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TECHNICAL DIGEST FEATURE

MAINTENANCE AND REPAIR OF SMALL AND MEDIUM SIZE DIESEL ENGINES

DEPARTMENT OF STATE

AGENCY FOR INTERNATIONAL DEVELOPMENT

Communications Resources Division

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November 1961

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FOREWORD

This report is one of a series of special reports prepared for the Technical Digest Service furnished by the Office of Technical Services, U. S. Department of Commerce, to the Agency for International Development for use in its program of technical assistance to the less industrially developed countries.

Each of the reports in this series is designed to provide detailed information on a single specific aspect of industrial and manufacturing equipment, processes and techniques.

The following report deals with the maintenance and repair of small and medium size diesel engines. It was prepared by John F. Holman & Co., Inc., 3301 Shepherd Street, N. W., Washington, D. C. Mention of the name of any firm, product, or process herein is not to be considered as a recommendation or endorsement by the Agency for International Development or the U. S. Department of Commerce.

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TABLE OF CONTENTS

Page

PART I

WHAT IS A DIESEL ENGINE? 1
ADVANTAGES OF A DIESEL ENGINE OVER A REGULAR GASOLINE COMBUSTION ENGINE OR STEAM DRIVEN ENGINE 2
APPLICATION OF DIESEL ENGINES 3

PART II

FUNDAMENTAL VARIATIONS IN THE DIESEL ENGINE 4
ENGINE DESIGN AND STRUCTURE 10
PARTS 12
FUEL 15
LUBRICATING OIL 17

PART III

INSTALLATION 18
OPERATION 18
MAINTENANCE AND REPAIR 23
INSPECTION 25
LUBRICATION AND PREVENTIVE MAINTENANCE 29
TROUBLE SHOOTING 31

APPENDIX 66
LIST OF MANUFACTURERS 67
BIBLIOGRAPHY 68

PART I

WHAT IS A DIESEL ENGINE?

Simply stated, the diesel engine is an oil engine which uses low grade oil for fuel and ignites this fuel by the heat of air compression.

The diesel engine is essentially one of the simplest of all prime movers. A comparison of the functioning of a gasoline engine to that of the diesel engine presents the best illustration of basic diesel theory.

The gasoline engine, as is well known, consists of a cylinder, within which a piston travels up and down. As the piston makes its downstroke, it "sucks in" air and gasoline vapor through an intake valve, filling the cylinder with it. The mixing of air and gasoline vapor occurs in the carburetor.

On the upstroke of the gasoline engine piston, the explosive mixture is compressed into roughly 1/6 the space it formerly occupied. At that instant an electric spark explodes the mixture, driving the piston down again with great force. This is called the power stroke. On the ensuing upstroke, the burnt mixture is pushed out of the cylinder through an exhaust valve.

The piston repeats this performance indefinitely. These strokes create the power that moves an automobile down the road.

A diesel engine has, in essence, the same cylinder and the same piston as the gasoline engine. However, it does not have an electric spark or a carburetor.

On the upstroke of the piston, it compresses only air. The piston in the gasoline engine crowds the contents of its cylinder into about 1/6 the space it formerly occupied. The piston of the diesel comes so close to the top of the cylinder that it crowds the air into approximately 1/15 the space it normally occupied. In other words, the air is compressed to approximately 350 to 500 pounds per square inch. The air, as a result, gets very hot -- from about 800 to 1100 degrees F. -- for as air is compressed rapidly, its temperature rises.

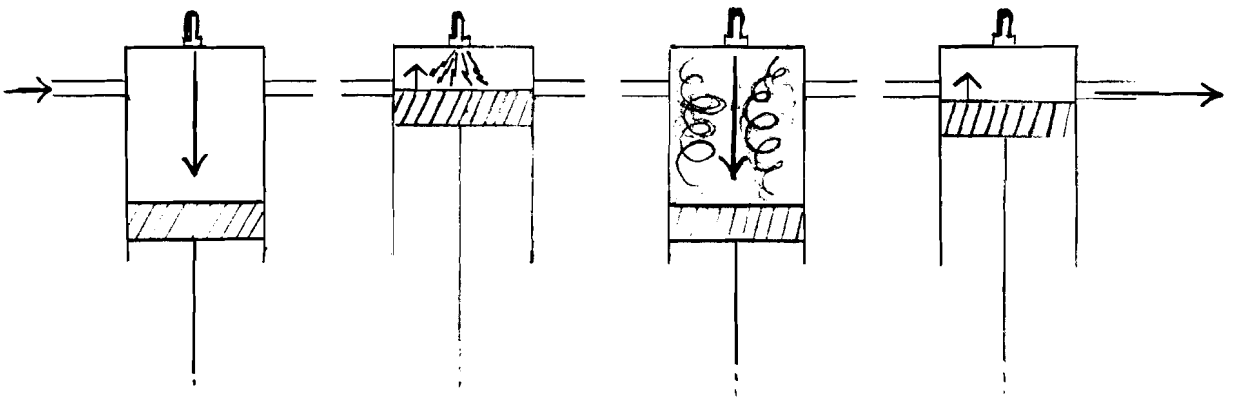


Fig. 1. Conventional Gasoline Engine Combustion Cycles

At the top of the upstroke in the diesel engine, fuel oil is sprayed into the cylinder containing the densely compressed, intensely heated air. This spraying must be done under high pressure, to overcome the pressure inside the cylinder. The fuel oil starts to burn immediately when it hits this intensely hot air. This burning increases the pressure and the temperature in the cylinder, thus forcing the piston down and creating the power stroke.

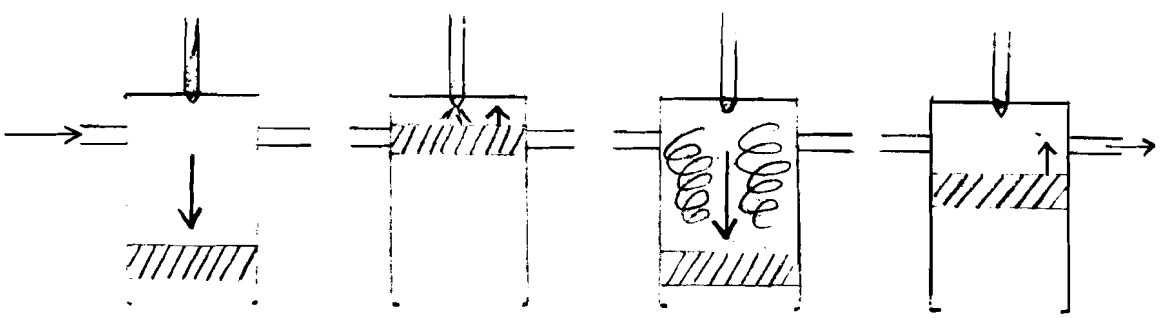


Fig. 2. Diesel Engine Combustion Cycles

ADVANTAGES OF A DIESEL ENGINE OVER A REGULAR GASOLINE COMBUSTION ENGINE OR STEAM DRIVEN ENGINE

In point of thermal efficiency, the diesel engine ranks highest of all types of engines.[1] In other words, a higher percent of the fuel fed into it is converted into useful power than in the case of any other engine. Thermal efficiency means the amount of heat energy derived from an engine compared to the amount put in. In other words, there is a certain amount of heat energy in a ton of coal before it is burned. If the amount of power that a locomotive finally delivers from that ton is only 6 to 8% of the

[1] This excludes any consideration of jet engines, gas turbines, rocket engines, etc.

amount originally contained in it, then the locomotive is only 6 to 8% efficient.

Steam turbines and condensing steam engines do much better than that. Their range of efficiency is 16 to 30%.

Gasoline engines average a little higher percentage. About 25% of the original energy contained in a gallon of gasoline is eventually delivered at the engine flywheel.

The diesel engine makes the most of this thermal efficiency. From the energy in a gallon of fuel oil, the diesel returns approximately 35%.

Another way of stating this is in terms of the British Thermal Unit, commonly called the B. T. U. For example, a pound of petroleum oil contains 19,000 B. T. U.'s. A diesel engine will convert about 7,000 of these into work, losing 12,000, which is a larger net conversion of original energy and a smaller loss than in any other type of prime mover.

The operating cost of the diesel is impressively low. Not only is the price of the fuel cheap, but less fuel is required to do the same amount of work as that performed by other engines of equal horsepower. The reason for this is the high thermal efficiency of the engine.

Also, the diesel engine consumes fuel only when it is running. This is in contrast to the steam engine, in which steam pressure must be kept up during its idle periods.

Reliability is another major asset of the diesel engine. It performs most regularly with a minimum of attention.

Maintenance and repair is very simple due to the simplicity of construction of the machinery.

APPLICATION OF DIESEL ENGINES

Diesels can be used for almost any purpose where regular, dependable power is required. They have been applied to aircraft, marine vessels, and all modes of mobile and stationary land equipment. A list of these applications would be interminable.

For the sake of convenience, diesel engine application can be divided into four general classes:

1. Industrial (plant manufacturing)

2. Public service (municipal power plants, telephone exchanges, office buildings)

3. Marine

4. Power for equipment (locomotives, cranes, shovels, oil well drilling rigs, etc.)

Small and medium size diesels are limited to the latter two categories because of the lighter work load required.

PART II

FUNDAMENTAL VARIATIONS IN THE DIESEL ENGINE

There are several variations of the basic pattern of the diesel, just as there are variations in the gasoline engine. The manufacture of an almost endless variety of diesel engines today does not indicate that designers or manufacturers are uncertain about which is the best type. The variety results from the unusual adaptability of the diesel engine, which makes it possible to modify the mechanical design to meet the requirements of some special application without sacrificing the basic advantage of high fuel economy. Physical dimensions, horsepower rating, rotative speed, arrangement of cylinders, type of pistons, and other mechanical design details have only a very slight influence upon this basic advantage. Because the diesel engine can be tailored to fit the requirements of a particular applications, diesel manufacturers have produced many special engine designs, each meeting the demands of a special application. Although individual designers' preferences account for some design difference, it is primarily the extraordinary adaptability of the diesel principle that has led to the building of so many types of diesels.

All of the variations listed below are applicable to the small and medium size diesel engines under consideration in this report.

Four-Stroke Cycle Diesel Engine

The four-stroke diesel engine has already been described above in Part I. A more exact description is as follows.

The four-stroke cycle engine requires two complete revolutions of the crankshaft to complete the cycle of events.

