DOCUMENT RESUME

ED 259 132 CE 041 757

TITLE	Fundamentals of Diesel Engines.
INSTITUTION	Marine Corps Inst., Washington, DC.
REPORT NO	MCI-13.35a
PUB DATE	5 Dec 84
NOTE	112p.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051)
EDRS PRICE	MF01/PC05 Plus Postage.
DESCRIPTORS	*Auto Mechanics; Correspondence Study; *Diesel Engines; *Equipment Maintenance; Independent Study; Military Personnel; *Military Training; Postsecondary Education; *Small Engine Mechanics; *Trade and Industrial Education

ABSTRACT

This student guide, one of a series of correspondence training courses designed to improve the job performance of members of the Marine Corps, deals with the fundamentals of diesel engine mechanics. Addressed in the three individual units of the course are the following topics: basic principles of diesel mechanics; principles, mechanics, and performance of diesel engines; and injection and control of diesel engines. Each unit contains a general objective, a series of work units each addressing a different subobjective, study questions, and answers to the study questions. Appendixes to the guide contain a conversion chart and reference information concerning the mathematics of diesel engine theory, energy, temperature, and pressure and volume. (MN)

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13.35a
5 Dec 84

1. ORIGIN

MCI course 13.35a, Fundamentals of Diesel Engines, has been prepared by the Marine Corps Institute.

2. APPLICABILITY

This course is for instructional purposes only.

J. M. D. HOLLADAY
Lieutenant Colonel, U. S. Marine Corps
Deputy Director

ACKNOWLEDGMENT

The Marine Corps Institute, Marine Barracks, Washington, D.C., gratefully acknowledges the important contributions provided by the following MCI personnel in developing and publishing this course:

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The Marine Corps Institute, Marine Barracks, Washington, D. C. gratefully acknowledges the importanat contributions provided by the Engineer Equipment Instruction company. Marine Corps Engineer School, Marine Corps Base, Camp Lejeune, North Carolina, for their assistance in the validation and formal review of this course.

INFORMATION

FOR

MCI STUDENTS

Welcome to the Marine Corps Institute training program. Your interest in self-improvement and increased professional competence is commendable.

Information is provided below to assist you in completing the course. Please read this guidance before proceeding with your studies.

1. MATERIALS

Check your course materials. You should have all the materials listed in the "Course Introduction." In addition you should have an envelope to mail your review lesson back to MCI for grading unless your review lesson answer sheet is of the self-mailing type. If your answer sheet is the pre-printed type, check to see that your name, rank, and social security number are correct. Check closely, your MCI records are kept on a computer and any discrepancy in the above information may cause your subsequent activity to go unrecorded. You may correct the information directly on the answer sheet. If you did not receive all your materials, notify your training NCO. If you are not attached to a Marine Corps unit, request them through the Hotline (autovon 288-4175 or commercial 202-433-4175).

2. LESSON SUBMISSION

The self-graded exercises contained in your course are not to be returned to MCI. Only the completed review lesson answer sheet should be mailed to MCI. The answer sheet is to be completed and mailed only after you have finished all of the study units in the course booklet. The review lesson has been designed to prepare you for the final examination.

It is important that you provide the required information at the bottom of your review lesson answer sheet if it does not have your name and address printed on it. In courses in which the work is submitted on blank paper or printed forms, identify each sheet in the following manner:

DOE, John J. Sgt 332-11-9999
08.4g, Forward Observation
Review Lesson
Military or office address
(RUC number, if available)

Submit your review lesson on the answer sheet and/or forms provided. Complete all blocks and follow the directions on the answer sheet for mailing. Otherwise, your answer sheet may be delayed or lost. If you have to interrupt your studies for any reason and find that you cannot complete your course in one year, you may request a single six month extension by contacting your training NCO, at least one month prior to your course completion deadline date. If you are not attached to a Marine Corps unit you may make this request by letter. Your commanding officer is notified monthly of your status through the monthly Unit Activity Report. In the event of difficulty, contact your training NCO or MCI immediately.

3. MAIL-TIME DELAY

Presented below are the mail-time delays that you may experience between the mailing of your review lesson and its return to you:

	TURNAROUND MAIL TIME	MCI PROCESSING TIME	TOTAL NUMBER DAYS
EAST COAST	16	5	21
WEST COAST	16	5	21
FPO NEW YORK	18	5	23
FPO SAN FRANCISCO	22	5	27

You may also experience a short delay in receiving your final examination due to administrative screening required at MCI.

4. GRADING SYSTEM

LESSONS			EXAMS	
GRADE	PERCENT	MEANING	GRADE	PERCENT
A	94-100	EXCELLENT	A	94-100
B	86-93	ABOVE AVERAGE	B	86-93
C	78-85	AVERAGE	C	78-85
D	70-77	BELOW AVERAGE	D	65-77
NL	BELOW 70	FAILING	F	BELOW 65

You will receive a percentage grade for your review lesson and for the final examination. A review lesson which receives a score below 70 is given a grade of NL (no lesson). It must be resubmitted and PASSED before you will receive an examination. The grade attained on the final exam is your course grade, unless you fail your first exam. Those who fail their first exam will be sent an alternate exam in which the highest grade possible is 65%. Failure of the alternate will result in failure of the course.

5. FINAL EXAMINATION

ACTIVE DUTY PERSONNEL: When you pass your REVIEW LESSON, your examination will be mailed automatically to your commanding officer. The administration of MCI final examinations must be supervised by a commissioned or warrant officer or a staff NCO.

OTHER PERSONNEL: Your examination may be administered and supervised by your supervisor.

6. COMPLETION CERTIFICATE

The completion certificate will be mailed to your commanding officer and your official records will be updated automatically. For non Marines, your completion certificate is mailed to your supervisor.

7. RESERVE RETIREMENT CREDITS

Reserve retirement credits are awarded to inactive duty personnel only. Credits awarded for each course are listed in the "Course Introduction:" Credits are only awarded upon successful completion of the course. Reserve retirement credits are not awarded for MCI study performed during drill periods if credits are also awarded for drill attendance.

8. DISENROLLMENT

Only your commanding officer can request your disenrollment from an MCI course. However, an automatic disenrollment occurs if the course is not completed (including the final exam) by the time you reach the CCD (course completion deadline) or the ACCD (adjusted course completion deadline) date. This action will adversely affect the unit's completion rate.

9. ASSISTANCE

Consult your training NCO if you have questions concerning course content. Should he/she be unable to assist you, MCI is ready to help you whenever you need it. Please use the Student Course Content Assistance Request Form (ISD-1) attached to the end of your course booklet or call one of the AUTOVON telephone numbers listed below for the appropriate course writer section.

PERSONNEL/ADMINISTRATION	288-3259
COMMUNICATIONS/ELECTRONICS/AVIATION	
NBC/INTELLIGENCE	288-3604
INFANTRY	288-3611
ENGINEER/MOTOR TRANSPORT	288-2275
SUPPLY/FOOD SERVICES/FISCAL	288-2285
TANKS/ARTILLERY/INFANTRY WEAPONS REPAIR	
LOGISTICS/EMBARKATION/MAINTENANCE MANAGEMENT/	
ASSAULT AMPHIBIAN VEHICLES	288-2290

For administrative problems use the UAR or call the MCI HOTLINE: 288-4175.

For commercial phone lines, use area code 202 and prefix 433 instead of 288.

U.S. GOVERNMENT PRINTING OFFICE : 1984 O - 432-363

PREFACE

FUNDAMENTALS OF DIESEL ENGINES has been designed to provide engineer equipment mechanics, MOS 1341, sergeants and below, with a source of study material on the basic fundamentals of diesel engines. The course will also be beneficial to those Marines in occupational fields 11, 18, 21, and 35 whose jobs require them to work closely with diesel engines. FUNDAMENTALS OF DIESEL ENGINES provides broad coverage on diesel engine principles, purposes, advantages, disadvantages, engine construction, fuel injection, combustion, and controlling the engine.

SOURCE MATERIALS

NAVEDTRA	Diesel Engines, 1970
TM 9-8000/T036A-1-76	Principles of Automotive Vehicles, Jan 1956
TM-2815-15/1	V-71 Detroit Diesel Engines, 1972

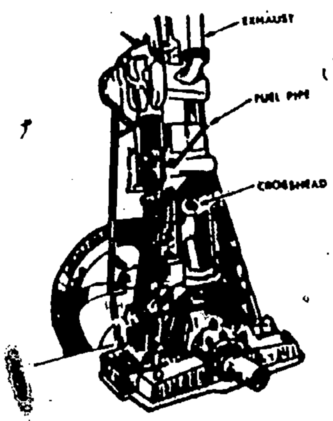
FUNDAMENTALS OF DIESEL ENGINES

COURSE INTRODUCTION

The purpose of this text is to serve as a source of information and a training aid for mechanics working on internal-combustion engines of the diesel design. The course is designed to present an uncluttered view of just the fundamentals of diesel engines, i.e., engine construction, diesel engine principles, engine performance, engine mechanics, structural engine parts, injecting the fuel, burning the fuel, and controlling the engine. Engine systems and auxiliaries are covered in other courses offered by MCI. A sound understanding of the fundamentals of diesel engines will enable the mechanic working on diesel engines to understand diesel malfunctions and inadequate performance.

The diesel engine bears the name of Dr. Rudolph Diesel, a German engineer. He is credited with constructing the first successful diesel engine using liquid fuel in 1897. His objective was an engine with greater fuel economy than the steam engine which used only a small percentage of the energy contained in the coal burned under its boilers. Dr. Diesel originally planned to use pulverized coal as fuel, but his first experimental engine in 1893 was a failure. After a second engine also failed, he changed his plan and used liquid fuel. The engine then proved successful.

The first diesel engines were low-speed, low-pressure heavy engines. The first steps of development were: (a) to increase the power for a given bore and stroke by raising the operating speed thus getting more power strokes per minute, and (b) to raise the gas pressure in the cylinders inside by improving the combustion. This was accomplished by obtaining a better utilization of the air inside of the cylinder. The next step was to reduce the weight of the engines by a more careful use of materials. Unnecessary weight was avoided where possible. Materials of higher strength for a given weight were used both in stationary and moving parts; for example, using high-grade alloys instead of cast-iron for exhaust valves, aluminum alloys instead of cast-iron for framework, and nickel cast-iron for cylinder liners. Particular attention had to be paid to lightening the reciprocating parts in order to reduce the undesirable forces of inertia as the engine speeds were gradually being increased. Another step was changing the engine shape to get more power for the same overall bulk. This was done by shortening the engines. Either a V-type cylinder arrangement was used or the cylinders were crowded together by using an X-type arrangement with a vertical shaft and several banks of cylinder rows as seen in the pancake engine.



Early diesel engine.

The last step was supercharging, i.e., increasing the amount of air taken in which permits an increase in the amount of fuel burned in the engine thus raising the useful pressure and the horsepower developed. While present diesel engines are tremendously improved as compared with diesel engines built 20 and even 10 years ago, further progress undoubtedly will take place. The probable procedure will be a further increase in the engine speed and the obtaining of more efficient combustion. However, improvements become more and more difficult because the present engines have almost reached the safe limits of high temperatures and stresses in many of their parts.

In the Marine Corps, diesel engines are used in a variety of applications. They come in all sizes from the small 2-cylinder diesel generator set to the 2-, 4-, 6-, 8-, and 12-cylinder in-line and V-type engines found in construction equipment, motor transport equipment, amtracs, and tanks. Horsepower ratings range from the 10-horsepower engine in the small 5 kw generator sets to the 750-horsepower engines in the M60 tank.

A thorough understanding of the fundamentals of internal-combustion engines as presented in this course is important for several reasons. First, it is essential for an understanding of the operation of various engines and the functions of the different parts. It is much easier for a person to do something properly when he understands the reasoning behind it. The understanding of the fundamentals underlying the operation of different engine parts helps to prevent undesirable operating conditions and thus reduces maintenance problems. A proper understanding of the fundamentals helps to solve new problems of operation and maintenance and suggests how to meet new conditions of operation. Furthermore, a good understanding of the fundamentals will help in dealing with an engine of a new type or a new design, since the basic principles for all engines are the same. The different shape of a certain engine part will not confuse a person who understands the purpose and operating conditions of that part or piece of auxiliary equipment. In case you, as a diesel mechanic, have to use a helper who has not received diesel engine training or have to teach a man to take your place in an emergency, a thorough understanding of the fundamentals will be invaluable. When the new man asks why, you will be able to answer. At the same time, it is well to remember that studying from a book is not enough regardless of how good the book may be. It takes several years of practical experience in operating and servicing diesel engines of various types to become a real diesel mechanic.

FUNDAMENTALS OF DIESEL ENGINES

ADMINISTRATIVE INFORMATION
ORDER OF STUDIES

Study Unit Number	Study Hours	Subject Matter
1	3	Basic Principles
2	3	Principles, Mechanics, and Performance
3	4	Injection and Control
	2	REVIEW LESSON
	2	FINAL EXAMINATION
	14	

RESERVE RETIREMENT CREDITS: 5

COLLEGE CREDITS: American Council on Education (ACE) has awarded 13.35a, FUNDAMENTALS OF DIESEL ENGINES, 3 semester hours in Fundamentals of Diesel Engines in the Vocational Certificate Category.

EXAMINATION: Supervised final examination without textbook or notes; time limit 2 hours.

MATERIALS: MCI 13.35a, Fundamentals of Diesel Engines, Review lesson and answer sheet.

RETURN OF MATERIALS: STUDENTS who successfully complete this course are permitted to keep the course materials.

Students disenrolled for inactivity or at the request of their commanding officers will return all course materials.

HOW TO TAKE THIS COURSE

This course contains three study units. Each study unit begins with a general objective that is a statement of what you should learn from the study unit. The study units are divided into numbered work units, each presenting one or more specific objectives. Read the objective(s) and then the work unit text. At the end of the work unit text are questions that you should be able to answer without referring to the text of the work unit. After answering the questions, check your answers with those listed at the end of the study unit. If you miss any of the questions, you should restudy the text of the work unit until you understand the correct responses. When you have mastered one study unit, move on to the next. After you have completed all of the study units, complete the review lesson and take it to your training officer or NCO for mailing to MCI. MCI will mail the final examination to your training officer or NCO when you pass the review lesson.

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MARINE CORPS INSTITUTE

STUDY GUIDE

Welcome to the Marine Corps Institute correspondence training program. By enrolling in this course, you have shown a desire to improve the skills you need for effective job performance, and MCI has provided materials to help you achieve your goal. Now all you need is to develop your own method for using these materials to best advantage.

The following guidelines present a four-part approach to completing your MCI course successfully:

1. Make a "reconnaissance" of your materials;
2. Plan your study time and choose a good study environment;
3. Study thoroughly and systematically;
4. Prepare for the final exam.

I. MAKE A "RECONNAISSANCE" OF YOUR MATERIALS

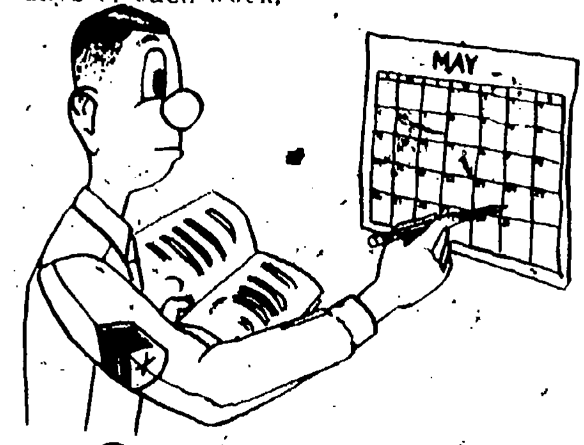
Begin with a look at the course introduction page. Read the COURSE INTRODUCTION to get the "big picture" of the course. Then read the MATERIALS section near the bottom of the page to find out which text(s) and study aids you should have received with the course. If any of the listed materials are missing, see Information for MCI Students to find out how to get them. If you have everything that is listed, you are ready to "reconnoiter" your MCI course.

Read through the table(s) of contents of your text(s). Note the various subjects covered in the course and the order in which they are taught. Leaf through the text(s) and look at the illustrations. Read a few work unit questions to get an idea of the types that are asked. If MCI provides other study aids, such as a slide rule or a plotting board, familiarize yourself with them. Now, get down to specifics!

II. PLAN YOUR STUDY TIME AND CHOOSE A GOOD STUDY ENVIRONMENT

From looking over the course materials, you should have some idea of how much study you will need to complete this course. But "some idea" is not enough. You need to work up a personal study plan; the following steps should give you some help.

(A) Get a calendar and mark those days of the week when you have time free for study. Two study periods per week, each lasting 1 to 3 hours, are suggested for completing the minimum two study units required each month by MCI. Of course, work and other schedules are not the same for everyone. The important thing is that you schedule a regular time for study on the same days of each week.



(B) Read the course introduction page again. The section marked ORDER OF STUDIES tells you the number of study units in the course and the approximate number of study hours you will need to complete each study unit. Plug these study hours into your schedule. For example, if you set aside two 2-hour study periods each week and the ORDER OF STUDIES estimates 2 study hours for your first study unit, you could easily schedule and complete the first study unit in one study period. On your calendar you would mark "Study Unit 1" on the appropriate day. Suppose that the second study unit of your course requires 3 study hours. In that case, you would divide the study unit in half and work on each half during a separate study period. You would mark your calendar accordingly. Indicate on your calendar exactly when you plan to work on each study unit for the entire course. Do not forget to schedule one or two study periods to prepare for the final exam.

(C) Stick to your schedule.

Besides planning your study time, you should also choose a study environment that is right for you. Most people need a quiet place for study, like a library or a reading lounge; other people study better where there is background music; still others prefer to study out-of-doors. You must choose your study environment carefully so that it fits your individual needs.

III. STUDY THOROUGHLY AND SYSTEMATICALLY

Armed with a workable schedule and situated in a good study environment you are now ready to attack your course study unit by study unit. To begin, turn to the first page of study unit 1. On this page you will find the study unit objective, a statement of what you should be able to do after completing the study unit.

DO NOT begin by reading the work unit questions and flipping through the text for answers. If you do so, you will prepare to fail, not pass, the final exam. Instead, proceed as follows:

(A) Read the objective for the first work unit and then read the work unit text carefully. Make notes on the ideas you feel are important.

(B) Without referring to the text, answer the questions at the end of the work unit.

(C) Check your answers against the correct ones listed at the end of the study unit.

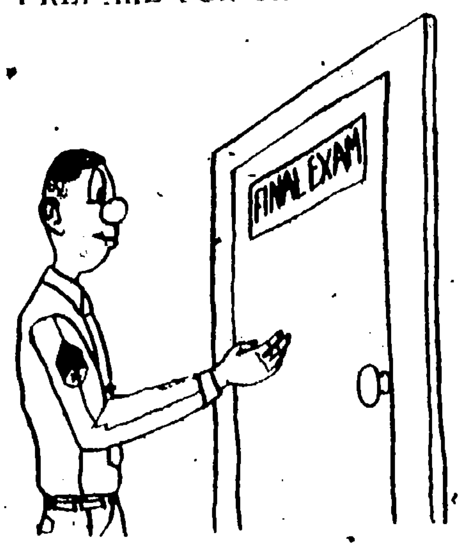
(D) If you miss any of the questions, restudy the work unit until you understand the correct response.

(E) Go on to the next work unit and repeat steps (A) through (D) until you have completed all the work units in the study unit.

Follow the same procedure for each study unit of the course. If you have problems with the text or work unit questions that you cannot solve on your own, ask your section OIC or NCOIC for help. If he cannot aid you, request assistance from MCI on the Student Course Content Assistance Request included with this course.

When you have finished all the study units, complete the course review lesson. Try to answer each question without the aid of reference materials. However, if you do not know an answer, look it up. When you have finished the lesson, take it to your training officer or NCO for mailing to MCI. MCI will grade it and send you a feedback sheet listing course references for any questions that you miss.

IV. PREPARE FOR THE FINAL EXAM



How do you prepare for the final exam? Follow these four steps:

(A) Review each study unit objective as a summary of what was taught in the course.

(B) Reread all portions of the text that you found particularly difficult.

(C) Review all the work unit questions, paying special attention to those you missed the first time around.

(D) Study the course review lesson, paying particular attention to the questions you missed.

If you follow these simple steps, you should do well on the final. GOOD LUCK!

STUDY UNIT 1

BASIC PRINCIPLES

STUDY UNIT OBJECTIVE: WITHOUT THE AID OF REFERENCES, YOU WILL IDENTIFY THE BASIC PRINCIPLES OF THE DIESEL ENGINE. IN ADDITION, YOU WILL IDENTIFY THE DIFFERENCES BETWEEN GASOLINE AND DIESEL ENGINES. LASTLY, YOU WILL IDENTIFY THE BASIC COMPONENTS OF THE DIESEL ENGINE.

Work Unit 1-1. BASIC PRINCIPLES OF THE DIESEL ENGINE

DESCRIBE THE OPERATION OF THE INTERNAL COMBUSTION ENGINE.

LIST THE MAJOR ADVANTAGES OF THE DIESEL ENGINE.

LIST THE MAJOR DISADVANTAGES OF THE DIESEL ENGINE.

The internal-combustion engine is an engine from which work is obtained by the burning or combustion of fuel within the engine cylinders themselves. A diesel engine is an internal-combustion engine which uses fuel oil injected in a finely divided state into the cylinder which contains air compressed to a comparatively high pressure and temperature. The temperature of the air must be high enough to ignite the particles of the injected fuel. No other means are used for ignition. Due to the method of ignition used, diesel engines are often called compression-ignition engines. This differentiates them from other internal-combustion engines called spark-ignition engines. These latter engines use gasoline as fuel and the mixture of gasoline and air is ignited by an electric spark.

The main advantages are: high power per pound of engine-installation weight particularly with present-day high-speed engines, high reliability in operation, low fuel consumption per horsepower per hour, reduced fire hazard as compared with gasoline engines, and high sustained torque.

There are some disadvantages to a diesel engine, the main one being cost. Because of the high pressures and temperatures at which a diesel works, sturdier construction is required; therefore, it costs more to build. Another disadvantage is that diesel engines are much heavier than gasoline engines of the same power rating due to the sturdier construction required. Peak horsepower is reached at a lower speed.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Describe the operation of the internal combustion engine.

____
____
____
____

2. List the major advantages of the diesel engine.

   a. _______________
   b. _______________
   c. _______________
   d. _______________
   e. _______________

3. List the major disadvantages of the diesel engine.

   a. _______________
   b. _______________
   c. _______________

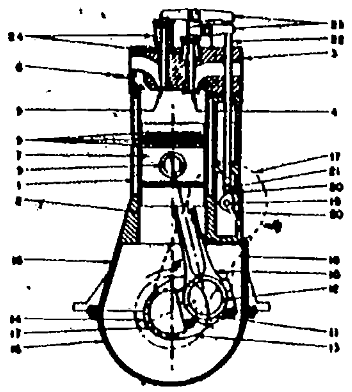
Work Unit 1-2. ENGINE CONSTRUCTION

IDENTIFY THE CONSTRUCTION OF THE DIESEL ENGINE.

General. Diesel engines vary greatly in outside appearance, size, number of cylinders, cylinder arrangement, and details of construction. However, they all have the same main basic parts which may look different but perform the same functions. There are only a very few basic main working parts to a diesel engine. The rest of the engine is composed of auxiliary parts, which assist the main working parts in their performance, and connecting parts necessary to hold the working parts together. The main working parts are: cylinder, piston, connecting rod, crankshaft, bearings, and fuel pump and nozzle.

Naturally, there are a number of other parts without which an engine could not operate, but their functions are more or less subordinate and will be discussed later.

Figure 1-1 is a schematic drawing of a typical diesel engine. Its purpose is to show the main working parts and their relation to the other parts.



Legend

1. Cylinder.
2. Cylinder liner.
3. Cylinder head.
4. Intake valve.
5. Exhaust valve.
6. Fuel injectors.
7. Piston.
8. Piston rings.
9. Wrist or piston pin.
10. Connecting rod.
11. Crankpin bearing.
12. Crankpin.
13. Crank cheek or crank web.
14. Crankshaft.
15. Engine frame.
16. Crankcase.
17. Timing chain sprocket.
18. Timing chain.
19. Camshaft.
20. Cams.
21. Cam follower.
22. Push rod.
23. Rocker arm.
24. Valve spring.

Fig 1-1. Schematic drawing of a diesel engine

Cylinder. The heart of the engine is the cylinder where the fuel is burned and the power developed. The inside of the cylinder is formed by the cylinder liner or sleeve and the cylinder head which seals one end of the cylinder and often, although not always, contains the valves to admit fuel and air and to eliminate the used gases. The diameter of the liner is known as the bore.

Piston. The piston seals the other end of the working space of the cylinder and transmits the power developed inside of the cylinder by the burning of the fuel to the outside via the connecting rod and crankshaft. A gas tight seal between the piston and the cylinder liner is produced by piston rings lubricated with engine oil. The distance that the piston travels from one end of the cylinder to the other is known as the stroke.

Connecting rod. The small end of the connecting rod or connecting eye is attached to the piston by the wrist pin or piston pin located in the piston; the big end has a bearing which is connected to the crankpin.

Crankshaft. The crankshaft obtains its rotary motion from the piston through the connecting rod and crankpin located between the crank webs or crank cheeks. The work of the piston is transmitted to the drive shaft. A flywheel of sufficient mass is fastened to the crankshaft in order to reduce speed fluctuation by storing kinetic energy during the periods when power is developed and giving it back during the other periods.

Camshaft. A camshaft is driven from the crankshaft by a chain drive or by timing gears. Through cam followers, push rods, and rocker arms, the intake and exhaust valves are opened by cams on the camshaft. Valve springs serve to close the valves.

Crankcase. A crankcase is constructed to protect the crankshaft, bearings, connecting rods, and related parts, to catch the oil escaping from the bearings of the moving parts, and to provide a reservoir for lubricating oil. If the crankcase is constructed to support the whole engine, it is called a bed plate.

Fuel pumps and nozzle. Fuel for diesel engines is delivered into the combustion space of the cylinder by an injection system consisting of a pump, fuel line, and injector, also called the injection or spray nozzle.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. The heart of the diesel engine where the fuel is burned is known as the

   a. crankcase. c. piston.
   b. cylinder. d. valve.

2. The crankshaft obtains its rotary motion from the piston through the

   a. intake valve. c. timing chain.
   b. exhaust valve. d. connecting rod and crankpin.

3. The camshaft is driven from the ____________ by a chain drive or timing chain.

   a. fuel pump c. crankshaft
   b. piston d. cylinder

4. The part that transmits the power from the burning fuel to the outside via the connecting rod is the

   a. piston. c. camshaft.
   b. valve. d. cylinder.

5. The section of the engine used to keep the connecting rod and the crankshaft well lubricated is the

   a. cylinder. c. crankcase.
   b. liner. d. crankpin.

6. Fuel is delivered to the combustion space by an injection system consisting of a fuel line, injectors or nozzles, and the

   a. camshaft. c. crankshaft.
   b. connecting rod. d. fuel pump.

7. The big end of the ____________ has a bearing which is connected to the crankpin.

   a. crankshaft c. camshaft
   b. connecting rod d. piston

Work Unit 1-3. ENGINE CLASSES.

IDENTIFY THE FIVE DIESEL ENGINE CLASSES

Diesel engines may be divided into five classes using different bases for the division. These five classes are the: operating cycle, cylinder arrangement, piston action, method of fuel injection, and speed.

Operating cycles. Diesel engines can be divided into two groups based on the number of piston strokes per cycle, in (1) four-stroke-cycle, or, for short, four-stroke engines, and (2) two-stroke-cycle, or two-stroke engines.

Cylinder arrangement

Cylinders-in-line. This is the simplest arrangement with all cylinders parallel, in line, as shown in figure 1-2. This construction is used for engines having up to 10 cylinders.

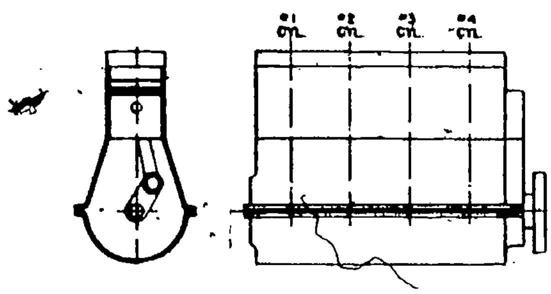


Fig 1-2. In-line engine.

V-arrangement. If an engine has more than 8 cylinders, it becomes difficult to make a sufficiently rigid frame and crankshaft with an in-line arrangement. The V-arrangement (fig 1-3a), with two connecting rods attached to each crankpin, permits reducing the engine length by one-half, thus making it much more rigid with a stiff crankshaft. This is a common arrangement for engines with 8 to 16 cylinders. Cylinders lying in one plane are called a bank. The angle between the banks may vary from 30° to 120°, the most common angle being between 40° and 75°.

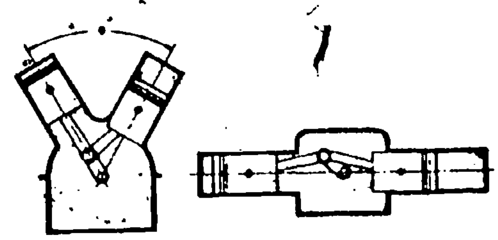


Fig 1-3. Vee-type engine.

Flat engine. The flat engine (fig 1-3b) is similar to a V-engine with an angle of 180° between the banks. This arrangement is used mostly for trucks and buses.

Multiple-engine units. In order to increase the engine power without increasing its bore and stroke, two or four complete engines, having six or eight cylinders each, are combined in one unit by connecting each engine to the main drive shaft 5 (fig 1-4a and 1-4b), by means of clutches and gears or clutches and roller chains. Figure 1-4a shows a twin-engine and figure 1-4b shows a quadruple-engine or quad.

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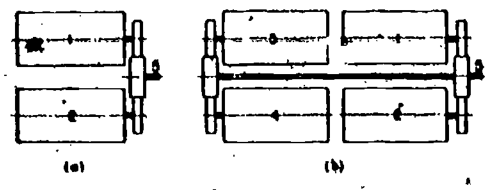


Fig. 1-4. Multiple-unit engines.

Vertical-shaft engines. A recent development is an engine with four connecting rods attached to one crankpin (fig 1-5). The four cylinders are all in one horizontal plane, the crankshaft thus being vertical. Four banks located one on top of the other and using one crankshaft with four cranks form a compact 16-cylinder engine under the name of the pancake engine.

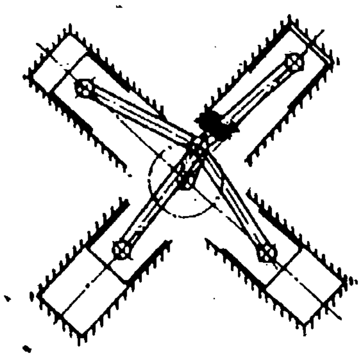


Fig 1-5. Top view of pancake engine.

Piston action

Single-acting engines use only one end of the cylinder and one face of the piston for the development of power. Nearly all diesel engines are single-acting.

Double-acting engines use both ends of the cylinder and both faces of the piston for the development of power. Double-acting engines are built only in large and comparatively low-speed units.

Opposed-piston engines are engines having two pistons per cylinder driving two crankshafts. This design presents many advantages from the viewpoint of combustion of fuel, engine maintenance, and accessibility of all parts except the lower crankshaft.

Fuel injection. Diesel engines are divided into air-injection engines and solid or mechanical-injection engines. The meaning of these terms and the differences between these two types are discussed in Study Unit 3. Therefore, at this time, we need only mention that air-injection engines are gradually disappearing.

Speed. All diesel engines can be divided into three classes in relation to speed; low-speed, medium-speed, and high-speed. The present trend is away from low- and even medium-speed engines and toward increasingly higher speed engines.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Diesel engines can be divided into two groups based on the number of ______________ per cycle.

   a. valves
   b. injections
   c. piston strokes
   d. turns of crankshaft

2. The simplest arrangement of having all cylinders parallel is known as

   a. in-line.
   b. vertical-shaft.
   c. flat-engine.
   d. pancake.

3. In order to increase the engine power without increasing its bore and stroke a(n) __________ engine is used.

   a. in-line
   b. vee-type
   c. multiple
   d. pancake

4. Engines using only one end of the cylinder and one face of the piston are said to be

   a. double-acting.
   b. single-acting.
   c. stationary.
   d. low-speed.

5. Diesel engines' fuel systems are divided into air injection or

   a. solid injection.
   b. liquid injection.
   c. mechanical injection.
   d. hydraulic injection.

6. All diesel engines can be divided into three classes for speed. These classes are

   a. 1st, 2nd, and 3rd.
   b. low, medium, and high.
   c. low, even, and higher.
   d. in-line, vee, and pancake.

7. The five classes of diesel engines are operating cycle, speed, fuel injection, cylinder arrangement, and

   a. weight.
   b. piston action.
   c. alinement of valves.
   d. four-stroke.

Work Unit 1-4. ENGINE MEASUREMENTS

IDENTIFY BORE AND STROKE.

IDENTIFY PISTON DISPLACEMENT.

IDENTIFY VACUUM IN THE CYLINDER.

IDENTIFY VOLUMETRIC EFFICIENCY.

Bore and stroke. The size of an engine cylinder is usually indicated in terms of bore and stroke (fig 1-6). Bore is the diameter of the cylinder. Stroke is the distance the piston moves in the cylinder or the distance between top dead center and bottom dead center. When reference is made to these two measurements, the bore is always given first. For example, a 4 x 4 cylinder means that the cylinder bore, or diameter, is 4 inches and the length of the stroke is 4 inches.

Piston displacement. Piston displacement is the volume of space that the piston displaces as it moves from bottom dead center to top dead center. The volume is figured by multiplying the length of stroke by the area of a circle having the diameter of the cylinder bore. Thus, a 4-inch diameter circle has an area of 12.566 square inches, and, therefore, this times 4 inches (length of stroke) equals 50.264 cubic inches, the piston displacement or the number of cubic inches the piston displaces as it moves from bottom dead center to top dead center.

Vacuum in the cylinder. When the piston starts to move downward in the cylinder on the intake stroke, it produces a vacuum in the cylinder. If both the intake and exhaust valves are closed, then no substance could enter to fill this vacuum. The cylinder would remain empty. However, at the same time that the piston starts to move down, the intake valve is opened. Now atmospheric pressure pushes air past the intake valve and into the cylinder. The cylinder, therefore, becomes filled with air (or with fuel-air mixture in gasoline engines).

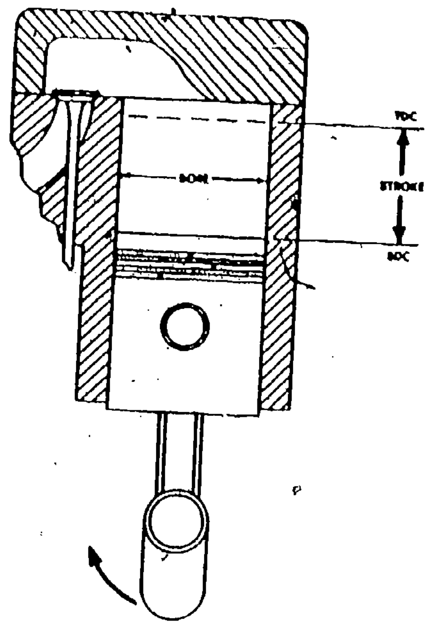


Fig. 1-6. Bore and stroke of an engine cylinder.

