensure that cranes which have not been properly certified as required by NAVFAC P-307 are not assigned to crane operations, and are tagged out of service.
- Maintain a crane equipment history file (24-part) in accordance with NAVFAC P-307.

2.2.1 NAVFAC P-307, Management of Weight Handling Equipment

The Crane Inspector should become thoroughly knowledgeable of the NAVFAC P-307, *Management of Weight Handling Equipment* (Figure 3-5). This publication provides the uniform Navy program for the management, maintenance, inspection, testing, certification, alteration, repair, and operation of weight handling equipment (WHE) at Navy shore installations. Its purposes are to ensure the equipment is safe to operate, to ensure weight handling operations are conducted safely and efficiently, and to ensure optimum equipment service life.



The P-307 provides requirements for the maintenance, inspection, test, certification, repair, alteration, operation, and/or use of weight handling equipment (WHE) under the technical cognizance of the Naval Facilities Engineering Command (NAVFAC). Activities covered include Navy shore activities, the Naval Construction Force (NCF), Naval Special Operating Units (SOU), and the Naval Construction Training Center (NCTC). These criteria are the minimum requirements for all applicable equipment. The P-307 meets or exceeds all applicable OSHA requirements for maintenance, inspection, testing, certification, repair, alteration, and operation of equipment covered within the P-307.

Units of the NCF and SOU are exempt from compliance with those portions of the P-307 that would preclude the execution of their wartime tasking in a strictly military unique operation. This

Figure 3-5 – NAVFAC P-307.

includes Elevated Causeway "Modular" (ELCAS "M"), Elevated Causeway "Navy Lighterage" (ELCAS "NL"), and contingency embarking operations and exercises. Commanders of these units should make every effort to ensure these inherently dangerous operations are conducted in the safest possible manner. Ample training and standard operation procedures should be established and reviewed annually.

The purposes of this publication are the following:

1. To maintain the level of safety and reliability built into each unit of applicable equipment by the original equipment manufacturer (OEM).
2. To ensure optimum service life.
3. To provide training and qualification standards for all personnel involved with maintenance, inspection, test, certification, engineering, rigging, and operation of WHE.
4. To ensure the safe lifting and controlling capability of WHE and promote safe operating practices through the engineering, inspection, test, certification, qualification, operation, and rigging requirements.

The quantity and types of cranes used throughout the Navy that come under the management of Naval Facilities Engineering Command are enormous. From the Naval Construction Force to port facilities to public work centers around the world, cranes are used to support dredging, pile driving, steel erection, ship loading, and ship repair. As per the P-307, cranes are listed into 4 Categories. In the Naval Construction Force and

Special Operating Units cranes within Categories 1 and 4 are primarily used and will be the categories that will be referred to. The categories are as follows:

Category 1 Cranes (*Figure 3-6*)

- o Portal cranes
- o Hammerhead cranes
- o Locomotive cranes
- o Derricks
- o Floating cranes (YD) Tower cranes
- o Container cranes
- o Mobile cranes (except those indicated as Category 4) including truck, cruiser, crawler, warehouse/industrial cranes, and cranes used for dragline, pile driving, clamshell, magnet, and bucket work
- o Aircraft crash cranes
- o Mobile boat hoists including self-propelled and towed types
- o Rubber-tired gantry cranes



Figure 3-6 – Example of Category 1 cranes.

Category 4 Cranes (Figure 3-7)

- Commercial truck-mounted cranes
- Articulating boom cranes, including ammunition handling truck/cranes with equipment category code 0704
- Pedestal-mounted commercial boom assemblies (fixed length and telescoping types) attached to stake trucks, trailers, flatbeds, or railcars, or stationary mounted to piers, etc., with certified capacities of 2,000 pounds and greater.



Figure 3-7 Example of Category 4 crane.

NOTE

Commercial truck-mounted cranes (described by ASME B30.5) and articulating boom cranes (described by ASME B30.22) of all capacities are Category 4 cranes and require a licensed operator even if the cranes are down rated for administrative purpose.

2.3.1 Navy Crane Center

In September 1997, the Secretary of the Navy signed SECNAVINST 11260.2, *Navy Weight Handling Program for Shore Activities*. These established the Navy Crane Center as a direct component of NAVFAC and as the cognizant activity responsible for standardizing and improving weight handling programs at Navy shore activities worldwide. As stated in the SECNAVINST, "Safe and reliable weight handling is critical to the operation of the Navy. Each day the Navy applies its extensive inventory of weight handling equipment to lift ordnance, naval nuclear propulsion plant components and equipment, new and spent nuclear fuels, electronic equipment, hot metals, components of ships and submarines, supplies, construction materials, and hazardous material items needed to support the Navy's worldwide commitments. Safe conduct of the operations is key to precluding damage to equipment or personal injury."

The Navy Crane Center employs approximately 80 civilians and provides engineering expertise, technical support, acquisition services, technical training, and auditing services throughout the world. They are engineers, project managers, contract specialists, equipment specialists, training specialists, safety specialists, information technology specialists, and support professionals dedicated to the support of our shore activities which provide a vast array of safe and reliable weight handling services to the fighting forces. Corporately, the center has centuries of experience in engineering, acquisition, and life cycle management of weight handling equipment (WHE).

Acquisition

- Procurement of Navy shore-based weight handling equipment with a capacity of 20,000 pounds or greater, all WHE for special applications, and WHE for other Department of Defense agencies when specifically authorized.

- Assistance in procurement, to ensure certifiability, of smaller capacity WHE.

In-Service Technical Support

- Engineering investigation, consultation, and solutions.
- Crane alterations and configuration control.
- Accident investigation, review, and analysis.
- Crane safety advisories and equipment deficiency memorandums.
- WHE deficiency reports.
- Equipment and procedure problem resolution

Policy

- Criteria for design, management, maintenance, inspection, testing, certification, alteration, repair, operation, and rigging for WHE.

Training

- Formal training for mechanics, inspectors, test personnel, riggers, operators, and certifying officials
- Hands-on training and program management assistance

Compliance

- Audits of Navy shore activities.
- Corrective action.
- Special purpose service validations and third party certifications.

2.4 0 Training

The P-307, Section 13, *Training and Qualification* provides the requirements for personnel involved in the operation, maintenance, inspection, and testing of Navy Weight Handling Equipment. These requirements apply to Navy military personnel.

The P-307, Section 13, Table 13-1 identifies the mandatory courses required for applicable personnel. These are one-time courses except for licensed crane operators who are required to take refresher courses. Personnel may not perform weight-handling maintenance, inspection, testing, operation, or rigging unless they have completed the required courses and are qualified by their supervisors. The courses are designed to reinforce and enhance existing knowledge for journeyman level personnel in the Navy WHE program. Except as noted, the required training will be provided by Navy Crane Center authorized instructors. The courses are designed to provide a minimum coverage of each subject and do not include hands-on applications.

Some courses are available online at Navy Knowledge Online (www.nko.navy.mil). Courses will be dropped from the Navy Crane Center training schedule as they become available online. Classroom training for these courses may still be provided by approved trainers upon request.

Additional training such as hands-on to enhance specific skills is encouraged. Such training is available from naval shipyards, other naval activities, and commercial training sources. Additional courses may be required to qualify personnel to perform unique critical job skills at an activity. Activities are responsible to ensure such supplemental training requirements are met.

2.5.0 Licenses

In accordance with COMFIRSTNCDINST 11200.2, road test licenses are no longer valid. The NCF equipment (cranes excluded) may be moved from yard to shop and shop to yard as required to accomplish repairs without the operator possessing a valid license. Shop inspectors who are required to road test or evaluate equipment must be qualified operators and must possess a valid operator's license (*Figure 3-8*). The Operator License File for each individual should be kept with the unit's license examiner (*Figure 3-9*).

NAME OF OPERATOR _____					DATE ISSUED _____				
					DATE EXPIRES _____				
LICENSE NO. _____					DATE EXPIRES _____				
DATE OF BIRTH _____	COLOR OF HAIR _____	COLOR OF EYES _____	HEIGHT _____	WEIGHT _____	THE HOLDER OF THIS CARD IS QUALIFIED TO OPERATE U.S. NAVY CRANES AS SPECIFIED ON REVERSE OF THIS CARD				
SI NATURE OF ISSUING OFFICIAL _____									
SI NATURE OF OPERATOR _____					RESTRICTIONS (Vision, Hearing, Other) _____				
Card must be carried at all times when operating Navy craned. Not transferable to other personnel. NOTE: INFORMATION ON THIS LICENSE IS SUBJECT TO SAFEGUARDING AND DISCLOSURE CONDITIONS OF THE PRIVACY ACT OF 1974.									

FRONT **BACK**
Figure 3-8 - Crane Operator License.

Figure 3-9 - Crane Operator License Record.

The P-307 covers inspection requirements in Section 2, *Maintenance*, Section 3, *Certification*, and Section 5, *Equipment History File* and gives examples of inspection attributes and sample forms in Appendix C, *Maintenance Inspection and Record for Category 1 and 4 Cranes (Figure 3-10)*. This checklist must be completed and accompany the 2-Kilo(s) as required and be filed in both the history jacket and the crane equipment history file.

Inspections should consist of observing the functioning of components and parts before, during, and after operation, and examination should be made by sight, sound, touch, and as necessary, by instrumentation, nondestructive testing, and disassembly. Disassembly should be limited to suspected or abnormal conditions.

Primary emphasis during inspections should be given to ensuring maximum safety by maintaining all load-bearing and load-controlling parts and operational safety devices in a safe and sound working condition.

1. *Journal of the American Medical Association*, 1997; 278: 1039-1044.

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2.6.1 Maintenance Inspections

Maintenance inspections should be performed at the frequencies and in the detail specified in the P-307, Section 2. Personnel performing maintenance inspections should be trained and qualified as inspectors per P-307, Section 13. In general, inspections should consist of observing the functioning of the specified components and parts before, during, and after operation. Examination should be by sight, sound, touch, and, as necessary, instrumentation, nondestructive testing, and disassembly.

During inspections you should give primary emphasis to ensuring maximum safety by maintaining all load-bearing and load-controlling parts and operational safety devices in a safe and sound working condition. As inspector, you should determine whether a deficiency constitutes a major deficiency (i.e., a deficiency of a load-bearing or load-controlling part or operational safety device that hinders the safe operation or reduces the load-bearing or load-controlling capability of the equipment or component). Inspectors should not engage in calculated risks or depend on their judgment alone where there is a doubt in their mind regarding a questionable condition. You should immediately refer questionable conditions of load-bearing and- load controlling parts and operational safety devices to the activity engineering organization and, if necessary, to the certifying official for resolution. If there is no activity engineering organization, the inspection organization should evaluate the deficiency and the certifying official should approve the resolution.

Use the Maintenance Inspection Specification and Record forms to record conditions at each inspection and file them in the equipment history file.

All work performed, including work to disassemble and reassemble components (including disassembly for inspections of P-307, Appendix C), should be documented on a shop repair order or other work document (this does not include removal and replacement of inspection covers). Prior to starting the work you, as inspector, or the engineer should review documents involving repair, replacement, disassembly, alteration, or adjustment to load-bearing parts, load-controlling parts, and operational safety devices. Work documents should clearly describe the work to be done, including replacement parts to be installed, and in-process inspection requirements for those items where inspection is not practical after completion of work, and they should identify appropriate test requirements. When an alteration is invoked, the work document should cite the applicable alteration number and the nature of the change. Components to be repaired or replaced should be identified to specific subsystems (e.g., main hoist motor to gearbox coupling) or location (e.g., hydraulic return hose for left rear outrigger jack). Except for cranes undergoing annual inspection and load test, work documents should indicate whether or not re-certification is required.

Before performing maintenance or repairs to cranes, take the following precautions as appropriate:

1. Position the crane to be repaired in a location where it will minimize interference with other cranes and operations in the area, and enable safe access for personnel working on the crane.
2. Put all controllers in the "off" position.
3. Control stored energy in accordance with the activity's 3-M lockout/tagout procedures. COMTHIRDNCDINST 4790.1, Appendix G is the Standard Operating Procedure (SOP) that pertains for ALFA Company motorized equipment only. 3-M Tagout was discussed in Chapter 2.

4. Place warning signs or barriers to alert personnel in the area of maintenance work being performed.
5. Where other cranes are in operation on the same runway, provide rail stops or other suitable means to prevent interference with the idle crane. After adjustments and repairs are made, do not return the crane to service until all guards have been reinstalled, safety devices reactivated, and maintenance equipment removed.

2.6.1.1 1.1 Maintenance Inspection Type and Frequency

Routine inspections should be scheduled and performed for the various categories of cranes. Annual maintenance inspections and Type "B" maintenance inspections should be performed in conjunction with the annual certification. The activity has the option of basing maintenance inspections on engine operating hours or electrically energized hours for cranes without a main engine as recorded on the hour meter on the main engine or main power source, or time intervals in calendar months (the scheduling basis may vary among cranes of the same type). The schedule shall establish either one or the other of these criteria (not whichever comes later). The scheduling basis (hour meter or calendar month) should be annotated in the equipment history file for the crane. "A" type "B" inspection should be accomplished before the option to change is exercised.

Type "A" Inspection (Appendix C). Calendar month basis - each 4 calendar months (plus 10 days) after certification. Hour meter basis - each 500 engine operating hours (plus 50 operating hours).

Type "B" Inspection (Appendix C). Calendar month basis - at every third type "A" inspection. Hour meter basis - each 2,000 engine operating hours (plus 200 operating hours), except that a type "B" inspection should be performed annually as a minimum.

Type "C" Inspection (Appendix C). Calendar month basis - at every third type "B" inspection. Hour meter basis - each 8,000 engine operating hours (plus 800 operating hours), except that a type "C" inspection should be performed every sixth annual certification as a minimum.

Note: A type "B" inspection should also include all items designated under type "A" inspection. A type "C" inspection should also include all items designated under type "A" and "B" inspections.

2.6.1.2 1.2 Lubrication and Servicing

In addition to the inspection specifications prescribed, each activity should develop local instructions, and schedule and perform lubrication and servicing. Activity and Navy experience and crane usage may be used as a basis for modifying Original Equipment Manufacturer (OEM) recommended programs. Modification of OEM recommended programs should be approved by the activity. Where the Navy's 3M program (OPNAVINST 4790.4) is utilized for shore-based cranes, the program should incorporate all OEM requirements into the specific crane's maintenance requirements cards.

2.6.1.2.1 2.6.1.2.1 Lubrication

Lubrication instructions should be developed using OEM manuals and instructions as a guide when available. Particular attention should be given to the amount of lubrication to be added at a given interval and to lubricant distribution, especially in areas subject to

small rocker motion (e.g., gudgeon or horizontal equalizer pins) or larger diameter bearings (e.g., slewing ring bearings). **Over-lubrication is often destructive and should be avoided.** New equipment, even though presumably lubricated by the OEM, should be checked for sufficient lubricant before being placed in service. Lubrication points on new or repaired equipment should be checked to verify lubricant acceptance and proper assembly. Lubrication instructions should minimize the number of different lubricants employed. Maximum utilization of existing lubricant inventories should be considered. In addition, consideration should be given to periodically cycling all moving parts on those cranes that are idle for long periods of time between use to prevent blown seals and seized or corroded components.

2.6.1.2.2 Servicing

Servicing specifications should be developed using OEM manuals and instructions for all mechanical and electrical equipment requiring periodic adjustments, tune ups, repairs, or alignments, such as brakes, clutches, engines, electrical and electronic control systems and individual devices, and similar systems and components. Where OEM manuals and instructions are not available or do not address requirements and standards to be used, national industrial standards and consensus standards should serve as minimum requirements.

2.6.1.3 1.3 Maintenance Inspection Specification and Record for Category 1 and 4 Cranes

Appendix C of the P-307 provides the minimum inspection requirements. Due to the various makes and models of cranes in the Navy inventory with unique or special components, these specifications may require additional instructions. Components need not be disassembled for inspection, except under the following circumstances:

1. where noted specifically to disassemble
2. where activity experience warrants disassembly of specific components
3. where problems indicated by these inspections require disassembly for further inspection

Where disassembly and reassembly are required, or for other detailed inspection guidelines, shop repair orders or other work documents should be used to properly document the necessary steps required for disassembly, reassembly, and/or other inspection guidelines. Deleting or reducing the frequency of these inspections requires Navy Crane Center approval. Justification should be provided with the activity's request. Additional or more frequent inspections based upon activity experience or OEM recommendations may be performed at the discretion of the activity. These prescribe the type of inspection, A, B, C, or annual, the components and parts to be inspected, and the inspection action.

These specifications include both non-operational and operational inspection criteria. Where necessary to ensure the safety of inspection and maintenance personnel, the crane should be de-energized in accordance with approved lockout procedures.

For inspections that involve fluids (lubricants, coolants, brake fluid, hydraulic fluid, etc.) or grease, inspect the fluid or grease for visual appearance, smell, and feel as well as for indications of damaged or malfunctioning components.

When you find an unsatisfactory condition, identify the item on the "Unsatisfactory Items" sheet, together with a statement of the condition observed (*Figure 3-11*). Detail any corrective action in terms of adjustments, repairs, or replacements of items on a

Record brake data measurements on the "Brake Data" sheet (*Figure 3-12*). Measurement attributes and criteria should be based on brake and/or crane OEM and/or activity engineering organization recommendations. In addition to minimum and maximum settings, a preferred setting should be specified where appropriate. Where measurements are inaccessible without disassembly, take those measurements only when the brake is disassembled.

For unique items not covered, additional inspection attributes should be included.

[illegible]

Figure 3-11- Sample Unsatisfactory Items Sheet.

BRAKE DATA SHEET OF

NOTE TO INSPECTOR: Fill in applicable data as recommended by the brake and/or crane OEM. Record actual measurement inspected in "INSP" block. If adjustments are made, record adjusted setting in "ADJ" block. Otherwise indicate "NA". List repair document number and corrective action required under remarks.

SAMPLE

3-25

2.6.2 Certification

Certifications should be based on the condition inspection and load test outlined in the P-307 (*Figure 3-13*). The purpose of the condition inspection is to ensure that the overall structural, mechanical, and electrical components of the equipment have been maintained in a safe and serviceable condition and are functioning properly. The purpose of the load test is to ensure by controlled operation with prescribed test loads that the equipment is capable of safely lifting and moving the rated load through all design motions. Technically competent inspection and test personnel should perform these inspections and tests under the direction of the test director. Upon successful completion of the condition inspection and load test, a Certification of Load Test and Condition Inspection should be signed by the test director, inspection personnel, and the certifying official.

The Certification of Load Test and Condition Inspection form should be similar to that shown in *Figure 3-14*. For mobile cranes, if sufficient space is unavailable to show all test loads and configurations, provide an attachment similar to the one shown in *Figure 3-15*. A card or tag with the crane identification number, certified capacity, and the certification expiration date, should be posted in a conspicuous location on or near the crane. The certification expiration date should be one day prior to the anniversary date of the certification. The crane may remain in service on the expiration date. For example, if a Category 1 crane is certified 30 June, the expiration date should be 29 June of the following year. The date of the certifying official's signature is the official certification date, from which the certification expiration date is determined. The crane should not be returned to service prior to obtaining the certifying official's signature except as provided in P-307 paragraph 2.5.4. The certifying official should withhold certification pending the correction of all inspection deficiencies existing after the load test that, in his or her judgment, could cause unsafe conditions.



Figure 3-13 – A 50-ton LinkBelt lattice boom crane being certified using an 11,850-pound weight in Okinawa.

Activity				Building/Location			
Crane Type	Type	OEM's rated Capacity				Certified Capacity (If different from OEM's rated capacity, explain in "Remarks")	
		Main	lbs.	feet		Main	lbs. feet
		Aux	lbs.	feet		Aux	lbs. feet Whip
		Whip	lbs.	feet			feet
☐ Annual Certification ☐ Quadrennial Load Test					Appendix "E" Applicable Crane Test Procedures Paragraphs (Include applicable subparagraphs.)		
☐ Interim Recertification(Reason)							
Category 1 or 4 Cranes *							
Boom length	Test Load %	Minimum Radius		Maximum Radius			
Hoist		Pounds	Feet	Pounds	Feet		
Main							
Aux							
Whip							
Other							
Hook Tr m Measurements		Base Meas.	Before Test	After Test			
Main H k							
Aux Hook							
Whip Ho k							
Other							
Category 2 Cranes							
Hoist	Test Load %	Hook Tram Measurements					
		Base Meas.	Before Test	After Test			
Main							
Aux							
Other							
Category 2 Cranes							
Hoist	Test Load %	Hook Tram Measurements		Test Director (Signature)		Date	
		Base Meas.	Before Test	After Test	Inspector (Signature)		Date
Main					Inspector (Signature)		Date
Aux					Inspector (Signature)		Date
Other					Inspector (Signature)		Date
Annual or Biennial Certification Since Hook NDT				Certifying Official (Signature)		Date	
				Expiration Date			
Remarks							
* For mobile cranes, list all test loads and configurations (e.g.. over side/over rear, boom extended/retracted, lifts on tires, traveling, etc.) If necessary, use figure 3-2							

Figure 3-14 - Certification of Load Test and Condition Inspection Form.

CERTIFICATION OF LOAD TEST AND CONDITION INSPECTION (SUPPLEMENT FOR MOBILE CRANE TESTS)							
Complete as applicable for the type of crane. Indicates "NA" for configuration that do not apply							
Crane No. _____							
Lattice Boom Crane			Telescoping Boom Crane				
Boom Length Feet _____							
On Outriggers	Test Load	Radius	On Outriggers	Test Load	Radius	Boom	h
Min. Radius			Min. Radius Boom Retracted				
Max. Radius			Min. Radius Boom Extended				
On Ties (Stationary)	Test Load	Radius	Max. Radius (Boom 50% Extended)				
Min. Radius			On Ties (Stationary)	Test Load	Radius	Boom	h
Max. Radius			Min. Radius				
On Ties (Pick and Carry (Describe configurations and list test loads/radii)			Max. Radius (Boom 50% Extended)				
			On Ties (Pick and Carry (Describe configurations and list test loads/radii/boom length)				
Other Configurations, including ancillary experiment if applicable. (Describe and list test loads/radii)							

Figure 3-15 - Certification of Load Test and Condition Inspection Form (attachment).

2.6.2 Annual Certification

The certification is valid for one year from the date of signature of the certifying official. The certification process should include a condition inspection and appropriate tests. For Category 1 and 4 cranes, the annual tests should include a load test.

2.6.2.2 Load Test Required

When the adjustment, repair, disassembly, alteration, or replacement of a load-bearing part, load-controlling part, or operational safety device requires a load test for verification of satisfactory work performed, recertification is required. To determine if a load test is required, the component's impact on holding strength should be assessed. If holding strength could be affected by the work performed (i.e., failure to make the

proper adjustment, repair, etc., could result in dropping or uncontrolled lowering of the load), then a selective inspection, load test, and recertification should be performed. This includes rotate and travel components when the rotate or travel function may operate on an inclined plane, such as the rotate function on floating and barge-mounted cranes, and a trolley on a luffing boom. When load tests are performed, they should include applicable portions of both the static and dynamic tests of P-307, Appendix E, *Crane Test Procedures*. The extent of inspection and testing may be limited, where practical, to those parts and components of systems affected, but should fully ensure that the adjustment, repair, disassembly, replacement, or alteration has been performed correctly, and that the crane operates properly.

2.6.3 Inspection

Perform a condition inspection before, during, and after the load test. For cranes in the biennial load test program in a non-load test year, complete only the "before" portion of the Crane Condition Inspection Record (CCIR). In this case, "during" and "after" columns would be marked "N/A." A CCIR similar to that shown in *Figure 3-16* should be used to record results of the inspection. The inspection should, in general, be by sight, sound, and touch with the depth and detail limited to that necessary to verify the overall condition. It is not intended to be in the same detail as a maintenance inspection. Mark each item on the CCIR as either satisfactory or unsatisfactory. Where an item or inspection is not applicable, use the symbol "NA" or blank out the appropriate block. Describe any unsatisfactory conditions in the "Remarks" portion of the form. The completed CCIR should be included with the crane certification form submitted to the certifying official. Except for Category 2 and 3 cranes, the condition inspection should be a separate inspection from the maintenance inspection addressed in section 2. For Category 2 and 3 cranes, if no major deficiencies are found in the maintenance inspection, and if no work is done between the maintenance inspection and the load test, the maintenance inspection may serve as the "before" portion of the condition inspection. Both inspection forms should be fully completed.

In the event that major deficiencies are identified by these inspections, the deficiencies should be corrected prior to starting or completing the load test. Document corrective action properly. If a major deficiency is found after the load test, it should be corrected, and a selective load test should be performed to test the component(s) corrected. When a selective load test is performed, perform a condition inspection on all items in the Crane Condition Inspection Record that experienced greater than normal loading to ensure that the load test has not caused any damage. Record a record of this retest in the "Remarks" portion of the Crane Condition Inspection Record. Elements of the pre-use inspection and the no-load portions of the Appendix E tests may be performed simultaneously with the "before" portion of the condition inspection.

For cranes idle for more than six months, perform a condition inspection and operational test prior to placing the crane in service; recertification is not required. Use the Crane Condition Inspection Record to record results of the inspection.

Note: Inspect components that are reasonably accessible without disassembly

Crane No.	Type:	Location:	Operator's Name:		Operator's License No.	
Purpose of Inspection		Legend: B= Before A=After D= During		Date Started:	Date Completed:	
Item No.	Inspect structural components for damaged or deteriorated members, and for evidence of loose and missing fasteners and cracked welds.			B	D	A Insp/ Init.
1	Inspect wire rope for wear, broken wires, corrosion, kinks, damaged strands, crushed or flattened sections, condition of sockets, dead end connections, and for proper lubrication.					
2	Inspect wire rope for wear, broken wires, corrosion, kinks, damaged strands, crushed or flattened sections, condition of sockets, dead end connections, and for proper lubrication.					
3	rotation.					
4	Inspect hoist brakes and clutches, and rotate brakes on floating cranes for condition, wear, proper adjustment and proper operation. Spot check horizontal movement brakes and clutches for condition, wear, proper adjustment and proper operation.					
5	Inspect controls and control components for condition and proper operation.					
6	Inspect motors for condition and proper operation.					
7	Inspect limit switches for condition and proper operation. (Hook lower limit switch inspections/verifications may be performed at the maintenance inspection in lieu of the CCIR. Annotate in Remarks block if performed at the maintenance inspection.)					
8	If load test is performed, inspect load indicators, load warning devices, and load shutdown devices for condition and working accuracy as specified in Appendix C or D as applicable. (This may be performed at the maintenance inspection in lieu of the CCIR. Mark N/A if performed at the maintenance inspection.)					
9	Inspect mechanical equipment (shafts, couplings, gearing, bearings, etc.) for condition and proper operation.					
10	Inspect sheaves for condition and evidence of loose bearings and misalignment.					
11	Inspect wheels, axles, and trolley rails (as applicable) for uneven wear, cracks, and for condition and evidence of loose bearings and misalignment.					
12	Inspect load chains and sprockets for condition and proper operation.					
13	Verify capacity chart or hook load rating data is in view of operator and/or rigging personnel.					

Figure 3-16 - Sample Crane Condition Inspection Record (1 of 2).

Item No.	Item Description	B	D	A	Insp/ Init.
14	Inspect operator's cab for cleanliness and operation of equipment.				
15	Inspect machinery house for cleanliness, proper safety guards, warning signs, and storage of tools and equipment.				
16	Verify proper operation of indicators, indicator lights, gauges, and warning devices.				
17	Verify current inspection of fire protection equipment.				
18	Verify that pressure vessel inspection certificates are posted and current. (See UFC 3-430-07 or appropriate document for test procedures.)				
19	Inspect outriggers, pads, boxes, wedges, cylinder mountings and level indicators for condition and proper operation.				
20	Inspect tires, crawler tracks, travel, steering, braking, and locking devices for condition and proper operation. (Applies to mobile cranes, boat hoists, rubber tired gantry cranes, and certain Category 4 cranes.)				
21	Verify accuracy of radius and/or boom angle indicator as specified in Appendix C.				
22	Inspect pawls, ratchets, and rotate locks for proper engagement and operation of interlocks.				
23	Inspect tanks, lines, valves, drains, filters, and other components of air systems for leakage and proper operation.				
24	Inspect reservoirs, pumps, motors, valves, lines, cylinders, and other components of hydraulic systems for leakage and proper operation.				
25	Inspect engines and engine-generator sets for condition and proper operation.				
26	Inspect counterweights and ballast for condition and evidence of loose and missing fasteners.				
27	Verify barge compartment (voids) cover bolts are installed.				
28	Verify accuracy of list and trim indicators against design data or previous test data.				
29	Inspect rotate path assembly and center pin sediment/support assembly or condition and proper operation.				
30	Inspect slewing ring bearings for condition and proper operation.				
31	Inspect travel trucks, equalizers, and gudgeons for condition and proper operation.				
Remarks:					
Inspector Signature/Date:		Test Director Signature/Date			
Figure 3-16 - Sample Crane Condition Inspection Record (2 of 2).					

2.6.4 ad Testing

Perform the load test in accordance with the procedures set forth in the P-307, Appendix E and any special requirements specified for the particular crane by the OEM or the activity engineering organization. Enter the actual test load(s), in pounds, and actual test load percentage together with a list of the applicable test paragraphs (including all applicable subparagraphs) of Appendix E on the Certification of Load Test and Condition Inspection. Elements of the pre-use inspection, "before" portion of the Crane Condition Inspection Record, and no-load portions of the Appendix E tests may be performed simultaneously.

2.6.4.1 Test Loads

The nominal test load should be 125 percent of the rated capacity (110 percent for mobile cranes, mobile boat hoists, rubber-tired gantry cranes, and Category 4 cranes). The actual test load should be within +5/-0 percent of the nominal test load. For mobile cranes, the actual test load should be based on the combination of test weights, rigging, and specified crane component weights (e.g., hooks, blocks, ancillary devices, etc., and for some cranes the hoist wire rope not accounted for in the load charts). Load testing with loads above the limits specified herein is not authorized. Follow OEM load chart instructions. For mobile boat hoists and Category 4 cranes, refer to OEM criteria for component weight requirements and values. For other types of cranes, the actual test load should be the weight of the load, including rigging gear, suspended from the hook. For cranes that cannot be load tested to the specified overload tests of the P-307 due to OEM restrictions or designs that prevent periodic overload tests, the cranes should be down-rated to 76 percent of the OEM's rated capacity (86 percent for mobile cranes, mobile boat hoists, and rubber-tired gantry cranes).

2.6.4.2 Test Weights

Testing of cranes should be done with the use of test weights (*Figure 3-17*). The use of dynamometers in lieu of lifting test weights is not permitted.

Test weights for crane tests (and for rigging gear tests where test weights are used) should be marked with a unique identification number and the weight in pounds. The weight marked should be the actual weight taken from the scale or other measuring device. Solid weights should be measured using calibrated equipment traceable to the National Institute of Standards and Technology, with a minimum accuracy of +/- 2% (i.e., indicated weight should be within +/- 2% of actual weight). Water bag type weights may be used, except for mobile crane and Category 4 crane tests. Water bag type weights

should be used and stored in accordance with OEM recommendations. The metering device/gauge used to determine the amount of water in the bag should be calibrated annually using equipment traceable to the National Institute of Standards and Technology and should ensure that the weight has a minimum accuracy of +/- 2%. Alternatively, a load-indicating device meeting the above calibration and accuracy requirements may be used in lieu of a metering device. A list of test weights, with identification numbers and weights, should be retained, include the type and serial number (or other identifier) of the weighing device(s) used to weigh the test weights. Where a lifting attachment supports multiple test weights (e.g., stacked weights or



Figure 3-17 - Construction mechanics hooking the hoist of the crane to a calibrating weight to certify the crane.

multiple weights suspended from a padeye), the total capacity should be marked on the attachment.

2.7.1 Equipment History File

Each activity should establish and maintain an individual equipment history file on each crane. The equipment history file should contain the documentation shown in *Figure 3-18*, Equipment History File, for the time period indicated. The files should be made available to Government oversight agencies (e.g., OSHA, Navy Crane Center) upon request. For convenience, the files may be together in one central location, or portions of the file may be located separately so long as they are available upon request. Electronic versions of these equipment history files are acceptable.

	Documentation	Minimum Retention Time
1	Maintenance Inspection Specification and Records (Indicate the scheduling basis, either hour meter or calendar month.)	
1.1	Type "A" inspection	Latest plus previous two (if on calendar basis) or latest plus previous two years (if on engine hour operating basis)
1.2	Type "B" inspection	Latest plus previous one
1.3	Type "C" inspection	Latest plus previous one
1.4	Type "Annual"	Latest plus previous one
2	Crane Operator's Daily Checklist (Monthly checklist for non-cab operated Category 3 bridge, gantry, and wall cranes)	Current month plus previous month
3	Shop Repair Orders or Other Work Documents	
3.1	Load-Bearing/Load-Controlling Parts and Operational Safety Devices	Seven years
3.2	All others	One year
3.3	Work Documents invoking Crane Alterations	Life of crane
4	Non-Destructive Test Reports	Latest (for component)
	Crane Condition Inspection Records (including interim s)	Current (including plus one previous annual record)
6	Certification of Load Test and Extensions	Current (including interim's and extensions) plus one previous annual certification
7	Third Party Certifications (for applicable cranes)	Current plus one previous certification
8	Wire Rope Breaking Strength Certification for New Cranes and for Replacement Wire Rope on Existing Cranes (including standing ropes) (rope manufacturer's certification that the rope meets the published breaking strength, or the actual breaking strength of a sample taken from the reel and tested) (Note: For cranes used in cargo transfer, a wire rope certification is required for running rope regardless of the age of the crane and it shall be a certification of actual breaking strength.)	Latest
9	Crane Alterations	Life of crane
10	Deficiency Reports (i.e., load bearing or load controlling parts or operational safety devices)	Life of crane
11	Purchase Contracts (If available)	Life of crane
12	Accident Reports	Life of Crane
13	Hook Tram Point Base Measurement	Life of hook
14	Operational Lifts Exceeding the Certified Capacity	Life of Crane
15	Specification Data Sheets	Life of Crane
16	Crane Acceptance Test (If available)	Life of Crane
17	Mobile Crane Operating Procedures for Ancillary Equipment	Life of Crane
17.1	Completed Procedures When Used	Seven Years
18	Crane Roller Clearance Data Standard of Acceptance	Life of Crane
19	Slewing bearing clearance readings	Life of bearing

20	Oil analysis/vibration analysis data	Life of component
20.1	(Alternate. Internal gear inspection report)	(Latest)
21	Material Inspection Report for Floating cranes (per OPNAVINST 4780.6	Latest, including waivers of depot availability
2	Coupling alignment data per appendices C or D	Latest
3	Lubrication Records	One year
4	Hoist Rollback Data	One year
5	Controlled Disassembly Reassembly Procedures	Life of crane
5.	Completed Procedures When Used	Seven years
6	Hoist brake actuator Belleville torque spring cycle limit	Life of component
7	Individual hoist brake actuator Belleville torque spring number of cycles	Latest
28	drives. Age of crane/component.	Life of crane/component
29	Setting of load shutdown device (see paragraph 11.5)	Life of crane/component
30	Copy of Rail Certification per NAVFACINST 11230.1	Current certification
31	Maintenance inspection, lubrication, or servicing deferral and justification.	Latest
32	Floating crane barge maintenance documentation (paragraph 2.1)	Latest plus previous year

Figure 3-18-Equipment History File.

2.8.0 Crane Safety

Crane accidents take a heavy and tragic toll each year in lives, serious injury, and/or property damage. Much of the crane safety is directed primarily towards the operation of the crane, but the mechanics and inspectors must also follow every safety precaution that pertains to the crane crew as well as to those that concern conducting maintenance and inspection. The inspector is susceptible to many of the same hazards associated with operations, such as moving/heavy parts and components, and sharp objects. In most accidents, a team member either performs an unsafe action or fails to perform a required safe action. In a vast majority of cases where team personnel are at fault, it is due to inattention, poor judgment, overconfidence, or haste to get the job done.

The Crane Inspector needs to fulfill all the same requirements as the operator. You need to understand the crane you will inspect. You should be thoroughly familiar with operating characteristics, including posted operational restrictions or limitations, of each type, make, and model of crane that may be inspected.

As Crane Inspector, you should read, thoroughly understand, and comply with all procedures, safety instructions, and precautions in the OEM's operation manual. The OEM's operation manual should be on the crane for all Category 1 and 4 cranes. Where instructions provided by the OEM are in conflict with local safety instructions or safety procedures provided in the P-307, you should refer such conflicts to the Maintenance Supervisor (A4) for resolution.

Manufacturers, particularly of mobile cranes, often issue information more current and supplemental to that in the operation manual furnished with a particular crane. Much of the information (although sometimes addressed in service bulletins) pertains to the safe operation of the crane. Activities should contact the OEM or authorized distributor for supplemental information applicable to their cranes, and, if practical, be added to the OEM's distribution list for such information.

The Navy Crane Center receives reports of equipment deficiencies, component failures, crane and rigging gear accidents, and other potentially unsafe conditions and practices. When applicable to activities other than the reporting activity, the Navy Crane Center will issue a Crane Safety Advisory (CSA), a Safety Message, or an Equipment Deficiency Memorandum (EDM). Generally, a CSA is a directive and often requires feedback from the activities receiving the advisory. An EDM is provided for information and can include deficiencies to non-load-bearing/load-controlling parts. A Safety Message may or may not be a directive and provides specific and general weight handling equipment safety information.

For each applicable CSA and Safety Message issued by the Navy Crane Center, activities should perform the corrective actions, tests, inspections, measurements, etc., and report to the Navy Crane Center as directed. Activities should track corrective actions associated with CSAs and Safety Messages. A list of all CSAs, Safety Messages, and EDMs in effect can be obtained from the Navy Crane Center website, <https://portal.navfac.navy.mil/ncc>.

Summary

It is crucial for vehicles and equipment coming out of the mechanic shops to be properly repaired and safe for operation. Re-work and injuries to operators due to vehicles or equipment not being safe to operate are not acceptable. The Shop Inspector is essential in ensuring that all vehicles and equipment that roll through the mechanic shops come under strict quality control.

The Shop Inspector may have to carry out different inspections for different operations. When CESE is received, before acceptance it must be inspected for damage and for verification that everything was received. All vehicles and equipment must have a DD Form 1342, Property Record Card filled out, and the Inspector is the primary source for gathering information to complete the form.

One of the major evolutions during a deployment is the BEEP. The inspectors during the BEEP are indispensable in ensuring the continuous flow of the CESE through the shops for a rapid completion.

During the deployment "inactive" CESE must still be maintained in operational condition for when it is needed. The inspector ensures that all the equipment within live storage is properly preserved and cycled to make certain the equipment does not deteriorate due to lack of usage.

The inspector must inspect deadline pieces and ensure their proper condition, provide accountability for components or parts removal, and cycle vehicles and equipment if possible.

The final inspection is an essential quality control measure to make certain that the vehicles and equipment coming out of the mechanic shops have been repaired and serviced properly. The inspector operates the equipment to check all its components and attachments. The final inspection can be used as a tool to establish if additional training needs to be conducted.

The Crane Inspector is a team member of the NCF Weight Handling Equipment Program who performs his or her duties in accordance with the P-307. The Navy Crane Center under the direction of COMNAVFAC is responsible for the execution of the Navy's crane program and conducts initial training for crane inspectors. Inspectors must be licensed as per the P-307 to inspect cranes. The Crane Inspector performs maintenance and certification inspections.

Review Questions (Select the Correct Response)

1. Which is NOT one of the inspector's responsibilities?
 - A. Using the latest testing equipment and methods.
 - B. Checking the file of operator trouble reports.
 - C. Performing inspections on construction projects.
 - D. Road testing or field testing the equipment.
2. **(True or False)** An inspector inspecting CESE arriving at an activity is referred to as an acceptance inspection.
 - A. True
 - B. False
3. The inspection of all CESE, whether new, overhauled, or from another unit, is known as what type of inspection?
 - A. Initial
 - B. Receipt
 - C. Safety
 - D. Turnaround
4. When equipment received is unsatisfactory as a result of improper packaging, what form must be submitted?
 - A. SF Form 361
 - B. SF Form 367
 - C. NAVSUP Form 1250-1
 - D. DD Form 1342
5. Which form is used to report acquisitions and transfers of the Navy equipment registration system?
 - A. NAVFAC Form 1342
 - B. DD Form 1342
 - C. DD Form 1348
 - D. DD Form 1349
6. When a piece of equipment is received without a USN registration number, what steps should be taken?
 - A. Contact CESO Code 1535, get the registration number by checking the CASEMIS, and add to the DD Form 1342.
 - B. Send a message to CESO for a number and add it to the DD Form 1342 before sending to CESO.
 - C. Complete the DD Form 1342, forward it to CESO, and request a number.
 - D. None of the above

7. **(True or False)** Authority to install an engine or component obtained from the Supply System or other sources is NOT assumed to be granted upon receipt of the engine or component.
- A. True
 - B. False
8. When must a corrected DD Form 1342 be prepared?
- A. An attachment is changed to sufficiently change its serial number.
 - B. A new engine is installed.
 - C. A new final drive is installed.
 - D. A damaged bucket is changed.
9. The BEEP is conducted in accordance with what directive?
- A. COMCBPAC/COMCBPLANTINST 11200.1
 - B. NAVFAC P-434
 - C. COMFIRSTNCDINST 11200.2
 - D. NAVFAC P-300
10. **(True or False)** All CESE not to be used for an extended period can be moved into storage to reduce maintenance hours.
- A. True
 - B. False
11. Equipment placed on deadline is that for which parts cannot be obtained or that which cannot be safely operated within how many hours?
- A. 48
 - B. 72
 - C. 96
 - D. Never
12. For the deadline inspection, which action should the inspector ensure?
- A. All disassembled components are thrown in a box in the unit.
 - B. All machine surfaces are left exposed so they can be checked.
 - C. All parts removed are immediately used so they are not lost.
 - D. All openings are covered and weathertight.
13. Final inspection is important because it can detect which deficiency?
- A. That equipment is not being operated properly.
 - B. That additional training may be required.
 - C. That repairs are not being performed properly.
 - D. All of the above

14. **(True or False)** The Crane Inspector is solely responsible for the WHE Program.
- A. True
 - B. False
15. The Crane Inspector is appointed in writing by the _____.
- A. Commanding Officer
 - B. A6
 - C. Test Director
 - D. Crane Crew Supervisor
16. Who is responsible for acquiring approval for any changes to cranes?
- A. Crane Certifying Officer
 - B. Crane Inspector
 - C. Equipment Maintenance Supervisor
 - D. ALFA Company Operations Supervisor
17. What is the title of the ALFA Company Operations Chief in the WHE Program?
- A. Crane Crew Supervisor
 - B. Crane Certifying Officer
 - C. Crane Test Director
18. The Crane Inspector must be thoroughly knowledgeable of what publication in relation to weight-handling equipment?
- A. P-306
 - B. P-307
 - C. P-315
 - D. P-434
19. When are units of the NCF and SOU exempt from compliance with the P-307?
- A. When the operations determine the work is priority one.
 - B. When working away from homeport.
 - C. Contingency embarking operations.
 - D. Never
20. In accordance with the P-307, cranes fall into 4 categories. What categories generally are within the NCF?
- A. 1 & 3
 - B. 2 & 3
 - C. 1 & 2
 - D. 1 & 4

21. The Navy Crane Center falls under the direction of what command?
- A. CESO
 - B. CECOS
 - C. FIRSTNCD
 - D. NAVFAC
22. How often must the Crane Inspector attend mandatory courses?
- A. Only once
 - B. Semi-annually
 - C. Annually
 - D. Every 3 years
23. **(True or False)** All NCF units, excluding cranes, may be moved from yard to shop without the operator possessing a valid license.
- A. True
 - B. False
24. In the P-307, in relationship to inspections, the NCF Crane Inspector is primarily concerned with Sections 2, 3, 5 and what other "section"?
- A. Section 9, Operator Checks
 - B. Appendix C
 - C. Appendix D
 - D. Section 12 Investigation and Reporting of Crane and Rigging Gear Accidents
25. Primary emphasis during inspections should be given to ensuring maximum by maintaining all load-bearing and load-controlling parts and operational safety devices in a safe and sound manner.
- A. load
 - B. stability
 - C. safety
 - D. input
26. How should stored energy be controlled?
- A. Following lockout/tagout procedures.
 - B. Complying with startup control procedures.
 - C. Hanging the key in the key box.
 - D. Giving the key back to the dispatcher for safe keeping.
27. At what interval are Type "B" inspections performed using the calendar month as basis?
- A. At each 4th calendar month (plus 10 days) after certification
 - B. At each 2,000 engine operating hours
 - C. At every third type "B" inspection
 - D. At every third type "A" inspection

28. In conjunction with an inspection schedule, there should be a schedule to perform _____ :
- A. servicing and maintenance
 - B. lubrication and preservation
 - C. lubrication and servicing
29. When an unsatisfactory condition is found, the item should be identified on what document?
- A. Unsatisfactory Parts Sheet
 - B. Unsatisfactory Items Form 307
 - C. Sample Maintenance Inspection and Record Sheet
 - D. Unsatisfactory Items Sheet
30. **(True or False)** It is acceptable when measurements are inaccessible without disassembly to take measurements when the brake is disassembled.
- A. True
 - B. False
31. Certifications should be based on the condition inspection and _____ .
- A. maintenance records
 - B. load test
 - C. modification test
 - D. type of work performed
32. The certification is valid for how long?
- A. From the date of the signing of the ERO.
 - B. Until any work is performed on the crane.
 - C. One year from the date of the signature of the certifying official.
 - D. One year from the date of the signature of the maintenance supervisor.
33. When performing the load test, where do you find the procedures for static and dynamic tests?
- A. P-300, Appendix C
 - B. P-307, Appendix D
 - C. P-307, Appendix E
 - D. P-434, Appendix F
34. The condition inspection should be performed before, during, and after the load test and is generally done by _____ .
- A. sight, sound, and touch
 - B. sight and touch by pulling off panels and guards
 - C. in-depth inspection by breaking down major component.
 - D. visual check only

35. **(True or False)** If a major deficiency is found after the load test, it should be corrected, and a selective load test should be performed to test the corrected component(s).
- A. True
 - B. False
36. According with the P-307, cranes that are not used for a period of six months should have what procedure(s) before being putting back into service?
- A. Condition inspection only
 - B. Condition inspection and dynamic test
 - C. Operational test only
 - D. Condition inspection and operational test
37. The load test should be performed as outlined in the P-307, Appendix E, and any special requirements specified by the .
- A. Civil Engineering Support Office
 - B. Navy Crane Center
 - C. COMNAVFAC
 - D. Original Equipment Manufacturer
38. The actual test load for mobile cranes should be based on the combination of what items?
- A. Hooks, blocks, and wire rope only
 - B. Weights, rigging, and specified crane components
 - C. Weights and rigging only
 - D. Weights, rigging, and boom
39. **(True or False)** The P-307 allows for the use of both test weights and dynamometers for crane testing.
- A. True
 - B. False
40. The equipment history file should be made available for review and should be .
- A. kept together in one central location
 - B. located separately so long as available upon request
 - C. kept electronically
 - D. All of the above.
41. What should Category 1 and 4 cranes have on them?
- A. Maintenance manual
 - B. OEMs operational manual
 - C. Parts manual
 - D. The P-307

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Construction Equipment Department Management and Operations Manual, NAVFAC P-434, Naval Facilities Engineering Command, Washington D.C., 1982.

Management of Civil Engineering Support Equipment, NAVFAC P-300 *Operational Test Procedures*, May 1997.

Maintenance and Material Management (3-M) System Policies and Procedures for the Naval Construction Force (NCF), COMFIRSTNCD 4790.1 (N43), February 2004.

Management of Weight Handling Equipment, NAVFAC P-307, Naval Facilities Engineering Command, Washington D.C, 2009.

Naval Construction Force (NCF) Equipment Management Instruction, COMFIRSTNCDINST 11200.2 (N43), June 2006.

SECNAVINST 11260.2, *Navy Weight Handling Program for Shore Activities*, Naval Facilities Engineering Command, Washington D.C., 2005.

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Chapter 4

Engine Troubleshooting and Overhaul

Topics

- 1.0.0 Horsepower and Horsepower Ratings
- 2.0.0 Graphs and Diagrams
- 3.0.0 Power Losses and Failures
- 4.0.0 Engine Troubleshooting
- 5.0.0 Gauge Care and Maintenance
- 6.0.0 Valves, Valve Mechanisms, and Cylinder Heads Servicing
- 7.0.0 Crankshaft Servicing
- 8.0.0 Cylinder Servicing
- 9.0.0 Pistons and Rings Servicing
- 10.0.0 Operational Testing

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Overview

This chapter discusses the troubleshooting and overhaul of an engine. You will first learn about horsepower, including a brief discussion on dynamometers and their role in engine overhaul.

Other topics will include graphs and diagrams, engine troubleshooting, valve maintenance, servicing of cylinder heads, crankshafts, cylinders, and pistons and rings, and the operational testing of the engine after the overhaul has been completed with pre-startup, initial startup and run-in.

As a supervisor, your expertise will be invaluable in the maintenance of the Naval Construction Force's extensive automotive and heavy construction equipment inventory.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand horsepower and horsepower rating.
2. Understand the use of graphs and diagrams for recording operational and maintenance data.
3. Understand engine power losses and failures.
4. Identify types of engine problems by troubleshooting.
5. Understand how to care and maintain gauges.

6. Understand how to service and troubleshoot valves, valve mechanisms, and cylinder heads.
7. Understand how to service crankshafts.
8. Understand how to service cylinders.
9. Understand how to service pistons and rings.
10. Understand how to conduct operational testing.

Prerequisites

None

This course map shows all of the chapters in Construction Mechanic Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Wheel and Track Alignment		C
Troubleshooting Transmissions, Transfer Cases and Differentials		M
Clutches and Automatic Transmissions		A
Troubleshooting Electrical Systems		D
Fuel System Overhaul		V
Engine Troubleshooting and Overhaul		A
The Shop Inspectors		N
Alfa Company Shop Supervisor		C
Public Works Shop Supervisor		E
		D

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 HORSEPOWER and HORSEPOWER RATING

Whenever someone mentions horsepower, the first thing that comes to mind is cars--fast cars with extreme torque, vehicles with large power and extreme speed. But what makes horsepower measuring so meaningful? And why is it called horsepower?

Engines are rated according to horsepower and torque. The speed and fuel setting of an engine will determine its actual rated horsepower setting. Horsepower is the ability to maintain a load at a desirable or fixed speed. It is a measure of how fast work can be done. Horsepower is produced as a direct result of combustion in the cylinder.

Combustion pressures force the piston down the cylinder, producing work. The amount of work produced on the power stroke can be determined using the following formula:

$$\text{Work} = \text{Force} \times \text{Distance}$$

Where:

Force = Pressure acting on the piston in psi

Distance = Length of piston stroke

The more fuel released into the cylinder during a given period, the greater the amount of horsepower produced

James Watt. The word horsepower was created in 1782 by an engineer named James Watt while he was developing a way to improve the power of a steam engine (*Figure 4-1*). While watching horses haul coal out of a coal mine, he came up with the idea of defining the power exerted by these animals. He found that, on average, a mine pony could do 22,000 foot-pounds of work in a minute. He then increased that number by 50 percent and pegged the measurement of horsepower at 33,000 foot-pounds of work in one minute.

What horsepower means is this: In Watt's judgment, one horse can do 33,000 foot-pounds of work every minute (*Figure 4-2*). So, imagine a horse raising coal out of a coal mine as shown in the illustration. A horse exerting 1 horsepower can raise 330 pounds of coal 100 feet in a minute or 33 pounds of coal



Figure4-1 – Portrait of James Watt (1736-1819) by Carl Frederik von Breda.