The events of the four-cycle engine are termed:

1. Admission Stroke: Atmospheric air is drawn into the cylinder.

2. Compression Stroke: Air is compressed and the heat of ignition produced.

3. Power Stroke: Fuel is injected and ignited, expansion then taking place.

4. Exhaust Stroke: Burned and expanded gases are foeced from the cylinder.

Two-Stroke Cycle Diesel Engine

The two-stroke cycle engine, usually called the "two-cycle" engine,

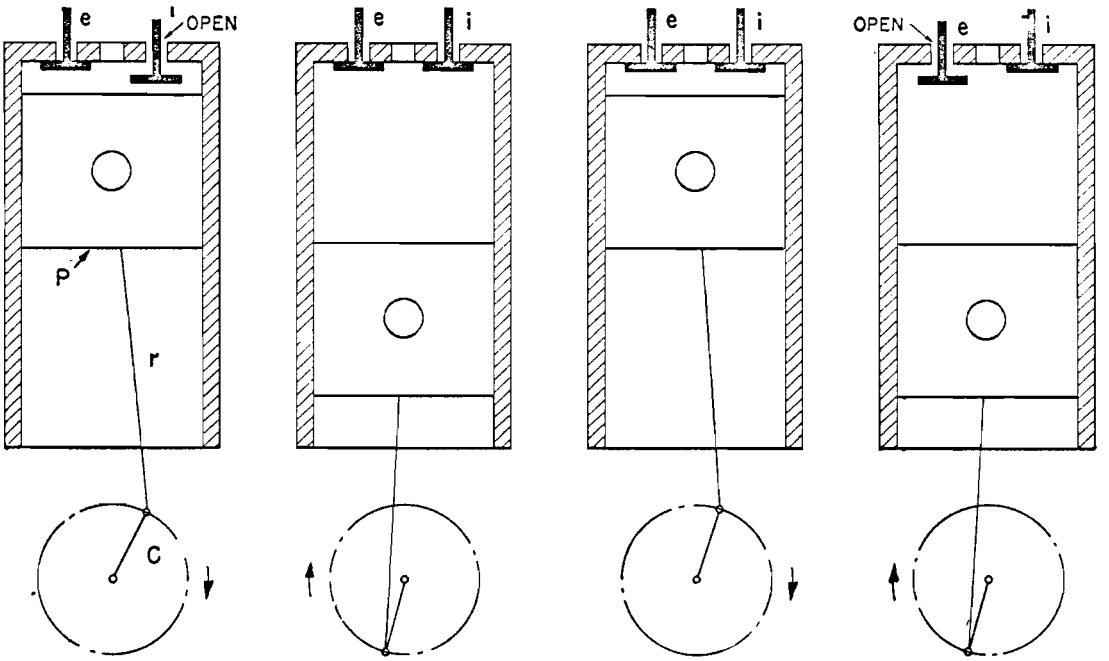


Fig. 3. Four-stroke-cycle Events

accomplishes the same results as the four-cycle engine. The steps in the cycle may be followed by a study of Figure 4.

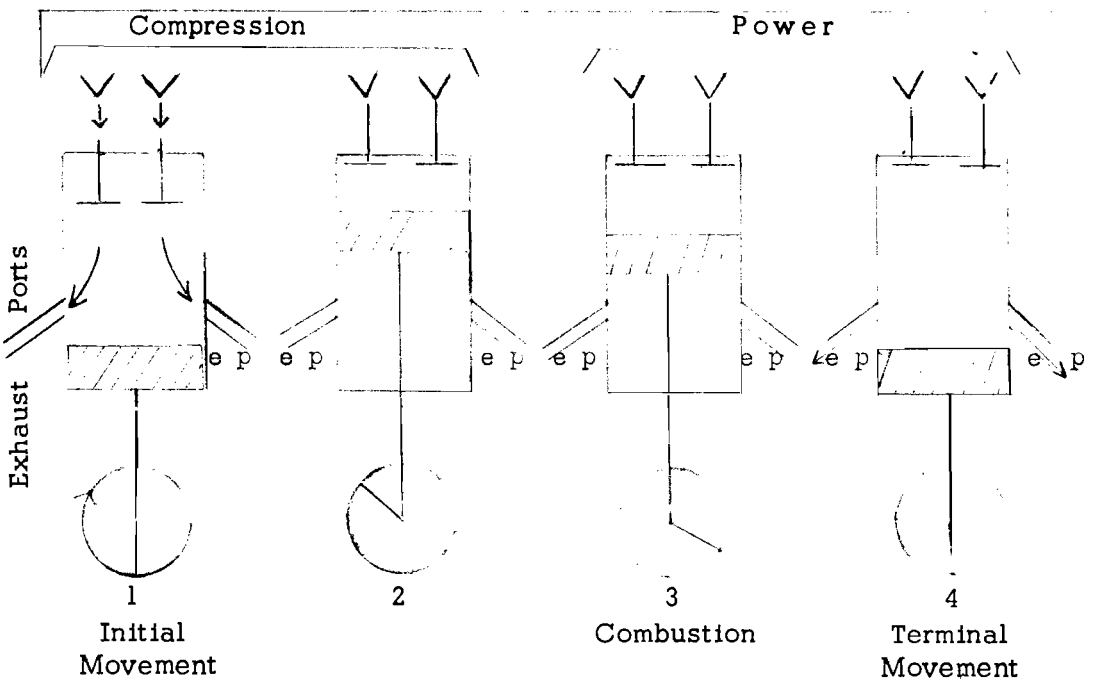


Fig. 4. Illustration of Two-stroke Cycle

The events of the two-stroke cycle engine are:

1. Compression stroke: This corresponds to the admission and compression strokes of the 4-cycle engine, the initial movement of the piston occurring while the cylinder is being filled with fresh air under pressure from a pump. The air enters the cylinder through air inlet valves in the cylinder head.

2. The second part of the first stroke occurs after the piston has covered the exhaust ports and the air inlet valve closes. The air is compressed in the combustion space.

3. When or just before the piston is at top center, and during the piston's initial movement away from top center, fuel is introduced and combustion takes place. This results in a period called the duration of injection and commencement of combustion. The important chemical processes of oxidation occur during this step. It is the most important event in the operation.

4. Power Stroke: As the piston continues to move away from the combustion space, combustion ensues, followed by the expansion of the charge. When the gases which create the power have almost spent their power producing force and about the maximum expansion practical, the piston uncovers the exhaust ports, which permit the escape of the gases. This is called the exhaust or the scavenging stroke. The process called "scavenging" is brought about by introducing new air through the air inlet valves which has been forced down by an auxiliary pump.

Number of Cylinders

Both two- and four-cycle engines have been built with from 1 to 10 or more cylinders in a line. V-type engines are built with even 16 or more cylinders. There is no such thing as a best number of cylinders from that standpoint alone, but there are distinct advantages and opportunities that various cylinder combinations offer.

In general, the more cylinders there are, the smoother the engine effort becomes and the size of the flywheel required becomes smaller. There are some individual exceptions to this. In marine work the question of direct reversibility may be the deciding factor in determining the number of cylinders.

Sometimes the floor space of the height available, as in locomotive work, dictates the number of cylinders for the engine chosen, but in such cases, due regard must be given to the other considerations mentioned below.

The greater the number of cylinders for a given power, the higher the RPM, the lighter the individual parts, the lighter the total engine weight, and the cheaper the engine and installation will be.

If the foundations are uncertain or a particularly smooth and vibrationless unit is desired, then six or more cylinders are desirable.

On the other hand, the more cylinders there are in line, the longer the engine must

be and more attention will be required to provide satisfactory longitudinal rigidity of the structure as a whole. In general, the lowest possible idling speed can be achieved by a greater number of cylinders. However, the size of the flywheel is very important in this respect.

A smaller number of cylinders makes it easier to divide the load between the cylinders and to get them to fire regularly at extremely light loads.

The greater the number of cylinders, the more the likelihood of difficulties due to torsional vibrations will occur.

Horizontal, Vertical, V-type and Radial Engines

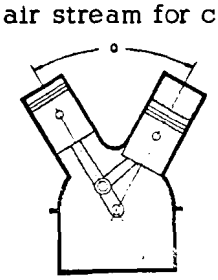
Horizontal diesels (cylinders lying flat) were widely used for stationary purposes years ago, but they have been largely superseded by vertical engines (cylinders upright) with more and smaller cylinders which run at higher speeds. The natural trend toward high speeds and lighter weights made the change inevitable. The horizontal engine had few cylinders, but the pistons, connecting rods, and other parts of vertical engines are lighter in weight and easier to handle. The multi-cylinder verticals give a steadier flow of power. The principal appeal of horizontal engines is in their simplicity and the smaller number of individual parts.

Another form of the horizontal engine has come into use for some special service applications. It is a multi-cylinder horizontal engine, which fits better into a small space. Such an engine is no more than the usual vertical engine turned over on its side, but with suitable changes in details of design. Some of these engines are built with two banks of cylinders, which are in a way the familiar V-type engine flattened out with a 180 degree angle between the two cylinder banks. Again, suitable changes are made in the details to meet the new conditions.

The vertical engine is the most universally used. The acceptance of multiple cylinders with higher speeds of rotation, smaller and lighter individual parts, and lower over-all cost of installation has brought the vertical engine forward rapidly. Most important of all, vertical engines are the most suitable for many of the service applications.

V-type engines are simply two vertical engines set alongside each other at suitable angles and combined into one structure with one crankshaft. The object is to get more power into a smaller space.

The radial engine is most suitable for airplane use, especially where the cylinders are spread out to the air stream for cooling, as in the familiar radial air-cooled gasoline-engine design.



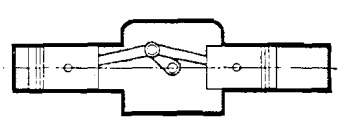


Fig. 5. V-Type Engine

Opposed-piston engines

Opposed-piston engines have been built primarily for two types of service application. One is for single-screw ships where the long combined stroke of the opposed piston permits a high power output with low speed, which consequently gives high propeller efficiency. The other type is used in airplanes, submarines, locomotives, and similar applications where high power output is required. This form of engine is favorable for good scavenging at high piston and rotative speeds. Good charging is accomplished simply, and thus high specific outputs can be obtained. The engine can be perfectly balanced. However, certain mechanical operations are required to accomplish all these results.