Atmospheric pressure. The miles and miles of air extending above presses downward or exerts pressure. Ordinarily, this pressure is not noticed because we are accustomed to it. If the air was removed from a container and the container were opened, this pressure would push air back into the container. This might be compared to what happens when an empty bottle is held under water and the cork is removed. The pressure of the water pushes water into the bottle. The higher we go into the air, the less pressure is found. The reason for this is that as we ascend there is less air above us; we climb toward the top of the atmosphere. This means there is less air to press down on us and, therefore, the pressure is less. Six miles above the earth, for example, the pressure is about 4.4 psi. Returning to earth, the air pressure increases. The nearer we approach to earth or the bottom of the ocean of air, the greater the pressure of air. At sea level, this pressure is about 14.7 psi.

Volumetric efficiency. Although the atmosphere exerts considerable pressure and rapidly forces air into the cylinder on the intake stroke, it does take time for the air to flow through the intake system and past the intake valve. If given enough time, enough air will flow into the cylinder to "fill it up." However, the air is given very little time to do this. For example, when the engine is running at 1,200 rpm, the intake stroke lasts only 0.025 second. In this very brief period, all the air that could enter does not have time to flow into the cylinder. The intake stroke ends too quickly. Nevertheless, this factor has been taken into consideration in designing the engine so that good operation will result even at high engine speed.

Measuring volumetric efficiency. The measure of the amount of fuel-air mixture that actually enters the cylinder is referred to in terms of volumetric efficiency. Volumetric efficiency is the ratio between the amount of fuel-air mixture that actually enters the cylinder and the amount that could enter under ideal conditions. The greater the volumetric efficiency, the greater the amount of fuel-air mixture entering the cylinder; and the greater the amount of fuel-air mixture, the more power is produced from the engine cylinder. At low speeds, more fuel-air mixture can get into the cylinder, and the power produced during the power stroke is greater. Volumetric efficiency is high, but at high speeds, the shorter time taken by the intake stroke reduces the amount of fuel-air mixture entering the cylinder. Volumetric efficiency then is lower. In addition, the air is heated as it passes through hot manifolds on its way to the cylinder, and it expands. This further reduces the amount of fuel-air mixture entering the cylinder and further reduces volumetric efficiency.

Increasing volumetric efficiency. Volumetric efficiency is higher at low engine speed because more fuel-air mixture gets into the cylinder. Volumetric efficiency can also be improved by use of a blower or air-compressing device. On gasoline engines, this device is called a supercharger. It raises the air pressure above atmospheric pressure so that the air is pushed harder on its way into the cylinder. The harder push, or higher pressure insures that more air will enter the cylinder. In a supercharged engine, the volumetric efficiency can run well over 100 percent. Since 100 percent efficiency means that the pressure inside the cylinder equals atmospheric pressure, a volumetric efficiency of more than 100 percent means the pressure inside the cylinder would be greater than atmospheric pressure at the end of the intake stroke. This increased volumetric efficiency increases engine power output. A supercharger is very important on airplane engines because the lowered air pressure (about 4.4 psi at a height of 6 miles) must be greatly increased if engine power output is to be maintained at high altitudes. Also, on 2-stroke-cycle engines, some form of device is required to increase the pressure of the ingoing fuel-air mixture.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Bore is the size of the

a. end of the piston.
b. stroke.
c. diameter of the cylinder.
d. distance the piston moves.

2. Stroke is the

a. diameter of the cylinder.
b. distance between TDC and BDC.
c. length of the piston rod.
d. distance between the crank and TDC.

3. The volume of space that the piston displaces from BDC to TDC is called

a. stroke.
b. vacuum in the cylinder.
c. bore.
d. piston displacement.

4. When the piston starts to move downward in the cylinder on the intake stroke, it produces

a. piston displacement.
b. bore and stroke.
c. vacuum in the cylinder.
d. ignition of fuel.

5. At lower speeds, the volumetric efficiency is

a. higher.
b. not changed.
c. low.
d. fluctuating.

6. Volumetric efficiency can be increased by using a

a. larger engine.
b. smaller engine.
c. blower.
d. heavier piston.

Work Unit 1-5. ENGINE OUTPUT

DEFINE WORK.

DESCRIBE ENERGY.

DEFINE POWER.

IDENTIFY THE DYNAMOMETER.

IDENTIFY TORQUE EFFECT.

IDENTIFY TORQUE-HORSEPOWER-SPEED RELATIONSHIP.

Engines vary in size and output. To compare engines, compare not only their size, but also the work they are capable of doing. These functions are explained below.

Work. Work is the movement of a body against an opposing force. When a weight is lifted from the ground, work is done on the weight. It is moved upward against the force of gravity. When a tank pushes over a tree, it does work on the tree as it forces it to the ground. If a 1-pound weight is lifted one foot, one foot-pound of work is done.

Energy. Energy is the ability to do work. As the speed of a tank is increased, the energy of movement of the tank increases. It can thereby knock over a tree more easily. The higher a weight is lifted from the ground, the more energy is stored in the weight. Then, when it falls, it will strike the ground harder; that is, it will do more work on the ground. Suppose a stake is being driven in the ground. The greater the distance the weight falls, the more work it does on the stake and the farther it drives the stake into the ground.

Power. Power is the rate of work. It takes more power to work quickly than to work slowly. Engines are rated in terms of the amount of work they can do per minute. A large engine that can do more work per minute is more powerful than a small engine which cannot work as hard. The work capacity of engines is measured in horsepower. A horsepower is a definite amount of power. Actually, it is the amount of power that an average horse was found to generate when working hard. The tests measuring horsepower were made many years ago at the time steam engines were being developed. It was found that an average horse could pull a weight of 200 pounds a distance of 165 feet in 1 minute. The amount of work involved here is 33,000 foot-pounds (165 times 200). If 100 pounds were lifted 330 feet, or if 330 pounds were lifted 100 feet, the amount of work would be the same, 33,000 foot-pounds. When this amount of work is done in 1 minute, then 1 horsepower is required. If it took 2 minutes to do this amount of work, then 16,500 foot-pounds per minute, or 1/2 hp, would be required. Or if 33,000 foot-pounds of work were done in 1/2 minute, then 66,000 foot-pounds per minute, or 2 hp, would be required.

Prony brake. A prony brake may be used to measure the actual housepower that an engine can deliver. This device usually makes use of a series of wooden blocks fitted around a special flywheel that is driven by the engine (fig 1-7). A tightening device is arranged so the blocks can be tightened on the flywheel. In addition, an arm is attached to this tightening device and one end of the arm rests on a scale. In operation, the wooden blocks are tightened on the flywheel. This loads up the engine and works it harder. Also, the pressure on the blocks tends to cause the arm to turn so that force is exerted on the scales. The length of the arm times the force exerted on the scales gives the engine torque in pound-feet. The results of the prony brake test can be converted into brake horsepower by using this formula:

$$\text{Bhp} = \frac{2\pi lnw}{33{,}000}$$

where l is length of the arm in feet, n is the speed in rpm, and w is the load in pounds on the scale. For example, suppose the arm is 3 feet long, the load on the scale is 50 pounds, and the speed is 1,000 rpm. Substituting in the formula gives:

$$\text{Bhp} = \frac{2 \times 3.1416 \times 3 \times 1{,}000 \times 50}{33{,}000} = 28.56 \text{ brake horsepower}$$

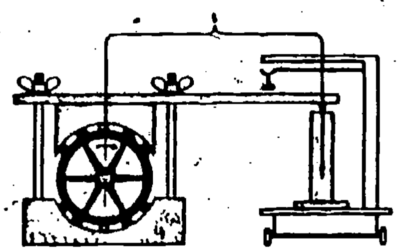


Fig. 1-7. Simplified drawing of a prony brake.

Dynamometer. The dynamometer is essentially a dynamo of a special type which can be driven by an engine. This special dynamo can absorb all the power the engine can produce and indicates this power on dials or gages. Although the dynamometer is more complicated than a prony brake, it is generally considered to be more flexible and accurate. In addition to measuring engine power output, the dynamometer can also be used to drive the engine for purposes of measuring the friction of the engine itself or of the various accessories.

Torque effect. Torque is the effect which rotates or tends to rotate a body. When the lid on a jar is loosened, a twisting force or torque is applied to it (fig 1-8). Torque is measured in pound-feet (not to be confused with work which is measured in foot-pounds). For instance, suppose a wrench is used to tighten a nut on a stud (fig 1-9). If the handle of the wrench were 1-foot long and a 10-pound force is put on its end, 10 pound-feet of torque would be applied on the nut. If the handle were 2 feet long and a 10-pound force is put on its end, 20 pound-feet of torque would be applied. Torque can be converted into work with the formula: ft-lb (work) = 2   n x lb-ft (torque) = 6.2832 n x lb-ft where n is the speed in revolutions per minute. For example, if an engine were checked on a prony brake and found to be delivering 100 pound-feet torque at 1,000 rpm, then it would be doing 682,320 foot-pounds of work every minute. This can be converted into horsepower by dividing it by 33,000. An illustration of a torque wrench in use is shown in figure 1-10.

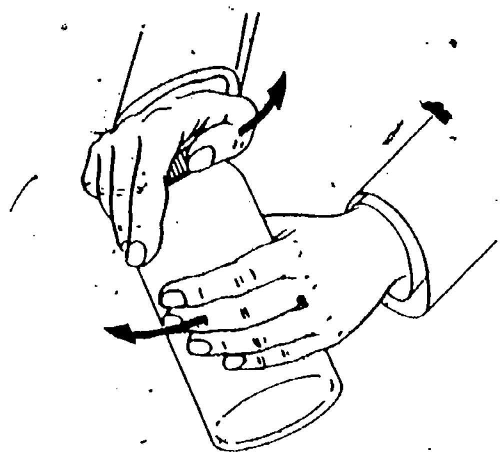


Fig 1-8. Applying twisting effort, or torque, on can lid.

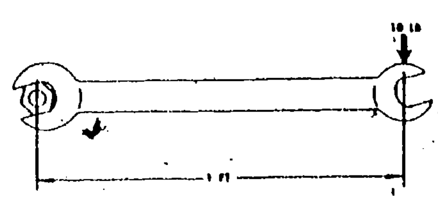


Fig 1-9. Applying torque with a wrench on a nut.

The engine exerts torque through gears and shafts connected to the wheels so that the wheels turn and the vehicle moves. The amount of torque that an engine produces varies with engine speed (fig 1-11). Note that torque increases and then, at an intermediate speed, falls off. The reason for this variation is that, with increasing speed, the engine is turning faster and is thus capable of supplying a greater twisting effort or torque. However, with further speed increases, volumetric efficiency falls off. Less fuel-air mixture gets to the cylinders with each intake stroke and thus the power strokes are not as powerful; torque falls off.

Fig 1-10. Torque wrench in use, tightening main bearing studs of an engine.

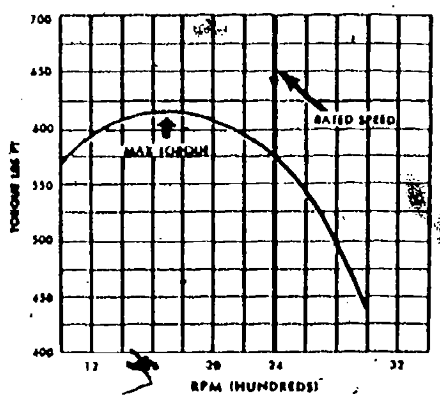


Fig 1-11. Relationship between torque and speed.

Torque-horsepower-speed (rpm) relatioship

Figure 1-12 shows the comparison between the horsepower and torque of an engine. Torque increases with speed (up to rated speed) as shown in figure 1-11. Horsepower also shows a change with speed, and this is more marked than with torque. Horsepower is directly related to both torque and speed. When both torque and speed are on the increase, as in the speed range of 1,200 to 1,600 rpm, then horsepower goes up sharply. When torque reaches maximum and then begins to taper off, the horsepower curve starts to drop. Finally, in the higher speed ranges when torque falls off sharply, horsepower also falls off. The horsepower formula Hp = 2 lnw given above shows that horsepower depends on both speed and torque, since torque equals w and is n is speed. Substituting the formula and dividing 2π (or 6.2832) into 33,000 gives:

$$Hp = \frac{\text{torque x rpm}}{5,252}$$

which shows the relationship between horsepower, torque, and speed more directly.

A rated speed is indicated in figures 1-11 and 1-12. This is the speed at which the governor is usually set in military vehicles. The rated speed is selected because, at higher engine speeds, wear on the engine increases rapidly and a disproportionate amount of fuel is used. Overspeeding or driving the engine above rated speed, only allows a slight increase of horsepower.

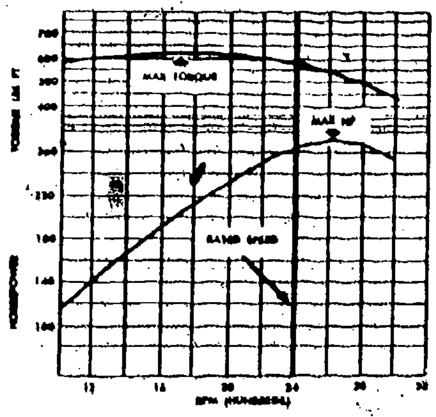


Fig 1-12. Relationship between torque and horsepower.

Gross and net horsepower. The gross horsepower of an engine is the amount of power the engine delivers before any accessories have been attached. Net horsepower is the power available at the flywheel after all accessories are attached.

Indicated horsepower. Indicated horsepower is the horsepower actually developed inside the engine cylinders. It is called "indicated" horsepower because an indicating device is required to measure this horsepower. This device measures the pressures developed in the engine cylinders and, by a series of steps, translates this data into indicated horsepower. Indicated horsepower is always considerably greater than horsepower delivered by the engine because power is lost from the engine in a number of ways (friction, heat-loss, etc.).

SAE horsepower. The Society of Automotive Engineers (SAE) developed a simplified method of calculating horsepower based on engine dimensions. This rating was used only for commercial licensing of vehicles. This formula is:

$$Hp = \frac{DN}{2.5}$$

where D is the cylinder diameter in inches and N is the number of cylinders.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Work is defined as ____________________

____

2. Energy is described as when the speed of a tank is increased

____

3. Power is defined as ____________________

____

4. If a 10-pound weight is lifted 6 feet in the air, then __________ foot-pounds of work is done.

   a. 30　　c. 60
   b. 10　　d. 6

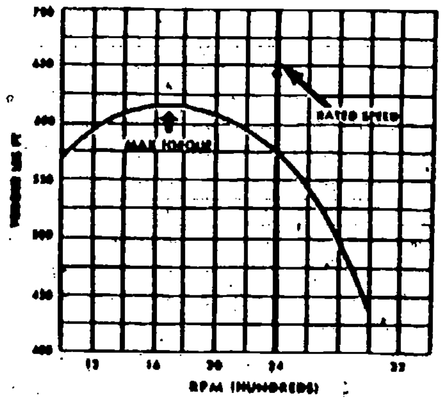
5. The item that is essentially a dynamo of a special type which can be driven by an engine is called a

   a. prony brake.　　c. torque effect.
   b. dynamometer.　　d. horsepower.

6. The effect that rotates or tends to rotate a body is called __________ effect.

   a. dynamic　　c. twist
   b. revolving　　d. torque

7. The illustration below identifies



a. dynamic torque effect.
b. torque-horsepower-speed relationship.
c. torque-speed relationship.
d. torque and horsepower relationship.

Work Unit 1-6. ENGINE EFFICIENCY

IDENTIFY ENGINE EFFICIENCY.

The term efficiency means the relationship between results obtained and the effort required to obtain those results. It is expressed as: efficiency = $\frac{\text{output}}{\text{input}}$. Suppose, for example, a set of pulleys were used to raise a 270-pound weight 2 feet and this required a 100-pound pull for 6 feet (fig. 1-13). It would take 600 foot-pounds to get out 540 foot-pounds. The ratio would be $\frac{540}{600}$ or 0.90. In other words, the efficiency of the pulleys would be 90 percent. There would be a loss of 10 percent of the work put in. The system of pulleys shows a loss (or is only 90 percent efficient) because of friction. No machine or engine is 100 percent efficient; all lose energy as explained below.

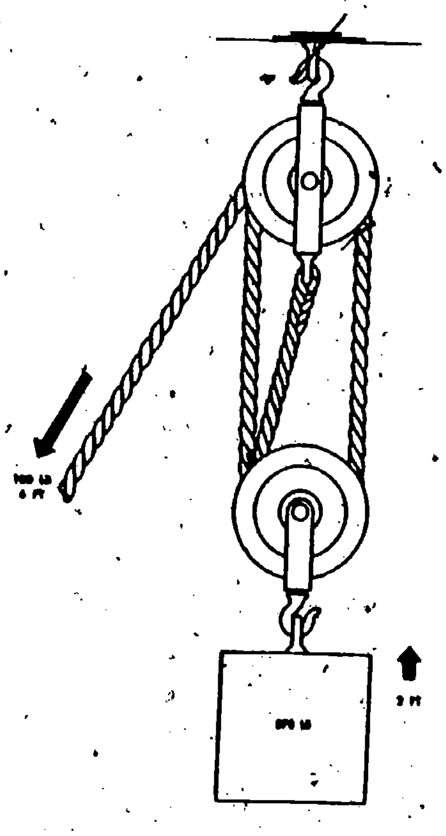


Fig 1-13. System of pulleys in which 600 foot-pounds must be expended to realize 540 foot-pounds of work.

Friction loss. Friction is a source of energy loss in any mechanical system. If a heavy plank is dragged across a rough floor, it offers some resistance to the movement. This resistance to movement would be less if the plank and floor were polished smooth. Resistance would be still less if the plank floated in water. This resistance to movement is called friction. Friction can be visualized as being caused by tiny irregularities, or high points, in the surfaces of the moving objects. These catch on each other and particles are torn off. All of these require force to overcome. If the plank and floor are made smooth, then the projecting points are much smaller and have less tendency to catch and tear off. Therefore, less force is required to pull the plank across the floor, and if the plank is floated in water, the surfaces can no longer rub against each other. There is, however, still some friction in the liquid. In the engine, friction occurs at all moving parts, even though the parts are, in effect, floating in films of oil.

Mechanical efficiency. The mechanical efficiency of the engine is the relationship between the power developed in the engine cylinders (indicated horsepower) and the power delivered by the engine (brake horsepower). Internal engine losses from friction and other factors always prevent brake horsepower from equaling indicated horsepower. A typical engine, for example, might develop 200 indicated horsepower as against an actual brake horsepower of 180. This engine would have a mechanical efficiency of:

$$\frac{\text{Brake horsepower}}{\text{Indicated horsepower}} = \frac{180}{200} = 90 \text{ percent}$$

Thermal efficiency. The definition of thermal efficiency is the relationship between the heat energy in the fuel and the engine power output (thermal means of or pertaining to heat). The term "thermal efficiency" relates to the heat energy of the fuel and the work output. The heat energy is the amount of heat the fuel will produce as it burns. Much of this heat is lost to the cylinder walls and cooling system. Still more is lost in the hot exhaust gases as they pass out of the cylinder. This heat that is lost cannot do anything to cause the engine to produce power. Therefore, only a relatively small part of the heat in the burning fuel can contribute anything toward pushing down on the pistons and thereby causing the engine to produce power. In actual practice, because of the great amount of heat lost to the cooling water and lubricating oil and in the exhaust gases, thermal efficiency may be as low as 20 percent. In other words, as much as 80 percent of the energy in fuel is lost. However, the remaining 20 percent is sufficient to operate the engine normally. Practical limitations prevent thermal efficiencies of much above 25 percent.

The overall thermal efficiency of an engine is the relationship between the fuel input and the power output. This relationship is commonly expressed in heat units called British thermal units (Btu). One Btu is equal to 778 ft-lbs of work; therefore, the horsepower output of an engine can be readily converted into Btu per unit of time. The source of power in an engine is fuel, and the Btu content of regularly used fuels has been determined by laboratory analysis:

$$\text{Thermal efficiency} = \frac{\text{power output in Btu}}{\text{fuel input in Btu}}$$

Example: An engine delivers 85 bhp for a period of 1 hour and in that time consumes 50 pounds (approx 7 1/2 gals) of fuel. Assuming that the fuel has a value of 18,800 Btu per lb, we find the thermal efficiency of the engine:

Power delivered by the engine is 85 bhp for 1 hour, or 85 hp-hours.

1 hp-hour =

$$\frac{33{,}000 \text{ ft-lb per min} \times 60 \text{ min}}{778 \text{ ft-lb per Btu}}$$

= 2,545 Btu

85 Bhp x 2,545 Btu = 216,325 Btu output

50 lb x 18,800 Btu per lb = 940,000 Btu input per hour

$$\text{Overall thermal efficiency} = \frac{216{,}325}{940{,}000}$$

= 0.230, or 23 percent

28

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. The relationship between results obtained and the effort required to obtain those results is known as engine

   a. operation.
   b. accuracy.
   c. efficiency.
   d. friction.

2. Three ways that a machine will lose efficiency are:

   a. ______________________________
   b. ______________________________
   c. ______________________________

Work Unit 1-7. THE MAIN STATIONARY PARTS OF THE DIESEL ENGINE

IDENTIFY THE FUNCTION OF THE MAIN STATIONARY PARTS OF THE DIESEL ENGINE.

DESCRIBE THE CYLINDER HEADS.

General. The main stationary parts of a diesel engine are designed to maintain the moving or working parts in their proper relative positions, so that the gas pressure produced by the combustion is effectively used to push the piston and rotate the crankshaft. The main requirement is strength, next comes low weight, and finally simplicity of design. Diesel engines that were built a few years ago were several times as heavy per horsepower output as the more modern engines. The reduction in weight in recent years has been possible due partly to the improvement in materials which provides greater strength per unit area, but mostly due to improved design and methods of calculation and manufacture which permit the use of lighter sections.

Engine frame. The frame connects the top of the cylinder to the supports for the crankshaft. In the earlier designs (at present used only in large, low-speed engines), the frame consisted of a separate cylinder block, crankcase, and bed plate with an oil pan or sump (fig 1-14). The main bearings, supporting the crankshaft, were held in the crankcase, while the pistons operated in the cylinder block above it. The gas-pressure load was taken up by tie bolts running from top to bottom. Cylinder block, crankcase, and bed plate were made of gray-iron castings.

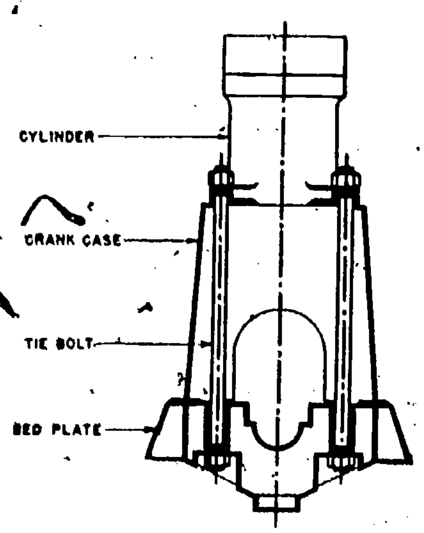


Fig 1-14. Engine frame with tie bolts.

Modern designs of high-power output engines have frames of welded steel with plates located at places where the loads occur (fig 1-15). The customary arrangement combines the cylinder block and oil pan with the main bearing supports, although a separate crankcase section is sometimes used. Cylinder blocks and crankcases of small high-speed engines are still made of cast iron.

The crankcase is often integral with the cylinder block. In the models where it is a separate section, it generally consists of a plain rectangular frame with cross-ribbing to provide rigidity. Occasionally, the main bearings are held by a cross-ribbing in the crankcase, but more often they are hung from the bottom of the cylinder block. Access doors are provided at every cylinder to permit assembly and observation of the bearings.

Cylinders and cylinder liners. The cylinders were separate units on some older models, but in modern engines they are secured within the block which also contains passages for cooling water, lubricating oil to the bearings, and intake air. Each cylinder is secured in a separate compartment with crossbracing between the compartments.

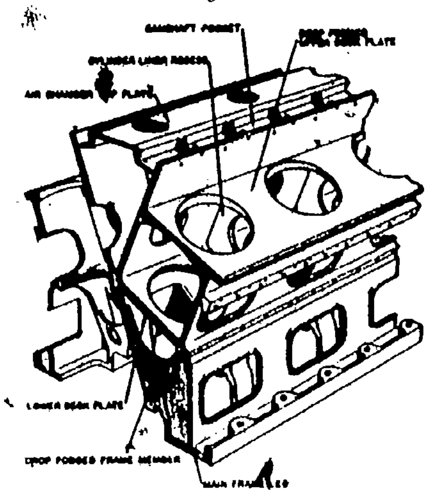


Fig 1-15. Sectional sketch of welded frame.

Dry liner. The dry liner is a simple sleeve with thin walls inserted in the cylinder block (fig 1-16). The cooling water moves about the outer cylinder and does not touch the liner. The liner is inserted in the cylinder with a light press fit. When worn or scored, it can easily be removed and replaced by a new liner.

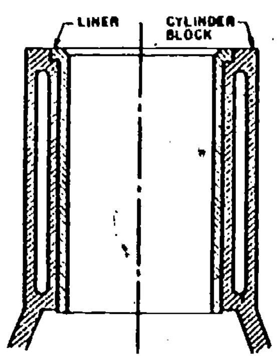


Fig 1-16. Dry liner.

Wet liner. The wet liner is a sleeve whose outer surface comes into direct contact with the cooling water (fig 1-17). The liner is normally sealed against water leakage at the top end by a gasket under the flange or a machined fit, and by rubber or neoprene rings around the lower end. The liner is free to expand or contract lengthwise. The thickness of the wall is such as to take the full working pressure of the gases.

Wet jacketed liner. The liner has its own cast-on or permanently shrunk-on jacket around the outside for the circulating cooling water (fig 1-18). The water is admitted into the bottom of the jacket and leaves through the top. This type is used mostly in two-stroke engines where it is difficult to obtain a watertight seal around the ports when using a wet liner because of the expansion of the liner due to heat during engine operation.

The cylinder liner must be made of material which will enable the piston and rings to move up and down with minimum friction and will give the least wear to both the liner and the piston parts. Cast iron is the usual material, although steel sleeves are sometimes used. A recent development has been a coating of 0.003- to 0.006- in electro-deposited porous chromium. The chromium resists wear, while the pores in the plating hold lubricating oil and maintain a lubrication film necessary to reduce friction and scoring.

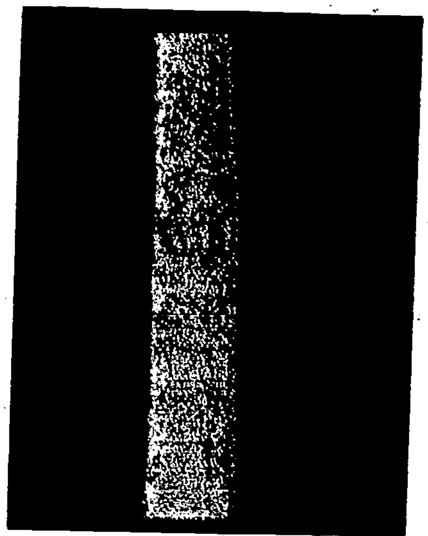


Fig 1-17. Wet liner.

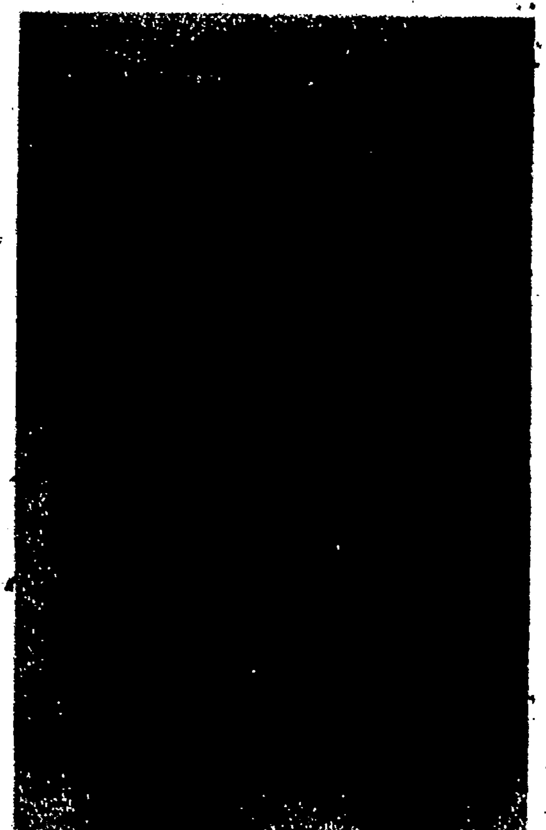


Fig 1-18 Water jacketed liner.

Cylinder heads. The cylinder head seals the combustion chamber and, in most engines, contains the valves and passages for intake and exhaust gases, the fuel injection nozzle, the air starting and relief valves, and passages for the cooling water from the cylinder jacket as shown in figure 1-18. It is a casting alloy iron, seldom made of aluminum. Because of the heat passing through the cylinder head from the combustion chamber and the exhaust passages, it has to be water-cooled. Such cooling prevents excessive temperatures which might crack it and which would interfere with the operation of the fuel injection nozzle and all other valves. The larger-bore engines have individual heads for each cylinder, while small-bore engines may have a single head covering all cylinders or pairs of cylinders.

Other parts. In older designs and in very large, low-speed diesel engines, the main and crankpin bearings consist of heavy cast-iron or cast-steel boxes with a thick, up to one-half inch, babbitt lining. Each bearing must be hand-scraped to a running fit with its journal. All modern diesel engines, regardless of size and speed, have precision bearings. Precision bearings are separate from the saddles and connecting rods. They consist of relatively thin steel, bronze, or brass shells with a lining of bearing metal which is generally 1/32-inch or less in thickness. The bearing metal may be one of several types which has proved satisfactory: lead-base babbitt, copper-lead, or cadmium-silver. Grooving is kept to the minimum, and wedge-type lubrication is used to the fullest extent.

X

Double-acting diesel engines require a crosshead and crosshead guide. The purpose of the crosshead guide is to take the side thrust coming from the angularity of the connecting rod which otherwise would be taken by the cylinder liner. The bearing surface of the crosshead guide is a flat slipper. Bearing loads are low and, with proper lubrication, an ordinary babbitt usually suffices as a bearing surface.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. The main stationary parts of the diesel engine are designed to maintain the working parts or moving parts in

   a. the crankcase.
   b. lubricating oil.
   c. proper relative positions.
   d. and out of the engine.

2. Describe the cylinder head. ____

____

____

____

Work Unit 1-8. THE MAIN MOVING PARTS OF THE DIESEL ENGINE

STATE THE MAIN FUNCTION OF THE CRANKSHAFT.

STATE THE PURPOSE OF THE PISTON.

IDENTIFY THREE PURPOSES OF PISTON RINGS.

IDENTIFY THE PURPOSE OF THE CONNECTING ROD.

IDENTIFY THE FUNCTION OF THE CAMSHAFT.

Crankshaft. The main function of the crankshaft is to transform the reciprocating motion of the pistons into rotary motion. The forces acting on a diesel engine crankshaft are high because of the high peak gas loads and the inertia forces of the moving parts. The main requirements are mechanical strength and lengthwise and torsional rigidity. The shafts have relatively large diameters and are supported by main bearings between each pair of cranks as shown in figure 1-19. At present, most crankshafts are forged, some from open-hearth but the majority from high-strength alloy steels. However, advances in understanding the stress distributions in diesel crankshafts are changing the situation. It has been found that the removal of metal at certain sections will redistribute the stresses and result in a stronger shaft. Casting permits easier application of such improved shapes. As a result, high-strength cast-iron and, in some cases, cast-steel crankshafts are being used in several modern diesel engines. Many forged steel shafts are surface-hardened by electrically heating the surface alone and quenching it with sprays of water. Surfacing of the journals with a harder metal, such as electro-deposited chromium which will take a smooth dense finish, is being considered to reduce shaft wear and improve bearing conditions. The shafts are drilled through the crank webs to admit pressure lubrication from the main bearings to the crankpins and wrist pins. In some cases, the oil is carried farther and is used for cooling the piston crowns.

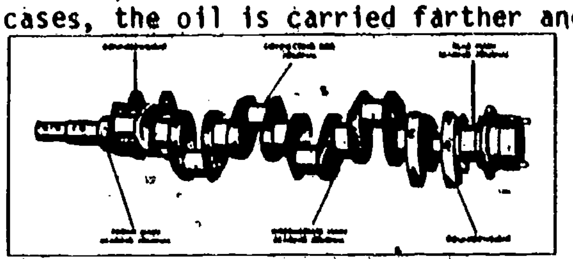


Fig 1-19. Crankshaft of a six-cylinder diesel engine.

Pistons. The purpose of the pistons is to transmit the energy of combustion through the connecting rods to the crankshaft. Pistons of single-acting engines usually are of the trunk-type. They must carry pressures varying from a slight vacuum to peak pressures of 1,000 to 1,200 psi with the resulting fluctuation in temperature setting up expansion stresses. They have to withstand high bearing and side-thrust loads from contact with the cylinder liner. Often, they have insufficient lubrication and have to resist wear on the outside cylindrical surface and in the ring grooves from the pressure and sliding action of the compression rings.

Pistons are usually cast because it is easier to provide satisfactory ribbing on the interior in a casting and still keep the weight low. However, forged pistons are used with some engines. Pistons of slow, heavy-duty engines, where strength is a more important factor than weight, are made of cast-iron. They may be cooled by water or oil circulated through baffles within the piston. Generally, they are cooled merely by air contact and with lubricating oil sprayed from the connecting rod cap under the crown of the piston. Pistons of higher speed engines have to be made as light as possible because of the effect of the mass on the bearing loads. For several years the tendency was to use aluminum pistons. Recently the trend has changed to pistons of cast-iron with very thin walls and cooled by lubricating oil circulated through the inside. The cast-iron has the advantage of having the same coefficient of expansion as the cylinder liner. This permits the use of smaller piston-to-liner clearances when cold without the danger of seizure when operating under a heavy load. Figure 1-20 shows a piston of a single-acting two-stroke engine, and figure 1-21 the piston of an opposed-piston two-stroke engine.

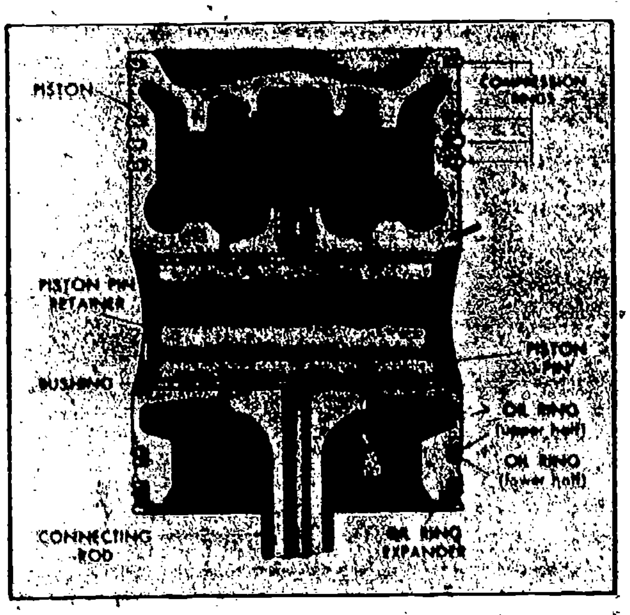


Fig 1-20. Piston of single-acting two-stroke engine.