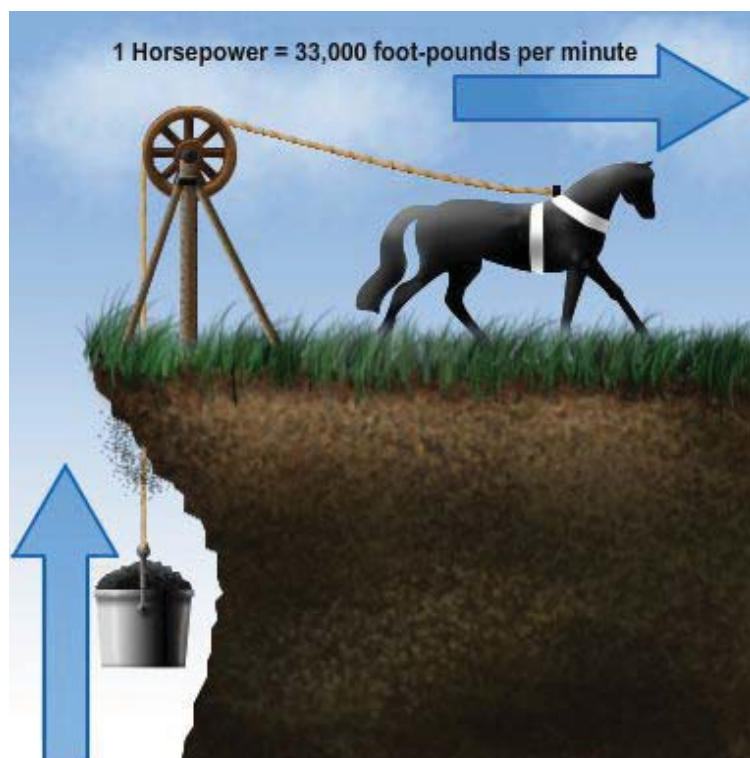


Figure4-2 - Illustration showing how James Watt determined horsepower.

1,000 feet in one minute, or 1,000 pounds 33 feet in one minute. You can make up whatever combination of feet and pounds you like. As long as the product is 33,000 foot-pounds in one minute, you have a horsepower.

Watt used his new found term to rate the power of the steam engine, (*Figure 4-3*). Since most people were unfamiliar with the steam engine, he had to come up with a comparison measurement that the normal farmer of the day would understand. The draft horse was widely used enough that most people of the time had at least an idea of the animal's capability. As with any measurement there are different variations and different methods of measuring horsepower, or hp. The normal measurement of horsepower is called mechanical horsepower.

$$1 \text{ HP} = \frac{33,000 \text{ ft/lb.}}{\text{Minute}}$$

Energy.

Energy is best defined as the capacity for producing work. Energy exists in a number of forms; kinetic, potential, electrical, thermal, chemical, and nuclear are its common forms.

1. **Kinetic energy** is the energy of motion, and any body in a state of motion is described as possessing kinetic energy.
2. Air in its compressed state and contained in a reservoir has the potential for creating motion and is therefore described as **potential energy**.

The first law of thermodynamics states that energy can neither be created nor destroyed; however, the way in which energy manifests itself can be changed. In an internal combustion engine, the potential heat energy of a fuel is released when it is combusted, producing pressure that acts on a piston and drives it through its power stroke producing kinetic energy. Not all of the potential heat energy of the fuel can be successfully converted to kinetic energy. This energy is described as rejected heat and must be dissipated to the atmosphere.

Effects of Heat Energy.

Heat is easily converted into mechanical energy. The sun's heat daily raises tons of water vapor high into the atmosphere so all the mechanical energy of falling water, whether as rain, in rivers, or in glaciers, stems directly from the sun's heat. In the heated engine, the heat released from the burning of fuel is converted into mechanical or kinetic energy.

Force.

Force is generally defined in terms of the effects it produces, although it should always be remembered that forces can be exerted with no result. If force is applied to a body at rest, it may be sufficient to cause the body to move; however, it might not. Using the



Figure 4-3 – 1769-James Watt's improved steam engine powered the industrial revolution.

standard system, force is measured in pounds.

In a diesel engine, force is represented by cylinder pressure. This force acts on the sectional area of the piston crown and is transmitted to rotary motion by acting on the crank throw. The amount of force is controlled by the amount of fuel delivered to the engine cylinder because of the excess air factor in diesel.

Work.

Work is accomplished when force produces a result. When the definition is applied to an engine, work is accomplished when force acting on the piston results in piston travel. In the following formula, standard values are always listed first:

$$\begin{array}{ccccc} \text{Work} & = & \text{Force} & \times & \text{Distance} \\ \text{(watt-second)} & & \text{(pounds)} & & \text{(feet)} \end{array}$$

To use a non-engine analogy to define work, if two persons of identical weight run exactly 100 yards, each has accomplished the same amount of work

Torque.

Torque is turning effort. In a typical engine, the force acting on the piston is transmitted to a crankshaft throw. The throw is a lever. Torque is the product of force on the torque arm or crank throw and its perpendicular distance from the shaft center. The greater the distance of the throw centerline from the crankshaft main centerline, the greater the leverage and the more potential torque. The ability to produce torque in an engine is directly related to its cylinder pressures. For instance, peak torque will always occur when cylinder pressures peak.

Example:

A bicycle has a crankshaft driven by a pair of throws called pedals, offset 180 degrees. Peak torque is at a maximum whenever muscle force acting on the pedals is at a maximum. High torque is required to propel a bicycle and the weight of its rider up a steep hill so a gear selection must be made so that the required torque is within the capabilities of its engine, the cyclist.

1.1.0 Indicated Horsepower (ihp)

Indicated horsepower is the power transmitted to the pistons from the expanding combustion gases. Indicated horsepower is not measured with a test instrument, but is mathematically calculated. Indicated horsepower does not take into account frictional power losses of moving parts or the power losses by accessory items such as water pumps, blowers, oil pumps, fuel injection pumps, and cooling fans.

The formula for calculating engine indicated horsepower is:

$$\text{IndicatedHorsepower} = \frac{P \times L \times A \times N \times C}{33,000}$$

where:

P = mean indicated **P**ressure in psi

L = **L**ength of stroke of the piston in feet

A = Piston cross sectional **A**rea

N = **N**umber of power strokes per cylinder per minute

C = Number of engine **C**ylinders

Example:

A four-stroke cycle, six-cylinder diesel engine with a bore of 5.0" and a stroke of 5.5" is run at a speed of 2,000 rpm. The mean effective pressure obtained from an indicator diagram is specified as 200 psi. Calculate the indicated horsepower of the engine.

First, use the engine specifications to construct the data required for the PLANCK formula:

P = (MEP) calculated by determining the average cylinder pressure through the compression stroke, subtracted from the average cylinder pressure through the power stroke. This data is provided: 200 psi.

$$\text{So, Indicated Horsepower} = \frac{200 \times L \times A \times N \times C}{33,000}$$

$$\frac{L \text{ Stroke } 5.5 \text{ Length in feet } 5.5}{12} \quad 0.458$$

$$\text{So, Indicated Horsepower} = \frac{200 \times 0.458 \times A \times N \times C}{33,000}$$

A = Piston sectional area: Bore diameter = 5.0", so radius = 2.5". To calculate the area of a circle, the square of the radius is multiplied by 3.1416:

$$= (2.5 \times 2.5) 3.1416 = 19.635$$

$$\text{So, Indicated Horsepower} = \frac{200 \times 0.458 \times 19.635 \times N \times C}{33,000}$$

N = number of power strokes per minute in one engine cylinder. So, a power stroke occurs once per two full rotations:

$$\frac{2000}{2} = 1000$$

$$\text{So, Indicated Horsepower} = \frac{200 \times 0.458 \times 19.635 \times 1000 \times C}{33,000}$$

C = Number of engine cylinders = 6

$$\text{So, Indicated Horsepower} = \frac{200 \times 0.458 \times 19.635 \times 1000 \times 6}{33,000}$$

Now the equation is complete and can be solved:

$$\text{Indicated Horsepower} = \frac{10791396}{33,000} = 327.012$$

Indicated Horsepower = 327 HP

1.2.0 Brake Horsepower (bhp)

This is the power measured at the flywheel of an engine and is the actual amount of power that can be delivered at a certain speed with a wide-open throttle. It is always lower than indicated horsepower (calculated power) because of the amount of power consumed by the engine in overcoming internal friction and pumping losses—usually about 10% to 20% less than indicated horsepower for the same engine. The term is used to describe actual engine power over calculated power and is derived from the

braking device, usually a dynamometer, that is applied to measure the horsepower the engine develops.

1.2.1 Calculating Brake Horsepower

$$\text{BrakeHorsepower} = \frac{\text{Force} \times \text{distance} \times \text{time}}{33,000\text{lb} \times 1\text{ft} \times 1\text{min.}}$$

Distance must take into account that an internal combustion engine rotates and, therefore, the distance factor is not linear but circular; to accommodate this 2π is used to construct the equation, which is simplified as follows:

$$2\pi = 2 \times 3.1416 = 6.2832$$

$$33,000 \div 6.2832 = 5252.10084$$

or, for calculation purposes, 5252

In the first brake formula, the valves time and distance are multiplied by each other and by the force value. In a diesel engine, force is expressed as torque. However, time and distance are commonly expressed as one value, rpm. So, for practical purposes, the brake power formula that is used becomes:

$$\text{BrakeHorsepower} = \frac{\text{Torque}(\text{lb. ft.}) \times \text{Time}(\text{rpm})}{5252}$$

$$\text{BrakeHorsepower}(\text{kW}) = \frac{\text{Torque} \times \text{rpm}}{9429}$$

This formula can be used to calculate brake horsepower providing the torque value and rotational speed values are known. For example, a Cummins 460 E SELECT is specified to produce a peak torque value of 1,550 lb.-ft. at 1,200 rpm; to calculate the amount of power this engine produces at this speed and torque:

$$\text{BrakeHorsepower}(\text{bhp}) = \frac{1550\text{lb. ft.} \times 1200\text{rpm}}{5252} = 354\text{BrakeHorsepower}$$

1.2.2 Dynamometers

A dynamometer is an instrument designed primarily to measure power. Essentially, it applies turning resistance to the torque output (twisting effort) to another machine and accurately measures the applied resistance. Power is the rate of accomplishing work. When power is tested on a dynamometer, its factors are torque and time. The torque output of an engine is accurately measured by the dynamometer and factored with time (rpm) to calculate its power. Most dynamometers are electronic, and will take care of the math and display the power in units of brake horsepower (bhp) or kilowatts (kW).

There are two general categories of dynamometers, and they are defined by the method used to apply a resistance to the turning effort of the engine or chassis being tested. An electromotive dynamometer is basically an electric motor turned in reverse. The engine is coupled to the dynamometer armature and rotates it. As current is switched to flow through the induction coils of the electromotive dynamometer, resistance to the turning effort of the engine increases. The more current flowed through the dynamometer coils, the stronger the electromagnetic field produced and the greater the amount of torque required by the engine. The second category of dynamometer is hydraulic. The hydraulic medium used is usually water, but other types of hydraulic media are also

used. The critical component in the hydraulic dynamometer is a load cell or multiple load cells. These use a principle similar to that used by a hydraulic driveline retarder such as the Caterpillar brake saver, where water is flowed through the cell and acts on an impeller. Inlet and outlet valves are used to control the flow of the hydraulic medium into and out of the load cell and define the torque required to rotate the impeller. All dynamometers measure torque. Most also measure rotational speed. When both torque and rpm are known, brake horsepower can be calculated using the equations discussed previously.

When performing chassis dynamometer testing of diesel engines whether for purposes of diagnosis or for performing an engine run-in routine, all of the gauges and instrumentation should be connected to the engine being tested. Loading an engine down on a dynamometer is the ultimate performance test for an engine, and it should be as thoroughly monitored as possible. It takes a little extra time to connect all the required gauges and instruments, but they will help ensure accurate diagnoses and complete reports. Electronic printouts do not look professional when half the data categories are left blank.

1.2.3 Engine Dynamometer

An engine dynamometer is a piece of test equipment that enables the mechanic to fully load-test the overhauled engine before it is reinstalled in the vehicle/equipment (*Figure 4-4*).

With an engine dynamometer, the engine can be fully checked and fine-tuned before it is placed into service. The engine is mounted in the stand, and fuel lines, cooling system hoses, exhaust system, oil lines, and all available instrumentation connected. A typical dynamometer will include the following gauges and meters for monitoring run-in conditions:

1. Fuel and oil pressure gauges
2. Coolant temperature gauges
3. Tachometer for engine rpm
4. Pyrometer for measuring exhaust gas temperature
5. Barometer for measuring air intake pressure

Most dynamometers will have one gauge upstream and one downstream of the air cooler to indicate how well it is doing the job.

Be particularly observant during any run-in procedure to detect possible problems that may develop. Monitor all gauges and readings on the dynamometer, vehicle dash display, or engine control panel. Look for the following problems:

1. Any unusual noises such as knocking, scraping, etc.
2. Any significant drop in engine oil pressure
3. Any significant rise in coolant temperature above 200°F
4. Any significant rise in oil temperature that exceeds 240°



Figure 4-4 – Water brake engine dynamometer.

5. Any exhaust temperature that exceeds the maximum acceptable limit for the specific engine involved
6. Any oil, coolant, fuel, or air inlet system leaks

If the engine develops any of these problems, it must be immediately shut down. Investigate and correct any problem before continuing the test.

1.2.4 Chassis Dynamometer

A chassis dynamometer allows for the controlled vehicle run-in without the need of a road test (*Figure 4-5*). The vehicle's drive axles are placed on a set of in-ground rollers and operated through a specific range of speeds and loads to monitor performance. Ensure the drive axles are properly aligned and in contact with the rollers, and then chain them into position.

A chassis dynamometer must be properly calibrated. On vehicles with bogie axles, the dynamometer must be adjusted so there is no more than a 5 mph difference between axle speeds during testing. On vehicles equipped with a power divider lockout control, the lockout should be engaged during testing. Vehicles without lockout control may require a specially fabricated lockout device. Finally, it may be necessary to disconnect the front propeller shaft from the transfer case. Check the engine manual for these and other precautions prior to testing.

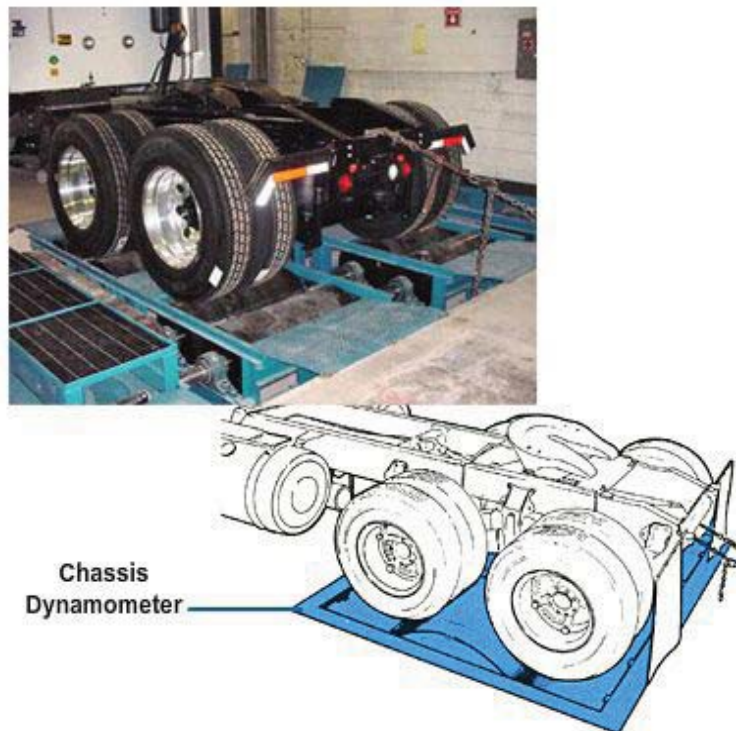


Figure 4-5 - A chassis dynamometer.

1.3.0 Friction Horsepower

Friction horsepower is the difference between indicated horsepower and brake horsepower. Actually, it is the power required to overcome friction within the engine, such as friction between engine parts, resistance in driving accessories, and loss due to pumping action of the pistons. The latter may be compared to the effort required to raise the handle of a hand-operated tire pump. It may be difficult to define friction horsepower properly, but with proper maintenance, it can be reduced to improve the mechanical efficiency of the engine.

1.4.0 Flywheel Horsepower

When speaking of horsepower, generally it is referred to as horsepower at the wheels. There are power losses through the drive train, etc., so wheel horsepower is always lower than flywheel horsepower. A dynamometer will attempt to calculate the losses of the vehicle/equipment caused by friction of the gears, bearings, drivetrain, etc. to obtain power at the flywheel. The flywheel horsepower (engine horsepower) is not 100% accurate, as the only way to get the exact flywheel horsepower is to remove the engine from the vehicle/equipment and bolt it to an engine dynamometer in a test cell. Brake

horsepower measures the power being put to the ground, while flywheel horsepower measures the power the engine produces.

1.5.1 Horsepower Considerations

The engine of any piece of equipment is taken for granted as long as it runs smoothly and efficiently. Eventually, however, in the course of normal operation engines stop operating efficiently or entirely. When this happens, the mechanic must be able to determine the cause and know what is needed to correct the problem.

Generally, the supervisor does not perform engine repairs, but due to your extensive experience in troubleshooting and overhauling, as supervisor you are responsible for seeing that these repairs are performed correctly and efficiently by assisting and instructing those performing the work.

Since the Naval Construction Force possesses several different models of internal combustion engines, both gasoline and diesel, for automotive and heavy construction equipment, it is impractical to specify any detailed troubleshooting or overhaul procedures for all the engines within the inventory. However, here are some elementary principles that apply to all engine troubleshooting and overhauls:

1. Consult the detailed repair procedures given in the manufacturers' instruction and maintenance manuals. Study the appropriate manuals and pamphlets before attempting any repair work. Pay particular attention to tolerances, limits, and adjustments.
2. Observe the highest degree of cleanliness in handling engine parts during overhaul.
3. Before starting repair work, be sure all required tools and replacements for known defective parts are available.
4. Keep detailed records of repairs, such as the measurements of parts, hours of use, and new parts installed. An analysis of these records will indicate the hours of operation that may be expected from the various engine parts and will help in determining when a part should be renewed to avoid a failure.

Since maintenance cards, manufacturers' technical manuals, and various instructions contain repair procedures in detail, this chapter will be limited to general information on some of the troubles encountered during overhaul, their causes, and methods of repair.

2.0.0 GRAPHS and DIAGRAMS

Graphs and diagrams are abbreviated methods of recording operational and maintenance data.

Manufacturers' operational and maintenance manuals often contain graphs and diagrams. The technical bulletins, prepared chiefly for tune-up mechanics, may use a particular graph or diagram to eliminate pages of written description that otherwise would be necessary.

2.1.0 Performance Curves

Figures 4-6 and 4-7 are examples of graphs that describe engine performance in terms of brake horsepower and fuel consumption. Dynamometer tests provide the data used in plotting the performance curves for each engine. *Figure 4-8* is another example of a graph. It shows that the amount of torque an engine produces varies with its speed. The relationship between torque and horsepower is shown in *Figure 4-9*.

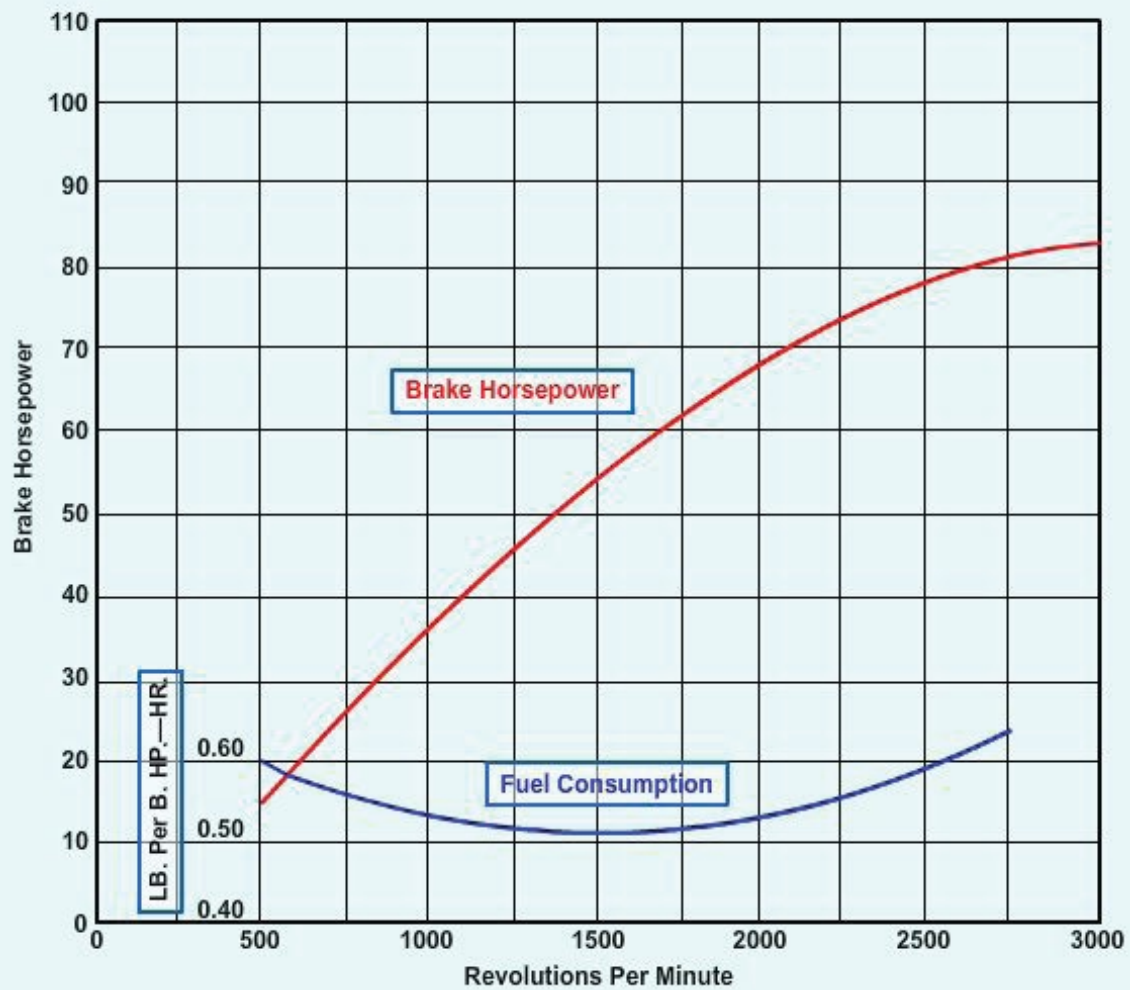


Figure 4-6 - Performance curves of a typical six-cylinder gasoline engine.

Horsepower is related to both torque and speed. When both are increasing, as they do between 1,200 and 1,600 rpm, then horsepower goes up sharply. As torque reaches maximum and begins to taper off, horsepower continues to rise to maximum. The horsepower starts to decline beyond rated speed where torque falls off sharply.

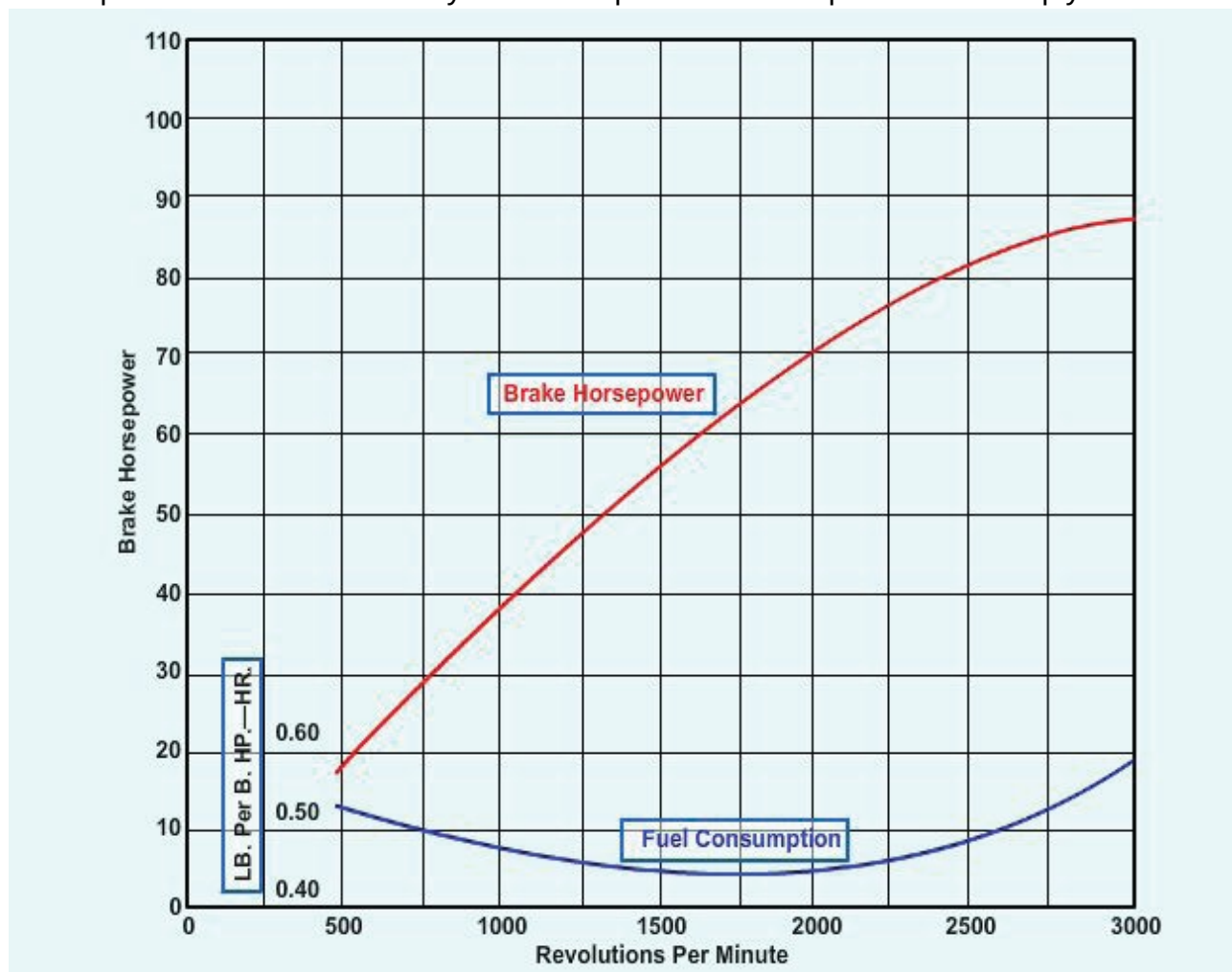


Figure 4-7 - Performance curves of a typical six-cylinder diesel engine.

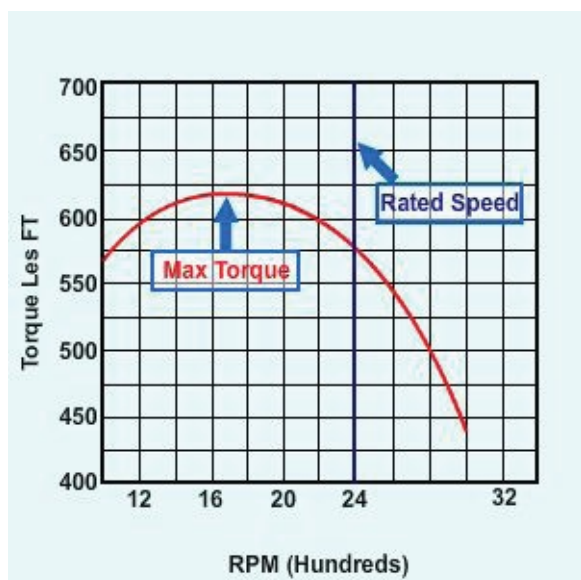


Figure 4-8 - Graph showing relationship between torque and speed.

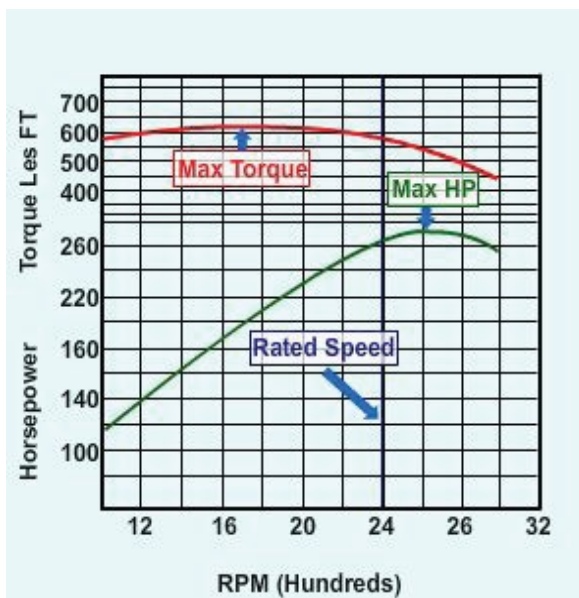


Figure 4-9 - Graph indicating the relationship between torque and horsepower.

2.2.0 Timing Diagrams

Engine timing is largely a matter of opening and closing valves or ports and of adjusting ignition or fuel injection so that these events occur at the proper time in the cycle of engine operation. Timing diagrams depict these events in relation to each other and in relation to top dead center (TDC) and bottom dead center (BDC). They are useful to the mechanic for quick and easy reference. However, before timing diagrams can be useful, you must recall a few facts about engine cycles.

The four-stroke-cycle engine makes two complete crankshaft revolutions in one cycle (intake, compression, power, and exhaust). The two-stroke-cycle engine completes a cycle with just one crankshaft revolution. With diesel engine cycles (two- and four-stroke), the event of fuel injection will be shown on the timing diagram instead of spark ignition, which is common to gasoline engine operating cycles.

2.2.1 r-Stroke-Cycle Engine Timing

Figure 4-10 shows a typical timing diagram for a four-stroke-cycle diesel engine. The actual length of the strokes shown and the beginning of fuel injection will vary a few degrees in either direction, depending on the specific manufacturer's recommendations. Follow the events in this cycle by tracing the circular pattern around two complete revolutions in a clockwise direction. Start TDC with the beginning of the POWERSTROKE. Compression is at its peak when fuel injection has been completed and combustion is taking place. Power is delivered to the crankshaft as the piston is driven downward by the expanding gases in the cylinder. Power delivery ends when the exhaust valve opens.

After the exhaust valve opens, the piston continues downward to BDC and then upward in the EXHAUST STROKE. The exhaust gases are pushed out of the cylinder as the piston rises to TDC, and the exhaust valve closes a few degrees after TDC to ensure proper scavenging. The crankshaft has made a complete revolution during the power and exhaust strokes.

The intake valve opens a few degrees before TDC near the end of the upward exhaust stroke to aid in scavenging the cylinder. As the crankshaft continues to rotate past TDC, the INTAKE STROKE begins. The intake stroke continues for the whole downward stroke and part of the next upward stroke to take advantage of the inertia of the incoming charge of fresh air.

The rest of the upward stroke is the COMPRESSION STROKE, which begins at the instant of intake valve closing and ends at TDC. FUEL INJECTION may begin as much as 40° before TDC and continue to TDC, thus completing the power cycle and the second complete revolution of the engine.

By showing an approximate ignition point in place of fuel injection, *Figure 4-10* could easily represent a timing diagram for a typical gasoline engine.

For additional information on diesel fuel injection system tests that can be made both in the shop and in the field, refer to the manufacturer's service manual.

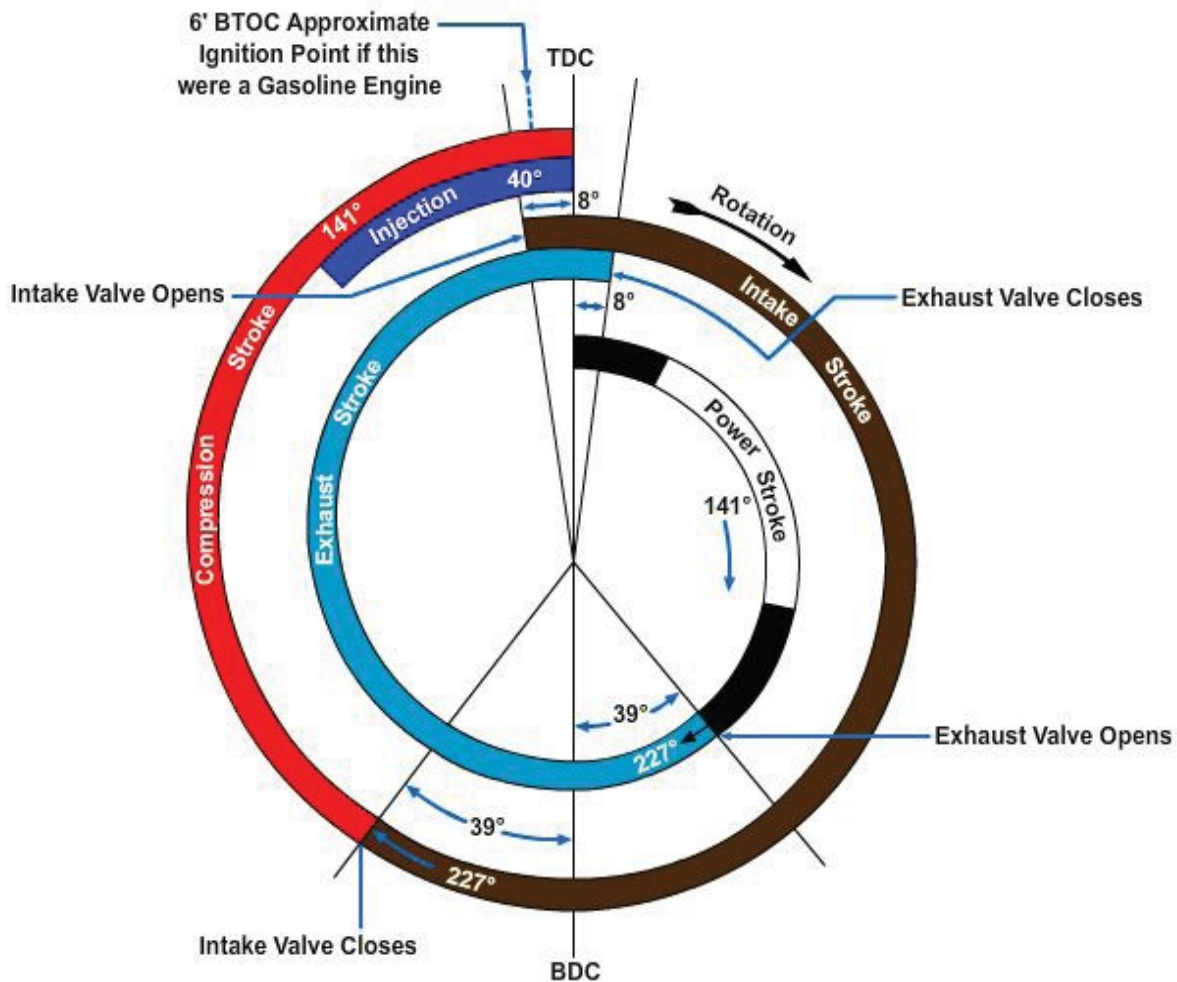


Figure 4-10 - Typical timing diagram of a four-stroke-cycle diesel engine.

2.2.2 Two-Stroke-Cycle Engines

Figure 4-11 shows a timing diagram of a two-stroke-cycle diesel engine. This engine is typical of the General Motors series, which uses a blower to send fresh air into the cylinder and to clear out the exhaust gases. The movement of the piston itself does practically none of the work of intake and exhaust, as it does in a four-stroke-cycle engine. This fact is important to the mechanic in detecting two-stroke-cycle diesel engine power losses.

Beginning at TDC in *Figure 4-11*, the fuel has been injected, and combustion is taking place. The piston is driven down, and the power is delivered to the crankshaft until the piston is just a little more than halfway down. The exhaust valves (two in each cylinder) open $92\frac{1}{2}^{\circ}$ after TDC. The exhaust gases blow out through the manifold, and the cylinder pressure drops off rapidly.

At 132° after TDC (48° before BDC), the intake ports are uncovered by the downward movement of the piston. Scavenging air under blower pressure swirls upward through the cylinder and clears the cylinder of exhaust gases. This flow of cool air also helps to cool the cylinder and the exhaust valves. Scavenging continues until the piston reaches $44\frac{1}{2}^{\circ}$ after BDC. At this point, the exhaust valves are closed. The blower continues to send fresh air into the cylinder for just a short time (only $3\frac{1}{2}^{\circ}$ of rotation), but it is sufficient to give a slight supercharging effect.

The intake ports are closed at 48° after BDC, and compression takes place during the

remainder of the upward stroke of the piston. Injection begins at about $22\frac{1}{2}^\circ$ before TDC and ends about 5° before TDC, depending on the engine speed and load.

The whole cycle is completed in one revolution of the crankshaft, and the piston is ready to deliver the next power stroke.

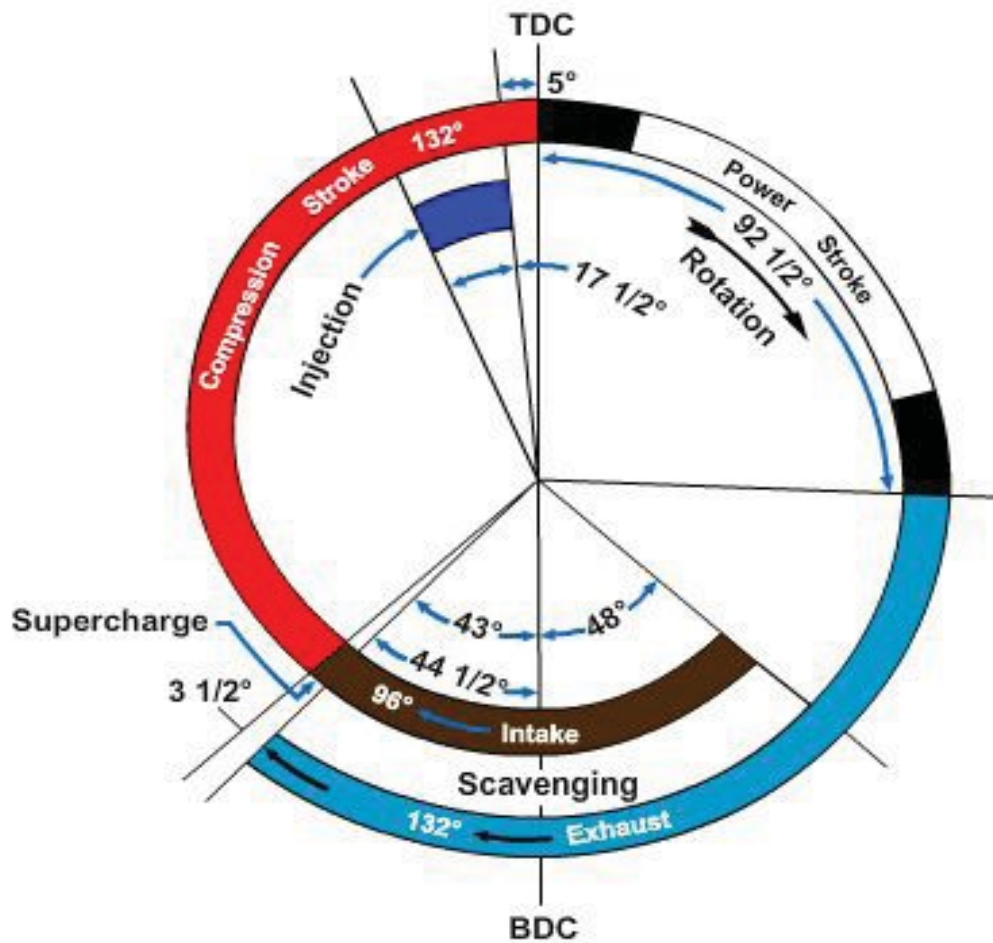


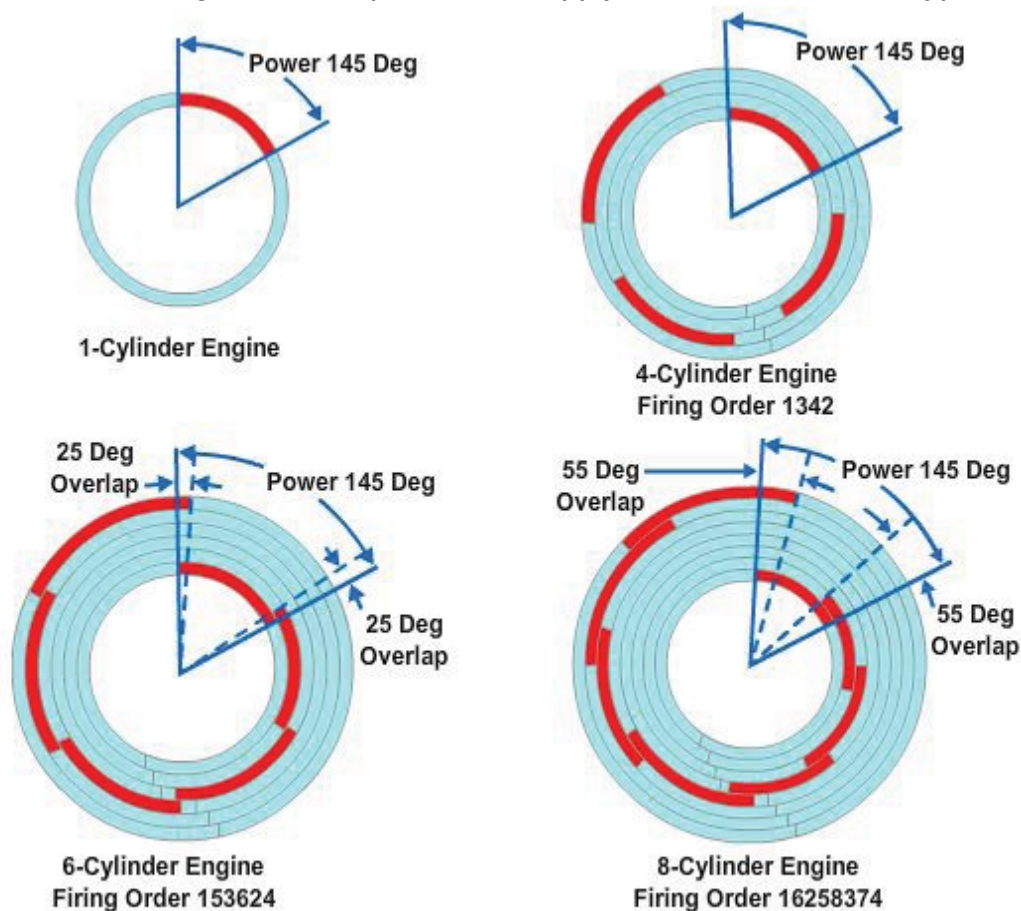
Figure 4-11 - Timing diagram of a two-stroke-cycle diesel engine.

2.2.3 Multiple-Cylinder Engines

Theoretically, the power stroke of a piston continues for 180° of crankshaft rotation on a four-stroke-cycle engine. Best results can be obtained, however, if the exhaust valves are opened when the power stroke has completed about four-fifths of its travel.

Therefore, the period that power is delivered during 720° of crankshaft rotation, or one four-stroke cycle, will be 145° multiplied by the number of cylinders in the engine. This may vary slightly according to the manufacturers' specifications. If an engine has two cylinders, power will be transmitted for 290° of the 720° necessary to complete the four events of the cycle. The momentum of the flywheel rotates the crankshaft for the remaining 430° of travel.

As cylinders are added to an engine, each one must complete the four steps of the cycle during two revolutions of the crankshaft. The number of power impulses for each revolution also increases, producing smoother operation. If there are more than four cylinders, the power strokes overlap, as shown in *Figure 4-12*. The length of overlap increases with the number of cylinders. The diagram for the six-cylinder engine shows a new power stroke starting each 120° of crankshaft rotation and lasting 145° . This provides an overlap of 25° . In the eight-cylinder engine, a power stroke starts every 90° and continues for 145° , resulting in a 55° overlap of power. Because the cylinders fire at regular intervals of firing order, this process will apply to either in-line or V-type engines.



Note - The circles shown above represent 720° not 360° because the crankshaft must rotate through 720° to complete the cycle once for all cylinders.

Figure 4-12 - Power strokes in one-, four-, six-, and eight-cylinder engines.

3.1.1 POWER LOSSES and FAILURES

Power failures can result from minor troubles, such as loose or bare wires and disconnected or damaged fuel lines. When reported by the operator, these troubles are easy to detect without too much checking and testing. The supervisor must, however, make the mechanics aware that there probably was, in addition, an actual or contributing cause to the power failure. The supervisor must train the mechanics to look for this cause while making repairs. Unless eliminated, this may be the cause of major trouble later on.

Too often, problems associated with power loss occur within the engine and are not easily identified. It is these hard-to-find problems, with little or no visual indication, that keep the shop mechanics busy. An operator may notice an apparent power loss in the equipment and, because there is excessive smoke coming from the exhaust, report the trouble as improper carburetion, or, in the case of a diesel engine, as injector trouble. A less experienced mechanic may notice an increased engine temperature in addition to the exhaust smoke and diagnose the loss of power as improper valve action or as trouble in the cooling system. The diagnoses are comparatively simple through visual indications. But, as a senior mechanic, you know that there are many causes of power loss that have little or no visual indications. Examples are incorrect ignition timing, faulty coil or condenser, defective mechanical, vacuum or electronic spark advance, worn distributor cam, or slipping clutch. Any of them can cause a power loss.

After a deficiency has been located in an engine, it is usually easy to make the necessary corrections to eliminate the conditions causing the deficiency. Careful analysis and straight thinking, however, are often needed to find the cause of engine deficiencies. If a supervisor has a thorough knowledge of the basic engineering and operating principles of an engine, his or her job of training the mechanics will be easier and more interesting. In diagnosing engine deficiencies, the supervisor must never jump to conclusions and make a decision on the nature of repairs to be made before being sure that what will be done will eliminate the trouble. The mechanics must be able to interpret the engine instrument indications as well as use the proper testing devices. Furthermore, they must be able to road test the equipment to determine whether repairs have been made satisfactorily and whether a part or several parts should be adjusted or replaced. Besides, the mechanic must know when and how to make emergency adjustments for every unit on the engine.

It may seem that some of the qualifications required of a good mechanic point to the know-how of an automotive engineer. However, no one person can know all about engines and also be an expert in repairing all types of powered equipment used in the Naval Construction Force. For instance, if the checks or instrument tests indicate some internal trouble in a magneto, carburetor, or fuel injection unit, the repairs should be made by mechanics who have experience or have been specially trained to use the equipment to do the particular job at hand. It is the supervisor who will be expected to have the answers to all the questions asked by less experienced mechanics.

The three basic factors that affect an internal combustion engine's power are as follows:

1. Compression
2. Ignition
3. Fuel delivery

In the diesel engine, fuel is injected into each cylinder, and ignition depends on the heat of compression; in the gasoline engine, ignition and carburetion are independent. In

both engines, of course, proper action and timing of all three factors are necessary for the engine to produce its rated power.

An engine will run and develop its rated power only if all of its parts function or operate as they should. If any of these parts wear or break, requiring replacement or adjustment, the performance charts and engine specifications are "tools" that will help the mechanic bring those parts back to their original relationship to each other.

There are more factors NOT directly associated with engine working parts that must be considered in correcting engine power losses.

- Operating conditions can affect engine power. For example, the usable horsepower of an engine is reduced by the number of accessories it must operate. If the engine is required to provide power for lifting operations at the same time it is delivering power to wheels or tracks, the engine may be overloaded and may not be able to develop its rated rpm; consequently, the rated horsepower would not be reached.
- Altitude can have an effect on engine power and must also be considered. As a rule, 2 1/2 percent of the output of an engine is lost for every 1,000-foot increase in elevation above sea level. Overheated air entering the cylinders has the same effect on engine power as an increase in altitude. In computing horsepower output, engineers will deduct as much as 1 percent for each 10°F rise in the intake air temperature above a "normal" temperature of 70°F.

4.0.0 ENGINE TROUBLESHOOTING

As a general rule when troubleshooting a system complaint, investigate the possible causes that can be eliminated easily and inexpensively before proceeding to those that require more time. Avoid component disassembly until you have exhausted all other investigative options. This practice will help avoid presenting an inflated repair for a simple problem. It makes sense to develop some procedures for troubleshooting engine problems in the mechanic shops. A set of procedures will help the mechanics manage their troubleshooting procedures. Engine OEMs produce some excellent troubleshooting charts for their own products.

The troubleshooting approach used by the mechanics will depend on whether the engine is hydromechanically or electronically managed, and on the engine OEM. Keep in mind that the troubleshooting procedure required of most electronically managed engines is structured and sequential and must be adhered to. The following sections discuss some typical engine problems along with their possible causes and solutions, with the focus on hydromechanical problems.

4.1.1 Excessive Oil Consumption

Excessive oil consumption would probably first be noted by the operator who has to add oil to maintain the proper oil level. Two main causes of excessive oil consumption are external leakage and burning in the combustion chamber. Verify the condition by monitoring oil consumption and analyzing exhaust smoke.

- Excess cylinder wall lubrication:
 - o High oil sump level
 - o Excessive connecting rod and big end bearing oil throwoff
 - o Plugged oil control/wiper rings

- o Oil pressure too high
- o Oil diluted with fuel

Solution: This type of problem usually requires an engine disassembly to diagnose and repair.

- External oil leaks:
 - o Steam or pressure wash the engine.
 - o Load on a chassis dynamometer.
 - o Road test to determine the source.
- High oil temperatures:
 - o Malfunctioning boost air heat exchanger
 - o Lug down engine loading
 - o Overfueling
 - o Incorrect fuel injection timing
 - o Problem with the oil cooler or engine cooling system

- Piston ring fit abnormally:
 - o Usually caused by wear

Solution: Replace the rings.

- Piston ring failure:
 - o Determine the cause
 - o Check for other damage

Solution: Replace the rings.

- Turbocharger seal failure:

Solution: Recondition the turbocharger (recore or replace).

- High oil sump level:
 - o This causes aeration.
 - o Determine the cause of high oil level.
 - o Check for presence of fuel and engine coolant in oil.

- Glazed cylinder liners or sleeves:
 - o Caused by improper break-in procedure
 - o Prolonged engine idling

Solution: Replace cylinder liners/sleeves or use a glaze-buster to machine crosshatch.

- Worn cylinder head valve guides or seals:

Solution: Measure to specification and recondition the cylinder head if required.

4.2.1 Low Oil Pressure

Verify the problem:

1. Check the oil sump level.
2. Install a master gauge (an accurate, fluid-fill gauge).
3. Investigate oil consumption history.
4. Determine the cause.

Some possible causes and suggested solutions:

- Restricted oil filter or oil cooler bundle:

Solution: Change the oil filter(s). If the problem persists, clean or replace the oil cooler bundle (core), and check or clean the filter and oil cooler bypass valves.

- Contaminated lube (fuel):

- o Detect by oil analysis or by odor.

Engine lube contaminated with fuel can have darker appearance and feel thin to the touch. If the cause is fuel, locate the source. This may be difficult and the procedure varies with the type of fuel system and the routing of the fuel to the injector.

Solution: Pressure testing the fuel delivery components may be required. Porosity in the cylinder head casting, failed injector O-ring seals, leaking fuel jumper pipes, and cracked cylinder head galleries are some possible causes. Perform repairs as required, and then service the oil and filters.

- Excessive crankshaft bearing clearance:

- o Inspect the bearings to determine the cause.
- o Visually check the crank journals to determine whether removal is required

Solution: Replace the bearings, ensuring that the clearance of the new bearings is checked.

- Excessive camshaft or rocker shaft bearing clearance:

Solution: Replace the bearings.

- Pump relief valve spring fatigued/stuck open:

Solution: Clean the valve and housing, replacing parts as necessary. Check the bypass/diverter valves in the oil cooler and filter mounting pad.

- Oil pump defect:

Solution: Recondition or replace the oil pump.

- Oil suction pipe defect:

Solution: Replace the oil suction pipe.

- Defect in oil pressure gauge or sending unit:

Solution: Replace the oil pressure gauge or sending unit.

- Broken-down (chemically degraded) lube oil:

Solution: Change the oils and filters.

4.3.0 Engine Noises

A variety of engine noises may occur. Although some noises have little significance, others can indicate serious engine trouble that will require prompt attention to prevent major damage to the engine. A listening rod can be of help in locating the source of a noise. The rod acts somewhat like the stethoscope a doctor uses to listen to a patient's heartbeat or breathing. When one end is placed at your ear and the other end at some particular part of the engine, noises from that part of the engine will be carried along the rod to your ear. By determining the approximate source of the noise, you can, for example, locate a broken or noisy ring in a particular cylinder or a main bearing knock.