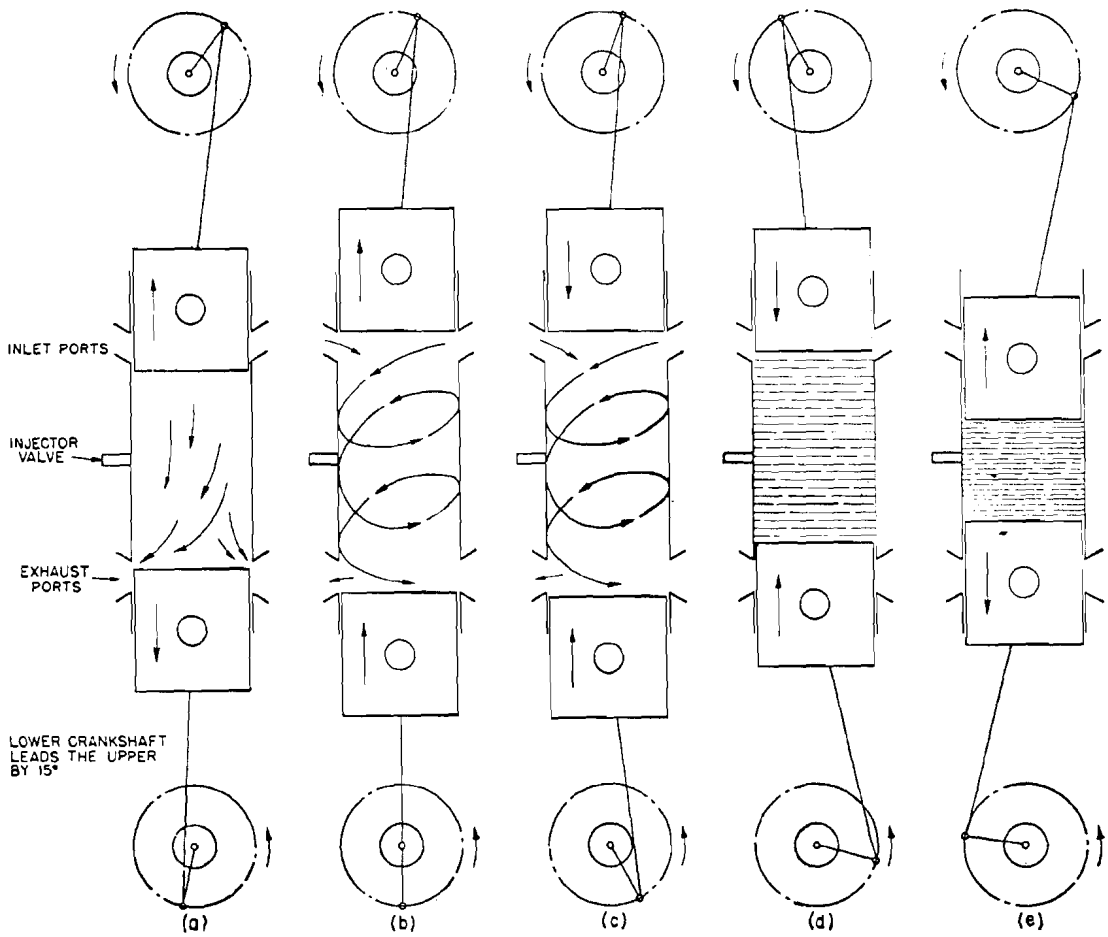


Fig. 6. Opposed-piston Engine Operation

This general type may be modified by reducing the size and thus shortening the stroke of one of the pistons so that it acts as an exhaust-port control. These small pistons are driven from a separate shaft connected to the crankshaft and develop some ten per cent of the total engine power. The same system is also used for double-acting

engines, the lower piston carrying the piston-rod studding box. Scavenging air enters through the ports in the cylinder walls controlled by the main piston.

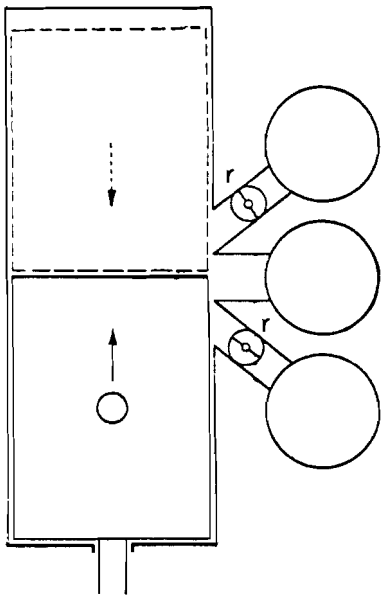


Fig. 7. Return Scavenging in a Double-acting Engine

Other Types

There are other types of opposed-piston type engines which have been built. Most of them have included some method of eliminating the crankshaft. Various forms of cam motions and inclined disks on shafts transfer the reciprocating motion of the pistons to the rotating motion of the shaft. They are all attractive, but the mechanical difficulties involved have so far prevented wide commercial acceptance. Sleeve valve engines have also been built and used. The over-all performances of all these forms have not been sufficiently superior to those of existing types to justify commercial displacement of the latter.

TABLE I

COMPARISON OF POWER STROKES

1. Steam reciprocating	Each stroke, out and in, is a power stroke or impulse stroke, which therefore gives two power strokes per revolution.
2. 2-Stroke Diesel (Single acting)	Each out stroke only is a power stroke or impulse stroke which therefore gives one power per revolution.
3. 4-Stroke Diesel (Single acting)	Each second out stroke only is a power stroke, which therefore gives one power stroke per two revolutions.
4. 2-Stroke Diesel (Double acting)	Each stroke out and in is a power stroke, giving two power strokes per revolution as in steam practice.
5. 4-Stroke Diesel (Double acting)	Each second stroke only is a power stroke, which gives one power stroke per revolution, and is nearly equivalent in power output to that of a 2-cycle single acting engine.

ENGINE DESIGN - Structure

The diesel engine differs little in physical appearance from the better known gasoline engine and the natural gas engine. The most noticeable differences are the diesel's greater physical dimensions and weight per horsepower; the extra size and weight are due principally to the higher maximum cylinder pressure of the diesel cycle and the consequent need for sturdier and more rugged construction. It is difficult to distinguish at a quick glance between an automotive diesel and a gasoline engine of the same rating that are operating at the same speed. Both are internal-combustion engines and have in common bases, housings, cylinders, heads, flywheels, etc. In both, the most common cylinder arrangement today is vertical, cylinders being either in line or grouped in a two bank V. The fuel used by the oil diesel is liquid; it is not volatile at the atmospheric temperatures at which gasoline is volatile. Therefore, the carburetor of the gasoline engine is replaced by injection pumps in the diesel engine. Since the pumps of an automotive diesel are usually grouped in a common block, they may not be immediately recognized as fuel-injection pumps.

One of the prime requisites in any engine is a structure rigid enough to absorb without undue deflection all the forces acting on it. There are two criteria for judging undue deflection. First, there must not be enough deflection to cause or permit undue wear or noise. Second, there should not be enough deflection to be casually obvious to the eye.

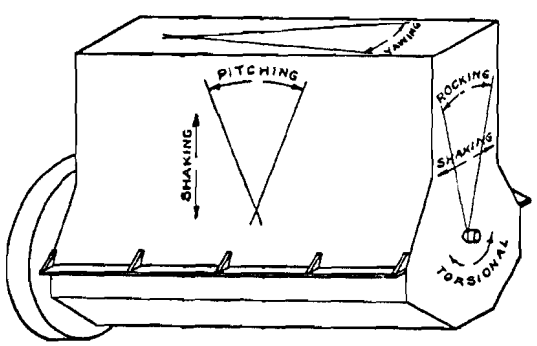


Fig. 8. Types of Engine Vibration.

The avoidance of deflection judged by the first criterion is mandatory for successful operation. It is particularly important that the alignment of the crankshaft be rigidly maintained. But it is frequently difficult and certainly not necessary to avoid very slight and inconsequential deflections that cannot be seen except by comparison with some adjoining part or by reflection of light on a wet surface. Variations are particularly noticeable in the larger engines, for it must be remembered that deflection is directly proportional to the length of the material under stress as well as to the stress itself.

Cast iron is the usual material utilized in the structure of diesel engines.

Cast-aluminum alloy is used to some extent in lightweight engines. Welded steel is used, especially for high-output lightweight engines, as for naval and railway use. The exact form of structure varies to some extent to suit the material used.

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 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 of 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, partially due to improvements in materials which provide greater strength per unit area, but mostly due to improved design and methods of calculation of manufacture which permit the use of lighter sections.

The engine 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.

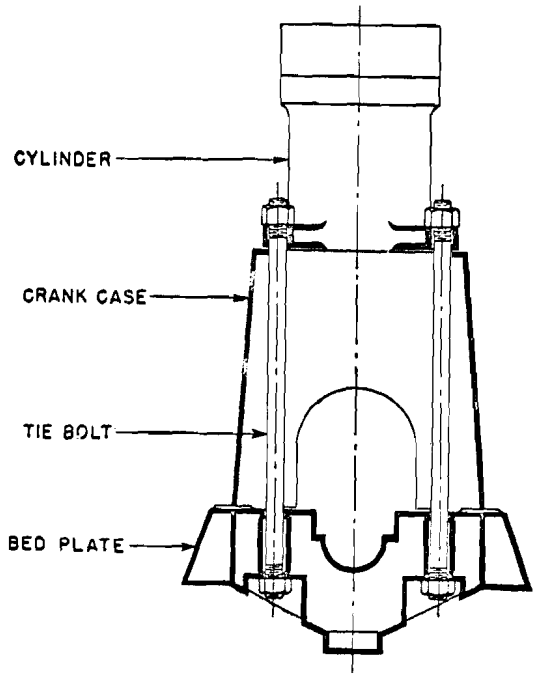


Fig. 9. Engine Frame with Tie Bolts

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.

Modern designs of high-power output engines have frames welded of steel with plates located at places where the loads occur. 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.

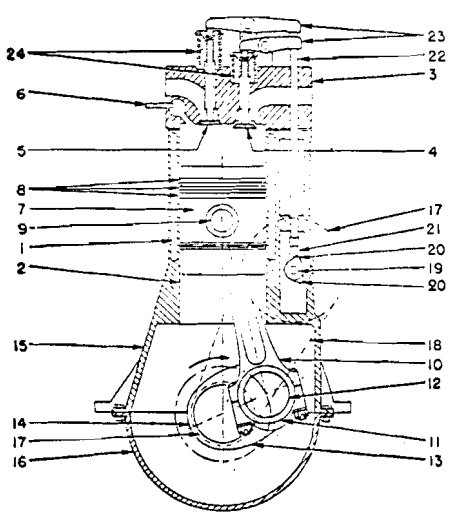
PARTS

All diesel engines 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 which assist the main working parts in their performance, and the connecting parts necessary to hold the working parts together.

The main working parts are:

1. Cylinder
2. Piston
3. Connecting rod
4. Crankshaft
5. Bearings
6. 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. The illustration below shows these parts.



1. Cylinder
2. Cylinder liner
3. Cylinder head
4. Intake valve
5. Exhaust valve
6. Fuel injector
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. 10 Schematic Drawing of a Diesel Engine

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.

The piston seals the other end of the working space of the cylinder and transmits to the outside the power developed inside of the cylinder by burning of the fuel. A gastight 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.

One end, called the small end of the connecting rod or conrod eye is attached to the wrist pin or piston pin located in the piston; the other or big end has a bearing which encloses the crankpin. The connecting rod transmits the reciprocating motion of the piston to the continuously rotating crankshaft during the working stroke, and vice versa during the other strokes.

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 propeller or generator drive shaft. A flywheel of a sufficient mass is fastened to the crankshaft in order to reduce speed fluctuations by storing kinetic energy during the periods when power is developed and giving it back during the other periods.