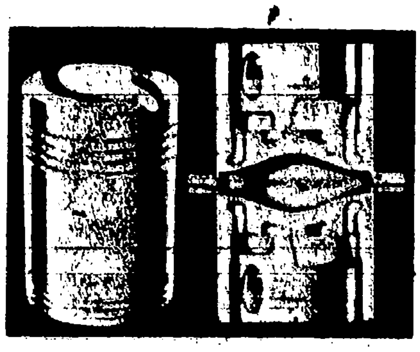


Fig 1-21. Piston of opposed-piston two-stroke engine.

Pistons for use in double-acting engines are built up of several sections and are closed at both ends because both ends are used for combustion chambers. They are cooled by oil entering and leaving through the piston rod.

Wrist pins. All of the load developed in the cylinder passes through the wrist or piston pin. It is the only connecting link between the piston and the connecting rod. Most wrist piston are supported at both ends by bronze bushings in the piston bosses and are maintained in place by caps which are fitted to each side of the piston. The connecting rod swings on a bronze bushing or needle bearing at the center of the pin. Such wrist pins are known as full-floating pins. In some engines the wrist pins are locked in the piston at the ends and are known as stationary pins. The disadvantage of this design is that all swinging movement is confined to the connecting rod bearing and there is some danger of less uniform wear. A third type, a semi-floating pin, is supported at both ends by bronze bushings in the piston bosses and is clamped in the middle in the connecting rod end.

Wrist-pin bearings operate under rather severe conditions. In addition to the great load from the piston pressure, there is the handicap of less efficient lubrication because the swinging motion does not help to form an oil film as much as the rotary motion of a journal. The wrist pin is made of a steel alloy of sufficient strength to carry the load and must have a fine-finish hardened surface to obtain good bearing action.

Piston rings. At the top of the piston are several compression rings which serve three purposes:

They seal the space between the piston and the liner thus preventing the high-pressure combustion gases, or the air charge during the compression stroke, from escaping down the liner.

They transmit heat from the piston to the water-cooled cylinder liner.

They damp out part of the fluctuations of the piston side thrust.

The oil-scraper or oil-control rings usually are located at the bottom end of the piston; in some engines they are place above the wrist pin. Small engines use one; larger engines use two or three oil-control rings to a piston. Their purpose is to scrape off most of the lubricating oil splashed upward by the crankshaft and connecting rod, thus reducing the amount of oil carried upward and burned in the combustion chamber. At the same time, they must allow sufficient oil to be carried to the upper part of the liner during the upstroke, so that there will be proper lubrication for the piston and the compression rings. Double-acting pistons have no oil-scraper rings as no oil is splashed on the liner.

Compression rings are made of gray cast-iron. Some types have special facings, such as a bronze insert, figure 1-22a, or a treated surface, to facilitate seating-in to the liner. To expedite the wearing in or seating of the ring face, some rings have a slight angle, 1/2 to 1 degree to the face, so that at first the contact area is very small, wear is rather fast, and later decreases.

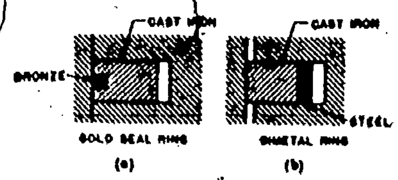


Fig 1-22. Compression piston rings.

The type of compression ring most widely used has a rectangular cross-section. The diameter of the ring is slightly larger than the cylinder bore, and part of the ring is cut away to permit it to go into the cylinder. The difference in diameters produces a pressure against the liner wall. The pressure of the upper rings is increased by the additional action of the gases. The combustion gases or compression air enter behind the ring through the vertical clearance which always exists between a ring and its groove and force the ring against the cylinder liner.

Some engines have compression rings with the bottom wall or both bottom and top walls beveled, making the ring thinner at the inside than on the outside diameter (fig 1-23). The groove in the piston is machined to the same shape. The gas pressure acting on the top wall, due to the beveled bottom surface, produces an additional force pressing the ring against the cylinder wall and helps to seal it. On the other hand, at each reversal of the side thrust of the piston, the ring slides slightly into the groove, is pressed against the upper groove wall, crushes the carbon which is deposited on it, and keeps the ring from sticking. Some engines use bi-metal rings, figure 1-22b, in which the cast-iron wearing face is brazed to a steel inner ring to obtain increased strength and to reduce the probability of ring fracture.

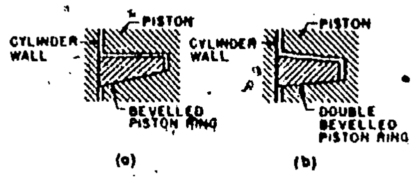


Fig 1-23. Bevelled piston rings.

The oil control rings have a narrow face so as to obtain a higher unit wall pressure and are often undercut to give a scraping edge. Some engines use flexible rings which follow the deviations in the cylinder liner bore. In some designs the ring has one, in others two narrow scraping edges, and the piston has rows of holes drilled-in it for draining the oil through the bottom of the ring grooves or through the lands between the grooves or both (figs 1-24a, b, and c). The oil scraped by the ring back into its groove and stop the scraping action. It is important that the drainage from the piston grooves be complete. Inadequate drainage means faulty scraping, higher lubricating oil consumption, and a darker color of the engine exhaust gases. Spring steel expanders are sometimes used behind the rings to increase the wall pressure and improve the scraping action.

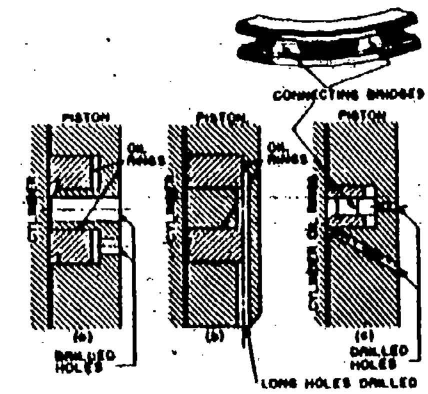


Fig 1-24. Oil control rings.

The gap between the ends of the compression rings when inserted cold in the cylinder must be sufficiently large so that, when the ring expands with the full piston temperature, the ends will not be pressed together and buckle the ring. The way in which the ends are cut varies. Most rings have the ends cut square, figure 1-25a. A design which makes gas blow-by more difficult has the ends cut at a 45^{0} angle, figure 1-25b. There are several designs of step-seal rings, figures 1-25c and 1-25d. However, there is little gained by this more complicated shape. Oil control rings in two-stroke engines are likely to catch the ring ends in the ports over which the rings slide because of the ring flexibility. To prevent this, sometimes the ends are notched and a pin is installed in the piston groove to hold the ring ends always in line with a bridge between the ports.

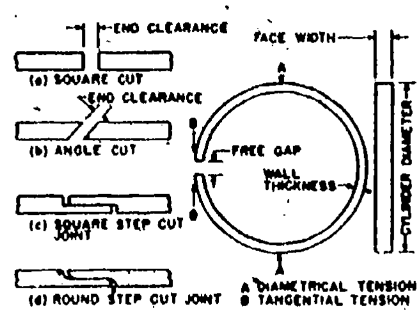


Fig 1-25. Piston rings.

Connecting rods. The purpose of the connecting rod is to transfer the up and down movement called reciprocating motion from the piston to the crankshaft, where it is transformed into rotary motion. Connecting rods used on military engines are mostly of the type used in automobiles, figure 1-26a. They have an eye at the small end for the piston pin bearing, a long shank, and a big-end opening which is split to take the crankpin precision bearing shells. The rods are forged of a high-strength alloy steel. Most connecting rods are rifle-drilled from the big end to the eye for oil flow from the crankshaft to the piston pin and, in some engines, to the piston crown to cool it. Very often the rod shank is H-shaped for maximum strength with minimum weight. Types of rods include: (1) the normal shape (fig 1-26a) used with only one cylinder to a crankpin of two cylinders, offset to the rods can operate side-by-side; (2) fork-and-blade rods in V-type engines (fig 1-26b) in which the big end of on rod has the normal shape while the rod of the piston in the opposite bank is widened and split into a fork shape straddling the first rod; (3) articulated connecting rods (fig 1-26c) in which one rod, the master rod, is of the conventional shape except that it has a projection off the shank with an eye to which the rod for the piston in the opposite bank, called the articulated or link rod, is attached. Finally, there is the rod type used on the pancake engine in which the big end of the rod consists of a short pad with the bearing metal directly on the rod. Four such rods are located radially around the outside of the pads to hold all four against the crankpin.

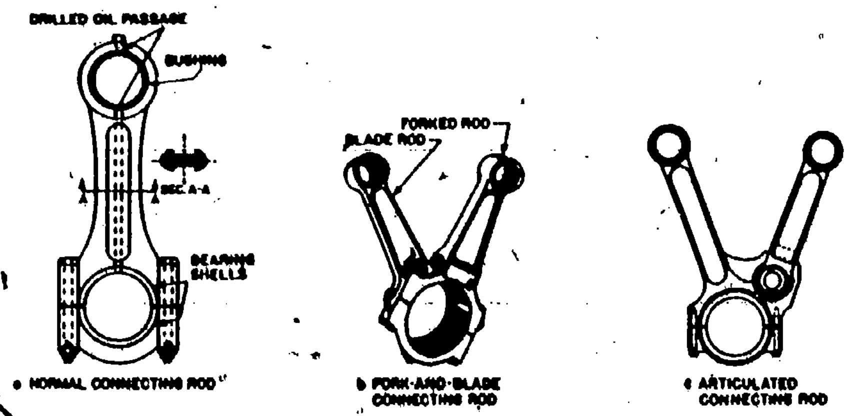


Fig 1-26. Connecting rods.

The connecting rod is connected to the piston by a piston pin. The pin passes through bearing surfaces in the piston and the connecting rod. The lower end of the connecting rod is attached to the crankpin. As the piston moves up and down in the cylinder, the upper end moves up and down but, because it is attached to the crankpin on the crankshaft, it must also move in a circle with the crankpin. Each movement of the piston from top to bottom is called a stroke. The piston takes two strokes as the crankshaft makes one complete revolution, an upstroke and a downstroke. When the piston is at the top of a stroke, it is said to be at top dead center (TDC). When the piston is at the bottom of a stroke, it is said to be at bottom dead center (BDC). These positions are called rock positions.

Camshaft (fig 1-27). In some engines the camshaft is a straight round shaft and the cams are separate pieces machined and keyed to the shaft. However, in most modern diesel engines the cams and the shaft are forged or cast in one piece. The function of the camshaft is to control the operation of the engine valves and, in some cases, the fuel injectors. This is usually accomplished through various intermediate parts such as push rods, cam followers, and rocker arms.

Fig 1-27. Camshaft

The camshaft is driven from the engine crankshaft by various means. Figure 1-28 shows three different types of camshaft drives. Figure 1-28a shows a drive by a train of straight spur or helical gears. Figure 1-28b shows a drive by two pairs of helical or screw gears and an intermediate vertical shaft. Figure 1-28c shows a chain drive; (m) is the camshaft, (g) is the camshaft sprocket, (d) is the crankshaft, and (p) is the crankshaft sprocket.

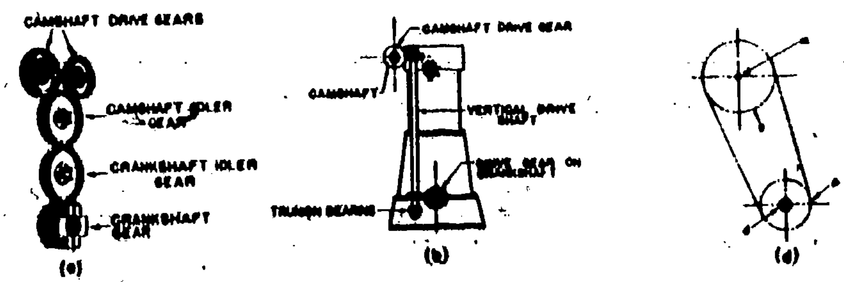


Fig 1-28. Types of camshaft drives.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. The main function of the crankshaft is to ____.

2. The purpose of the piston is to ____.

3. The three purposes of piston rings are to

   a. seal the space, provide weight and force, and spread the load.
   b. seal the space, damp out fluctuations, and increase vacuum.
   c. seal the space, transmit heat, and damp out fluctuations.
   d. increase vacuum, transmit heat, and spread the load.

4. The purpose of the connecting rod is to

   a. transmit the energy of combustion.
   b. transfer reciprocating motion.
   c. transmit heat to the liner.
   d. balance out the torque force.

5. The function of the camshaft is to

   a. control the operation of the engine valves.
   b. transmit energy from the piston.
   c. transfer energy to the final drives.
   d. change reciprocating motion into rotary motion.

Answers to Study Unit #1 Exercises

Work Unit 1-1.

1. The internal combustion engine is an engine from which work is obtained by the burning or combustion of fuel within the engine cylinders themselves. Fuel oil is injected into the cylinder and mixing occurs with air that is hot enough to ignite the mixture.
2. a. High reliability in operation
   b. High power per pound of engine
   c. Low fuel consumption per horsepower per hour
   d. Low fire hazard
   e. High sustained torque
3. a. Higher cost
   b. Peak horsepower reached at a lower speed
   c. Heavier weight per horsepower pound than spark-ignition engine

Work Unit 1-2.

1. b.
2. d.
3. c.
4. a.
5. c.
6. d.
7. b.

Work Unit 1-3.

1. c.
2. a.
3. c.
4. b.
5. a. and c.
6. b.
7. b.

Work Unit 1-4.

1. c.
2. b.
3. d.
4. c.
5. a.
6. c.

Work Unit 1-5.

1. Work is defined as being the movement of a body against an opposing force.
2. the energy of movement of the tank is increased.
3. the rate of work.
4. c.
5. b.
6. d.
7. b.

Work Unit 1-6.

1. c.
2. Friction loss
   Mechanical efficiency
   Thermal efficiency

Work Unit 1-7.

1. c.
2. The cylinder head seals the combustion chamber and usually contains the valves and passages for intake and exhaust gases, the fuel injection nozzle, the air starting and relief valves, and passages for the cooling water.

Work Unit 1-8.

1. transform the reciprocating motion of the pistons into rotary motion.
2. transmit the energy of combustion through the connecting rods to the crankshaft.
3. c.
4. b.
5. a.

PRINCIPLES, MECHANICS, AND PERFORMANCE OF THE DIESEL ENGINE

STUDY UNIT OBJECTIVE: WITHOUT THE AID OF REFERENCES, YOU WILL IDENTIFY THE OPERATING CHARACTERISTICS AND PRINCIPLES OF THE DIESEL ENGINE. IN ADDITION, YOU WILL IDENTIFY SCAVENGING, PISTON AND CRANK TRAVEL, COMBUSTION AND IGNITION DELAY, IGNITION AND TIMING, AND THE CHARACTERISTICS OF SUPERCHARGING.

Work Unit 2-1. OPERATING PRINCIPLES IN THE DIESEL ENGINE

IDENTIFY THE DIFFERENCE BETWEEN THE TWO AND FOUR STROKE CYCLE ENGINE.

EXPLAIN THE COMPRESSION RATIO OF A DIESEL ENGINE.

IDENTIFY TWO METHODS OF BURNING FUEL WITHIN THE CYLINDER.

A series of events which reoccur regularly and in the same sequence is known as a cycle. The cyclic sequence of events in a diesel engine is (1) filling of the engine cylinder with fresh air (intake); (2) compression of the air charge in order to raise its pressure and temperature needed to ignite and burn the fuel efficiently; (3) combustion of the fuel and expansion of the hot gases; and (4) emptying the cylinder of the burned gases by exhausting them. When these four events are completed, the cycle is repeated.

Four-stroke cycle. When these four events take place during four strokes of the piston, the cycle is called a four-stroke cycle. The positions of the piston when it is nearest to the cylinder head and farthest away form it are called top and bottom dead center respectively, indicated as TDC and BDC. The reason for this designation is that at these positions the connecting-rod center-line coincides with the crank-throw center-line and the piston cannot be moved by gas pressure acting upon its surface. The force to keep the piston going up and down must come from the rotating crank acting through the connecting rod. The four main events in a four-stroke cycle are shown in figure 2-1.

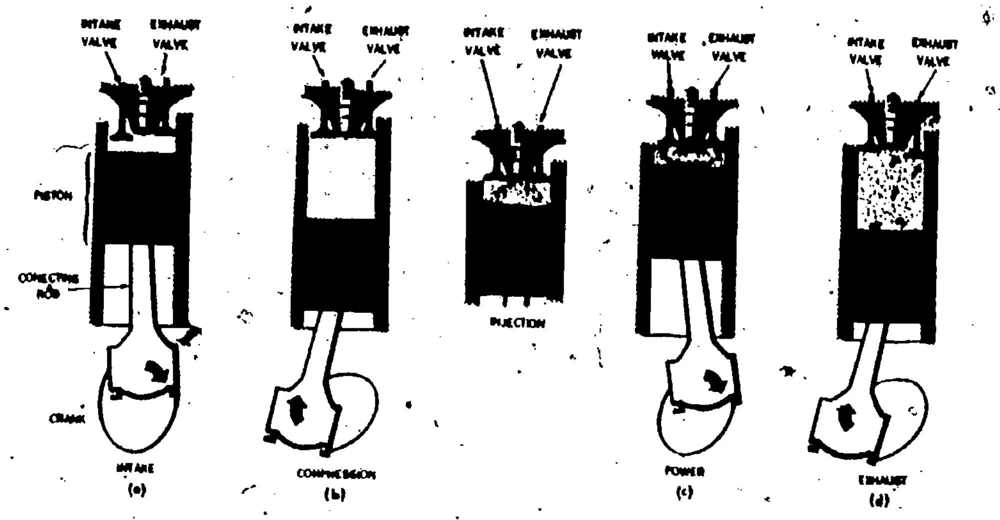


Fig 2-1. Four-stroke-cycle diesel engine.

During the first intake stroke (fig 2-1a), the piston moves downward by the connecting rod, the lower end of which is moved by the crank. The piston motion creates a vacuum in the cylinder as it moves downward. Outside air is drawn into the cylinder through the intake valve which opens at about the beginning of the intake stroke and stays open until the piston reaches bottom dead center (BDC).

When the piston has passed BDC, the second or compression stroke begins (fig 2-1b). The intake valve closes and the upward motion of the piston pushed by the crank and the connecting rod begins to compress the air charge in the cylinder.

Shortly before the piston reaches top dead center (TDC), liquid fuel in a finely atomized spray is admitted into the cylinder containing hot compressed air. The fuel is ignited by the heat of the air compressed in the cylinder and burns during the first part of the downward piston stroke. During this downward or third stroke called working or power stroke (fig 2-1c), the hot gases, whose pressure was considerably increased by the combustion of the fuel charge, force the piston downward and expand due to the increasing cylinder volume.

Shortly before the piston reaches the bottom dead center, the exhaust valve opens (fig 2-1d), and the hot products of the combustion, having a relatively high pressure in spite of the previous expansion, begin to rush out through the exhaust ports into the outside atmosphere. During the following fourth or exhaust stroke, the piston moves upward, pushed by the crank and connecting rod, expelling the remaining products of combustion. Near top center the exhaust valve is closed, the intake valve is opened, and the whole cycle starts again. As can be seen, the four strokes require two engine revolutions. Thus, in a four-stroke-cycle engine, one power stroke obtained for every two engine revolutions. Actually, the dividing points between the four main events do not come at the very beginning ~~and~~ end of the corresponding strokes. The differences are smaller in low-speed engines and increased as the engine speed increases. The intake valve is opened 10 to 25 crank-angle degrees before top dead center and is closed from 25 to 45 crank-angle degrees after bottom center. The fuel injection starts some 7 to 26 degrees before TDC. In order to release the exhaust gases in proper time, the exhaust valve begins to open 30 to 60 degrees before BDC and close 10 to 20 degrees after TDC.

Two-stroke-cycle events. A two-stroke is completed in two strokes or one revolution of the crankshaft, whereas a four-stroke cycle is completed in four strokes or two revolutions of the crankshaft. In other words as two-stroke-cycle engine completes the four events in a cycle in two strokes of the piston. On stroke is down and one is up. Each up and down movement of the piston will turn the crankshaft once. So a two-stroke-cycle provides power to the crankshaft on each revolution or turn. Compare this to the four-stroke cycle engine which will have two up and two down movements but only one of those movements will be a power stroke. The main mechanical difference between the two-stroke and four-stroke engine is the method of removing the burned gases and filling the cylinder with a fresh charge of air. In a four-stroke engine these operations are performed by the engine piston during the exhaust and suction strokes. In a two-stroke engine these operations are performed near the bottom dead center by means of a seperate air pump or blower.

The compression, combustion, and expansion events do not differ from those of a four-stroke engine. The filling of the cylinder, called scavenging, with a fresh charge may be explained as follows: when the piston has travelled 80 to 85 percent of its expansion stroke, exhaust valves e, e (fig 2-2a), are opened, the exhaust gases are released and begin to escape from the cylinder. The piston continues to move toward the bottom center and soon uncovers ports s, s, through which slightly compressed air begins to enter the cylinder. This air, having a slightly higher pressure than the hot gases in the cylinder, pumps out the hot gases through valves e, e (fig 2-2b). This operation is called scavenging. The air admitted is called scavenge air and the air admittance ports, scavenge ports. About the time when the piston on its upward stroke close ports s, s, the exhaust valves e, e are also closed (fig 2-2c), and the compression stroke begins.

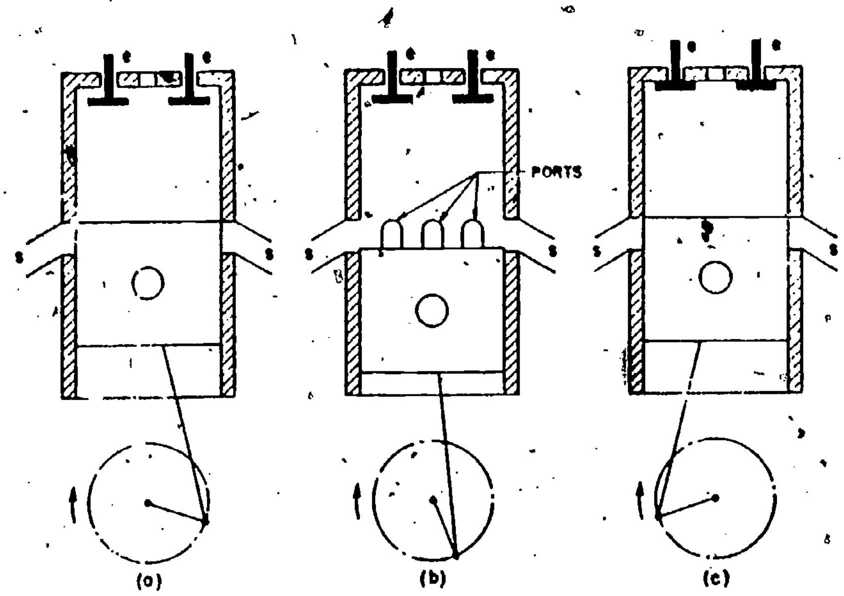


Fig 2-2. Scavenging of a two-stroke engine.

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The advantage of a two-stroke operation is the elimination of one scavenging and one charging stroke required in four-stroke-cycle operation. Thus, the cylinder delivers one power stroke for every revolution of the engine as compared with one power stroke for every two revolutions in a four-stroke-cycle engine. It might appear that a two-stroke-cycle engine could produce twice as much horsepower as a four-stroke-cycle engine of the same size operating at the same speed. However, this is not the case. In order to scavenge the burned gases at the end of the power stroke and during the time both the intake and exhaust ports are open, the fresh air rushes into and through the cylinder. A portion of the fresh air mingles with the burned gases and is carried out the exhaust port. Also, due to a much shorter period the intake port is open (as compared to the period intake valve in a four-stroke-cycle engine is open), a relatively smaller amount or air is admitted. Hence, with less air, less power per power stroke is produced as compared to the power produced in a four-stroke-cycle engine of like size operating at the same speed and with other conditions being the same. To increase the amount of air entering the cylinder, auxiliary devices are used with two-stroke-cycle engines.

These advantages are very important, an hence two-stroke engines are used in the Marine Corps much more often than four-stroke engines. A disadvantage of two-stroke operation is higher working temperatures of the piston and cylinder head due to combustion occurring every revolution and resulting in distortion of these and related parts.

Compression. There are two reasons for compressing the air charge during the second or compression stroke. The first is to raise the thermal or overall efficiency of the engine by increasing the final temperature of combustion. This applies to all internal-combustion engines both of the spark-ignition type as well as the so-called diesel type. The second is to increase the temperature of the air charge so that, when the finely atomized fuel is injected into the hot compressed air, the fuel will ignite and begin to burn without any outside source of ignition such as the spark plug used in automobile engines.

The compression ratio of an engine (fig 2-3) is the volume in one cylinder with the piston at bottom dead center (displacement volume plus clearance volume) divided by the volume with the piston at top dead center (clearance volume). This figure indicates the actual amount that the air drawn into the cylinder will be compressed. For example, suppose that an engine cylinder has an air volume of 60 cubic inches with piston at bottom dead center and a volume of 10 cubic inches with the piston at top dead center. This gives a compression ratio of 60 divides by 10 or 6:1. That is, the air is compressed from 60 to 10 cubic inches, or to 1/6 of its orginal volume, on the compression stroke. Compression ratio is designated by r. Compression ratio = volume at bottom dead center (V_1) - volume at top center (V_2) or

$$r = V_1 \div V_2.$$

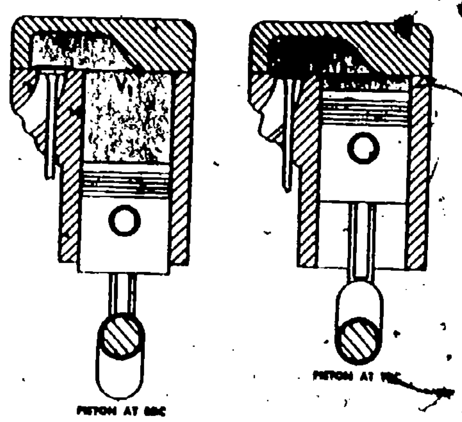


Fig 2-3. Compression ratio is ratio between "V_1" and "V_2".

The volume V_2 is called the compression or combustion space. The volume V_1 is equal to the sum of the piston displacement of one cylinder plus the combustion spaces.

Diesel engines use compression ratios of 12:1 up to about 22:1. Theoretically, the higher the compression ration, the higher the thermal efficiency of the engine an the lower its fuel consumption. As the compression ratio is increased, the air drawn into the cylinder is compressed into a smaller space. This means a higher initial pressure at the start of the power stroke. It also means that the burning gases can expand a greater amount. Thus, there are higher pressures for a longer period on the power stroke. More power is obtained with each power stroke. Therefore, increasing compression ratio increases the power output of an engine. Racing-car builders shave cylinder heads so as to reduce the volume of the combustion chambers and thereby increase ratios. By this one act, the power output of an engine can be increased several horsepower. However, an increase of the compression ratio is accompanied by higher gas pressures and combustion temperatures. This causes stresses and pressures in various engine parts. To counteract these ill effects, stronger heavier parts are required which excessively increase the weight of an engine. Higher temperatures and pressures also increase the wear and tear of an engine and thus decrease it reliability. One way to avoid problems brought about by increasing compression ratios is to find a fuel that will not cause difficulty from combustion.

Combustion. There are two distinctly different methods of burning the fuel in an engine cylinder: (a) at a constant volume and (b) at a constant pressure. Combustion at constant volume means that during combustion the volume does not change and that all the heat energy developed by the fuel goes into an increase of the gas temperature and pressure. In the case of an engine combustion at constant volume means that combustion proceeds at such high rate that the piston has practically no time to move during combustion. Such a combustion is obtained when the piston is passing top center. The advantage of this method of fuel combustion is a high thermal efficiency. Its disadvantage is a very sudden pressure increase and resulting noisiness of the engine. Such combustion comes close to that of a spark-ignition gasoline engine.

Combustion at constant pressure means that during combustion the temperature increases at such a rate that the resulting increase of pressure is just enough to counteract the influence of the increasing volume, and the pressure does not change. The heat energy developed by the fuel goes partly into an increase of the gas temperature and partly into performing outside work. In the case of an engine with constant pressure combustion, the fuel is burned so that the pressure attained at the end of the compression stroke is maintained during the greater part of the combustion event. Such a combustion was used in the original low-speed, air-injection diesel engine. Its advantage is a smoothly running engine producing a more even torque due to the extended combustion pressure. However, it is not suitable for high-speed diesel engines.

High-speed diesel engines of the present operate on a cycle which is approximately a combination of the above two methods. Part of the fuel is burned rapidly almost at a constant volume near the top dead center. The rest is burned while the piston begins to move away from the top center. However, the pressure does not remain constant, but usually increases and then decreases. In general, this cycle more nearly resembles the constant-volume combustion cycle than the cycle of the original diesel engines. Its advantage is high efficiency with low fuel consumption. Its drawback is in the difficulty of preventing rough and noisy operation of the engine.

EXERCISE: Answer the following questions and check your responses against those listed at the end of thiss study unit.

1. A two-stroke cycle is completed in _______ revolutions of the crankshaft.

   a. one
   b. two
   c. three
   d. four

2. A four-stroke cycle is completed in _______ revolutions of the crankshaft.

   a. one
   b. two
   c. three
   d. four

3. The filling of the cylinder with a fresh air charge is called

   a. pressure.
   b. scavenging.
   c. replenishment.
   d. intake stroke.

4. A series of events that reoccur regularly and in the same sequence is known as a

   a. stroke.
   b. crank.
   c. cycle.
   d. power stroke.

5. The four events that take place in the operation of the diesel engine are the intake of fresh air, combustion of the fuel, ____________ and

   a. compression and release.
   b. exhaust and compression.
   c. exhaust and detonation.
   d. detonation and compression.

6. Shortly before the piston reaches bottom dead center in a four-stroke-cycle engine, on the third stroke the

   a. fuel is injected into the cylinder.
   b. exhaust valve closes.
   D. exhaust value opens.
   c. outside air is being drawn into the cylinder.

7. The major advantage of the two-stroke cycle engine is that

   a. it reaches maximum speed quicker.
   b. it eliminates the extra up and down stroke.
   c. the pressure in the cylinder is less.
   d. it shuts down much more quickly.

8. Explain the compression ratio of a diesel engine.

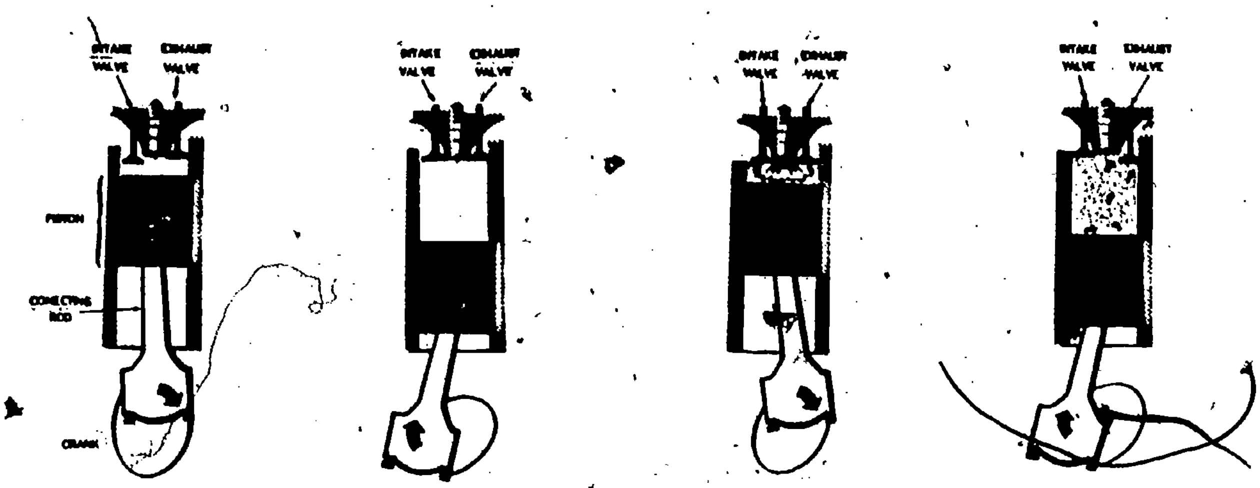
   ____

9. Explain why either a high or low compression ratio is better for use in a diesel engine.

   ____

10. The two methods of burning the fuel in the engine cylinder are ____________ or ____________.

11. From the illustration below identify each of the four-stroke cycles shown. Place your answer in the spaces provided.



a. ____________ b. ____________ c. ____________ d. ____________

Work Unit 2-2. THE DIFFERENT METHODS OF SCAVENGING

GIVEN A SPECIFIC SITUATION, IDENTIFY CROSS-FLOW SCAVENGING.

GIVEN A SPECIFIC SITUATION, IDENTIFY RETURN-FLOW SCAVENGING.

GIVEN A SPECIFIC SITUATION, IDENTIFY UNIFLOW SCAVENGING.

GIVEN A SPECIFIC SITUATION, IDENTIFY TWO METHODS OF PROVIDING AIR PRESSURE TO THE CYLINDER.

General. Figure 2-2 illustrates one of several methods of cylinder scavenging. In some engines the exhaust gases are let out through ports, uncovered by the piston the same as the scavenge ports. There are three basically different methods of scavenging: direct or crossflow scavenging (fig 2-4), loop or return-flow scavenging (fig 2-5), and uniflow scavenging (fig 2-2).

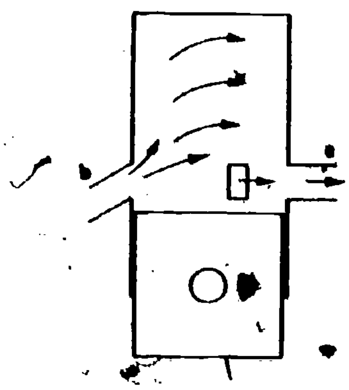


Fig 2-4. Direct cross-flow scavenging

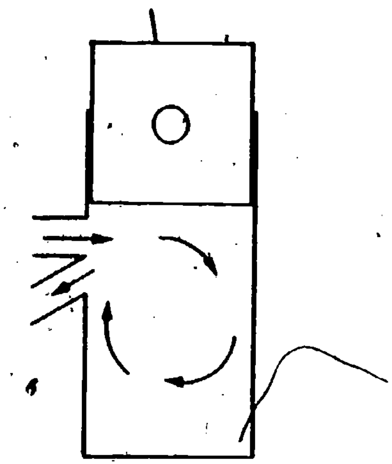


Fig 2-5. Return or loop scavenging.

a. Direct or cross-flow. In direct or cross-flow scavenging (fig 2-4) the piston uncovers first the exhaust ports, e, and releases the pressure; going down farther, the piston uncovers the scavenge ports, b, and begins to admit slightly compressed air whose stream is directed mainly upward as indicated by the arrows, and thus pushes out the exhaust gases through ports e. Having passed the dead center, the piston first closes the scavenge ports and soon afterward the exhaust ports. The fact that the exhaust ports are closed after the scavenge ports, permits some of the air charge to escape from the cylinder. This is a disadvantage of the scavenge method. However, it has the definite advantage of simplicity of construction and maintenance due to absence of valves which must be kept tight.

b. Loop or return-flow. Loop or return-flow scavenging (fig 2-5) is similiar to cross-flow scavenging in the sequence of the port opening. The direction of air flow is different as indicated by the arrows. Its advantage is that the bulky scavenge-air and exhaust-gas receiver are located on one side of the cylinder, thus giving better accessibility. This method is particularly suitable for double-acting engines, because the operation of the exhaust valves (fig 2-5) for the lower combustion space becomes very complicated. When used for double-action engines (fig 2-6), the scheme is improved by the introduction of rotary exhaust valves, r. During the release of the exhaust gases, valve r is open but is being closed when the piston on the return stroke covers the scavenge ports. This arrangement eliminates the escape of air charge during the beginning of the compression stroke when the exhaust ports are not yet covered. Some time after the exhaust ports are covered by the piston, the rotary valve is opened, getting it ready for the next cycle. As shown in figure 2-6, the length of the piston is exactly equal to the length of the stroke. This is done in order to control the exhaust and scavenge events alternately by the upper and lower edges of the piston.