4.3.1 Valve and Tappet Noise

When checking hydraulic valve lifters, remember that grit, sludge, varnish, or other foreign matter will seriously affect operation of these lifters. If you find any foreign substance in the lifters or engine where it may be circulated by the lubrication system, you need to do a thorough cleaning job to avoid a repetition of lifter trouble.

To help prevent lifter trouble, change the engine oil and oil filter as recommended in the service manual. Faulty valve lifter operation usually appears under one of the following conditions:

Rapping noise only when the engine is started. When engine is stopped, any lifter on a camshaft lobe is under pressure of the valve spring; therefore, leak down or escape of oil from the lower chamber can occur. When the engine is started, a few seconds may be required to fill the lifter, particularly in cold weather. If noise occurs only occasionally, it may be considered normal, requiring no correction. If noise occurs daily, however, check for (a) oil too heavy for prevailing temperatures, or (b) excessive varnish in lifter.

Intermittent Rapping Noise. An intermittent rapping noise that appears and disappears every few seconds indicates leakage at the check ball seat due to foreign particles, varnish, or defective surface of the check ball or seat. Recondition, clean, and/or replace lifters as necessary.

Noise at idle and low speed. If one or more valve lifters are noisy on idle at up to approximately 25 mph but quiet at higher speeds, it indicates excessive leak down or faulty check ball seat on the plunger. With engine idling, lifters with excessive leak down rate may be spotted by pressing down on each rocker arm above the push rod with equal pressure. Recondition or replace noisy lifters.

Generally noisy at all speeds. Check for high oil level in crankcase. With the engine idling, strike each rocker arm above the push rod several sharp blows with a mallet; if the noise disappears, it indicates that foreign material was keeping the check ball from seating. Stop the engine and place the lifters on the camshaft base circle. If there is lash clearance in any valve train, it indicates a stuck lifter plunger, worn lifter body lower end, or worn camshaft lobe.

Loud noise at normal operating temperature only. If a lifter develops a loud noise when the engine is at normal operating temperature, but is quiet when engine is below normal temperature, it indicates an excessively fast leak down rate or scored lifter plunger. Recondition or replace the lifter.

4.3.2 Noise

There are two distinct types of rod knock. The gudgeon pin end or wrist pin or little end bearing makes a light metallic clack. Often you can hear the double clack as the connecting rod reverses the piston direction. The main connecting rod bearing or big end makes a loud, deeper toned knock and is very bad news. Engines can run for a surprisingly long time with little end knock. Big end knock is usually rapidly terminal.

Disconnecting the spark plug wire (and carefully grounding it in the case of high energy ignition!) and then running the engine will cause almost all little end knocks to disappear. The main source of little end knock is the combustion event hammering the piston down onto the bearing, taking up the excess clearance with a clack. If the wrist pin is really loose, then disconnecting the spark plug can change a double clack to a single as the lightly loaded piston reverses direction.

Disconnecting the spark plug rarely makes big end knock disappear altogether.

The really troublesome thing about connecting rod problems is if it does cease, a new block will be required, so the risk of continuing to run the engine is quite high. Always run an engine at low rpm if you suspect rod knock of either type. Not generally known is the fact that inertia loads on the TDC reversal of the piston on the exhaust to intake stroke is when loads on the connecting rod peak due to no downward pressure on the piston face and high speed loading of the bearings.

The noise a connecting rod makes can be similar to detonation (the cause of the sound is similar, the cylinder rings with the banging of the piston on the rod bearings in the one case, and with the sound of the detonation wave hitting the piston face in the other), but a shot connecting rod should make noise at idle. Also, changing ignition timing or increasing octane will cause pinging to go away, but a worn connecting rod will continue to knock.

4.3.3 Piston-Pin Knock

Piston-pin knock is a sharp, metallic rap that can sound more like a rattle if all the pins are loose. It originates in the upper portion of the engine and is most noticeable when the engine is idling and the engine is hot. Piston-pin knock sounds like a double knock at idle speeds. It is caused by a worn piston pin, piston pin boss, piston pin bushing, or lack of lubrication resulting in worn bearings. To correct the problem, install oversized pins, replace the boss or bushings, or replace the piston.

4.3.4 Piston-Ring Noise

This sound can be heard during acceleration as high-pitched rattling or clicking in the upper part of the cylinder. It can be caused by worn rings or cylinders, broken piston ring lands, or insufficient ring tension against the cylinder walls. Ring noise is corrected by replacing the rings, pistons, or sleeves or reboring the cylinders.

4.3.5 Piston Slap

Piston slap is commonly heard when the engine is cold and often gets louder when the vehicle accelerates. When a piston slaps against the cylinder wall, the result is a hollow, bell-like sound. Piston slap is caused by worn pistons or cylinders, collapsed piston skirts, misaligned connecting rods, excessive piston-to-cylinder wall clearance, or lack of lubrication resulting in worn bearings. Correction requires either replacing the pistons, reboring the cylinder, replacing or realigning the rods, or replacing the bearings. Shorting out the spark plug of the affected cylinder might quiet the noise.

4.3.6 Crankshaft Knock

Crankshaft knock is a heavy, dull, metallic knock that is noticeable when the engine is under load or accelerating. When the noise is regular, it can be contributed to worn main bearings. When irregular and sharp, the noise is probably due to worn thrust bearings.

4.4.0 Engine Testing

The Navy provides accurate and dependable testing equipment for use within the mechanic shops. But having the testing equipment in the shop is NOT enough. The supervisor and the crew must know how to use this equipment since proper use provides the quickest and surest means of finding out what is wrong and where the fault lies with an engine or component. Three of the most widely testing instruments used to check an engine for mechanical problems are the cylinder compression tester, vacuum gauge, and cylinder leakage tester.

4.4.1 Compression Test

The engine power results from igniting a combustible mixture that has been compressed in the combustion chamber of an engine cylinder. The tighter a given volume of fuel mixture is squeezed in the cylinder before it is ignited, the greater the power developed. Unless approximately the same power is developed in each cylinder, the engine will run unevenly. The cylinder compression tester is used to measure cylinder pressure in psi as the piston moves to TDC on the compression stroke (*Figure 4-13*).

Some terms associated with the compression are the following:

- **Compression ignition (CI)** is commonly used to describe any diesel engine or one in which the cylinder fuel air charge is ignited by the heat of compression. The elimination of spark plugs, coils, ignition wiring, distributors, and transistorized ignition controls is a major factor in the diesel's simplicity and lower cost of maintenance.
- **Compression ratio** is a comparison of the volume of air in a cylinder before compression with its volume after compression. A 16:1 compression ratio means that at the top of the compression stroke, the air in the cylinder takes up 1/16 the volume it did when the piston was at the bottom of the compression stroke. The compression ratios in a diesel engine are high. The compression ratio is determined by comparing the amount of space in the cylinder when the piston is at the top of its travel to the space available when the piston is at its lowest point of travel (*Figure 4-14*).
- **Compression pressure** is the actual cylinder pressure developed on the compression stroke. Actual compression pressures range from 350 psi to 700 psi in CI engines. The higher the compression pressure, the more heat



Figure 4-13 - Compression tester kit.

developed in the cylinder. However, the work done by the piston on its compression stroke must be subtracted from the work it receives through the power stroke.

In measuring compression pressures of all cylinders with a compression gauge, the different cylinders of an engine may vary as much as 20 pounds. The variation is caused largely by the lack of uniformity in the volume of the combustion chamber. It is nearly impossible to make all the combustion chambers in a cylinder head exactly the same size. For example, in a given engine with chambers the same volume, the compression pressure would be about 120 pounds in all cylinders. However, if one combustion chamber is $\frac{1}{3}$ cubic inch too small, the pressure will be about 126 pounds, and if it is $\frac{1}{3}$ cubic inch too large, the compression pressure would be about 114 pounds. This is a variation of 12 pounds. Also note that a carbon deposit will raise the compression pressure at any given ratio by reducing the combustion chamber volume-the greater the deposit, the higher the pressure.

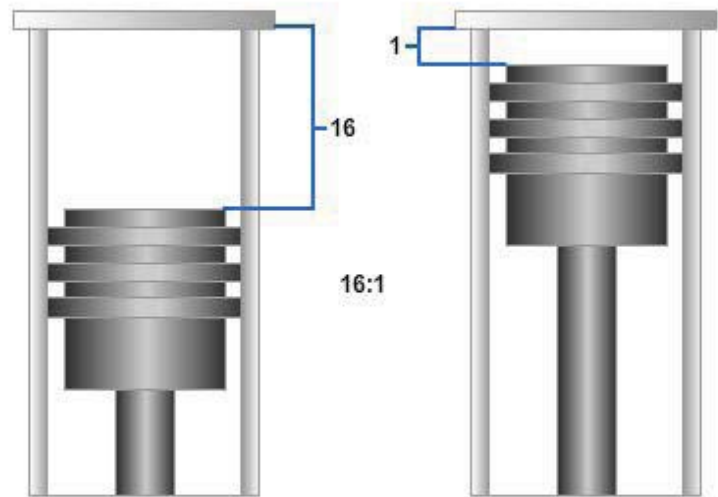


Figure 4-14 - Compression ration.

To make a compression test, first warm up the engine. Warming up will allow all the engine parts to expand to normal operating condition and will ensure a film of oil on the cylinder walls. Remember that the oil film on the walls of the cylinder helps the expanded piston rings seal the compression within the cylinder. After the engine is warmed to operating temperature, shut it down and remove all the spark plugs. Removing all the plugs will make the engine easier to crank while you obtain compression readings at each cylinder. The throttle and choke should be in a wide-open position when compression readings are taken. Some compression gauges can be screwed into the spark plug hole. Most compression gauges, however, have a tapered rubber end plug and must be held securely in the spark plug opening until the highest reading of the gauge is reached.

Crank the engine with the starting motor until it makes at least four complete revolutions. Normal compression readings for gasoline engine cylinders are usually 100 psi or slightly higher. Compression testing is faster and safer when there are two mechanics assigned to the job. Remember that the compression test must be completed before the engine cools off.

Unless the compression readings are interpreted correctly, it is useless to make the tests. Any low readings indicate a leakage past the valves, piston rings, or cylinder head gaskets. Before taking any corrective action, make another check to try to pinpoint the trouble. Pour approximately a tablespoon of heavy oil into the cylinder through the spark plug hole, and then retest the compression pressure. If the pressure increases to a more normal reading, it means the loss of compression is due to leakage past the piston

rings. If adding oil does not help compression pressure, the chances are that the leakage is past the valves. Low compression between two adjacent cylinders indicates a leaking or a blown head gasket. If the compression pressure of a cylinder is low for the first few piston strokes and then increases to near normal, a sticking valve is indicated. Near normal compression readings on all cylinders indicate that the engine cylinders and valves are in fair condition. Indications of valve troubles by compression tests may be confirmed by taking vacuum gauge readings.

4.4.2 Vacuum Gauge Test

When an engine has an abnormal compression reading, it is likely that the cylinder head will have to be removed to repair the trouble. Nevertheless, the mechanics should test the vacuum of the engine with a gauge. The vacuum gauge provides a means of testing intake manifold vacuum, cranking vacuum, fuel pump vacuum, and booster pump vacuum. The vacuum gauge does NOT replace other test equipment, but rather supplements it and diagnoses engine trouble more conclusively.

Vacuum gauge readings are taken with the engine running and must be accurate to be of any value. Therefore, the connection between the gauge and intake manifold must be leak proof. Also, before the connection is made, see that the openings to the gauge and intake manifold are free from dirt or other restrictions. When a test is made at an elevation of 1,000 feet or less, an engine in good condition, idling at a speed of about 550 rpm, should give a steady reading of from 15 to 22 inches on the vacuum gauge. The average reading will drop approximately 1 inch of vacuum per 1,000 feet at altitudes of 1,000 feet and higher above sea level.

When the throttle is opened and closed suddenly, the vacuum reading should first drop to about 2 inches with the throttle open, and then come back to a high of about 24 inches before settling back to a steady reading as the engine idles. This is normal for an engine in good operating condition.

If the gauge reading drops to about 15 inches and remains there, it would indicate compression leaks between the cylinder walls and the piston rings or power loss caused by incorrect ignition timing; a vacuum gauge pointer indicating a steady 10, for example, usually means that the valve timing of the engine is incorrect. Below normal readings that change slowly between two limits, such as 14 and 16 inches, could point to a number of troubles. Among them are improper carburetor idling adjustment, maladjusted or burned breaker points, and spark plugs with the electrodes set too closely.

A sticking valve could cause the gauge pointer to bounce from a normal steady reading to a lower reading and then back to normal. A broken or weak valve spring would cause the pointer to swing widely as the engine is accelerated. A loose intake manifold or a leaking gasket between the carburetor and manifold would show a steady low reading on the vacuum gauge.

Vacuum gauge tests only help to locate the trouble. They are not always conclusive, but as you gain experience in interpreting the readings, you can usually diagnose engine behavior.

4.4.2.1 Vacuum Gauge

Few tools or test devices are more useful and versatile than a vacuum gauge. A vacuum gauge can tell as much about the internal and external workings of an engine as the combination of a voltmeter, compression gauge, stethoscope, and timing light.

An engine's vacuum readings can provide information about its running parameters, provided you know how to read the gauge.

Atmospheric pressure is measured at 14.7 pounds/square inch at sea level. That pressure corresponds to the weight of air holding a column of mercury 29.92 inches in height. By definition, vacuum is pressure below normal atmosphere, commonly caused by a suction that is taking the air molecules away from a particular location. In engines, of course, the air is being sucked in by the vacuum created by the movement of the pistons.

All vacuum gauge faces are graduated in inches of mercury, although some have additional scales in millimeters of mercury.

Note also that most vacuum gauges are equipped with an additional scale that measures fuel pump pressure. This allows the user to connect the hose directly to the fuel line entering the carburetor to measure the fuel pump's pressure. Since many fuel system problems can be traced to the pumps themselves, such a tool can save a lot of troubleshooting time. Is this a great tool, or what?

The most important thing to do when using a vacuum gauge is to connect it to a constant vacuum source on the engine. Some manifolds incorporate a plug that may be removed for such purposes. If none exists, the next best place to connect is the PCV hose. If that's too hard to reach, connect to the power brake vacuum hose (on the engine side of the one-way valve in the hose).

Lastly, you can connect to the vacuum line at the carburetor, but make sure the line has vacuum at idle. Many distributors were designed to get advance vacuum only when the throttle plate was opened, in which case there was no vacuum at idle. Make sure you've connected things properly.

4.4.2.2 Vacuum Gauge Scenarios

The following scenarios are typical examples and are not absolute "drop-dead" numbers. Read the maintenance manuals for the correct reading for your engine.

4.4.2.2.1 Normal Vacuum Reading

Normal vacuum reading is typically 15-22 inches, with needle holding steady. This means that the engine's compression is fine and there are no vacuum leaks or ignition anomalies.

4.4.2.2.2 Acceleration/Deceleration

- a. Rapid acceleration: When the engine is accelerated its vacuum will initially drop close to zero and then slowly start to rise. This is because the wide-open throttle plate momentarily allows atmospheric pressure in, equalizing the pressure in the intake system.
- b. Deceleration: If the engine is decelerated (throttle plate closed while engine is revved up) the vacuum will momentarily go way up, frequently to 25-30 inches, and then drop to normal. This is due to relative inequality between the closed (throttle plate) intake system and the cylinder's suction.

4.4.2.2.3 High Performance Engines

High performance engines-those with high-lift, long duration, large overlap-will show a normal vacuum reading lower than "stock" engines, typically around 15 inches. The needle will remain steady, but a little "needle shake" is to be expected. This is because

of valve overlap, where both intake and exhaust valves are momentarily open together.

4.4.2.2.4 ne with Worn Rings or Diluted Oil

Normal operation shows about 15-17 inches. Rapid acceleration causes the needle to rise only to about 20-23 inches (normal would be 26-30). Reason? Lower vacuum due to gases bypassing the rings.

4.4.2.2.5 Sticking Valves

If the problem is sticking valves, the needle remains steady, but quickly flicks down and then back up. The drop downward is usually around 3-4 inches on the scale. This flick of the needle occurs when a particular faulty valve is actuated.

4.4.2.2.6 eaking Valves

Engines that have burned or constantly-leaking valves will exhibit vacuum readings. There is an evenly-spaced downward flicking of the needle, usually over about 6-8 inches.

4.4.2.2.7 Poorly Seated Valves

A regularly downward flicking of the needle over just 2-4 inches indicates poorly seated valves. This is in contrast to quick movements of the needle.

4.4.2.2.8 Worn Valve Guides

When you see the needle regularly swing back and forth over 4-6 inches, it means the valve guides are worn. You can check this diagnosis by gradually increasing the engine speed. If the needle grows steady, you can assume the guides are worn.

4.4.2.2.9 Weak Valve Springs

When the needle oscillates violently over 10-14 inches as the engine speed is increased, it means there are weak valve springs. In this condition the reading at idle can be relatively steady.

4.4.2.2.10 Valve Timing/Intake Leak

A low, steady reading of about 10 inches indicates late valve timing or a possible slight intake leak. To see if the problem is a leak, spray starter fluid over the intake area where it is bolted to the heads. If the engine smoothes up or increases speed, there is a leak. Late valve timing means lots of work to correct things.

4.4.2.2.11 Retarded Ignition Timing

A steady but "mediocre" needle reading of about 15 inches indicates retarded ignition timing. This is easy to fix rotation of the distributor. If the same reading is accompanied by a regular pulsation (not a flicker) of the needle, check the gap on the spark plugs or for defective breaker points.

4.4.2.2.12: Major Intake Leak

A low, steady reading of 3-6 inches means there is a major intake leak. Check the carburetor mounting flange gaskets and manifold gaskets. If nothing is found, go through each vacuum hose on the vehicle looking for loose connections or split hoses.

4.4.2.2.13 Blown Gasket

If the needle starts off at normal vacuum but drops off in a regular manner, suspect a blown gasket. Generally, such problems are accompanied by smoke and other more obvious symptoms, so very few head gasket failures are diagnosed by vacuum gauges.

4.4.2.2.14 Exhaust System

When an engine first starts and idles, the needle shows a normal reading, but as the engine speed increases the needle slowly goes to zero, suspect a clogged exhaust system. Excessive back pressure is the cause here.

4.4.2.2.15 Idle Mixture

If the carburetor's idle mixture is adjusted improperly, the vacuum gauge needle will move slowly back and forth between about 13-17 inches. Adjustment of the mixture screws will make the movement go away and return the needle to normal.

4.4.3 Cylinder Leakage Test

Another aid in locating compression leaks is the cylinder leakage test. The principle involved is that of simulating the compression that develops in the cylinder during operation. Compressed air is introduced into the cylinder through the spark plug or injector hole, and by listening and observing at certain key points you can make some basic deductions.

The cylinder leakage tester is used to test cylinder leakage by applying regulated air to the cylinder at a controlled volume and pressure and producing a percentage of leakage specification. There are commercial cylinder leakage testers, (*Figure 4-15*) available, but actually the test may be conducted with materials readily available in most repair shops. In addition to the supply of compressed air, a device for attaching the source of air to the cylinder is required. For a gasoline engine, this device can be made by using an old spark plug of the correct size for the engine to be tested. By removing the insulator and welding a pneumatic valve stem to the threaded section of the spark plug, you will have a device for introducing the compressed air into the cylinder.



Figure 4-15 – Cylinder leakage tester

The next step is to place the piston at TDC or "rock" position between the compression and power strokes. Then you can introduce the compressed air into the cylinder. Note that the engine will tend to spin. Now, by listening at the carburetor, throttle body or intake manifold, the exhaust pipe, and the oil filler pipe (crankcase), and by observing the coolant in the radiator, when applicable, you can pinpoint the area of air loss. A loud hissing of air at the intake manifold area would indicate a leaking intake valve or valves. Excessive hissing of air at the oil filler tube (crankcase) would indicate an excessive air leak past the piston rings. Bubbles observed in the coolant at the radiator would indicate a leaking head gasket.

As in vacuum testing, indications are not conclusive. For instance, the leaking head

gasket may prove to be a cracked head, or the bad rings may be a scored cylinder wall. The important thing is that the source of trouble has been pinpointed to a specific area, and a fairly broad, accurate estimate of the repairs or adjustments required can be made without dismantling the engine.

In making a cylinder leakage test, remove all the spark plugs so that each piston can be positioned without the resistance of compression of the remaining cylinders. The commercial testers, such as the one shown in *Figure 4-15*, have a gauge indicating a percentage of air loss. The gauge is connected to a spring-loaded diaphragm. The source of air is connected to the instrument and counterbalances the action of the spring against the diaphragm. By adjusting the spring tension, you can calibrate the gauge properly against a variety of air pressure sources within a given tolerance.

5.0.0 GAUGE CARE and MAINTENANCE

As a supervisor, you will be responsible for the care and maintenance of the engine testing equipment, such as the cylinder compression tester, vacuum gauge, and cylinder leakage tester. As the supervisor, you must impress upon the less experienced mechanics that these precision gauges and testers are fragile instruments that can be damaged through improper use or rough handling. They should be put back in the case they came in and returned to a safe place in the tool room immediately after being used so they are not lying around with the possibility to be damaged. Keeping the gauges and testers clean is about all the maintenance that is required if handled properly. If they are dropped, stepped on, broken, or jarred out of calibration, the gauges or testers will probably have to be returned to the manufacturer for repair or replacement.

6.0.0 VALVES, VALVE MECHANISMS, and CYLINDER HEADS SERVICING

Even if an engine has been properly maintained and serviced, the first major repair the engine will need is an overhaul involving the valves.

6.1.0 Valve Troubles

Some of the common valve troubles that you may encounter in working with engines, and their possible causes are indicated below.

Sticking valves will produce unusual noise at the cam followers, pushrods, and rocker arms and may cause the engine to misfire. Sticking is usually caused by resinous deposits left by improper lube oil or fuel. The cause could also be due to worn valve guides, a warped valve stem, insufficient oil, cold engine operation, or overheating.

To free sticking valves without having to disassemble the engine, use one of several approved commercial solvents. If the engine is disassembled, use either a commercial solvent or a mixture of half lube oil and half kerosene to remove the resins.



Do not use the kerosene mixture on an assembled engine since a small amount of this mixture settling in a cylinder could cause a serious explosion.

Bent valves or slightly warped valves tend to hang open. A valve that hangs open not only prevents the cylinder from firing, but also is likely to be struck by the piston and bent so that it cannot seat properly. Bent valves are generally from the meeting between the piston and valve. Causes here typically include a broken timing chain or belt, weak

or broken valve springs, over revving the engine, valve sticking (insufficient guide clearance or lubrication, overheating, etc.) and insufficient valve-to-piston clearance (excessive valve lift, valve reliefs not cut deeply enough into pistons, wrong pistons, not enough deck height, heads milled too much, etc.). Symptoms of warped or slightly bent valves will usually show up as damage to the surface of the valve head. To lessen the possibility that cylinder head valves will be bent or damaged during overhaul, NEVER place a cylinder head directly on a steel deck or grating; use a protective material such as wood or cardboard. Also, NEVER pry a valve open with a screwdriver or similar tool.

Burned valves are indicated by irregular exhaust gas temperatures and sometimes by excessive noise. In general, the primary causes of burned valves are a sticking valve, insufficient valve tappet clearance, a distorted seat, overheated engine, lean fuel-air mixture, pre-ignition, detonation, valve seat leakage or valve heads that have been excessively reground.

The principal cause of burned exhaust valves is small particles of carbon that lodge between the valve head and the valve seat. These particles come from incomplete combustion of the fuel or oil left by the piston rings in the cylinder. The particles hold the valve open just enough to prevent the valve head from touching the valve seat. The valve is cooled by several means, including its contact with the valve seat. When carbon particles prevent contact, the heat normally transferred from the valve head to the seat remains in the valve head. The valve seat seldom burns because the water jackets surrounding the seat usually provide enough cooling to keep its temperature below a dangerous point.

Valve breakage can happen to either the intake or exhaust valves, and they generally break in one of two places, where the head is joined to the stem, or where the keeper grove(s) are machined into the end of the stem. Nevertheless, breakage of the valves is destructive due to the pieces falling into the combustion chamber and inflicting damage on the piston and head. Valve breakage may occur by valve overheating, detonation, excessive tappet clearance, seat eccentric to stem, cocked spring or retainer, or scratches on the stem caused by improper cleaning.

Loose valve seats can be installed only by installing them properly. Clean the counter bore thoroughly to remove all carbon before shrinking in an insert. Chill the valve seat with dry ice and place the cylinder head in boiling water for approximately 30 minutes; then drive the insert into the counter bore with a valve insert installing tool. Never strike a valve seat directly. Conduct the driving-in operation quickly, before the insert reaches the temperature of the cylinder head. When replacing a damaged valve with a new one, inspect the valve guides for excessive wear. If the valve moves from side to side as it seats, replace the guides.

6.2.0 Valve Adjustments

When mechanical solid lifters are used, the valves require periodic adjustment. Proper and uniform valve adjustments are required for a smooth running engine. Incorrect valve adjustment will upset the amount of air-fuel mixture pulled into the cylinder. It also affects valve lift and duration. This will affect combustion and reduce engine efficiency.

Unless the clearance between valve stems and rocker arms or valve lifters is adjusted according to the manufacturer's specifications, the valves will not open or close at the proper time, and engine performance will be affected. Too great a clearance will cause the valves to open late. Excessive clearance may also prevent a valve from opening far enough and long enough to admit a full charge of air or fuel mixture (with either a diesel or gasoline engine), or it will prevent the escape of some exhaust gases from the

cylinder. A reduced charge in the cylinder obviously results in engine power loss. Exhaust gases that remain in the cylinder take up space, and when combined with the incoming charge, reduce the effectiveness of the mixture. Valves adjusted with too little clearance will overheat and warp. Warped valves cannot seat properly and will permit the escaping combustion flame to burn both the valve and valve seat.

When reassembling an engine after reconditioning the valves, make sure the adjusting screws are backed off before rotating the engine. A valve that is too tight could strike the piston and damage either the piston or the valve, or both. Adjust the valves according to the manufacturer's specifications, following the recommended procedure.

On any engine where valve adjustments have been made, be sure that the adjustment locks are tight and that the valve mechanism covers and gaskets are in place and securely fastened to prevent oil leaks.

6.2.1 Overhead Valves

There are several different methods of adjusting the valves on an overhead cam engine. In many overhead cam designs, the valves are adjusted like the mechanical lifters in a push rod engine. Most overhead valves are adjusted "hot", that is, valve clearance recommendations are given for an engine at operating temperatures. Before valve adjustments can be properly effected, the engine must be run and brought up to normal operating temperature.

To adjust a valve, remove the valve cover and measure the clearance between the valve stem and the rocker arm. Loosen the locknut and turn the adjusting screw in the rocker arm, in the manner shown in *Figure 4-16*. On engines with stud-mounted rocker arms, make the adjustment by turning the stud nut. A rocker arm adjustment screw is turned until the correct size feeler gauge fits between the cam lobe and the follower, valve shim, or valve stem.

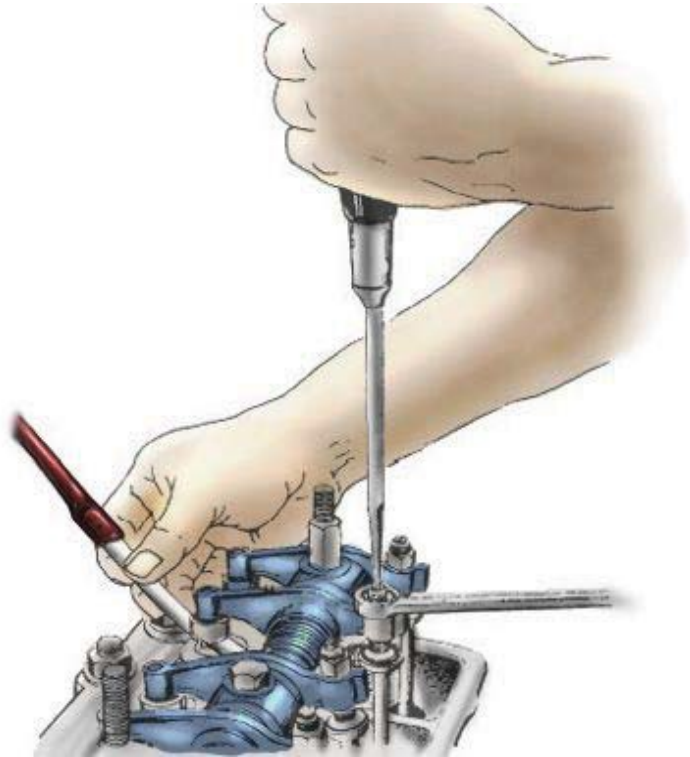


Figure 4-16 Adjusting the valves on an overhead cam engine.

6.3.1 Valve Removal

To remove the valves from the cylinder head, the valve spring retainers and the valve springs must be removed. To aid in spring and retainer removal, use a valve spring compressor to compress the spring (*Figure 4-17*). First adjust the tool to fit the valve assembly and then proceed as follows:



WARNING

Valve springs are under considerable tension and can fly from the cylinder head with considerable force. Wear proper face and eye protection when compressing springs and removing valve keepers.



Figure 4-17 -Valve spring compressor.

1. Depress the handle of the spring compressor tool until the valve spring is compressed (*Figure 4-17*).
2. Remove the upper retainer ring from the valve stem.
3. Remove the valve spring.
4. Remove the lower spacer and remove the valve from the head.

6.4.0 Valve Grinding

Valve grinding is done by machining a fresh, smooth surface on the valve faces and the valve stem tips. Valve faces can burn, pit, and wear as the valves open and close during engine operation. Valve stem tips wear because of friction from the rocker arms or followers.



WARNING

Wear a face shield when grinding valves. The grinding stone could shatter, throwing debris into your face.

6.4.1 Valve Grind Machine

A valve grind machine is used to resurface valve faces and stems (*Figure 4-18*). Although there are some variations in design, most valve grind machines are similar. They use a grinding stone to remove a thin layer of metal from the valve face and the valve stem tip.



Figure 4-18 – Valve grind machine.

Before grinding a valve, dress the stone by using a diamond-tipped cutting attachment to true the grinding surface. The cutting tool is generally provided with the valve grind machine. Follow the equipment manufacturer's instructions.



Be careful when using a diamond cutting tool to dress a stone. Wear eye protection and feed the tool into the stone slowly. If the tool is fed in too fast, tool or stone breakage may occur.

The chuck angle is generally set by loosening a lockout and rotating the grinding machine's chuck assembly to the desired cutting angle. A degree scale is provided so that the angle can be precisely adjusted.

An interference angle (a 1° difference between valve face angle and valve seat angle) is recommended for some older engines. If, for example, the valve seat angle is 45° , the chuck is set to grind the valve face to 44° . The interference angle provides a thin line of contact between the valve face and the valve seat, reducing the valve's break-in time. Older engines, which have hardened valves and seats, do not require an interference angle. The valve face and valve seat should be ground to matching angles.

Direct the coolant on the valve head while grinding. Move the valve into the stone slowly to prevent valve or stone damage. Only cut or grind a valve face enough to remove the dark pits. If the valve face is shiny all the way around, stop grinding.

Chuck the valve in the valve grind machine by inserting the valve stem into the chuck. Make sure the stem is inserted so that the chuck grasps the machined surface nearest the valve head. The chuck must not clamp onto an unmachined surface or runout will result.

6.4.2 Grinding the Valve Face

Turn on the valve grind machine and the cooling fluid. Gradually feed the valve face into the stone. At the same time, slowly move the valve back and forth over the stone. Use the full face of the stone, but do not let the valve face move out of contact with the stone while grinding.

Grind the valve only long enough to "clean up" its face. When the full face looks shiny, with no darkened pits, shut off the machine and inspect the face. Look carefully for pits and grooves.

Some valve refacing machines are equipped with a carbide tip instead of a grinding wheel.

Grinding, by removing metal from the valve face, will increase valve stem height (distance the valve stem extends above the surface of the head). This affects the spring tension and valve train geometry. Grind the face of each valve as little as possible.

If the valve head wobbles as it turns on the valve grind machine, the valve is either bent or chucked improperly. Shut off the machine and find the cause.

A sharp valve margin indicates excess valve face removal and requires valve replacement. Manufacturers give a specification for minimum valve margin thickness. If the margin is too thin, it will not dissipate heat fast enough. The head of the valve can actually begin to melt, burn, and blow out of the exhaust port.

If not noticed during initial inspection, a burned valve will show up during grinding operations. Excess grinding will be needed to remove the deep pits and grooves found on a burned valve. Replace the valve if it is burned.

Repeat the grinding and inspecting operation on the other valves. Return each ground valve to its place in an organizing tray. Used valves should be returned to the same valve guide in the cylinder head. The stems may have been select-fit at the factory.

6.4.3 Valve Stem Tip

A second stone on the valve grind machine is normally provided for truing the valve stem tips.

After grinding the tip flat, you may have to chamfer the tip. If so, mount the valve in the V-block chuck that is at an angle to the stone. Slowly rotate the valve in the chuck as you feed the tip into the stone.

Grind as little off the stem tip as possible. Many stems are hardened. Too much grinding will cut through the hardened layer and result in rapid wear when the valve is returned to service.

An indicator is provided on the valve grind machine to show the depth of cut for both the valve face and the valve stem tip. Generally, the same amount of metal should be removed from the face and the tip. This will help keep valve train geometry correct.

6.5.0 Valve Guide Servicing

Valve guides support the valves in the cylinder head. They are machined to a diameter that is a few thousandths of an inch larger than the diameter of the valve stems, providing a very small clearance between the stem and the guide. This clearance is important for a number of reasons. It prevents the lubricating oil from being drawn past the valve stem and into the combustion chamber during the intake stroke, prevents burnt gases from entering the crankcase area past the valve stems during the exhaust stroke, and helps keep the valve cool. The small valve guide clearance also keeps the valve face in perfect alignment with the valve seat.

Although valve guides may be cast with the head, removable valve guide inserts are used in most cases. Removable guide inserts are press-fit into the cylinder head, (Figure 4-19).

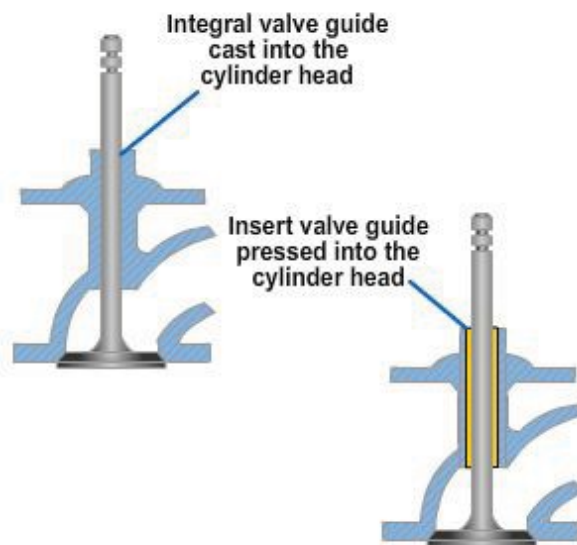


Figure 4-19 – Valve guides.

6.5.1 Checking Stem-to-Guide Clearance

Before checking valve stem-to-guide clearance, clean the valve stem with solvent to remove all gum and varnish. Clean the valve guides with solvent and/or a wire-type expanding valve guide cleaning tool. Then insert the proper valve into its guide and hold the head against the valve seat tightly. Mount a dial indicator on the valve spring of the cylinder head so that the indicator's foot rests against the valve stem at a 90° angle. Move the valve slightly off its seat and measure the valve guide-to-stem clearance by moving the stem back and forth to actuate the dial indicator. If the dial indicator reading is not within the manufacturer's specifications, determine if the stem or the guide is responsible for the excessive clearance.

In an alternate method of checking the valve stem-to-guide clearance, the dial indicator is mounted on the combustion side of the cylinder head. Before mounting the indicator, move the valve head away from its seat a predetermined distance, either by a special collar tool, which is placed on the valve stem between the head of the valve and the guide, or by simply measuring the distance between the valve head and the seat with a scale. After positioning the valve and mounting the dial indicator, move the valve head back and forth to actuate the indicator. If the indicator shows more clearance than specified, measure the valve stem with a micrometer. Compare the stem's diameter to specifications to determine whether the problem is caused by a worn valve guide or worn valve stem.

Other measuring techniques are available to the mechanic. A bore gauge, a micrometer, or an inside caliper-type small hole gauge can be used to determine valve guide wear. Remember, guides do not wear uniformly. Therefore, plugs, valve stems, or pilots should never be used to measure valve guides. Measure the inside diameter of the guides at several different points. Careful measurement and inspection of the guides will help detect bell mouthing or elliptical wear. These conditions normally occur at the ends of the guides.

6.5.2 6.5.2 Knurling

Knurling is one of the fastest methods of restoring the inside diameter of a worn valve guide. It is the method usually chosen to recondition integral guides. Knurling raises the surface of the guide's inside diameter by cutting tiny furrows through the metal. As the knurling tool cuts into the guide, metal is raised or pushed up on either side of the cuts. This decreases the diameter of the guide hole. A burnisher or reamer is used to press the ridges flat and shave off the peaks. The final result produces the proper size hole and restores the correct guide-to-stem clearance. Knurling can be done with either a tap-type knurling tool or a power-driven tool. With power knurling, a drill speed reducer is usually required.

6.5.3 Reaming

Reaming increases the diameter of the guide hole so it can be fitted with an oversized valve (valve with a larger stem). Reaming can also be used to restore the guide to its original diameter after installing inserts or knurling. The advantage of reaming for an oversized valve is that the finished product is totally new. This guide is straight, the valve is new, and the clearance is accurate. Installing an oversized valve is generally considered to be superior to knurling. The process is also relatively quick and easy. The only tool required is a reamer.

6.5.4 Thin-Wall Inserts

The use of thin-wall-inserts offers a number of important advantages over knurling and reaming. The liners provide the benefits of a bronze guide surface, including better lubrication, which reduces wear, and tighter clearances. Thin-wall liners can be used as either integral or replacement guides which are either cast iron or bronze. Thin-wall liners are faster, easier, and less expensive to install than new guides. Installing thin-wall guide liners also maintains guide centering with respect to the valve seats.

6.5.5 Threaded Bronze Inserts

The use of threaded bronze inserts is another method used to restore worn guides. In this method, the worn guides are tapped and the threaded bronze inserts are installed in the tapped holes. They provide better lubrication, excellent wear qualities, and tight clearance, but they are more expensive and difficult to install.

6.6.0 Valve Seat Grinding

After installing new valve seats, or when the old seats are in serviceable condition, grind or cut the faces of the seats. The equipment used to grind valve seats is a valve seat grinder (*Figure 4-20*).



Figure 4-20 – Valve seat grinding.

Two general types of valve seat grinders are in use. One is a concentric grinder, the other, an eccentric grinder. Only the concentric grinder is discussed here because of its greater availability.

In the concentric valve seat grinder, a grinding stone of the proper shape and angle is rotated in the valve seat, and the stone is kept concentric with the valve guide by means of a self-centering pilot that is installed in the guide. Check the self-centering pilot for trueness before using.

To grind a valve seat, install the correct size pilot (metal shaft that fits into the valve guide and supports the cutting stone or the carbide cutter). The pilot should fit snugly in the valve guide and should not wiggle. A damaged pilot will cause the seat position to move in relation to the valve guide. The valve guide must be kept clean and in good condition. Most concentric grinders automatically lift the stone off the valve seat about once every revolution to allow the stone to clean itself of dust and grit by centrifugal action.

Select the correct stone for the valve seat. It must be slightly larger in diameter than the seat and must also have the correct face angle.

Dress the stone using the diamond cutter provided with the grinding equipment. Set the cutter to the correct angle, usually 45° or 30°. Slowly feed the diamond cutter into the stone while spinning the stone with the power head. Cut only enough to clean up and true the stone.

To use hand cutters, follow the same procedures explained for grinding stones. Fit the correct size pilot securely into the guide. Select the correct diameter and angle cutter. Fit the cutter down over the pilot. Then, while applying a very light downward force, turn the cutter on the seat. Make sure you turn the cutter in the direction indicated by the arrow on the tool. Remove only enough material to clean up the seat and make it totally burnished.

To test the contact between the valve seat and the valve, mark lines with a soft pencil about 1/4 inch apart around the entire face of the valve. Next, put the valve in place and rotate, using a slight pressure, one-half turn to the right and then one-half turn to the left. If rotating removes the pencil marks, the seating is good.

Another method for checking the valve seating is to coat the valve face lightly with

Prussian blue and turn it about one-fourth turn in the seat. If the Prussian blue transfers evenly to the valve seat, it is concentric with the valve guide. Be sure to wash all the Prussian blue from the seat and valve. Then lightly coat the valve seat with Prussian blue. If the blue again transfers evenly, this time to the valve when it is turned in the seat, you can consider the seating to be normal.

Prussian blue is a deep blue pigment mixed with a grease-like substance to stain metal that is often used to check the contact point between the valve face and valve seats. Apply a small amount of Prussian blue on the valve seat or face. Tap the valve down on the seat to mark the Prussian blue and make the contact point visible.

6.7.0 Valve Seat Insert Replacement

Valve seat replacement is needed when a valve seat is cracked, burned, pitted, or recessed in the cylinder head. Replacement is only needed when wear or damage is severe. Normally, valve seats can be machined and returned to service.

To remove a pressed-in valve seat, split the old seat with a sharp chisel. Then pry the seat out of the cylinder head. To remove an integral seat, use a seat-cutting tool to machine the seat from the cylinder head. Extreme care must be taken not to damage the head.

To install a valve seat, a technique used is to shrink the seat by chilling it in dry ice. The seat will expand when returned to room temperature. This helps lock the seat in the cylinder head. Use a driving tool to force the seat into the recess in the head. Seat installation tools vary. Follow the manufacturer's directions.

Staking the valve seat involves placing small dents in the cylinder head next to the seat. The stakes force the head metal over the seat and keep the seat from falling out. Top cutting may be needed to machine the top of the seat flush with the surface of the combustion chamber.

6.8.0 Valve Spring Testing

Corrosion and metal fatigue are common causes of valve spring failure. After prolonged use, valve springs tend to weaken, lose tension, or even break. Broken valve springs cause excessive valve noise and may cause erratic exhaust gas temperatures. When a valve spring breaks, serious damage can occur. When a spring breaks, it may collapse enough to allow the valve to drop into the cylinder, where it can cause damage. Similarly, the valve stem keepers may release the valve and allow it to drop into the cylinder, causing severe damage to the piston, cylinder head, cylinder, and adjoining parts. During engine service, always test each valve spring to make sure it is in working condition.

Valve spring squareness, as shown in *Figure 4-21*, can be checked with a combination square. Place the spring next to the square on a flat surface. Rotate the spring while checking for a gap between the side of the spring and the square. Replace

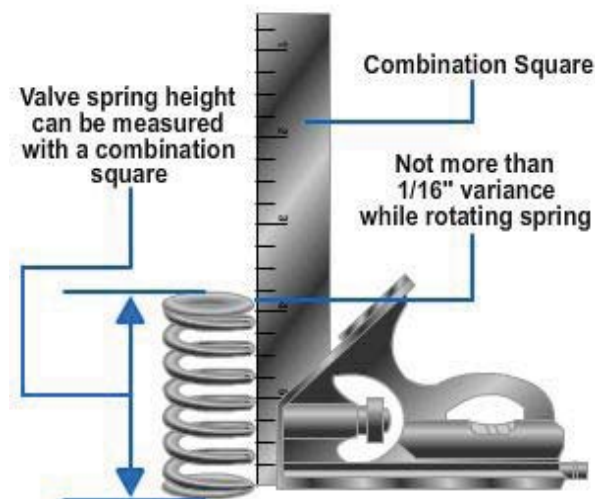


Figure 4-21 – A combination square used to check valve spring squareness.

the spring if it is not square. Not more than 1/16" variance is the norm while rotating the spring.

Valve spring free height can be measured with the combination square or with a valve spring tester (*Figures 4-22*). Simply measure the length of each spring in a normal, uncompressed condition. If too long or too short, replace the spring.

Valve spring tension, or pressure, is measured with a valve spring tester (*Figure 4-22*). Compress the spring to the specified height and read the scale. Spring pressure must be within specifications. If spring pressure is too low, the spring has weakened and needs replacement or shimming. The valve spring tension must be within 10% of the original tension specification. If not, replace the valve.



Figure 4-22 – A valve spring tester

6.9.0 Valve Lifter Servicing

There are two types of valve lifters: the solid type and the hydraulic type. Procedures for removing and servicing the two types are quite different.

Solid lifters are removed from the camshaft side on some engines. This requires removal of the camshaft. The lifters must be held up by clips or wires so that the camshaft can be extracted. Then the clips or wires are removed so that the lifters may be extracted. Most valve lifters can be extracted from the pushrod or valve side of the engine block, in which case extraction of the camshaft is not necessary. Be sure to keep the lifters in the proper order so that they may be replaced in the same bores from which they were removed.

If the lifter screw face is worn or pitted, it may be refaced on a valve re-facing machine. If the lifter bore in the block becomes worn, it maybe re-bored by reaming; then oversized lifters must be installed.

The contact surface between a lifter and a cam lobe is one of the highest friction and wear points in an engine. Hydraulic lifters can also wear internally, causing valve clatter or tapping noise.

Inspect the bottom surface that contacts with the cam lobe of each lifter for wear. An unworn lifter will have a slight hump, or convex shape, on the bottom. A worn lifter will be flat or concave on the bottom. Replace the lifters if the bottom is worn.

Never install used lifters on a new camshaft. Used lifters will cause rapid cam lobe wear and additional lifter wear. Install new lifters



Figure 4-23 – Hydraulic lifters.

whenever a camshaft is replaced.

Lifter leak-down rate is measured by timing how long it takes to push the lifter plunger to the bottom of its stroke under controlled conditions.

6.9.1 Hydraulic Lifters

On some engines, hydraulic lifters, shown in *Figure 4-23*, are tested by the leak-down-rate test. In testing, insert a feeler gauge between the rocker arm and the valve stem, and note the time it takes the valve lifter to leak enough oil to permit the valve to seat. As the valve seats, the feeler gauge becomes loose and signals the end of the test. If the leak-down-rate time is too short, the lifter is defective and must be replaced. In any case, be sure to follow the manufacturer's recommended procedures for performing this test.

To remove the hydraulic lifters, remove the pushrod. On engines with shaft-mounted rocker arms, you can move the rocker arm by compressing the spring so that the pushrod can be removed. Thus, the rocker arm assembly does NOT have to be removed.

After the lifter has been removed, check the bottom or cam side to ensure that it is flat. To do this, place a straightedge across the lifter bottom. If light can be seen between the straightedge and the lifter, the lifter should be discarded.

When disassembling the lifter, be sure to clean all the parts in a cleaning solvent. Reassemble and fill the lifter with clean, light engine oil. Also, make sure that all lifters are replaced in the same bore from which they were removed. Work on one lifter at a time so that parts are not mixed

6.10 Camshaft Checking

The camshaft must be checked for bearing journal or cam wear and alignment. In checking alignment, place the camshaft in a set of V-blocks, and use a dial indicator to check the runout of the journals when the shaft is turned. Journals should be checked with a micrometer and the reading compared to the manufacturer's specifications. The cam wear should be measured with a micrometer; however, if wear shows across the full face of the cam, you can be almost certain that excessive wear has taken place.

6.11.0 Camshaft Bearing Replacement

Cam bearing diameter indicates cam bearing wear. Measure bearing diameter with a bore gauge or a telescoping gauge and an outside micrometer (*Figure 4-24*). A-Dial bore gauge is used to quickly and accurately measure cylinder wear. B-Telescoping gauge used to measure internal part bores or openings. C-Micrometer used for measuring external dimensions, diameters, or thicknesses.

If the bearings are worn, they must be replaced. Generally the mechanic will replace the cam bearings during an engine overhaul since they are critical to engine oil pressure.



Figure 4-24 - Tools used for camshaft bearing replacement

The two-piece cam bearings used on many OHC engines simply snap into place, like rod and main bearings. However, one-piece cam bearings must be forced in and out of the block or head with a special tool.

When installing cam bearings, do not dent or mar the bearing surfaces. Also, make sure you align the oil holes in the engine with the holes in the cam bearings. Since exact procedures vary, refer to the OEM for details.

6.12.0 Valve Timing

The relationship between the camshaft and the crankshaft determines the valve timing. Gears, drive chains, and reinforced neoprene belts are used to drive the camshafts that open and allow the valves to close in relation to the position of the pistons in the cylinders. The gear drive sprockets, or cogs as the case may be, of the camshaft, and crankshafts are keyed in position so they cannot slip.

With directly driven timing gears, one gear usually has a mark on two adjacent teeth, and the other, a mark on only one tooth. To time the valves properly, you need to mesh the gears so that the two marked teeth of the one gear straddle the single marked tooth of the other gear. In chain-driven sprockets, you can obtain correct timing by having a certain number of chain teeth between the marks or by lining up the marks with a straightedge. Engines using a continuous neoprene belt have sprockets, or cogs, attached to the camshaft and crankshaft. The belt has square-shaped internal teeth that mesh with the teeth on the sprockets. All engines with this system use a timing belt tensioner. Timing marks on this system vary with each manufacturer.

7.0.0 CRANKSHAFT SERVICING

7.1.0 Bearing Cap Removal

When removing bearing caps, if they are not already marked, be sure to mark them so they will be replaced on the same journal from which they were removed. If bearing caps stick, carefully work them loose by using a soft-faced hammer, to avoid distorting them, and tapping the cap lightly on one side and then the other.



Figure 4-25 – A broken crankshaft.

7.2.0 Crankshaft Removal

The crankshaft is one of the most highly stressed engine components. The stress increases four times as the engine speed doubles. The crankshaft must be rejected if there is any sign of a crack because a cracked crankshaft may break if it continues in service (*Figure 4-25*). Crankshaft cracks can be detected initially with a close visual inspection.

Once the bearing caps have been removed, lift the crankshaft out of the engine block. Usually one or two people do this seemingly simple operation by hand. With larger crankshafts, use a hoist as demonstrated in *Figure 4-26* by lifting above the center with a rope sling around two of the throws.



Do not "bang" around or put unnecessary stress on the crankshaft, causing damage that will have to be repaired prior to the crankshaft being re-installed into the engine, which will result in needless down time and expense.



Figure 4-26 - Removing the crankshaft with a hoist.

7.3.0 Crankshaft Journal Check

Journals wear out-of-round and become tapered. Out-of-round and taper are measured using a micrometer to take measurements at a number of different locations on each journal. Rough journals and slight bends can be rectified by grinding the journals on true centers. Forged shafts with excess bend should be straightened before grinding.

The preferred method of measuring crankshaft journals is as follows. Remove the crankshaft from the engine block and clean the surfaces to be measured. Using the outside micrometer, measure the journals at several points from side to side and from top to bottom across the bearing surface (*Figure 4-27*). Measurements around the journal will show if the journal is out of round.

Those measurements across the surface show if the journal is tapered. If one side of a crankshaft journal is worn more than the other, the journal is tapered. To measure journal taper, use the outside micrometer. Measure both ends of each journal. Journals that are tapered or out-of-round more than .003 must be reground. Be sure that you always refer to manufacturer's specifications when performing any crankshaft work. If not within spec limits, send the crankshaft for turning.

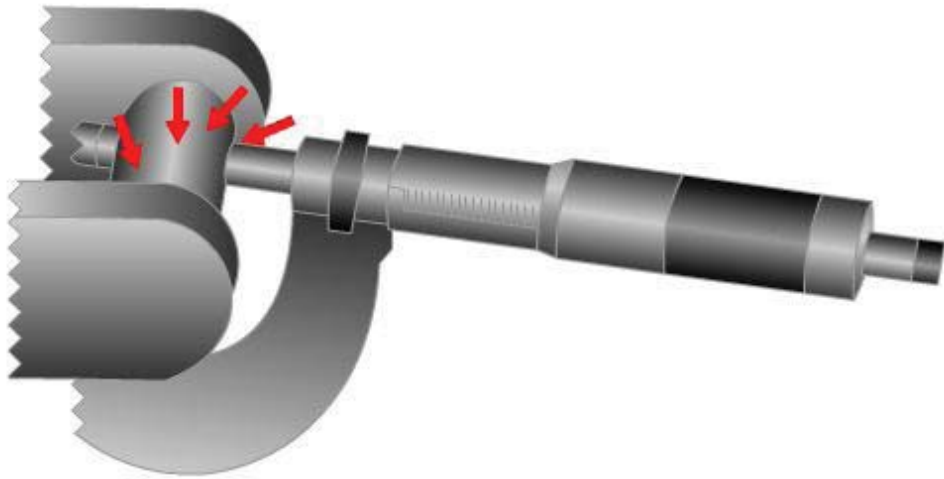


Figure 4-27 - Measuring journals

7.4.0 Checking or Bearing Fit

You should always check bearing fit or oil clearance when installing new bearings. When the bearing caps are off, you should measure the journals so that you can detect wear, out of roundness, or taper. You can check bearing clearance with either feeler stock or Plastigage (*Figure 4-28*).