A camshaft is driven from the crankshaft by a chain drive or by riming 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.

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.

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 injection or spray nozzle.

Fuel Injection System

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

1. Meter or measure the correct quantity of fuel injected.
2. Time the fuel injection.
3. Control the rate of fuel injection.
4. Atomize or break up the fuel into fine particles according to the type of combustion chamber.
5. 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 Table II:

		Mechanical Injection Systems		
Requirement	Air-Injection System	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

TABLE II

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

6. Promptness in the speed of action of the governor. It may be expressed in terms of the time in seconds required for the governor 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 resistance.

Clutch Coupling

A device to connect two shafts so that they will act as one is called a coupling. A device to connect or disconnect at will a part which transmits power, such as a gear, pulley, etc., to or from a rotating shaft is called a clutch. If two shafts must be connected or disconnected while in operation, the device to be used has the features both of a coupling and a clutch and is called a clutch coupling. However, in practice such a device usually is called simply a clutch, as for example, the connection between the engine shaft and the drive shaft in an automobile.

Gears

For minimum weight and size for a given power output, diesel engines must have a relatively high rotative speed. On the other hand, for maximum efficiency, propellers must rotate at a relatively low speed, particularly where high thrust capacity is desired, as in a towing vessel. Reduction gears are used to correlate these two conflicting requirements and thereby, to obtain a low propeller-shaft speed with a high diesel engine speed. Ordinarily reduction gear ratios do not exceed 3:1, although reduction ratios up to 6:1 are sometimes used.

Engine Systems

Besides all these various parts of the diesel engine, there are integral engine systems, the proper functioning of which are essential to the entire operation of the

diesel. These systems are:

1. The fuel system
2. The lubricating systems
3. The cooling systems
4. The air-intake system
5. The exhaust system

Auxiliary Equipment

There is also auxiliary equipment to be used with the diesel engine. Auxiliaries include equipment which, generally speaking, is not part of a diesel engine itself. In most cases, it is not made by the engine builder, but by a manufacturer specializing in this type of equipment. Frequently the items of auxiliary equipment are also used in other than diesel-engine installations. The auxiliary equipment includes such items as:

1. blowers 2. pumps (fuel, oil and water) 3. heat exchangers 4. piping

It would be difficult to explain the variations in the parts and systems of the diesel engine. These vary depending on the size, application, and manufacturer of the individual engine. An examination of these variations would constitute enough material to write a volume far larger than the one at hand. Further information on this subject should be obtained from manufacturers' bulletins or handbooks applicable to the engine of particular interest to the reader.

F U E L

Fuels for diesel engines are quite varied and include everything from light fuel oil, distillates only slightly heavier than kerosene to the heavy distillates, and in many cases the residual oils from the refinery still. In general, the small high-speed engines burn the light distillates, the medium-size solid-injection engines burn the heavier distillates, and only the large air-injection engines can successfully burn the heavier residuals. The larger engines running at slower speeds and having larger nozzle openings are best suited to handle the heavier types of fuel. The problem of selecting the proper fuel is of an economic nature. Recommendations by the manufacturer should be followed.

There are three general classes of crude oils, namely:

1. The paraffin base oil. 2. The asphalt base oils. 3. The mixed base oils.

The chemical characteristics of the different crudes vary with respect to such properties as sulphur content, and other substances that must be removed or reduced in quantity during the refining process.

The refining process consists of heating the crude oil in stills. The heating is carried out very slowly, the temperature rising gradually higher and higher until it

drives off the vapors. These vapors are led through a pipe from the top of the still to a condenser where the vapor is condensed into a liquid.

The first vapors are driven from the still at low temperature and constitute the high-test naphthas. As the heating process is continued, there will gradually come from the still, heavier and heavier vapors, until in successive stages, there will be driven off gasolines, kerosenes, gas oils, fuel oils, etc.

These respective stages are called "cuts," each liquid being of a greater specific gravity than the one preceding it. By watching the flow from the condenser, the operator of a still can divert the various cuts into different tanks. This, in brief, is the process of fractioning any crude oil into its various components. Some of these components or "fractions" must be treated chemically and refined again in order to prepare them for commercial use.

Diesels can ignite and partially burn almost any form of liquid petroleum (gasoline, naphtha, kerosene, gas oils, distillates, crudes, residuals and bunker fuels) but such practice may not be either satisfactory or economical. Probably the greatest feature of the diesel engine is its ability to burn a cheaper and heavier fuel than the gasoline engine can. However, there are certain limitations as to the characteristics of the fuel which will yield the greatest over-all economy of operation. Fuels containing thick tarry substances may burn only partially, leaving a gummy substance to stick to the pistons and rings. Fuels may have poor compression-ignition properties (cetane number) or, they may contain high percentages of sulphur which cause damage to the fuel injection system, piston, cylinder rings, and other parts exposed to the fuel. The price of fuel varies in proportion to its cleanliness and good properties. Therefore, the question arises as to how much contamination or poor qualities may be allowed in the fuel without damaging the engine.

The qualities or properties of a fuel which are usually specified or limited are referred to as the Fuel Specifications. The following points are usually included in fuel oil specifications for diesel engines:

Cetane number: The ability to ignite from compression, bottom sediment and water.
Carbon Residue: Heavy non-volatile carbon.
Sulphur: A destructive element if present in quantities.
Gravity of API: The weight of the oil compared to water.
Ash: The minerals and non-combustible solids.
Pour Point: The lowest temperature at which the oil will flow.
Flash Point: The temperature of first vapor flash.
Fire Point: The temperature of the oil for continuous burning.
Boiling Point, Distillation Points, and End Point: Indicate the combination of various hydrocarbons contained in the fuel.
Viscosity: The fluidity of the oil at certain temperature.
BTU: The heat content per pound of the fuel.
Diesel Index Number: A number derived from the gravity and aniline point indicating the suitability of the oil as iesel fuel. It is related to the cetane number.

There are other properties which are specified occasionally for some special or peculiar service, but the above list includes those which are used quite frequently.

This list may be divided into two parts, viz., the contaminants and the properties of the fuel. The contaminants are detrimental or damaging substances in the fuel and consist of ash, sulphur, bottom sediment and water, and carbon residue. The remainder of the list specifies the properties of the petroleum hydrocarbons in the fuel.

LUBRICATING OIL

The lubrication of the large, heavy-duty slow-speed diesel engine installed for stationary service does not constitute a serious problem. In mobile equipment, weight is an important factor and ratings are usually based on a much higher brake mean effective pressure than is customary in stationary engine practice. Also, to conserve space and weight the auxiliary equipment is smaller and may be less accessible for care and servicing; the engine may stand overnight in a gravel pit or along a highway in weather well below zero, and yet it is expected to start easily; and, the operator may be driving a tractor or running a dragline, having a number of duties besides merely caring for the engine.

The small diesel engine is more sensitive about lubricating oils and fuel oils than the stationary diesel engine. The mobile diesel is usually subjected to more severe operating conditions, greater variation of operating conditions, and more rapidly varying loads, while the stationary diesel engine is installed in a clean warm building, is seldom overloaded or subjected to shock loads, and is constantly watched, the mobile diesel may have to start in weather 20° F below zero, drive a snow plow or drag-line where the load is varying every second, and all this under conditions where it is impossible to give it the same care and attention which are accorded to the stationary installation.

Lubricating oil, in its varied role as lubricant, coolant, scavenger and sealer, can be of great assistance in protecting the engine and helping it to furnish cheap, economical and dependable power. Engine manufacturers have recognized that good lubrication is essential to the satisfactory operation of their engines, and have specified oils or written specifications for oils suitable for their particular engines. Such specifications usually include the following properties:

Gravity, in ° API
Viscosity @ 100° F, in seconds Saybolt Univ.
Viscosity @ 130° F, in seconds Saybolt Univ.
Viscosity @ 210° F, in seconds Saybolt Univ.
Pour Point, in ° F.
Flash Point, in ° F.
Fire Point, in ° F.
Viscosity Index, on Dean and Davis scale.
Neutralization Number, in Mgs of KOH/gram.
Carbon Residue, in percent by weight.
Sulphur, in percent by weight.
Corrosion, by various test methods.
Bottom Sediment and Water, none permitted in new oil.

There are other properties which are occasionally included, but the above list includes the more common items.

PART III

INSTALLATION

The objectives to be kept in mind in laying out and equipping installation are: safety, reliability, economy of operation, and accessability for low maintenance cost.

The problem of the installation varies with the size and type of the engine. Since the diesel is inherently a self-contained unit with few auxiliaries, installation is relatively a simple matter. Usually the engine builder either installs the engine or makes definite recommendations. These recommendations should always be carefully followed. Every installation must meet the requirements of all insurance, fire, and safety laws or regulations.

OPERATION

Engine Starting

An internal-combustion engine is started by some external source of power until favorable combustion conditions have been established so that the engine will run under its own power. The favorable conditions necessary in a diesel engine for starting are:

1. A temperature of the air charge, as the result of its compression, high enough for the ignition of the fuel.
2. Satisfactory atomization and dispersal of the fuel charge. Both of these requirements demand that the engine be accelerated to what is known as its "firing speed". This firing speed must be great enough to-
   a. prevent leaking of the air past the piston during compression, lowering the final compression pressure and final temperature below the value required for fuel ignition.
   b. limit the time of the compression stroke (in four-stroke diesels) sufficiently to prevent an excessive quantity of heat from being lost to the cylinder walls, thus lowering the final air temperature.
   c. cause the fuel pump cams to actuate the injection pumps sharply, thus preventing nozzle dribble.
   d. produce an injection pressure high enough so that the fuel droplets will penetrate the dense compressed air, and
   e. provide adequate air or gas swirl in combustion systems where such swirl is an essential feature.

Engine starting can be prevented or made sluggish by the following adverse conditions:

1. too heavy an external load
2. a very low ambient air temperature

3. too viscous a lubricating oil
4. fuel of poor ignition quality
5. faulty timing, maladjustment, or excessive wear of engine

Diesel engines, because of their high compression ratio are almost never started by hand. There are five methods in general use today to start diesel engines:

1. By the admission of compressed air at least 250 to 350 psig to the cylinders of the engine in turn during their firing stroke.
2. By applying compressed air at 80 to 150 psig to an air motor which is geared to the engine flywheel.
3. By applying electric current from a battery or other source to an electric starting motor geared to the engine flywheel.
4. By means of a small gasoline engine of the hand-starting type which is geared to the engine flywheel.
5. By applying electric current to special cranking coils built into the driven generator, which, during the starting process, acts as an electric motor to turn the engine over.