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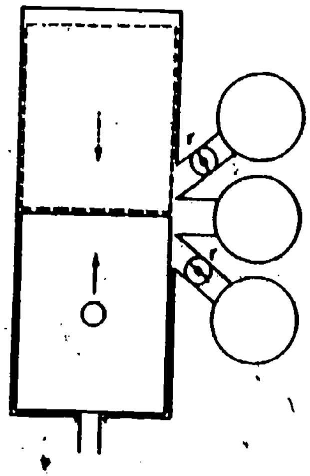

Fig 2-6. Return scavenging in a double-acting engine.

c. Uniflow scavenging. The opposed-piston method is shown in figure 2-7. The lower piston controls the exhaust ports, the upper one the scavenge ports. To obtain the necessary preliminary release of the exhaust gases or an uncovering of the exhaust ports ahead of the scavenge ports, the crank of the lower crankshaft is advanced in respect to the crank of the upper crankshaft. The lower crankshaft leads the upper crank by some 10 to 15 degrees. In this way the exhaust ports are opened first (fig 2-7a). When the pressure is sufficiently lowered, the scavenge ports are uncovered (fig 2-7b), and scavenging begins to take place. After the exhaust ports are closed, more air is admitted (fig 2-7c) until the scavenge ports are also covered and compression of the air charge takes place (fig 2-7d). Just before the pistons reach the point at which they are closest together, fuel is injected, ignited, and burns while the expansion stroke starts (fig 2-7e). The power delivered by the upper pistons to the upper crankshaft is transmitted to the lower main crankshaft by means of an intermediate vertical shaft and two pairs of bevel gears. The advantages of this method are:

(1) Very efficient scavenging of the cylinder and hence greater power is developed.

(2) Absence of valves and valve-operating gears.

(3) Absence of cylinder heads which are complicated castings and a source of trouble in engine operation.

(4) Good accessibility for the inspection and repair of parts, with the exception of the lower crankshaft.

The two scavenge methods shown in figures 2-3 and 2-7 are classified as uniflow scavenging. In both cases, the exhaust gases and scavenging air are flowing in the same direction with less chance for formation of turbulences wich are unavoidable with cross- and return-flow scavenging.

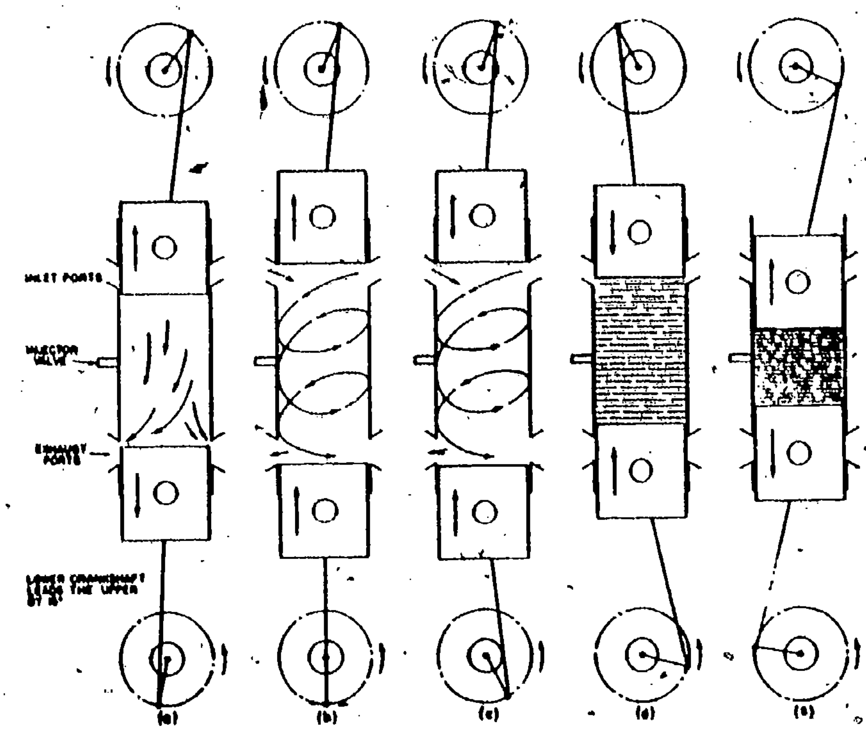

Fig 2-7. Opposed-piston engine operation.

There are basically two methods of providing air pressure to the cylinder. These are by the compression of air in the crankcase and by using a pump.

Compression of air in the crankcase takes place through a check valve. The descending piston creates a back pressure on its expansion stroke. This movement causes the check valve to close. This method produces little air pressure and is generally used only on The two-stroke cycle engine.

The pumps that are used come in may varieties but they all fall into a general category of being either blowers or superchargers. These will be covered later within this study unit.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

Identification (items 1-3): Identify the three methods of scavenging as given in the situations provided below.

1. The piston uncovers first the exhaust ports, and releases the pressure. Going down farther, the piston uncovers the scavenge ports and begins to admit slightly compressed air, whose stream is directed mainly upward, an thus pushes out the exhaust gases.

   a. Return-flow scavenging
   b. Uniflow scavenging
   c. Cross-flow scavenging

2. The sequence of the port openings is the same as in the first situation, but the air flow is different. The air port and exhaust gas port are located on the same side of the cylinder, thus giving better accessibility.

   a. Return-flow scavenging
   b. Uni-flow scavenging
   c. Cross-flow scavenging

3. The lower pistons control the exhaust ports and the upper one the scavenge ports. In order to obtain the proper sequence for intake and exhaust, the lower crankshaft will precede the upper crankshaft by 10-15 degrees.

   a. Return-flow scavenging
   b. Uni-flow scavenging
   c. Cross-flow scavenging

4. The two methods of providing air pressure to the cylinder are by the use of a

   a. pump and a blower.
   b. blower and a supercharger.
   c. pump and compression of air in the crankcase.
   d. supercharger and compression of air in the cylinder.

Work Unit 2-3. THE DIFFERENCES IN A COMPARISON BETWEEN THE GASOLINE AND DIESEL ENGINES

STATE MECHANICAL SIMILARITIES BETWEEN GASOLINE AND DIESEL ENGINES.

STATE THE MAIN DIFFERENCES IN PRINCIPLES OF OPERATION BETWEEN GASOLINE AND DIESEL ENGINES.

General mechanical construction. The diesel engine is mechanically similar to the gasoline engine but is heavier in construction. Both engine types use air, fuel, compression, and ignition. Intake, compression, power, and exhaust occur in the same sequence. Arrangements or pistons, connecting rods, and crankshafts are similiar. Both are internal combustion engines; that is, they extract energy from a fuel-air mixture by burning the mixture inside the engine.

Fuel intake and ignition of fuel-air mixture. In principles of operation, the main differences between gasoline and diesel engines (fig 2-8) are the two different methods of introducing the fuel into the cylinder and of igniting the fuel-air mixture. Fuel and air are mixed together before they enter the cylinder of a gasoline engine. The mixture is compressed by the upstroke of the piston and is ignited within the cylinder by a spark plug. (Devices other than spark plugs, such as "firing tubes," are sometimes used). Air alone enters the cylinder of a diesel engine. The air is compressed by the upstroke of the piston and the diesel fuel is injected into the combustion chamber near the top of the upstroke (compression stroke). The air becomes greatly heated during compression and the diesel fuel ignites and burns as it is injected into the heated air. No spark plug is used in the diesel engine; ignition is by contact of the fuel with the heated air, although "glow plugs" are used in some models of diesel engines to assist in starting. Pressure developed by the compression stroke is much greater in the diesel engine. For each pound of pressure exerted on the air, there will be a temperature increase of about 20°F. At the top of the compression stroke (when pressure is highest), the temperature in the chamber will be about 1,000°F. this heat ignites the fuel almost as soon as it is injected into the cylinder. The piston, actuated by the expansion of burning gases, then moves down on the power stroke. In a gasoline engine, the heat from compression is not enough to ignite the fuel-air mixture and a spark plug is necessary.

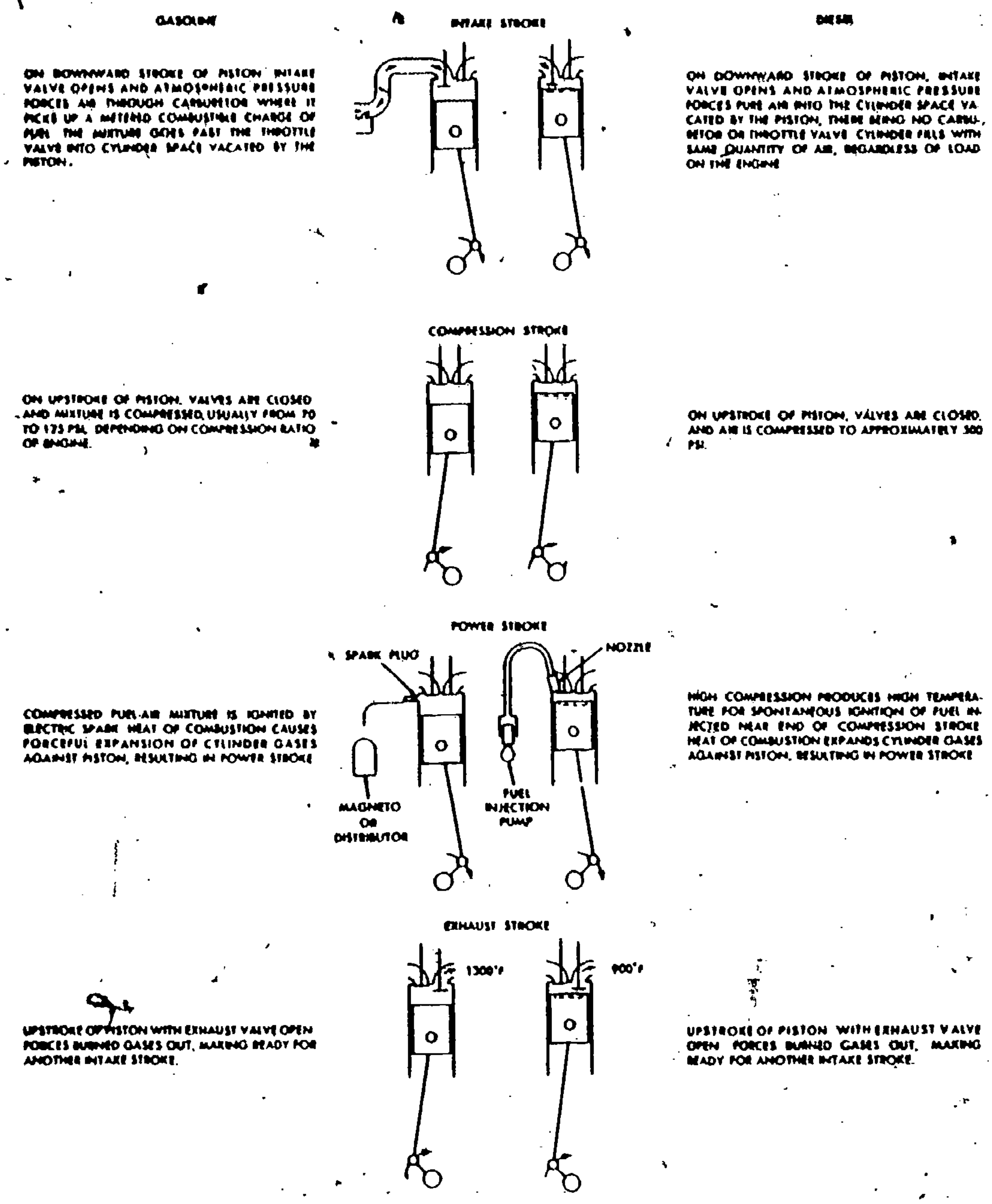

Fig 2-8. Comparison of sequence of events in diesel and gasoline engines.

Control of speed and power. The speed and the power output of diesel engines are controlled by the quantity of fuel injected into the cylinder. This is opposed to the common gasoline engine which controls speed and power output by limiting the amount of air admitted to the carburetor. The difference is that the diesel engine controls the quantity of fuel, whereas the gasoline engine regulates the quantity of air. In the diesel engine, a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder on each intake stroke. Because the quantity of air is constant, the amount of fuel injected determines power output and speed. As long as the amount of fuel injected is below the maximum established by the manufacturer in designing the engine, there is always enough air in the cylinder for complete combustion. A device in the carburetor of the gasoline engine controls the amount of air admitted. The amount of air and its velocity, in turn, control the quantity of fuel that is picked up and mixed with air to be admitted to the cylinder. The amount of mixture available for combustion determines power output and speed. It is apparent, therefore, that the controlling factor is the quantity and velocity of air passing through the carburetor.

Combustion process. In the diesel engine, there is continuous combustion during the entire length of the power stroke. Pressure resulting from combustion remains approximately constant throughout the stroke. In the gasoline engine, however, combustion is completed while the piston is at the upper part of its travel. This means that the volume of the mixture stays about the same during most of the combustion process. When the piston does move down and the volume increases, there is little additional combustion to maintain pressure. Because of these facts, the cycle of the gasoline engine is often referred to as having constant-volume combustion while the diesel cycle is said to have constant-pressure combustion.

EXERCISE: Answer the following questions and check your responses against those listed at he end of this study unit.

1. The designs of the gasoline diesel engines are similar, but the ______________ is heavier in weight.

2. Both engine types use air, fuel, ignition, and ______________.

3. In both engines, intake, compression, power, and exhaust occur in ______________.

4. There are similarities in the arrangement of pistons, connecting rods, and ______________.

5. The control and speed of the ______________ engine is controlled by the quantity of fuel injected into the cylinder.

6. The control and speed of the ______________ engine is controlled by the amount of air provided to the carburetor.

7. Combustion is completed while the piston is at its uppermost point of travel in the ______________ engine.

8. Combustion continues for the length of the power stroke in the ______________ engine.

Work Unit 2-4. THE MECHANICS OF PISTON AND CRANK TRAVEL

EXPLAIN THE MOVEMENT OF THE PISTON.

IDENTIFY INTERTIA.

IDENTIFY ONE FUNCTION OF THE FLYWHEEL.

The movements of the piston are transmitted to the crankshaft by means of a connecting rod. These three members (piston, connecting rod, and crankshaft) transformed the up and down motion of the piston, called reciprocating motion, into rotary motion. For all practical purposes, the travel of the crankpin can be considered to be a uniform motion along a circle described with the radius equal to the length of the crank throw.

While the crankpin travel is uniform and has a constant velocity, the piston travel is not uniform and the piston speed constantly varies. At each dead center, the piston comes to a standstill; its speed becomes zero. As the piston begins to move, the speed gradually increases and reaches a maximum when the angle (a) (fig 2-9) formed by the crank and the cylinder centerline is equal to 90°. After the position, the piston speed begins to decrease and at the dead center again becomes zero.

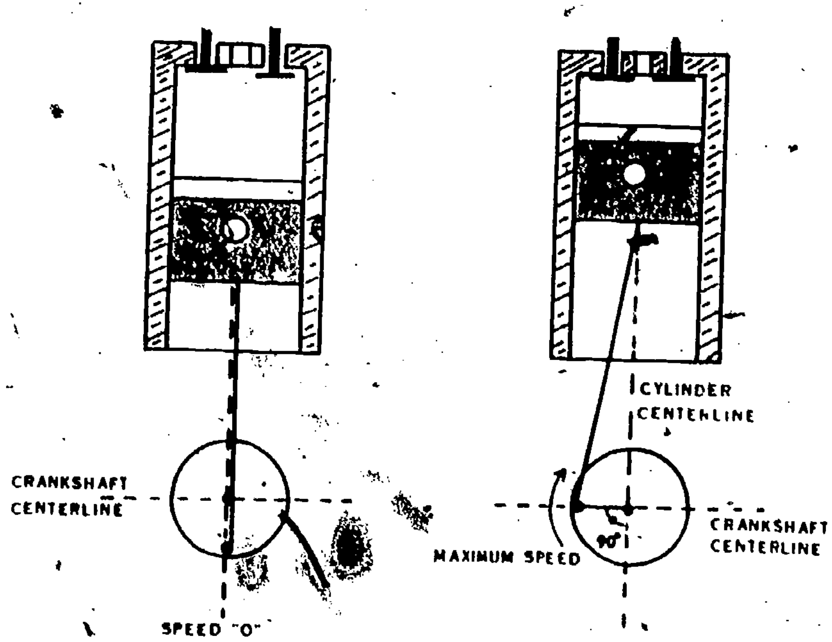

Fig 2-9. Piston speed.

Inertia is the resistance of a body to change of motion. It is the tendency of an object to remain stationary, or to continue to move if it is moving. Inertial as such cannot be measured directly; however, it can be expressed in terms of the force which must be applied to a body in order to change its velocity. As with any force, inertial forces are expressed in pounds. Since the change of velocity is called acceleration, inertia may be defined as being equal to that force which must be applied to a body in order to impart to it a certain acceleration, either to speed it up or to slow it down as the case may be. The force of inertia of a body depends upon the rate of change of its velocity. The shorter the time during which a change takes place, the higher the required acceleration and the greater the force of inertia becomes.

A flywheel stores up energy during the working stroke and gives it back during the rest of the cycle. It serves four main purposes: (1) to keep the variations in speed within desired limits at all loads; (2) to limit the instantaneous rise or fall in speed during sudden changes of load; (3) to carry the pistons over the compression pressure when running at low or idling speed; (4) to help bring the engine up to speed when starting.

In multicylinder engines, the torque at the end of the crankshaft becomes more uniform, and the required weight of the flywheel becomes very small. The cranks, crankpins, and large ends of the connecting rods have considerable weight and exert the same influence as a flywheel. Therefore, in some large, multicylinder, marine diesel engines, flywheels are not necessary and hence are not used.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Explain the movement of the piston.

____

____

2. The resistance of a body to a change in motion is called

a. stationary.
b. inertia.
c. tendency.
d. acceleration.

3. Which of the following is a function of the flywheel?

a. To store energy throughout the cycles like a battery
b. To illuminate the limits of torque rise
c. To regulate the combustion of the fuel
d. To help bring the engine up to speed when starting

Work Unit 2-5. COMBUSTION AND IGNITION DELAY

IDENTIFY IGNITION DELAY.

DESCRIBE COMBUSTION IN THE DIESEL ENGINE.

Regardless of how finely atomized the fuel injected into the combustion space of the cylinder filled with hot air is, it takes some time before the relatively cold fuel spray becomes heated and vaporized enough to ignite and start burning. This time element is rather small when expressed as a fraction of a second, but quite noticeable when referred to as the number of degrees the crank travels between the moment when the fuel is introduced into the cylinder and when the first particles of it are ignited. This time element is called ignition delay or ignition lag and amounts to several degrees of crank travel.

After ignition has started, the fuel, which by this time has already been introduced in the cylinder, will burn. This combustion usually is accompanied by a rather quick pressure rise. In the mean time, the pump continues to deliver fuel, and during the third period of combustion, the fuel burns more or less as it is introduced. However, since the supply of oxygen in the air charge gradually is being used up by the combustion, the fuel particles introduced toward the end of the injection have more difficulty meeting the necessary particles of oxygen. Combustion is consequently retarded and, when injection is terminated, some unburned fuel is still present in the cylinder and continues burn. The piston by this time has moved away form the dead center and its speed increases; therefore, the pressure begins to fall in spite of additional heat being developed by the rest of the fuel.

The whole procedure can be illustrated by the pressure-crank angle diagram (fig 2-10). Point A is the start of the injection, point B is where ignition occurs, and period A-B is ignition delay. Up to point C the pressure rises very fast. Period B-C corresponds to burning of the fuel introduced up to this point and represents the first or uncontrolled combustion. From C to D the fuel burns more or less as it is introduced, giving the second or controlled combustion. From point D the fuel burns with the pressure dropping - this is after-burning. After-burning may continue through a considerable distance of the expansion stroke.

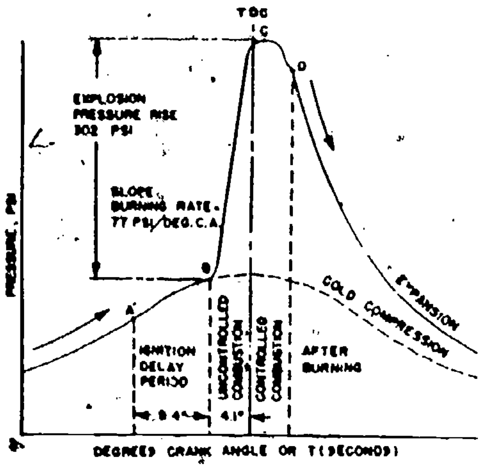

Fig 2-10. Pressure-time diagram of combustion process.

The highest thermal efficiency is obtained from the fuel which burns at the highest compression ratio at top center. In practice, burning of the fuel must start before top dead center and be completed after top dead center. The shorter the period of combustion, the higher the thermal efficiency, and the lower the fuel consumption. However, an excessively short burning period requires a fast pressure rise and produces high maximum pressures. This is undesirable as far as the quietness of engine operation, pressures, and stresses in various engine parts are concerned.

In order to obtain efficient, smokeless combustion, the fuel injected into the cylinder must be broken up into very fine particles and must be well atomized, and the fuel particles must be distributed uniformly through the whole combustion space. In air-injection engines, the distribution of the fuel is accomplished through a thorough mixing of the injection air carrying the atomized fuel with the air in the cylinder. In mechanical or solid-injection engines, distribution is accomplished by using nozzle tips with several holes and by directing the fuel sprays so as to reach the desired portions of the combustion space or by using pintle-type nozzles with a cone-shaped spray. In larger engines, fuel is distributed better by using two or more separate fuel nozzles, each having several holes or fan-shaped sprays. However, fuel distributed by separate sprays is not sufficient. Fuel distribution in the air charge is improved by stirring up the air in the combustion space and by creating air turbulences, thus mixing air having too much fuel with air which does not have any fuel.

While theoretically 1 lb of air is sufficient to burn completely 0.065 lb of fuel oil, actually not all of the oxygen of the air will be reached by the fuel particles. Hence, only a smaller amount of fuel, on the average not over 0.052 or even 0.043 lb, can be burned efficiently with 1 lb of air in the combustion chamber.

Turbulences in the air charge help to reduce the amount of air not reached by the fuel particles and thus help to increase the power output of the engine. Turbulences may be created by various means, including special shaped of the piston crown or of the entire combustion chamber. Figure 2-11 shows examples of different turbulent heads. In figure 2-11a a turbulences are created by restriction through which the air has to pass when the piston moves upward. The air velocity at the restriction is several times higher than before and after it, and the change of velocity creates a turbulent flow into which the fuel is injected form the fuel nozzle. Figure 2-11b shows a Recardo-Coment head used in Waukesha diesel engines; here turbulences are created not only by the restriction, but also by forcing the air to travel on a circular path. Figure 2-11c shows a turbulent head used in Hercules diesel engines which is similar to the Ricardo head. However, it has an additional feature. When the piston approaches the dead center, it begins to cover partially the air passage between the cylinder and turbulence chamber. This increases the air velocity in the passage, and makes a more turbulent flow of air into which the fuel is injected from the nozzle, f.

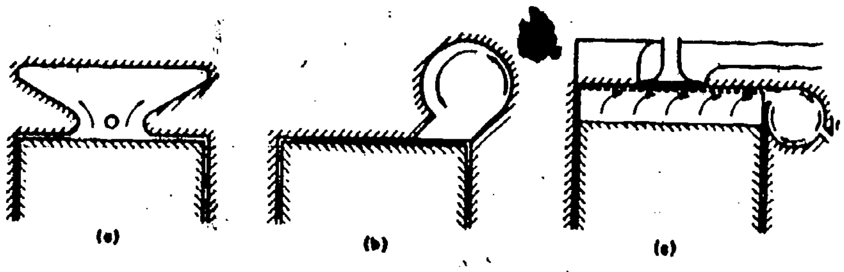

Fig 2-11. Turbulent heads.

Turbulence in a two-stroke engines is created by making the scavenge-air ports tangential or angled as shown in figure 2-12. Note that a circular movement of the air created during scavenging continues up to the time of fuel injection, in spite of the fact that the air has been displaced from one end of the cylinder to the other and compressed to a small fraction of its original volume.

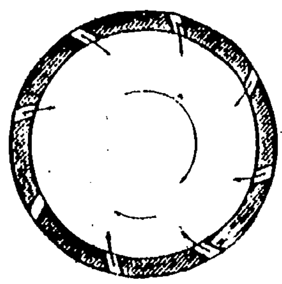

Fig 2-12. Turbulence in a two-stroke engine.

Another method of creating turbulence is used in the so-called Lanova energy cell (fig 2-13). The fuel is injected from the nozzle; a part of the fuel is atomized as it leaves the nozzle, ignites, and burns in the main combustion chamber. The rest is injected in a more or less solid stream into the so-called energy cell or minor air cell. Here it is atomized or broken up in a fine mist form and ignited. The resulting combustion raises the pressure in the minor air cell over the pressure in the main combustion chamber and throws the burned and unburned fuel back into the main chamber. This creates a strong turbulence (indicated by the curved arrows) and helps to burn the rest of the unburned fuel.

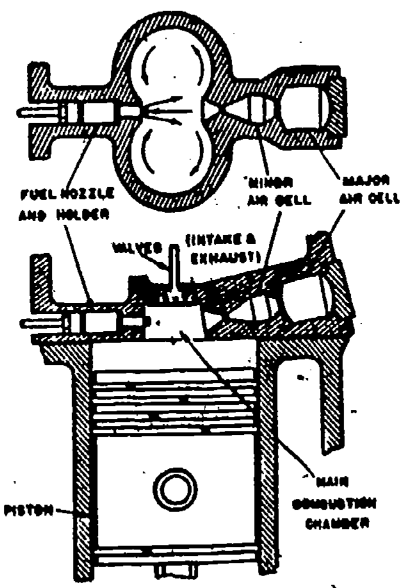

Fig 2-13. Lanova combustion chamber with energy cell.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. The time it takes before the cold fuel spray is heated to the combustion point is known as

   a. time lag.
   b. ignition delay.
   c. retarded combustion.
   d. retarded ignition.

2. Turbulence in the air charge will

____

____

3. Turbulence in the two-stroke engine is created by

____

____

4. The combustion chamber that uses the energy cell principle is the

____

5. The highest thermal efficiency is obtained from

____

Work Unit 2-6. IGNITION AND TIMING.

IDENTIFY CORRECT FUEL TIMING.

As already explained, there exists a certain time lag between the time that the fuel is injected into the cylinder and the time that it ignites and begins to burn and raise the cylinder pressure. This time lag, called ignition delay, requires an advance of the fuel injection several crank-angle degrees efore top dead center. In addition, it should be noted that there is another lag in the fuel injection. The beginning of the delivery stroke of the injection pump is set to correspond to a certain position of the engine crankshaft. The injection timing is checked by slowly turning the engine over. The actual admission of the fuel into the cylinder will start several crank-angle degrees later. The reason for this time lag is the mechanical flexibility of the injection mechanism, taking up of clearances between the various rollers, pins, and levers, and the compressibility of the fuel oil, especially noticeable with a long fuel line. This lag is called injection lag and amounts also to several crank-angle degrees.

Both the ignition lag and injection lag depend upon a number of various factors and may vary considerably from engine to engine. The following data obtained from an actual test may serve as an illustration. In an engine operating at 900 rpm, the injection was set to begin at 22^0 before top center (BTC); actual injection started about 17^0 BTC which gives an injection lag of 5^0; ignition started 8^0 BTC which gives an igniton delay of 9^0 or a total lag of 14^0 behind the nominal fuel timing. On the other hand, the pump delivery stroke was cut off at 3^0 BTC, but due to the expansion of the fuel compressed in the fuel line the actual end of injection occurred slightly after TC. In other engines the lag may be greater or smaller.

The only way to determine the correct fuel timing is by operating the engine, changing the timing, and finding the timing at which the engine operates best, i.e., has the lowest fuel consumption, carries the highest load without smoking, and runs the smoothest. Such timing is worked out at the factory and is given in the instruction book. The operator should maintain this timing unless the engine operating conditions are radically changed, such as running the engine at a different speed or using a different fuel. In this case the proper timing must be found again as mentioned before.

The opening of both the exhaust and intake valves occurs before the corresponding dead center, and their closing occurs after it. The causes are partly in the mechanical lag of action due to clearances which must be taken up, and the flexibility of the long push rods and rocker arms but chiefly in the necessity of a gradual opening and closing of the valves. Thus, an appreciable period of time elapses between the moment when the valve begins to leave the seat, and the moment when it has sufficiently moved away form the seat to allow exhaust gases to pass from the cylinder, in the case of an exhaust valve, and air into the cylinder, in the case of an intake valve. The same holds true for the closing of the valves, but in reverse. Several crank angles before a valve touches its seat, the passage becomes so restricted that the flow of gases practically stops. The gradual opening and closing is necessary to overcome the forces of inertia on the parts of the valve actuating mechanism without exerting undue pressures between the cams, cam followers, and various pins and bearings during the opening of a valve and the pounding of the valve against its seat when the valve is being closed.

The best timing depends upon a number of factors such as valve lift, shape of cam, speed of engine, and restrictions in the cylinder head passages. The proper timing is found and set when the engine is tested at the factory and is given in the manufacturer's instruction book. The proper timing should be maintained and checked in operation. Even a slight change of the clearance between the cam and the cam followers, which can occur when a valve is ground or when the valve actuating mechanism is disassembled and put together without careful checking, will affect the timing. An increase of the clearance will retard the opening of a valve and advance its closing. A decrease of the clearance will act in the opposite direction. An excessive decrease of the clearance may prevent the valve from seating properly with all related consequences such as loss of power or burning of the valve seat.

The same remarks apply to the timing of the exhaust valves of two-stroke engines.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. The only way to find correct fuel timing is by operating the engine, changing the timing and

   a. finding the best timing for the operation of the engine.
   b. removing the incorrect timing form the engine.
   c. reading the appropriate mark on the flywheel.
   d. locating the ignition lag within the engine.

2. The best timing depends on a number of factors such as the shape of the cam, speed of the engine, restrictions in the cylinder head passages, and the

   a. correct center rating.
   c. valve lift.
   d. piston design.
   d. crank angle.

Work Unit 2-7. SUPERCHARGING

IDENTIFY SUPERCHARGING.

NAME THREE BLOWERS.

EXPLAIN TURBOCHARGING.

Supercharging is an increase in the power which an engine of given piston displacement and speed can develop. Since the power in a diesel engine is developed by the burning of fuel, an increase of power requires that more fuel be burned. Therefore, more air must be available since each pound of fuel requires a certain amount of air. A given volume will hold a greater weight of any gas, including air, if the gas pressure is increased. Thus, supercharging means a higher pressure of air charge in the cylinder at the beginning of the compression stroke. In order to increase the air pressure in four-stroke engines, the air charge is not sucked into the cylinder or, as it is called, is not admitted due to natural asporation by the receding piston. The air charge is pushed in instead by a higher pressure created by a separate air pump or blower. There are three types of blowers used: (1) reciprocating piston pumps similar to an air compressor; (2) rotating positive-displacement blowers of the Roots-blower type; and (3) centrifugal high-speed blowers similar to centrifugal pumps.

When a supercharger is applied to a four-stroke engine, the main change required in the engine design is a change in timing of the intake and exhaust valves. The intake-valve opening time is advanced and the exhaust-valve closing is retarded. The two valves are designed to stay open simultaneously for about 80 to 160 degrees, the selection depending upon the normal engine speed. This simultaneous opening is called overlapping. Test have shown that an overlap of 40 to 50 degrees increases the power output of an engine about 5 percent if the supercharging is very small. This is sufficient only to eliminate the vacuum in the cylinder during the suction stroke. The power output of an engine is increased up to 8 percent with a supercharger pressure of 12 inches mercury, as compared to an overlap of 10 to 20 degrees commonly used in unsupercharged engines. The total power gain due to supercharging varies form 20 to 50 percent depending upon the supercharging pressure. In present-day naval engines this varies from 5.0 in to about 12 inches mercury.

It should be noted that, simultaneously with an increase of the mean effective pressure, supercharging also increases the maximum or firing pressure and the maximum temperatures. On the other hand, the fuel consumption per horesepower-hour (hp-hr) usually decreases with supercharging due to an increase of turbulence and hence better mixing of the fuel with the air charge.

Two-stroke engines usually have a blower to obtain scavenge air and their supercharging is obtained simply by increasing the amount and pressure of scavenge air. In addition, a slight change of the exhaust and scavenge timing is made in order to retain more scavenge air at the beginning of the compression stroke.

Turbocharging is much like supercharging. The difference lies in the design. The turbocharger uses exhaust gases to propel the comprassor which provides the high air pressure. The net result is the same so don't be confused by the different terms.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. An increase in the power which an engine of given displacement and speed can develop is the object of

   a. inertia.
   b. governing.
   c. supercharging.
   d. vacuum.

2. Supercharging may be done through the use of three blowers. Name these three blowers.

   ____
   ____
   ____

3. Explain turbocharging.

   ____
   ____

Answers to Study Unit #2 Exercises

Work Unit 2-1.

1. a.
2. b.
3. b.
4. c.
5. b.
6. d.
7. b.
8. Volume in one cylinder with the piston at BDC divided by the volume with the piston at TDC.
9. The higher the compression ration, the higher the thermal efficiency if the engine, and the lower its fuel consumption.
10. Constant volume and constant pressure
11. a. intake
    b. compression
    c. power
    d. exhaust

Work Unit 2-2.

1. c.
2. a.
3. b.
4. c.

Work Unit 2-3.

1. diesel engine
2. compression
3. same sequence
4. crankshafts
5. diesel
6. gas
7. gas
8. diesel

Work Unit 2-4.

1. Movements of the piston are transmitted to the crankshaft by means of a connecting rod. By these three members, the up and down motion (reciprocating) is transformed into rotary motion.
2. b.
3. d.

Work Unit 2-5.

1. b.
2. help reduce the amount of air not reached by the fuel charge (particles) and thus help to increase the power output of the engine.
3. making the scavenge air ports tangential or angled. This creates a circular movement of air that continues up to the time of injection.
4. Lanova combustion chamber
5. fuel burned at the highest compression ratio at top dead center (TDC).

Work Unit 2-6.

1. a.
2. c.

Work Unit 2-7.