Plastigage is a small plastic string that is used to measure a very tight clearance between two engine half circle metal bearings that enclose a spinning circular crankshaft, camshaft, or piston tie rod end.

Plastigage is cut and laid across the width of the contact surface. The two half circle bearings are assembled and tightened to factory specifications, then disassembled to examine the Plastigage width.

The width of the compressed Plastigage indicates clearance between the parts. The range of Plastigage is determined by its color: green for 0.001-0.003-inch, red for 0.002-0.006, and blue for 0.004-0.009-inch clearances.

Before checking bearing clearance with Plastigage, wipe the journal and the bearing clean of oil. Then place a strip of the Plastigage lengthwise in the center of the bearing cap. Install the cap next and tighten it into place. When the cap is removed, you can measure the amount of flattening of the strip with a special scale. Do NOT remove the flattened strip from the cap or the journal to measure the width, but measure it in place. Not only does the amount of flattening measure bearing clearance, but uneven flattening also indicates a tapered or worn crankshaft journal or bearing.



CAUTION



Do not turn the crankshaft with the Plastigage in place.

When using feeler stock to check main bearing clearances, place a piece of stock of the



Figure 4-28 – Using Plastigage to check bearing clearance.

correct size and thickness in the bearing cap after it is removed. Coat the feeler stock lightly with oil. Then replace and tighten the bearing cap. Note the ease with which the crankshaft can be turned. As a word of caution, do not completely rotate the engine, which could damage the bearing. Turn it only about an inch in one direction or the other.

If the crankshaft is locked or drags noticeably after the bearing cap has been replaced and tightened, then the bearing clearance is less than the thickness of the feeler stock. If it does not tighten or drag, place an additional thickness of feeler stock on top of the first and again check the ease of crankshaft movement. Clearance normally should be about .002 inch. Be sure to check the engine manual for exact specifications.

7.5.0 Crankshaft Installation

Install the main bearing upper halves, following the order established during disassembly. Align the holes in each bearing shell with its mating port in the cylinder block. Apply a film of engine oil to each bearing wear surface and crankshaft journal. Lubricate the back of the bearings.

Make certain the crankshaft is clean prior to installing it in the cylinder block. Carefully lift and install the crankshaft into the cylinder block using a hoist and slings positioned to balance the weight. Slide the thrust washer upper halves into the cylinder block at the proper locations. Ensure the lubrication grooves in each bearing half are positioned to face toward the crankshaft wear surface. Install the main bearing lower halves onto their respective bearing caps, observing the order established during disassembly. At this point in the reassembly, a bearing clearance check using Plastigage may be performed.

Apply a film of engine oil to the wear surface of each bearing shell. Install the main bearing caps according to the order observed during disassembly. Install the bearing cap mounting bolts and washers. Snug the bolts but do not tighten, as the manual may specify a specific tightening sequence. After checking the service manual, tighten the bearing cap bolts to specification.

7.6.0 Crankshaft End Play Check

Crankshaft end play is the amount of front-to-rear movement of the crankshaft in the block. It is controlled by the clearance between the main thrust bearing and the crankshaft thrust surface or journal. Crankshaft end play will become excessive if the thrust bearings are worn, producing a sharp, irregular knock. If the wear is considerable, the knock will occur each time the clutch is engaged or released; this action causes sudden endwise movement of the crankshaft.

Crankshaft end play should only be a few thousandths of an inch. To measure this end play, you can use a feeler gauge as shown in *Figure 4-29*, or mount a dial indicator on the block. Position the dial indicator against the crankshaft so that the indicator stem is parallel to the crank centerline.

Pry the crankshaft back and forth in the block. Indicator movement equals crankshaft end play. Compare the measurements to the specifications. If the end play is incorrect, check the thrust bearing insert size and the crankshaft thrust journal width.

7.7.0 Crankshaft Storage

When removing the crankshaft with rigging, be sure to protect machined surfaces. Avoid laying down a crankshaft because it can warp out of shape or become bent. When storing a crankshaft, make certain it has support along the shaft's entire length to prevent warping. If the crankshaft is small enough, it may be possible to simply stand it on the flywheel end. Also, do not store crankshaft or bearing parts on any metal surface. When a shaft is removed from the engine, it should be placed on a wooden plank with all journal surfaces protected. If the shaft is to be exposed for some time, it is best to protect each journal surface with a coating of heavy grease.

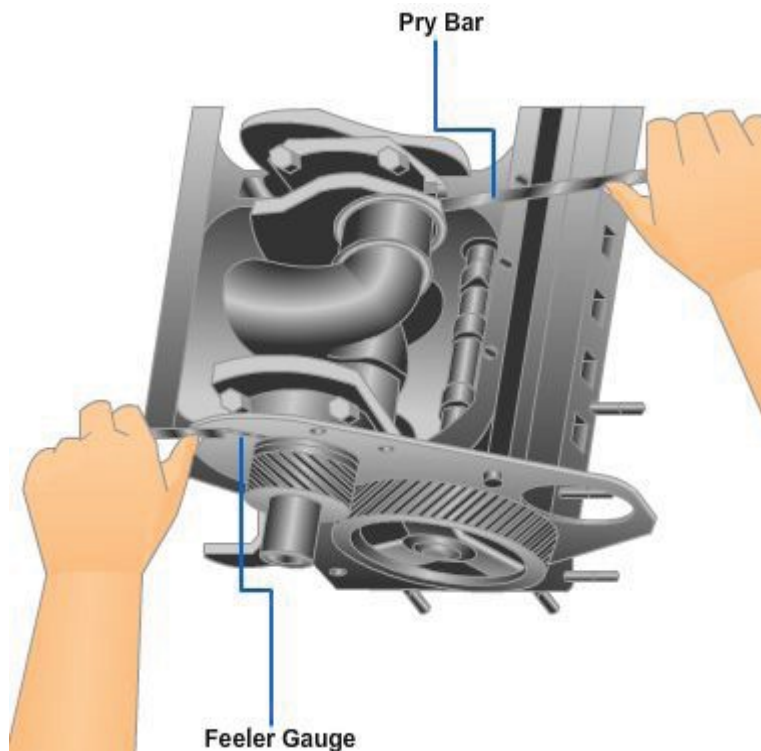


Figure 4-29 - Checking crankshaft end play using a feeler gauge.

8.0.0 CYLINDER SERVICING

There are certain limits to which cylinders may become tapered or out-of-round before they require refinishing. If they have only a slight taper or are only slightly out-of-round (consult the manufacturer's manual for the maximum allowable taper or out-of-round), new standard rings can be installed.

When cylinder wear goes beyond the point recommended in the engine manufacturer's specifications, loss of compression, high oil consumption, poor performance, and heavy carbon accumulations in the cylinder will result. In such cases, the only way to put the engine back into good operating condition is to refinish the cylinders and fit new pistons (or oversized pistons) and rings.

8.1.0 Cylinder Walls Check

As a first step in checking cylinder walls, wipe them clean and examine them carefully for scored places and spotty wear (which shows up as dark, unpolished spots on the walls). Holding a droplight at the opposite end of the cylinder from the eye will help in the examination. If scores or spots are found, you should refinish the cylinder walls. Next, measure the cylinders for taper and oval wear. This can be done with an inside micrometer or by a special dial indicator. As the dial indicator is moved up and down in

the cylinder and turned from one position to another, any irregularities will cause the needle to move. This will indicate how many thousandths of an inch the cylinder is out-of-round or tapered. The permissible amount of taper or out-of-roundness in a cylinder varies somewhat with different engines. Engine manufacturers issue recommendations based on experience with their own engines. When the recommendations are exceeded, the cylinders have to be refinished.

Cylinder taper is the difference in the diameters measured at the top of the cylinder and at the bottom of the cylinder. It is caused by less lubricating oil at the top of the cylinder and more oil splashing on the lower area of the cylinder. As a result, the top of the cylinder wears faster (larger) than the bottom, producing taper.

Cylinder out-of-roundness is a difference in cylinder diameter when measured front-to-rear and side-to-side in the block. Piston thrust action normally makes the cylinder wear more at right angles to the centerline of the crankshaft. Maximum allowable cylinder out-of-round is typically 0.00005".

A dial bore gauge is a tool used to quickly and accurately measure cylinder wear (*Figure 4-30*). Slide the bore gauge up and down the cylinder



Figure 4-30 – Dial bore gauge.

8.2.0 Cylinder Refinishing

There are two methods of refinishing cylinders: honing and boring. Cylinders are refinished by honing when wear is not too great; otherwise, they are bored with a machine, and oversized pistons and rings are installed.

Cylinder honing is used to true worn cylinders and to break the glaze on used cylinders before installing new piston rings. It must also be used to smooth rough cylinders after boring.

The term deglazing is generally used when referring to very light honing that simply scuffs the cylinder wall to aid ring break-in. The glazed cylinder wall causes rings to "skate" on the highly polished finish and discourages the minute amount of wear which is necessary to mate piston rings with the bore.

8.2.1 Cylinder Honing

A cylinder hone produces precisely textured, cross-hatched pattern on the cylinder wall to aid ring seating and sealing. Tiny scratches from the hone cause initial ring and cylinder wall break-in wear. This makes the ring fit in the cylinder perfectly after only a few minutes of engine operation.

There are several types of hones:

- Brush hone-has small balls of abrasive material formed on the ends of round metal brush bristles. It is desirable when the cylinder is in good condition and requires very little honing (*Figure 4-31, View A*).

- Flex hone-has hard, flat, abrasive stones attached, to spring-loaded, movable arms. It is used when the cylinder wear is slight and a moderate amount of honing is needed (*Figure 4-3, View B*).
- Rigid hone (sizing hone)-has adjustable stones that lock into a preset position. It will remove a small amount of cylinder taper or out-of-roundness (*Figure 4-31, View C*). A rigid hone will accurately remove more cylinder material than a flex hone. This type of hone should be used in badly worn cylinders that are still within spec. wear limits.
- Honing machine-a large piece of equipment used to rigid hone the cylinders. This type of machine is often found in a machine shop and is used after boring (*Figure 4-31, View D*).



Figure 4-31 – Type of hones.

A rigid hone or a honing machine can be used like a boring bar to true a cylinder when wear does not exceed acceptable limits. Do not hone more than manufacturer's recommendations.

After honing, it is very important to remove all honing grit (bits of stone and metal) from inside the engine. If this grit is not removed, it will act like grinding compound on bearings, rings, and other vital engine parts.

First, wash out the cylinders with a warm solution of water and soap. A soft bristle brush, not a wire brush, will quickly loosen particles inside the honing marks on the cylinder walls. After washing, rinse the block thoroughly with clean, hot water and blow the cylinders dry with compressed air.

Next, soak a clean shop rag in fresh engine oil and wipe the cylinder down thoroughly with the oil-soaked rag. The heavy oil will pick up any remaining grit embedded in the cylinder's honing marks. Wipe the cylinders down until the rag comes out perfectly clean.

After cleaning and oiling, recheck the cylinder for scoring and scratches. If honing did not clean up all the vertical scratches in the cylinder, cylinder boring or sleeving may be needed.

8.2.2 Cylinder Boring

Cylinder boring is needed to remove deep scratches, scoring, or excess wear from the cylinder walls. It involves machining the cylinders to a larger diameter. After boring,

oversized pistons must be installed in the engine.

The machine shop will use a large boring bar (machine tool) to cut a thin layer of metal off the cylinder walls. Normally a cylinder block is bored in increments of 0.010" or 0.25 mm.

Overbore limit, typically 0.030" - 0.060", is the largest possible diameter increase to which a cylinder can be bored. It is specified by the engine manufacturer and can vary with block design. If the overbore limit is exceeded, the cylinder wall can become too thin. The wall can distort or crack when used from combustion heat or pressure

Oversized pistons and rings are required to fit a cylinder block that has had its cylinders bored out. The pistons must match the oversize of the cylinders.

Boring cylinders and installing oversized pistons will help restore the engine to like-new condition. New pistons and rings will operate on freshly machined cylinder surfaces, providing excellent ring sealing and renewed life to the engine.

Cylinder sleeving involves machining one or more of the cylinders oversize and pressing in a cylinder liner. Sleeving is needed when the damage to the cylinder wall is too severe to correct with boring.

Sleeving allows the bad cylinder to be restored to its original diameter. The same size pistons can be reused. If only one cylinder is damaged, for instance, all of the other pistons and cylinders may be good and usable. This provides savings in time and money.

8.3.0 Cylinder Liners Placement

Using replaceable cylinder liners can save time and costly machine work. First, determine the type of liners, wet or dry, that are used in the unit being rebuilt. Dry liners do not require a water seal and can simply be pulled out and the new liner pressed into place. Wet liners have grooves cut into them for fitting O-ring seals to prevent water leakage into the crankcase.



When installing the wet type of liners, use care to prevent damage to the O-ring seals.

8.3.1 Dry Cylinder Liners

Before installing press-fit dry sleeves, inspect and measure the cylinder diameters. If the cylinders are distorted, the block must be rebored to accept oversized liners. Otherwise, the sleeves may conform to the distorted cylinders. In some cases, air pockets will form between the sleeves and the block, causing localized hot spots that often result in a breakdown of the contact surfaces. Check the cylinder sleeve's outside diameter with an outside micrometer. Before installing the sleeve, heat the block and pack the sleeve with dry ice. After removing the dry ice from the sleeve, coat it with an appropriate lubricant and press or drive it into the cylinder until it touches the lip at the bottom of the cylinder. To drive the sleeve down into the cylinder, use a cylinder driver or hammer and a sleeve driver.

When installed properly, the sleeve will extend slightly above the deck of the block. A boring bar with a face tool installed in the cutter head is used to machine the top of the sleeve flush with the deck. After installation, the sleeve should be bored to the desired size, just like any other cylinder. The sleeved cylinder is then chamfered and washed.

The important factors to consider when installing a dry liner with a flange include the

following:

- If fitted correctly, a flanged liner should enter the cylinder block one-half to three-quarters of its length and require only a light tapping to gently set it in place against the base of the counterbore.
- A liner that is loose will not make proper contact with the cylinder block and will result in poor heat dissipation. A loose fit can be spotted by an accumulation of carbon deposits on the liner's outside diameter and distinct dark areas caused by the restricted heat. This occurs because the deposits will act as a heat dam, which restricts the heat from being dissipated into the block and coolant.
- A liner that is tight can cause serious damage-even more damage than one that is too loose. Block distortion, liner collapse, poor heat transfer, hot spots, and scuffing are common results of excessive tightness.

8.3.2 Wet Cylinder Liners

Before installing a wet cylinder liner, clean all deposits from under the liner's flange and the mating counterbore in the cylinder block. The liner must rest flatly in the counterbore to prevent distortion; if the flange surface is uneven, re-machine it.

Clean the lower sealing surfaces in the block and on the liner to prevent coolant leaks when the liner is installed. Place new seals on the liner and lubricate both the seals and mating surfaces in the block. Check to be sure the seals are not twisted or crimped. A roll or twist increases the density of the seal in the area of the twist. The dense area produced by the twist creates a hard spot that attracts heat. A twisted seal can also distort the liner, reduce the piston operating clearance, and promote failure.

To remove twists from seals, insert the shaft of a small screwdriver under the seal at a right angle to the seal groove and rotate the screwdriver around the liner three or four times. On O-rings, a parting line is usually visible in the center of the outside diameter of the seal. This line should be parallel to the groove when the twist is eliminated.

Insert the liner into the cylinder until it contacts the crevice seal, place the palms of your hands on the upper end of the liner, and push it downward with quick, even pressure.

To continue the installation, tap the liner near its inside diameter with a large, soft-faced hammer. Tap alternately from side to side, gradually working around the entire circumference of the liner. When the liner is 1.5" above the deck, blow some compressed air into the counterbore to remove any material that may have accumulated. Deposits in the counterbore can cause distortion of the liner. When the counterbore is clean, continue to drive the liner fully into the block.

After the liner is seated properly, clean the liner flange with a brass wire brush to ensure an accurate measurement of the flange height above the block deck. Check the flange height above the block deck using a sled dial arrangement.

If a cylinder block deck is resurfaced, the cylinder block counterbore depth must be recut to specifications. If the cylinder block deck has not been resurfaced, but there is excessive pitting or erosion of the cylinder block counterbore, recut the counter bore as required.

Shims are also available to re-establish the correct flange height. Shims are manufactured in various thicknesses. Use only the number of shims necessary to obtain the correct liner height. Check the shim's thickness with a micrometer. If more than one shim is required, position the thickest shim on the bottom of the counterbore. Position the shim(s) into the cylinder liner counterbore.

When installation is complete, carefully clean the cylinder liner as previously described. Check the liner diameter using a dial bore gauge. Take readings at 180° apart at two levels.

After installing a new wet liner, check the top of the block and the cylinder heads for flatness. Check the counterbore depths for waviness and variations. Be sure counterbores are clean and free of dirt and carbon. Also measure the liner flange height.

9.0.0 PISTONS and RINGS SERVICING

When service is required on pistons and rings, they must first be removed from the engine. Where removal is to be from the top of the cylinder block, take the cylinder head off and examine the cylinder for wear. If the cylinder is worn, there will be a ridge at the upper limit of the top ring travel. Remove this ridge. If not removed, it will damage the piston and rings as they are forced out of the top of the cylinder.

To remove this ridge, use a reamer. Before placing the ridge reamer in the cylinder, be sure the piston has been placed at BDC. Stuff rags into the cylinder to protect the piston and piston rings from metal shavings during the reaming operation. Be sure to adjust the cutters to the correct depth of cut. After the reaming operation is complete, remove the rags and wipe the cylinder wall clean. Repeat the operation for each cylinder.

Before you can detach the connecting rods from the crankshaft, you must remove the oil pan. With the cylinder head and oil pan off, crank the engine so that the piston of the No.1 cylinder is near BDC. Examine the piston rod and rod cap for identifying marks, and, if none can be seen, mark them with numbering dies to ensure replacing them in the same cylinders from which they were removed. Remove the rod nuts and cap them with a wrench, and slide the rod and piston assembly up into the cylinder away from the crankshaft and out of the cylinder. Place the assembly on a workbench and repeat this operation until all piston and rod assemblies have been removed.

9.1.1 Piston Cleaning

After the piston assemblies are removed from the engine and disassembled, clean them with a detergent solution or an approved solvent, and blown dry with compressed air. To remove stubborn carbon deposits, use a chemical solvent that does not harm the piston's surface coating. Never scrape the piston with a groove cleaner or a broken piston ring. Hard scraping will scratch the machined surfaces of the piston. The two best methods of cleaning pistons are chemical and bead cleaning.

- Chemical soaking in a recommended piston cleaner will soften the carbon on the piston. The carbon can then be easily removed using a pressure rinse that will minimize any chance of damage. Be sure to follow the solution manufacturer's instructions for proper use.
- In bead cleaning, the pistons are blasted with glass beads, crushed walnut shells, or other material, using a machine. After this, the pistons are cleaned as after the chemical soaking method, following the manufacturer's instructions on the use of the cleaning product.

After the pistons have been cleaned, lightly engrave the proper bore number on the bottom of the piston to ensure the piston is reinstalled in the proper cylinder.



WARNING

Never use gasoline to clean parts. Gasoline is highly volatile, and the slightest spark or flame could ignite the fumes causing a deadly fire.



WARNING

Use extreme care when using an air gun. Wear goggles and avoid aiming the gun at yourself or anyone else. If air is injected into the bloodstream, death could result.

9.2.1 Piston Fitting

Pistons are made of aluminum, which is prone to wear and damage. It is critical that each piston be checked thoroughly. Look for cracked skirts, worn ring grooves, cracked ring lands, worn pin bores, and any other wear or damage. Trouble that could affect piston performance and service life must be identified.

After the piston has been cleaned, use a large outside micrometer to measure piston wear. Compare the readings to the specifications to determine the amount of wear that has occurred. The specifications will detail the measurements and allowable clearances as well as the maximum and minimum allowable piston and cylinder wall taper. Most of the pistons encountered will be cam ground pistons. A piston has a major axis and minor axis. The major axis is at right angles to the piston pin, and the minor axis is parallel to the piston pin. Both trunk and crosshead pistons are frequently cam ground, so that they are slightly elliptical rather than perfectly round. A cam ground piston is constructed so that its diameter parallel to the minor axis is less than that along the major axis. This is done to compensate for the different rates of thermal expansion that occur in the piston's minor and major axis diameters (*Figure 4-32*). Since the pin bore boss causes the minor axis to be thicker than the major axis, it expands more as it heats up. Therefore, the diameter parallel to this axis is smaller to allow for greater expansion.

Piston size is measured on the skirt, just below the piston pin hole. Adjust the micrometer for a slight drag it is pulled over the piston. If the piston wear exceeds specifications, replace or knurl the piston(s).

Piston taper is measured by comparing piston diameter at the top, even with the pin hole, of the skirt-to-piston diameter at the bottom of the skirt. The difference between the two measurements equals piston taper. If taper is not within the service manual limits, replace or knurl the piston.

Piston knurling can be used to increase the diameter of the skirt a few thousandths of an inch. Knurling makes dents in the skirts, pushing up the metal next to the dents. This increases the piston diameter.

To find the piston clearance, subtract the piston diameter from the cylinder diameter. The difference between the cylinder diameter measurement and the piston diameter measurement will equal piston clearance.

Average piston-to-cylinder clearance is about 0.001". Since specifications vary, always refer to the service manual.

Another way of measuring piston clearance is using a long, flat feeler gauge which is placed on the piston skirt; then the gauge and piston are pushed into the cylinder. A spring scale is used to pull the feeler gauge out of the cylinder. When the spring scale reading equals specifications, the size of the feeler gauge equals piston clearance.

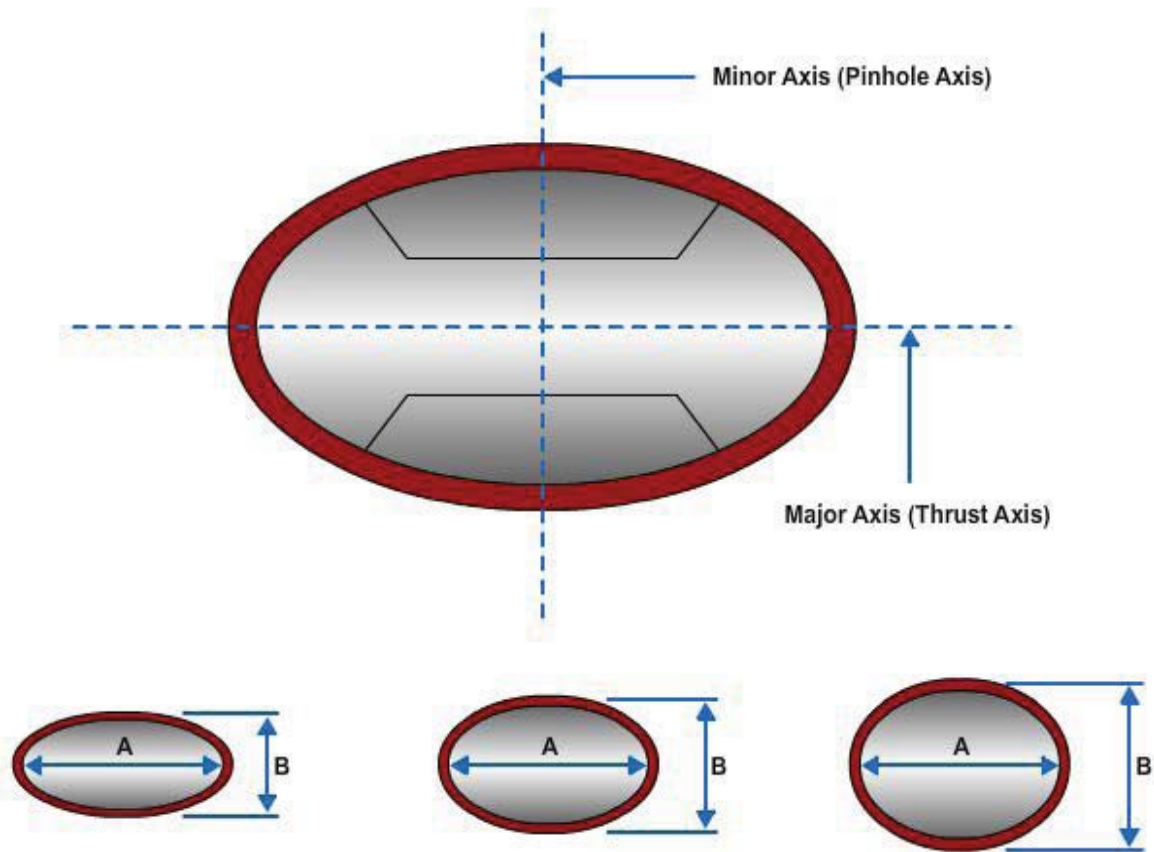


Figure 4-32 -Cam ground pistons are elliptical in shape.

When piston-to-cylinder clearance is excessive, do the following:

- Knurl the pistons.
- Install new standard-size pistons, providing cylinders are not worn beyond specifications.
- Bore the cylinders and install oversized pistons.
- Sleeve the cylinders.

9.3.1 Piston Pins Fitting

Depending on the type and make of engine, the piston pin may either be free-floating or press-fit:

- **Free-floating**--where the pin will turn in both the rod and piston (*Figure 4-33*).
- **Press-fit**-- where the pin is force-fit into the rod but



Figure 4-33 - A free-floating piston.

turns in the piston.

During piston and rod service, check the pin clearance on both free-floating and press-fit pins. Check the pin-to-connecting-rod fit on the free-floating piston pins. With press-fit pins, the piston pin should be locked tightly in the connecting rod.

To check excessive piston pin clearance, clamp the connecting rod I-beam lightly in a vise and, holding the piston straight up, rock the piston. If play can be detected, the pin, rod bushing, or piston bore is worn. A small telescoping gauge and an outside micrometer should be used to determine exact clearance after pin removal.

To remove a free-floating pin from the piston, use snap ring pliers to compress and fit out the snap rings on each end of the pin. Then, push the pin out of the piston with your thumb. In some cases, a brass drift and light hammer blows may be needed to drive the pin from the piston.

When the pin is worn, it should be replaced. If the pin bore in the piston measures larger than specifications, the piston must generally be replaced. In some cases, the pin bores can be reamed larger and oversized piston pins can be used.

To remove a pressed-in piston pin, you will need to use a press and a driver setup.



When pressing out piston pins, wear eye protection and make sure the piston is secured.

Measure pin and pin bore wear. Compare your measurements to the specifications and replace or repair parts as needed. If needed, send new pistons and pins to the machine shop for fitting.

Before installing a piston pin, make sure the piston is facing in the right direction in relation to the connecting rod. Normally, a piston will have a marking on its head that should point toward the front of the engine.

One edge of the connecting rod's big end bore end must face the outside of the crank journal during piston installation. The rod may also have an oil spray hole or rod numbers that must face in a specified direction. Check the vehicle's shop manual for directions.

To start a pressed-in piston-pin, tap it into the piston bore with a brass hammer. Then use a press to force the pin into the piston. The connecting rod small end must be centered on the pin.

After pushing a free-floating piston pin into the piston, install the snap rings to secure the pin. Make sure the snap rings are fully seated in their grooves.

9.4.0 Piston Rings Fitting

Before installing piston rings, the piston should be cleaned and the ring grooves checked for carbon or dirt deposits. Rings must be installed with the top side up to provide proper oil control. Refer to the service manual for the proper instructions on the piston rings being installed. Generally, each new ring set contains an instruction sheet.

Install the compression rings on the piston and stagger the ring gaps. To avoid overstressing the rings during installation, do not spread the rings more than needed to slip them onto the piston. Using a ring expander will make this task much easier (*Figure 4-34*).

The use of a ring expander prevents the possibility of overspreading the rings. Select the correct ring for the ring groove. Use the ring expander tool to expand the piston ring, and then place the ring and tool over the piston. Set the ring in the groove and release the tool. Double check the installation to make sure that the ring is in the right groove and is not upside down.



Figure 4-34 – A piston ring.

Generally, the oil control rings are installed with the scraping edge down. Make sure that the ring ends do not overlap. Install the bottom ring with the gap positioned 45° from the top oil ring gap. A common method for checking the ring gap and clearance is shown in *Figure 4-35*. To determine whether the ring has the proper end gap, place it in the cylinder, pushing it about halfway down in the cylinder bore. With the ring square with the cylinder bore (use a piston to straighten the ring in the cylinder), measure the gap between the ring ends with the feeler gauge. If the gap is less than the minimum specified, remove the ring and dress ends with a fine-cut mill file until correct clearance is obtained.

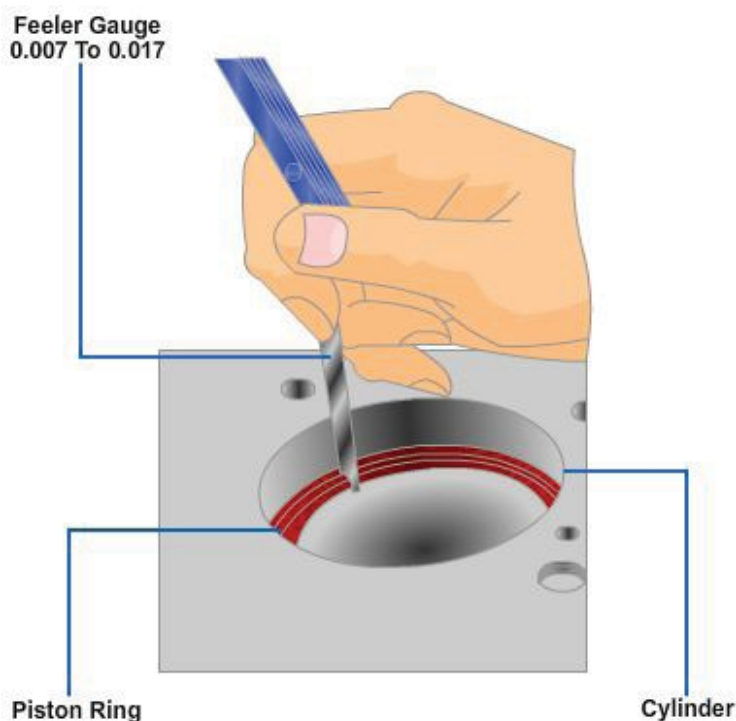


Figure 4-35 – Checking piston ring gap.

10.1.1 OPERATIONAL TESTING

Large engines are expensive items. Repairs, as evidenced by the preceding overhaul procedures, are costly and time consuming. The engine must be properly run-in before being released for use. Because of this, to get the most out of the newly overhauled engine, use proper initial startup and run-in procedures. The durability and service life of a rebuilt engine are directly affected by the quality of the run-in procedures.

An engine can be run-in using one of three methods:

1. Highway run-in
2. Engine dynamometer

3. Chassis dynamometer

The exact procedure for the run-in will vary depending on the type of method used, but in all cases the rebuilt engine must be properly prepared before starting for the first time.

10.1.0 Pre-startup

Regardless of the method used for engine run-in, the engine must be properly prepared before starting for the first time. The following may be used as a general guide:

Lubrication System: The lubricating oil film of the rotating parts and bearings of an overhauled engine is usually insufficient for proper lubrication when the engine is started for the first time after an overhaul. Install new oil filters and fill a pressure prelubricator (usually an electrically or pneumatically actuated oil pump) with the OEM recommended oil and connect the supply line to the main oil gallery. Prime the engine lubrication system with sufficient oil. There are various points on the engine into which the pressure line may be tapped, but if no other is apparent, the oil gauge line may be disconnected and the pressure tank applied at that point. Remove the oil level dipstick, and check the crankcase level. Add oil, if necessary, to bring it to the full mark on the dipstick.



DO NOT OVERFILL! Excessive overfilling of the lubrication system will cause damage.

When using a prelubricator, it is unnecessary to prime the oil filters. Some OEMs prefer that the oil filters are never primed due to the risk of contaminating the oil during the procedure. When priming filters, pour the oil into the inlet side of the filter and never into the outlet side.

Turbocharger: Disconnect the turbocharger oil inlet line and pour approximately one pint of clean engine oil into the turbo, ensuring that the bearings are lubricated for the startup. Reconnect the oil line.

Air Intake System: Check the integrity of the air intake system, checking all the hose clamps, support clamps, piping, charge air cleaner, and the air cleaner element(s). Always replace the air cleaner element after an engine overhaul.

Cooling System: Fit a new coolant filter and if required, separate conditioning additives. Fill the cooling system with the recommended coolant mixture. Ensure that all or at least most air is purged from the cooling system. Remove a plug from the water manifold during filling to facilitate air to escape.

Fuel System: Install new fuel filters, priming them as required, with the correct grade of filtered fuel. Next, prime the fuel system by actuating a hand pump or external priming pump.



Avoid priming a fuel system by charging the fuel tanks with compressed air. This practice can be particularly dangerous when ambient temperatures are high.

Electrical System: Ensure that the batteries hold a proper level of charge. This is especially critical with some electronically managed engines in which the engine/electronic control module requires a specific minimum operating voltage.

Recheck all mounting bolts, and be sure that all belt drives are in place and proper

tension. Check around to ensure there are no loose objects or items lying around to get caught into moving components.

10.2.0 Initial Startup and Run-in

Upon starting the newly overhauled engine, if you do not observe any oil pressure in the first 10 to 15 seconds, shut the engine down and find the cause. If oil pressure is observed, allow the engine to warm up at an idle. Do NOT load the engine before it is fully warmed up. During this warm-up period, check for any leaks and listen for any abnormal noises that could indicate trouble. After the warm-up period, shut the engine down and check all fluid levels, repair any leaks, and re-torque. In the case of any bolts, tighten as required.

After doing a thorough re-inspection of the vehicle, re-start the engine and prepare for a road test. In the case of road type vehicles such as pickups, tractor-trailers, and dump trucks, operate any auxiliary components such as a dump bed and hook a trailer up to the tractor before heading out on the road.

Once on the road, bring the vehicle up to speed and test the performance through the torque rise profile. Operate through all the operating gears and loads as feasible. A road test of at least 30 minutes after the specified engine operating temperature has been reached is usually adequate to break in a rebuilt engine. When diagnosing engine malfunctions, the road test duration will depend on the data revealed during the route.

10.2.1 500-Mile/50-Hour Check

The most probable time for a newly overhauled engine to malfunction is during its initial run-in and break-in period. Therefore, it is absolutely necessary that when these units are returned to service, they are done so with special instructions to the dispatcher and yard boss; for instance, only light loads for the first 500 miles/50 hours, and watch all fluid levels, temperatures, and pressures carefully. Last, ensure that the unit is brought into the shop after the break-in period for an oil and filter change. The unit is now ready for full service.

Summary

This chapter presented information on engine troubleshooting and overhaul that you, as supervisor, will be able to use to help your mechanics do an efficient and competent job maintaining the NCF's automotive and heavy equipment engines. This information included a discussion of the different types of horsepower, graphs and diagrams used to describe engine performance, causes of power loss and failure, and care and maintenance of engine gauges and test equipment. This chapter also provided troubleshooting guidelines for various engine components such as valves, camshafts, crankshafts, cylinders, and pistons. Finally, you were given information on performing a pre-start check of all systems and components, as well as a run-in to make sure the vehicle/equipment is ready for use.

Review Questions (Select the Correct Response)

1. **(True or False)** Observing the highest degree of cleanliness in handling engine parts during overhaul is an elementary principle that applies to engine troubleshooting and overhaul.

A. True
B. False
2. The amount of work produced on the power stroke can be determined by what formula?

A. Torque x Pressure
B. Force x Pressure
C. Force x Distance
D. Distance x Time
3. Horsepower was the "invention" of_____.

A. James Watt
B. Rudolf Diesel
C. John Waite
D. Nikolaus August Otto
4. The formula for 1 horsepower is_____.

A. Minute / 33,000 ft/lb
B. 33,000 ft. / hour
C. 330 ft/lb. / minute
D. 33,000 ft/lb. / minute
5. Air in its compressed state and contained in a reservoir has the potential for creating motion. What type of energy is this?

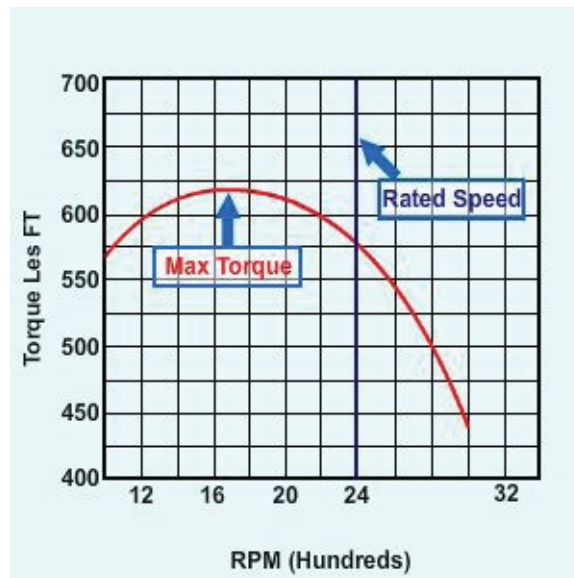
A. Kinetic
B. Potential
C. Heat
D. Impending
6. In a diesel engine, force is represented by what type of pressure?

A. Pneumatic
B. Piston
C. Cylinder
D. Valve

7. Torque very simply is_____effort.
- A. twisting
 - B. turning
 - C. thrusting
 - D. cranking
8. **(True or False)** The formula for indicated horsepower is $P \times L \times A \times N \times C / 33,000$.
- A. True
 - B. False
9. A four-stroke-cycle, eight-cylinder diesel engine with a bore of 6.0" and stroke of 6.5" is run at a speed of 2,500 rpm. The mean effective pressure obtained from an indicator diagram is specified as 240 psi. Calculate the indicated horsepower of the engine.
- A. 11145.1
 - B. 1114.51
 - C. 111.451
 - D. 22290.19
10. Brake horsepower is measures at what component?
- A. Driveshaft
 - B. Crankshaft
 - C. Differential
 - D. Flywheel
11. **(True or False)** A dynamometer is used to accurately measure torque.
- A. True
 - B. False
12. What piece of test equipment enables the mechanic to fully load test the engine before it is reinstalled?
- A. Engine overhauler
 - B. Chassis dynamometer
 - C. Engine dynamometer
 - D. Engine dynamics analyzer
13. The chassis dynamometer allows for a controlled vehicle_____.
- A. run-in
 - B. run-out
 - C. tie-in
 - D. None of the above

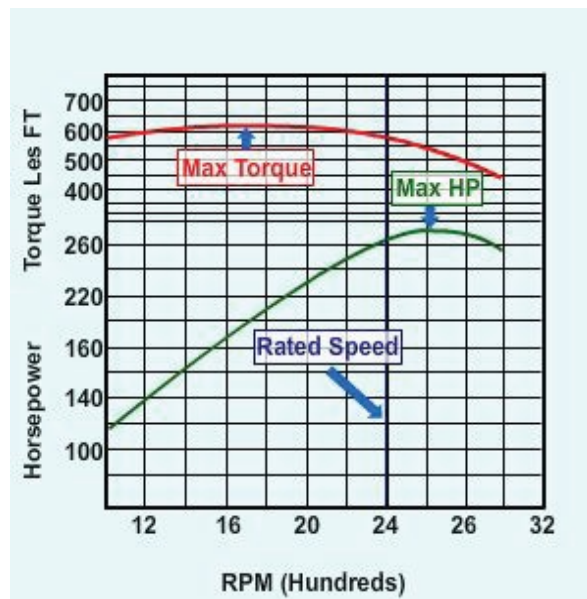
14. The difference between indicated horsepower and brake horsepower is referred to as _____ horsepower.
- A. flywheel
 - B. indicated
 - C. brake
 - D. friction

Refer to the figure below when answering question 15.



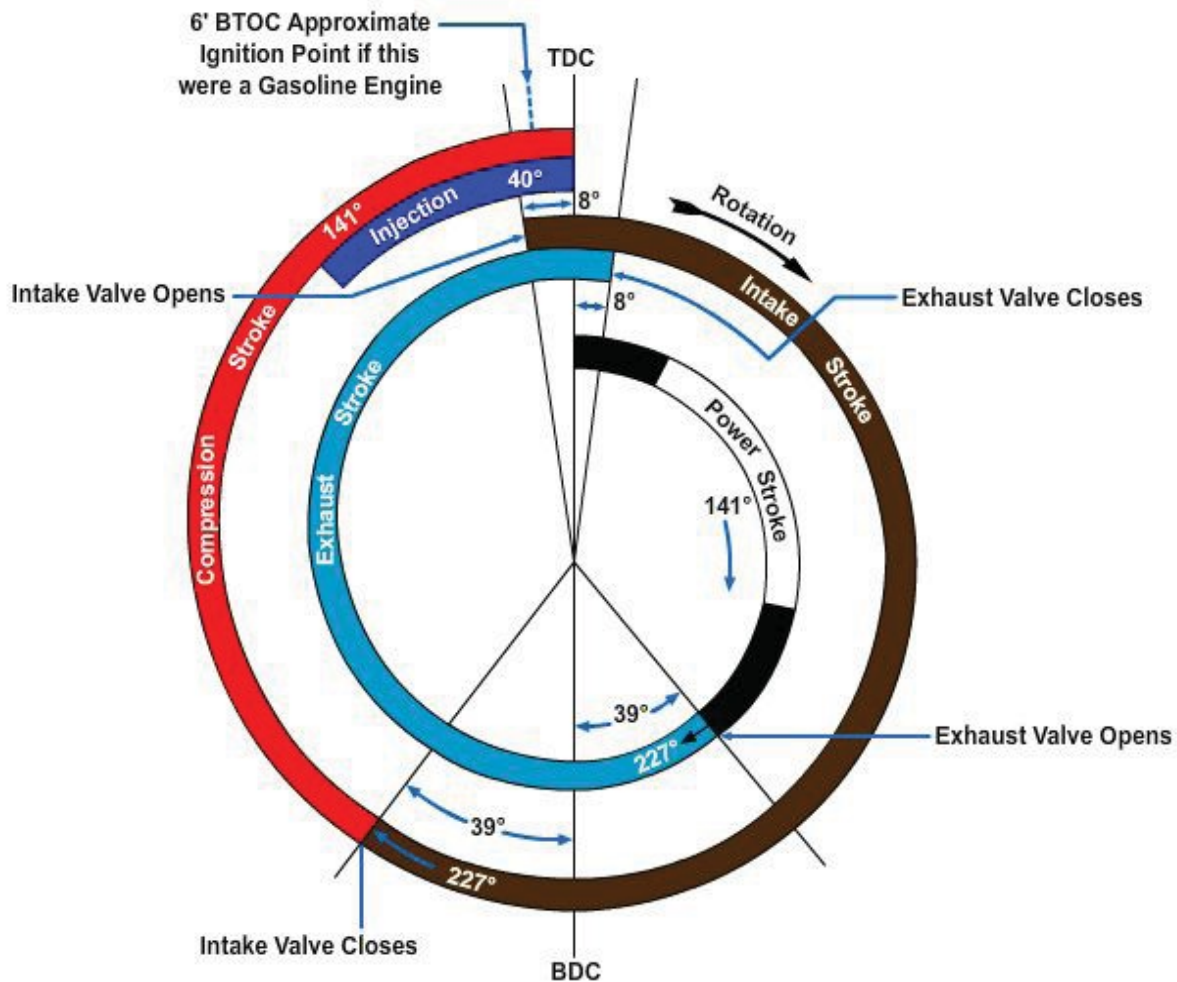
15. Engine torque increases steadily in which of the following speed ranges?
- A. 1,200 to 1,600 rpm
 - B. 1,800 to 2,000 rpm
 - C. 2,000 to 2,400 rpm
 - D. 2,400 to 3,200 rpm

Refer to the figure below when answering question 16.



16. In which of the following speed ranges does torque NOT fall while horsepower rises??
- A. 1,000 to 1,700 rpm
 - B. 1,800 to 2,600 rpm
 - C. 2,700 to 2,900 rpm
 - D. 3,000 to 3,200 rpm

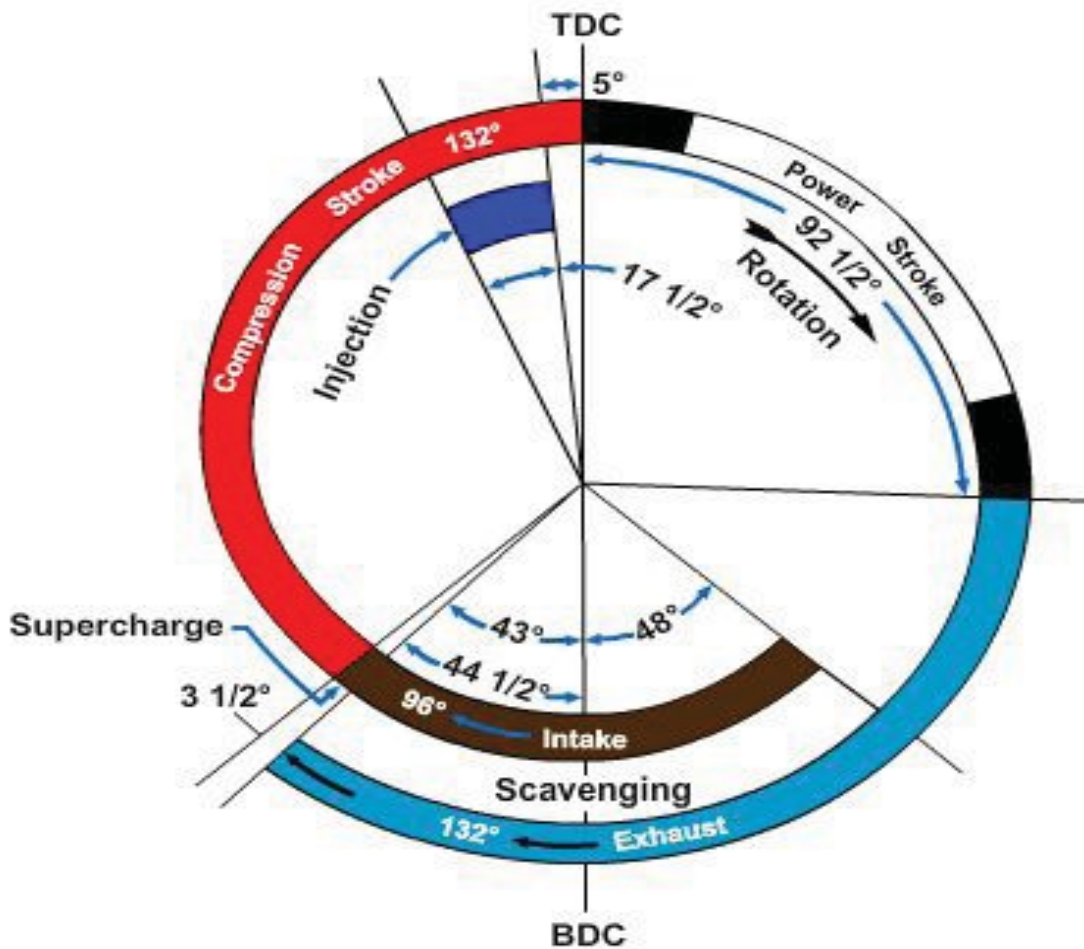
Refer to the figure below when answering questions 17 and 18.



17. The intake valve of a four-stroke-cycle diesel engine opens during which event?
 - A. A few degrees before TDC as the piston nears the end of its exhaust stroke
 - B. A few degrees after TDC as the piston nears the end of its exhaust stroke
 - C. Just as the piston reaches TDC on its exhaust stroke
 - D. At 40° before TDC as the piston nears the end of its compression stroke

18. What stroke of a four-stroke-cycle diesel engine begins slightly before TDC, continues through BDC, and ends during the next upstroke of the piston?
 - A. Power
 - B. Exhaust
 - C. Intake
 - D. Compression

Refer to the figure below when answering question 19.



19. What is the relationship between fuel injection timing and piston position?
- A. When the piston is at TDC, fuel is about to be injected.
 - B. When the piston is at TDC, fuel has already been injected.
 - C. When the piston is at TDC, fuel is being injected.
 - D. When the piston is at BDC, fuel is being injected.
20. Which malfunction can cause an engine to lose power?
- A. Incorrect ignition timing
 - B. Defective spark advance
 - C. Worn distributor cam
 - D. All of the above
21. **(True or False)** You do not have to consider the effects of altitude when analyzing engine power.
- A. True
 - B. False

22. What are two main causes of excessive oil consumption?
- A. Excessive driving and clogged air filters
 - B. External leakage and burning in the combustion chamber
 - C. Diluted fuel and high oil pressure
 - D. Oil sludge and clogged oil filter
23. Valve and tappet noise that is intermittent rapping noise that appears and disappears every few seconds indicates what condition?
- A. Leakage at check ball seat due to foreign particles, varnish, or defective surface of check ball or seat
 - B. Excessive leak or faulty check ball seat
 - C. Flywheel restriction
 - D. Overheating
24. Connecting rods make two distinct knocks. One is a metallic clack by the gudgeon pin end and the other is a loud, deep toned knock of the_____.
- A. cam shaft
 - B. distributor
 - C. connecting rod bearing
 - D. crankshaft
25. The sound you may hear during acceleration as high-pitched rattling or clicking in the upper part of the cylinder is_____.
- A. piston-ring noise
 - B. piston-pin knock
 - C. piston slap
 - D. piston whine
26. What is a cylinder compression tester used to measure?
- A. Valve compression as it moves when the piston moves to TDC on the compression stroke
 - B. Cylinder pressure in psi as the piston moves to BDC on the power stroke
 - C. Cylinder pressure in psi as the piston moves to TDC during ignition
 - D. Cylinder pressure in psi as the piston moves to TDC on the compression stroke
27. **(True or False)** The compression ratio is determined by comparing the amount of space in the cylinder when the piston is at top of its travel to the space available when the piston is at its lowest point of travel.
- A. True
 - B. False

28. The vacuum gauge provides a means of testing all these except which one?
- A. Intake manifold vacuum
 - B. Cranking vacuum
 - C. Fuel pump vacuum
 - D. Air compressor vacuum
29. The vacuum gauge is considered one of the most useful and versatile tools or test devices in the mechanic's TOA. If the gauge is reading 15-22 inches with the needle holding steady, what does this indicate?
- A. Engine has worn rings or dilutes oil.
 - B. The engine's compression is fine and there are no vacuum leaks.
 - C. Valve guides are worn.
 - D. Valve springs are weak.
30. Using the vacuum gauge, when you observe the needle swing back and forth over 4-6 inches, what does this indicate?
- A. Sticking valves
 - B. Normal operation
 - C. Worn valve guides
 - D. Weak valve springs
31. **(True or False)** A device for introducing compressed air into the cylinder of an engine can be made by removing the insulator from an old spark plug and welding a pneumatic valve stem to the threaded end of the plug.
- A. True
 - B. False
32. When using compressed air to test an engine cylinder for leakage, you notice air bubbles in the radiator coolant. The bubbles indicate that air is probably being released by what means?
- A. Leaking head gasket
 - B. Leaking intake valve
 - C. Defective exhaust valve
 - D. Piston ring
33. Unusual noise at the cam followers, pushrods, and rocker arms is an indication of _____ valves.
- A. bent
 - B. burned
 - C. cracked
 - D. sticking

34. Valve breakage can happen to either the intake or exhaust valves are destructive causing damage to the_____.
- A. piston and oil pump
 - B. piston and head
 - C. cams and head
 - D. oil return and fuel pump
35. When valves are adjusted with too little clearance, they will_____.
- A. overheat and warp
 - B. admit a full charge of air or fuel mixture
 - C. prevent the escape of exhaust gases
 - D. open late
36. In order to remove the valves from the cylinder head, you must first remove what parts?
- A. Valve inserts and retainers
 - B. Valve springs only
 - C. Rocker arms and lifters
 - D. Valve spring retainers and valve springs
37. Grinding by removing metal from the valve face will increase stem height. This affects the spring tension and_____.
- A. valve train geometry
 - B. valve seat geometry
 - C. valve spacing
 - D. valve seat
38. The clearance between the valve stem and guide is important for a number of reasons. Which of these is NOT one of them?
- A. Keeps the valve face in perfect alignment with the valve seat.
 - B. Allows the valve to heat up.
 - C. Prevents the lubricating oil from being drawn past the stem.
 - D. Prevents burnt gases from entering the crankcase.
39. What is the fastest method to restore the inside of a worn integral valve guide?
- A. Lining
 - B. Boring
 - C. Reaming
 - D. Knurling

40. What method of valve guide restoration is considered superior to knurling by allowing oversized valves to be installed?
- A. Reaming
 - B. Boring
 - C. Thin-wall inserts
 - D. Threaded bronze inserts
41. **(True or False)** Threaded bronze inserts provide better lubrication, excellent wear qualities, and tight clearance, and they are fairly inexpensive and easily installed.
- A. True
 - B. False
42. During the process of grinding valve seats, a valve seat grinder is kept concentric with the valve guide by what means?
- A. Upper and lower grinding stones
 - B. Centered grinding stones in the chuck
 - C. Self-centering pilot in the valve guide
 - D. Centrifugal force
43. One method of checking the valve seating is to coat the valve face lightly with Prussian blue and twist the valve one-quarter turn in its seat. How can you tell whether the valve seat is concentric with the valve guide?
- A. Prussian blue will transfer evenly to the valve seat.
 - B. There will be no trace of Prussian blue on either the valve or its seat.
 - C. The shade of Prussian blue will grow brighter.
 - D. Prussian blue will collect in a pile on the valve seat.
44. When inserting a new valve seat, you should use which technique?
- A. Heat the engine block or cylinder head to expand the valve opening and then drop the insert in.
 - B. Shrink the seat by chilling it in dry ice and use a driving tool to force the seat into the recess in the head.
 - C. Hold the insert with pliers then tap slowly on all sides with a rubber mallet.
 - D. Squeeze the insert with a special insert tool and then drop it in place.
45. Which is not a normal check done on valve springs?
- A. Squareness
 - B. Free height
 - C. Horizontal dimension
 - D. Tension

46. **(True or False)** When you install a new camshaft, it is generally acceptable to reinstall the old lifters because the new cams will conform to the old lifters.
- A. True
 - B. False
47. To indicate the end of a leak-down rate test on a hydraulic valve lifter, what action takes place as the valve seats?
- A. The feeler gauge loosens.
 - B. The feeler gauge binds.
 - C. The oil leaks fast.
 - D. The oil leaks slow.
48. In the installation of new camshaft bearings, it is important that you take which step?
- A. Line-ream them before they are installed.
 - B. Line up the oil holes with those in the block.
 - C. Stake them, whether or not the old bearings were staked.
 - D. Stagger the oil holes in the bearings with those in the block.
49. Journals must be ground if they are tapered or out-of-round in excess of what measurement, in inches?
- A. .001
 - B. .002
 - C. .003
 - D. .004
50. After the crankshaft is installed and the bearing caps are put in place, what action should you take?
- A. Snug and tighten them from front to back.
 - B. Put every other bolt in first, tighten them, then the others.
 - C. Torque the bolts down as you go.
 - D. Snug the bolts first and then follow the specified tightening sequence.
51. Crankshaft end play will become excessive if the _____ is/are worn, producing a sharp, irregular knock.
- A. roller bearings
 - B. thrust bearings
 - C. flywheel
 - D. throw bearings
52. It is best to store a crankshaft by which method?
- A. Storing it off the floor on the metal shelf.
 - B. Placing it on a wood surface.
 - C. Cleaning off all oil and placing it carefully on the floor.