TABLE III

SELECTION OF STARTING METHOD

Starting Method	Where Used
Admission of compressed air to cylinders	Marine and stationary engines of medium to large size, and applications where a high torque at a low rpm may be necessary to turn over the driven equipment. An example of the latter is a long line shaft or a high starting torque machine driven without the benefit of a disconnecting clutch.
Air starting motor geared to engine flywheel	Marine and stationary engines of small to medium size, and applications where there is available a supply of air at the necessary pressure.
Electric starting motor geared to engine flywheel	Small marine and stationary engines, particularly those of the automotive type.
Gasoline engine geared to the flywheel	Small stationary engines, particularly those located in isolated or temporary installations, where the unit should be as completely self-sufficient as possible. Also, where excessively long cranking intervals may be required to counteract influence of extreme cold.
Starting or cranking coils in driven generator	Medium to large engines for diesel-electric locomotives and marine electric-drive installations.

If any work has been done on the engine since it was last run, it is good practice to turn over a two-cycle engine at least one complete revolution and, a four-cycle engine at least two complete revolutions to make sure that everything is mechanically clear and that the engine will operate freely. Engines that are started by compressed air and which have starting valves on only a few of the cylinders must first be spotted so that, when the starting air is turned on, it will be effective on one of the cylinders.

Make sure that the cooling-water system is properly filled. Where there are independently-driven pumps, start them and make sure that the proper rate of flow is established.

Make sure that the lubricating-oil system is filled to the proper level with clean oil of the right grade and viscosity. Where arrangements are made for doing so, start the circulation of oil through the engine and, if it is at all possible, get a good supply of oil to every bearing. If the engine has a mechanical lubricator for supplying oil to the working cylinders, get the lines leading to the cylinders filled with oil and pump a small quantity into the cylinders. It is vitally important to have a supply of lubricating oil in all the bearings when the shaft first starts to turn over, and the normal supply should follow immediately.

Make sure that all the air is worked out of the fuel-injection system. This is most important, because no injection system will work satisfactorily when there are bubbles in it. After freeing the entire system up to and including the cylinder-injection valves, pump a small quantity of fuel to make sure that the injection valves themselves are filled so that injection into the cylinders will begin as soon as the engine starts. Make sure that there is a good supply of fuel in the tanks that feed the fuel-injection pump.

Examine the starting system to make sure that the battery is fully charged in the case of electric starting, and that the starting tanks are charged to full pressure if compressed air is used.

When all this has been done, arrange the governor or hand throttle to give from one-half to three-quarters full-load fuel and start the engine. If ignition is not obtained promptly, shut the engine down and locate the difficulty. Never keep the electric starter of compressed-air starter on longer than is necessary. On the other hand, those engines that are started as gasoline engines or by separate gasoline-starting engines are purposely arranged to have the starting arrangement function indefinitely until the engine is warm enough to make normal operation possible.

Immediately after starting, check the lubricating-oil pressure, the cooling water, and fuel supply. It is good practice to operate the engine at moderate speed and at part-load until it gets warmed up to normal operating temperature. It will then be in condition to run at full speed and take full load to better advantage. On the other hand, it is not good practice to start the engine before it is needed and to idle it indefinitely.

The recharging of the battery of the electric system or the renewal of the full pressure in the air-starting tanks should be attended to immediately after the engine is started. This routine step is protection against unexpected stops soon after starting.

Engines that are located indoors are usually in heated rooms so that there is no difficulty in starting them during cold weather, even though the air intake may be from the outside. On the other hand, engines that are housed in unheated buildings or are out of doors, exposed to all temperature changes, should have special attention given to them, not only to make them start easily in cold weather, but to prevent excessive wear due to these conditions of operation.

The best starting practice under such conditions is gradually to warm the jacket cooling water and thus the engine cylinders themselves. It is also good practice to warm the lubricating oil so that it flows freely from the beginning and so that the lubrication of the bearing and cylinder walls will start promptly. Heating the intake air is of considerable assistance in starting any engine in cold weather, although, if the engine itself is warm, this is seldom necessary.

Where it is not possible to take the foregoing precautions, the next best procedure is to run the engine slowly and under a light load for several minutes after starting, in order to warm up gradually and give it time to assume normal operating temperature and condition before putting it to full speed and normal load. The idea is to get the engine up to normal temperature gradually but fairly promptly.

Engine jackets should be carefully drained if the engine is to be left standing exposed to low temperatures. Anti freeze solutions can be used, but alcohol should in general be avoided because it boils off at the normal cooling water operating temperatures. Extra precautions should be taken to make sure that all moisture is drained from the fuel tanks.

Operating the Engine

The operating routine must vary a great deal with the size and type of engine and the character of the installation. An engine of the automotive, industrial or railway type will not receive more than casual attention from the operator of the machine in which the engine is installed. The same thing holds true, but in a slightly different way, for automatic stationary plants. On the other hand, medium- and large-size marine installations and stationary central stations always have an operator on duty. He may have many other duties to perform in addition to watching the main engine or engines themselves, but he is always in the immediate vicinity and makes certain definite inspection rounds regularly. Engines that receive little or no attention during operation require automatic controls that will shut them down in case operating conditions become abnormal for any reason. Recording instruments covering pressures and temperatures are valuable accessories in such plants and are always useful when applied to the important pressures and temperatures in plants where operators are in constant attendance. In any case, a full complement of instruments to indicate pressure and temperature is essential.

The most important thing to be watched during operation is the combustion. That is the main feature of the diesel engine, and it deserves close attention at all times. Fortunately there are two simple means of gauging the continued efficiency of the combustion: the temperature of the exhaust gases and the color of the exhaust. Too low a temperature indicates poor cooling, overload conditions, bad combustion, or

difficulties with the injection system. The exhaust should be colorless; it should be almost invisible. If there is a light haze or if there is a very light blue color, the indications are that one or more cylinders are not firing. If the exhaust is brown or black, it is an indication of poor combustion or overload.

It is particularly important to make sure that all the cylinders are firing when the engine is operating at the lighter loads or just after it has been started. The balance of load between the several cylinders should be maintained under all conditions. The division of the load is indicated by the temperature given by the pyrometer terminals in the exhaust from the several cylinders. Before adjusting the fuel pumps to correct any apparent load inequalities, first make sure that the pyrometers are giving accurate readings. In most cases, frequent pyrometer readings will show the trend of the temperatures and load divisions. Also any difficulties with the pyrometer itself would probably be indicated; in case of doubt, the pyrometer can be checked by interchanging the terminals in adjacent cylinders. Comparison of the readings will show at once whether the pyrometer or the engine is at fault.

During operation, watch all pressures and temperatures. It is excellent practice to make up a log sheet on which are tabulated all pressures and temperatures with the load readings. The trend of these readings will frequently foreshadow approaching difficulties or help to locate troubles when they occur. A running record of fuel-oil and lubricating-oil consumption is an important check on regular operation and performance.

Ample supplies of clean soft water, clean cool lubricating oil, and clean fuel are essential at all times. This means that the filters and any water-softening apparatus that may be used should receive regular attention. If the cooling water is not perfectly clean and soft, then the mud and scale must be removed frequently. Closed cooling systems should be cleared of rust and sediment by flushing out occasionally. Watch constantly for water in the lubricating oil and in the fuel oil. Drain the starting-air tanks regularly to eliminate all moisture and lubricating oil.

In automotive-type or other small engines it is good practice to drain and change the lubricating oil every 50 to 100 hrs. of operation. In large engines which have much larger quantities of lubricating oil in the system and which usually have better filtering equipment, the change is made only about once a month or every 750 hrs. of operation. Of course, if continuous filtering or centrifuging is employed, then the system need rarely be drained. Rather there is a continual cleaning of the oil in the system with frequent additions of make-up oil.

The intake-air cleaners must be given regular attention.

Never overspeed, and never overload the engine beyond comfortable limits. To do so simply invites trouble and increases maintenance attention and costs. Make the necessary adjectments to keep the engine in good operating condition, but never experiment or tinker. If the observations of pressures, temperatures, and other conditions indicate that the performance is normal and up to standard, let the engine operate as it is.

It is good practice to test all the emergency devices at as regular intervals as

possible without interfering with regular operation.

Stopping the Engine

Make sure first that the starting equipment if fully charged. Then take off the load and shut the engine down by shutting off the fuel supply. Never use any other method for stopping the engine, because all possibility of accumulation of fuel in the cylinders must be eliminated.

After the shaft has stopped rotating, shut off the lubricating-oil supply. The cooling-water circulation should be continued in all cases where it is possible, certainly in engines with cylinders 10 in. in diameter and over, until the engine is thoroughly cooled and the cylinder parts have attained a temperature approaching that of the cooling water or the atmosphere. If this residual heat is not removed in this way, the accumulation in the hotter parts of the cylinders will cause excessive local temperatures with ensuing distortion and possible damage to the engine.

Always leave the engine in such condition that it can be started easily and promptly. If there are inspections or adjustments to be made, do the work immediately after shutting down. Never delay it until just before starting, because this may mean rushing it in order to complete it in time, and it is always possible that unexpected difficulties will be found that will require more time for their correction or attention than will be available.

MAINTENANCE AND REPAIR

Inspections should be rigid and regular. It is well to start with a rather frequent schedule and to ease it off as conditions warrant, but in any case the inspection must be made to suit the operating schedule. In general, inspection schedules are based upon the total hours of operation; on the other hand, if operations are rather intermittent, it is well to shorten the schedule as far as total hours of operation are concerned and to base it partly upon calendar time. This is particularly true in the case of engines that are operated seasonally.

Automotive-type diesel engines may need an inspection and possibly a light valve grinding about every 25,000 miles. They should be thoroughly overhauled, and in some cases liners should be rebored or replaced about every 70,000 to 100,000 miles.

Engines that operate in seasonal work, such as some tractor engines and some small marine engines working 2000 or 3000 hours per year, need only a careful annual inspection, provided they are well taken care of during the idle season. Thorough overhaulings need come only every 2 or 3 years and perhaps at even more infrequent intervals.

The better design, better materials, and better lubrication used in present-day engines mean less wear and tend to reduce the frequency of overhauls.

As schedules for such work must be based upon engine performance and upon results of the routine inspections, a good operator and a careful observer during the inspections will quickly detect abnormal wear or abnormal tendencies that will lead to

difficulties if not corrected.

Every manufacturer issues an instruction book that gives detailed instructions for adjusting the various parts of the engine; these suggestions should be followed. It is important to keep on hand a good supply of spare parts such as fuel-injection pump parts, spray valves, inlet and exhaust valves and bearing shells. It is especially important to maintain a full supply of such consumable stores as gaskets and packing material.

General Procedures

In many cases, a mechanic is justified in replacing parts with new material rather than attempting repair. However, there are times where a slight amount of reworking or reconditioning may save on considerable added expense. Crankshafts, cylinder liners and other parts are in this category. For example, if a cylinder liner is only slightly worn and within usable limits, a honing operation to remove the glaze may make it suitable for reuse with a standard size and piston and new piston rings, thereby saving the expense of new parts. Exchange assemblies such as injectors, fuel pumps, water pumps and blowers, are also desirable service items.