1. c.
2. Reciprocating piston pump, rotating positive-displacement blower, and centrifugal high-speed blower
3. The turbocharger uses exhaust gases to propel the compressor which provides the high air pressure and achieve the same end result as the supercharger.

STUDY UNIT 3

INJECTION AND CONTROL OF THE DIESEL ENGINE

STUDY UNIT OBJECTIVE: WITHOUT THE AID OF REFERENCES, YOU WILL IDENTIFY THE COMPONENTS AND PROCEDURES USED IN COMMON FUEL INJECTION SYSTEMS. IN ADDITION, YOU WILL IDENTIFY THE COMBUSTION AND GOVERNING OF POWER AND THE COMPONENTS THAT EACH ENGINE WILL HAVE AS CONTROL MECHANISMS.

Work Unit 3-1. FUEL INJECTION SYSTEMS

LIST THE FIVE MAIN REQUIREMENTS FOR INJECTION OF FUEL.

IDENTIFY TWO METHODS OF FUEL INJECTION.

The fuel injection system, in delivering the fuel to the combustion chamber, must fulfill the following main requirements:

a. Meter or measure the correct quantity of fuel.
b. Time the fuel injection.
c. Control the rate of fuel injection.
d. Atomize or break up the fuel into fine particles according to the type of combustion chamber.
e. Properly distribute the fuel in the combustion chamber.

There are two different methods of fuel injection: air injection and mechanical or solid injection. Solid injection can be subdivided into three distinctly different groups: (1) common-rail, (2) individual-pump, and (3) distributor systems. The means of fulfilling the five requirements listed above vary according to the system used and are shown in the following table:

Table 3-1. Injection requirements and systems.

Requirement	Air-Injection System	Mechanical InjectionSystems		
		Common-Rail	Individual Pump	Distributor
Metering	Pump	Injection valve	Pump	Pump
Timing	Fuel cam	Fuel cam	Pump cam	Fuel cam
Injection rate	Spray valve	Injection valve	Pump cam	Fuel cam
Atomization	Spray valve	Injector tip	Injector	Injector
Distribution	Spray valve	Injector tip	Injector	Injector

a. Metering. Accurate metering or measuring of the fuel means that, for the same fuel control setting, exactly the same quantity of fuel must be delivered to each cylinder for each power stroke of the engine. Only in this manner can the engine operate at uniform speed with a uniform power output.

b. Timing. Proper timing means beginning the fuel injection at the required moment. This is essential in order to obtain the maximum power for the fuel-air mixture and thus insure fuel economy and clean burning. When the fuel is injected too early in the cycle, ignition may be delayed because the temperature of the air at this point is not high enough. An excessive delay gives rough and noisy operation of the engine and also permits some fuel to be lost due to wetting of the cylinder walls and piston head. This in turn results in poor fuel economy, high exhaust gas temperature, and smoke in the exhaust. When fuel is injected too late in the cycle, all the fuel will not be burned until the piston has traveled well past top center. When this happens, the engine will not develop its maximum power, the exhaust will be smokey, and the fuel consumption will be high.

c. Rate of fuel injection. The rate of fuel is important for the same reason that correct timing is important. If the start of the injection is correct, but the rate of injection is too high, the results will be similar to an excessively early injection; if the rate is too low, the results will be similar to an excessively late injection.

d. Atomization. Atomization of fuel must be according to the type of combustion chamber in use. Some chambers require very fine atomization; others can operate with coarser atomization. Proper atomization aids the starting of the burning process and insures that each minute particle of the fuel will be surrounded by particles of oxygen with which it can combine. A more detailed discussion of atomization is given in work unit 3-2.

e. Distribution. Proper distribution of the fuel must be obtained so the fuel will penetrate all parts of the combustion chamber where oxygen is available for combustion. If the fuel is not properly distributed, some of the available oxygen will not be used and the power output of the engine will be low.

In order to be practical, the fuel injection system, and especially the high-pressure pump, must have the following additional features:

a. Maintain its adjustment for a reasonable period of time, not lose it due to the vibration connected with the high engine speed.
b. Be economical of power.
c. Be light and not too bulky, especially in small engines.
d. Be quiet in operation.

Air injection was used in early diesel engines; at present it is seldom used and only for large engines operating on heavy viscous fuels.

In air-injection engines, the potential energy of the compressed air is converted into kinetic energy. This kinetic energy of the expanding air is used to feed the fuel into the cylinder from the spray valve, to atomize the fuel, and to create turbulence in the combustion chamber for mixing the fuel and air.

The air-injection system consists of three main elements:

- The fuel pump for metering the fuel.
- The compressor for supplying the injection air.
- The spray valve.

a. Fuel pump. The type generally used has a plunger for each cylinder the engine, and the quantity of fuel is controlled by varying the effective length of the plunger stroke. The only function of the pump is to meter accurately the required quantity of fuel and deliver it to the spray valve.

b. The spray valve. Figure 3-1 shows a spray valve consisting of a needle valve held on its seat by a heavy spring, atomizer disks with holes to break up the fuel and mix it with the injection air as both flow through the valve, and a flame plate with an orifice through which the fuel-air mixture is admitted to the combustion chamber. The needle valve is lifted mechanically by a lever actuated by a cam on the camshaft.

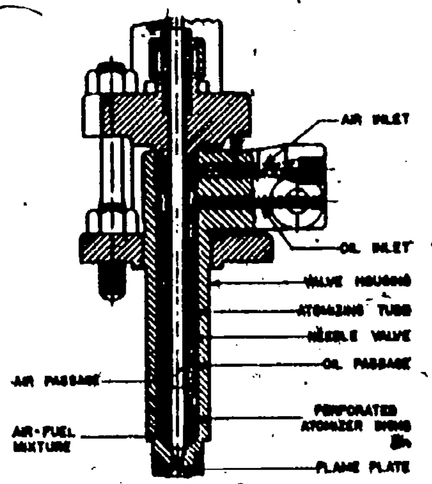

Fig 3-1. Typical air-injection fuel nozzle.

The timing and duration of injection are controlled by the fuel cam. The rate of injection, the atomization of the fuel, and the distribution in the combustion chamber are all controlled by the number and size of the orifices in the atomizer disks and in the flame plate, and by the injection-air pressure. Injection-air pressures vary from 750 to 1,200 psi, the usual pressure being about 1,000 psi. Air injection fulfills the five main requirements adequately but has the following disadvantages: the compressor absorbs a comparatively large amount of power, is rather heavy and bulky, and is not suitable for high-speed, small-bore engines.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. List the five main requirements for the fuel injection system.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

2. Two methods of fuel injection are

   a. diesel and gas.
   b. air and water.
   c. air and solid.
   d. diesel and mechanical.

3. Three types of mechanical injection systems are ______________, ______________, and ______________.

Work Unit 3-2. MECHANICAL INJECTION SYSTEMS

IDENTIFY THE COMMON-RAIL SYSTEM.

IDENTIFY THE PUMP INJECTION SYSTEM.

STATE THE PURPOSE OF THE JERK PUMP.

IDENTIFY TWO TYPES OF FUEL NOZZLES.

DESCRIBE TWO TYPES OF CLOSED-END NOZZLES.

IDENTIFY THE UNIT INJECTOR SYSTEM.

IDENTIFY THE DISTRIBUTION SYSTEM.

As already stated, all mechanical-injection systems may be subdivided into three main groups: common-rail, individual-pumps, and distributor systems. The differences in construction in engines of different manufactures are such that it may help in their discussion to subdivide further the main groups. The common-rail system may be divided into the basic system and a modification, such as that used in Cooper-Bessemer engines. The individual-pump system may be divided into the original system, with a separate pump and fuel injector for each cylinder, and a modification, in which the pump and injector are combined in one unit.

Atomization is a term applied to the breaking up of the fuel stream into mist-like sprays. With mechanical injections, atomization is obtained as follows: the liquid fuel, subjected to a high pressure, passes through a small opening into the combustion space filled with air, the pressure of which is considerably lower. As a result, the fuel streams develop high velocity. This creates great friction between the liquid stream and the air in the combustion space. Due to this friction, minute particles of fuel are broken off the stream, then the freshly exposed particles are again broken off, and so on, until the whole liquid stream is broken up into very small particles or globules. Atomization literally means breaking up into atoms. Actually, each globule is not one atom but consists of many atoms. Therefore, the term atomization, while an exaggeration, gives a general idea of the aim of the process.

In mechanical injection the distribution of the fuel in the combustion chamber, generally speaking, is obtained by two means: penetration and air turbulence. Penetration is the distance through which fuel particles are carried by the kinetic energy given to them when they leave the fuel nozzle. Friction between the fuel and the air in the combustion space gradually absorbs this energy. Penetration depends upon various characteristics of the fuel-injection system, chiefly upon the injection pressure and the size of the nozzle hole, and is reduced by finer atomization. Thus, the best conditions are obtained by a compromise between minimum necessary penetration and the desirable fineness of atomization.

Air turbulence, discussed in Study Unit 2 is independent of the fuel injection system and is only an additional tool in obtaining good combustion.

a. Common-rail system. This system consists of a high-pressure, constant-stroke and constant-delivery pump which discharges into a common rail or header to which each fuel injector is connected by tubing. A spring-loaded by-pass valve on the header maintains a constant pressure in the system, returning all excess oil to the fuel supply tank. The fuel injectors are operated mechanically. The amount of oil injected into the cylinder at each power stroke is controlled by the lift of the fuel admission valve. The operation of the injection system is shown in figure 3-2. The fuel cam gives an upward motion to the push rod; through the rocker arm and intermediate lever this motion is transmitted to the needle valve; the space above the needle valve seat is connected at all times with the fuel header and sealed from the top by a packing gland (fig 3-3). When the needle valve is lifted from its seat, the fuel is admitted to the combustion space through the small holes drilled in the injector tip below the valve seat. Passing through these tiny holes, the fuel is divided into small streams which are broken up or atomized as previously explained. The amount of fuel injected is controlled in accordance with the power requirement by means of a wedge (fig 3-2), which changes the lash. When the wedge is pushed to the right, the valve lash is decreased. The motion of the cam follower will then be transmitted earlier to the push rod. The fuel needle will be opened earlier, closed later, and its lift will be slightly greater. Therefore, more fuel will be admitted per cycle. When the wedge is pulled out to the left, the valve lash is increased. The needle valve will be lifted later and closed earlier, and less fuel will be admitted. The position of the control wedge is changed either by the governor or, in variable-speed engines, by hand. The fuel-injection pressure is adjusted to suit the operating conditions by changing the spring pressure in the by-pass valve, called fuel-pressure regulator. Fuel-injection pressures from 3,200 psi to about 5,000 psi are used at rated load and speed, depending upon the type of engine. In order to reduce the pressure fluctuations in the system caused by the intermittent fuel discharge from the pumps and withdrawals by the fuel valves, the volume of the fuel in the system is increased by attaching to the fuel header an additional fuel container called the accumulator which has a relatively large capacity. The area past the needle-valve seat and through the passage between the valve seat and the valve tip containing the orifices is several times as large as the area through the orifices on the tip. The control of the fuel jets is largely by the orifices. The valve tip commonly used with this system has several holes or orifices.

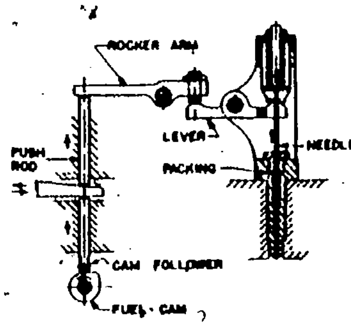

Fig 3-2. Control of fuel admission in a common-rail system.

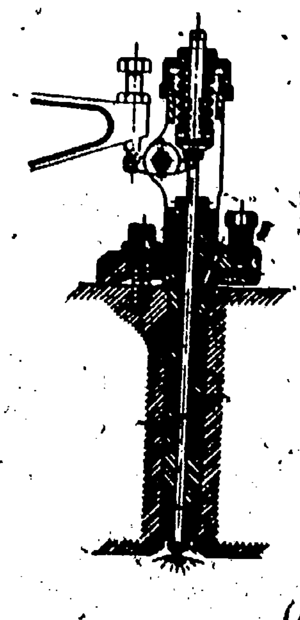

Fig 3-3. Injection nozzle for common-rail fuel system.

The common-rail system is not suitable for high-speed, small-bore engines, because it is difficult to control accurately the small quantities of fuel injected into each cylinder at each power.

The Cooper-Bessemer system is similiar but differs from the original common-rail system chiefly in that the functions of the fuel needle valve are divided between two separate pieces of equipment, the fuel injector and the injection nozzle, as shown in figure 3-4. Another difference lies in the fact that the pressure regulation is accomplished by the high-pressure pump itself.

The pump plunger, on its downward stroke, first closes small holes that connect the pump barrel with the fuel admission line. A further downward motion increases the oil pressure in the pump until it opens the spring-loaded discharge valve and delivers the oil into the injection system. During the return stroke the spring moves the plunger upward; this creates a vacuum. When the plunger uncovers the holes on top, oil from the suction side enters into the pump. The oil from the fuel-oil pressure tank on its way to the suction side of the pump is admitted first to the inner side of a sleeve. This sleeve and a second sleeve surrounding it have two mating holes. By turning the sleeves, one relative to the other and to the housing, the amount of fuel admitted to the pump is adjusted to meet the load and speed requirements. The outer sleeve is set and turned by the governor so as to admit the amount of fuel corresponding to the load carried by the engine. The inner sleeve is turned by a mechanism set to maintain a prescribe constant pressure in the system. If the pressure goes up, the sleeve is turned to decrease the effective area of the opening between the two sleeves. The amount of fuel taken by the pump is thus reduced, and as a result, the pressure in the system goes down. On the other hand, when the pressure begins to drop, the sleeve is turned in the opposite direction, the effective opening area is increased, more fuel goes into the pump, and the pressure goes up. The injection nozzle consists of a spring-loaded plunger with a conical end which acts as a valve. It is raised from its seat by the oil pressure when the valve in the fuel injector is opened. The nozzle is returned to its seat by the spring in the upper part of the nozzle when the injector valve is closed and the oil pressure between this valve and the nozzle begins to drop. A quick closing to the injection nozzle and elimination of after-dribbling of the fuel into the combustion space is obtained as follows: the lifter plunger is drilled lengthwise at its center from the valve end to a point in line with the recess in the injector body (fig 3-4). Another hole, drilled at a right angle to the central hole, connects with it, forming a passage from the lifter end to the recess and through it to the drain tank. The bottom of the injector valve is lapped to a seat with the end of the lifter plunger so that when the two are brought in contact during injection, the passage through the plunger is sealed. As soon as the fuel cam releases the lifter plunger, the valve is closed by its spring (fig 3-4). The oil pressure on the end of the lifter plunger will move it downward, and a small amount of fuel oil is spilled to the drain tank, relieving the oil pressure in the nozzle. The lifter spring will then return the lifter plunger to a contact with the valve. This arrangement also acts as a safety feature which prevents the fuel oil from passing into the engine cylinder except when necessary, even if the injector valve should leak at its seat. The system gives good results but, like any common-rail system, is not suitable for small-bore engines.

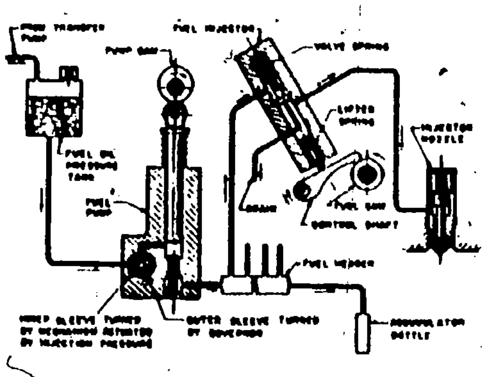

Fig 3-4. Cooper-Bessemer fuel-injection system.

b. Individual pump

(1) Features of pump-injection system. This system, also known as the jerk-pump system, has two essential parts to each cylinder, the injection pump and the fuel nozzle. The requirements which a pump in this system must fulfill, both in respect to metering and timing, are such that they can be met only by a precision piece of equipment.

- Accuracy. In operation on a high-speed diesel engine, these injection pumps must measure and deliver, under high pressure and at exactly the required time, an exceeding small quantity of fuel.

- Metering. The volume of the fuel injected is extremely small compared with the piston displacement. At full load, the volume of the fuel injected is about 1/20,000 of the piston displacement. When the engine is idling, the volume of fuel required is only about 1/5 of that at full load; this gives a volume ratio of about 1/100,000.

The difficulty of accurately measuring such small quantities of fuel so that all cylinders receive exactly the same amount is quite evident.

- Timing. An idea of the accuracy of timing required may be obtained from the following considerations. Ordinarily the period during which the fuel is injected does not exceed 20^0 of crank travel. If the engine speed is 2,000 rpm, the whole injection period corresponds approximately to 60 x (20/360) - 2,000 = 1/600 sec.

The start and end of injection cannot vary more than approximately 1^0 of crankshaft rotation.

- Injection pressures. Such minute quantities must be injected within such close time limits under pressures which may run as high as 6,000 psi and in some injector types even up to 30,000 psi; most high-speed engines, however, use injection pressures of 2,400 to 3,000 psi.

- Precision workmanship. All injection fuel pumps of the jerk-pump type have plungers fitted closely to the pump barrels by lapping. Lapping means finishing hardened surfaces by working them against the surfaces of laps with an exceedingly fine abrasive material. From a number of plungers and barrel which above have been lapped truly round and cylindrical but differ slightly in diameter, the plungers are fitted to their barrels by selective assembly. In this way a fit is obtained with a clearance less than 0.0001 inch. Such a fit gives very little leakage even with the high pressures created. No packing of any kind is necessary. Due to the method of fitting a plunger to its barrel, these parts are not interchangeable. If a plunger or barrel is worn or damaged, both pieces must be replaced.

- Pressure waves. Fuel oil, like all liquids, is compressible. Therefore, when the pump plunger at the beginning of the actual delivery strikes the oil in the pump barrel, the oil is not accelerated at once in the whole fuel line. The motion of the plunger increases the pressure first in the particles of the oil nearest to the plunger. This pressure increase is transmitted gradually through the line until it reaches the nozzle. On the other hand, due to its inertia, the liquid column in the line has a tendency to move away from the plunger. Thus, the initial blow of the plunger sets up a compressive wave in the fuel line. When this wave reaches the nozzle which presents a certain resistance, it is reflected and travels back to the plunger, increasing the pressure created by the plunger. After it reaches the plunger, it returns to the nozzle. This fluctuation of the pressure at the discharge and of the fuel line disturbs the fuel discharge through the nozzle. During the moment when the pressure at the nozzle is low, the fuel discharge is decreased and the atomization becomes poorer. The disturbances are particularly noticeable in engines operating at variable speed. In addition, the pressure waves may produce vibration of the tubing connecting the pump and the nozzle and cause its breakage. The building up of pressure waves is affected by many factors, the chief ones being the inside diameter and length of the fuel-line tubing. The proper length and diameter are determined by the engine builders and should never be changed as a change may cause serious trouble.

(2) Jerk pump. In order to obtain proper atomization of the fuel spray, injection pressure in the fuel line must consistently be maintained sufficiently high from the very start to the end of the injection. Also, since this pressure is proportional to the plunger speed, the latter, too, must be reasonably high during the whole injection period. This high pressure is obtained by using for the fuel delivery only part of the plunger stroke, after the plunger has acquired a certain speed, and discarding the initial part of the stroke. This method produces a sudden acceleration of the fuel in the line, causing a jerk, hence the name for the pump (fig 3-5).

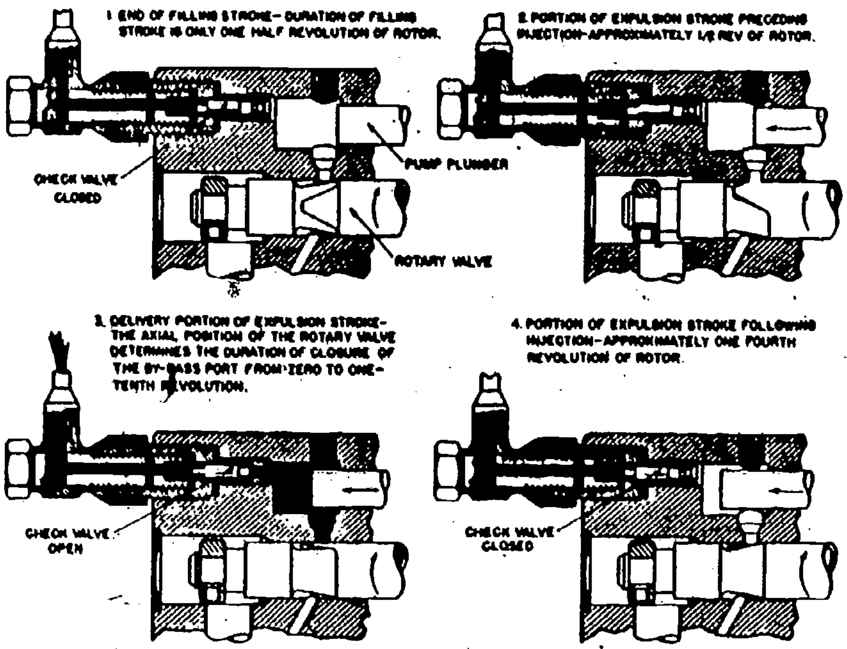

Fig 3-5. Jerk pump with rotary by-pass valve.

In most jerk pumps, the total plunger stroke is constant and the metering is controlled by varying the length of the effective part of the plunger stroke by one of the following methods:

- The fuel is admitted into the pump barrel through ports in the barrel controlled by a spiral groove or scroll, also called the helix, on the plunger. The plunger can be turned in the barrel while moving back and forth. This changes the portion of the plunger stroke during which the ports are covered and the fuel is delivered to the nozzle.

- The fuel is admitted into the pump barrel through ports in the barrel which are controlled by a separate valve.

(3) Plunger-controlled pumps. The principle of this type of pump can be better understood by referring to figure 3-6. At the bottom of the plunger stroke (fig 3-6a), the suction and pressure release ports are both in communication with the inner pump space. When the plunger has moved a certain distance and covered both ports, fuel delivery begins with a jerk and lasts until the lower edge of the spiral begins to uncover the release port (fig 3-6b). At that point the pressure drops and fuel delivery stops. The plunger continues to travel a short distance to the top of its stroke and then begins to move downward. If the plunger is turned about 60° (fig 3-6c), the distance between the top edge of the plunger and the edge of the spiral sliding over the release port is shorter, and the fuel delivery stops earlier. Finally, if the plunger is turned 90° more, the release port stays uncovered, and no fuel is delivered.

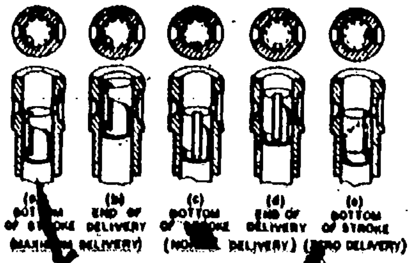

Fig 3-6. Barrel with various plunger positions.

In the operation as shown in figure 3-6, the beginning of the effective stroke always occurs at the same moment, but the end of the injection changes with the engine load. It is later with a higher load and greater fuel delivery, and earlier with a lower load and smaller fuel delivery. The middle of the injection stroke is advanced with a load increase.

This condition can be reversed by making a spiral edge on the top of the plunger and a square groove at its bottom. In this case, the beginning of the injection will be earlier with an increase in the load and later with a decrease in it, while the end will always be constant. The middle of the injection will be retarded with an increase of the load, a condition, however, which is not desirable. By making both edges spiral, inclined in opposite directions, the middle of the injection stroke can be kept constant for all loads. Naturally, the compressibility of the fuel and the mechanical flexibility in the pump mechanism will retard the actual start of injection into the cylinder, producing an injection lag.

(4) Valve-controlled pumps. Figure 3-5 may serve to explain the principle of such a pump. The pump plunger has a constant stroke and is a plain cylinder. The fuel delivery is controlled by the rotary valve with a wedge-shaped end. When the plunger, traveling to the left, approaches its middle position, the rotary valve closes the admission port, having moved the slanting fuel-cut-in edge across it. When, due to rotation of the valve, the other slanting edge reaches the port, the inside of the pump comes in contact with the low-pressure space, the pressure is released, and fuel delivery is cut off. The rotary valve can be moved axially, by the governor or by hand, and this changes the distance from the cut-in to the cut-off slanting edge and with it the duration of the fuel-injection period.

The plunger of plunger-controlled pumps is pushed by a cam with a cam follower during the delivery stroke and returned by a spring. The pumps are built either as separate units for each engine cylinder or as a multi-plunger, in-line unit for all cylinders.

The pumps with a rotary valve are conveniently built around this valve. The axis of the individual cylinders, instead of being in one plane, is at an equal distance from the axis of the driving shaft and is equally spaced around it and the centrally located rotary valve. Instead of cams, a swash plate, also called a wobble plate, is used as the driving member (fig 3-7), and is keyed to the drive shaft. By the use of shoe-plates containing spherically shaped sockets, the rotary motion of the swash plate is converted into a straight-line back-and-forth motion which is transmitted to the ball-ended tappets. Each tappet operates one pump plunger. The plungers and tappets are returned by springs (fig 3-7). The drive shaft also turns the rotary valve which is located on the same axis as the shaft. The main body of the pump is symmetrical with the drive shaft. It can be conveniently flange-bolted to the timing-gear housing of the engine.

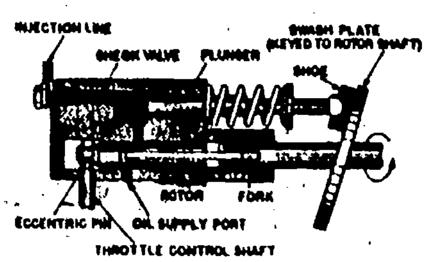

Fig 3-7. Section of a rotary valve.

c. Fuel nozzles. The nozzles are either for the open or the closed type. The open type usually is a simple spray nozzle with a check valve which prevents the high-pressure gases in the engine cylinder from passing to the pump. Although simple, it is generally not used because it does not give proper atomization. The closed-type nozzle is used more commonly. Basically, it is a hydraulically operated, spring-loaded needle valve. Most closed nozzles open inward under the pressure acting on the differential area of the needle valve and are seated by a spring when the pressure is cut off (fig 3-8). The larger cylindrical part of the valve has lapped fit with the nozzle body. There are two main types of such nozzles: the pintle-type and the hole-type nozzle. The valve of the pintle nozzle (fig 3-9a and 3-9b) is provided with a pin or pintle protruding from the hole in the bottom of the nozzle in which there is a close fit. The fuel delivered by such a nozzle must pass through an annular or ring-shaped orifice. The spray is in the form of a hollow cone whose outside angle, which may be any angle up to 80^0, is determined by selecting certain dimensions. A valuable feature of the pintle nozzle is its self-cleaning property which prevents carbon deposits from building up in and around the orifices.

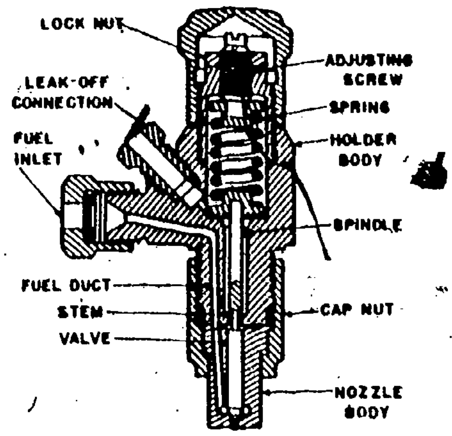

Figure 3-8. Bosch fuel-injection nozzle.

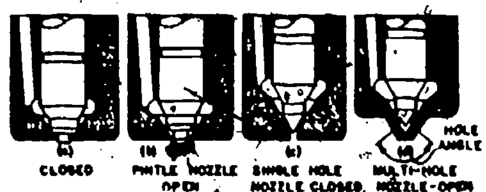

Figure 3-9. Types of closed nozzles.

In the hole-type nozzle there may be one (fig 3-9c) or several spray orifices (fig 3-9d) in the form of straight, round holes drilled through the tip of the nozzle body below the valve seat. The spray from the single-hole nozzle is relatively dense and has a greater penetration. The general spray pattern of a multi-hole nozzle, which may or may not be symmetrical, is determined by the number, size, and arrangement of the holes. Orifices used are from 0.006 in., and up to 0.0225 in. in diameter, and their number may vary from 3 up to as many as 18 nozzles for large-bore engines. Multi-hole nozzles are used generally in engines with an undivided combustion chamber.

Figure 3-8 shows a pintle nozzle assembled in a nozzle holder with the spring and connections for the fuel-pressure line and leakage drain. The pressure necessary to open the needle valve may vary from 1,500 psi to about 3,000 psi.

Figure 3-10 shows a hydraulically operated fuel nozzle which opens outward. It is of the pintle type, has an opening pressure of about 1,500 psi to 2,000 psi and produces a cone-shaped spray. The advantages of this type of nozzle are its compactness and light weight. These factors make it particularly suitable for small-bore high-rpm engines.

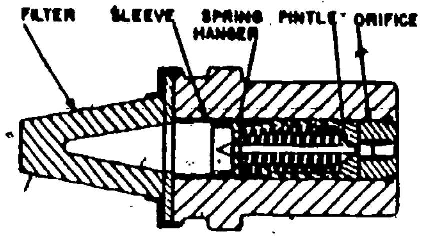

Fig 3-10. Section through nozzle tip.

d. Unit injector. The unit injector combines a pump and fuel-spray nozzle in one unit as shown in figure 3-11. The pump is of the jerk type with ports controlled by helical-grooved edges in the plunger. The amount of fuel is controlled by turning the plunger. The nozzle is of the open type with a spherical check valve. The spray tip has several small-diameter orifices. However, there are also unit injectors in existence which have closed-type nozzles with hydraulically operated differential needle valves and multi-hole nozzle tips.

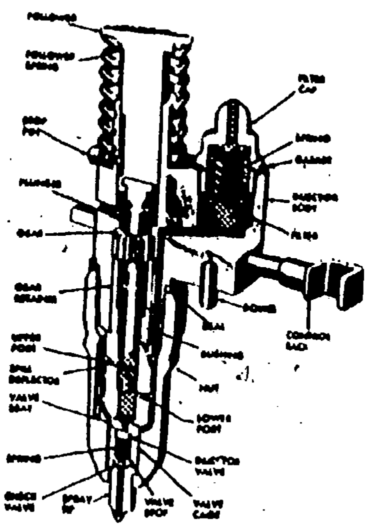

Fig 3-11. Unit injector with spherical check valve.

The pump plunger receives its downward motion, the delivery stroke, from fuel cam through a rocker arm which acts on the plunger follower. The plunger is returned by the plunger spring. The fuel, under a pressure of about 35 psi, is admitted through a small filter (fig 3-11) and fills the annular supply chamber around the pump plunger barrel, called a bushing. As the plunger moves downward, fuel is displaced into the supply chamber, at first through the lower port, and later, when the lower edge of the plunger closes this port, through a central and a transverse part or crosswise drilled holes in the plunger and the upper port. When the upper helical edge has covered the upper port, the fuel from the pump plunger barrel is forced down into the nozzle body, opening the spherical check valve, past the flat check valve, and into the spray tip. From there it is forced through the orifices into the cylinder. The fuel-injection pressure is raised approximately to 20,000 psi as the fuel passes through the nozzle. Injection continues until the lower helix on the plunger uncovers the lower port in the plunger barrel. The fuel then begins to by-pass through the holes in the plunger and through the lower port into the supply chamber. This releases the pressure on the fuel in the plunger barrel. The check valve spring causes the spherical check valve seat. On the return stroke, the upward movement of the plunger fills the plunger barrel with fuel oil which flows from the supply chamber through the lower port. The function of the flat check valve is only to close the inside of the nozzle against gases from the cylinder.

Turning of the plunger in order to change the effective length of the stroke is accomplished by a gear and rack connected to the governor or hand throttle. The middle part of this plunger has a hexagonal cross section which slides through a corresponding hole in the gear, thus forcing the plunger to turn with the gear. The effective stroke is determined by the relative positions of the helices and the upper and lower ports.

The advantage of the unit-injector construction is in the absence of long fuel lines which cause pressure waves and sometimes mechanical troubles. However, one disadvantage lies in the high pressures created. Such pressures result in faster wear of the spray orifices and the need to dismantle a considerable part of the valve gear in order to take out one unit injector. Another disadvantage is the greater chance of fuel leaks into the engine sump and dilution of the lubricating oil.

e. Distributor system. The distributor type of fuel injection system is used on small and medium size diesel engines. It is a popular system because of its lightness, low cost, simplicity of design, and the ease with which it can be adapted to small diesel engines. In this system, fuel under 130 psi to 150 psi pressure is supplied by a gear transfer pump, as shown in (fig 3-12), through an indexed rotating distributor to a metering plunger during its downward stroke. This plunger has a variable stroke, controlled by the governor, and receives its upward motion from a multi-lobe cam and the downward motion spring. During the upward stroke, this plunger sends the fuel through other passages in the same distributor to the individual injectors on each engine cylinder. The fuel enters at the top of the injector (fig 3-13), flows through an inlet passage past a spring-loaded check valve, and fills the chamber under the injector plunger which, except at the end of injection, is off its seat. The injector plunger is operated by a cam through a rocker lever and link. As the fuel is delivered from the distributor to the injector during the suction stroke of the engine, the injector plunger is gradually lifted and the fuel fills the space in the cup under the plunger. At the time of injection the plunger is pushed downward and the fuel, prevented by the check valve from returning to the distributor, is injected into the combustion space. It is finely atomized by being forced under a relatively high pressure through six small holes, 0.006 to 0.008 in. in diameter, depending upon the size of the engine.

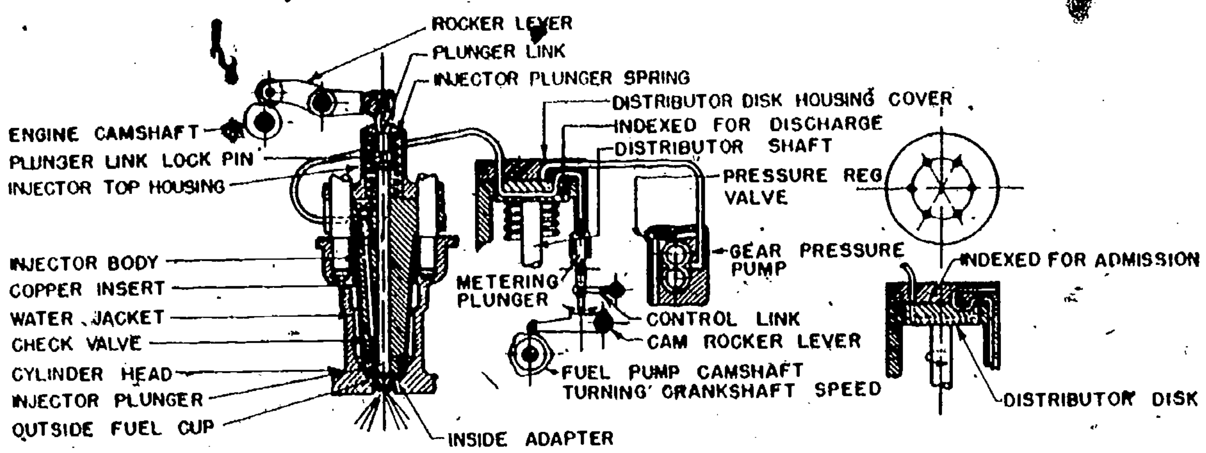

Fig 3-12. Diagram of distributor-type low-pressure fuel-injection system.