53. What causes the cylinder to taper?
- A. More lubricating oil at the top and less in the lower portion of the cylinder
 - B. Less lubricating oil at the top and more at the lower area of the cylinder
 - C. Oil entering the cylinder unevenly
 - D. Piston unevenly distributing the lubricating oil along the cylinder walls
54. In order to true worn cylinders and break the glaze on the cylinders you will use what method?
- A. Boring
 - B. Reaming
 - C. Honing
55. What type honing is recommended when the cylinder is in good condition?
- A. Flex
 - B. Machine
 - C. Brush
 - D. Flex
56. Cylinder boring is required when the cylinder has which condition?
- A. Deep scratches, scoring, excess wear on the walls
 - B. Deep scratches, scoring, excess wear on the piston heads
 - C. Excessive wear or cracking on the piston rings
 - D. Minimal wear on the walls
57. If only one or two cylinders need to be bored, what should you do to install the same size pistons?
- A. Bore all the other cylinders.
 - B. Press in a cylinder liner.
 - C. You cannot install the same size piston.
58. After boring the cylinder you can fit it with a dry liner. How should you install the liner?
- A. Press in the liner with a cylinder press, then heat the block at resistance.
 - B. Freeze the block with dry ice and heat the liner.
 - C. Heat the block and pack the sleeve with dry ice, then press or drive it into the cylinder.
 - D. Line it up carefully then drive with a rubber hammer work around the edge as it goes in.
59. A liner that is loose will not make proper contact with the cylinder block and will result in_____.
- A. poor heat dissipation
 - B. leaking oil
 - C. leaking gases
 - D. leaking oil and gases

60. On wet cylinder liners, what is used to re-establish the correct flange height?
- A. Spacers
 - B. Gaskets
 - C. Liner risers
 - D. Shims
61. For what reason should a cylinder ridge be removed on an engine being overhauled?
- A. To prevent damaging the cylinders.
 - B. To prevent damaging the piston and rings as they are removed.
 - C. To prevent damaging the cylinders when the pistons are installed.
 - D. To prevent damage to the pistons and rings when they are installed.
62. **(True or False)** Scraping the sides of the piston during cleaning may leave scratches that can cause excessive cylinder wall wear.
- A. True
 - B. False
63. A cam ground piston is slightly elliptical in order to compensate for_____.
- A. cylinder wall expansion
 - B. ring expansion
 - C. oil pressure
 - D. thermal expansion of the piston
64. **(True or False)** To start a pressed-in piston pin, tap it into the piston bore with a 5-lb. hammer to ensure proper pressure.
- A. True
 - B. False
65. Although installing piston rings is a fairly simple process, make certain that the ring ends do not_____.
- A. connect
 - B. stagger
 - C. overlap
66. Piston ring clearance is measured at what position on the piston?
- A. Between the ring and the top of the groove
 - B. Between the ring and bottom of the groove
 - C. At the ends of the piston ring

67. Before starting a newly overhauled engine, you should inspect which system?
- A. Lubrication
 - B. Cooling
 - C. Electrical
 - D. All of the above
68. Upon starting a newly overhauled engine, you must shut down the engine if no oil pressure is observed in what maximum number of seconds?
- A. 5
 - B. 10
 - C. 15
 - D. 20
69. A newly rebuilt engine should be run with light loading for at least (a) how many hours and (b) what number of miles?
- A. (a) 10 (b) 100
 - B. (a) 50 (b) 500
 - C. (a) 100 (b) 1,000
 - D. (a) 250 (b) 2,500

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Modern Automotive Technology 7th Edition, James Duffy, The Goodheart-Wilcox Company, Inc., 2009. (ISBN: 978-1-59070-956-6)

Diesel Technology 7th Edition, Andrew Norman and John Corinchock, The Goodheart-Wilcox Company, Inc., 2007. (ISBN- 13: 978-1-59070-770-8)

Heavy Duty Truck Systems 4th Edition, Sean Bennet, Delmar Cengage Learning, 2006. (ISBN-13:978-1-4018-7064-5)

Medium/Heavy Duty Truck Engines, Fuel & Computerized Management Systems, 2nd Edition, Sean Bennett, Thomson Delmar Learning, 2004. (ISBN- 1-4018-1499-9)

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Chapter 5

Fuel System Overhaul

Topics

- 1.0.0 Gasoline Fuel Injection Systems
- 2.0.0 Diesel Fuel Injection Systems
- 3.0.0 Air Induction Systems
- 4.0.0 Diesel Engine Cold Starting Devices
- 5.0.0 Emission Systems

To hear audio, click on the box.



Overview

The fuel system is the life blood of a vehicle or a piece of construction equipment. Fuel systems have become more complicated, but along with that, they have become more efficient, more environmentally safe, and easier to troubleshoot through electronic diagnostics.

In the following chapter, we are going to discuss fuel systems overhaul. The topics to be covered will include gasoline fuel injection systems, small engine carburetors, diesel fuel injection systems, air induction systems, cold starting devices for gasoline and diesel fuel injection systems, and emission systems.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand how to troubleshoot and overhaul gasoline fuel injection systems.
2. Understand how to troubleshoot and overhaul small engine carburetors.
3. Understand how to troubleshoot and overhaul diesel fuel injection systems.
4. Understand how to troubleshoot the air induction system.
5. Understand the principles of cold starting devices for gasoline and diesel fuel injection systems.
6. Understand how to troubleshoot and overhaul emission systems.

Prerequisites

None

This course map shows all of the chapters in Construction Mechanic Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Air Conditioning Systems		C
Air Compressor Overhaul		M
Inspecting and Troubleshooting Brake Systems		
Hydraulic Systems		A
Wheel and Track Alignment		D
Troubleshooting Transmissions, Transfer Cases and Differentials		V
Clutches and Automatic Transmissions		A
Troubleshooting Electrical Systems		N
Fuel System Overhaul		C
Engine Troubleshooting and Overhaul		E
The Shop Inspectors		D
Alfa Company Shop Supervisor		
Public Works Shop Supervisor		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 GASOLINE FUEL INJECTION SYSTEM

A typical gasoline injection system uses pressure from an electric fuel pump to spray fuel into the engine's intake manifold. Like a carburetor, the gasoline injection system must provide the engine with the correct air-fuel mixture for specific engine operating conditions. Unlike a carburetor, however, the injection system uses pressure, not engine vacuum, to feed fuel into the engine. This makes a gasoline injection system very efficient.

A gasoline injection system has several advantages over a carburetor-type fuel system. A few of these include:

- Improved atomization. Fuel is forced into the intake manifold under pressure, which helps break fuel droplets into a fine mist.
- Better fuel distribution. There is a more equal flow of fuel vapors into the cylinder.
- Smoother idle. A lean fuel mixture can be used without rough idle because of better fuel distribution and low-speed atomization.
- Improved fuel economy. . Higher efficiency results from more precise fuel metering, atomization, and distribution.
- Lower emissions. A lean, efficient air-fuel mixture reduces exhaust pollution.
- Better cold-weather drivability. Injection provides better control of mixture enrichment than a carburetor choke.
- Increased engine power. Precise metering of fuel to each cylinder and increased airflow can result in more horsepower output.
- Simpler. Electronic fuel injection systems have fewer parts than computer-controlled carburetor systems.

1.1.0 Timed Fuel Injection System

In gasoline engines, the timed fuel injection system injects a measured amount of fuel in timed bursts synchronized to the intake strokes of the engine. Timed injection is the most precise form of fuel injection; it is also the most complex.

1.1.1 Electronic-Timed Fuel Injection

The electronic fuel injection (EFI) system can be divided into four subsystems:

1. Fuel delivery system
2. Air induction system
3. Sensor system
4. Computer control system

1.1.1.1 Fuel delivery System

The fuel delivery system of an EFI system as shown in *Figure 5-1* includes:

- An electric fuel pump
- A fuel filter

- A pressure regulator
- Fuel injectors (injector valves)
- Connecting line
- Hoses

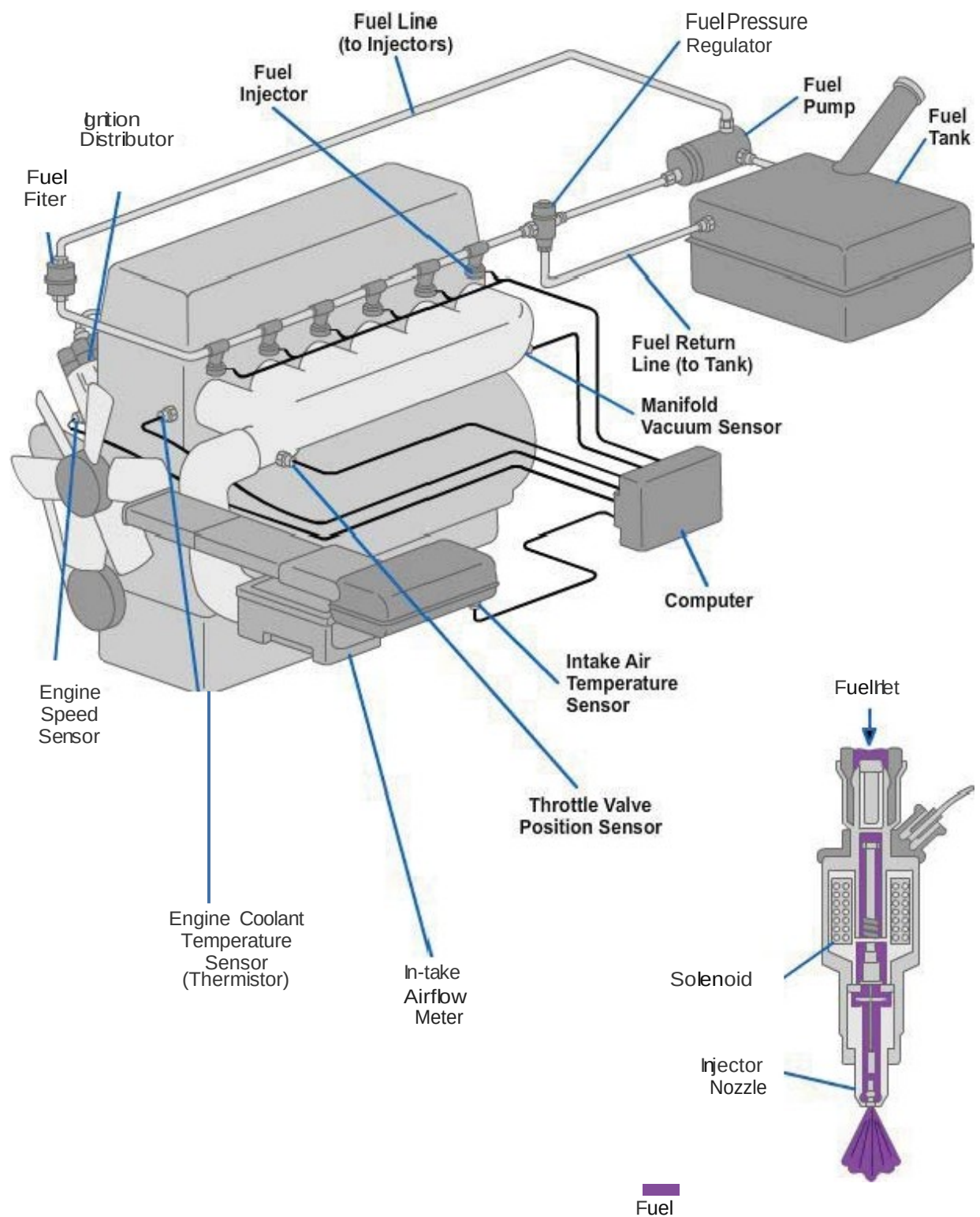


Figure 5-1 -Electronic-timed fuel injection system.

The electric fuel pump draws fuel out of the tank and forces it into the pressure regulator. The fuel pressure regulator controls the amount of pressure entering the injector valves. When sufficient pressure is attained, the regulator returns excess fuel to the tank. This maintains a preset amount of fuel pressure for injector operation. Engine vacuum is ported into the fuel pressure regulator. This allows the pressure regulator to lower fuel pressure slightly at idle speed (low engine load) and increase with higher engine speed (higher engine load).

A fuel injector for an EFI system, *Figure 5-2* is simply a coil- or solenoid-operated fuel valve. When not energized, the spring pressure holds the injector closed, keeping fuel from entering the engine. When current flows through the injector armature and the injector valve opens, fuel then squirts into the intake manifold under pressure. *Figure 5-3A* illustrates how current through the injector coil builds a magnetic field. The field attracts and pulls up on the armature to open the injector. Fuel then sprays out of the injector. *Figure 5-3B* illustrates when the

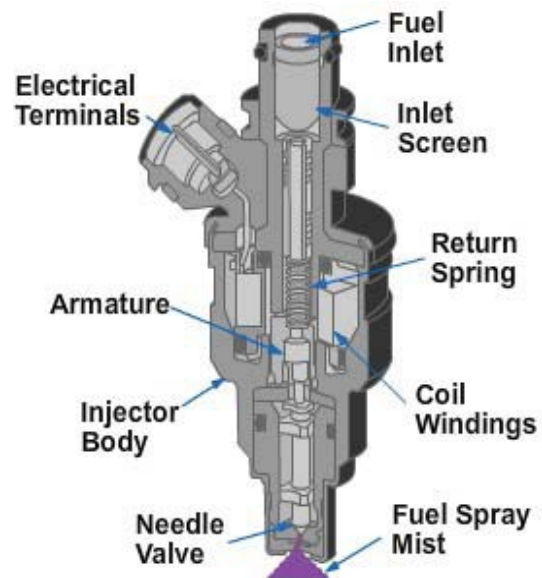


Figure 5-2 – Cutaway shows the major parts of an electronic fuel injector.

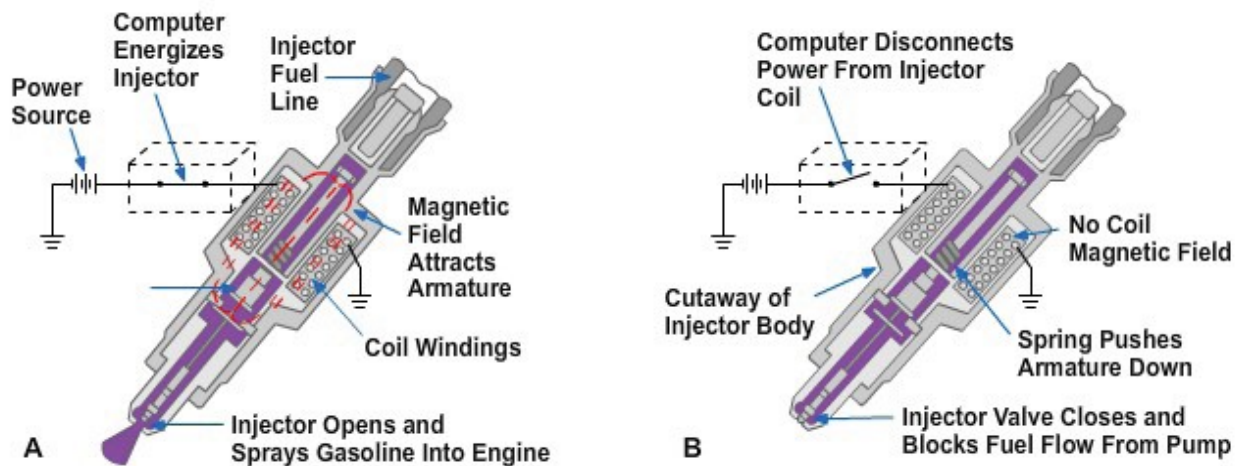


Figure 5-3 -EFI injector operation.

control module breaks the circuit, the spring pushes the injector valve closed to stop the fuel.

1.1.1.2 Air Induction System

An air induction system for an EFI system typically consists of a/an:

- Air filter
- Throttle valves
- Sensors
- Connecting ducts

Air flow enters the inlet duct and flows through the air filter. The air filter traps dust and debris and prevents it from entering the engine. Plastic ducts then route the clean air into the throttle body assembly. The throttle body assembly in multipoint injection systems simply contains the throttle valve and idle air control device. After leaving the throttle body, air flows into the engine intake manifold. The manifold is divided into runners (passages) that route the air into each cylinder head intake port.

1.1.1.3 Sensor System

The EFI sensor system monitors engine operating conditions and sends information about these conditions to the control module. An engine sensor is an electrical device that changes its electrical output (resistance, voltage, or current) with a change in a condition, such as temperature, pressure, or position. For example, a temperature sensor's resistance may decrease as temperature increases. The control module analyzes the increased current flow through the sensor to determine if a change in injector valve opening is needed.

Oxygen sensor, which is also called an exhaust gas sensor or lambda sensor, shown in *Figure 5-4*, measures the oxygen in the engine's exhaust gases as a means of checking combustion efficiency. The exhaust gas oxygen sensor is one of the most



Figure 5-4 - Oxygen sensor along with cutaway view showing the components of an oxygen sensor.

important sensors controlling engine operation. The signals from the exhaust gas oxygen sensor are used by the powertrain control module to monitor air/fuel mixture. On-board diagnostics generation one (OBD-I) is a computer control system installed on vehicles built prior to 1996. These vehicles use one oxygen sensor located in the exhaust manifold or exhaust pipe before the catalytic converter.

Vehicles with on-board diagnostics generation two (OBD-II), (enhanced diagnostic system required on 1996 and newer vehicles and also called for the standardization of codes, data link connectors, and terminology), these vehicles use at least two oxygen sensors—one before the catalytic converter and one after the catalytic converter. The primary sensor is located before the catalytic converter and is used to monitor the oxygen content of the exhaust gases entering the converter. The secondary oxygen sensor, or catalyst monitor, is located after the catalytic converter. It monitors the oxygen content of the gases leaving the converter to determine how well the catalyst elements are working.

The voltage output of the oxygen sensor varies with changes in the oxygen exhaust. If an increase in oxygen from a lean mixture makes the sensor output voltage decrease, a decrease in oxygen from a rich mixture causes the sensor output to increase. In this way, the sensor supplies data on oxygen content to the computer. The computer can then alter the opening and closing of the injectors to adjust the air-fuel ratio for maximum efficiency.

Open and Closed Loop. The term open and closed loop refers to the operating mode of a computerized engine control system. See *Figure 5-5*.

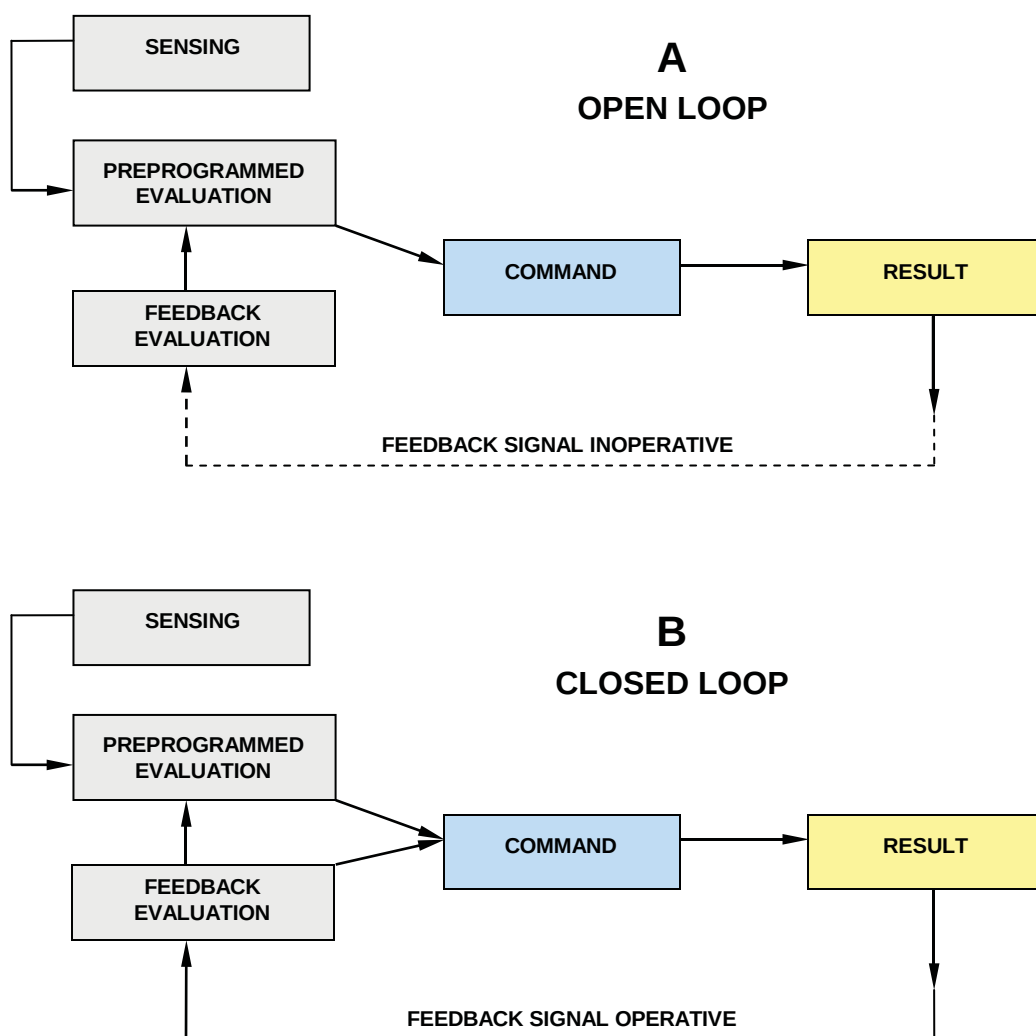


Figure 5-5 – The basic flow of information in an EFI system A- In open loop. B- In closed loop.

When the engine is cold, the computer operates open loop (no feedback from the sensors). After the engine warms to operating temperature, the system changes to closed loop (uses feedback from sensors to control system) operation.

An oxygen sensor must heat up to several hundred degrees before it will function properly. This is the main reason computer systems have an open loop mode. The computer has preprogrammed information (injector pulse width, engine timing, idle speed motor rpm, etc.) that will keep the engine running satisfactorily while the engine sensor is warming up.

When the engine and oxygen sensors are cold, no information flows to the computer. The computer ignores any signals from the oxygen sensor. The "loop of information" is open.

After the sensor and engine are warm, the oxygen sensor, and other sensors begin to feed data to the computer. This forms an "imaginary loop" (closed loop) as electrical data flow from the engine exhaust to the engine, the oxygen sensor, the computer, the injectors, and back to the oxygen sensor. Normally, the computer system functions closed loop to analyze the fuel mixture provided to the engine. This lets the computer "doublecheck itself."

Manifold absolute pressure (MAP) sensor measures pressure, or vacuum, inside the engine intake manifold. Manifold pressure is an excellent indicator of engine load. High pressure (low intake vacuum) indicates a high load, requiring a rich mixture. Low manifold pressure (high intake vacuum) indicates very little load, requiring a leaner mixture. The manifold pressure sensor varies resistance with changes in engine load. This data is used by the computer to alter the fuel mixture, *Figure 5-6*.



Figure 5-6 - Engine manifold absolute pressure (MAP) sensor.

Throttle position sensor (TPS) is a variable resistor, potentiometer, or multiposition switch connected to the throttle valve shaft. It provides data input in the power output of the engine, *Figure 5-7*.

When the operator presses on the accelerator pedal for more power, the throttle shaft and sensor are rotated. This changes the internal resistance of the sensor. The resistance change is proportional to angle change in degrees. The resulting change in current signals the computer to alter outputs to actuators, as needed.

A throttle position sensor is very important in determining computer outputs. Depending upon the make of vehicle, it can affect air-fuel ration, spark advance, emission control system operation, turbocharger boost, transaxle torque converter lockup, and air conditioner compressor engagement.

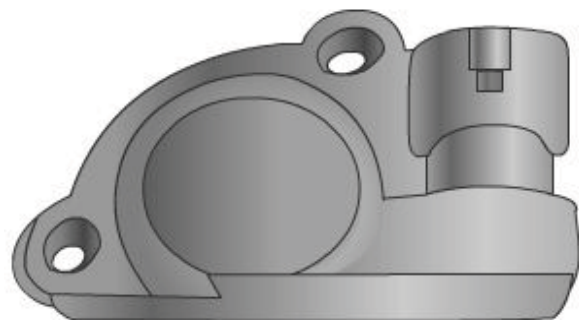


Figure 5-7 - Throttle position sensor.

Engine coolant temperature sensor monitors the operating temperature of the engine. It is mounted so that it is exposed to the engine coolant. When the engine is cold, the sensor might provide a low resistance (high current flow). The computer would then richen the air-fuel mixture for the cold

engine operation. When the engine warms, the computer knows to make the mixture leaner.

Airflow sensor is used in EFI systems to measure the amount of outside air entering the engine. This helps the computer determine how much fuel is needed. The airflow sensor usually contains an air flap or door that operates a variable resistor. Increased airflow opens the flap more, changing the position of the variable resistor. Information is then sent to the computer indicating air inlet volume.

Intake air temperature sensor measures the temperature of the air entering the engine. Cold air is denser than warm air, requiring more fuel for the proper ratio. The intake air temperature sensor helps the computer compensate for changes outside air temperature and maintain an almost perfect air-fuel mixture ratio.

Crankshaft position sensor is used to detect engine speed. It allows the computer to change injector timing and duration with changes in engine rpm. Higher engine speeds generally require more fuel.

Fuel pressure sensor mounts on the fuel rail and sends an electronic signal proportional to the pressure inside the rail to the electronic control unit (ECU). The ECU can then control fuel pump speed and/or fuel injector pulse width to compensate for variations in fuel system pressure. A fuel pressure sensor is often used in returnless fuel injection systems.

Fuel temperature sensor monitors the temperature of the fuel rail. Fuel temperature has a slight effect on a fuel density and how much air and fuel must be atomized together to achieve a stoichiometric mixture and efficient combustion. The ECU, upon the signal from the fuel temperature sensor, can fine tune fuel metering, ignition timing, boost pressure, and other engine operating parameters. In some vehicles, a fuel pressure sensor and a fuel temperature sensor are housed in a single unit.

1.1.1.4 Computer Control System

The computer control system uses electrical data from the sensors to control the operation of the fuel injectors and other engine performance-related devices. A wiring harness connects the sensors to the input of the computer (control module). Another wiring harness connects the output of the computer to the fuel injectors.

The engine control module is the "brain" of an electronic fuel injection system. It is a preprogrammed microcomputer. The control module uses sensor inputs to calculate when and how long to open the fuel injectors. To open an injector, the control module completes, or closes, the circuit between the battery and the injector coil. To close the injector, the module disconnects, or opens, the circuit between the battery and the injector coil.

1.2.1 Throttle Body Injection (TBI) Systems

Throttle body injection, as shown in *Figure 5-8*, is a form of continuous injection—one or two injectors delivering gasoline to the engine from one central point in the intake manifold. Though throttle body injection does not provide the precise fuel distribution of the direct port injection, it is cheaper to produce and to provide a degree of precision fuel metering. The throttle body injection unit is usually an integral one and contains all of the major system components. The unit mounts on the intake manifold in the same manner as a carburetor. Airflow sensors and electronic computers usually are mounted in the air cleaner body.

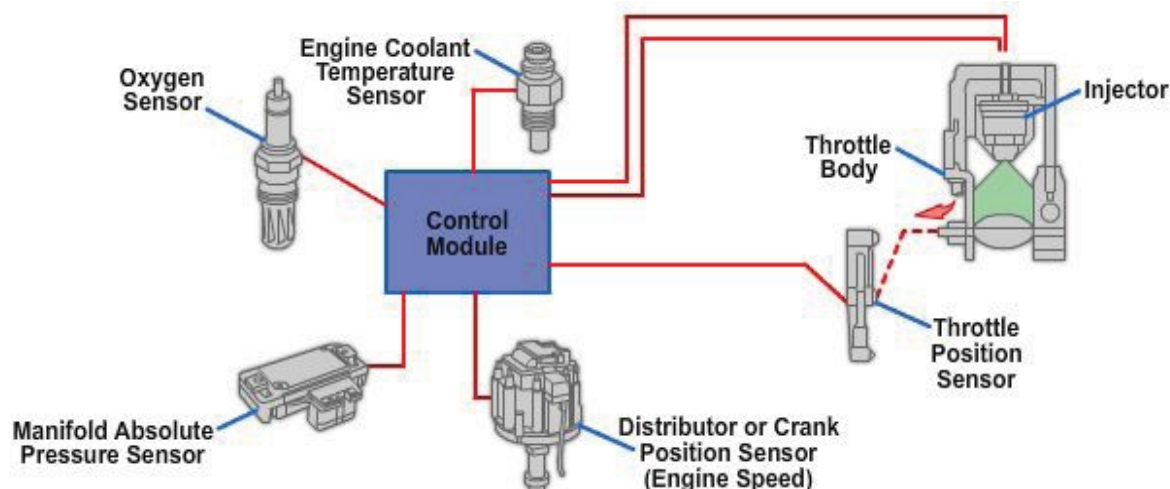


Figure 5-8 - Throttle body injection has sensors and a control module-operated injector mounted inside the throttle body.

A throttle body injection system (TBI) uses one or two injector valves mounted in a throttle body assembly. A diagram of an injector and its control circuits is shown in *Figure 5-9*. The injector(s) spray fuel into the top of the throttle body air horn. The fuel spray mixes with the air flowing through the air horn. The mixture is then pulled into the engine by intake manifold vacuum.

The TBI assembly, as shown in *Figure 5-10*, typically consists of:

- **Throttle body housing** — the metal casting that holds the injectors, fuel pressure regulator, throttle valves, and other parts. The TBI throttle body housing bolts to the pad on the intake manifold.

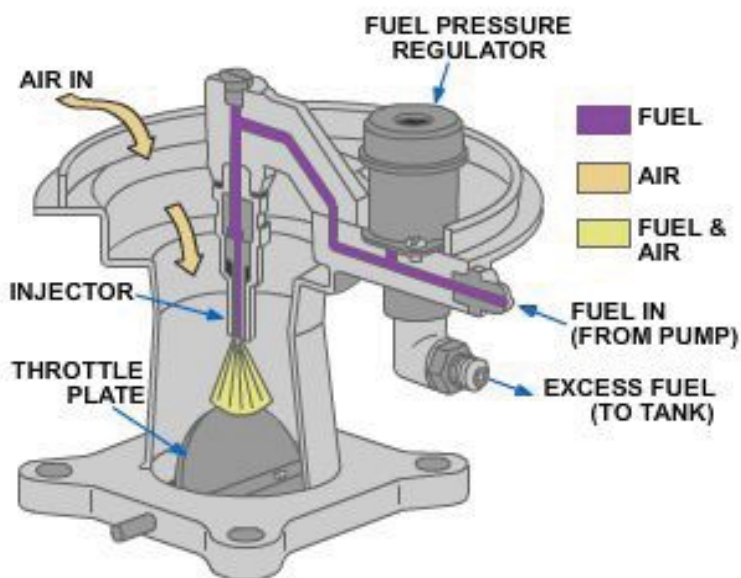


Figure 5-9 - Throttle-Body Injection Assembly with cutaway view of the TBI injector.

Throttle plates are mounted in the lower section of the housing. A linkage mechanism or cable connects the throttle plates with the accelerator. An inlet fuel line connects to one fitting on the throttle body housing. An outlet return line to the tank connects to another fitting on the housing.

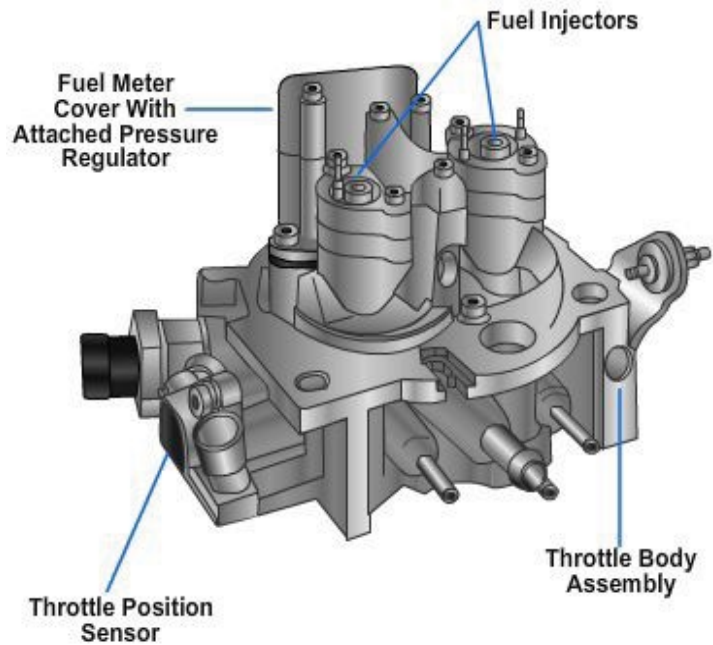


Figure 5-10 – Throttle body.

- **Fuel injector-**a solenoid-operated fuel valve mounted in the upper section of the throttle body assembly. The throttle body injector consists of the electric solenoid coil, armature or plunger, ball or needle valve, ball or needle seat, and injector spring. Wires from the engine control module connect to the terminals on the injectors. When the engine control module (ECM) energizes the injectors, a magnetic field is produced in the injector coil. The magnetic field pulls the plunger and valve up to open the injector. Fuel can then squirt through the injector nozzle and into the engine.
- **Fuel pressure regulator-** a spring-loaded bypass valve that maintains constant pressure at the injectors.
- **Throttle positioner-** a motor assembly that opens or closes the throttle plates to control engine idle speed.
- **Throttle position sensor-** a variable resistor connected to the throttle plates and senses their opening or closing. When the throttle opens or closes, the sensor changes resistance and signals the computer. The computer can richen or lean the mixture, as needed.
- **Throttle plates-** butterfly valves that control air-flow through the throttle body.

Throttle Body Injector Service. A quick check of the operation of a throttle body injection system can be done by watching the fuel spray pattern in the throttle body. Remove the air cleaner. With the engine cranking or running, each injector should form a rapidly pulsing spray of fuel.

Testing TBI Injectors. If fuel system pressure is within specifications but the TBI injector does not spray fuel, follow service manual procedures to test for power to the injector solenoid.

No power (current) to the injector indicates a problem with the wiring harness or electronic control module.

If you have power but no fuel spray pattern, the injector may be bad. Make sure to have adequate fuel pressure before condemning a fuel injector.

Replacing TBI Injectors. Although exact procedures vary with throttle body design, there are a few rules to follow when replacing a TBI injector. These rules include:

1. Relieve system fuel pressure before removing any throttle body component.
2. Disconnect the negative battery cable.
3. Label all hoses and wires before removal.
4. Do not damage the throttle body housing when pulling or prying out the injector.
5. Install new rubber O-rings. It may be required to lubricate the O-ring with approved lubricant to aid new injector installation.
6. Double-check that you have installed all injector washers and O-rings correctly.
7. Push the injector into the throttle body by hand. Avoid using a hammer or pliers. You may damage the new injectors.
8. Make sure the injector is fully seated in the throttle body. Normally, a tab must fit into a notch, ensuring correct alignment.
9. Check for fuel leaks after the TBI injector installation. Test drive the vehicle.

Throttle Body Rebuild. A throttle body rebuild, like a carburetor rebuild, involves replacing all gaskets, seals, and other worn parts. Remove and disassemble the throttle body, making sure all plastic, rubber, and electrical parts are removed.

The metal parts are soaked in carburetor cleaner, washed in cold soak cleaner, and blown dry.



Carburetor cleaner is a very powerful solvent. Wear eye protection and rubber gloves when using this type of cleaner. Follow the directions on the solvent label in case of an accident.

Inspect each part carefully for signs of wear or damage. Then, reassemble the TBI unit following the instructions in a manual.

Install the throttle body on the engine the same as a carburetor. Use a new base plate gasket. Tighten the holddown fasteners equally and to the proper torque. Make sure all vacuum hoses are connected to the correct vacuum port on the throttle body. Start the engine. Check for leaks and smooth system operation.

1.3.1 Servicing and Precautions

When a vehicle equipped with a gasoline type of fuel injection system has a problem, check all other systems first, such as ignition, air intake, charging, exhaust systems, and so forth, before you work on the fuel injection system. The fuel injection system is usually the last (least problematic) system to cause trouble. There are servicing precautions you should observe before you work on gasoline fuel injection systems:

1. Do not jump the battery to start the vehicle.

2. Do not disconnect the battery cables from the battery with the engine running.
3. When charging a battery in the vehicle, disconnect the negative (grounded) terminal.
4. Do not remove or attach the wiring harness plug to the electronic control unit (computer) with the ignition on.
5. Before performing a compression test, check the manufacturer's repair manual for special instructions.
6. Always make sure all other systems are in good working order before you adjust or troubleshoot the gasoline fuel injection system.

These precautions are general and apply to most systems. Nevertheless, use good judgment, and always check your manufacturer's repair manual for proper specifications and procedures.

Preventive maintenance is the most frequent type of servicing you will perform on a gasoline fuel injection system. Preventive maintenance consists of periodic visual checks and scheduled fuel filter service. Fuel filters are the cartridge type, in line type, and disposable type.

All fuel injection system control sensors, such as temperature, oxygen, manifold absolute pressure, and so forth, are electrically connected to the electric control module (ECM). Some of these sensors, such as the oxygen sensor, have a regular maintenance cycle. Check your manufacturer's repair manual for special instructions pertaining to these sensors.

Be sure the air intake system is sealed properly. Early detection will save fuel and prevent engine damage. Air leaks are a problem to gasoline fuel injection systems. If the air leak is after the air filter, dirt will be ingested into the engine, causing internal damage to the engine. Air leaks that bypass temperature sensors can cause false readings to be delivered to the ECM, changing injection quantity. Un-metered air leaks in the intake manifold can cause a lean fuel-air mixture to be delivered to the combustion chambers.

During regular maintenance and always after reassembly, you should check for fuel leaks. Gasoline leaks, however small, are extremely dangerous. They must be dealt with immediately. Clean around all areas to be disassembled. Heavy layers of dirt and grime may make some leaks hard to find. Install new seals on leaking connections and replace cracked or leaking hoses.



Gasoline fuel injection systems operate with fuel pressures up to five times greater than that of standard gasoline fuel systems. Any replacement fuel lines used should be approved for higher pressures. Failure to do so will result in an unsafe fuel system on the vehicle with the danger of possible explosion and fire.

Clean around all areas before reassembly. When you tighten injector line nuts (injector head), use new seals and proper torque specifications. When you tighten fuel lines, use flare nut type of wrenches because regular open-end wrenches may damage these fuel line fittings.

1.4.0 Carburetors (Small Engine)

Small gas engines serve us in a number of ways. They power chain saws, pumps, generators, air compressors, welders, compactor/tamper (jumping jack), vibratory plate compactor, numerous types of lawn care equipment, pressure washers, paint sprayers, cement/mortar mixers, concrete saws, and the list goes on. Many of these gas-powered tools and equipment are contained in the Naval Construction Force Table of Allowance.

Small gas engines are made up of individual systems that work together. In this topic, we are only going to discuss small engine carburetors, their theory of operation, basic components, types and application. There are several manufacturers of small engine carburetors and we will only include a few in our topic. They are all generally similar and contain most of the same components and characteristics.

1.4.1 Theory of Operation

Carburetion. The carburetor is an essential part of internal combustion engines. Gasoline engines cannot run on liquid gasoline. The main function of the carburetor is to mix the fuel and air and feed it into the engine, where it is ignited and used to thrust the pistons downward inside the engine block. The fuel must be vaporized and mixed with air in the proper proportions for varying conditions. The basic physics behind the function of a carburetor is called the Bernoulli Principle and the venturi effect. The Bernoulli Principle states that speed of the air is inversely proportional to the pressure. It is the throttle plate or butterfly of the carburetor that manages the amount of air that is delivered to the engine.

The carburetor must create an air fuel mixture that is correct for different circumstances such as:

- Cold or hot starting
- Idling
- Part throttle
- Acceleration
- High speed operation

Air enters the top of the carburetor and is mixed with liquid fuel. The air fuel mixture is forced into the intake manifold by atmospheric pressure and burned in the combustion chamber of the engine. The mixture will vary, depending on conditions. The proportion is given as the number of pounds of air compared to the number of gallons of gasoline.

At normal operating speed, a small engine will use an air-fuel mixture of about 14.7 pounds of air to 1 pound of gasoline.

Carburetors work on the principle of air pressure differences. When discussing pressure differences, we will talk about the following:

1. **Vacuum.** An absolute vacuum is an area completely free of air or atmospheric pressure. Although an absolute vacuum is not reached in a small engine, any pressure less than atmospheric pressure is generally referred to as a vacuum.

2. **Atmospheric pressure.** Atmospheric pressure is the pressure produced by the weight of air molecules above the earth. A partial vacuum is produced by the piston on the intake stroke. When the intake valve opens, atmospheric pressure forces air through the carburetor to fill it.
3. **Venturi effect.** Carburetion would not be possible if not for the venturi effect. A venturi is a restriction in an air passage that increases air speed or velocity. This increase in velocity reduces pressure, causing fuel to be drawn into the air stream. The venturi effect is an example of the Bernoulli Principle. Fluid velocity must increase through the constriction in a tube. The kinetic energy is created by the drop in pressure. Carburetors use tubes called a venturi to achieve this effect. Particles of fuel are vaporized by air rushing through the venturi, as illustrated in *Figure 5-11*.

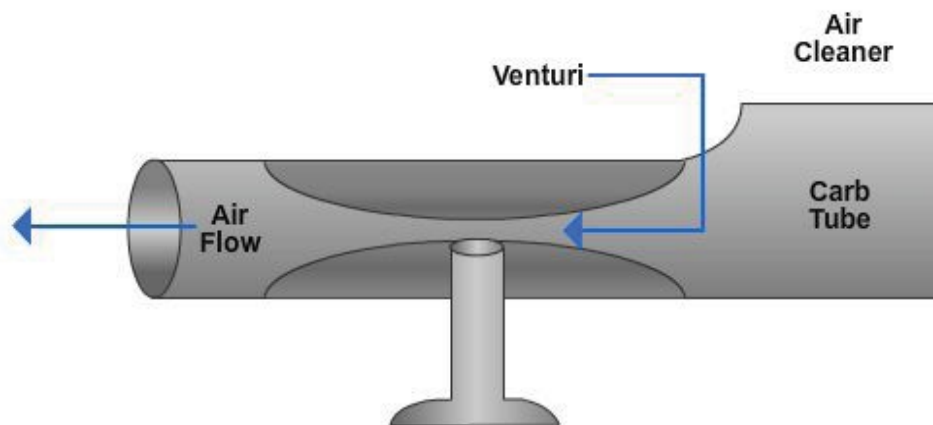


Figure 5-11 – Venturi effect.

Vaporization. Although the venturi breaks the fuel into fine particles, it is further vaporized by the heat of the engine in the intake manifold and by the engine's swirling action of the air in the combustion chamber.

Combustion. Cold fuel is difficult to vaporize, this is why we choke or prime a cold engine to help get it started. Over choking or priming can cause raw fuel to be pulled into the combustion chamber, resulting in bypass or the condition of flooding.

1.4.2 retor Components

A carburetor is a metering device for mixing fuel and air, as illustrated in *Figure 5-12*. The correct mixture in the combustion chamber is essential for the engine to run properly. Two conditions must be met for proper carburetion: the fuel must be introduced to the incoming air stream and it must be vaporized.

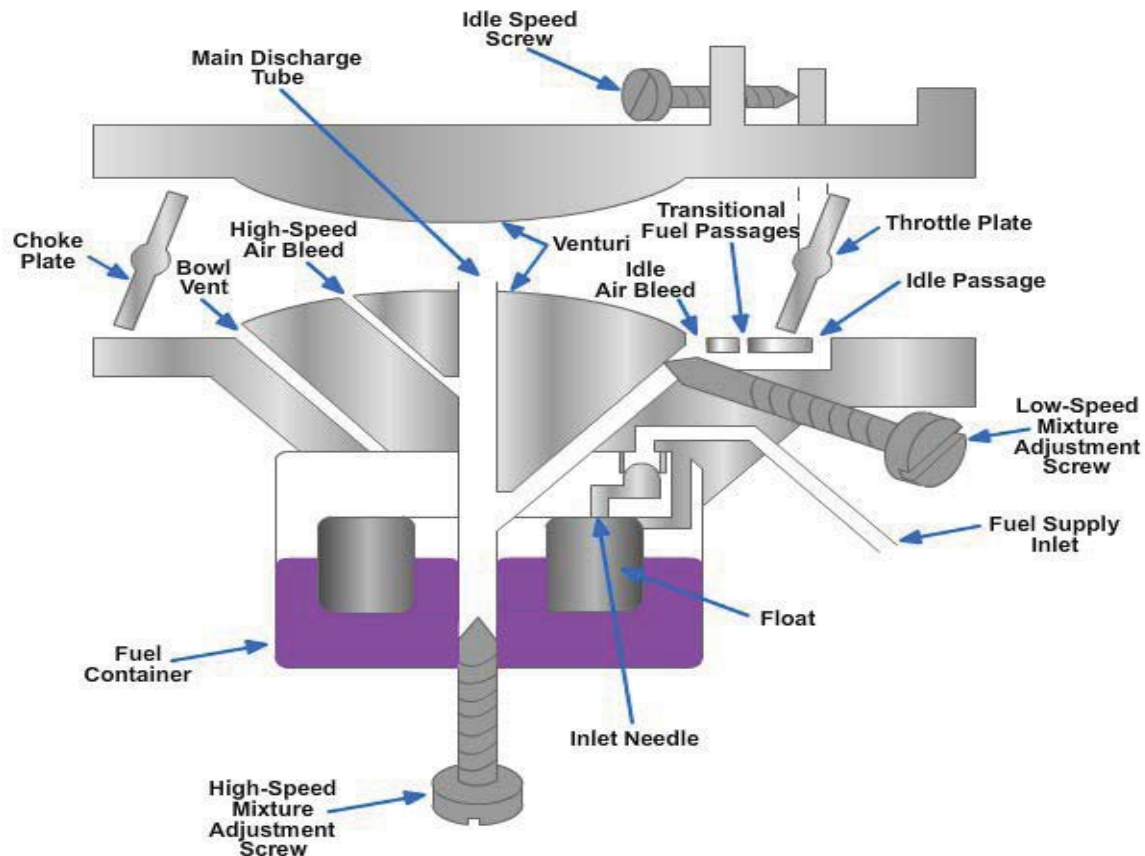


Figure 5-12 - Carburetor components.

Venturi. The venturi is the narrowed portion of the carburetor tube where the suction is created and the velocity of the incoming air is increased. Below the venturi there is a valve called a throttle plate, which can be opened and closed by the throttle control. This valve controls the engine speed by restricting the air flow to the engine and subsequently, the amount of air and fuel mixture that is delivered.

When the gas pedal is depressed, the throttle plate is opened allowing fuel to be drawn into the air stream. These tiny holes on the smallest section of the venturi are called jets. When the throttle is opened, the vacuum in the intake manifold is decreased. As the velocity of air increases, the low pressure raises the air speed to draw additional fuel into the stream through the nozzle located at the center area of the venturi.

Main Discharge Tube. The main discharge tube is the part through which the fuel travels from the fuel container to the air stream in the venturi during high speed operation.

The main discharge tube of the carburetor is a tube, one end of which is connected to the venturi, and the other end is in the fuel container found below. While air is flowing through the venturi, the effect will be the same as putting a straw in your mouth and sucking on it. If one end of the straw is placed into the liquid, the fluid will be drawn up the straw. The fuel container can be the float bowl, part of the fuel tank, or the entire fuel tank. The fuel is actually pushed through the main jet tube by the difference in pressure between the atmosphere and the venturi throat, as shown in *Figure 5-13*. Normal atmospheric pressure pushes on the fuel in the reservoir and moves the fuel to the low pressure area in the venturi.