Various factors such as the type of operation of the unit, hours in service and next overhaul period must be considered when determining whether new parts are installed or used parts are reconditioned to provide trouble-free operation.

Disassembly

Before any major disassembly, the engine must be drained of lubricating oil, water and fuel. On engines cooled by a heat exchanger, the fresh water system and raw water system must both be drained. Lubricating oil should also be drained from any power transmission attached to the engine.

To perform a major overhaul or other extensive repairs, the complete engine assembly, after removal from the engine base and drive mechanism, should be mounted on an engine overhaul stand; then the various subassemblies should be removed from the unit. When only a few items need replacement, it is not always necessary to mount the engine on an overhaul stand.

Parts removed from an individual engine should be kept together so they will be available for inspection and assembly. Those items having machined faces, which might be easily damaged by steel or concrete, should be stored on suitable wooden racks or blacks or a parts dolly.

Cleaning

Before removal of sub-assemblies from the engine (but after removal of the electrical equipment) the exterior of the engine should be thoroughly cleaned. Then, after each subassembly is removed and disassembled, the individual parts should be cleaned. Thorough cleaning of each part is absolutely necessary before a part can be satisfactorily inspected. Below are listed various items of equipment needed for general cleaning.

Steam Cleaning

A steam cleaner is a necessary item in a large shop and is most useful for removing heavy accumulations of grease and dirt from the exterior of the engine and its subassemblies.

Solvent Tank Cleaning

A tank of sufficient size to contain the largest part which will require cleaning (usually the cylinder block) must be provided and provisions made for heating the cleaning solution to approximately 180 F.

This tank is filled with a commercial heavy-duty solvent which is heated to the above temperature. Large parts are lowered directly into the tank with a hoist; small parts are placed in a wire mesh basket and lowered into the tank. The parts are immersed in the cleaning tanks long enough to loosen all grease and dirt.

Rinsing Bath

Another tank of similar size containing hot water should be provided for rinsing the parts.

Drying

Parts may be dried with compressed air. The heat from the hot tanks will quite frequently complete the drying of parts without the use of air.

Rust Proofing

If parts are not to be used immediately after cleaning, they should be dipped in suitable rust proofing compound.

INSPECTION

The purpose of parts inspection is to determine which parts can be used and which must be replaced. Although the engine overhaul specifications given throughout the text will aid in determining which parts should be replaced, considerable judgment must be exercised by the inspector.

The guiding factors in determining the usability of worn parts, which are otherwise in good condition, is the clearance between the mating parts and the rate of wear on each of the parts. If it is determined that the rate of wear will maintain the clearances within the specified maximum allowable until the next overhaul period, the reinstallation of used parts may be justified. Rate of wear of a part is determined by dividing the amount the part has worn by the hours it has operated.

Many service replacement parts are available in various undersize and oversize as well as standard sizes. Also, service kits for reconditioning certain parts and service sets which include all of the parts necessary to complete a particular repair job are available.

In addition to measuring the used parts after cleaning, the parts should be carefully inspected for cracks, scoring, chipping, and other defects.

A complete discussion of the proper methods of precision measuring and inspection are outside the scope of this volume. However, every shop should be equipped with standard gauges such as dial bore gauges, dial indicators, and inside and outside micrometers.

Assembly

Following cleaning and inspection, the unit should be assembled using new parts as determined by the inspection.

Use of the proper equipment and tools makes the job progress faster and produces better results. Likewise, a suitable working space with proper lighting must be provided. The time and money invested in providing the proper tools, equipment, and space will be repaid many times.

Keep the working space, the equipment, tools, and engine assembled and parts clean at all times. The area where assembly operations take place should, if possible, be located away from the disassembly and cleaning operation. Also, any machining operations should be removed as far as possible from the assembly area.

Particular attention should be paid to storing of parts and subassemblies, after removal and cleaning, and prior to assembly, in such a place or manner as to keep them clean. In case there is any doubt as to the cleanliness of such parts, they should be recleaned.

An overhaul inspection check sheet will aid the mechanic in keeping a written record of the parts replaced and the repairs as they are made on the unit. It may also serve as a permanent record of the maintenance performed on a particular unit. A check sheet may be made similar to the one shown on the following page.

TABLE IV

OVERHAUL INSPECTION CHECK SHEET

NO.	INSPECT	OK	REPLACEMENTS AND REMARKS
	CYLINDER BLOCK		
1	Machined Surface & Tapped Holes		
2	Dowels		
3	Oil & Water Plugs		
4	Air Box Drains, Fittings		
5	End Plates and Gaskets—Clean Surface		
6	Bolts Tightened to Torque		
	CRANKSHAFT		
1	Cleaned & Plugged		
2	Smooth Surfaces—Journals, Fillets & Seal Surfaces		
3	Thrust Bearings Installed		
4	Main Bearings Installed		
5	End Play		
6	Front Keyway—Key		
7	Seal Spacer or Cone, Hub or Cop Installed, Front Cover & Oil Seal, Crank Timing Gear, Oil Slingers		
8	Bolts Tightened to Torque		
	PISTONS, RODS & LINERS		
1	Ports Clean—Burred & O.D. Smooth		
2	Liner to Block Fit		
3	Piston O.D. & Liner I.D. Matched Fit		
4	Compression Rings		
5	Oil Rings		
6	Conn. Rod Bearings		
7	Nuts Tightened—Cotter-Pins		
	CAM SHAFT		
1	End Bearings & Thrust Bearings		
2	Intermediate Bearings & Lock Screws Fitted Into Place		
3	Gears & Bal. Wt. Lock Nuts Tightened		
4	Gear Timing & Markings		
5	End Play & Back Lash		
6	Bolt Interference		
7	Tachometer Drive		
	OIL PUMP		
1	Gear Lash, Pump Shimmed		
2	Outlet Pipe & By-Pass Inlet Pipe, Screen & Gaskets		
3	Filter Adapter, Oil Cooler, Housing & Gaskets		
4	Pressure Relief Valve		
5	Bolts Tightened to Torque		
6	Check Suction Lines for Leak		
	CYLINDER HEAD		
1	Cam Rollers Free		
2	Cam Followers—Guides Tightened		
3	Oil Gallery Plugs In Place		

TABLE IV - continued

OVERHAUL INSPECTION CHECK SHEET (Cont'd.)

NO.	INSPECT	OK	REPLACEMENTS AND REMARKS
	CYLINDER HEAD (Continued)		
4	Fuel Manifold Connections		
5	Head Gaskets		
6	Injectors		
7	Crabs		
8	Cylinder Head Nuts & Bolts—Tightened to Torque		
9	Injector Timing & Valve Lash		
10	Fuel Lines Tight		
11	Control Tube Free		
12	Exhaust Valves & Inserts		
	BLOWER, PAN, FLYWHEEL HOUSING & FLYWHEEL		
1	Gear Train Lubricated		
2	Oil Seal, Gaskets & Housing Installed		
3	Bolts Tightened to Torque		
4	Flywheel Interference		
5	Pan Gasket & Sealer		
6	Pan Bolts Installed and Tightened		
7	Drain Plugs & Gasket		
8	Blower Drive Hub & Bearing Support		
9	Blower Drive—Oil Line Tight		
10	Blower Drive Gear Lash		
11	Oil Filter Tube Assembly—Tight		
12	Blower Gasket & Sealer		
13	Blower Assembly		
14	Governor to Blower Gasket		
15	Governor Control Link		
16	Blower Shaft		
	MISCELLANEOUS		
1	Starter		
2	Generator		
3	Voltage Regulator		
4	Water Manifold & Gaskets, Thermo. Housing & Gaskets & Thermostats. By-Pass Tube & Hoses		
5	Vibration Damper		
6	Balance Wt. Cover, Gasket		
7	Air Box Inspection Covers & Gaskets		
8	Valve Rocker Arms Cover & Gaskets		
9	Inspection Approved		
10	Lube Oil in Engine		
	Water Connected		
	Fuel Connected		
	Approved for Run-In		

LUBRICATION AND PREVENTIVE MAINTENANCE

To get performance from a small or medium size Diesel power unit, the Operator should adhere to the following schedule and instructions on lubrication and preventive maintenance.

The daily instructions pertain to routine or daily starting of a unit and not to a new unit or one that has not been operated for a considerable period of time.

The time intervals given in the chart on the following page are actual operating hours of a unit. If the lubricating oil is drained immediately after a unit has been run for some time, most of the sediment will be in suspension and therefore will drain readily.

LUBRICATION AND PREVENTIVE MAINTENANCE CHART

Item	Operation	Time Interval								
		Daily	8 Hours	50 Hours	100 Hours	200 Hours	300 Hours	500 Hours	1000 Hours	2000 Hours
	LUBRICATION SYSTEM									
1.	Engine Oil	X			X					
2.	Oil Filter				X					
3.	Oil Cooler								X	
	COOLING SYSTEM									
4.	Coolant	X							X	
5.	Heat Exchange Electrodes							X		
6.	Hoses							X		
7.	Radiator									X
	FUEL SYSTEM									
8.	Fuel Tank							X		
9.	Fuel Strainer & Filter	X					X			
	AIR SYSTEM									
10.	Blower Screen								X	
11.	Air Cleaners		X							
12.	Air Box Drains				X			X		
13.	Crankcase Ventilation								X	
	ELECTRICAL SYSTEM									
14.	Cranking Motor								X	X
15.	Battery-Charging Generator							X		X
16.	Battery				X					
	MISCELLANEOUS									
17.	Tachometer			X						
18.	Throttle Controls					X				
19.	Engine Tune-Up				X			X		
20.	Drive Belts							X		
21.	Power Take-Off		X	X				X		
22.	Marine Gear	X				X *		X §		
23.	Hydrostarter System								X	X
24.	Vibration Damper									4000 Hours