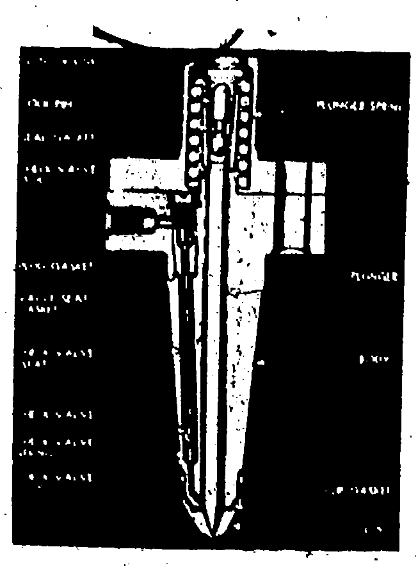

Fig 3-13. Injector, cross section.

The advantage of this system is the absence of high-pressure lines and pressure waves. Its disadvantage is the relatively large inertial of moving parts, making it unsuitable for very high speeds. Another disadvantage, more or less eliminated in the new-type injector, is dilution of the lubricating oil in the engine crankcase due to fuel oil leaking past and up the injector plunger.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. In the common-rail system consists of a high pressure, constant-stroke and constant-delivery pump which discharges into a ______________ to which each injector is connected by tubing.

   a. tub
   b. pump
   c. common-rail header
   d. tank

2. The common-rail system is not suitable for high speed, low bore engines, because

   a. its functions are too slow.
   b. there is difficulty in controlling small quantities of injected fuel.
   c. it lacks of power.
   d. its speed cannot be controlled during higher pressure.

3. The system that has two essential parts two each cylinder, the injection pump and fuel nozzle is the

   a. common-rail.
   b. pump injection system.
   c. unit injector system.
   d. Cooper-Bessemer.

4. State the purpose of the jerk pump.

   ____

5. Two types of fuel nozzles are the ______________ and

   a. air, solid.
   b. valve, plunger.
   c. open and closed.
   d. rotor and fork.

6. Describe the pintle type nozzle.

   ____

   ____

7. Describe the hole-type nozzle.

   ____

   ____

8. The system that combines a pump and a fuel spray nozzle in one unit is the

   a common-rail system.
   b. distributor system.
   c. pump-injector system.
   d. unit-injector.

9. The system that is used because of its lightness, low cost, and simplicity of design is the

   a. distributor system.
   d. common-rail system.
   c. unit injector system
   d. metering system.

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Work Unit 3-3. COMBUSTION WITHIN THE DIESEL ENGINE

DEFINE THE THREE MOST IMPORTANT QUALITIES OF DIESEL FUEL.

IDENTIFY FOUR TYPES OF COMBUSTION CHAMBER DESIGNS.

IDENTIFY FOUR TYPES OF COMBUSTION CHAMBER DESIGNS.

The fuels used in modern high-speed diesel engines are a product of the petroleum refining process. They are heavier than gasoline because they are obtained from the leftovers or residue of the crude oil after the more volatile such as gasoline and kerosene have been removed. The large, slow-running diesel engines used in stationary or marine installations will burn almost any grade of heavy fuel oil, but the high-speed diesel engines used in automotive installations require a fuel oil as light as kerosene. Although diesel fuel is different from gasoline, its specification requirements are just as exacting as those of gasoline. Of the various properties to be considered in selecting a fuel for diesel engines, the most important are cleanliness, viscosity, and ignition quality.

a. Cleanliness. Probably the most necessary property of a diesel fuel is cleanliness. The fuel should not contain more than a trace of foreign substance; otherwise, fuel pump and injector difficulties will occur. Diesel fuel, because it is heavier and more viscous than gasoline, will hold dirt in suspension for longer periods of time. Therefore, every precaution must be taken to keep dirt out of the fuel system or to eliminate it before it reaches the pumps. Water is more objectionable in diesel fuels than it is in gasoline because it will cause ragged operation and corrode the fuel system. The least amount of corrosion of the accurately machined surfaces in the injection equipment will cause it to become inoperative.

b. Viscosity. The viscosity of an oil is an indication of its resistance to flow. The higher the viscosity, the greater the resistance to flow. The viscosity of a diesel fuel must be sufficiently low to flow freely at the lowest temperatures encountered, but it must also be high enough to lubricate the closely fitted pump and injector plungers properly. It must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. The viscosity of a fuel also determines the size of the fuel-spray droplets which, in turn, govern the atomization and penetration qualities of the spray.

c. Ignition quality. The ignition quality of a diesel fuel is its ability to ignite spontaneously under the conditions existing in the engine cylinder. The spontaneous-ignition point of a fuel is a function of temperature, pressure, and time. Since it would be difficult to reproduce artificially these factors as they exist in an engine cylinder, the best apparatus for measuring the ignition quality of a fuel is an actual diesel cylinder running under controlled operating conditions. The yardstick used for measuring the ignition of diesel fuels is the cetane-number scale. The cetane number of fuel is obtained by comparing the operation of the unknown fuel in a special test engine with the operation of a known reference fuel in the same engine. The reference fuel is a mixture of alpha-methyl-naphthalen, which will hardly ignite when used alone, and cetane, which will readily ignite at temperatures and pressures obtained in a diesel cylinder. The cetane number indicates the percent of cetane in a reference fuel which will just match the ignition properties of the fuel being tested.

It has been observed that diesel engines knock, particularly at light loads. This knock is believed to be due to the rapid burning of the charge of fuel accumulated during the delay period between the time of injection and ignition. When the fuel is injected, it must first vaporize, then superheat until it finally reaches the spontaneous-ignition temperature under the proper conditions to start combustion. Time is required for sufficient fuel molecules to go through this cycle to permit ignition. As stated earlier, this time is called ignition lag or ignition delay. During this same time, other portions of the fuel are being injected and are going through the same phases but behind the igniting portion. Therefore, as the flame spreads from the point of ignition, appreciable portions of the charges reach their spontaneous-ignition temperatures at practically the same instant. This rapid burning causes a very rapid increase in pressure which is accompanied by a distinct and audible knock. Increasing the compression ratio in the diesel engine will decrease the ignition lag and thereby decrease the tendency to knock. Increasing the compression ratio in a gasoline engine leads to pre-ignition and, in addition, tends to make detonation worse. Knocking in the diesel engine is affected by a large number of factors besides compression ratio, however. The type of combustion chamber, air flow within the chamber, the type of nozzle the injection pressure conditions, the fuel temperature are all factors as are the characteristics of the fuel itself. For these reasons, more can be done in the design of a diesel engine to make it operate smoothly without detonation than is possible with the gasoline engine.

The fuel injected into the combustion space of a diesel engine must be thoroughly mixed with the compressed air and distributed as evenly as possible throughout the chamber if the engine is to function properly. None of the liquid fuel should strike the chamber walls. It is essential that the shape of the combustion chamber and the characteristics of the injected fuel spray be closely related. There are many types of combustion chambers in use today, but they are all designed to produce one effect -- to bring sufficient air into contact with the injected fuel to provide complete combustion at a constant rate. All modern combustion chamber designs may be classified under one of the following headings: open, precombustion, turbulence, or divided chambers. Designs which fall under two or more headings will be covered under the heading which is the most applicable.

a. Open chamber. The open chamber (fig 3-14) is the simplest form of chamber, but its use is limited to slow-speed engines and a few high-speed 2-stroke-cycle engines. The fuel is injected directly into the combustion space at the top of the cylinder. The combustion space, formed by the top of the piston and the cylinder head, is shaped to provide a swirling action of the air as the pistons comes up on the compression stroke. There are no special cells, pockets, or passages to aid the mixing of fuel and air. This type of chamber requires higher injection pressures and a greater degree of fuel atomization than is required by the other types to obtain the same degree of mixing.

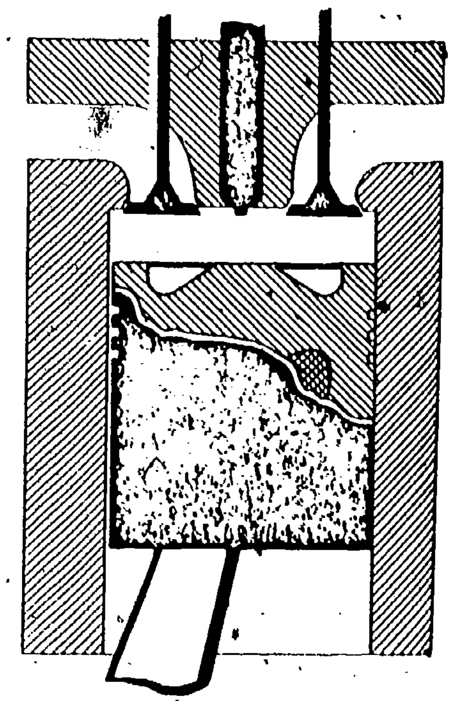

Fig 3-14. Diesel engine open combustion chamber.

b. Precombustion chamber. The precombustion chamber (fig 3-15) is an auxiliary chamber at the top of the cylinder. It is connected to the clearance volume above the piston through a restricted throat or passage. The precombustion chamber conditions the fuel for final combustion in the cylinder and distributes the fuel throughout the air in the cylinder in such a way that complete, clean burning of all fuel is assured. On the compression stroke of the engine, air is forced into the precombustion chamber and, since the air is compressed, it becomes hot. Thus, at the beginning of injection this small chamber contains a definite volume of air. Consequently, combustion of the fuel actually starts in the precombustion chamber, since the fuel is injected into the chamber. Only a small part of the fuel is burned in this chamber because there is only a limited amount of oxygen present with which it can unite. The small predetermined amount that burns creates heat which, in turn, creates high pressure within the precombustion chamber. As injection continues, this high pressure forces the fuel at great velocity into the cylinder. There is ample oxygen present in the cylinder to burn all the fuel completely, regardless of the speed or load under which the engine is operating. Fuel injection pressures need not be as high with this type of chamber as in the open type. A coarser spray is satisfactory because the function of the chamber is to vaporize the fuel further before it enters the cylinder.

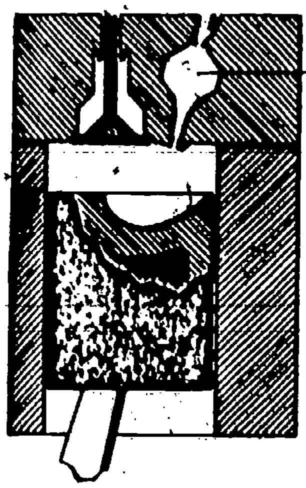

Fig 3-15. Diesel engine precombustion chamber.

c. Turbulence chamber. The turbulence chamber (fig 3-16) is similar in appearance to the precombustion chamber, but its function is different. There is very little clearance between the top of the piston and the head, so that a high percentage of the air between the piston and the cylinder head is forced into the turbulence chamber during the compression stroke. The chamber is usually spherical. The opening through which the air must pass becomes smaller as the piston reaches the top of the stroke, thereby increasing the velocity of the air in the chamber. This turbulence speed is approximately 50 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is the greatest. This insures a thorough mixing of the fuel and the air with the result that the greater part of combustion takes place in the turbulence chamber itself. The pressure created by the expansion of the burning gases is the force that drives the piston downward on the power stroke.

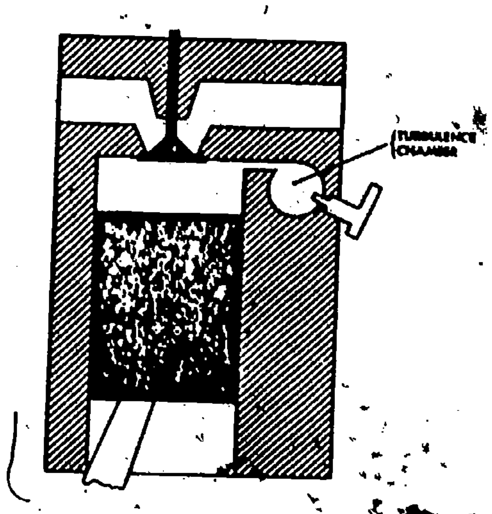

Fig 3-16. Diesel engine turbulence chamber.

d. Divided chamber. The divided chamber, or combination precombustion chamber and turbulence chamber, probably is better known by the trade name Lanova combustion chamber. Like the open chamber combustion system, the main volume of air remains and the principal combustion takes place in the main combustion chamber, but unlike the open chamber combustion system, the combustion is controlled. Like the turbulence-chamber type, the Lanova system depends on a high degree of turbulence to promote thorough mixing and distribution of the fuel and air, but unlike it, this entails no increase in pumping losses. Ninety percent of the combustion chamber is directly in the path of the in-and-out movement of the valves. The turbulence in the Lanova system is dependent upon thermal expansion and not on engine speed as are the other systems.

Primarily, the Lanova system involves the combination of the figure-8 shaped combustion chamber situated centrally over the piston on a small air chamber known as the energy cell, as shown in figures 3-17 and 3-18. In it latest development, this energy cell is composed of two separate chambers, an inner and an outer. The inner chamber, which is the smaller of the two, opens into the narrow throat between the two lobes of the main combustion chamber through a funnel-shaped venturi passage. The larger outer chamber communicates with the inner one through a second venturi. Directly opposite the energy cell is the injection nozzle.

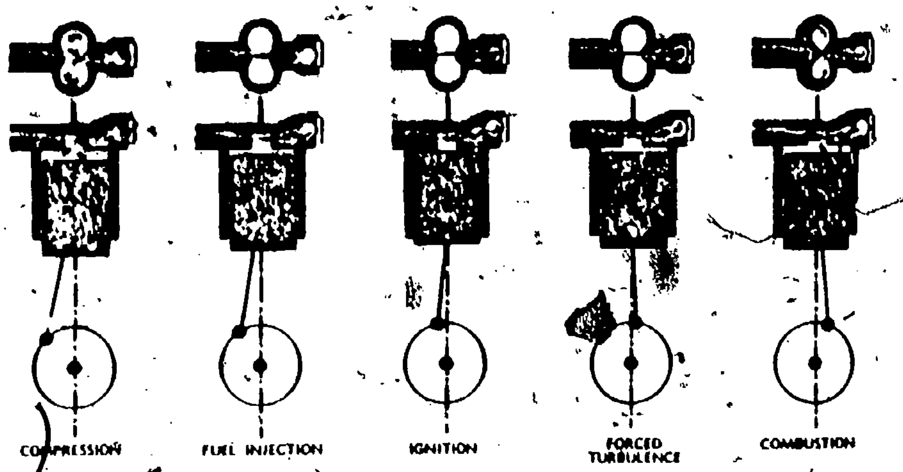

Fig 3-17. Lanova divided chamber--piston positions.

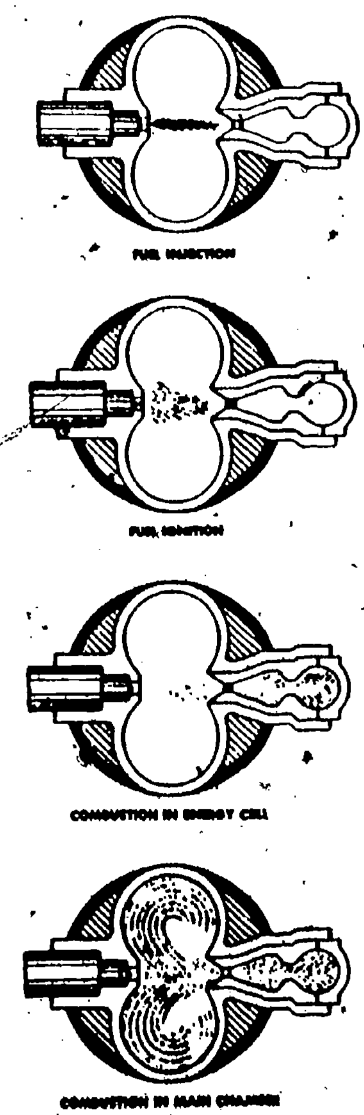

Fig 3-18. Lanova divided chamber--fuel combustion.

During the compression stroke, about 10 percent of the total compressed volume passes into the energy cell, the remainder staying in the figure-8 shaped combustion chamber. The fuel is injected in the form of a pencil stream which passes directly across the narrow throat of the combustion chamber, most of it penetrating into the energy cell. A small portion of the boundary layer follows the curvature of the combustion chamber lobes and swirls into vortexes within them, thus indicating a weak combustion. The fuel entering the energy cell is trapped for the most part in the small outer cell, but a small part passes into the larger outer cell where it meets a sufficient quantity of superheated air to explode violently. This explosion produces an extremely rapid rise to high pressure within the steel energy cell. This pressure blows the main body of the fuel lying in the inner cell back into the main combustion chamber where it meets the main body of air. Here, because of the shape of the chamber, it swirls around an exceedingly high rate of turbulence, thus burning continuously as it issues from the energy cell. Because of the restriction of the two venturi connecting the energy cells, the blowback of fuel into the combustion chamber is controlled so that this operation consumes an appreciable period of time. This control of the fuel produces a prolonged and smooth combustion in which the rate of pressure rise on the piston is gradual

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Define the following:

   Cleanliness ______________________________

   Viscosity ______________________________

   Ignition Quality ______________________________

2. The simplest combustion chamber is the

   a. precombustion chamber.
   b. turbulence chamber.
   c. open chamber.
   d. divided chamber.

3. The combustion chamber with an auxiliary chamber at the top of the cylinder is the

   a. pre-combustion chamber.
   d. turbulence chamber.
   c. open chamber.
   d. divided chamber.

4. The chamber that has very little clearance between the top of the cylinder and the head is the

   a. precombustion chamber.
   b. turbulence chamber.
   c. open chamber.
   d. divided chamber.

5. The combustion chamber that has two rounded spaces shaped like a figure eight cast in the cylinder head is the

   a. precombustion chamber.
   b. turbulence chamber.
   c. open chamber.
   d. divided chamber.

6. The combustion chamber that is better known as the Lanova energy cell is the

   a. precombustion chamber.
   b. turbulence chamber.
   c. open chamber.
   d. divided chamber.

Work Unit 3-4. DIESEL ENGINE LOADS

DEFINE TWO TYPES OF ENGINE LOADS.

To control an engine means to keep it running at a desired speed, either in accordance with or regardless of the changes in the load carried by the engine. The control of an engine depends upon two factors: its own performance characteristics and the type of load which it drives. The total load of an engine consists of two parts (1) the internal load, or friction horsepower due to the friction, windage, and pumping losses within the engine itself and required by the attached engine-driven auxilaries; and (2) the external load, connected to the main drive shaft which takes the useful or brake horsepower output of the engine.

As explained earlier, the indicated horsepower is equal to the total load or the sum of the friction and brake horsepower. The indicated horsepower necessary to balance this total load at any speed depends upon the pressures developed during combustion of the fuel and the resulting mean indicated pressure. The combustion process and the mean pressure developed by it depend primarily upon the quantity of fuel injected on the firing stroke, if all other conditions remain substantially the same.

Most diesel fuel-injection systems are designed so that the amount of fuel delivered at a fixed setting or position of the fuel control is approximately the same per injection regardless of the engine speed. The total load at any speed, therefore, can be balanced by regulating the fuel control to the setting required to give the necessary mean indicated pressure. In other words, the setting of the fuel control regulates the speed of a diesel engine under any load.

The frictional forces or the internal load of an engine increase rapidly with an increase in the engine speed. This also is usually true of the external load, so that, in general, greater mean indicated pressures are required to balance the total load at higher speeds. An example of this type of external load is a direct-connected propeller. The sum of the power required to drive a propeller and the friction power gives the total power required from the engine at various speeds. With this type of total load, the speed of a diesel engine will increase only if more fuel is injected and will decrease if less fuel is injected. This type of load, which increases with speed more rapidly than the engine output increases with speed, is essentially self-governing under normal operation. This is true because any fuel setting will provide the combustion pressures which balance the total load on the engine only at one speed. The speed under these conditions, then, will vary in proportion to the fuel setting. If the load conditions were perfectly constant, manual regulation of the fuel control would provide adequate speed control.

When an engine is operating at constant speed, the internal load remains approximately the same. Under these conditions, the combustion pressures necessary to balance the total load will vary directly with changes in the external load. An example of this type of load is a direct-connected electric generator which normally must operate at constant speed. An increase or decrease in electric load connected to the generator will require correspondingly greater or reduced combustion pressures to keep the engine speed constant. Therefore, in order to maintain constant speed operation, it is necessary to change the amount of fuel injected in proportion to the external load changes.

When two or more engines are connected electrically or mechanically to the same load, they cannot independently vary in speed. Examples of this type of load are the multiple-unit diesel-electric power systems and the multiple-unit propulsion systems in which two or more engines drive a single propeller shaft. Under these conditions, the fuel injected in each engine must be regulated so that the total load is distributed proportionally between the engines while their relative speeds are maintained.

When an engine is running without a load at slow idling speed, the friction power is relatively small. The quantity of fuel, therefore, which must be injected per firing stroke to balance the internal load is extremely small, especially in small engine cylinders. These small fuel quantities are difficult to inject regularly and as a result the idle-speed stability is poor; i.e., the engine speed will vary. Furthermore, a slight adjustment of the fuel-control setting at idle position will cause relatively large changes in the amount of fuel injected. This, in turn, results in comparatively large changes in engine speed, making it very difficult to regulate an engine under idling conditions. The problem of regulating the fuel control to meet these various operating loads is often further complicated by certain characteristics of the fuel-injection system itself. Under these conditions it is not possible to regulate manually the fuel control of a diesel engine satisfactorily and some type of governor is necessary.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Define two types of engine loads.

   a. Internal loads ____________________

   b. External loads ____________________

Work Unit 3-5. FUNCTIONS AND USAGES OF THE GOVERNOR ON THE DIESEL ENGINE

DESCRIBE THE PRIMARY FUNCTION OF THE GOVERNOR.

DESCRIBE THE FOUR CLASSIFICATIONS OF GOVERNORS.

IDENTIFY SIX GOVERNING CHARACTERISTICS.

DESCRIBE TWO TYPES OF GOVERNORS.

GIVEN FOUR TYPES OF MECHANICAL AND HYDRAULIC GOVERNORS AND FOUR ILLUSTRATIONS DEPICTING FOUR GOVERNOR ASSEMBLIES, MATCH EACH GOVERNOR WITH THE PROPER ILLUSTRATION.

Governors are found on all the diesel engines that we have in the Marine Corps. There are many different types and uses, too many to cover in depth. In the following pages, you will learn the basics that will apply to the majority of governors we presently use.

a. Functions. A governor is essentially a speed-sensitive device designed to control the speed of an engine under varying load conditions. The type of load and the degree of control desired determine the kind of governor to be used. Governors for diesel engines may be classified according to their primary functions as follows:

(1) Constant-speed gonvernors: to maintain the same engine speed from no load to full load.

(2) Variable-speed governors: to maintain any desired engine speed from idle to top speed.

(3) Speed-limiting governors: to control the minimum engine speed or to limit its maximum speed only.

(4) Load-limiting governors: to limit the load which the engine will take at various speeds.

Some governors are designed to perform two or more of the above functions by incorporating their operating mechanics in the same unit.

b. Governing characteristics. Governors employed for controlling the speed of diesel engines must have certain characteristics to fit the type of load which the engine is to drive. The principal characteristics which determine the degree of governor control of the engine may be defined as follows:

- Speed drop is the decrease in speed of the engine from no load to full load expressed in rpm, or as a percent of normal or average speed, usually the latter.

- Isochronous governing is maintaining the speed of the engine truly constant, regardless of the load--in other words, with perfect speed regulation or zero speed drop.

- Hunting is the continuous fluctuation of the engine speed, slowing down and speeding up, form the desired speed due to overcontrol by the governor.

- Stability is the ability of the governor to maintain the desired engine speed without fluctuations or hunting.

- Sensitivity is the change in speed required before the governor will make a corrective movement of the fuel control and is generally expressed as a percent of the normal or average speed.

- Promptness is the speed of action of the governor. It may be expressed in terms of the time in seconds required for the governors to move the fuel control from no-load to full-load position. Promptness depends upon the power of the governor--the greater the power, the shorter the time required to overcome the resistances.

(1) Hunting. It is said that a governor is hunting if its flyweights and control sleeve do not assume at once a definite position corresponding to the speed, but move up and down. Hunting occurs due to a lag in action of the control mechanism, indicating poor sensitivity and resulting in a large speed change before any governor action takes place. The engine will slow down or speed up too much before any corrective regulation of the fuel control is made. When the controls begin to move, they will continue to move even after the correct speed has been obtained. This will result in an over correction of the engine speed in the opposite direction. After that the governor will start to act in the opposite direction. The engine speed will fluctuate or hunt to this over control by the governor.

Hunting may also occur due to the slowness of action of the corrective control mechanism as indicated by slow reaction time, if the power of the governor is too small. This lag in action will permit too great a change in engine speed to occur during a change in engine load before the proper correction is made, even if the governor is sufficiently sensitive. Due to this lag, the speed of the engine will be changed too much in the opposite direction before the governor action stops. Slow reaction time thus results in hunting, due to overcontrol of the governor in the same manner as with poor sensitivity. Any method of reducing the friction in the operating mechanisms of a governor will tend to increase its stability.

(2) Sensitivity. If an engine is running and its governor is in equilibrium, it requires a considerable change in engine speed, due to a change in the load, before the governor will begin to act and adjust the fuel delivery to correspond to the changed load. This lag in governor action is caused by friction and lost motion in the governing mechanism and is called sensitivity. Sensitivity is determined by testing an engine first with an increasing and then with a decreasing load. Due to lag in the governor action, the speed corresponding to a certain load which was obtained when the load was increasing is always lower than the speed corresponding to the same load when decreasing. Sensitivity is expressed numerically as the difference of the two speeds divided by their average, in percent. Thus, the greater this figure, the less satisfactory is the sensitivity of the governor. Usually the difference between the two speeds is greatest near half-load conditions.

c. Types of governors. The types of governors in which the centrifugal force of the rotating weight is balanced by a helical coil spring are commonly known as spring-loaded centrifugal governors. Centrifugal governors may be classified into two main types depending upon the regulating force employed to operate the fuel control. These types are:

- Mechanical governors in which the centrifugal force of the rotating weights directly regulates the fuel supply by means of a mechanical linkage which operates the fuel-control mechanism.

- Hydraulic governors in which the centrifugal force of the rotating weights regulates the fuel supply indirectly by moving a hydraulic pilot valve controlling oil under pressure, which operates the fuel-control mechanism.

(1) Spring -loaded centrifugal governor. A spring-loaded centrifugal governor is illustrated by the diagram in figure 3-19, showing the low- and high-speed positions of the weights. The governor has two rotating weights called flyweights or flyballs. These are fastened to the upper ends of ball-crank levers mounted on pivots at their corners to the yoke. The yoke is usually connected by gears to revolve with the engine. The inner ends of the toes of the flyweight levers bear against the thrust bearing of the control sleeve, which operates the fuel-regulating mechanism. The speeder spring, often referred to simply as the governor spring, bears against the upper end of the control sleeve and tends to move it, together with the fuel-regulating mechanism, downward in the direction to supply more fuel. The centrifugal force acting outward on the flyweights has tendency to move the control sleeve, together with the fuel-regulating mechanism, upward against the action of the spring, in the direction to supply less fuel. When the centrifugal force of the rotating flyweights is exactly balanced by the force of the spring, the control sleeve assumes a fixed position, the fuel-regulating mechanism remains at a certain setting, and the engine speed remains constant so long as the load does not change.

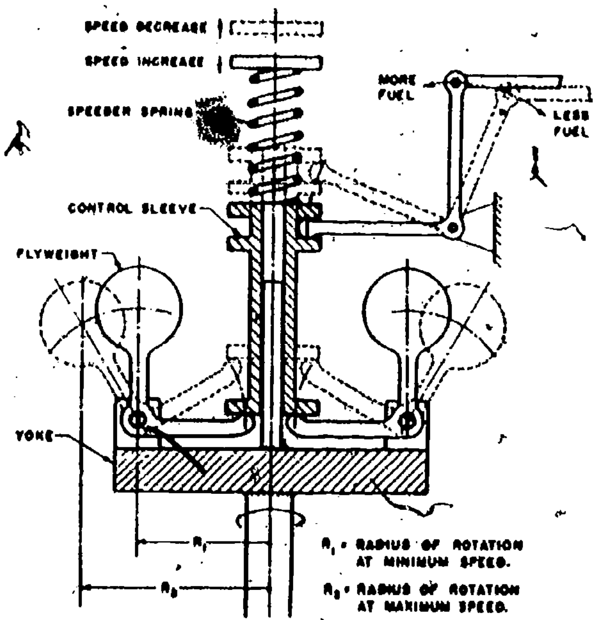

Fig 3-19. Elementary spring-loaded centrifugal governor.

If, however, the load on the engine decreases, the engine will begin to speed up because the fuel-regulating setting for the original load will supply more fuel than is necessary for the reduced load. As the speed of the engine increases, it drives the governor faster also and increases the centrifugal force of the flyweights. This increase in centrifugal force moves the control sleeve in the direction to supply less fuel, compressing the spring further until the centrifugal force again is balanced by the increase in spring force. The reduction in fuel supplied prevents the engine from increasing in speed more than is necessary for the governor to operate the fuel-control mechanism the amount required to balance the reduced load.

If, on the other hand, the load on the engine increases, the engine will begin to slow down because the fuel supplied for the original load is less than is necessary for the increased load. As the speed of the engine decreases, the centrifugal force of the governor flyweights also decreases. This unbalances the spring force which then moves the control sleeve in the direction to supply more fuel, until the decrease in centrifugal force is balanced by the decrease in spring force due to the increase in its length.

(a) Constant-speed governors. With mechanical governors in which the control sleeve is directly connected to the fuel-regulating mechanism, the spring length must be changed a certain amount for every change in the setting of the fuel control. This requires a centrifugal force different from that of the flyweights, and, consequently, a different engine speed in order for the governor to balance every change in load. Therefore, all mechanical governors have a speed drop and so cannot provide isochronous governing. By proper design, however, the speed drop of mechanical governors can be held to four to five percent, so that for practical purposes such governors may be classed as the constant-speed type.

(b) Variable-speed governors. If the control speed of an engine must be changed while in operation, a variable-speed governor is required which may be adjusted to maintain any desired control speed within the operating range of the engine.

The simplest method of obtaining variable-speed governing with spring-loaded centrifugal governors is to provide a means for varying the initial compression of the speeder spring as shown by the diagram in figure 3-19. Thus, if the initial spring force is increased by compressing the spring to a shorter length, the engine speed must increase before the centrifugal force developed by the flyweights can balance the greater spring force. If the initial compression of the spring is decreased, the engine speed necessary for the centrifugal force of the flyweights to balance the reduced force will be decreased.

(c) Two-speed governors. In many installations, it is desirable that the governor control the engine so that it idles at low speeds rather than at high speeds under no-load conditions. In order to accomplish this with a mechanical governor it is necessary to provide two different springs. One is a soft spring, which takes a small force to compress it per inch, to provide better sensitivity and lower speed drop at low speeds; the other is a stiff spring, which takes a larger force to compress it per inch, to provide sufficient stability at high speeds.

The springs must be arranged to act either singly or in combination. An example of an elementary form of this type of governor is shown in figure 3-20. For low-speed operation, the governor control is put in the position in which only the soft inner spring is acting, thereby providing better sensitivity and speed regulation under idle conditions. For high-speed operation, the governor control is put in the position in which both springs must act together, which provides better control under full-speed conditions.

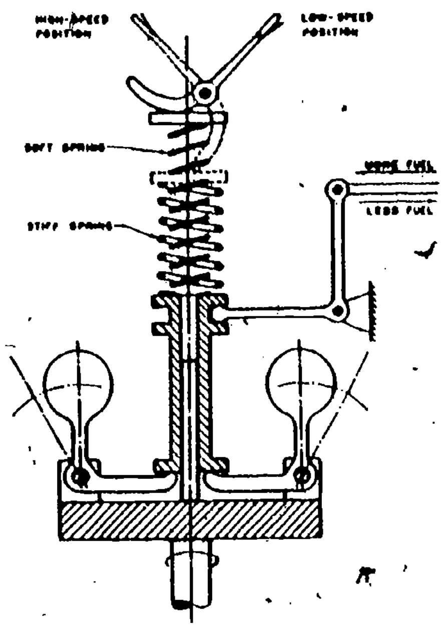

Fig 3-20. Two-speed centrifugal governor.

(d) Influence of friction. Friction has a pronounced effect on the characteristics of governors. The friction in a governor includes all the forces which oppose the motion of the control sleeve and the fuel-control mechanism. In a spring-loaded centrifugal governor, the force to move the control sleeve must be supplie by the difference between the centrifugal force of the flyweight and the force of the speeder spring during a period of unbalance. In other words, the change in speed necessary to actuate the governor or make it operate depends directly upon the total frictional resistance which oppose the governor action. Any methods of decreasing the forces which must be overcome by a governor to operate the fuel-control mechanism will, therefore, increase its sensitivity.

Every governor depends upon a change in speed for its corrective action. The extent of the speed change necessary to produce this action determines the amount of the resulting movement of the control mechanism. Thus, the more sensitive the governor, the less will be the corrective action required after a change of the engine load. The rapidity of the control movement, which depends on the promptness of the governor action, also influences the amount of corrective action required when the speed changes. Both these characteristics affect the stability or steadiness of the governor by their effect on hunting.

(e) Shortcomings. Mechanical governors have the following shortcomings:

1 They have poor sensitivity, since the speed sensitive element also must furnish the force to move the engine speed control.

2 Their power is relatively small unless they are excessively large.

3 They have an unavoidable speed drop and, therefore, cannot provide real constant speeds necessary when driving A.C. generators which must be held to exact speeds.

Practically all these shortcomings of mechanical governors may be overcome through the use of hydraulic governors.

(2) Elementary hyraulic governors. The only method of obtaining truly constant speed or isochronous governing from a spring-loaded centrifugal governor is to restore the speeder spring to its original tension after every speed change regardless of the movement of the fuel-control mechanism. When the speeder spring is kept under the same tension, the centrifugal force of the flyweights necessary to balance it will be developed only at one corresponding speed. The governor, therefore, must regulate the fuel supply to keep the engine at the same speed regardless of load. This can be accomplished with a spring-loaded centrifugal governor by using an indirect connection between the control sleeve and the fuel-control mechanism. Such an indirect connection to operate the fuel-control mechanism may be provided by an independent energy source. In hydraulic governors, this is most conveniently furnished by oil pressure produced by a special pump.

An elementary form of hydraulic governor is illustrated in figure 3-21. The speed-sensitive element in the governor is a pair of spring-loaded flyweights and a helical coil spring. The speed-sensitive element operated a pilot valve which controls the flow of oil to and from a hydraulic power piston shown at right. When the governor is operating at control speed, the lower end of the plunger of the pilot valve registers with and just closes the ports in the pilot-valve bushing and there is no flow of oil (fig 3-21). When the governor speed rises above the speed at which the pilot ports are closed, the flyweights move out, raising the pilot-valve plunger (fig 3-21). This opens the port from the power piston to drain into the sump. The spring on the power piston forces the power piston down toward no-load positions. The oil displace drains through the center of the pilot-valve bushing. The fuel-control mechanism is connected to the power-piston rod end. When the governor speed decreases below the control speed, the flyweights move in, lowering the pilot-valve plunger (fig 3-21). This opens the port to the power piston and connects it to a supply of oil pressure which acts on the power piston, forcing it up toward full-load position.