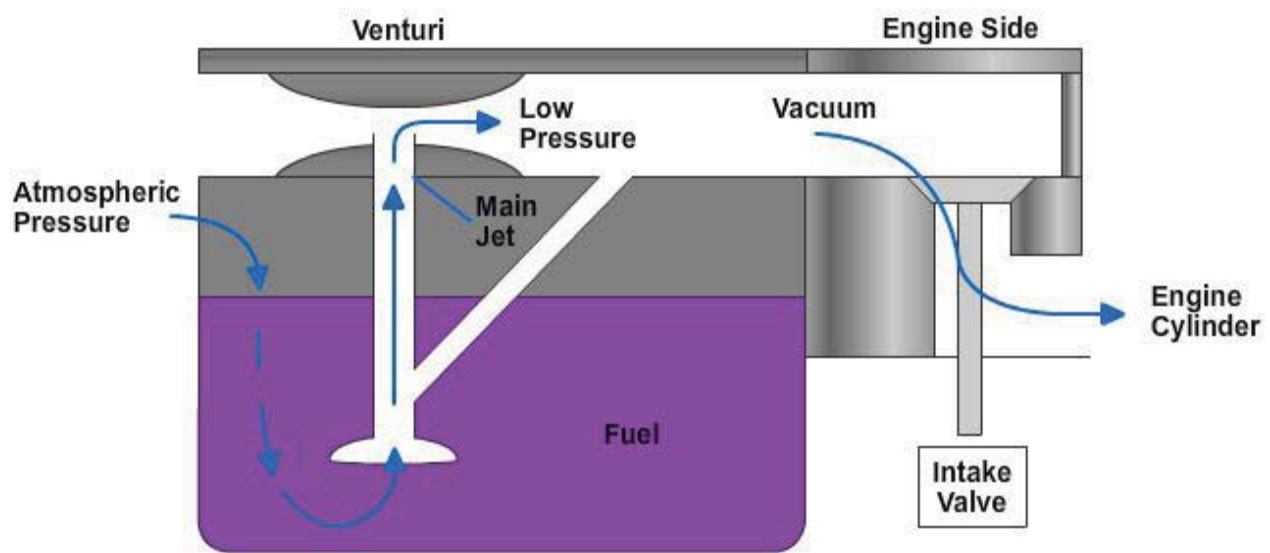


Figure 5-13 – Fuel is pushed through the main jet tube.

The greater the volume of air passing through the venturi, the higher the vacuum and the larger the amount of fuel that will be sprayed into the air stream at the main discharge tube.

Fuel Container. The fuel container holds the fuel for use by the different metering circuits in the carburetor.

Fuel Supply Inlet. The fuel inlet is where fuel enters the fuel container from the engine's fuel block

Float. The float is used to control the level of fuel in the fuel container. An essentially unchanging level of fuel must be maintained. Proper metering of fuel-to-air ratios is dependent on a constant distance from the venturi to the surface of the fuel in the container.

When the engine speed or load increases, fuel is rapidly pulled out of the fuel bowl and into the venturi. This makes the fuel level and float drop in the bowl. Fuel enters the bowl, and the float rises.

Bowl Vent. The bowl vent allows atmospheric air pressure to enter the carburetor system. The difference in atmospheric pressure (relatively high) and the venturi pressure (relatively low) pushes the fuel from the fuel container into the venturi while the

engine is operating. The vent tends to maintain the air pressure above the surface of the fuel in the bowl at atmospheric levels.

The bowl vent may be an external or internal type. An external vent can be found on the outside of the carburetor body. An internal vent is commonly found in the carburetor air horn near the choke side of the carburetor. An advantage of an internal vent is that a larger venturi can be used to maximize the horsepower of the engine. The pressure supplied to the surface of the fuel in the fuel container is higher than the atmospheric pressure, since air moving through the carburetor is forced into the vent opening.

High-Speed Mixture Adjustment Needle. The high-speed mixture adjustment needle is used to control the amount of fuel entering the air stream at high speed. It can be turned in to decrease the amount of fuel, which makes the air-fuel mixture lean, or turned out for a rich air-fuel mixture.

High-Speed Air Bleed. The high-speed air bleed allows air to break up the fuel before entering the air stream in the venturi. When the air enters the carburetor, it forms a slight pressure near the venturi as the molecules are backed up while waiting to enter the venturi. This backup of air molecules increases the pressure slightly on the choke side of the venturi. With the high-speed air bleed located in this high-pressure area, some of the air moves through this channel to mix with the fuel in the main discharge tube.

Throttle Plate. The throttle plate controls the air flow through the venturi, thereby controlling the fuel flow to the engine. When the throttle plate is closed, all the air flow to the engine ceases.

Choke Plate. The choke plate partially blocks off the air flow, creating low pressure throughout the carburetor to provide a rich in-fuel mixture for cold starting. The fuel is drawn into the limited air flow from the main discharge tube and idle passages.

Idle Passage. The idle passage connects the carburetor's bowl to the engine side of the throttle plate. Fuel is forced through this passage when the throttle plate moves to the idle position.

Low-Speed Mixture Adjustment Screw. The low-speed mixture adjustment screw is used to meter the precise amount of fuel for engine operation at idle.

Idle Air Bleed. The idle air bleed allows air to atomize the fuel entering the air stream while the engine is idling. This premixing of the fuel and air increases the efficiency of engine combustion. When the throttle plate is in the idle position, the transitional fuel passage also allows air to bubble into the idle passages.

Transitional Fuel Passages. The transitional fuel passage provides a temporary fuel supply to the engine during the transition from idle to high-speed operation. As the throttle plate begins to open, both the transitional fuel passages and the idle passage provide the air-fuel mixture.

Idle Speed Screw. The throttle plate must be held open slightly by the needle speed screw. When the throttle plate is opened fully, the air flow into the engine is limited by the size of the venturi.

Inlet Needle. The inlet needle opens as the float level drops and fuel is allowed to enter the bowl area. As the fuel rises, the float pushes the inlet needle back and shuts off the incoming fuel. When the engine is operating, the float pushes the inlet needle back and shuts off the incoming fuel. When the engine is operating, the float and inlet needle regulate the incoming fuel flow to maintain the proper fuel level in the fuel container.

Carburetor Systems. When the air-fuel mixture is drawn into the cylinder on the intake stroke of the piston and the engine is cold, the gasoline vapors tend to condense into large drops on their way to the cylinder. Because all the gasoline supplied to the cylinders does not vaporize, it becomes necessary to supply a rich mixture to have enough vapor for combustion to occur. This is accomplished by a choke system, enrichment system, or primer system.

Choke System. When the choke is tilted in the carburetor to restrict the amount of air entering the air horn, greater suction is created and a larger amount of fuel is drawn into the combustion chamber from the idle passages and the main discharge tube, as shown in *Figure 5-14*.

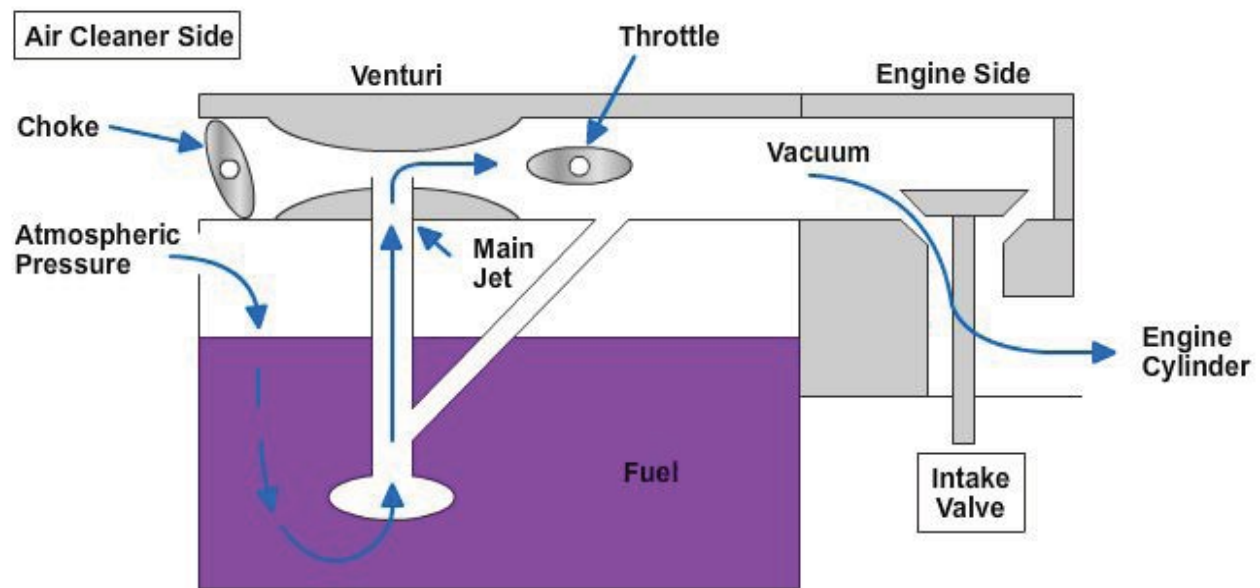


Figure 5-14- Choke system.

Enrichment System. An enrichment system is an air-fuel metering circuit separate from other carburetor circuits. Fuel for the circuit is drawn from the float bowl through an enrichment jet. The enrichment jet is activated by the user through a special lever. When the plunger is down, the enrichment circuit is blocked and does not operate. When the plunger is raised, a rich air-fuel mixture is discharged from the enrichment port, which is located directly behind the venturi.

Primer System. The primer system provides a rich mixture by increasing the pressure in the top of the fuel bowl to force extra fuel down on the float to force a higher than normal float bowl level and create a rich condition. In a diaphragm carburetor, the diaphragm may be lifted mechanically or pneumatically.

1.4.3 Types and application

1.4.3.1 Briggs & Stratton

Briggs & Stratton Manufacturers three different basic type of carburetor:

1. Vacu-Jet
2. Pulsa-Jet
3. Flo-Jet

Because environmental safety demands stricter emission and performance controls, many manufacturers realize that it is more cost-effective to contract another manufacturer that specializes in carburetors to design and build them. Briggs & Stratton has entered into partnership with Walbro carburetors, and together they are producing a Flo-Jet type of carburetor with both of their names on it.

1.4.3.1.1 Vacu-Jet Carburetor

The Vacu-Jet is a simple carburetor that is used in many small displacement Briggs & Stratton engines and functions adequately. It is adjusted differently from other carburetors because of its unique features.

Vacu-Jet Identification. The easiest way to identify the Vacu-Jet design is to check the engine's model number, as shown in *Figure 5-15*. Another method is to recognize its appearance, but this could be difficult due to the design changes if you do not work on them often, as indicated in *Figure 5-16*. *Figure 5-16A* is a Vacu-Jet all-temperature carburetor with automatic choke. *Figure 5-16B* is a Vacu-Jet Choke-A-Matic. The most reliable method of identification is when the carburetor is separated from the fuel tank and only one pickup tube is present.

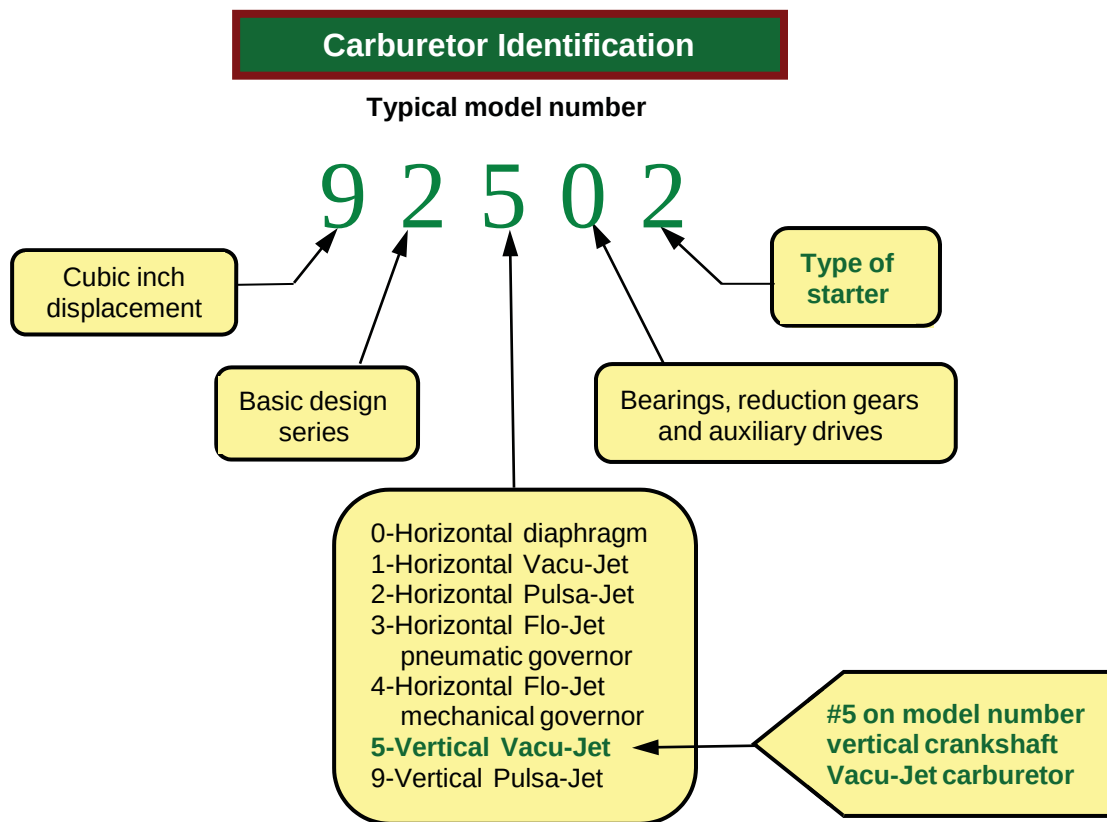


Figure 5-15 - Example of Briggs & Stratton Vacu-Jet identification by using the model number.

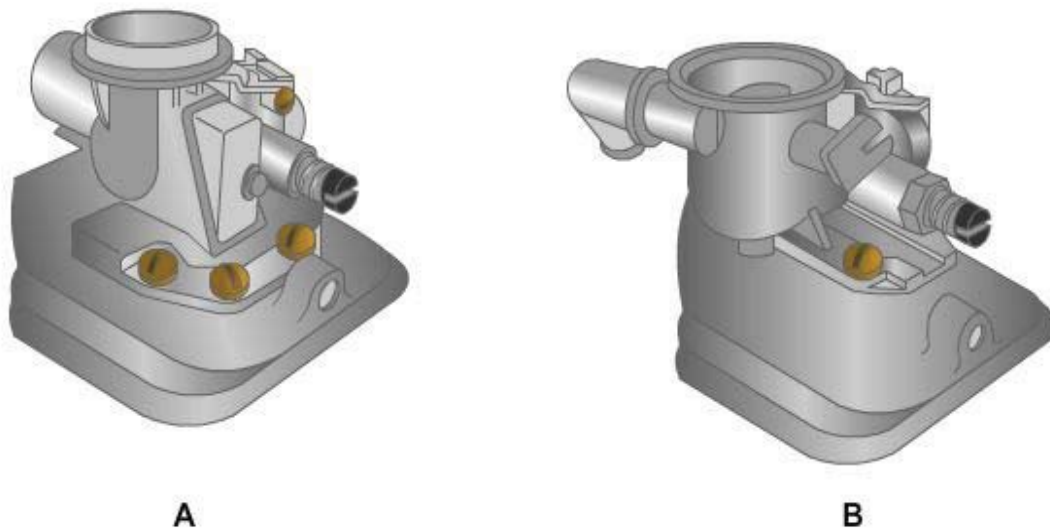


Figure 5-16 - Example of two Vacu-Jet models.

Vacu-Jet design. Fuel has to be lifted to the venturi. The atmospheric pressure enters the vent in the fuel cap and pushes on the mass of fuel. A single pickup tube extends

into the fuel through the bottom of the carburetor. When air passes through the venturi of the carburetor, the pressure in this area is reduced.

- **Fuel tank below carburetor.** The fuel from the tank is pushed up through the tube to the low-pressure area in the venturi. As the fuel is used up in the tank and the level is lowered, the greater the distance the fuel must be lifted. The change in the distance that the fuel must be lifted can cause a variation in the air-fuel mixture in the engine.
- **Single fuel pickup tube.** This carburetor is identified by a single fuel pickup tube incorporating a check valve. The one-way valve helps to keep the fuel in the tube when the engine is not operating. Hard starting may indicate that the check valve is not working.
- **Single mixture adjustment screw.** The amount of fuel flow through the single tube is regulated and adjusted by a single screw and a limiting orifice which affects both the high- and low-speed mixture adjustment. The limiting orifice, as shown in *Figure 5-17*, does not allow excess fuel to enter and wash down the oil from the cylinder wall.
- **No acceleration pump.** Many of these carburetors are used on lawnmowers, where rapid acceleration is needed. The carburetor is adjusted to run "richer" to compensate for this.

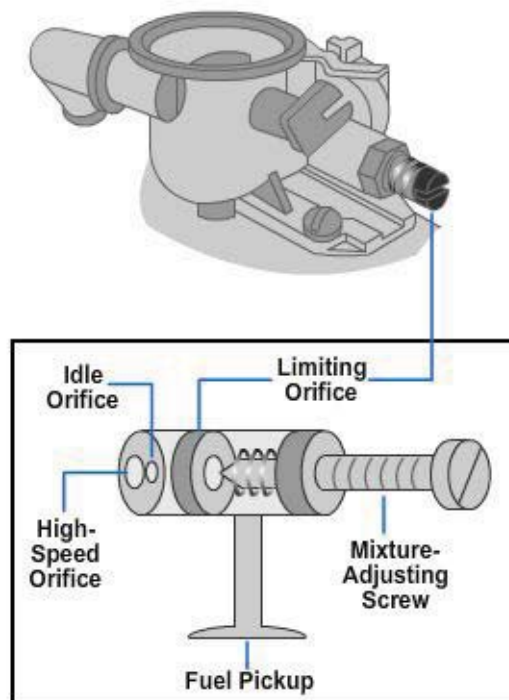


Figure 5-17 – Limiting orifice.

Initial Carburetor Vacu-Jet Adjustment. The air cleaner must be assembled to the carburetor before running the engine. The best carburetor adjustment is obtained with the following steps:

1. Make sure that the level of fuel in the tank is approximately 1/2 full.
Note: Originally, Briggs & Stratton recommended that the fuel tank be 1/2 full or full when adjusting. Many warm restart problems have prompted a change in this initial fuel tank level. The distance the fuel has to be lifted will affect the mixture adjustment. At 1/2 full, we have an average operating condition, and the adjustment will be satisfactory even if the engine is run with the tank full or nearly empty.
2. Gently turn the needle valve clockwise until it seats. The valve may be damaged by turning it too far.
3. Open the needle valve 1 1/2 turns counterclockwise. This initial adjustment will permit the engine to be started.

4. Next, with a warmed-up engine for 3 to 5 minutes operating time, make the final adjustment.

Final Carburetor Vacu-Jet Adjustment.

1. Place the speed control lever in the FAST position.
2. Turn the needle valve in clockwise until the engine speed just starts to slow. Now open the needle valve $\frac{1}{2}$ -turn counterclockwise.
3. With your fingers, rotate the throttle plate counterclockwise and hold it against the throttle plate stop while adjusting the rpm. Turn the idle speed adjustment screw to obtain 1750 rpm, as recommended by the factory specifications. Use a tachometer to set the idle speed. If the idle speed is lower than recommended, the engine may not perform properly.
4. Release the throttle plate. The engine should accelerate smoothly. If the engine does not accelerate properly, the carburetor should be readjusted, usually to a slightly richer mixture, by opening the needle valve an additional $\frac{1}{4}$ -turn counterclockwise.
5. Check the adjustment by moving the engine control from SLOW to FAST speed. The engine should accelerate smoothly. If the engine tends to stall or die out, increase the idle speed or re-adjust the carburetor, usually to a slightly richer mixture.

Note: Previously, Briggs & Stratton recommended that the carburetor be adjusted to the "midpoint," between too rich and too lean. The adjustment worked well with an engine being started for the first time, but not in the case of a hot engine. The midpoint proved to be too rich and resulted in an engine that was hard to restart. Based on this new information, the company adopted new procedures.

Starting a flooded Vacu-Jet. Flooding can occur if:

1. The engine is tipped at an angle for a prolonged period of time.
2. The engine is cranked repeatedly when the spark plug wire is disconnected.
3. The carburetor mixture is adjusted too rich.

If flooding occurs in a Vacu-Jet with an automatic choke, move the governor control to STOP and pull the starter rope at least six times; in this situation, the governor spring holds the throttle plate in a closed (idle) position. Thus, cranking the engine with a closed throttle creates a higher vacuum, which opens the choke rapidly, permitting the engine to clear itself of excess fuel. Then, move the control to the FAST position and start the engine. If the engine continues to flood, lean the carburetor needle valve $\frac{1}{4}$ -turn clockwise.

1.4.3.1.2 Pulsa-Jet Carburetor

The Pulsa-Jet is a carburetor that incorporates a diaphragm fuel pump and a constant level fuel chamber, as illustrated in *Figure 5-18*. The fuel tank, fuel pump, and constant level fuel chamber serve the same functions as the gravity feed tank, the float, and the float chamber of the conventional "float type" carburetors.

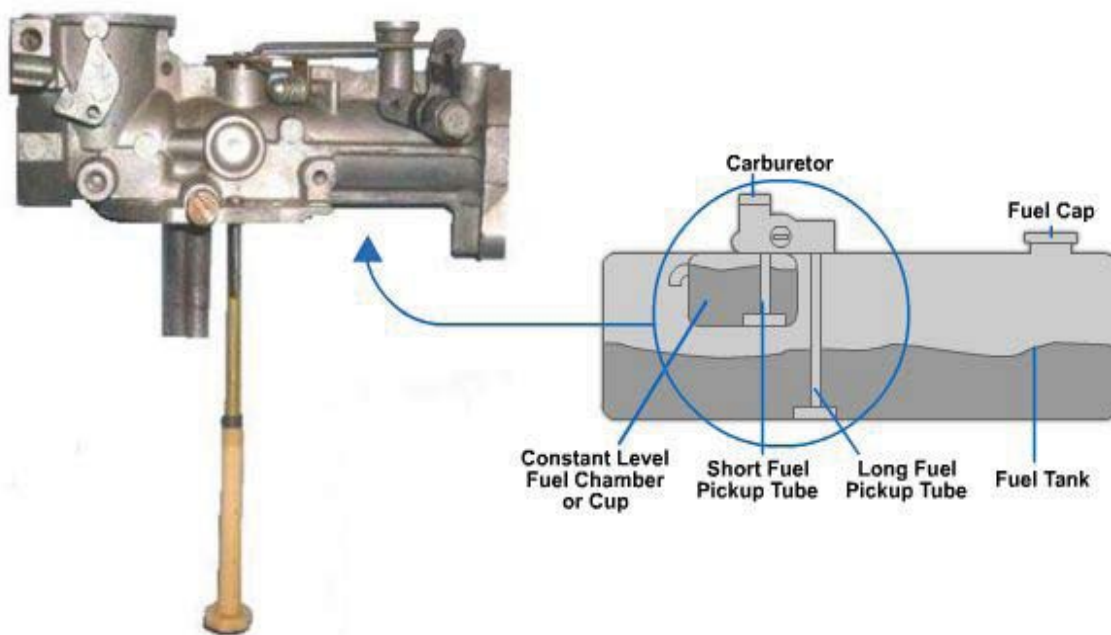


Figure 5-18 – Pulsa-Jet carburetor.

With this carburetor, the fuel level stays constant in the small chamber, no matter what fuel level exists in the main tank. Very little "lift" is required to draw the gasoline into the venturi. The venturi can be made larger, as shown in *Figure 5-19*, permitting a greater volume of air-fuel mixture to flow into the engine, enhancing the volumetric efficiency of the engine and increasing the horsepower.

Pulsa-Jet construction. When the carburetor is removed from the fuel tank, notice that there are two differently sized fuel pipes. The long one transfers fuel from the large tank to the small fuel cup by means of a fuel pump, while the short tube transfers the fuel from the fuel cup to the venturi.

Pulsa-Jet identification. Just as with the Vacu-Jet carburetor, identification of the Pulsa-Jet is by using the model number. Using the example in *Figure 5-15* for Pulsa-Jet, the center number (5) will change to either a 2 for horizontal crankshaft or 9 for vertical crankshaft. The other method again is by visual recognition if you are that familiar with the various models.

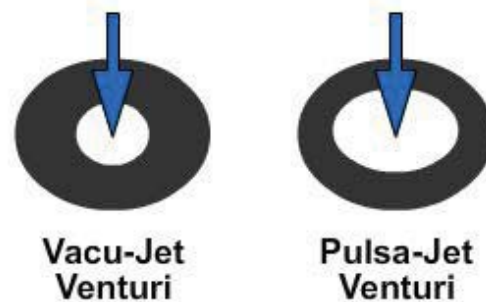


Figure 5-19 – Pulsa-Jet uses a larger venturi than the Vacu-Jet.

Pulsa-Jet fuel pump. The built-in fuel pump is actuated by the changes in pressure in the carburetor air horn or throat. When the piston is moving downward on the intake stroke, a low-pressure area builds on the engine side of the venturi, as illustrated in *Figure 5-20*. The low pressure is transferred to the pump diaphragm through a hole in the bottom of the air horn. The diaphragm is raised upward against the tension of the

spring, and the area below the diaphragm develops a lower pressure or suction as it attempts to expand. The space increases as fuel is sucked through valve, which is a one-way flap that permits fuel to flow into the chamber, but not through valve #2, which is also a one-direction flexible flap that allows fuel to exit the compartment only.

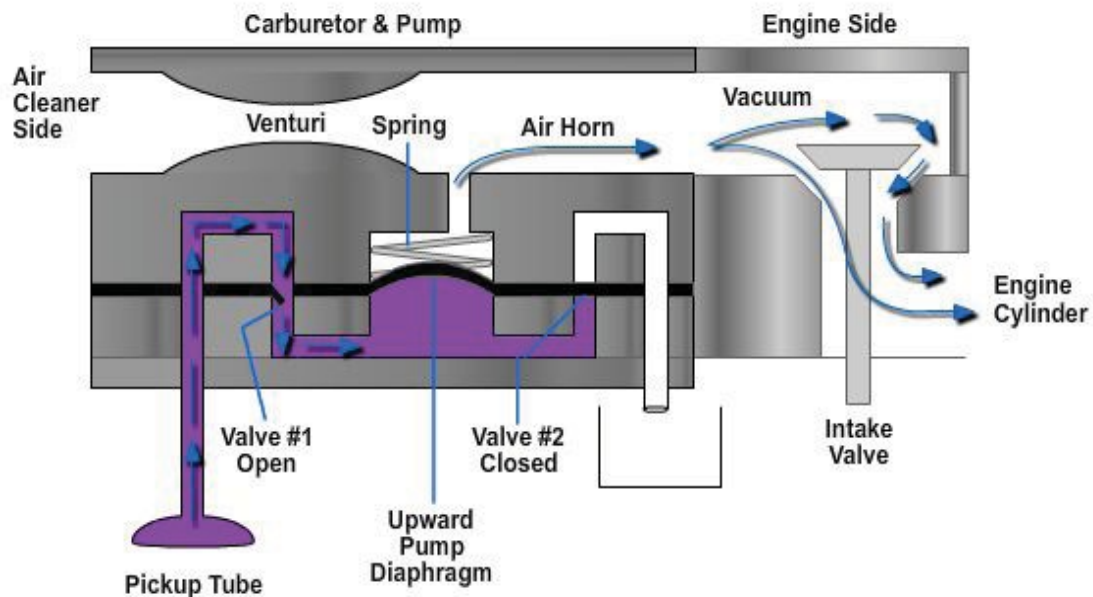


Figure 5-20 - The vacuum from the piston movement moves the pump diaphragm upward.

When the piston is not on the intake stroke, the engine's intake valve is closed, as shown in *Figure 5-21*, and the engine vacuum in the venturi area disappears. The spring that is located in the upper pump area pushes the diaphragm downward, causing an increase in the pressure in the lower chamber. The added pressure attempts to drive the fuel out of the area, but only valve #2 is allowed to open, as valve #1 is held shut by pressure. Fuel is pushed into the small fuel cup of the carburetor.

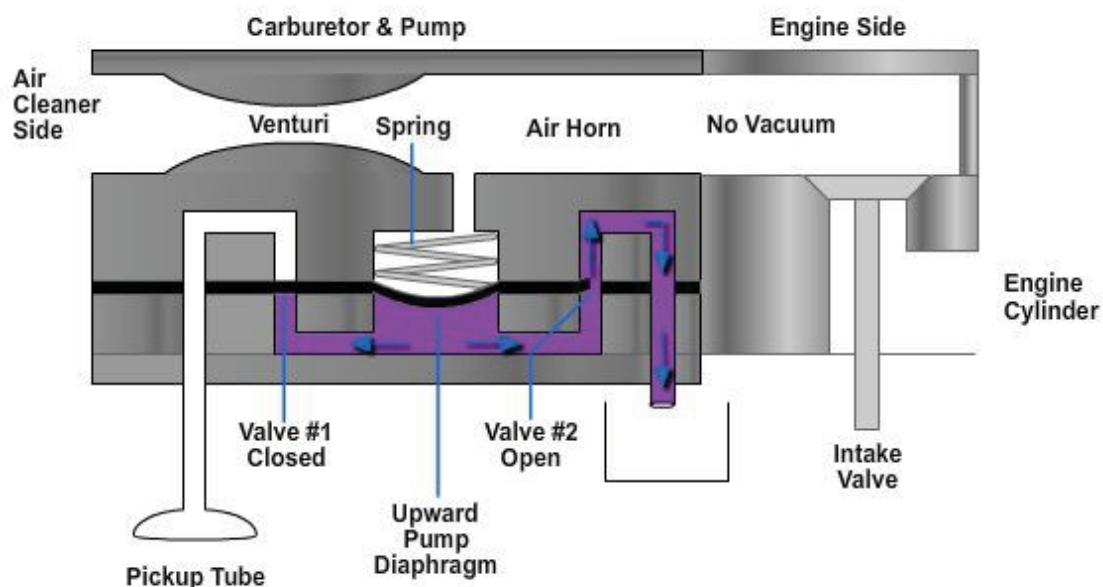


Figure 5-21 - The spring pushes the pump diaphragm downward when no vacuum is present.

The vacuum/no vacuum condition creates an action of the fuel pump's diaphragm, which along with the two pump valves, moves the fuel along from the pick-up tube to the small fuel cup. Keep in mind that the diaphragm separates the air compartment and spring from the fuel compartment.

A common mistake in re-assembling the carburetor is the placement of the fuel pump spring and spring cover. The inexperienced person will place it into the fuel tank side of the diaphragm. The correct position, as shown in *Figure 5-22*, is in the recess on the carburetor side of the diaphragm. This is a calibrated spring and should never be stretched. If the spring is bad, it should be replaced.

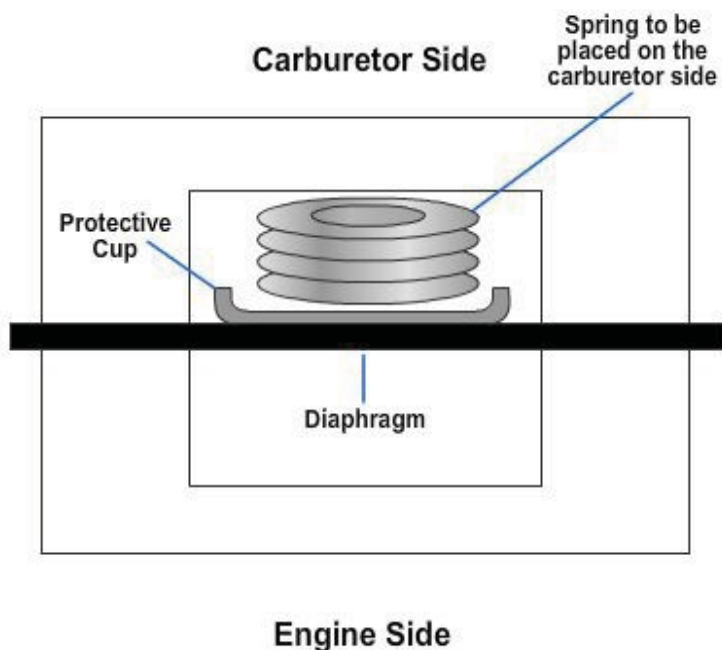


Figure 5-22 – Correct placement of the fuel pump spring.

Pulsa-Jet variations. The newer Pulsa-Jet aluminum carburetor has a fixed main fuel jet with an adjustable idle fuel circuit, as shown in *Figure 5-23*. With the carburetor removed from the tank, Pulsa-Jet carburetors can be seen to have two fuel pickups. *Figure 5-23A* shows that the shorter pickup tube is part of the carburetor casting in this fixed-jet version. (In the adjustable-jet version, the shorter pickup tube is plastic and screws into place.) For this particular carburetor, the main jet is located on the side of the shorter fuel pickup tube and is fixed (not adjustable). *Figure 5-23B* shows a version of the Pulsa-Jet carburetor that has a fixed jet at the bottom of the pedestal. A venturi is cast as an integral part of the carburetor body, improving the engine's starting, idling, acceleration, and response to load. The fuel tank is vented through a passage within the carburetor. These aluminum body carburetors are equipped with a throttle plate shaft dust seal.

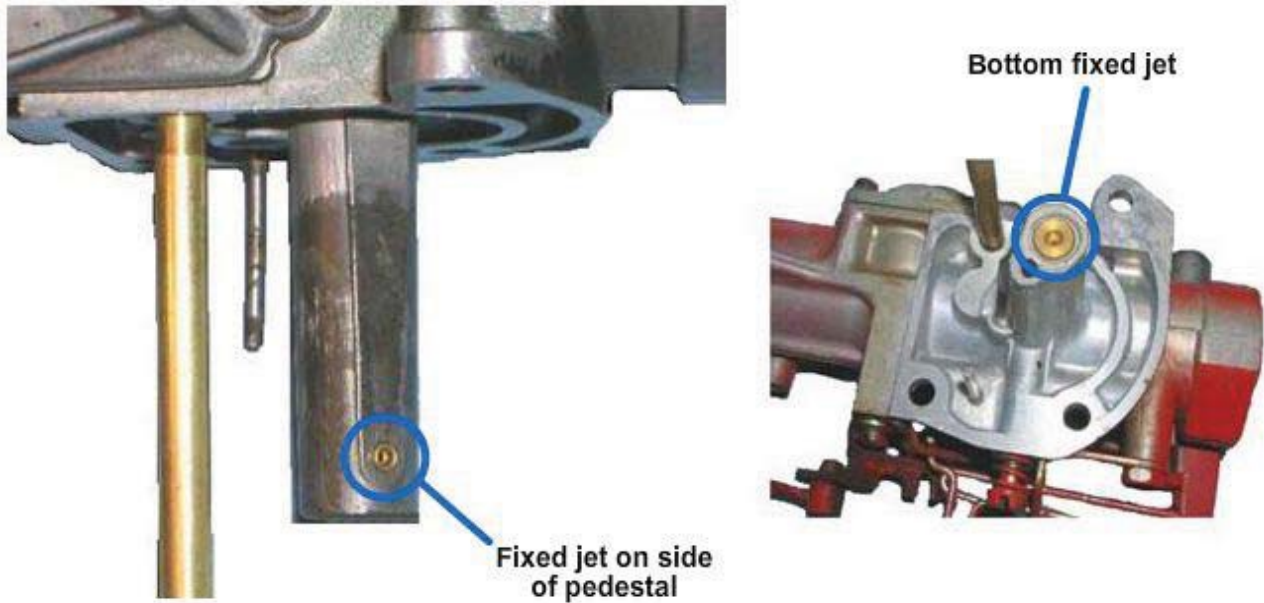


Figure 5-23 - Pulsa-Jet carburetors have two fuel pickup tubes.

A 0.046-inch diameter hole has been placed in the fuel tank's reservoir cup. When an engine runs out of fuel, both the tank and reservoir cup are nearly empty of fuel. When the fuel tank is filled to a level above this hole, fuel will transfer into the reservoir cup. This reduces the number of pulls required to "prime" the reservoir cup, allowing for quicker and easier starting.

1.4.3.1.3 Pulsa-Prime Carburetor

Another Pulsa-Jet family carburetor is the "Pulsa-Primer" carburetor, as shown in *Figure 5-24*. The main body of the carburetor is injection-molded, glass-reinforced nylon polymers. By using plastic for the body construction, no machining is required. The Pulsa-Prime carburetor has no idle system and no air or fuel adjustments. The governor system will allow for a 600 rpm decrease in speed from the top no-load speed, but the engine will never reach a true idle speed. The carburetor has high-speed jets that will provide fuel throughout the operating speed of the engine.

Primer. A wet bulb primer has been added to the carburetor. This eliminates the need for the automatic choke. The wet bulb primer will inject fuel directly into the throat of the carburetor for quick start with a cold engine through the high-speed nozzle. The primer

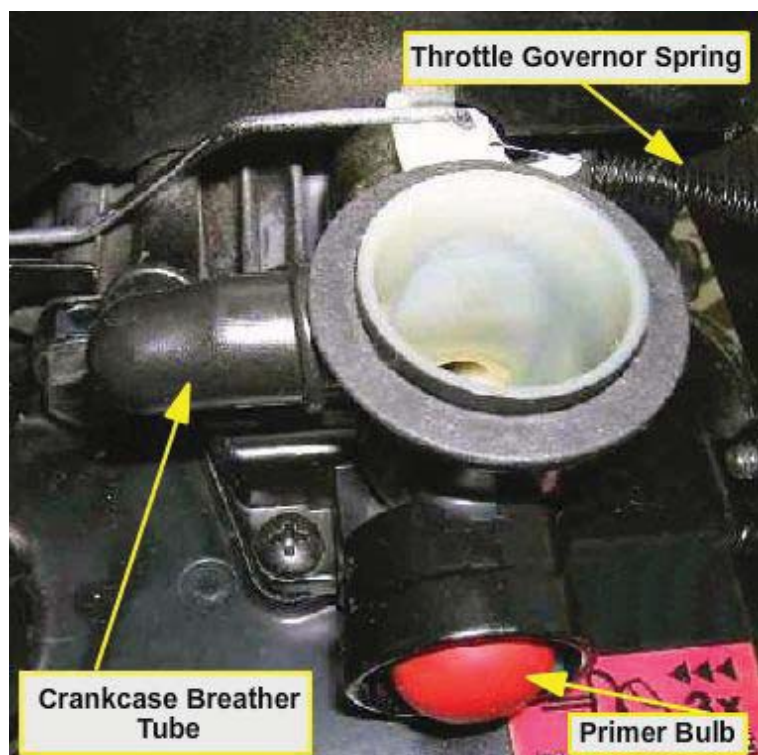


Figure 5-24 - "Pulsa-Prime" carburetor.

bulb should be firmly pressed three times before starting the engine. Priming is usually unnecessary when restarting a warm engine. The primer bulb will also assist when starting after refueling.

Pressing on the primer bulb compresses air inside the carburetor body seating and the check valve in the fuel pipe. Air is pushed past the primer check valve. When the primer bulb is released, a vacuum now exists inside the primer fuel pipe. Air pressure inside the fuel tank pushes the fuel past the fuel pipe check valve and up the fuel pipe, past the check valve to begin filling the fuel pump cavity. Fuel also moves through the primer passages to the primer bulb. Pushing the primer bulb only one time on a dry fuel system will not fill all passages. On the third push, fuel will fill the fuel pump, pushing fuel past the outlet valve into the fuel well in the top tank, through the jet screen and up the fixed jet.

Cleaning the Pulsa-Prime Carburetor. The Pulsa-Prime carburetor should be cleaned on a regular basis to keep the carburetor operating properly. Debris and contaminants should be removed and the filter screens should be cleaned. The carburetor is removed from the fuel tank when the fuel tank is cleaned. Remove any debris from the filter screens on the fuel pump pickup tube (long tube) and the main jet assembly, as shown in *Figure 5-25*. An easy way to remove the fuel from a Pulsa-Prime fuel tank is to utilize a clear or opaque turkey baster. The fuel can be suctioned out and examined or discarded.

Fuel Pump Spring. The fuel pump spring must be installed for the fuel pump to operate properly. Install the spring as shown in *Figure 5-26*.

High-Altitude Compensation. When the Pulsa-Prime carburetor is used at high altitudes and performance is poor, remove the main air jet air bleed, as shown in *Figure 5-27*. By removing the main air jet bleed, more air is allowed to mix with the fuel and lean the mixture, which is necessary for proper performance at higher altitudes.

Initial Carburetor Pulsa-Jet Adjustment. The air cleaner must be assembled to the carburetor before running the engine:

1. Gently turn the needle valve clockwise until it just seats. The valve may be damaged by turning it in too far.
2. Open the needle valve 1 1/2 turns

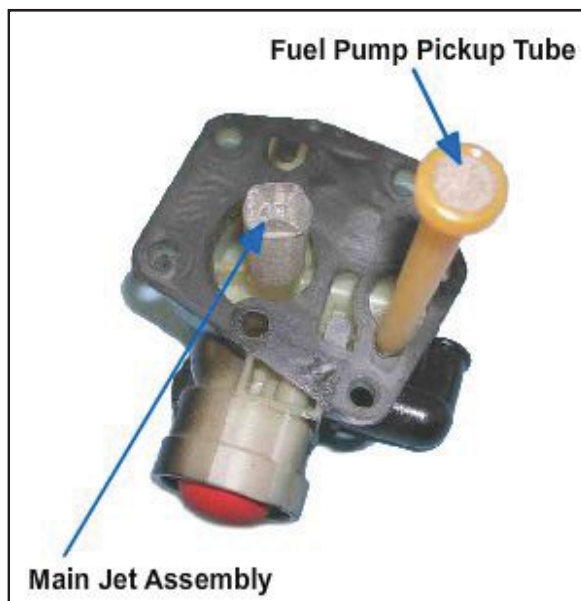


Figure 5-25 – Clean the debris from filter screens.



Figure 5-26 - Diaphragm spring.

counterclockwise. This initial adjustment will permit the engine to be started.

3. Next, with a warmed-up engine (3 to 5 minutes operating time), make the final adjustments.

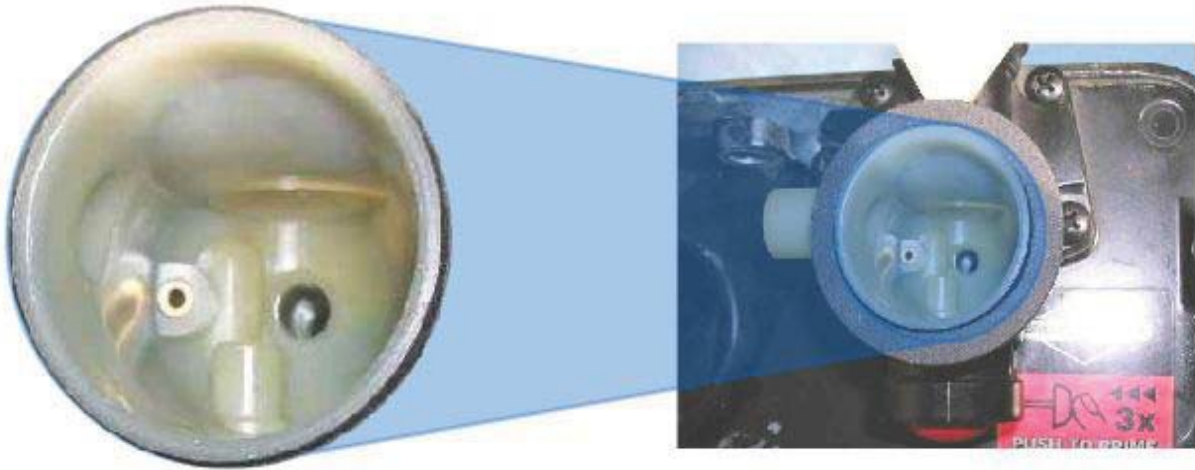


Figure 5-27 – Main jet air bleed.

Final Carburetor Puls-a-Jet Adjustment

1. Place the speed control lever in the FAST position.
2. Turn the needle valve inward (clockwise), until the engine speed just starts to slow. Now open the needle valve $\frac{1}{2}$ -turn counterclockwise.
3. With your fingers, rotate the throttle plate counterclockwise and hold it against the throttle plate. Stop while adjusting idle rpm. Turn the idle speed adjusting screw to obtain 1750 rpm, as recommended by the specifications. Use a tachometer to set the idle speed. If the idle speed is lower than recommended, the engine may not perform properly.
4. Release the throttle plate. The engine should accelerate smoothly. If the engine does not accelerate properly, the carburetor should be readjusted, usually to a slightly richer mixture, by opening the needle valve an additional $\frac{1}{4}$ -turn counterclockwise.
5. Check the adjustment by moving the engine control from SLOW to FAST speed. The engine should accelerate smoothly. If the engine tends to stall or die out, increase the idle speed or readjust the carburetor, usually to a slightly richer mixture.

NOTE

Previously, Briggs & Stratton recommended that the carburetor be adjusted to the "midpoint," between too rich and too lean. The adjustment worked well with an engine being started for the first time, but not in the case of a hot engine. The midpoint proved to be too rich and resulted in an engine that was hard to restart. Based on this new information, the company adopted new procedures.

1.4.3.1.4 Automatic Choke (Vacu-Jet and Pulsa-Jet)

Theory of operation. The automatic choke provides a rich mixture condition when starting the engine. A diaphragm under the carburetor is connected to the choke shaft by a rigid link. A calibrated spring under the diaphragm holds the choke valve closed, as shown in *Figure 5-28, View A*, when the engine is not running. When the engine starts, the choke opens as the vacuum created in front of the venturi is transferred via a calibrated passage to the area below with a choke diaphragm. As the diaphragm and choke link move downward, as shown in *Figure 5-28, View B*, the choke is pulled open.

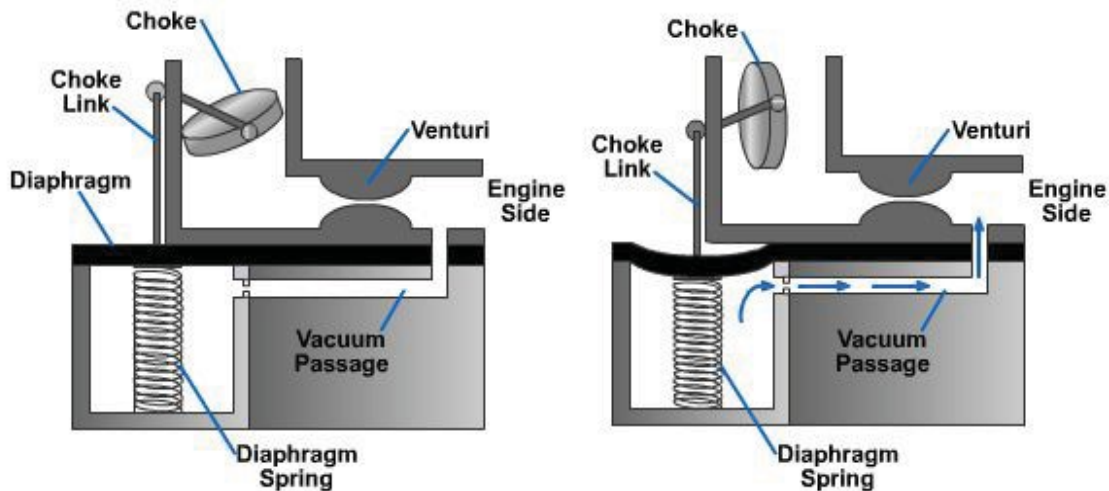


Figure 5-28 - Automatic choke.

This system has the ability to respond in a fashion similar to an acceleration pump. As the speed decreases during heavy loads, the choke valve partially closes, resulting in a richer mixture and improved acceleration performance.

Preloading diaphragm. Before tightening the carburetor mounting screws in a staggered sequence, move the choke plate to an over-center position and hold it there. This pushes the choke link downward to the bottom of its travel and pre-stretches the diaphragm. Tighten the screws in a crossing sequence to 35 inch-pounds.

Automatic choke inspection.

1. Remove the air cleaner and replace the stud. Observe the position of the choke valve. It should be fully closed.
2. Move the speed control to the stop position. The governor spring should be holding the throttle plate in a closed position. Pull the starter rope rapidly. The choke valve should alternately open and close.
3. If the engine can be started, run for 3 to 5 minutes at normal operating speed. Close the needle valve by turning clockwise enough to make the mixture lean, and then adjust the needle valve $\frac{1}{2}$ -turn open counterclockwise.
4. Allow the engine to run at idle speed for 3 to 5 minutes. Again, close the adjusting speed needle; the mixture should become so lean that the engine will stop. If the engine continues to run at idle with the needle valve closed, a fuel leak is occurring at the diaphragm.

Bimetal choke. An engine equipped with a safety stopping mechanism can be expected to be stopped, and then restarted, on a frequent basis. This means that the

engine must start easily each time. The bimetal automatic choke carburetor is used in these situations.

The diaphragm springs that are used in the automatic choke carburetors may look alike but will vary in function, depending on usage. Therefore, utilize only the spring recommended in the parts manual for the engine being worked on. The springs have been color-coded according to their strength. The stronger the spring, the longer the engine will be kept in the choke condition. The springs from the strongest to the weakest are: no color, red, blue, and green.

The operation of the automatic choke remains the same at moderate engine starting temperatures. However, at "hot" or "cold" starting temperatures, the bimetal choke carburetor, as shown in *Figure 5-29*, automatically compensates for temperature changes by influencing the choke opening time.

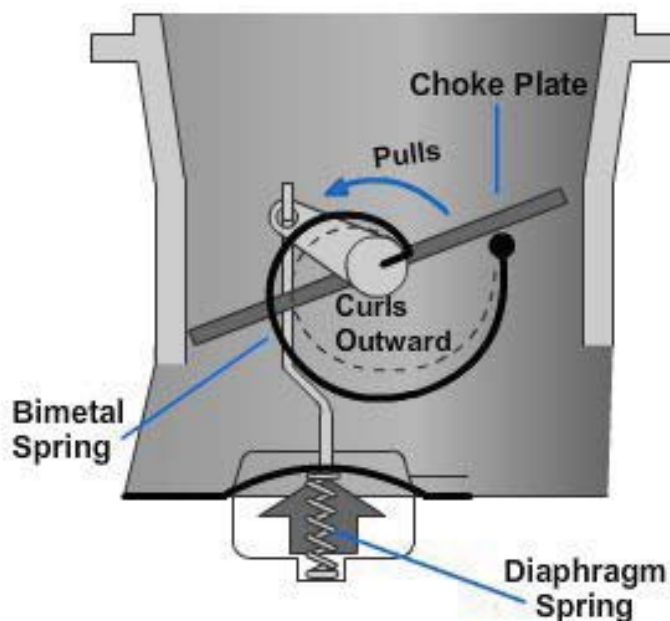


Figure 5-29 - Bimetal choke compensates for temperature changes.

At higher engine starting temperatures, the "hot" crankcase air passing through the breather tube causes the bimetal spring to expand and curl outward. This action causes the inner end of the bimetal spring to "pull" the choke shaft/choke plate open, but since the diaphragm spring is opposing this force, the choke plate continues to remain closed. This action does, however, make it easier for starting vacuum to open the choke plate quickly and improve "hot" starting problems.

At lower engine starting temperatures, the "cold" ambient air causes the bimetal spring to contract and curl inward. This action causes the inner end of the bimetal spring to "push" the choke shaft/choke plate closed, which assists the diaphragm spring in holding the choke plate closed longer. The result is a slightly longer period of a rich air-fuel mixture, assuring improved "cold" temperature starting.

Automatic choke inspection areas. When a problem is suspected in the automatic choke system, certain areas should be inspected to determine whether:

1. The carburetor is adjusted too lean to too rich.
2. The fuel pipe check valve is inoperative (Vacu-Jet only).
3. There is a bent air cleaner stud.
4. There is a sticking choke shaft due to dirt.
5. The choke spring is damaged or too short.

6. The diaphragm is not preloaded.
7. The diaphragm is ruptured or the vacuum passage is restricted.
8. Gasoline or oil is in the vacuum chamber.
9. There is a leak between link and diaphragm.
10. The diaphragm folded during assembly.

1.4.3.1.5 Flo-Jet Carburetor

The Flo-Jet resembles the internal workings of the carburetors generally found on vehicles. The fuel tank is mounted higher than the carburetor, and gasoline flows into it by the pull of gravity. A float inside the carburetor bowl regulates the flow of gasoline, similar to the float inside your toilet tank that regulates the level and flow of water.

Flo-Jet identification. The easiest way to identify the Flo-Jet design is to check the engine's model number. If you refer back to *Figure 5-15*, the #5 in the model number would change to 3 for horizontal Flo-Jet pneumatic governor or 4 for horizontal Flo-Jet mechanical governor. You can identify by recognition of the carburetor, but only the most experienced should rely on that method. *Figures 5-30, View A – 5-30, View C* illustrates three models of Flo-Jet carburetors. Notice their differences in appearance.