* Allison Torqmatic Marine Gear
§ Twin Disc Marine Gear

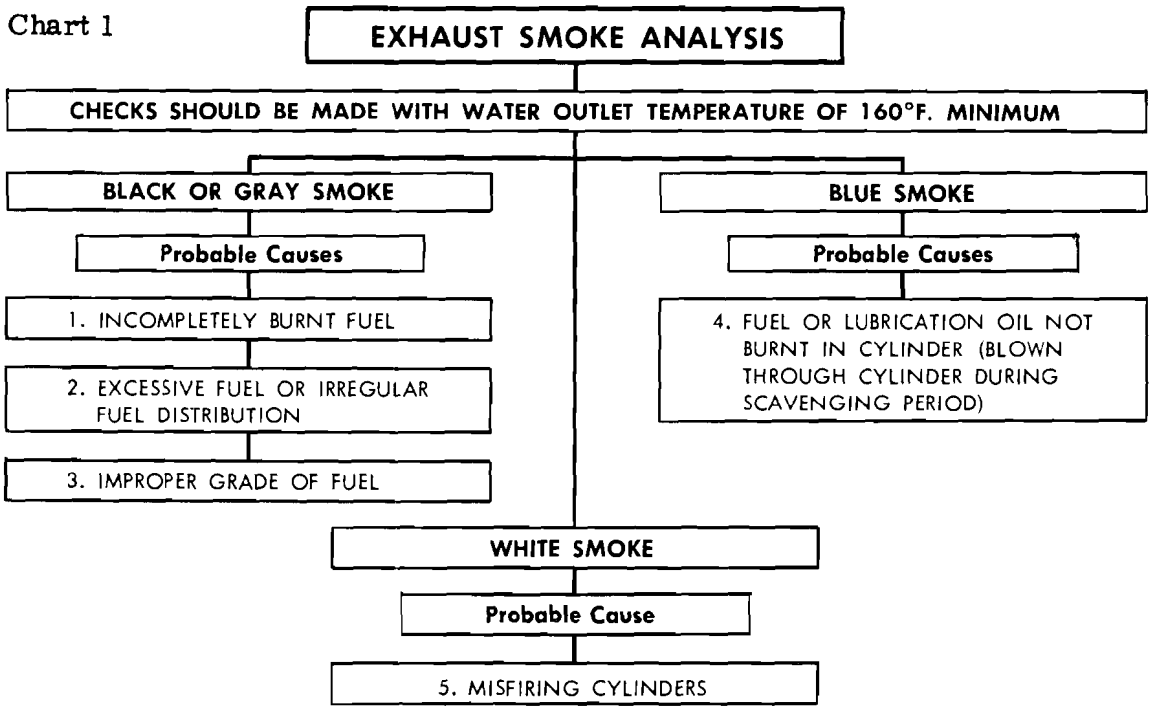
TROUBLE SHOOTING

Certain abnormal conditions which sometimes interfere with satisfactory engine operation, together with methods of determining cause of such conditions, are covered in the Trouble Shooting Charts on the following pages.

The Trouble Shooting Charts are presented to help minimize the time required to locate and correct trouble that may occur during operation of the unit.

Each Trouble Shooting Chart is numbered in its upper left-hand corner. These numbers are used only to permit ease of reference between charts.

Chart 1



SUGGESTED REMEDY

1. High exhaust back pressure or restricted air inlet causes insufficient air for combustion and will result in incompletely burnt fuel.

   High exhaust back pressure is caused by faulty exhaust piping or muffler obstruction and is measured at exhaust manifold outlet with a manometer. Parts causing high exhaust back pressure should be replaced.

   Restricted air inlet to the engine cylinders is caused by clogged cylinder liner ports, air cleaner, blower to air inlet horn screen. These items should be cleaned. Check emergency stop to see that it is completely open and readjust if necessary.

   Inadequate air supply to engine compartment can cause incomplete combustion. The engine compartment should be altered or the air intake moved to provide an adequate supply of air for complete combustion.

2. Check for improper injector rack setting and timing of injectors. Time fuel injectors as outlined in "Fuel Injector Timing" and perform appropriate governor tune-up to correct this condition.

   Replace faulty injectors if this condition still persists after timing the injectors and performing engine tune-up.

   Lugging of the engine will cause incomplete combustion and should be avoided. Operate unit as outlined in "Engine Operation".

3. Check for the use of improper grade of fuel. Consult the "Fuel Oil Specifications" for the correct fuel to use.

4. Check for internal lubricating oil leaks, see chart "High Lubricating Oil Consumption".

   Check for internal fuel oil leaks, such as leakage at air heater nozzle. Overhaul faulty assembly.

5. Check for faulty injectors and replace as necessary.

   Check for low compression and consult chart "Hard Starting".

   The use of low cetane fuel will cause this condition and can be corrected by consulting and following the "Fuel Oil Specifications".

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Chart 2

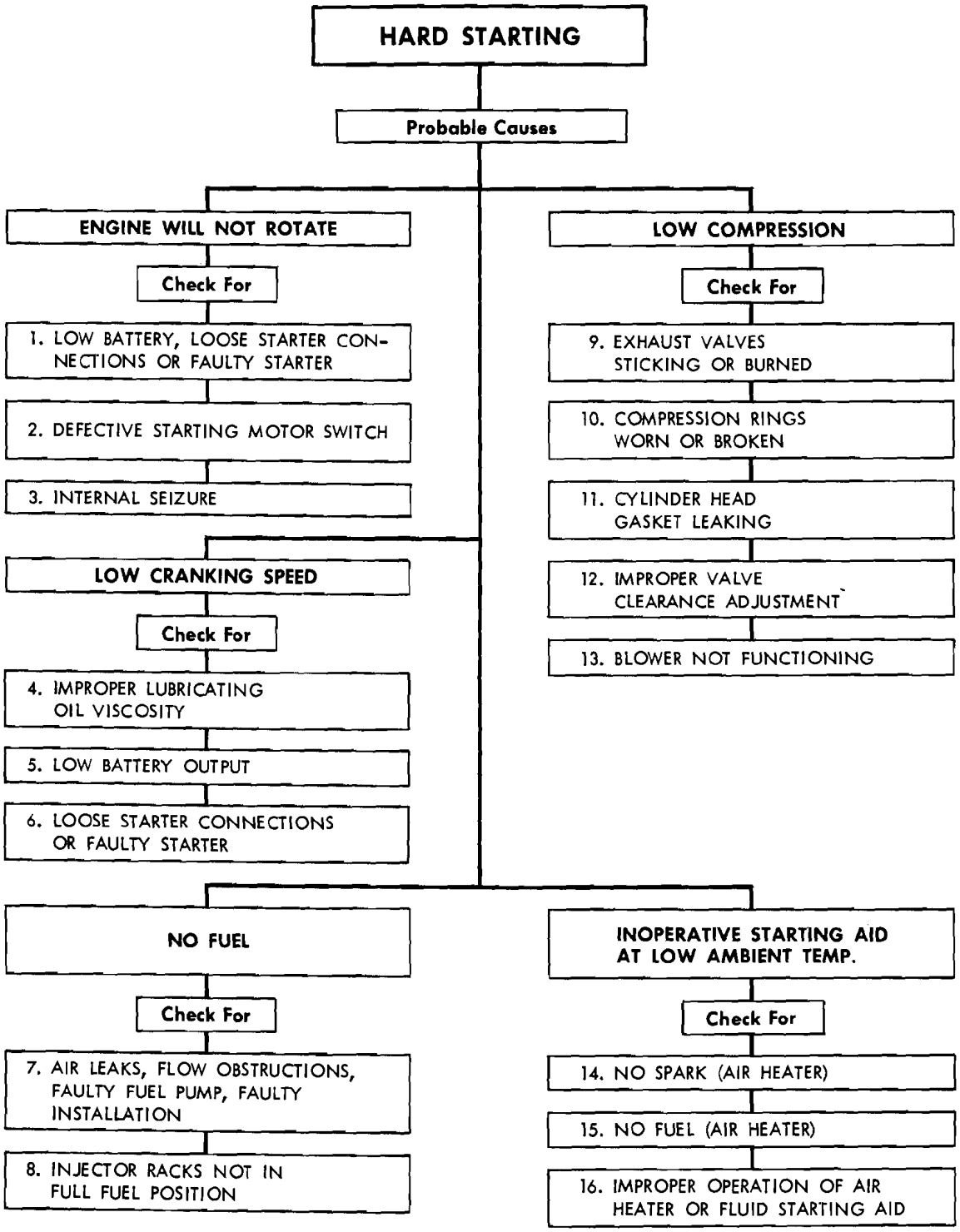

HARD STARTING
Probable Causes
ENGINE WILL NOT ROTATE
Check For
1. LOW BATTERY, LOOSE STARTER CONNECTIONS OR FAULTY STARTER
2. DEFECTIVE STARTING MOTOR SWITCH
3. INTERNAL SEIZURE
LOW CRANKING SPEED
Check For
4. IMPROPER LUBRICATING OIL VISCOSITY
5. LOW BATTERY OUTPUT
6. LOOSE STARTER CONNECTIONS OR FAULTY STARTER
NO FUEL
Check For
7. AIR LEAKS, FLOW OBSTRUCTIONS, FAULTY FUEL PUMP, FAULTY INSTALLATION
8. INJECTOR RACKS NOT IN FULL FUEL POSITION
LOW COMPRESSION
Check For
9. EXHAUST VALVES STICKING OR BURNED
10. COMPRESSION RINGS WORN OR BROKEN
11. CYLINDER HEAD GASKET LEAKING
12. IMPROPER VALVE CLEARANCE ADJUSTMENT
13. BLOWER NOT FUNCTIONING
INOPERATIVE STARTING AID AT LOW AMBIENT TEMP.
Check For
14. NO SPARK (AIR HEATER)
15. NO FUEL (AIR HEATER)
16. IMPROPER OPERATION OF AIR HEATER OR FLUID STARTING AID

Chart 2(Cont'd.)

HARD STARTING (Cont'd.)

SUGGESTED REMEDY

1. Refer to Items 2 and 3 and perform operations listed.

2. Replace starting motor switch.

3. Hand crank engine at least one complete revolution. If engine cannot be rotated through a complete revolution, internal damage is indicated and the engine must be disassembled to ascertain the cause of binding.

4. Use the proper lubricating oil viscosity as recommended in the "Lubricating Oil Specifications".

5. Recharge battery if specific gravity is low. Replace battery if it is damaged or worn out and will not accept a recharge.

   Properly connect leads after replacing terminals that are damaged or corroded.

   At low ambient temperatures the use of a starting aid will facilitate keeping the battery fully charged by reducing the cranking time.

6. Tighten starter connections. Inspect starter commutator and brushes for wear. Replace brushes if badly worn and overhaul cranking motor if commutator is damaged.

7. To check for air leaks, flow obstruction, faulty fuel pump, or faulty installation consult chart "No Fuel or Insufficient Fuel".

8. Inspect for binding governor to injector linkage that will prevent the governor from positioning the injector racks into the FULL FUEL position. Remove any bind found and readjust governor and injector controls if necessary.

9. Cylinder head must be removed and overhauled to correct this condition.

10. Inspect compression rings through hand hole covers in side of cylinder block and overhaul cylinder assembly if rings are badly worn or broken.

11. To check for compression gasket leakage remove coolant filler cap and operate engine. A steady flow of gases from coolant filler indicates either the cylinder head gasket is damaged or the cylinder head is cracked. Remove cylinder head and replace gaskets. Check cylinder head by pressure testing before replacing on engine.

12. Check exhaust valve clearance and adjust correct clearance.

13. Inspect blower drive shaft and drive coupling. Replace damaged parts.

14. Inspect for poor or shorted connections, defective coil, points inoperative, cracked electrode porcelain, or inoperative or improperly adjusted pressure switch. Adjust or replace faulty parts.