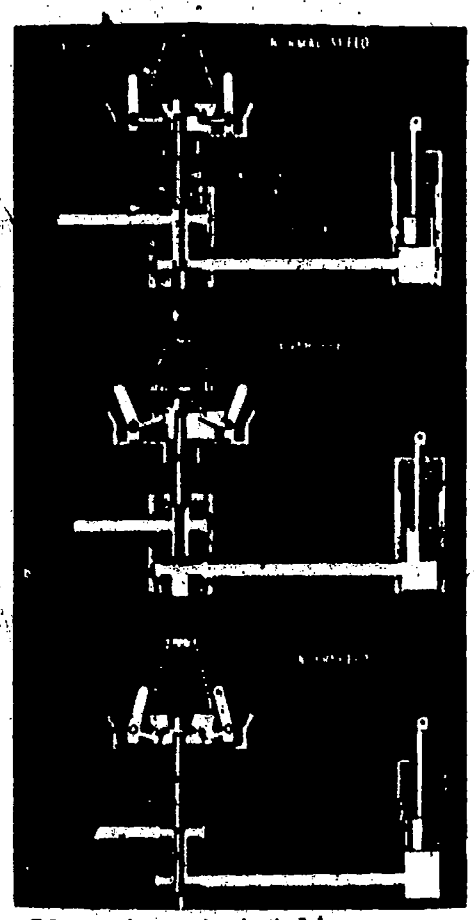

Fig 3-21. Elementary hydraulic governor.

The length of the lower end of the pilot-valve plunger is exactly the same as the width of the ports in the pilot-valve bushing. Since the plunger is moved directly by the speed-sensitive element, there is only one speed at which the ports will stay closed. Figure 3-21 shows an elementary isochronous or constant-speed hydraulic governor. From the above discussion it is clear that with this governor there is no direct relation between the governor speed and the setting of the fuel controls. If the governor speed drops below the fixed or control speed, the power piston will be moved upward and will increase the fuel supply. If the governor speed rises above control speed, the power piston will be moved down toward decreased fuel. The power piston will be set at any required position between no-load and full-load. The engine will operate, under equilibrium conditions exactly at control speed.

The pilot valves are constructed so that the fluid pressures are balanced and produce no thrust on the plungers. The oil pressure applied to the recess of the pilot-valve plunger in figure 3-21 acts equally on the ring-shaped areas at both ends and no axial force is produced. The plungers in governor pilot valves are usually rotated in the bushing to maintain an oil film between these parts and thus reduce friction and prevent sticking. The holes in the pilot-valve sleeve are arranged in pairs so that there is no side thrust exerted on the plunger. The lower fitted length of the plunger, called the land, exactly covers the holes in the bushing, so that slight movement of the plunger starts a change in the fuel setting. All of these factors contribute to the high sensitivity of hydraulic governors, some of which will respond to a speed change of 0.01 percent. This high sensitivity makes it possible for a hydraulic governor to maintain a control speed with great precision. Sensitivity is also important because it permits the governor to act immediately when a speed change is just beginning and thus prevents developing of larger speed fluctuations.

(3) Actual hydraulic governors. As previously explained, hunting due to overshooting will result if an engine returns to control speed after a speed change and the fuel controls are set as required during the speed change. The simple hydraulic governor has the same fault. As long as the speed is above or below the control speed, the simple hydraulic governor will continue to adjust the fuel system to decrease or increase the delivery of fuel to the engine. There is always a lag between the moment that a change in fuel setting is made and the time the engine reaches a new equilibrium speed. Therefore, the engine will always return to control speed with the fuel delivery overcorrected and hunting due to overshooting will result.

To avoid over shooting, a governor mechanism must anticipate the return to normal speed and must discontinue changing the fuel control setting slightly before the new setting required for sustaining the control speed has actually been reached. A mechanism which enables a governor to anticipate the return to control is termed a compensating device which every hydraulic governor must have.

The simplest method of compensating for a hydraulic governor is to provide a speed drop with an increase in load. While this method does prevent truly isochronous governing with this type of hydraulic governor, the speed drop can be held to minimum and the governor still possesses the advantages of fine sensitivity and large regulating forces.

One mechanism employed to provide this compensation is illustrated in figure 3-22. The lever controlling the tension of the speeder spring is moved by linkage with the fuel-control mechanism. In operation, the movement of the hydraulic power piston, which regulates the fuel-control setting, also acts to change the tension of the speeder spring. Thus, an increase in fuel corresponding to an increase in load is produced by an upward motion of the power piston. This motion raises the right end of a lever fastened to the end of a shaft and thus turns the shaft which operates the fuel-control mechanism. At the same time, a pin in the fuel-control lever located in a slot of the forked lever slightly lifts the upper spring and thus decreases the spring force. This lowered spring force will require less centrifugal force, and, consequently, a lower control speed is necessary for balance. By adjusting the leverage of the linkage between the fuel-control and the speeder spring, depending upon the characteristics of the engine, the amount of speed drop necessary to obtain the compensation required will be provided and stable operation will result.

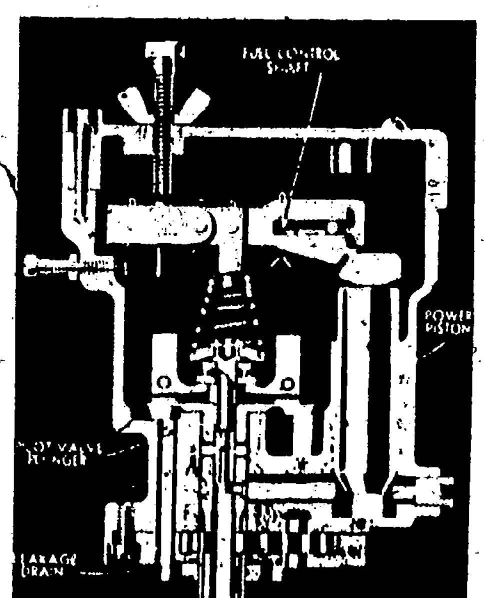

Fig 3-22. Hydraulic governor with compensation.

(a) Isochronous governor compensation. In order to obtain compensation of hydraulic governors and yet maintain truly isochronous governing, another method must be used. One mechanism which provides compensation without speed drop is illustrated in figure 3-23. The pilot-valve plunger operates in a movable pilot-valve bushing in which are located the ports controlling the oil flow. The movement of this valve bushing during a speed change is controlled by the receiving compensating piston to which it is attached. It should be noted that under constant-speed operation, the compensating spring will hold the pilot-valve bushing in its central position. Thus, until there is an actual change in the fuel-control mechanism, the action of the pilot valve is the same as in the simple hydraulic governor shown in figure 3-21. The compensating action of the valve bushing is controlled hydraulically by transfer and by leakage of oil pressure between the compensating receiving piston and the compensating actuating piston. The rate of compensation is adjusted to fit the engine characteristics by regulating the oil leakage through the compensation valves.

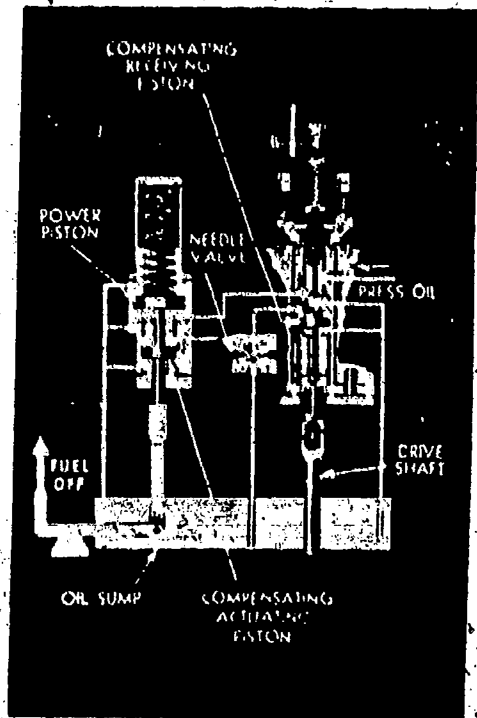

Fig 3-23. Hydraulic governor with speed drop.

The operation of this hydraulic compensating device during the change in load may be explained as follows: when the load on the engine increase, the speed will start to decrease, causing the speeder spring to overbalance the reduced centrifugal force of the flyballs. This action moves the pilot-valve plunger down, as shown in figure 3-23, so that the control port in the bushing, which is normally covered by the lower land on the pilot-valve plunger, is uncovered and put in connection with the supply of oil under pressure. The oil under pressure then flows through the open control port to the bottom of the power-piston cylinder, begins to lift the power piston, and begins to move the fuel control toward more fuel in the same manner as in an elementary hydraulic governor. In this governor, however, the actuating piston is connected to the power piston and thus moves up with it. As the actuating piston moves up, it forces the oil above it through passages, partly to the compensation needle valves and partly to the top of the receiving piston. During a rapid movement of the power piston, however, very little oil can leak past the needle valves. When the power piston first moves up, the oil from the actuating piston will force the receiving piston down against the action of the compensating spring. The pilot-valve bushing will thus move down as the fuel-control mechanism is moved toward less fuel. When the pilot-valve bushing moves down, the control port will come opposite and again be covered by the lower land on the pilot-valve plunger, which previously had been moved down under the action of the speeder spring. This will cut off the oil pressure to the power piston and prevent further increase in the fuel supply.

When the fuel supply is increased, however, the speed of the engine will start to pick up and as the engine speed gradually returns to normal, the centrifugal force of the flyweights will move the pilot-valve plunger back to its normal central position. By proper adjustment of the compensation needle valves, the oil above the receiving piston can be made to leak out at a certain rate. This will allow the compensating spring to act gradually to move the receiving piston up as the oil is forced back to the needle valves. Thus, the pilot-valve bushing may be returned to its normal central position at the same rate as the pilot-valve plunger, so that the central port is kept covered and no further regulation of the fuel control takes place.

When there is a decrease in load and the engine starts to speed up, the same sequence of operation takes place in the opposite direction. In this case, the increased centrifugal force due to the increase in engine speed moves the pilot-valve plunger up. This uncovers the control port and allows the oil trapped in the bottom of the power-piston cylinder to drain back to the oil sump. The power pistons thus moves down under the action of the power spring and moves the fuel control in the direction toward less fuel. As the power piston moves down to decrease the fuel, the actuating piston is also moved down with it. This movement draws oil partly through the compensation needle valves and partly from above the receiving piston. If this action occurs rapidly, very little oil is drawn through the needle valves, and thus the receiving piston is moved up against the action of the compensating spring. Since the pilot-valve bushing also moves up with the receiving piston, the control port will be closed when it comes opposite the land on the pilot-valve plunger. This will cut off the oil line from the bottom of the power-piston cylinder, thus trapping the oil and preventing further decrease in the fuel supply. When the fuel supply is decreased, however, the speed of the engine will start to slow down. As the speed gradually returns to normal, the flyweights move in and the pilot-valve plunger will return to its normal control position. During the speed correction, the compensating spring begins to move the pilot-valve bushing back to its central position also. As the speed decreases, oil will be draw up from the oil sump to permit the receiving piston to return to its normal central position at the same rate as the pilot-valve plunger. By proper needle-valve adjustment, the pilot-valve plunger may be returned to its normal central positions so that after the initial fuel change, the control port is closed and no further fuel regulation takes place.

If the power piston is moved the first time to give exactly the fuel setting required to balance the change in load before the control port is closed by the compensating system and the port remains closed while the engine returns to control speed, there is no hunting at all. This condition is known as dead-beat governoring and is difficult to obtain in practice. However, if the governor compensation is adjusted correctly, only a slight amount of hunting of [illegible] magnitude will occur following a load change which will quickly be damped out, resulting in stable operation throughout the operating range.

(b) Load distribution. An engine equipped with an isochronous governor can carry any load between no load and the maximum load or overload that the governor will permit. If two or more engines are coupled to a single load, they cannot all be equipped with truly isochronous governors unless the engines are connected to electric generators having special characteristics which allow for operation in parallel with isochronous governors. Since isochronous governors permit any fuel setting within the capacity of the systems, providing the speed remains constant, they are incapable of distributing the load between two engines in a predictable manner. Engines which are to be operated in parallel must use governors with a speed droop. Not more than one engine in such a system may be governed truly isochronously. A simple method of introducing speed drop is to use a suitable linkage between the fuel-control mechanism and the speeder-spring compression regulator, such as shown in figure 3-22. A similar mechanism may be attached to a compensating isochronous hydraulic governor to obtain speed drop. Adjustment of the lever linkage may be made to obtain the desired speed drop required to distribute the load adequately.

(4) Load-limit governors. At any particular engine speed, there is a rather definite maximum sustained load which an engine can carry without damage. An ordinary governor, whether isochronous or built with speed drop, is sensitive only to speed. If the engine slows down, the governor will increase the fuel supply even though this may overload the engine. To prevent the governor from increasing the fuel supply beyond that required for a safe load, the governor may be equipped with a maximum-fuel stop. If a fixed stop were used, it would permit the engine to be overloaded at low speeds if it were set to allow the maximum safe load at full speed. To give full protection throughout the full engine-speed range, and at the same time to allow the engine to develop its maximum permissible power, the governor may be equipped with a variable maximum-fuel stop which will permit the delivery of the maximum safe fuel supply at any engine speed. Such a device is know as a torque limiter.

The maximum fuel delivery permitted by a torque limiter may be set slightly below the smoke limit for the engine, so that the engine will automatically give practically smokeless operation.

If a very heavy load is put on an engine so that a maximum-fuel stop comes into operation, then the engine speed will drop below the governor control speed, and the engine will operate with a fixed rack setting as if it had no governor. Most types of loads demand less driving torque as speed decreases. In most cases the engine will be able to carry the load without stalling at some reduced speed. The engine will develop a somewhat reduced torque and a greatly reduced power as its speed decreases, but it will probably still be able to drive a ship or run an overload generator at some below-normal speed.

A typical load-limit governor is illustrated in figure 3-24. It consists of a spring-loaded centrifugal governor which operates a hydraulic pilot valve for controlling the load-limiting mechanism. This mechanism consists of a spring-loaded plunger or piston to whose right end is attached a stop or cam which limits the movement of the main fuel controls. There is also a sloping cam surface cut into the lower side of the load-limit piston on which rides the roller attached to the top of the speeder spring. The position of the load-limit piston thus controls the compression on the speeder spring. In operation, when the speed increases, the centrifugal forces of the flyweights moves the pilot-valve plunger up and uncovers the control port. This permits oil trapped in the load-limit cylinder to drain out and allows the spring-loaded piston to move to the left. This moves the load-limit stop to the position permitting maximum opening of the fuel controls. When the engine slows down, the pilot-valve plunger will move down and open the control port so that it connects with the supply of oil under pressure. The oil pressure acting on the load-limit piston will move it to the right until the control port is again covered. As the load-limit piston moves to the right, the roller riding on the piston cam surface will move up to reduce the speeder-spring compression so that the centrifugal force of the flyweights will be balanced at a lower speed. Thus, for every engine speed there is a corresponding position of the power piston which will provide the necessary spring compression to balance the centrifugal force of the flyweights and maintain the pilot-valve plunger in its control position covering the control port.

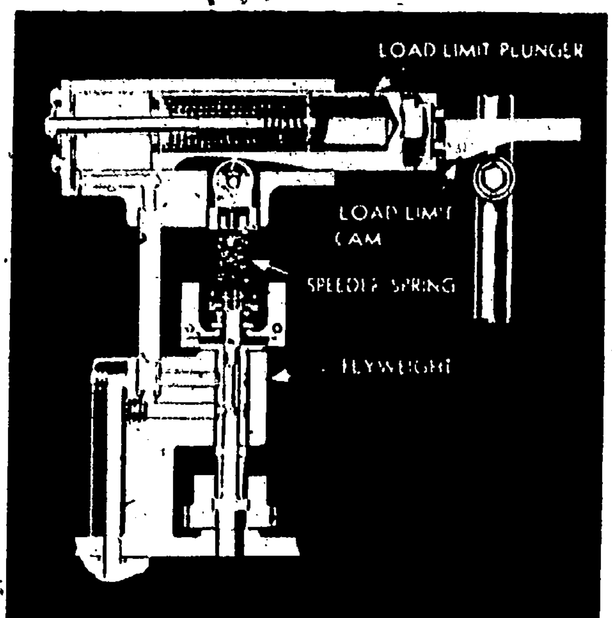

Fig 3-24. Load-limit hydraulic governor.

At very low speeds, the load-limit piston must be move all the way to the right before the speeder-spring compression can be reduced sufficiently to balance the low centrifugal force of the flyweights. As a result, the load-limit cam will stop the movement of the fuel control at its lowest limit by means of the steep slope on the end of the cam. This will prevent overloading of the engine at low speeds where the engine is more likely to smoke. By properly designing the slope of the load-limit cam, the load for each position corresponding to a certain engine speed will thus be limited to prevent over load.

(5) Over speed governors and trips. Over speed governors are employed as safety devices to protect engines from damage due to over speeding from any cause. When an engine is equipped with a regular speed governor of any type, the over speed governor will function only in the event of failure of operation of the regular governor. If the engine speed is manually controlled, the over speed governor will function in case the speed increases beyond a safe limit before the operator can control it.

Since over speed governors are essentially emergency controls, they must operate either to stop combustion or limit the combustion pressures in the engine cylinder in order to slow it down. This control of combustion may be obtained by either regulation of the fuel or air supply. Most over speed governors function to cut off or limit the fuel supply to the engine cylinders. In some two-stroke engines, however, it is possible for an engine to run away by burning lubricating oil which may happen to be taken in with the fresh air. Where this may occur, the governor is arranged to cut off the air supply to the cylinder and thus to stop the engine. Over speed governors which bring an engine to a full stop by cutting off all the fuel or air supply are commonly known as over speed trips. If the over speed control merely slows the engine down but allows it to continue to run at safe operating speeds, it is better termed an over speed governor.

Over speed governors and trips of all types depend upon a spring-loaded centrifugal-governor element for their action. The spring in this case is preloaded to a force which will overbalance the centrifugal force ofthe flyweights until the engine speed rises above the desired maximum. When the speed is reached, the centrifugal force overcomes the spring force and puts to action the controls which cut off or limit the air or fuel supply.

The actual operation of the fuel or air controls may be accomplished directly by the centrifugal force of the over speed governor, as in a mechanical governor, or it may be supplied by oil pressure, as in a hydraulic governor. In an overspeed trip, the shut-off control may be operated by the force of a power spring which is put under tension when the trip is manually reset and is held there by means of a latch. When the maximum speed limit is exceeded, a spring-loaded centrifugal flyweight will move out and trip the latch, allowing the power spring to operate the shut-off control.

EXERCISE: Answer the following questions and check your responses against those listed at the end of this study unit.

1. Describe the primary function of the governor.

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2. Describe the four classifications of governors.

   a. Constant-speed: ______________________

   b. Variable-speed: ______________________

   c. Speed-limiting: ______________________

   d. Load-limiting: ______________________

3. The decrease in the speed of the engine from no-load to full-load expressed in the rpm is called

   a. hunting.
   b. speed droop.
   c. sensitivity.
   d. stability.

4. Maintaining the speed truly constant, regardless of the load with perfect speed regulation is called

   a. promptness.
   b. hunting.
   c. sensitivity.
   d. isochronous governing.

5. The continuous fluctuation of the engine speed, slowing down and speeding up from the desired speed due to overcontrol by the governor is called

   a. hunting.
   b. promptness.
   c. stability.
   d. sensitivity.

6. The ability of the governor to maintain the desired speed without fluctuating is called

   a. hunting.
   b. promptness.
   c. stability.
   d. isochronous governing.

7. The change in speed before the governor will make a corrective movement of the fuel control is termed

   a. sensitivity.
   b. stability.
   c. promptness.
   d. isochronous governing.

8. The speed or action of the governor is called

   a. sensitivit.y
   c. stability.
   b. promptness.
   d. speed droop.

9. Describe two types of governors.

   a. Mechanical ______________________

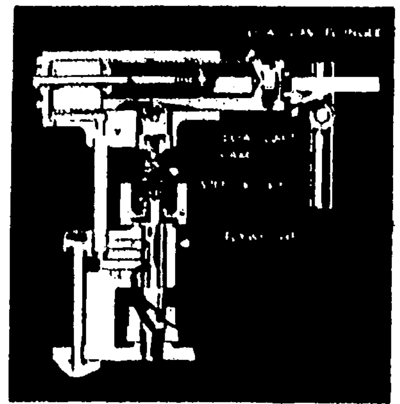
   b. Hydraulic ______________________

Matching: Column 1 (items 10-13) lists the four types of mechanical and hydraulic governors. Column 2 contains four illustrations depicting the four governor assemblies. Match the type of governor in column 1 with its appropriated illustrationn in column 2. Place your answers in the spaces provided.

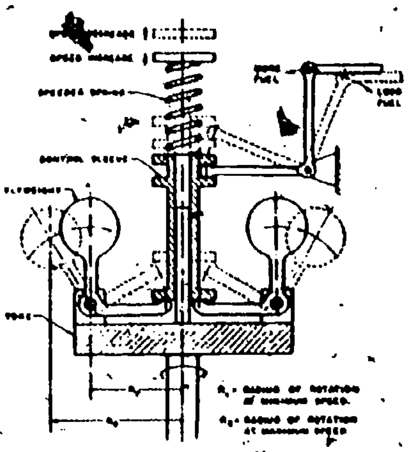
	Column 1 Governor
______ 10.	Spring loaded centrifugal
______ 11.	Elementary hydraulic
______ 12.	Hydraulic with compensation
______ 13.	Load-limt hydraulic

Column 2 Illustration

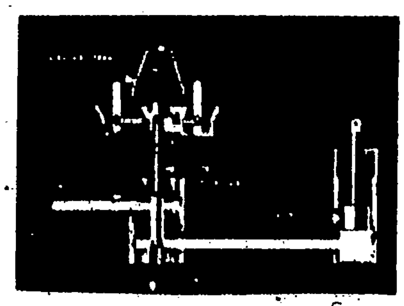
a.



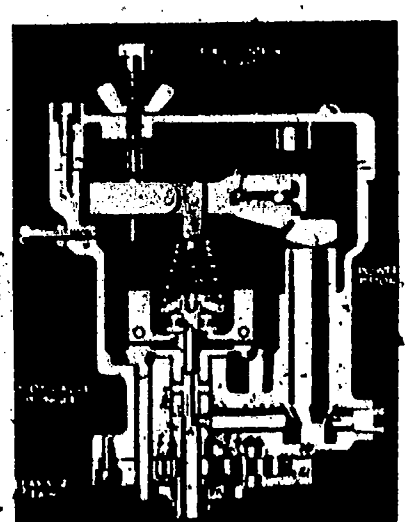
b.



c.



d.



Answers to Study Unit #3 Exercises

Work Unit 3-1.

1. a. Meter or measure the correct quantity of fuel.
   b. Time the fuel injection.
   c. Control the rate of injection.
   d. Atomize or break up the fuel into fine particles according to the type of combustion chamber.
   e. Properly distribute the fuel in the combustion chamber.
2. c.
3. Common-Rail, individual pump, and distributor

Work Unit 3-2.

1. c.
2. b.
3. b.
4. High pressure is obtained on the part of the plunger stroke, after the plunger has required a certain speed, and discarding the initial part of the stroke. The jerk pump then produces a sudden accleration in the line causing a jerk.
5. c.
6. The valve of the pintle nozzle is provided with a pin or pintle protruding from the hole in the bottom or the nozzle, in which there is a close fit. The fuel delivered by such a nozzle must pass through an annular or ring-shaped orifice.
7. In the hole-type nozzle, there may be one or several spray orifices in the form of straight round holes, drilled through the tip of the nozzle body below the valve seat.
8. d.
9. a.

Work Unit 3-3.

1. Cleanliness is the most necessary quality of diesel fuel. The fuel should not contain more than a trace of foreign substances or materials or problems with the fuel pump and injectors will occur. Water is more objectionable than dirt because while the dirt may be suspended for long periods, the water will cause a ragged operation and corrode the fuel system.
   Viscosity of an oil is an indication of its resistance to flow. The higher the viscosity, the greater the resistance to flow. Diesel fuel must have a low viscosity to flow at the lower temperatures that are encountered while having enough viscosity to lubricate the closely fitted fuel pump and injector plungers properly.
   Ignition Quality of a diesel fuel is its ability to ignite spontaneously under the conditions found in the engine cylinder. Instead of the octane rating found in gasoline, diesel is rated by cetane.
2. c.
3. a.
4. b.
5. d.
6. d.

Work Unit 3-4.

1. a. Friction horsepower due to the friction, windage, and pumping losses within the engine itself and required by the attached engine driven auxiliarys.
   b. The load connected to the main drive shaft which takes the useful or brake horsepower output of the engine.

Work Unit 3-5.

1. A governor is essentially a speed-sensitive device designed to control the speed of an engine under varying load conditions.
2. a. Constant-speed governors maintain the same engine speed from no-load to full-load.
   b. Variable-speed governors maintain any desired engine speed from idle to top speed.
   c. Speed-limiting governors control the minimum engine speed or limit its maximum speed only.
   d. Load-limiting governors limit the load which the engine will take at various speeds.

3. b.
4. d.
5. a.
6. c.
7. a.
8. c.
9. a. Mechanical governors are those in which the centrifugal force of the rotating weights directly regulates fuel supply by means of a mechanical linkage which operates the fuel-control mechanism.
   b. Hydraulic governors are those in which the centrifugal force of the rotating weights regulates the fuel supply indirectly by moving a hydraulic pilot valve controlling oil under pressure, which operates the fuel-control mechanism.
10. b.
11. c.
12. a.
13. d.

Review Lesson

Instructions: This review lesson is designed to aid you in preparing for your final examination. You should try to complete this lesson without the aid of reference materials, but if you do not know an answer, look it up and remember what it is. The enclosed answer sheet must be filled out according to the instructions on its reverse side and mailed to MCI using the envelope provided. The questions you miss will be listed with references on a feedback sheet (MCI-R69) which will be mailed to your commanding officer with your final examination. You should study the reference material for the questions you missed before taking the final examination.

A. Multiple Choice: Select the ONE answer which BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

1. In the diesel engine, work is obtained from burning the combustible fuel within the engine's

   a. precombustion chamber.
   b. cylinder head.
   c. cylinders.
   d. piston.

2. Which of the following is NOT a major advantage of the diesel engine?

   a. Higher reliability of operation
   b. Higher cost
   c. Lower fuel consumption per horsepower per hour
   d. Low fire hazard

3. One disadvantage of the diesel engine is its

   a. longer life span.
   b. higher torque (sustained).
   c. weight per horsepower per pound.
   d. power per pound.

4. The fuel is burned in the

   a. piston.
   b. cylinder.
   c. crankcase.
   d. valves.

5. A flywheel of sufficient mass which reduces speed fluctuations is fastened to the

   a. crankshaft.
   b. connecting rod.
   c. camshaft.
   d. piston.

6. A camshaft is driven from the crankshaft by a series of gears or the

   a. flywheel.
   b. timing chain.
   c. connecting rod.
   d. rocker arm.

7. Piston rings, lubricated with oil, provide a gas tight seal between the liner and the

   a. piston.
   b. cylinder head.
   c. cylinder.
   d. cam follower.

8. The terms single-acting, double-acting, and opposed piston are terms used for engines that are classified by their

   a. operating cycle.
   b. piston action.
   c. cylinder arrangement.
   d. method of fuel injection

9. All diesel engines be divided into ____ classes in relation to speed.

   a. 2
   b. 3
   c. 4
   d. 5

10. An engine that is classified by its method of fuel injection will use either an air or a ______________________ injection system.

a. solid
b. multiple plunger
c. unit injection
d. distributor

11. Bore is the diameter of the cylinder while stroke is the

a. length of the connecting rod.
b. diameter of the piston.
c. distance the piston moves.
d. volume of space the piston displaces.

12. The volume of space that the piston displaces as it moves from BDC to TDC is known as

a. bore and stroke.
b. vacuum.
c. piston displacement.
d. volumetric efficiency.

13. When the piston starts to move downward in the cylinder on the intake stroke, it produces

a. combustion.
b. exhaust.
c. vacuum.
d. pressure

14. Volumetric efficiency is the ratio between the amount of fuel-air mixture that enters the cylinder and the amount

a. of escaping fuel air mixture.
b. that could enter under ideal conditions.
c. of pressure within the cylinder.
d. of power produced.

15. Volumetric efficiency can be increased by using a blower or a(n)

a. fuel with a lower cetane rating.
b. supercharger on the diesel engine.
c. air-compressing device.
d. lower fuel-air mixture.

16. The movement of a body against an opposing force is defined as

a. energy.
b. work.
c. power.
d. force.

17. The faster a tank travels, the more work it can do as it pushes over trees. This is due to more ______________ stored in the tank.

a. energy
b. fuel
c. power
d. work

18. The rate of work is identified as being

a. energy.
b. foot-pounds.
c. power.
d. horsepower.

19. The dynamometer is essentially a dynamo of a special type that can

a. absorb all the power the engine can produce.
b. drive equipment exerting enormous power.
c. be made of a series of wooden blocks around a flywheel.
d. be less complicated, although less flexible, than a prony brake.

20. The effect which rotates or tends to rotate a body is called

a. work.
b. energy.
c. power.
d. torque.

21. When both torque and speed are on the increase, as in the speed range of 1,200 to 1,600 rpm, then horsepower

a. drops gradually.
b. drops sharply.
c. increases gradually.
d. increases sharply.

22. Resistance to movement is called

a. surgence.
b. friction.
d. drag.
d. obstuction.

23. The mechanical efficiency of the engine is the relationship between the power developed in the engine cylinder and the power delivered by the engine is ________________; the power delivered by the engine is

a. brake horsepower; indicated horsepower.
b. mechanical efficiency; thermal efficiency.
c. indicated horsepower; brake horsepower.
d. thermal efficiency; mechanical efficiency.

24. The relationship between the fuel input and the power output is called

a. efficiency.
b. thermal efficiency.
c. mechanical efficiency.
d. power efficiency.

25. The three types of cylinder liners discussed in this course are dry liner, wet liner, and

a. machined liner.
b. cast-steel liner.
c. water jacketed liner.
d. teflon liner.

26. The part of the engine that seals the combustion chamber and may contain the valves is the

a. cylinder liner.
b. crankcase.
c. cylinder head.
d. crosshead guide.

27. The transformation of reciprocating motion into rotary motion is the function of the

a. piston.
b. connecting rod.
c. crankshaft.
d. camshaft.

28. The transmission of energy of combustion through the connecting rod to the crankshaft is the purpose of the

a. valves.
b. piston.
c. camshaft.
d. cylinder head.

29. The three purposes of piston rings are to: seal the space between the piston and liner; transmit heat from the piston to the water; and to

a. stop oil from being burned.
b. spread lubricating oil on to the liner.
c. prevent high pressure air from escaping into the head.
d. damp out part of the fluctuation.

30. Transference of up and down motion to where it is changed to rotary motion is the purpose of the

a. camshaft.
b. connecting rod.
c. babbit.
d. compression rings.

31. The control of the operation of the engine valves is the function of the

a. crankshaft.
b. camshaft.
c. trunnion.
d. flywheel.

32. In the illustration below, identify the stroke-cycles.

a. Intake
b. Power
c. Exhaust
d. Compression

33. A two-stroke cycle is completed in ____ revolutions of the crankshaft.

a. 1
b. 2
c. 3
d. 4

34. Compression ratio is the volume at bottom dead center divided by the volume at

a. high speed.
b. TDC.
c. constant pressure.
d. low speed.

35. A higher compression ratio will achieve

a. more power.
b. higher reliability.
c. less engine wear.
d. lower combustion temperature.

36. The two methods of burning fuel within the cylinder are

a. constant volume and constant injection.
b. constant pressure and constant volume.
c. injection and turbulence.
d. pressure and injection.

B. Identification: Identify the three methods of scavenging as given in the situations provided below (items 40-42). For each item, select the ONE letter (a, b, or c) indicating your choice. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

37. The piston uncovers first the exhaust ports, and releases the pressure. Going down further, the piston uncovers the scavenge ports and begins to admit slightly compressed air, whose stream is directed mainly upward, and thus pushes out the exhaust gases.

a. Return-flow scavenging
b. Uniflow scavenging
c. Cross-flow scavenging

38. The lower piston controls the exhause ports and the upper one the scavenge ports. In order to obtain the proper sequence for intake and exhaust, the lower crankshaft will precede the upper crankshaft by 10-15 degrees.

a. Return-flow scavenging
b. Uniflow scavenging
c. Uni-flow scavenging

39. The sequence of port openings is the same as in the first situation, but the air flow is different. The air port and exhaust gas port are located on the same side of the cylinder, thus giving better accessibility.

a. Return-flow scavenging
b. Uniflow scavenging.
c. Uni-flow scavenging

C. Multiple Choice: Select the ONE answer that BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each.

40. Air pressure is provided to the cylinder by two methods. These two methods are:

a. compression of air and inlet ports.
b. use of a pump and compression of air in the crankcase.
c. use of a pump and use of a blower.
d. use of a pump and compression of air in the cylinder.

41. The gas and the diesel engine are similar mechanically as both

a. have pistons, connecting rod and camshaft arrangements nearly the same.
b. have the stroke-cycle sequence of intake, power, and exhaust.
c. types use air, fuel, compression, and ignition.
d. burn the air-fuel mixture externally.

42. The control and speed in the diesel engine are controlled by the

a. amount of air provided to the cylinder.
b. quantity of fuel injected into the cylinder.
c. short combustion period.
d. speed limits engineered in the engine.

43. The movements of the ______________ are transmitted to the crankshaft by the means of a connecting rod.

a. valves
b. piston
c. cam
d. cylinder

44. The resistance of a body to a change in motion is called

a. work.
b. stoppage.
c. inertia.
d. crankpin.

45. What stores up energy during the working stroke and gives it back during the rest of the cycle?

a. Piston
b. Flywheel
c. Crankshaft
d. Crankpin

46. The time it takes before the cool fuel spray becomes heated and vaporizes so as to ignite is called

a. retardation.
b. time lag.
c. ignition delay.
d. retarded ignition.

47. The highest thermal efficiency is obtained from the fuel which burns at the ______________ at top dead center.

a. slowest speed
b. lowest pressure
c. highest compression ratio
d. highest pressure

48. Turbulence in the two stroke engine is created by making the

a. valves for intake smaller.
b. ports larger and much deeper.
c. scavenge air ports closer together.
d. scavenge air ports tangential or angled.

49. The only way to find the correct timing is by

a. operating the engine, measuring valve clearance, and changing the timing.
b. operating the engine, finding the best timing, and changing the timing.
c. starting the engine, running the engine, and finding the best timing.
d. changing the timing, running the engine, and using the timing tool.

50. Supercharging has as its object an increase in the power which

a. can be achieved through speed and control.
b. changes the design of the engine.
c. an engine could develop if all of the factors of inertia remain the same.
d. an engine of given piston displacement and speed can develop.

51. Three types of blowers are:

a. mechanical, pneumatic, and solid.
b. reciprocating, rotating, and centrifugal.
c. mechanical, centrifugal, and pneumatic.
d. pneumatic, rotating, and reciprocating.