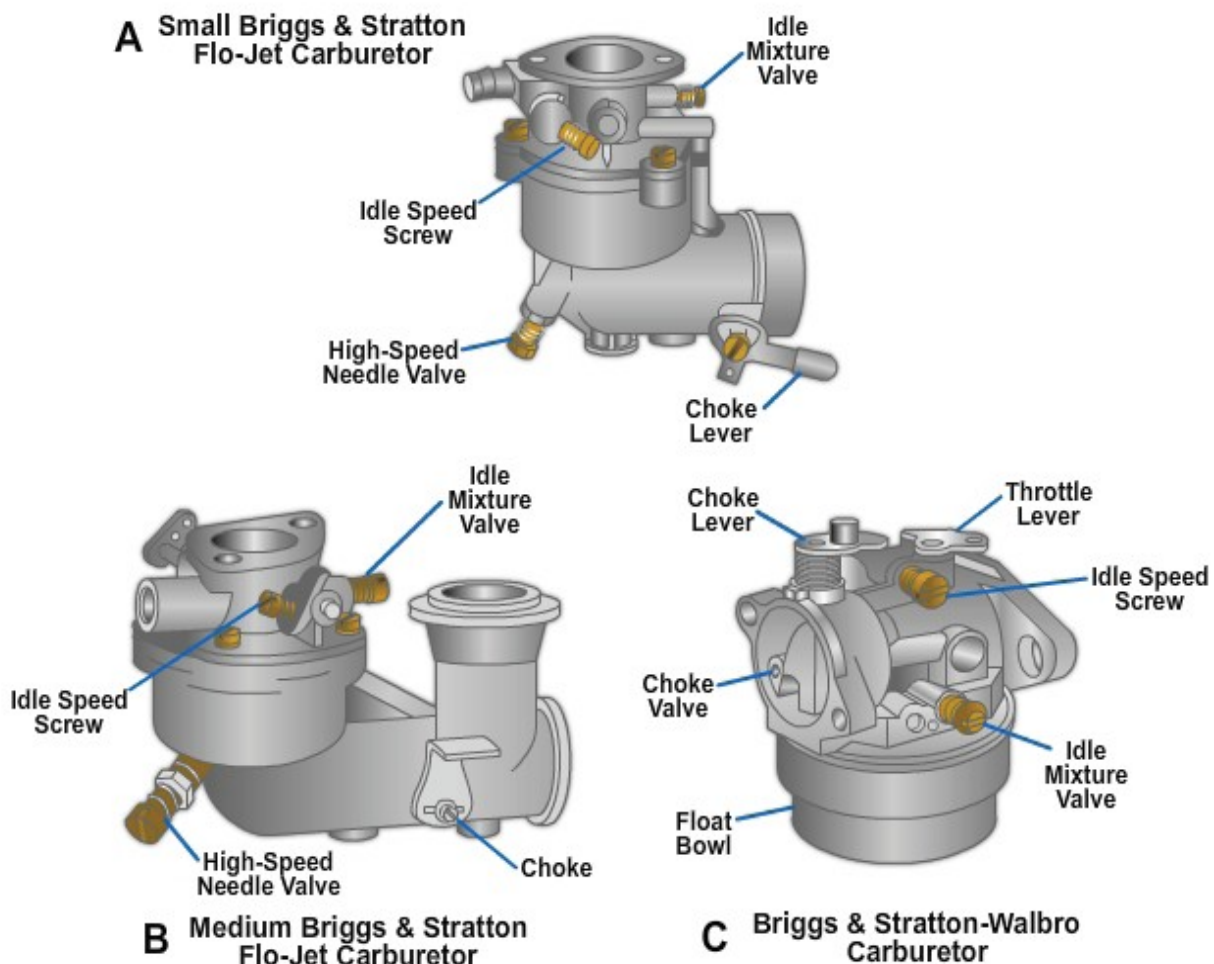


Figure 5-30 - Flo-Jet carburetors.

Flow-Jet carburetor

adjustment. Prior to the separation of the upper and lower half of the carburetor, unscrew the packing nut and remove the high-speed needle valve, as shown in *Figure 5-31*. Next, remove the nozzle (emulsion tube), as shown in *Figure 5-32, View A*. The nozzle must be removed by using a screwdriver without a taper (Briggs & Stratton tool #19280), as shown in *Figure 5-32, View B*, since the nozzle is made of brass, a soft metal, and is easily stripped or damaged. See *Figure 5-32, View C*. Failure to remove the nozzle will result in a carburetor that may leak when the engine is not operating. The nozzle has holes along its length that must be cleared in addition to the hole down the center (Figure 5-32, View D).



Figure 5-31 - Packing nut and high-speed needle valve.

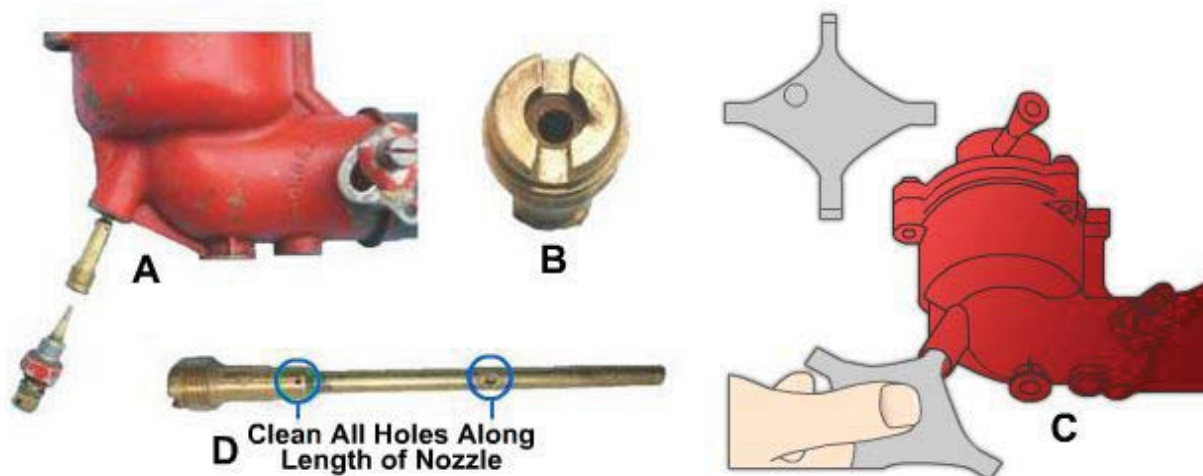


Figure 5-32 - Remove and clean nozzle.

Flo-Jet carburetor cleaning. Particles of dirt and debris in the fuel system will create erratic engine operation and affect carburetor adjustments. If this problem is suspected, clean the entire fuel system, including the carburetor. Install a fuel filter in the fuel line and adjust the float level.

Flo-Jet float adjustment. With the body gasket in place on the upper body and the float valve and float installed, the float should be parallel to the body mounting surface. If not, bend the tang on the float with needle nose pliers until it is parallel. **DO NOT PRESS ON THE FLOAT.**

Initial Flo-Jet adjustments. Before starting the engine, the air cleaner should be clean and assembled to the carburetor. If the mixture valves are adjusted without the air cleaner in place, difficulties will be encountered after the air cleaner is attached. Some

resistance to the air intake is caused by the cleaner, and this will result in added suction in the air horn (which was not present when the adjustments were made).

1. Gently turn the maximum valves clockwise until they just seat. Valves may be damaged by turning them too far and too tightly.
2. Open the high-speed needle valve 1½ turns counter clockwise and the idle valve one turn. This initial adjustment will permit the engine to be started.
3. Start engine and allow it to warm up for approximately 5 minutes prior to final adjustment.

Final Flo-Jet adjustment.

1. When the engine is warm and running, place the speed control lever in the FAST position.
2. Turn the high-speed needle valve inward until the engine slows (clockwise-lean mixture). Then turn it outward, past smooth operating point (counterclockwise-lean mixture). Now turn the needle valve to midpoint between rich and lean.
3. Adjust the idle to 1750 rpm according to the specifications by rotating the throttle plate counterclockwise and holding it against the stop and turning the idle mixture valve screw.
4. While holding the throttle plate against the idle stop, turn the idle mixture needle valve clockwise until the engine slows. Then turn it counterclockwise, past the smooth operating point. Set it at a midpoint between rich and lean.
5. Recheck the idle rpm and release the throttle plate. If the engine does not accelerate properly, readjust the high-speed mixture valve approximately ¼ turn counterclockwise (rich).

Flo-Jet problems.

Leakage. Carburetor leakage is not only irritating, but also a safety concern. The first step toward finding the cause of the problem is to identify when leak occurs.

Float bounce is one cause for the Flo-Jet carburetor to leak. Float bounce is a condition that typically occurs when the engine/equipment is transported. The use of a fuel shut-off valve is recommended for the use on all float-style carburetor systems.

The fuel supply (fuel tank) may be located too far above the carburetor, resulting in excessive pressure at the fuel tank inlet needle and a leak. The maximum tank height recommended for gravity feed fuel systems is 45 inches. The use of an inline filter is recommended for all float-style carburetor systems.

If the carburetor leaks shortly after the engine is turned OFF, it may be due to a long coast-down period, which is a prolonged spinning of the engine. A long coast-down period will cause accumulation of unburned fuel. Whenever possible, slow the engine's speed to an idle before shutting OFF the engine. Using the choke as a means to shut off the engine will only aggravate the leakage condition and is not recommended.

The remaining causes for Flo-Jet carburetion leakage involve parts that are loose, missing, assembled/adjusted incorrectly, damaged, or affected by contaminants in the fuel system, such as dirt, water, or additives. Understanding the design of the carburetor is necessary to efficiently isolate and identify the actual cause of the problem.

Common causes. A common cause of fuel leakage in a two-piece Flo-Jet carburetor is an improper seal between the main nozzle and the lower half of the carburetor. There are three ways to correct this problem:

Option #1

1. Take an old nozzle and grind all the threads off the outside. Do not leave any sharp edges that could damage the threads inside the carburetor
2. Put a small amount of fine lapping compound on the shoulder of the nozzle.
Note: Lapping is precision mating of metal parts by placing an abrasive paste for cutting, smoothing, and finishing of metal surfaces.
3. Using a screwdriver as a lapping tool, lap the nozzle into the carburetor before reassembly. This will remove corrosion and restore a sealing surface. Be sure to thoroughly clean the carburetor before reassembly.

Option #2. Use a part from the Briggs & Stratton carburetor repair kit #391413 for servicing a Pulsa-Jet carburetor. Using a teflon washer from the kit, force the washer over the end of the nozzle. The washer will act as a gasket, stopping any leakage between the nozzle and carburetor body.

Option #3. Replace the lower half of the carburetor or the entire carburetor assembly.

Damage at the float valve seat/bushing may be the result of abrasives, corrosion, or careless use of tools. If the condition is limited to the seat/bushing, the problem can be corrected quickly and easily. Pressed-in float valve seat/bushing are replaceable on all float-style carburetors.

Hard to restart. When the warm engine is difficult to start, the primary cause is a rich or flooded condition. If an engine has a hard hot restart symptom, first check the engine's spark plug to determine if a flooded condition exists. This is accomplished by removing the plug and observing the tip to see if it is covered with fuel. Hard hot restart can be caused by an improperly adjusted engine and/or equipment controls, or by a partially restricted air filter. Perform all initial adjustments and recheck for a hard restart condition before attempting more repairs.

A damaged adjusting needle, O-ring, or loose needle/seat will cause a rich condition, which contributes to hard hot restart problems. Inspect for missing, damaged, or loose parts.

Another critical factor is the engine's idle speed. When the engine's idle rpm is set too low, hesitation occurs during acceleration. To eliminate this situation, some mechanics make the air-fuel mixture richer, which will cure the hesitation, but also will cause a hot restart condition.

Winter-grade fuel used in warm weather may vaporize too rapidly and cause a flooding (hot restart) condition.

1.4.3.1.6 Small Briggs/Walbro One-Piece Flo-Jet Carburetor

Diaphragm carburetor with fuel pump. The diaphragm carburetor is widely used, especially in chainsaws and cutoff saws or other tools/equipment where the engine may be used in many different positions, as shown in *Figure 5-33*. Most diaphragm carburetors have a built-in fuel pump, as illustrated in *Figure 5-34*, to ensure that the fuel supply is available to the carburetor, regardless of the position of the fuel tank.

With small variations to the basic overhaul technique, you can easily and correctly tune adjustable carburetors not only on the various chainsaws, but also on the other equipment within the TOA with two-stroke engines.

Fuel pump operation. The fuel pump side of the carburetor is identified by the presence of a fuel inlet fitting. When the pump cover is removed, a fuel gasket and diaphragm are found. Each revolution of the engine produces two changes in crankcase air pressure. The downward movement of the piston creates a positive pressure in the crankcase, while the upward movement creates a negative pressure (vacuum). These impulses are channeled to the fuel pump diaphragm through an impulse channel hole. The impulses actuate the diaphragm just above the fuel reservoir in the pump chamber by moving up and down to pump fuel from the tank. The pump's "one-way flap valves" work in conjunction with the crankcase pressure variations to keep the fuel moving in one direction. A negative impulse, as shown in *Figure 5-35*, brings fuel from the fuel line through valve #1 and closes valve #2. A positive impulse, as shown in *Figure 5-36*, closes valve #1 and pushes the fuel through valve #2 into the metering side of the carburetor.

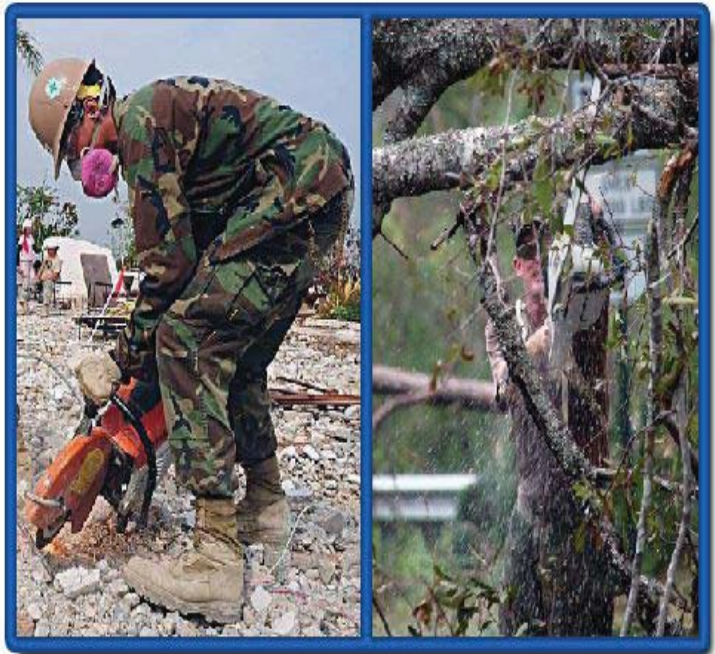


Figure 5-33 – The cutoff saw and chainsaw can be used in various positions due to the diaphragm carburetor.

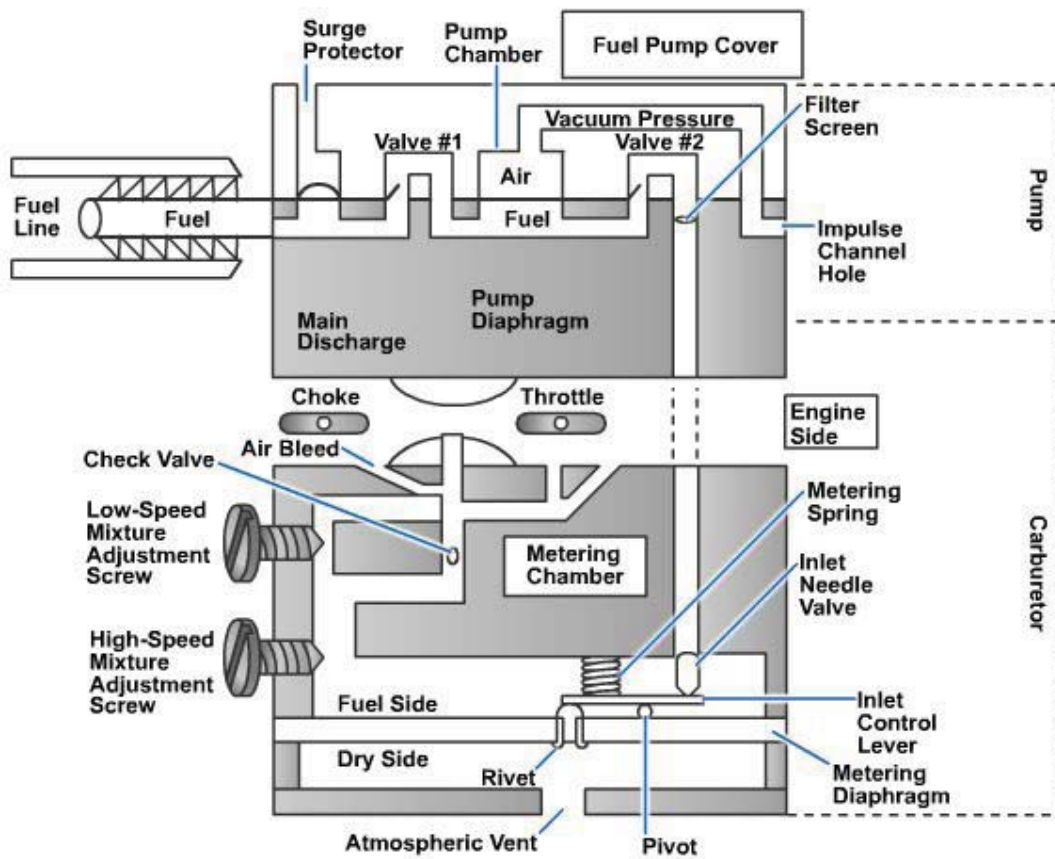


Figure 5-34 - Diaphragm carburetor with fuel pump.

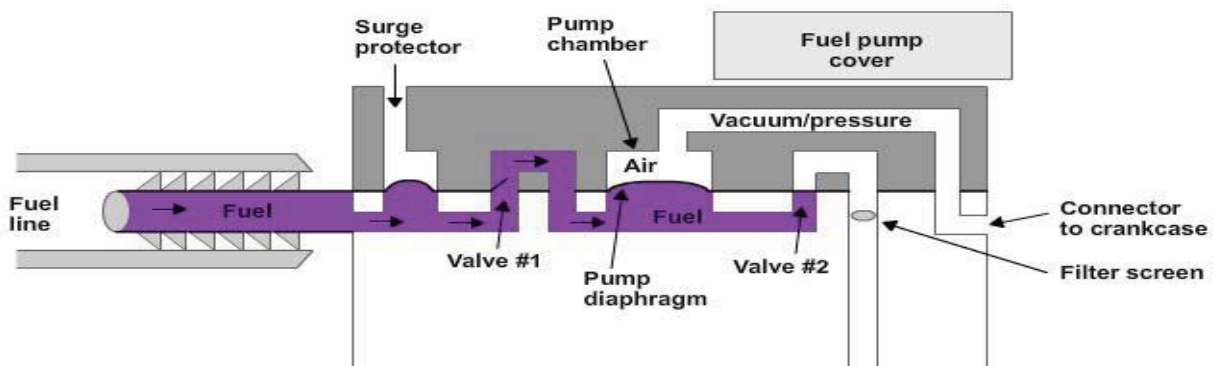


Figure 5-35 - Negative impulse.

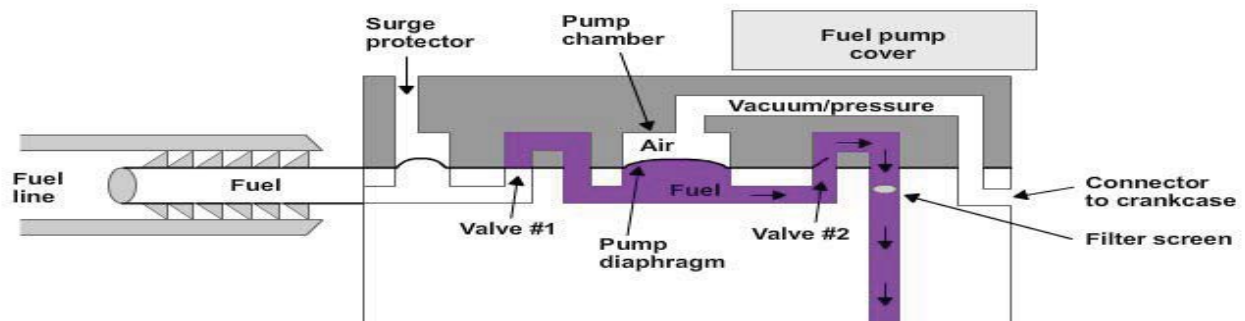


Figure 5-36 - Positive impulse.

The impulse channel hole in the carburetor may be external or internal. The external channel is connected atop the fuel pump cover, while the internal connects through the mounting against the crankcase. This hole may be plugged with foreign material or from improper gasket installation.

A surge protector is installed in many diaphragm carburetors. When the demand for fuel is low and the pressure in the fuel tank is great, the stress is relieved by the flexible part of the diaphragm expanding so that the excess pressure is relieved.

Diaphragm carburetor operation. Fuel flows from the fuel pump to the inlet needle valve. The valve opens and closes according to the movement of the metering diaphragm. The dry side (lower) is exposed to atmospheric pressure through an atmospheric vent in the bottom cover. The fuel side is influenced by the degree of vacuum in the venturi, as shown in *Figure 5-37*.

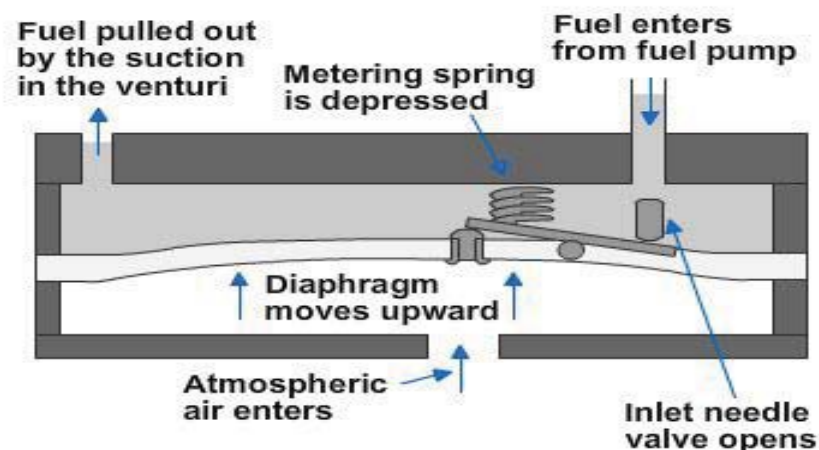


Figure 5-37 - Diaphragm moves upward as fuel is removed.

As the fuel is elevated into the venturi through either the main discharge tube or the idle ports, atmospheric pressure moves the diaphragm upward against the calibrated metering spring. This depresses the inlet control lever, allowing the inlet needle valve to open. Fuel can then flow from the pump side into the metering chamber and through the idle and high speed channels. The inlet needle may have a viton tip, which not only resists the effects of exotic fuels, but also is more resistant to wear. When the discharge of fuel decreases or ceases from the idle or main ports, the incoming fuel pushes the diaphragm downward against the inlet lever, and the flow of fuel is halted.

Diaphragm Engine Operation. Starting a cold engine requires a rich fuel mixture. The choke shutter is in a closed position, as shown in *Figure 5-38, View A*, which exaggerates the vacuum in the venturi. A larger quantity of fuel is drawn in both the main discharge and the idle circuits.

When the engine is started, the choke shutter is opened to allow additional air to mix with the fuel, as shown in *Figure 5-39, View B*. Fuel is drawn up the main discharge port, and the volume of fuel is controlled by the high-speed adjusting needle. Some carburetors are assembled with a fixed jet, the jet hole size is calibrated to supply the correct amount of fuel required by the engine at high-speed operation. This orifice size is critical and should not be altered in any manner. Clean only with compressed air.

When the engine is idling, as shown in *Figure 5-39, View C*, the throttle plate is narrowly open. Engine suction is now permitted only through the low-speed discharge ports, and the volume is controlled by the low-speed mixture adjusting screw.

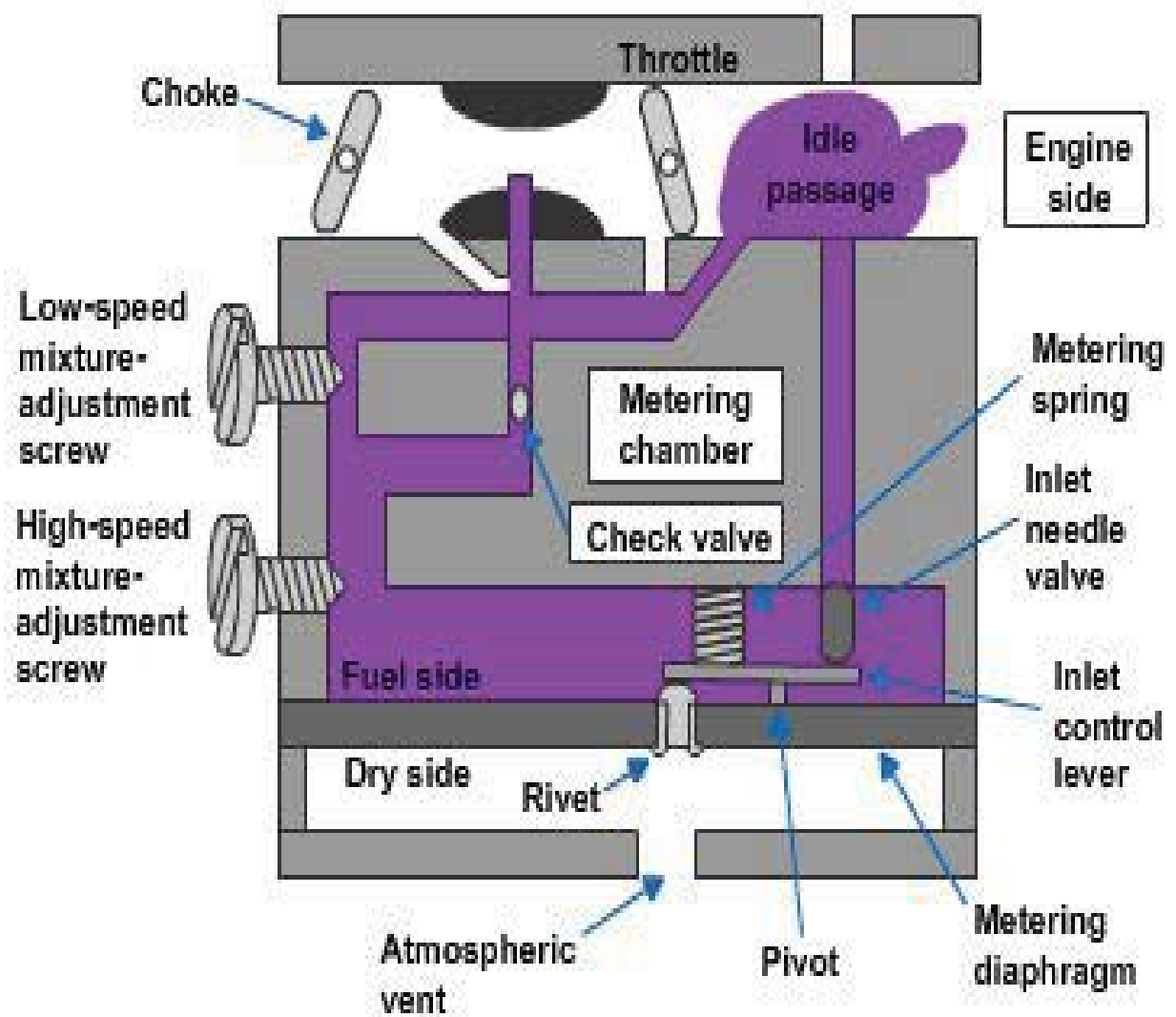


Figure 5-38 - Diaphragm carburetor operation.

Diaphragm Carburetor Service. To ensure long life and top performance of your tools and equipment, a regular general overhaul of the carburetor is advised. Before beginning disassembly, remove all excess dirt and debris from the carburetor. Do not use a cloth, as tiny lint particles are likely to adhere to the components and cause malfunction. Always keep a clean work surface.

Remove pump cover. Beneath the fuel pump cover is the pump gasket. Around the pump gasket there should be clean, well-defined imprints indicating properly sealed-off areas of the pump surface, such as the fuel intake chamber, pulse chamber, and the inlet and outlet valve areas, as shown in *Figure 5-39*. Any cross-leaking between these areas may cause starting and high-speed problems.

Inspect pump valves. Check the flaps of the valves for any excessive wear, peeling, rupture, or distortion. Make certain that they rest flat against the pump surface. If one is curled, the diaphragm should be replaced.

Inspect inlet screen. The inlet screen is located in the chamber above the inlet needle on the fuel pump side of the carburetor, as shown in *Figure 5-40*. This screen filters fuel to the metering chamber. The screen mesh is very small and difficult to identify. Clogging of the screen will restrict fuel flow, affect acceleration, and impair high-speed performance. Remove this delicate mesh carefully with a sharp object and clean it thoroughly.

Metering cover and diaphragm. The vent hole is exposed to the atmosphere, where it may become clogged with dirt. Check for tearing or peeling of the gasket in this area. The diaphragm must be flexible and show no signs of deterioration.

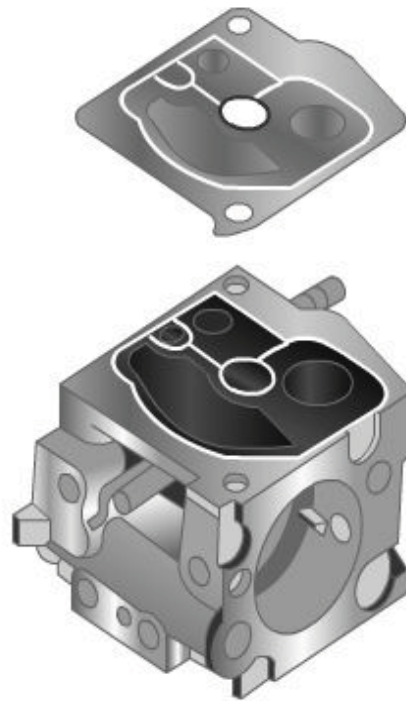


Figure 5-39 - Well-defined imprints indicate proper sealing.

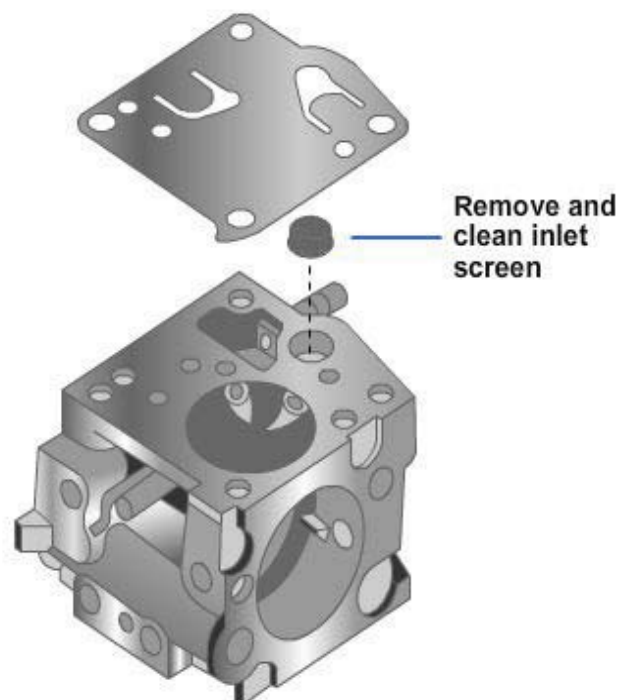


Figure 5-40 – Remove and clean inlet screen.

Lever height. Lever height must be adjusted properly and the lever must move easily, as shown in *Figure 5-41*.

Disassemble the inlet seat components. Hold the inlet lever down with your index finger when removing the fulcrum pin retaining screw, as there is a tension spring directly underneath. Check the lever for wear at the point of contact. Keeping the inlet needle/fulcrum spring in place during assembly can be very tricky. A very small amount of clean, lithium-based grease can be placed in the well where the spring seats. This will hold the spring erect and lessen the chance of it dropping out.

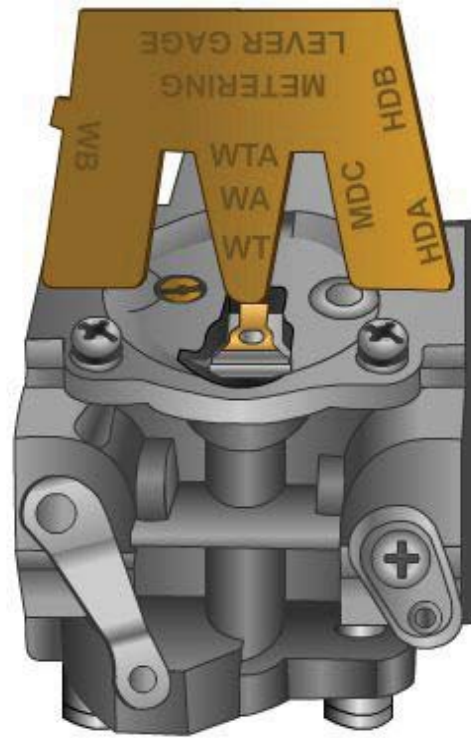


Figure 5-41 – Lever height must be adjusted.

High- and low-speed needles.

Remove the high- (*Figure 5-42, View A*) and low speed (*Figure 5-42, View B*) mixture adjustment needles and check for rusting or damaged threads. Roll them on a flat surface to inspect for a bend. A bent needle point can damage the precision-machined orifice.

Remove Welch plug. This can be accomplished by using a pointed punch, as shown in *Figure 5-43*, or by drilling a hole in the center using a 1/8-inch drill. When a new plug is put in, expand it with a punch.

Rinsing and air cleaning. With all pump and metering components and mixture needles removed, clean the parts in a solvent. After rinsing, blow thoroughly through all the channels. Do not use drills or any hard metal objects to clean away obstructions. Soft tag wire may be used carefully.

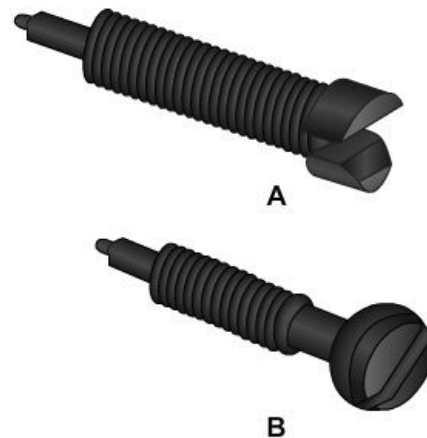


Figure 5-42- Check needles for damage.

Pressure test. When the carburetor is fully assembled, pressure test the inlet seat to detect any leaks that may remain. Connect the pressure inflator to the fuel inlet fitting and apply 5 psi. If there is no leakage around the inlet needle, this should hold steady for about 4 seconds. Depress the metering diaphragm with a pointed instrument, such as a pencil, and repeat this test.

A bow-off pressure test can also be done. Continue to pump until the inlet needle is unseated. This will usually occur between 15 to 25 psi. The dial needle will be seen to drop and should stabilize above 5 psi.

Final inspection. Check the throttle plate and choke shafts. They should open and close freely. When closed, the throttle plate should completely seal the throttle bore.

Diaphragm Carburetor Adjustments.

There are only three basic carburetor adjustments:

1. Low-speed (L) fuel mixture needle
2. High-speed (H) fuel mixture needle
3. Screw for setting idle speed

Make initial adjustments before starting the engine.

Initial adjustments.

1. Gently close the high-low speed mixture needles by turning them clockwise until they are lightly seated. The points of the needles are delicate and rest in a metered orifice. Do not over torque or damage to the needles may occur.
2. Turn the screws outward about 1 1/2 turns. This is usually a rich condition because most carburetors are designed for best fuel flow at about one turn open. Start turning the engine from the rich side of the adjustments.
3. Turn the idle speed screw outward until it does not touch the idle stop. Then screw it back inward until it barely touches the throttle plate lever. At this point you can pre-adjust the screw by turning it an additional 1 1/2 turns.

Final adjustments.

1. Start the engine and flick the trigger a few times. If necessary, reset the idle speed so that the clutch is not engaging. Most small two-stroke cycle engines idle between 2500 and 3000 rpm.
2. Turn the low-speed mixture needle inward about 1/4 turn from the initial setting. The engine speed will increase slightly because you are going from a rich condition to a less rich, or lean, condition. If the clutch starts to engage, back off slightly on the idle speed screw. Accelerate the engine to flush out excess fuel from the crankcase and repeat, alternating from low-speed needle to idle speed screw and back again. About the third time you turn the low-speed needle, engine speed will decrease slightly. Stop at this point. You are just on the lean edge of the best idle mixture. If you squeeze the trigger, the engine will probably stumble a little during acceleration. Richen (turn counterclockwise) the low-speed mixture needle just enough to get quick, smooth acceleration. Use the idle speed screw one last time to achieve correct idle speed.
3. The high-speed mixture needle is adjusted at wide-open throttle plate with a load on the engine. Close the needle clockwise just far enough to hear the engine increase in speed and break into the fringe of a clean, or "bumblebee," sound. This adjustment is too lean to do work. Open the needle counterclockwise far enough to hear again the rich sound of four-cycling as the speed decreases slightly. What you are doing here is tuning by ear, like a piano tuner. Remember,

To do a thorough rebuild of the carburetor, punch a hole in the Welch plug and pop it out. This will enable you to check for clogged passages and replace it with a new one.



Figure 5-43- Remove Welch plug to check clogged passages.

the fuel is the only source of lubrication for the two-stroke engine, and that rich four-cycle sound is good assurance. If you set it too rich, you will lose power and invite faster carbon buildup. The engine should break into a clean sound when you put it to work. Take caution to avoid running the engine too long at wide-open, no-load situation. You should be able to set the adjustment in about 10 to 15 seconds.

2.0.0 DIESEL FUEL INJECTION SYSTEMS

2.1.0 Caterpillar Fuel Injection Systems

2.1.1 Sleeve Meter Fuel System

The sleeve metering system uses a sliding collar sleeve through which the stroking plunger moves. The sleeve and plunger are lapped together to make a matched set. The position of the sleeve collar controls the length of the plunger's effective stroke, thereby determining the amount of fuel delivered. A control unit or lever connected to the governor is used to control the position of the sleeve collar.

2.1.1.1 1.1 Components

The main components of a fuel injection pump using the sleeve metering fuel system are the barrel, plunger, and sleeve. The plunger moves up and down inside the barrel and sleeve, as shown in *Figure 5-44*. The barrel remains stationary, but the sleeve can be moved up and down on the plunger to make a change in the amount of fuel injected. Located in the inlet side of the system is a priming pump. When you open the bleed valve and operate the priming pump, air is removed from the injection pump housing filters and suction lines.

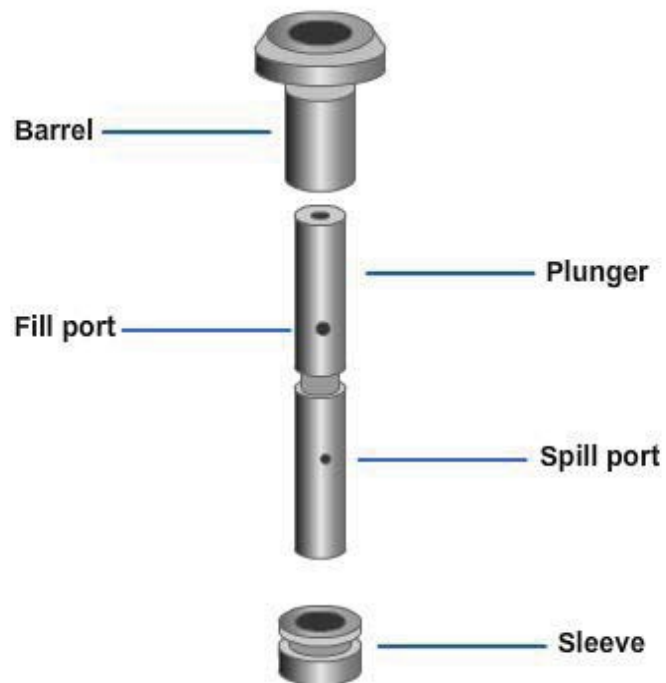


Figure 5-44 - Sleeve metering barrel and plunger assembly.

2.1.1.2 Operations

When the engine is running, pressurized fuel from the transfer pump goes in the center of the plunger through the fuel inlet during the plunger's downward stroke. Fuel cannot go through the fuel outlet at this time because the fuel outlet is blocked by the control sleeve, as shown in *Figure 5-45, View A*. The action of the cam lobe lifts the plunger from its BDC position. As the plunger moves upward in the barrel, it closes the inlet port, as shown in *Figure 5-45, View B*, and injection can begin. This is because the fuel pressure above the plunger increases to the point where it opens the delivery valve and high pressure fuel can flow through the lines to the injection nozzles.

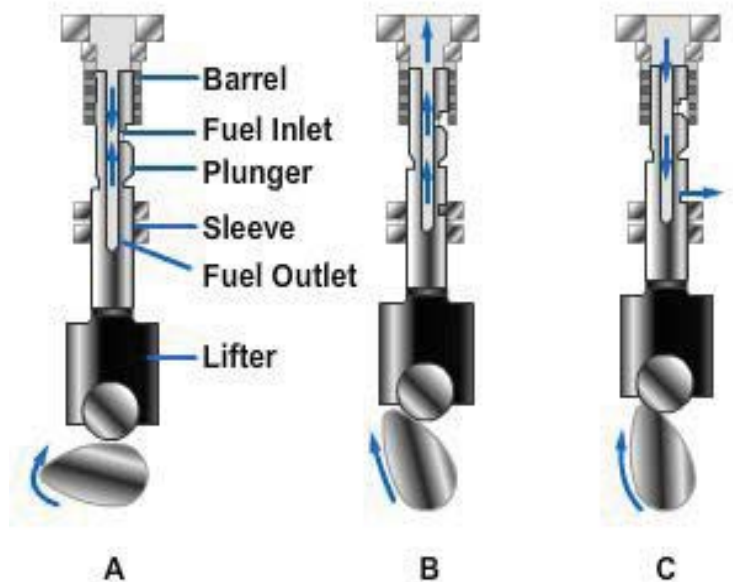


Figure 5-45- Components and operation of sleeve metering system.

Injection stops when the fuel outlet is lifted above the edge of the sleeve, as shown in *Figure 5-45, View C*. This is the end of the plunger's effective stroke. With the outlet now open, pressure above the pumping plunger is lost and the fuel above and inside the plunger passes through the fuel outlet and returns to the fuel injection housing.

When the sleeve is raised on the plunger, the fuel outlet will be covered for a longer time, increasing the effective stroke and causing more fuel to be injected. If the sleeve is located low on the plunger, the fuel outlet is covered for a shorter period of time and fuel delivery is decreased. The metering sleeve allows infinitely variable amounts of fuel to be delivered to the injection nozzles.

Figure 5-46 illustrates a sleeve metered multiple plunger inline pump equipped with a mechanical governor. The lever of the governor is connected by linkage and governor springs to the lever sleeve control shafts. Any movement of the lever causes a change in position of the sleeve control shafts. When the lever is moved by governor action to feed more fuel to the engine, the lever acts to compress the governor springs and move the thrust collar forward. As the thrust collar moves forward, the connecting linkage will cause the sleeve control shafts to turn. The turning movement of the control shafts causes the sleeve levers to lift the sleeves, increasing the amount of fuel sent to the cylinders.

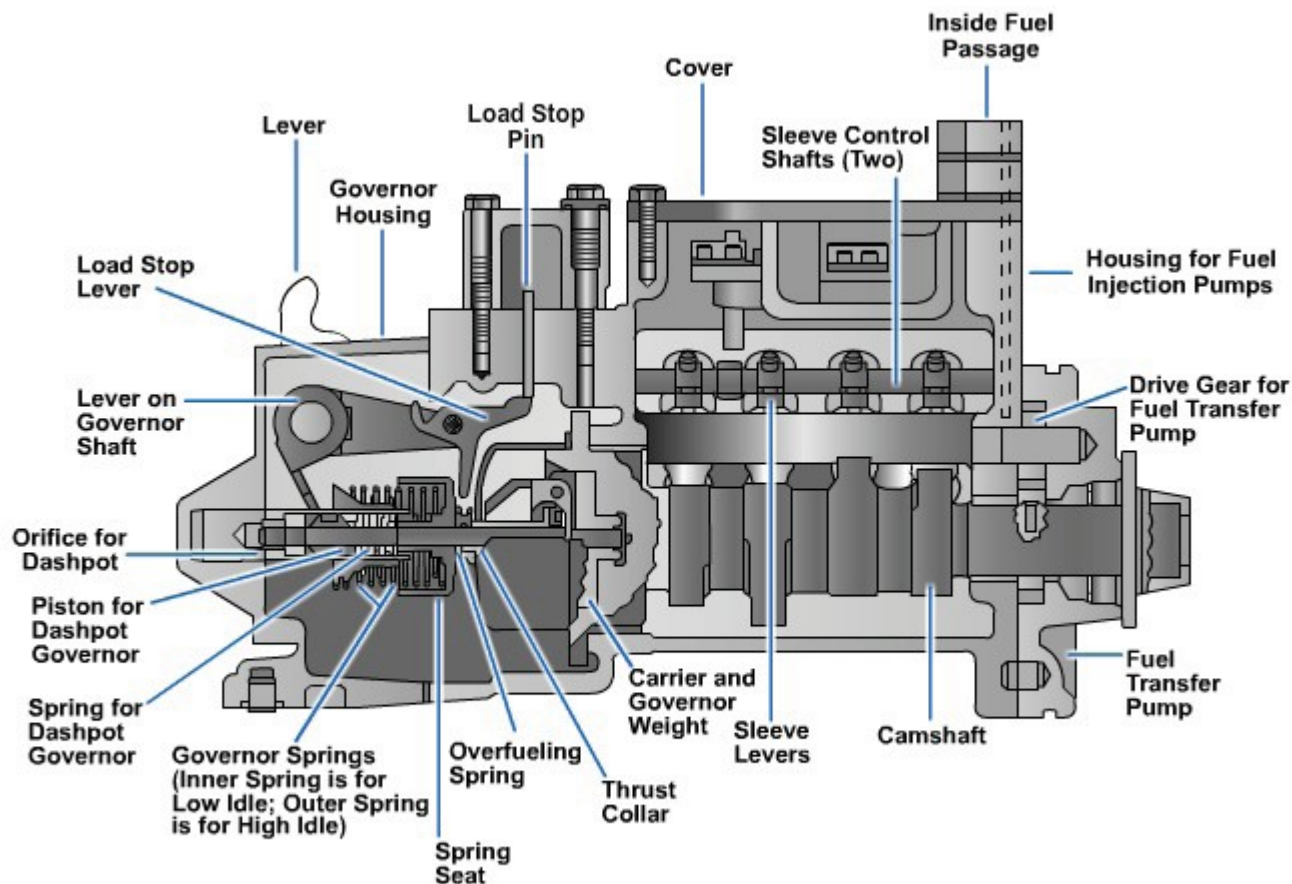


Figure 5-46 - Components of a multiple plunger inline fuel injection pump equipped with sleeve metering and a mechanical governor.

2.1.1.3 Governor

A governor is needed to regulate the amount of fuel feed to the cylinders. The governor ensures that there is sufficient fuel delivered at idle to prevent the engine from stalling. It also cuts the fuel supply when the engine reaches its maximum rated speed. Without a governor, a diesel engine could quickly reach speeds that would destroy it. The governor is included in the design of the fuel injection pump.

The mechanical type governor shaft of the governor for the sleeve metering fuel system controls the position of the sleeve on the plunger, which regulates the amount of fuel injected. The volume of fuel injected is equal to the displacement of the plunger lift into the barrel between the start and end of injection. The start-up control sets the fuel injection pumps at full stroke to aid in starting, regardless of the throttle position. Normal governor operation takes over at low-idle speed, approximately 500 rpm.

Various applications call for different types of engine speed governing. The governing requirements for diesel engines in heavy-duty trucks differ from earthmoving equipment to the type used in stationary generators. The functions designed into a governor depend on the type of load placed on the engine and the degree of control required.

Limiting speed governors have been developed to prevent the engine from stalling at low idle speed and to prevent racing. All speeds in between can be controlled by the operator. This type of governor is generally used in on-highway vehicles.

Variable speed governors are often used on drill rigs, tractors, excavators, locomotives, and marine engines. This type of governor gives the engine automatic speed control and is easily adjusted during operation. It can control flow over a wide range, from low idle to maximum speed. For example a bulldozer may experience many changes in load per minute as it operates over varying terrain and conditions. The operator cannot anticipate these rapid changes, but a variable speed governor can adjust fuel delivery to maintain the proper engine speed during all load levels.

Constant speed governors maintain engine speed at a constant rpm, regardless of the load. These governors are generally used to control engine speed on generators and other stationary applications. Overspeed governors are designed to prevent the engine from exceeding a specified maximum speed. A load-limiting governor limits the load that the engine must handle at various speeds. The purpose is to prevent the engine overloading.

There are some terms that are integral to governors which describe their state or operation:

- **High idle speed, top engine limit or maximum no-load speed** is the highest rpm at which the governor permits the engine to operate. This speed is achieved when the throttle linkage is moved to its maximum position with no-load acting on the engine.
- **Low idle speed** is the rpm at which the engine operates when the throttle linkage is in the closed position. It is the lowest rotational speed at which the engine can operate without stalling. For on-highway applications, engine low idle speeds are generally in the 475 to 525 rpm range.
- **Rated speed** or maximum full-load speed is the engine rpm at which the engine will generate its maximum horsepower as specified by the manufacturer.
- **Maximum torque speed** is the rpm at which an engine creates the most torque.
- **Speed droop** is the change in engine speed caused by a change in engine load. Speed droop is expressed in rpm or more often, as a percentage of maximum full-load speed.
- **Under run** is what the engine will experience if the governor fails to maintain low idle speed whenever the engine rpms drop quickly from higher speeds. If the governor permits the engine to fall below low idle, the engine may stall.
- **Over run** occurs when the governor allows the engine to exceed its maximum rated speed. Over run is most likely to occur in on-highway applications when the vehicle is descending a steep grade. The vehicle's wheels start to drive the engine, forcing it above its rated maximum speed.
- **Deadband** is a narrow speed range during which no measurable speed correction is made by the governor.
- **Sensitivity** is the change in engine speed necessary before the governor begins making a change in the amount of fuel delivered to the cylinders. Sensitivity is often expressed as a percentage. A governor that responds to a speed change of 4% is more sensitive than one that requires a 7% change before responding.
- **Promptness** is the length of time required for the governor to move the fuel control mechanism from a no-load to a full-load position.

- **Hunting or surging** is a continuous engine speed fluctuation (slowing down and speeding up) from the desired rpm setting. This condition is most likely to occur at idle. Many governors are equipped with an adjustable buffer screw or bumper spring that is set to minimize this undesirable condition.
- **Stability** is the ability of the governor to maintain the desired engine speed without fluctuations or hunting.

2.1.1.3.1 Mechanical governors

Speed sensing is by means of rotating flyweights driven at a speed proportional to engine rpm. In a mechanical governor, centrifugal force generated by the rotating flyweight acts directly on the fuel control mechanism, see *Figure 5-47*. The governor spring tension is set to oppose the centrifugal force and will define the top engine limit or high idle speed. The thrust collar, also known as thrust washer or thrust sleeve, acts as an intermediary between the spring force and centrifugal force and is connected to the fuel control mechanism. Governor spring tension is usually designed to be variable and increases with accelerator pedal travel:

- Centrifugal force (produced by rotating the flyweights) acts on the thrust sleeve to attempt to decrease fueling.

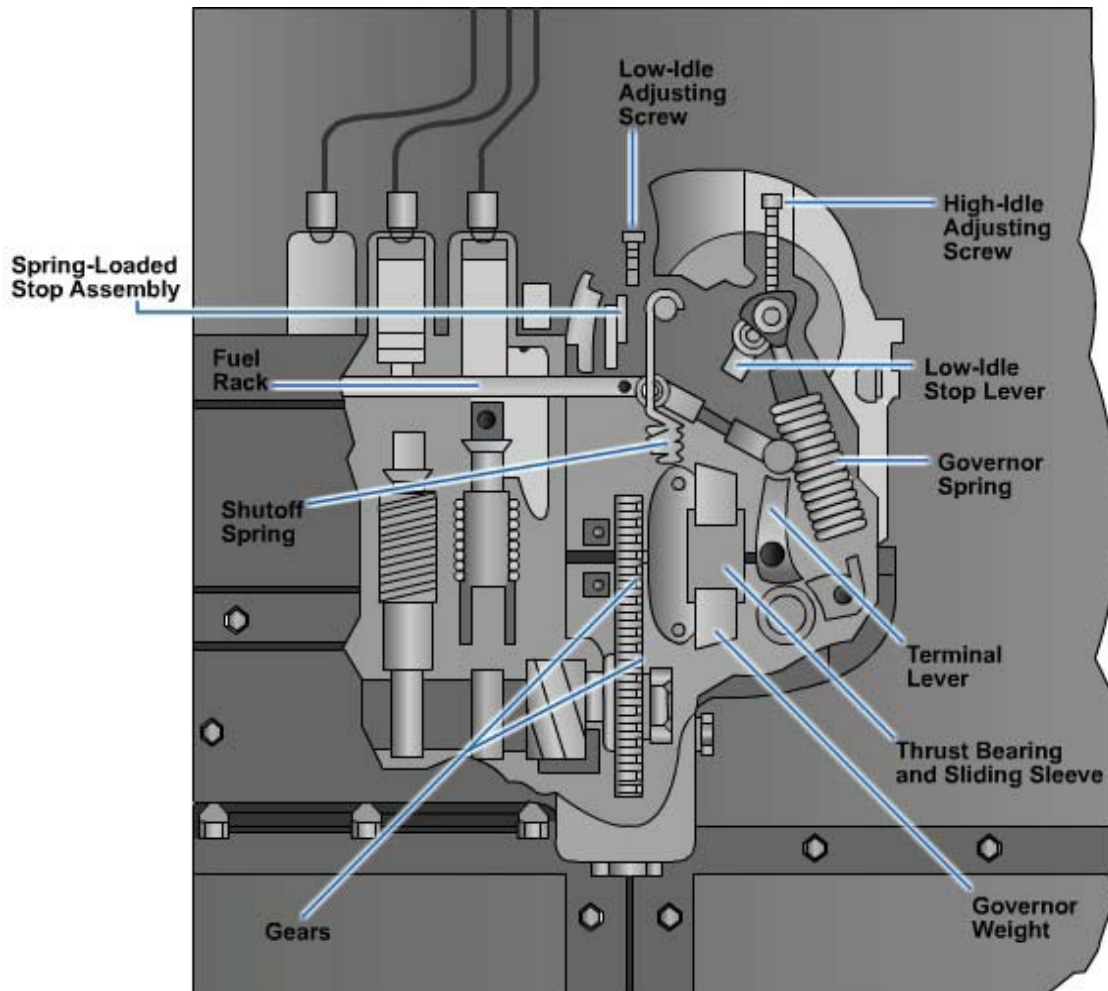


Figure 5-47 - Cutaway view of a mechanical governor.

- Spring force (often variable and increased with accelerator pedal travel) acts on the thrust sleeve to attempt to increase fueling.

2.1.2 Mechanical Electronic Unit Injector (MEUI)

The mechanical electronic unit injector is a common unit injector with an electronic solenoid that is controlled by the ECM. Mechanical pressure is created by the camshaft moving a roller and a pushrod, and a follower pressing on top of the injector unit. The rate and amount of fuel injected into the cylinder is controlled by the opening and closing of the solenoid that is controlled by the ECM.

2.1.3 Hydraulic Electronic Unit Injection (HEUI)

The HEUI is an integral pumping, metering, and atomizing unit controlled by electronic/engine control module (ECM) switching apparatus. The unit is essentially an EUI that is actuated hydraulically rather than by cam profile. While following this description of HEUI, refer to *Figure 5-48 C6-* and *Figure 5-49 C7*. At the base of the HEUI is a hydraulically actuated, multi-orifii nozzle. When the HEUI pumping element achieves the required nozzle opening pressure value, the valve retracts, permitting fuel to pass around the nozzle and exit the nozzle orifii directly to the engine cylinder. A valve close orifice (VCO) or sacless nozzle design is used.

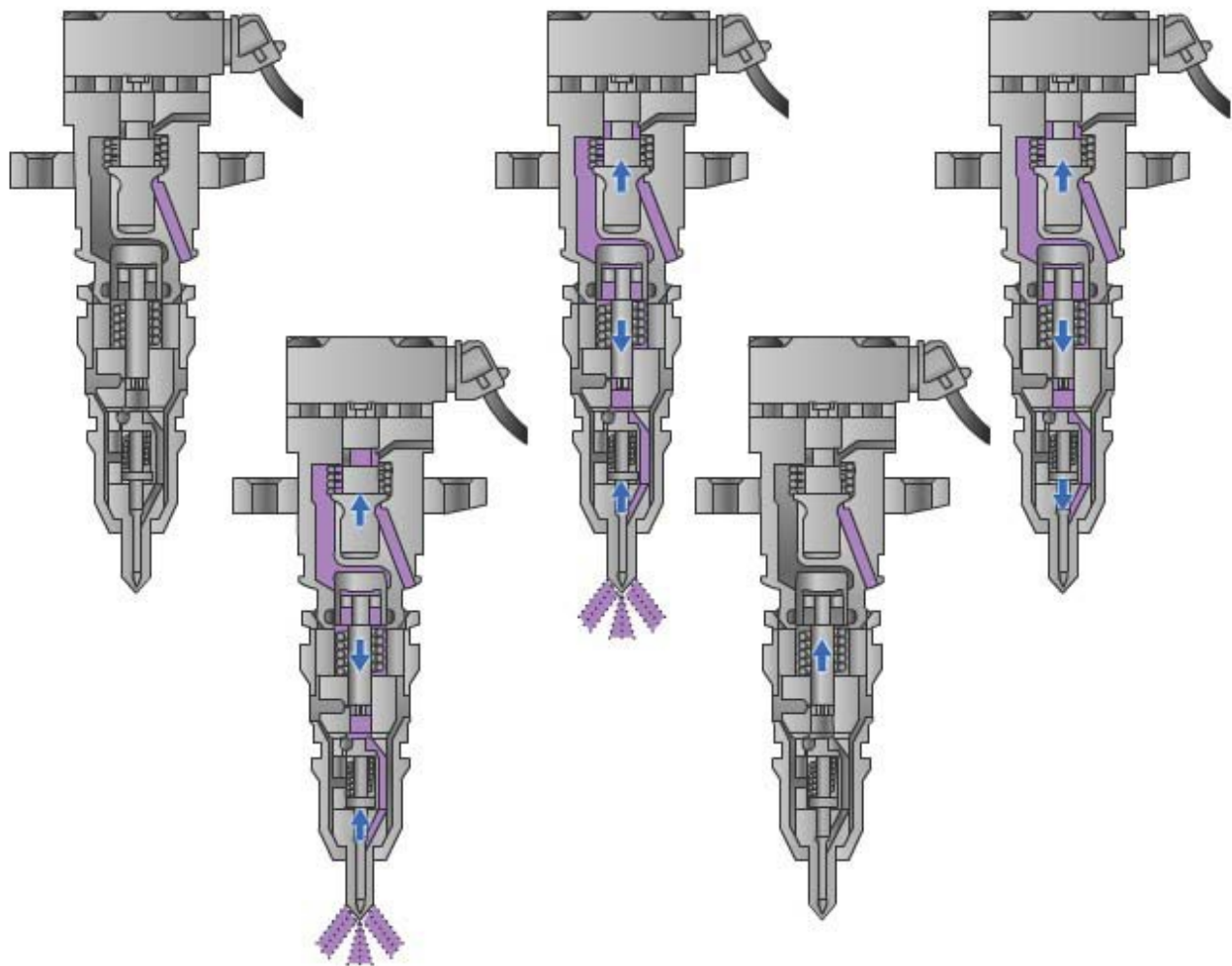


Figure 5-48 – The HEUI injection cycle.

The amplifier or intensifier piston is responsible for creating injection pressure values. This component is termed an amplifier piston in International Truck terminology and an intensifier piston in Caterpillar terminology; amplifier piston will be used herein to maintain continuity. When the HEUI is energized, high-pressure oil supplied by a

stepper pump acts on the amplifier piston and drives its integral plunger downward into the pumping chamber

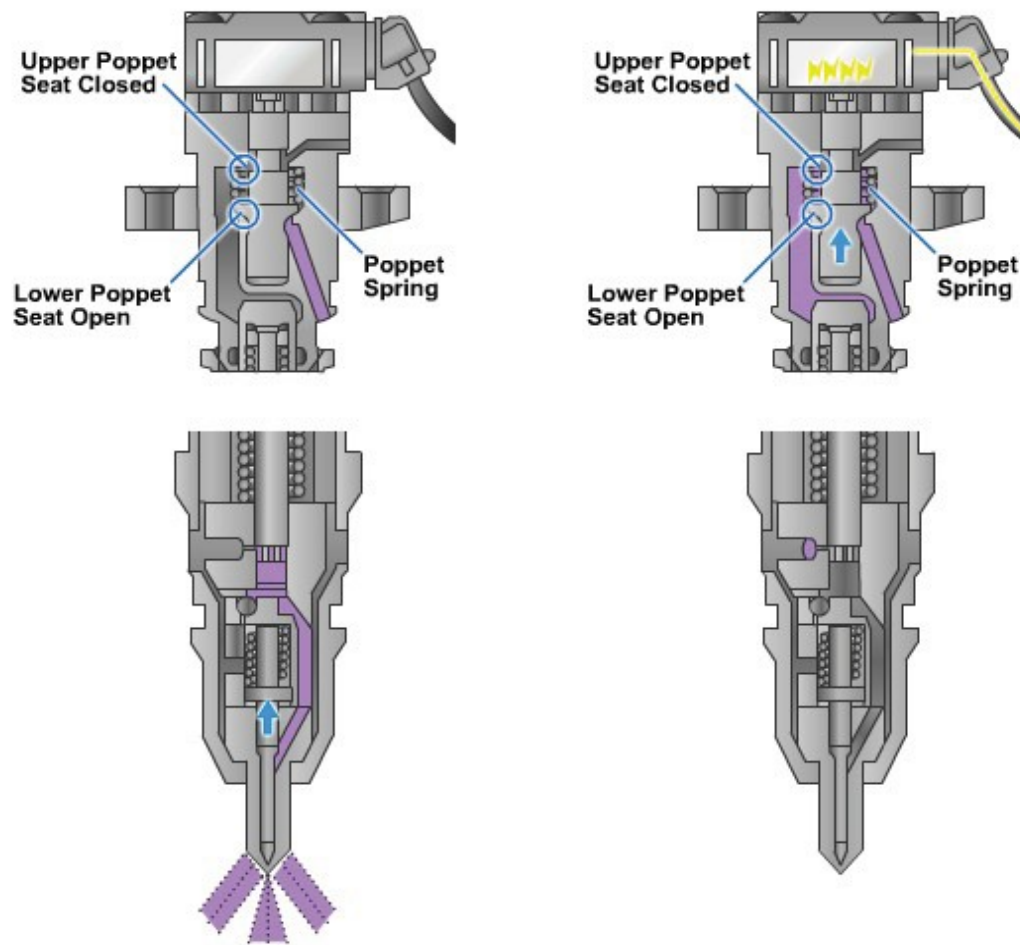


Figure 5-49 - The HEUI injection control and pulse.

A duct connects the pump chamber with the pressure chamber of the injector nozzle valve. The amount the HEUI is de-energized, the oil pressure acting on the amplifier piston collapses, and the amplifier piston return spring plus the high-pressure fuel in the pump chamber retracts the amplifier piston, causing the almost immediate collapse of the pressure holding the nozzle valve open. This collapse results in rapid ending of the injection pulse. In fact, the real time period between the moment the HEUI solenoid is de-energized and the point that droplets cease to exit, the injector nozzle orifices is claimed to be significantly less with HEUI than with equivalent EUI systems.

HEUIs typically have normal operating pressure (NOPs) of 5,000 psi with a potential for peak pressures of up to 28,000 psi attainable, depending on application. The oil pressure acting on the HEUI amplifier piston is "amplified" by seven times in the fuel pump chamber. This amplification is achieved because the sectional area of the amplifier piston is seven times that of the injection plunger, which means that the descent velocity of the injection plunger is variable and dependent on the specific actuation oil pressure value at a given moment of operation. Because the ECM directly controls the actuation oil pressure value, it can therefore control injection pressure. The injection pressure determines the emitted droplet size: the higher the injection pressure, the smaller the droplets, which is what is meant by rate-shaping ability of HEUI. In short,

rate shaping allows the ECM to optimize the extent of atomization to suit the combustion conditions at any given moment of operation.

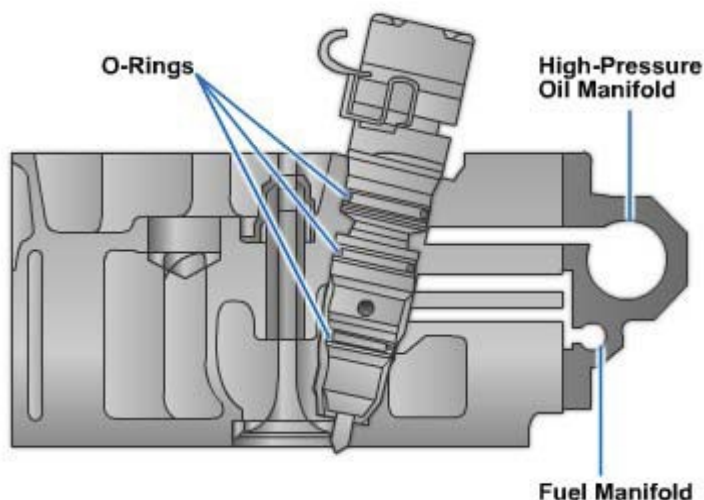
Rapid pressure collapse enabled by HEUIs avoids the injection of larger-sized droplets toward the end of injection that would be difficult to completely oxidize in the "afterburn" phase of combustion. At the completion of the HEUI duty cycle or pulse width (PW), the pressurized oil that actuated the pumping action is spilled to the rocker housing.

HEUI injectors are capable of being driven or switched at high speeds. The latest versions have plunger and barrel geometry that provide pilot injection. Pilot injection is a term used to describe an injection pulse that is broken into two separate phases. In a pilot injection fueling pulse, the initial phase injects a short duration pulse of fuel into the engine cylinder, ceases until the moment of ignition, and at that point, resumes injection, pumping the remainder of the fuel pulse into the engine cylinder. Pilot injection is used as cold-start and warm-up strategy in EUI systems to avoid excess of fuel in the engine cylinder at the point of ignition and as a result, minimize the tendency to cold-start detonation. HEUI systems with the pilot injection feature are designed to produce a pilot pulse for each injection. This has been proven to reduce both hydrocarbon (HC) and oxides of nitrogen (NO_x) emissions.

HEUI Oil and Fuel Manifold.

Actuation oil and fuel at charging pressure are routed to the HEUI units of an oil/fuel manifold on the cylinder head. The HEUIs are inserted into the cylindrical bores in the cylinder head, and they use a dedicated external annulus separated by O-rings to access the oil and fuel rifles.

Figure 5-50 shows a cylinder head cross section showing the oil/fuel manifold and the ducts that connect them to individual HEUIs.



2.1.3.1 Heui Subcomponents

The HEUI injector assembly can be subdivided, as shown in *Figure 5-51*.

Figure 5-50 – HEUI oil and fuel manifold.

Solenoid. The solenoid is switched by the ECM using a 115v coil-induced voltage. The HEUI electrical terminals connect the solenoid coil with wiring to the ECM injector drivers.

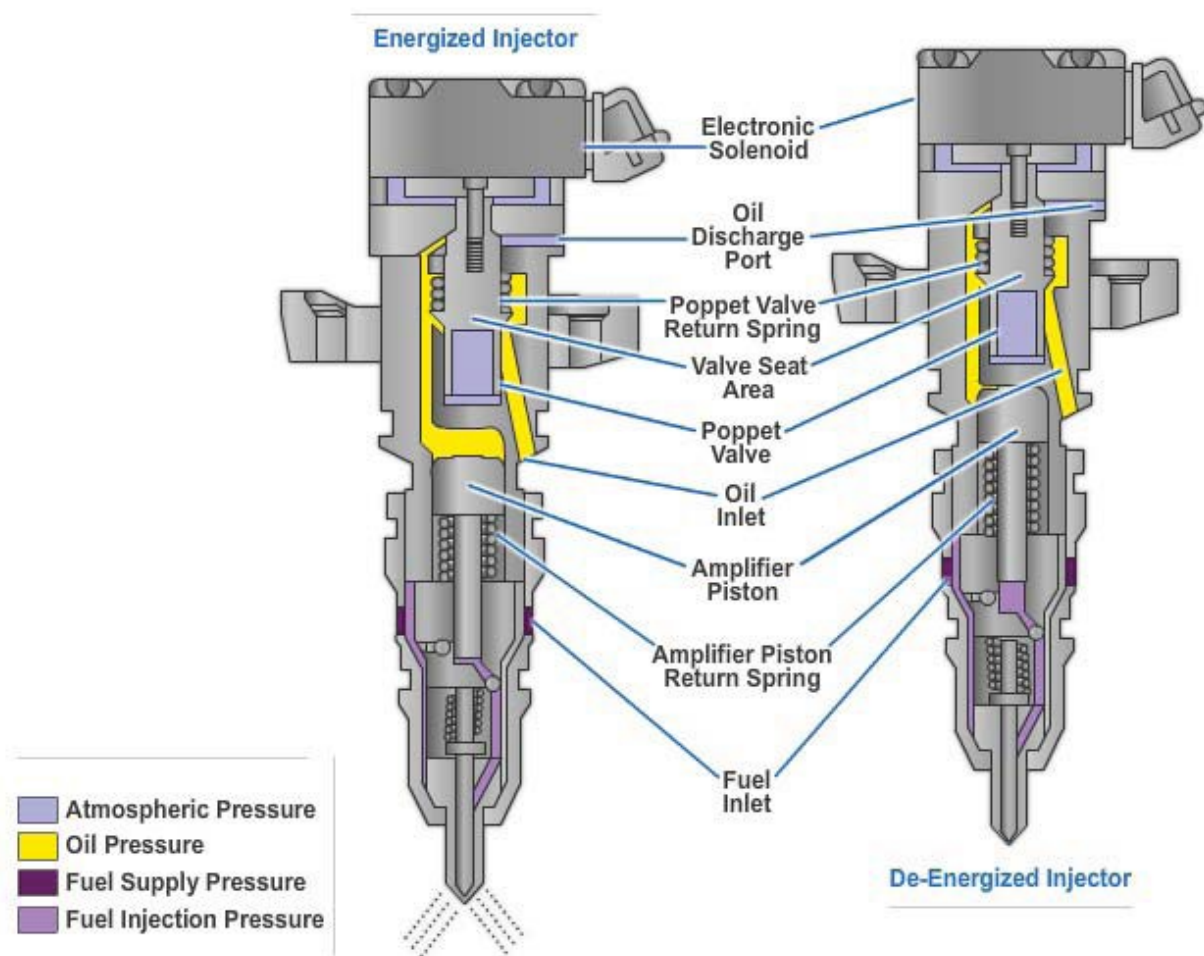


Figure 5-51 - International Trucks HEUI internal components and operating phases.

Poppet Valve. The HEUI poppet valve is integral with the solenoid armature. It is machined with an upper and lower seat. For most of the cycle, the poppet valve seat loads the lower seat into a closed position, preventing high pressure oil from entering the HEUI. The upper seat is open, venting the oil actuation spill ducting. When the HEUI solenoid is energized, the poppet valve is drawn into the solenoid, opening the lower seat and admitting high-pressure oil from the injection pressure regulator (IPR). When the poppet valve is fully open, the upper seat seals, preventing the oil from exiting the HEUI through the spill passage.

Intensifier or Amplifier Piston. The intensifier/amplifier piston is designed to actuate the injection plunger, which is located below it. When the poppet control valve is switched by the ECM to admit high-pressure oil into the HEUI, the oil pressure acts on the sectional area of the amplifier piston. The actual oil pressure (managed by the ECM) determines the velocity at which the plunger located below the amplifier piston is driven into the injection pump chamber. The sectional area of the amplifier piston determines how much the actuating oil pressure is multiplied in the injection pump chamber. This value is specified as seven times in current HEUI systems. In other words, an actuating oil pressure of 3,000 psi would produce an injection pressure potential of 21,000 psi. The amplifier piston and injection plunger are loaded into their retracted position by a spring.

Plunger and Barrel. The plunger and barrel form the HEUI pump element. The first versions of the HEUI injectors did not offer the pilot injection feature. This description will use the recently introduced HEUI with the PRIME feature. The injection cycle shown in *Figure 5-48* shows a HEUI with the PRIME feature. The acronym **PRIME** is produced from the words **preinjection metering**. As the injection plunger is driven into pump chamber, fuel is pressurized for a short portion of the stroke, actuating and opening the injector nozzle. The pressure rise is of short duration because when the PRIME recess in the plunger registers with the PRIME spill port in the barrel, the pressure in the pump chamber collapses as fuel spills through the PRIME spill port. This closes the injector nozzle and injection ceases. However, the moment the PRIME recess in the plunger passes beyond the spill port, fuel is once again trapped in the pump chamber and pressure rise resumes. This results in the injector being opened for the delivery of the main portion of the fuel pulse. The fueling pulse continues until the ECM ends the effective stroke by de-energizing the HEUI solenoid. At this point, the poppet control valve is driven onto its lower seat, opening the upper seat and permitting the actuating oil to be vented. With no force acting on the amplifier piston, the plunger is driven upward by the combined force of the high-pressure fuel in the pump chamber and the plunger return spring. This causes an almost immediate collapse of pump chamber pressure and results in almost instantaneous nozzle closure. A feature of the HEUI is its ability to almost instantly effect nozzle closure at the end of the plunger effective stroke.

Injector Nozzle. The HEUI injector nozzle is a multi-orifii injector nozzle of the valve closes orifice (VCO) type that is a little different from any other injector nozzle used in a mechanical unit injector (MUI) or electronic unit injector (EUI) assembly. A duct connects the nozzle pressure chamber with the HEUI pump chamber. A spring loads the injector nozzle valve onto its seat. The spring tension defines the nozzle opening pressure (NOP) value. When the hydraulic pressure acting on the sectional area of the nozzle valve is sufficient to overcome the spring pressure, the nozzle valve unseats, permitting fuel to pass around the nozzle seat and through the nozzle orrifi. The nozzle valve functions as a simple hydraulic switch. Because of the nozzle differential ratio, the nozzle closure pressure is always lower than the NOP. For instance, a Caterpillar version of the HEUI with a NOP identified at 4,500 psi will not close until the pressure drops to 4,000 psi.

2.1.3.2 Stages of Injection

When the newer PRIME HEUIs are used, the injection pulse can be divided into five distinct stages. Refer back to *Figure 5-48* and *Figure 5-49* to follow the stages of injection.

Preinjection. The HEUI internal components are all located in their retracted positions, as shown in *Figure 5-52*. In fact, they are in the preinjection position for most of the cycle. The poppet valve seat is spring loaded into the lower seat, preventing the high-pressure actuating oil from entering the HEUI, and the amplifier piston and plunger are both in their raise position. Fuel enters the HEUI to charge the pump chamber at the charging pressure value, as shown in *Figure 5-53*.

Pilot Injection. The pilot injection phase begins when the plunger is first removed into the HEUI pump chamber. The pressure rise created opens the injector nozzle to deliver a short pulse of fuel. The pilot injection phase ends when the PRIME recess in the HEUI plunger is driven downward enough to register with the PRIME spill port, causing the pump chamber pressure to collapse and the nozzle valve to close.

Delay. The delay phase occurs between the ending of the pilot injection phase and restart of the fuel pulse. The objective is to cease fueling the engine cylinder while the prime pulse of the fuel is vaporized and heated to its ignition point. It is important to note that the plunger is still being driven through its stroke during this phase because the HEUI poppet control valve is in the open position, and oil pressure continues to drive the amplifier piston downward.

Main Injection. When the PRIME recess in the plunger passes beyond the PRIME spill port, fuel is once again trapped in the HEUI pump chamber because it can no longer exit through the spill port. The resulting pressure rise opens the injector nozzle a second

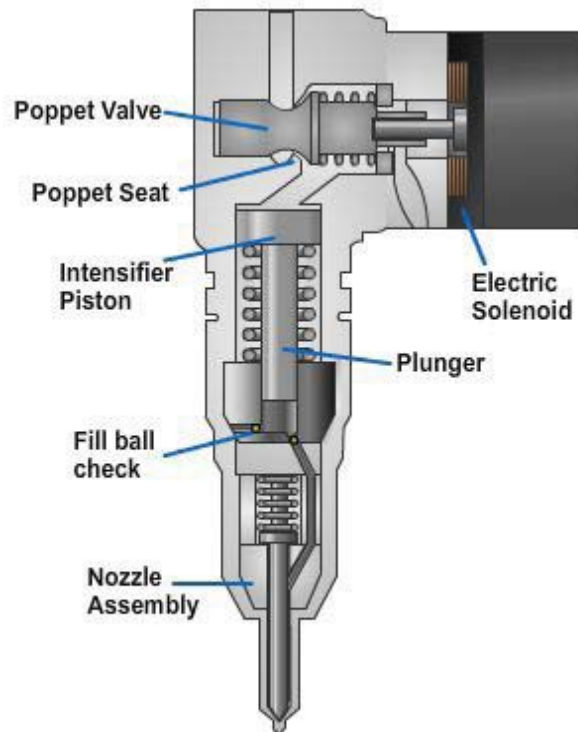


Figure 5-52 - Caterpillar HEUI preinjection cycle: subcomponent identification.

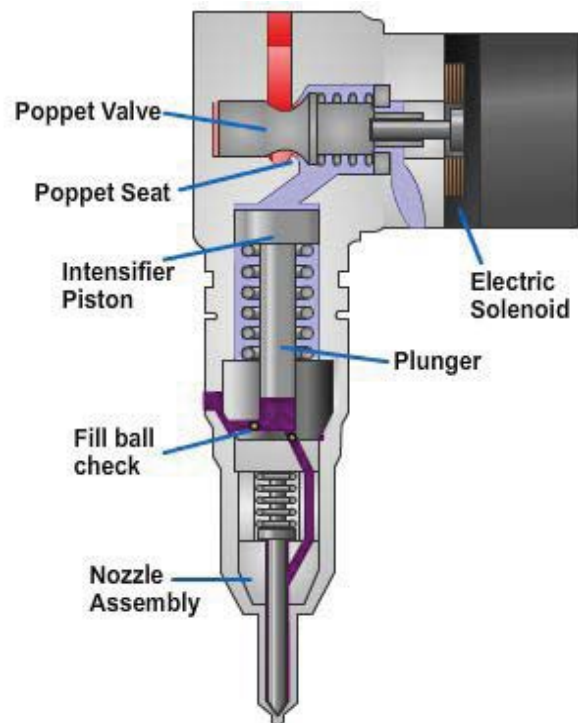


Figure 5-53 - Caterpillar HEUI fill cycle.

time to deliver the main volume of fuel to be delivered. In an HEUI injector with no PRIME feature, the plunger has no cross and center drillings and PRIME recess, so main injection begins when the plunger leading edge passes the spill port on its downward stroke, as shown in *Figure 5-54*.

End of Injection. The end of injection begins with the de-energizing of the HEUI solenoid. The armature is released by the solenoid coil and a spring drives the poppet valve downward to seat on its lower seat. The instant the poppet valve starts to move downward, the upper seat is exposed, permitting the actuating oil inside the HEUI to spill. When the actuating oil pressure acting on the amplifier piston is relieved, the fuel pressure in the HEUI pump chamber combined with the plunger return spring collapses the fuel pressure almost instantly. Injection ends when there is insufficient pressure to hold the nozzle valve in its position, and the three moving assemblies (poppet valve, amplifier/plunger, and nozzle valve) in the HEUI are all in their return positions outlined in the preinjection phase, as shown in *Figure 5-55*.

2.1.3.3 ECM Functions

The ECM has four functions:

1. Reference voltage regulator
2. Input conditioning
3. Microcomputer
4. Outputs

Reference Voltage. Reference voltage (V-Ref) is delivered to system sensors that divide this input and return a percentage of it as a signal to the ECM. Thermistors

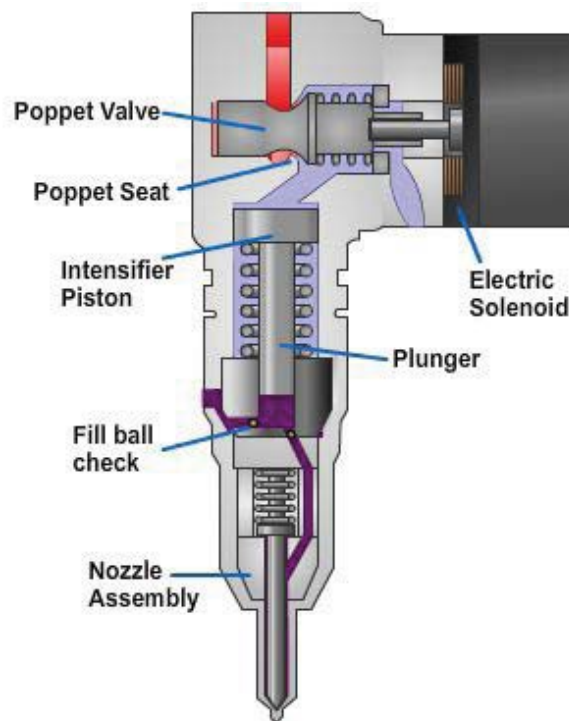


Figure 5-54 - Caterpillar HEUI effective stroke.

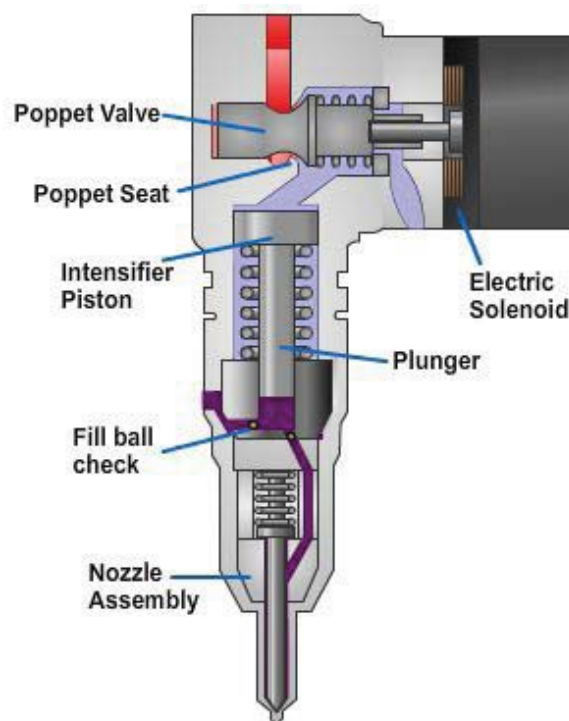


Figure 5-55 – Caterpillar HEUI end of injection.

(temperature sensors) and potentiometers (TPS) are examples of sensors requiring reference voltage. Reference voltage values use area at 5V pressure and the flow is limited by a current-limiting resistor to safeguard against a dead short ground. Reference voltage is also used to power up the circuitry in Hall effect sensors used in the system, such as the camshaft position sensor (CPS).

Input Conditioning. Signal conditioning consists of converting analog signals to digital signals, squaring-up sine wave signals, and amplifying low intensity signals for processing.

Microcomputer. Both Caterpillar and International Trucks HEUI microprocessors function similarly to other vehicle system management computers. It stores operating instructions control strategies and tables of values and calibration parameters. It compares sensor monitoring and command inputs with the logged control strategies and calibration parameters and then computes the appropriate operating strategy for any given set of conditions. The current Caterpillar ECM, the advanced diesel engine management (ADEM IV) uses a 32-bit processor and a clock speed of 24 mHz. As with your home computing system, you can expect the computing power on truck engine management systems to increase as each year passes.

ECM computations occur at two different speeds, referred to as foreground and background calculations.

- Foreground calculations are more critical functions, and these are computed as a higher frequency than background calculations. Engine speed control and throttle position signals are categorized as foreground calculations; in other words an immediate response to a changing condition or command is required.
- Background calculations are processed at a lower frequency and include input signals, such as ambient temperature and engine temperature.

The difference in foreground and background computations is simply speed at which the microprocessor is required to react to a change in operating characteristics. A change in throttle position requires an immediate adjustment in engine fueling, and therefore, this command input requires almost instant response by the ECM.

However, while an increase in coolant temperature could have serious consequences if ignored, engine overheat conditions occur gradually, so an almost instant reaction by the ECM is not required.

Diagnostic strategies include monitoring input data on a continuous basis and flagging codes when an abnormal operating parameter is detected. Calibration tables and operating strategies are retained in read-only memory (ROM). This data is not lost by opening the ignition circuit or disconnecting the vehicle batteries as it is magnetically retained. Random-access memory (RAM) data is electronically retained and thus is only retained while a circuit is energized.

HEUI system ECM RAM stores information sourced from electronic monitoring and data processing/manipulation, which is volatile and as such, is dumped each time the ignition circuit is opened. When KAM is used, it is nonvolatile RAM and functions to log fault codes. Out-of-normal parameters may also result in adaptive strategies being written into KAM; subsystem failure or component wear are examples. KAM data is retained when the ignition circuit is opened but dumped when the vehicle batteries are disconnected. Both Caterpillar and International Trucks PRIME are described as vehicle personality module (VPM) and are both customer and proprietary data programmable. The function of the VPM is to trim engine management to a specific chassis application and customer requirements. The engine family rating code (EFRC) is located in the

VPM calibration list and can be read with an electronic service tool (EST), which identifies the engine power and emission calibration of the engine.

Outputs. The switching apparatus within the ECM can be referred to as actuator control. The ECM controls the system actuators by delivering a signal to the base of the transistor output drivers. These drivers, when switched, ground the various actuators circuits. The actuators may be controlled through a duty cycle (that is, percent time on/off), controlled by modulating pulse width or simply switched on and off, depending on the actuator type.

2.1.3.4 Injection Driver Module (IDM)

The injector driver module is responsible for switching the HEUIs. In older International Trucks, the IDM was housed separately from the ECM housing. Currently, International along with Caterpillar integrates all the engine modules into a single housing.

The IDM has four functions:

1. Electronic distributor for the HEUIs
2. Powers the HEUIs
3. Output driver for the HEUIs
4. IDM and HEUI diagnostics

Electronic Distributor for the HEUIs

The ECM determines engine position from the camshaft position (CMP) sensor located at the engine front cover. The ECM uses the signal to determine cylinder firing sequence and then delivers this command data to the IDM as a fuel demand command signal (FDCS). FDCS contains injection timing and fuel quantity data. *Figure 5-56* shows the relationship between the IDM and ECM and the FDCS.

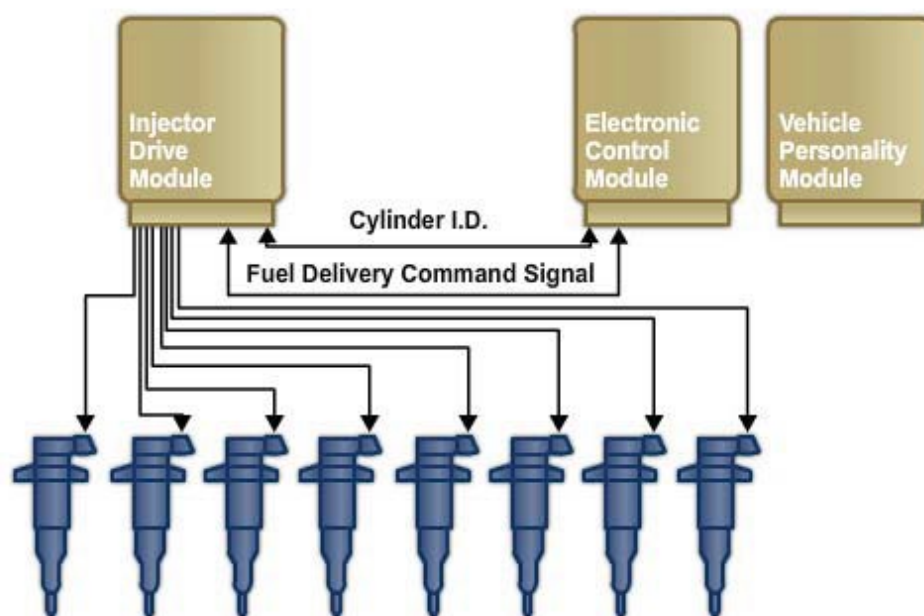


Figure 5-56 - Injection Driver Module (IDM) operation.

Power the HEUIs. The IDM supplies a constant 115v DC supply to each HEUI. This 115v DC supply is created in the IDM by making and breaking a 12v source across a coil using the same principles employed by the ignition coil in a spark ignited (SI) engine. The resultant 115v induced is stored in capacitors until discharged to the HEUIs, as indicated in *Figure 5-57*.

Output Driver for the HEUIs.

The IDM is responsible for switching the HEUIs. The unit controls the effective stroke of the HEUI by closing the circuit to ground. The direct control of the HEUI is managed by an output driver transistor in the IDM. When the FDCS signal is delivered from ECM processing cycle, the beginning of injection (timing) and fuel quantity is determined. *Figure 5-58* shows the role of the output drivers and *Figure 5-59* shows the role of the timing sensor.

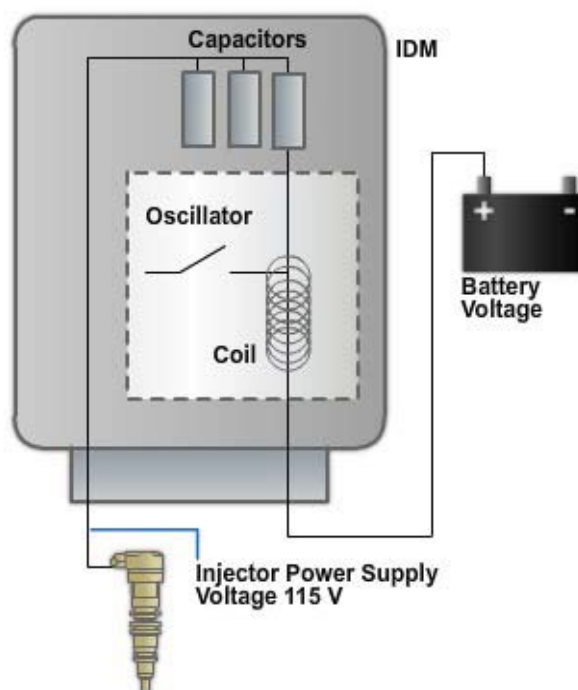


Figure 5-57 – IDM: power source.

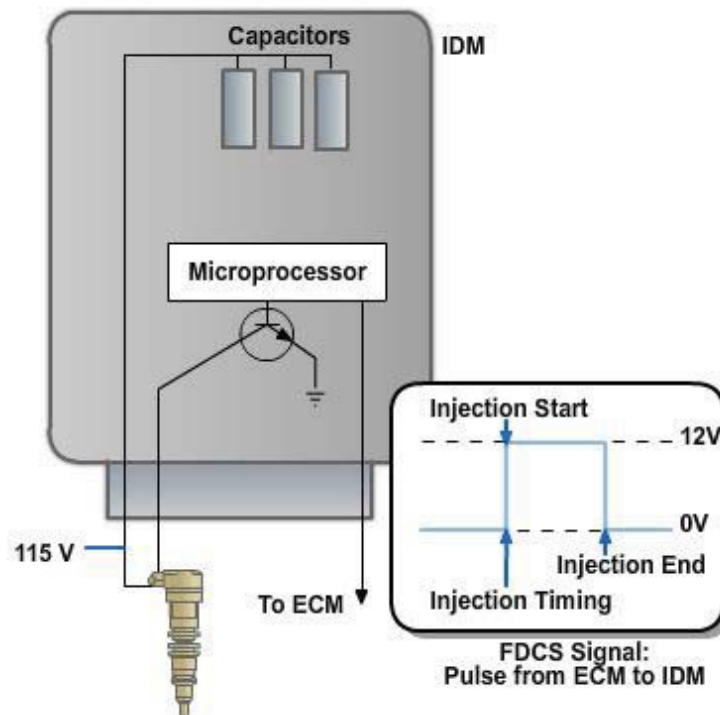


Figure5-58 - Injector driver module operation: output driver operation.

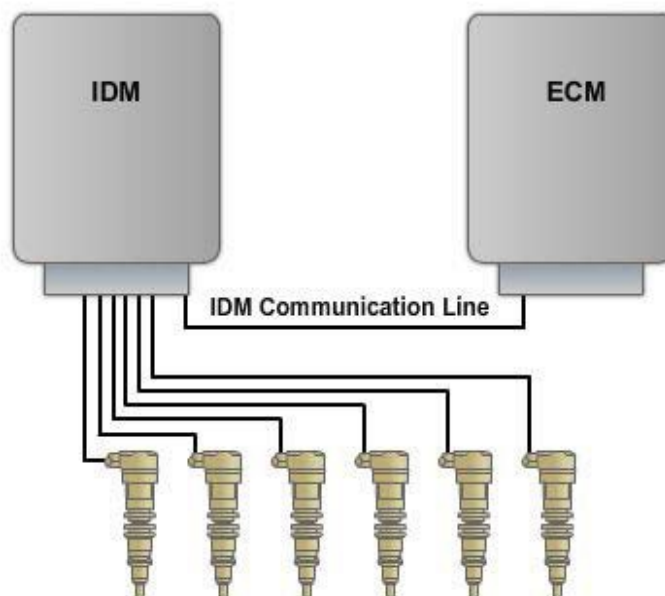


Figure5-59 – IDM and ECM communications signals and relationship

IDM and HEUI Diagnostics.

The ECM software is capable of identifying faults within its electronic circuitry and can determine whether an HEUI solenoid or its wiring circuit is drawing too much or too little current. In the event of such an electronic malfunction, a fault code is logged. The self-diagnostics can also set an ECM code, indicating that the module has failed and requires replacement; see *Figure 5-60*.

2.1.3.5 Injection Actuation Pressure

The ECM is responsible for maintaining the correct injection actuation pressure during operation. This means monitoring and adjusting the high-pressure oil circuit responsible for actuating HEUI fueling. It does this by comparing actual injection pressure with desired injection pressure and using the injection actuation pressure solenoid valve to attempt to keep the two values equal. Actual injection pressure is signaled to the ECM by the injection actuation pressure sensor. Desired injection actuation pressure is based on the fueling algorithm effective at any given moment of operation. In processing, the ECM will evaluate any differential between actual and desired actuation pressures and will modulate an output signal to the injection actuation control solenoid valve to keep the values close.

Figure 5-61 shows a Caterpillar HEUI schematic. Note the location of the high-pressure pump, injection actuation pressure (IAP) valve, and the IAP sensor a little downstream from the IAP control valve solenoid.

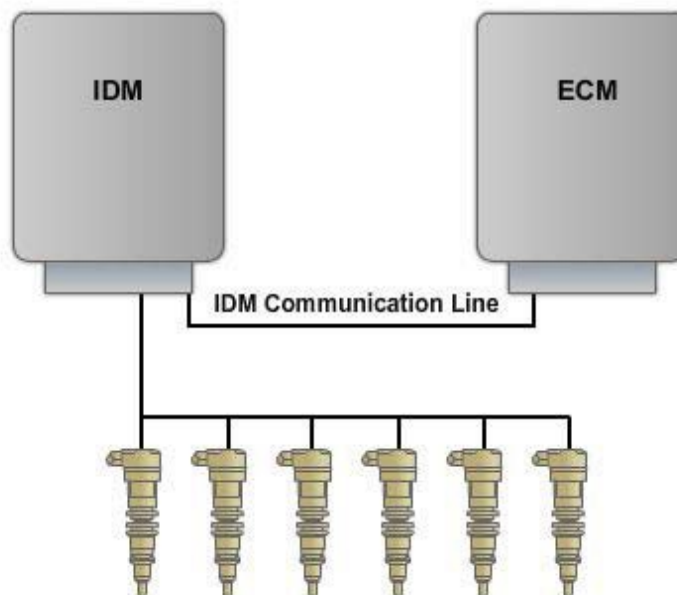


Figure 5-60 - IDM diagnostic operation.

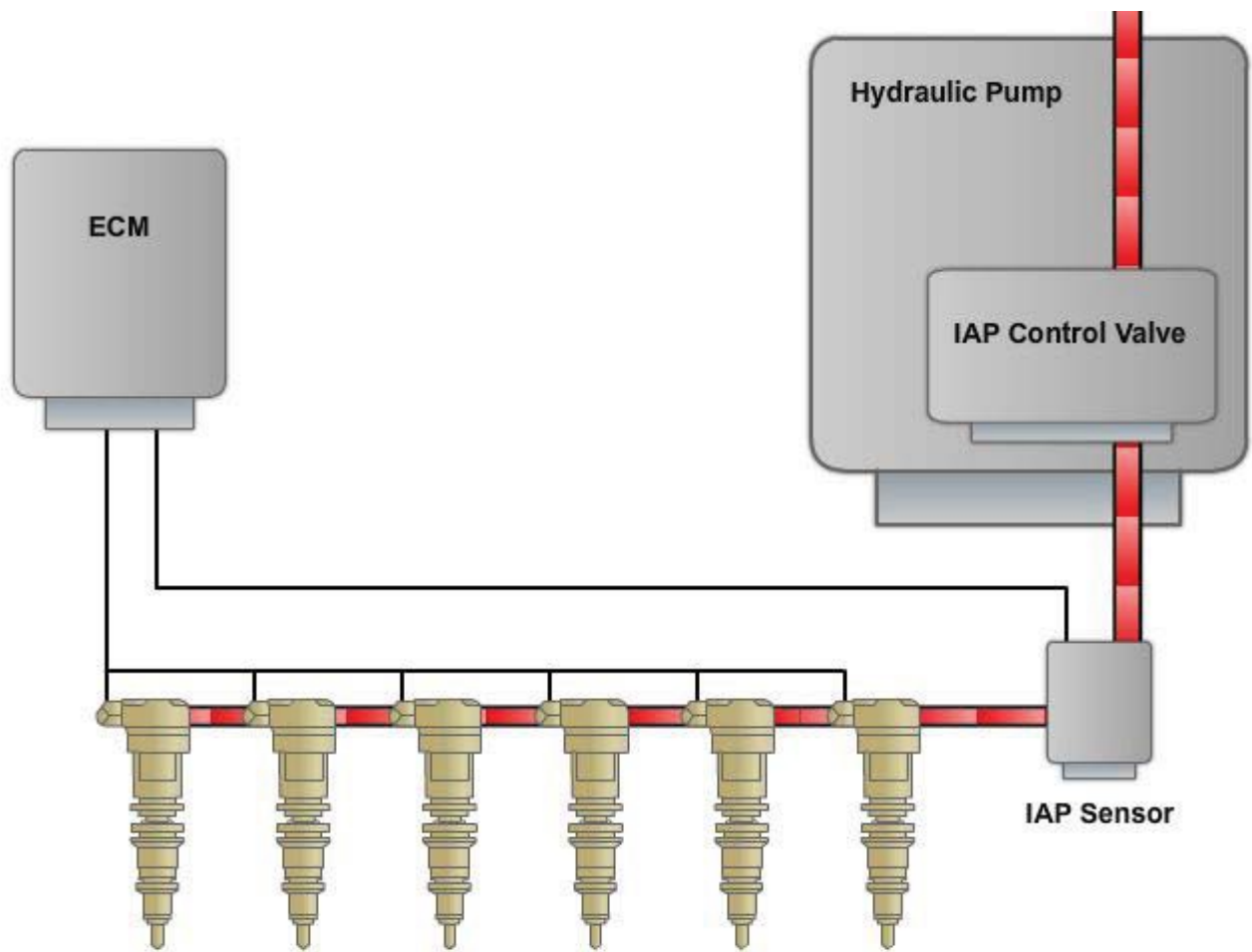


Figure 5-61 - Caterpillar HEUI schematic.

2.1.3.6 Caterpillar Electronic Technician (ET)

Electronic Technician (ET) is the Windows platform software used to read, program, and troubleshoot Caterpillar advanced diesel engine management (ADEM) systems. The software makes full use of Windows graphics, and user-friendly instructions take the technician from step to step in programming and diagnostic procedures. ET will do the following on a Caterpillar HEUI system:

- Test injector solenoid
- Test injection actuation pressure (IAP)
- Identify active faults
- Identify logged faults
- Identify logged events
- Display engine configuration data
- Rewrite customer programmable parameters
- Flash new software
- Print configuration and test results

Two ET tests are distinct to HEUI systems as follows:

Injector Cutout Test. ET will perform an injector cutout test on an HEUI-managed engine. Unlike the cylinder cutout test on Caterpillar EUI systems in which the ability to cut between one and five cylinders during the test produces a comprehensive cylinder balance analysis, currently HEUI cylinder cutout is one cylinder at a time. The test sequence must be performed with the engine at operating temperature and with intermittent loads, such as A/C disconnected.

Test sequence:

1. Governor maintains programmed idle speed.
2. ET turns off one injector at a time, this means the functioning five HEUIs must increase their duty cycle if the specified engine rpm is to be maintained.
3. The ADEM ECM measures the average duty cycle of the five functioning HEUIs at each stage of the cutout test.
4. The ECM assigns a test value for each HEUI tested.
5. The cutout test cycle is then repeated.

Injection Actuation Pressure Test. The injection actuation pressure (IAP) test checks high-pressure oil pump and IAP valve operation. The test is always performed at low idle. It functions by having ET read desired IAP pressure versus actual IAP pressure using ADEM ECM data. The IAP test sequence uses four desired pressure values:

1. 870 psi
2. 1450 psi
3. 2100 psi
4. 3300 psi

The IAP test sequence compares these with actual IAP values read by the IAP pressure sensor.

2.1.3.7 International HEUI Diagnosis

The International Trucks electronic engine PC software, known as EZ-Tech, is used to read, diagnose, and program customer data to HEUI engines. Proprietary data programming can be effected by modem to the International Trucks data hub, known as TechCentral and vehicle electronic programming software (VEPS).

International Trucks' Self-Test. International Trucks' HEUI electronics are capable of performing self-test procedures. When the dash-mounted self-test input (STI) button is depressed and the ignition circuit is closed, the ECM begins the self-test cycle. When complete, the oil/water and warn engine dash lights are used to signal fault codes. All International Trucks fault codes are three digits. Following is the sequence:

1. Oil/water light flashes once, indicating the beginning of the active faults display.
2. Warn engine light flashes each digit of the active fault code, pausing between each. The oil/water light will flash once between each active code readout when multiple codes are logged. Code 111 indicates no active fault codes.
3. Oil/water flashes twice to indicate that inactive fault codes will be displayed. Inactive fault codes are then blinked out in the same manner as active fault codes.
4. When all codes have been displayed, the oil/water light will flash three times.

5. Test sequence can be repeated by retracing the preceding steps, but all active faults should be repaired before progressing to later tests.

International Trucks' HEUI, like all electronically managed systems, requires that troubleshooting strategies be sequentially and scrupulously followed using the correct instrumentation and tooling as follows:

- MPSI ProLink 9000
- International Trucks' Cartridge for ProLink (ZTSE 43667)
- Fluke 88 DMM
- Hickok Breakout Box (ZTSE 4346)
- Breakout "T" (ZTSE 4347)
- PC and proprietary software

2.2.1 Stanadyne Fuel Systems

The original distributor injection pump, the Roosa Master, was an **opposed inlet metered pump**. This type of injection pump used only one metering valve to control the fuel and either two or four opposed plungers to pump the fuel. One component, the distributor rotor, is used to distribute the metered fuel out through the hydraulic head to the injectors. These pumps have a fuel delivery capacity of engines rated between 10 - 40 hp per cylinder.

Over the years, the Seabees have been associated with the "Roosa Master Fuel Injection Pump" on the diesel engine inventory. The original Roosa Master Company is now the Diesel Systems Division of Stanadyne Automotive Corporation. Stanadyne DB4 and DM4 (four-plunger) and DB2 and DM2 (two plunger) distributor pumps are highly refined versions of the Roosa Master pump that reflect almost 40 years of design evolution and improvement.