52. The pump that uses exhaust gases to propel the compressor which provides high air pressure is called a

a. blower.
b. supercharger.
c. turbocharger.
d. mean blower.

53. The five requirements for the injection of fuel are

a. metering, timing, rate of injection, atomization, and distribution.
b. metering, injection, blowing, combustion, and breathing.
c. timing, rate of metering, injection, mixture, and combustion.
d. rate of injection, timing, metering, mixture, and vacuum.

54. Two methods of fuel injection are air and

a. solid.
b. water.
c. diesel.
d. nozzles.

D. Matching: Given a list of four types or parts of the fuel injection systems in column 1 (items 55-58) and four definitions or uses in column 2, match the item in column 1 (items 55-58) with its appropriate definition or use in column 2. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

Column 1 Type/part	Column 2 Definition/use
55. Distributor System	a. This system is not suitable for highspeed, small-bore engines because it is difficult to control accurately the small amounts of fuel injected into each cylinder.
56. Unit Injector System	b. This system has two essential parts to each cylinder, the injection-pump and fuel nozzle.
57. Common-Rail System	c. This system combines a pump and a fuel spray nozzle in one unit.
58. Pump Injection System	d. This system is used because of its low cost, lightness, and simplicity of design.

F. Multiple Choce: Select the ONE answer that BEST completes the statment or answers the question. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

59. Two types of fuel nozzles are the __________ and __________ type.

a. valve and plunger
b. air and mechanical
c. open and closed
d. rotor and fork

60. Two types of closed-end fuel nozzles are the _______ and

a. rotor, fork.
b. pintle, hole.
c. rail, pump.
d. hole, saddle.

61. The jerk pump produces a sudden acceleration of _______________ causing a jerk.

a. the fuel in the cylinder
b. the fuel in the lines
c. air pressure in the cylinder
d. air and fuel mixture in the cylinder

62. The three most important qualities of diesel fuel are

a. viscosity, cetane rating, and lubrication.
b. ignition quality, lubrication, and viscosity.
c. viscosity, knock, and ignition quality.
d. viscosity, ignition quality, and cleanliness.

G. Matching: Given a list of four types of combustion chambers in column 1 (items 63-66) and characteristics of each type in column 2, match the type of combustion chamber in column 1 with its characteristics in column 2. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

Column 1 Combustion Chamber	Column 2 Characteristic
63. Divided Chamber	a. The combustion chamber that has two rounded spaces shaped like figure eights cast in the cylinder head
64. Open Chamber	b. The chamber that has very little clearance between the top of the cylinder and the head
65. Turbulence Chamber	c. The chamber with an auxiliary chamber at the top of the cylinder
66. Precombustion Chamber	d. The simplest form of chamber with its use limited to slow-speed diesel engines and a few high-speed 2-stroke-cycle engines

H. Multiple Choce: Select the ONE answer that BEST completes the statement or answers the question. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

67. The two types of engine loads are __________ and

a. increased, lessened.
b. heavy, light.
c. internal, external.
d. normal, abnormal.

68. The speed-sensitive device used to control the speed of the engine under varying conditions is the

a. regulator.
b. injector.
c. governor.
d. fuel pump.

I. Matching: Given a list of four classifications of governors in column 1 (items 67-72) and the functions of each listed in column 2, match the classification in column 1 with its function in column 2. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

Column 1 Classification	Column 2 Function
69. Constant-speed	a. Maintains any desired speed from idle to top speed
70. Variable-speed	b. Maintains the same engine speed from no-load to full load
71. Speed-limiting	c. Limits the load which the engine will take at various speeds
72. Load-limiting	d. Controls the minimum engine speed or limits its maximum speed only

J. Matching: Given a list of five governing characteristics in column 1 (items 73-77) and a brief definition of each in column 2, match the characteristic in column 1 with its definition in column 2. After the corresponding number on the answer sheet, blacken the appropriate circle.

Value: 1 point each

Column 1 Characteristic	Column 2 Definition
73. Hunting	a. Decrease in the speed of the engine from no-load to full load expressed in rpm or as a percent of normal or actual speed
74. Stability	b. The ability of the governor to maintain the desired engine speed without fluctuating
75. Speed droop	c. The continuous fluctuation of the engine speed slowing down and speeding up, from the desired speed due to over control by the governor
76. Sensitivity	d. The speed of the action of the governor expressed in the terms of the time in seconds required for the governor to move from no-load to full load
77. Promptness	e. The change in speed required before the governor will make a corrective movement of the fuel control and is generally expressed as a percent of the normal or average speed.

K. Multiple Choce: Select the ONE answer that BEST completes the statment or answers the question. After the corresponding number on the answer sheet, blacken the appropriate circle.

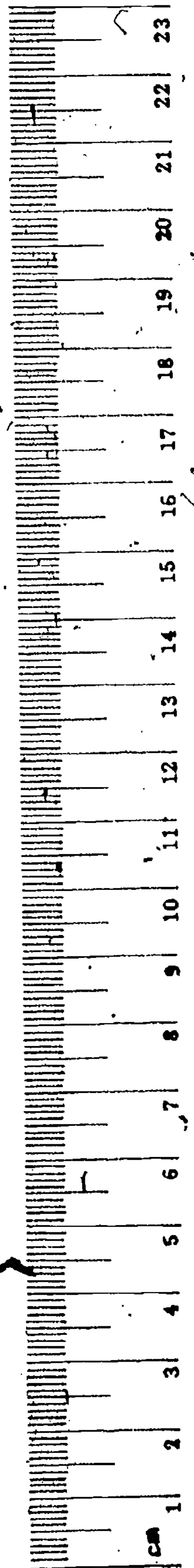
Value: 1 point each

78. The two types of governors identified in the course are

a. internal and external.
b. mechanical and hydraulic.
c. isochronous and metering.
d. constant and variable flow.

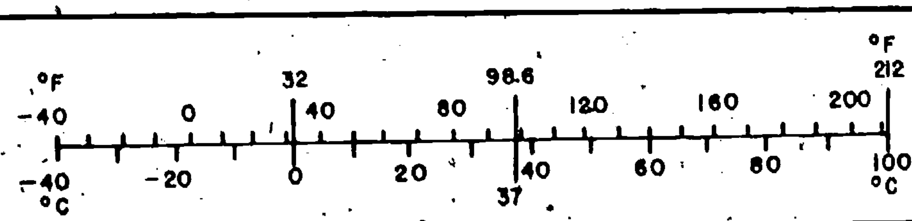
Total Points: 78

CONVERSION TABLES



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric tons (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

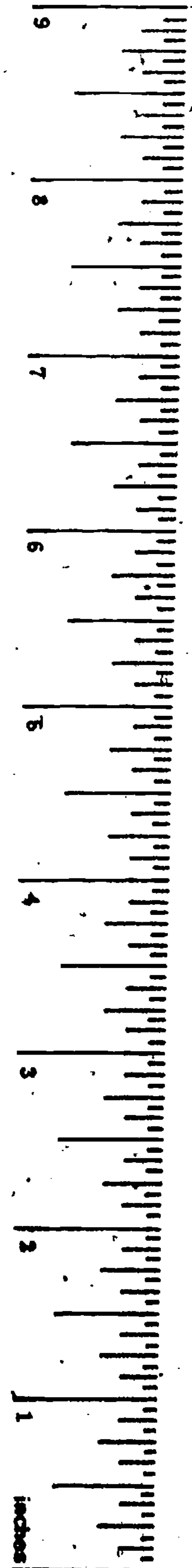


METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric tons	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 cm (exactly).

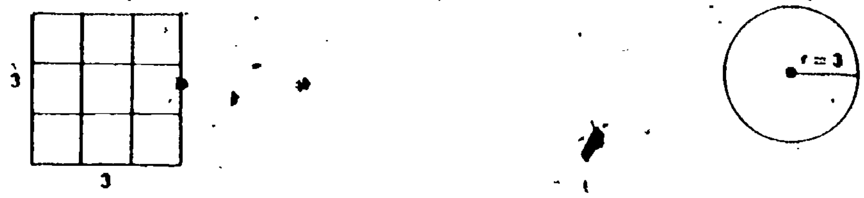


APPENDIX II

MATHEMATICS OF DIESEL FUNDAMENTALS

1. Computations of terms found in this course.

a. Area. Area is a measure of surface and is expressed as the product of the length and width or of two characteristic lengths of the surface. Areas are expressed in square units such as square feet or square meters (fig App-1).

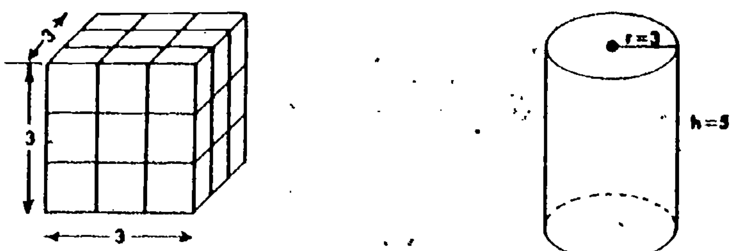


Area (square rectangle)=lenght x width
Area = 3 units x 3 units
Area = 9 square units

Area (circle) = (radius)^2
Area = 3.14 r^2
Area = 3.14 (3 units)^2
Area = 28.26 square units

Fig App-1. Computing area.

b. Volume. Volume is a measure of space and is expressed as the product of area and length or of three characteristic lenghts of the space. Volumes are measured in cubic units such as cubic feet, cubic inches, or in liters (fig App-2).



Volume (square, rectangle) = length x width x height
= 3 units x 3 units x 3 units
= 27 cubic units

Volume (cylinder) = Area x height
= r x h
= 3.14 (3 units)^2 (5 units)
= 3.14 (9 square units) (5 units)
= 141.30 cubic units

Fig App-2. Computing volume.

c. Linear motion. Linear motion is the length of the line along which a point or a body has moved from one position to another. Linear distance is measured in units of length such as feet, inches, or meters (fig App-3).

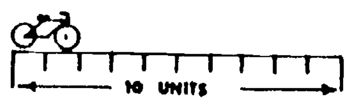


Fig App-3. Linear motion.

d. Rotary motion. Rotary motion is the movement of a point or body in a circular motion. Let us consider that the object shown in figure App-4 will be rotating clockwise in a circle around point A. The position ofthe object may be expressed by the angle through which it moves. There are 360^0 in a circle. The object starts facing 0^0. As it rotates 1/8 of the entire circle around point A, it can be said to have moved 45^0 (1/8 or 360^0 = 45^0). If it moved halfway around, it could be said to have moved or rotated 180^0. If it went all the way around, it would have finished one complete circle or 360^0.

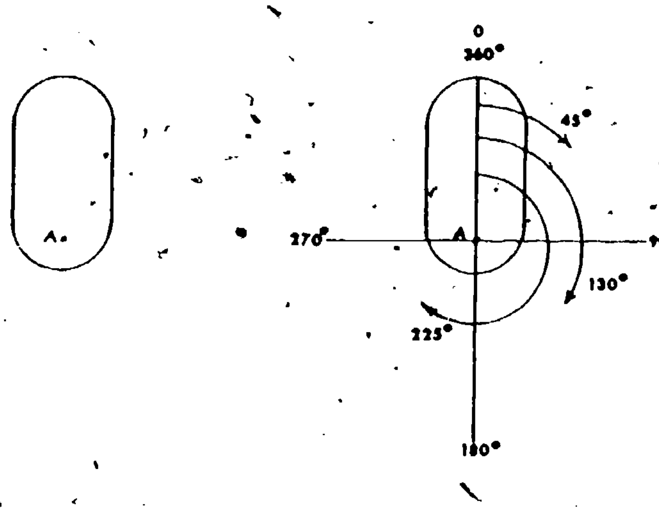
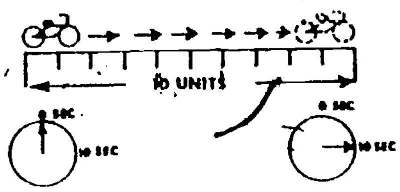


Fig App-4. Rotary motion.

e. Velocity. Velocity is the distance traveled by a moving object in a unit of time such as seconds, minutes, or hours. Velocity is computed by dividing the distance traveled by the time used for the travel:

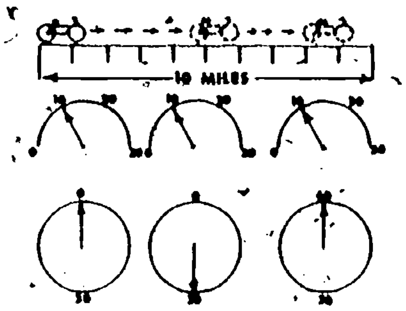


$$\text{Velocity} = \frac{\text{distance}}{\text{the time it takes to go that distance}}$$

$$\text{Velocity} = \frac{10 \text{ units}}{10 \text{ sec}} \text{ or } \frac{1 \text{ unit}}{1 \text{ sec}}$$

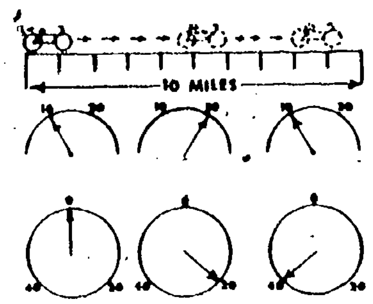
Fig App-5. Computing velocity.

Velocity may be uniform or varying. If the motion is uniform i.e., when the velocity is constant, the above expression will give the actual velocity. If the motion, and, hence, also the velocity, is not uniform as in the reciprocating motion of a piston in an engine cylinder, then the above expression will give the average velocity. The average piston velocity is referred to as piston speed. The velocity of a moving vehicle or aircraft is generally called speed and is expressed in miles per hour (mph) or kilometers per hour (kph) (fig App-6 and App-7). The formulas and examples will be given in the English system and their equivalent in the metric system.



$$\text{actual velocity} = \frac{\text{distance}}{\text{time}}$$
$$= \frac{\text{10 miles (16 kilometers)}}{\text{60 min}}$$
$$= \frac{\text{10 miles (16 kilometers)}}{\text{1 hour}}$$
$$= \text{10 mph (16 kph)}$$

Fig App-6. Computing uniform velocity.



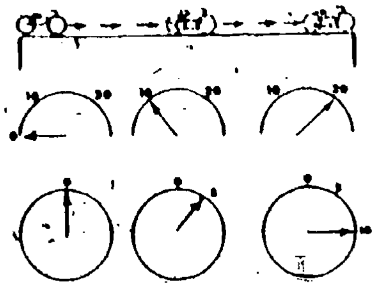
$$\text{average velocity} = \frac{\text{distance}}{\text{time}}$$
$$= \frac{\text{10 miles (16 km)}}{\text{40 min}}$$
$$= \frac{\text{10 miles (16 km)}}{\text{.67 hrs}}$$
$$= \text{15 mph (24 kph)}$$

Fig App-7. Computing average velocity.

When referring to the flow of liquids or gases, the rate of flow is called velocity and is expressed in terms of feet per minute (ft/min), feet per second (ft/sec) or meters per minute (m/min), meters per second (m/sec). On the other hand, the term speed is applied when referring to the rotary motion of a mechanism. Thus, engine speed is said to be so many revolutions of its crankshaft per minute and is designated as revolution per minute (rpm).

f. Acceleration. Acceleration is the change of velocity of a moving body in a unit of time. Accleration may be uniform or varying. It is considered positive when the velocity increases and negative when the velocity decreases. Negative accleration is called deceleration.

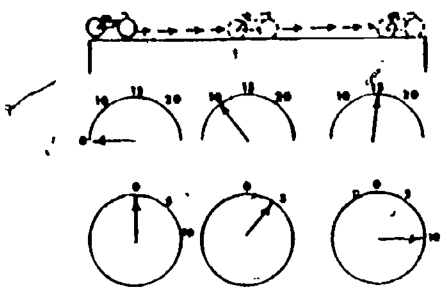
Acceleration is computed by dividing the change in velocity by the time during which this change takes place. If the acceleration is uniform, then this expression will give the actual acceleration (fig App-8).



$$\text{Actual acceleration} = \frac{\text{change in velocity}}{\text{change in time}} = \frac{10 \text{ mph } (16 \text{ kph})}{5 \text{ min}} = \frac{10 \text{ mph } (16 \text{ kph})}{5/60 \text{ hrs}} = 120 \text{ mph}^2 \ (192 \text{ kph}^2)$$

Fig App-8. Computing actual acceleration.

If the change in velocity is not uniform, then this expression will give the average acceleration (fig App-9).

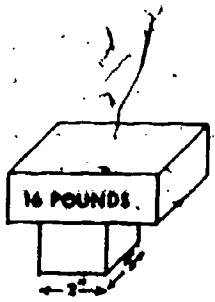


$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{change in time}} = \frac{0 \text{ mph (kph) to } 15 \text{ mph } (24 \text{ kph})}{0 \text{ min to } 10 \text{ min}} = \frac{15 \text{ mph } (24 \text{ kph})}{10 \text{ min}} = \frac{15 \text{ mph } (24 \text{ kph})}{10/60 \text{ hrs}} = 90 \text{ mph } (144 \text{ kph}) = 90 \text{ mph}^2 \ (144 \text{ kph}^2)$$

Fig App-9. Computing varying acceleration.

When the velocity is expressed in ft/min, acceleration will be expressed in ft/min per minute or ft/min^2. If the velocity is expressed in ft/sec, the acceleration will be expressed in ft/sec per second or ft/sec^2.

g. Pressure. Pressure may be defined as a force acting on a unit or area. Pressure may be exerted by a solid body, a fluid, or a gas. Pressure can be computed by dividing the force which is being exerted by the area over which it is being exerted. In figure App-10, 16 pounds (7.2 kg) of pressure are being placed on a square block with an area of 2 inches by 2 inches (5.08 cm by 5.08 cm) or 4 square inches (25.8 cm^2). The pressure is computed as follows:



pressure = force / unit [illegible]

= 16 lb[illegible] kg/f) / 2" x 2" (5.08 cm x 5.08 cm)

= 16 lbs/f (7.2 kg/f) / 4 square inches (25.8 cm²)

= 4 psi (28kPa)

Fig App-10. Computing pressure.

In the case of contact between two solid bodies, the surfaces have a perfect uniform contact only in exceptional cases. The presence of an uneven are a will give higher pressures at the high spots, and lower, if any, at the places of depression. In such a case, the pressure as determined in the above example will give only the average value. However, when a force and equal in all directions regardless of the shape of the walls.

h. Specific gravity. Water is a common liquid and is often used as a standard by which other liquids are compared. It can be useful to know if a liquid is lighter or heavier than water. Specific gravity is a term used to compare the weight of the same quantity of water.

$$\text{Specific gravity} = \frac{\text{weight of a certain volume of liquid}}{\text{weight of that same volume of water}}$$

On gallon (3.785 liters) of water weights 8.34 pounds (3.75 kg). If the weights of a liquid were equal to the weight of water, if would have a specific gravity of one. If it were twice as heavy as water, if would have a specific gravity of two. If you knew that a fuel oil has a specific gravity of .84, how much would a gallon (3.785 liters) of that fuel oil weigh? Remember the formula:

$$\text{Specific gravity} = \frac{\text{weight of a certain volume of liquid}}{\text{Weight of that same volume water}}$$

Insert what we know in the formula:

$$.84 = \frac{\text{weight of a certain volume of liquid}}{8.34 \text{ pounds per gallon (3.75 kg per liter)}}$$

To find the weight of the fuel multiple .84 x 8.34 pounds per gallon (3.75 kg per liter). The answer is 7 pounds per gallon (3.15 kg per liter).

Work is being done when a force is moving a body through a certain distance. Work is measured by the product of the force (f) multipied by the distance (d) moved in the direction ofthe force:

Work = force x distance
W = f x d

Work is expressed in foot-pounds or inch-pounds in the English system (fig App-11) and in Joules (J) in the metric system.

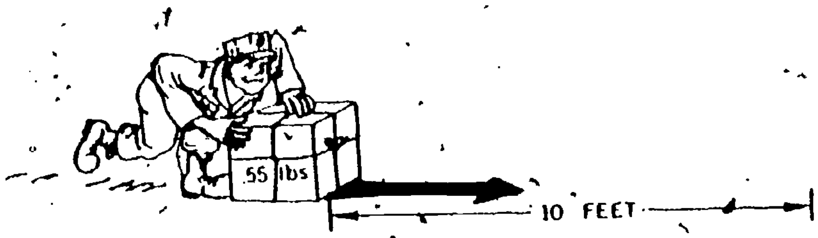


Fig. App-11. Work being performed.

English

work = weight x distance moved
= 55 lbs x 10 ft
= 550 ft-lb

Metric

work = weight x distance moved
= 24.95 kg - f x 3.048 m x c.f.
= 745.7 J

Note: The conversion factors (c.f.) can be found in standard metric conversion charts.

Example: Find the work necessary to raise the weight of 100 lb (45.35 kg) a distance of 2 3/4 ft (.84 m). The work to be done is 100 x 2.75 ft-lb or 45.35 kg x .84 m x c.f. = 373.57 J.

Power is the rate at which work is performed, or the number of units of work performed in one unit of time. 550 ft-lb per second or 745.70 watts is called a horsepower (hp).

Power = work - time

Using the example above, determine the power required to do the work if the work is to be performed: (a) in 5 sec or (b) in 25 sec.

English

(a) $\frac{275 \text{ ft-lb-f}}{5 \text{ sec}}$ = 55 ft-lb-f/sec = $\frac{55 \text{ ft-lb-f/sec}}{550 \text{ ft-lb-f/sec}}$ = 1 hp

(b) $\frac{275 \text{ ft-lb-f}}{25 \text{ sec}}$ = 11 ft-lb-f/sec = $\frac{11 \text{ ft-lb/sec}}{550 \text{ ft/sec}}$ = .02 hp

Metric

(a) $\frac{373.57 \text{ J}}{5 \text{ sec}}$ = 74.71 watts = $\frac{74.71 \text{ watts}}{745.70 \text{ watts}}$ = .1 hp

(b) $\frac{373.57 \text{ J}}{25 \text{ sec}}$ = 14.94 watts = $\frac{14.94 \text{ watts}}{745.70 \text{ watts}}$ = .02 hp

Note: The answers in the metric system have been rounded off to two decimal places.

Electric power is measured in units called watts; 1,000 watts are called 1 kilowatt (kw). The conversion factor between hp and kw is 1 hp = 0.746 kw or 1kw = 1.341 hp.

ENERGY

1. Conservation of engery

a. General. Energy of a body is the amount of work it can do. Energy exists in several different forms; a body may possess energy through its position, motion, or condition. Energy due to a position occupied by a body is called mechanical potential energy. An example of mechanical potential energy is a body located at a higher level such as water behind a dam. When a body is moving with some velocity, it is said to possess energy of motion or kinetic energy; for example, a ball rolling upon a level floor. A third form of energy is internal energy or energy stored within a body, a gas, liquid, or solid. It exists due to the forces between the molecules or atoms composing the body such as in steam or gas under pressure. Chemical energy in fuel or in charged storage battery is also classified as internal energy. These three forms of energy (mechanical potential, kinetic, and internal) have in common the characteristics of being forms in which energy may be stored away for future use.

Work can be classified as mechanical or electrical energy in the state of transformation or transfer. Work done by raising a body stores mechanical potential energy in the body due to the force of gravity. Work done to set a body in motion stores kinetic energy. Work done in compression a gas stores internal energy in the gas. Electrical work can be transformed into mechanical work by means of electric motor. After that it may undergo other changes the same as mechanical work. Heat, like work, is energy in the state of transfer from one body to another due to a difference in temperatureof the bodies.

b. Units of energy. There are two basic independent units energy:

- The foot-pound (ft-lb) is the amount of energy as shown by work and is equivalent to the action of a force of 1 lb through a distance of 1 ft.

- The British thermal unit (Btu) is the energy required to raise the temperature of 1 lb or pure water by 1^0 F at standard atmospheric pressure of 14.70 psia.

The conversion factor from ft-lb to Btu units, often called the mechanical equivalent of heat, is 1 Btu = 778 ft-lb (1055 J.)

There are two other energy units used in engineering calculations derived from the basic unit of ft-lb:

- The horespower-hour (hp-hr) which is the transfer of energy at the rate of 33,000 ft-lb per min during 1 hr, or a total of 1,980,000 ft-lb, or, using the factor 778, 1 hp-hr = 1,980,000 - 778 = 2,544 Btu (2684 J).

- The kilowatt-hour (kw-hr) which is the transfer of energy at the rate of 1,000 watts (W) per hour or 1.341 hp per hour which is equivalvent to 44,253 ft-lb per min during 1 hr or a total of 2,66,180 ft-lb or also 1 kw-hr = 2,655,180 - 778 = 3,412 Btu.

The prinicple of conservation of energy states that energy may exist in many varied and interchangeable forms but may not be quantitatively destroyed or created. Thus, mechanical energy may be transformed into heat, or vice versa, but only in a definite relation as given before: 1 Btu = 778 ft-lb.

APPENDIX IV

TEMPERATURE

a. General. the temperature of a body is a characteristic which can be determined only by comparison with another body. When two bodies are placed in close contact, the one which is hotter will begine to pass heat to the other and is said to have a higher temperature.

The scales of temperature are set arbitrarily. At present, there are two temperature scales used on this country, the Fahrenheit scale and the centigrade or Celsius scale. On the Fahrenheit scale the two reference points are the freezing point of water, designated as 32^0 F, and the boiling point of water under normal barometric pressure, designated as 212^0 F. The distance on the scale between these two points is divided into 180 equal parts called degrees. On the centigrade or Celsius scale, the freezing point of water is designated as 0^0 C, and the boiling point of water under normal barometric pressure is designated as 100^0 C. The distance on this scale is divided into 100 equal parts called degrees. Both of these temperature scales are continued in both directions, above the boiling point and below the freezig point. Temperatures below 0^0 on both scales are designated by a minus (-) sign.

In theoretical calculations pertaining to gases, another scale called the absolute or Rankine scale is used. In this scale unit, the degree is the same as the Fahrenheit scale, but the absolute zero is placed at -460^0 F. Thus, the relation between the absolute temperature, designated T, and the corresponding Fahrenheit temperature, designated t, is

Degree Rankine = degree Fahrenheit + 460
(English) $T = t + 460$
(Metric) $T = (C + 273.15)(1.8)$

In technical calculations pertaining to gases, 60^0 F is called normal or standard temperature.

As stated before, heat is a form of energy in a state of change; it is expressed in British thermal units (Btu). Quantitatively, a flow of heat is determined by the change of temperature of a body. Heat is conveyed if the temperature of the body rises and taken away if the temperature goes down. A quantitative measurement of heat is possible only by comparison with the behavior of some other body selected as a standard. Since the heat unit (Btu) is determined with the aid of water, water is used as a standard for determination of the behavior of all other substances in respect to a change of heat.

b. Specific heat. The specific heat of a substance is the ratio of heat flow required to raise by 1^0 the temperature of a certain weight of the substance to the heat flow required to raise by 1^0 the temperature of an equal weight of water. Due to the definition of 1 Btu, the specific heat of water is 1.0 (becuase water is used as the standard) or 1 Btu/lb-deg F, and numerically the specific heat of a substance is equal to the heat flow, in Btu, required to raise by 1^0 the temperature of 1 lb of the substance. Denoting the specific heat by c, the heat flow Q required to raise the temperature of W lb of a substance from t_1 to t_2 degree F is:

Heat = Weight (of body) x specific heat x temperature difference or

$$Q = Wc(t_2 - t_1)$$

In general, specific heat varies with the temperature, and for gases, specific heat also depends upon conditions of pressure and volume. For many calculations, a meand value of specific heat can be used.

c. Heat transfer. Generally speaking, heat is transferred by three methods: conduction, radiation, and convection. Conduction is energy transfer by actual contact form one part of a body having a higher temperature to anther part of it or to a second body having a lower temperature. Radiation is energy transfer through space from a hotter body to a colder body. Convection is not a form of energy transfer. Convection is a process in which a body and the energy in it are moved from one position to another without a change of state. An example of convection is the movement of heated air from one part of a room to another. A basic principle of heat flow is that heat can flow from one body to a second only if the temperature of the first body is higher than the temperature of the second body.

PRESSURE AND VOLUME

Pressure was covered earlier in this course. Additionally, it should be mentioned that the pressure of a gas often expressed by the height of the column of a liquid which will balance the gas pressure in the space under consideration. The liquid used is either water or mercury. The relation between the various units can be established noting that one cubic foot of fresh water at room temperature weighs 62.4 pounds. Since one cubic foot contains 1,728 cubic inches, the weight of one cubic inch of water is 62.4 - 1,728 = 0.0361 lb. Therefore, a column of water 1 in. high acting upon 1 sq. in. will produce a pressure of 1 psi, the column must be higher in the proportion of 1 - 0.0361 = 27.70 in. Mercury is 13.6 times as heavy as water, and therefore a column of mercury must be shorter in this proportion of 1 psi = 27.70 - 13.6 = 2.036 in mercury, and conversely 1 in mercury = 1 - 2.036 = 0.491 psi.

Instruments measure the pressure of gases in respect to the pressure of atmospheric air, also called barometric pressure. Pressures measured are called gage pressures and indicate pounds per square inch gage (psig) and pounds per square foot gage (psfg). Th actual pressure exerted on the gas can be obtained by adding the barometric pressure to the gage pressure. This pressure is called absolute pressure and is indicated as pounds per square foot absolute. If absolute pressure is designated P_a, gage pressure P_g, and barometric pressure b, then the relation can be written as

abs. pressure = gage pressure + barometric pressure or $p_a = p_g + b$.

The barometric pressure b is not constant, since it changes with the altitude and weather conditions. Normal or standard barometric pressure at sea level is taken as 29.92 in or mercury or 29.92 - 2.036 = 14.70 psia (101325 Pascals (Pa)).

Volume is the space occupied by a body, a solid, liquid, or gas. If the body is a vapor or gas, its volume must be confined from all sides. In engines, the volume of gas is usually confined by a cylinder having one end closed by a stationary cylinder head and the other end closed by a movable head called a piston. The piston has provisions for a gas tight seal. When the piston changes its position, the volume of the gas changes. When the piston approaches the cylinder head, the volume is beig decreased and the gas is compressed. When the piston moves away from the cylinder head, the volume increases and the gas expands.

Temperature has a definite effect upon the pressures and volume of gases. If a certain volume of a gas in a tight container is heated, the pressure will rise. Unless the heating stops, the container may burst. If the same volume of gas is cooled or has its temperature lowered, the pressure inside the container will be lowered. You may be able to remember what effect temperature has on a gas by thinking of gas as being excited when it is heated and calmed down when cooled. When gas is excited, it pushes out against the walls of the container holding it. It, therefore, exerts more pressure on the container. When gas is calm, it will exert less pressure against the walls of its container.

By way of summary, you shoud remember that, in dealing with gases, the three measurable quantities (pressure, volume, and temperature) are called gas properties or characteristics. The three characteristics are connected by simple relation, which for any gas can be written as $pV = WRT$ where p is the absolute pressure in pounds per square foot absolute, V is the volume in cubic feet, W is the weight of the gas in pounds, T is the absolute temperature in degrees Rankine, and R is a constant called the gas constant. The numerical value of R is known for all gases. It is expressed in ft-lb per lb per degree Rankine. The equation above shows that if the three characteristics for a certain amount of gas are known, the weight can be found, or if the weight is known, any one of the three characteristics can be found if the other two are measured.

T&E-1

STUDENT COURSE CONTENT ASSISTANCE REQUEST

DATE:

COURSE NUMBER COURSE TITLE

NAME RANK MOS

SOCIAL SECURITY NUMBER

1. Use this form for any questions you may have about the course. Write out your question and refer to the study unit, work unit, or study question with which you are having problems. Complete the self-addressed block on the reverse side. Before mailing, fold the form and staple it so that MCI's address is showing. Additional sheets may be attached to this side of the form.

MY QUESTION IS: OUR ANSWER IS:

SIGNATURE (TITLE OR RANK)

STUDENT: Detach and retain this portion.

DATA REQUIRED BY THE PRIVACY ACT OF 1974
(5 U.S.C. 522A)

1. AUTHORITY: Title 5, USC, Sec. 301. Use of your Social Security Number is authorized by Executive Order 9397 of 22 Nov 43.

2. PRINCIPAL PURPOSE: The Student Course Content Assistance Request is used to transmit information concerning student participation in MCI courses.

3. ROUTINE USE: This information is used by MCI personnel to research student inquiries. In some cases information contained therein is used to update correspondence courses and individual student records maintained by the Marine Corps Institute.

4. MANDATORY OR VOLUNTARY DISCLOSURE AND EFFECT ON INDIVIDUAL NOT PROVIDING INFORMATION: Disclosure is voluntary. Failure to provide information may result in the provision of incomplete service to your inquiry. Failure to provide your Social Security Number will delay the processing of your assistance request.

INSTRUCTIONS TO STUDENT

1. Fold so that MCI address is outside
2. Insert course number in square marked "Course Number" below.
3. Seal with scotch tape or one staple
4. Mail to MCI

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 12486 WASHINGTON D. C.

POSTAGE WILL BE PAID BY U.S. MARINE CORPS

UNITED STATES MARINE CORPS
MARINE CORPS INSTITUTE
P. O. BOX 1775
ARLINGTON, VA 22223

STUDENT REQUEST/INQUIRY
MCI - R14 K

DATE SENT: ________
DATE RECEIVED AT MCI: ________

COURSE NUMBER	COURSE TITLE

COMPLETE ALL PORTIONS OF SECTION 1

Section 1. Student Identification

Rank	Initials	Last Name	MOS

SSN	REPORTING UNIT CODE (RUC)
___ - __ - ____	

MILITARY ADDRESS

ZIP CODE

INSTRUCTIONS: Print or type name, rank, and address clearly. Include ZIP CODE. Only Class III Reservists may use civilian address.

Section 2. CHECK THE APPROPRIATE BOX AND FILL IN THE APPROPRIATE SPACES.

FOR REGULAR AND CLASS II RESERVE MARINES THIS FORM MUST BE SIGNED BY THE COMMANDING OFFICER OR HIS REPRESENTATIVE, i.e. TRAINING NCO.

1. ☐ EXTENSION - Please grant an extension. (Will not be granted if already on extension.)
2. ☐ NOTICE OF COURSE COMPLETION - Final Exam Sent On ________. (New exam will be sent if exam not received at MCI.)
3. ☐ REENROLLMENT - Student has course materials (See para. 4003 of Vol. I of MCI Catalog for information on reenrollment.)
4. ☐ OVERDUE FINAL EXAM - Last (Review) lesson sent on ________. Please send exam.
5. ☐ Please send new ANSWER SHEETS.
6. ☐ Please send missing course materials (Not included in course package.) Lessons ____ Manual ____ Other ________
7. ☐ CHANGE - Rank ________ Name ________ Social Security Number ☐☐☐-☐☐-☐☐☐☐ RUC ________
8. ☐ OTHER (explain) ________

FOR MCI USE ONLY
1. D ____
2. On SMF ____ K ____ L ____
3. C ____
4. L ____
5. Q ____
6. P ____
7. E ____
8. ________

DATE COMPLETED ________

ORIGINATOR CODE ________

Note: This form will not be returned by MCI. If request is valid, transaction will show on next UAR or on MCI-R1_ form.

____
SIGNATURE-TITLE OR RANK
(MUST BE CO OR REPRESENTATIVE)

STUDENT: Detach and retain this portion.

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