15. Check valve and seals of hand pump, spray nozzle, fuel filter, and valve in pump suction line. Clean valves, spray nozzle, and filter and replace seals and defective parts.

    If the ambient temperature is less than 10°F. above the pour point of the fuel oil, consult and follow the "Fuel Oil Specifications".

    Check the installation of the starting aid components and assemble the items correctly.

16. Operate the starting aid according to the instructions under "Cold Weather Starting Aids".

Chart 3

ABNORMAL ENGINE OPERATION

Probable Causes

UNEVEN RUNNING OR FREQUENT STALLING

Check For

1. LOW COOLANT TEMPERATURE
2. INSUFFICIENT FUEL
3. FAULTY INJECTORS
4. LOW COMPRESSION PRESSURES
5. GOVERNOR INSTABILITY (HUNTING)

LACK OF POWER

Check For

6. IMPROPER ENGINE ADJUSTMENTS (TUNE-UP) AND GEAR TRAIN TIMING
7. INSUFFICIENT FUEL
8. INSUFFICIENT AIR
9. ENGINE APPLICATION
10. HIGH RETURN FUEL TEMPERATURE
11. HIGH AMBIENT AIR TEMPERATURE
12. HIGH ALTITUDE OPERATION

DETONATION

Check For

13. OIL PICKED UP BY AIR STREAM
14. LOW COOLANT TEMPERATURE
15. FAULTY INJECTORS

SUGGESTED REMEDY

1. Watch engine cooling temperature gauge and if the temperature does not reach 160°F to 185°F while engine is operating, consult chart "Abnormal Engine Coolant Temperature".
2. Check engine fuel spill back and if return is less than 1/2 gallon per minute consult chart "No Fuel or Insufficient Fuel".
3. Check injector timing and the setting of the

Chart 4

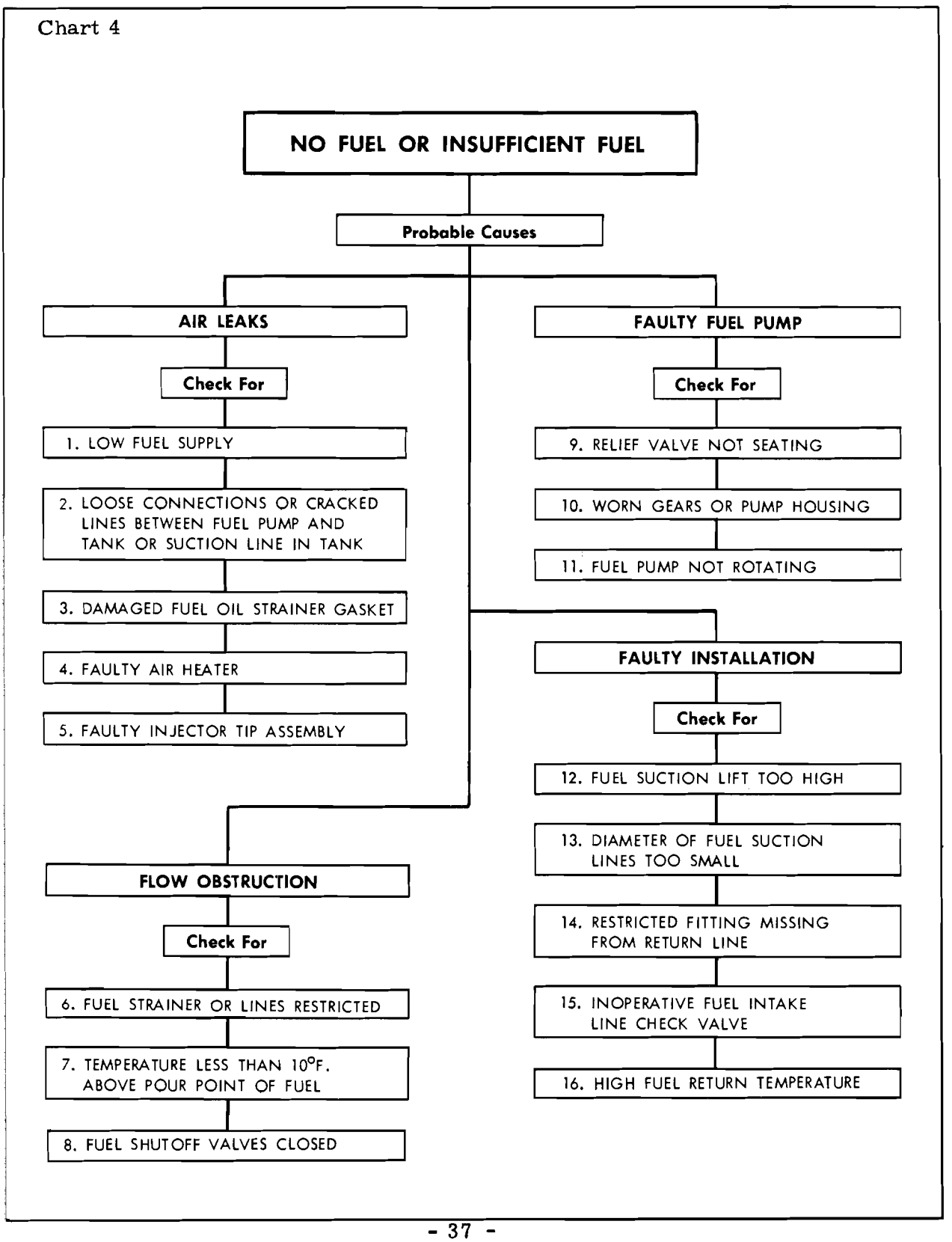

NO FUEL OR INSUFFICIENT FUEL
Probable Causes
AIR LEAKS
Check For
1. LOW FUEL SUPPLY
2. LOOSE CONNECTIONS OR CRACKED LINES BETWEEN FUEL PUMP AND TANK OR SUCTION LINE IN TANK
3. DAMAGED FUEL OIL STRAINER GASKET
4. FAULTY AIR HEATER
5. FAULTY INJECTOR TIP ASSEMBLY
FLOW OBSTRUCTION
Check For
6. FUEL STRAINER OR LINES RESTRICTED
7. TEMPERATURE LESS THAN 10°F. ABOVE POUR POINT OF FUEL
8. FUEL SHUTOFF VALVES CLOSED
FAULTY FUEL PUMP
Check For
9. RELIEF VALVE NOT SEATING
10. WORN GEARS OR PUMP HOUSING
11. FUEL PUMP NOT ROTATING
FAULTY INSTALLATION
Check For
12. FUEL SUCTION LIFT TOO HIGH
13. DIAMETER OF FUEL SUCTION LINES TOO SMALL
14. RESTRICTED FITTING MISSING FROM RETURN LINE
15. INOPERATIVE FUEL INTAKE LINE CHECK VALVE
16. HIGH FUEL RETURN TEMPERATURE

Chart 3 (Cont'd.)

ABNORMAL ENGINE OPERATION (Cont'd.)

SUGGESTED REMEDY

rack. If the engine was not tuned up correctly, perform engine tune-up. Erratic engine operation may also be caused by leaking injector spray tips. Remove and replace faulty injectors.

4. Check compression pressures within cylinders and consult chart "Hard Starting" if compression pressures are low.

5. Engine hunting may be caused by binding governor to injector operating linkage or by faulty adjustments when performing the engine tune-up. These items may be corrected by performing the appropriate engine tune-up procedure as outlined for the governor.

6. Incorrect setting of the governor gap, injector rack, injector height, or valve clearance will result in lack of power. The engine should be adjusted according to the appropriate tune-up procedure.

   Check engine gear train timing. Improperly timed gear train will result in a loss of power due to the valves and injectors being actuated at the wrong time in the engine's operating cycle.

7. Perform engine spill back check and if less than 1/2 gallon per minute is returning to the fuel tank consult the chart "No Fuel or Insufficient Fuel".

8. Check for damaged or clogged air cleaners and clean, repair or replace damaged parts.

   Inadequate air supply in engine compartment will cause loss of power. Provide an adequate supply of air for engine.

   Inspect cylinder liner ports through hand hole covers in cylinder block. If liner ports are over 50% clogged they should be cleaned.

   When it is determined that the engine is not getting an adequate supply of air into the cylinders, with the resulting poor combustion, check for damaged or clogged air cleaners, inadequate air supply to engine compartment, cylinder liner ports over 50% clogged, blower air intake obstructed, or high exhaust back pressure. The faulty parts should be cleaned, repaired or replaced.

   Check compression pressures; if found low, consult the chart "Hard Starting".

9. Application drives of poor design waste power and should be replaced by more efficient assemblies.

   Incorrect operation of the unit may result in excessive loads on the engine. Operate unit according to approved procedures outlined in "Engine Operation".

10. Refer to item 16 on Chart 4.

11. Check ambient air temperature. A power decrease of .15 to .5 horsepower per cylinder, depending upon injector size, for each 10°F. temperature rise above 90°F. will occur. Relocate the engine air intake to provide a cooler source of air.

12. Engines lose horsepower with increases in altitude. The percentage of power loss is governed by the altitude at which the unit is operating.

13. Check air cleaners to see that they have been filled to the proper level with the same viscosity lubricating oil that is used in the engine.

    Clean air box and drain tubes to prevent accumulations that may be picked up by the air stream and enter the engine's cylinders.

    Inspect blower oil seals by removing air inlet horn and watching through blower inlet for oil radiating away from blower end plates while engine is running. If oil is passing through seals, overhaul blower.

    Check for a defective blower to cylinder block gasket. Replace gasket if necessary. If blower has been removed install a new gasket.

14. Refer to item 1 of this chart.

15. Check the injector timing and the rack setting. If the engine was not tuned up correctly, perform engine tune-up. If the engine is correctly tuned up the erratic operation may be caused by injector check valve leaking, spray tip holes enlarged, or a broken spray tip. Replace all injectors found faulty.

Chart 4 (Cont'd.)

NO FUEL OR INSUFFICIENT FUEL (Cont'd.)

SUGGESTED REMEDY

1. The fuel tank should be filled above the level of the engine suction tube.

2. Make "Fuel Flow Test" and if air is present tighten loose connections and replace cracked lines.

4. Check for and correct air leaks in hand pump and suction lines.

5. Make "Fuel Flow Test" and if air is present, with all fuel lines and connections assembled correctly, check for and replace faulty injectors.

6. Make "Fuel Flow Test" and replace fuel strainer and filter elements fuel lines as necessary.

7. Consult "Fuel Oil Specifications" and use the fuel oil recommended.

8. Open fuel shut-off valves.

9. Make "Fuel Flow Test" and, if inadequate, clean and inspect valve seat assembly.

10. Replace gear and shaft assembly or fuel pump if housing is damaged.

11. Check condition of fuel pump drive and blower drive and replace defective parts.

12. Maximum lift of fuel pump is 48" at sea level, reduce vertical lift of fuel if suction lift is higher.

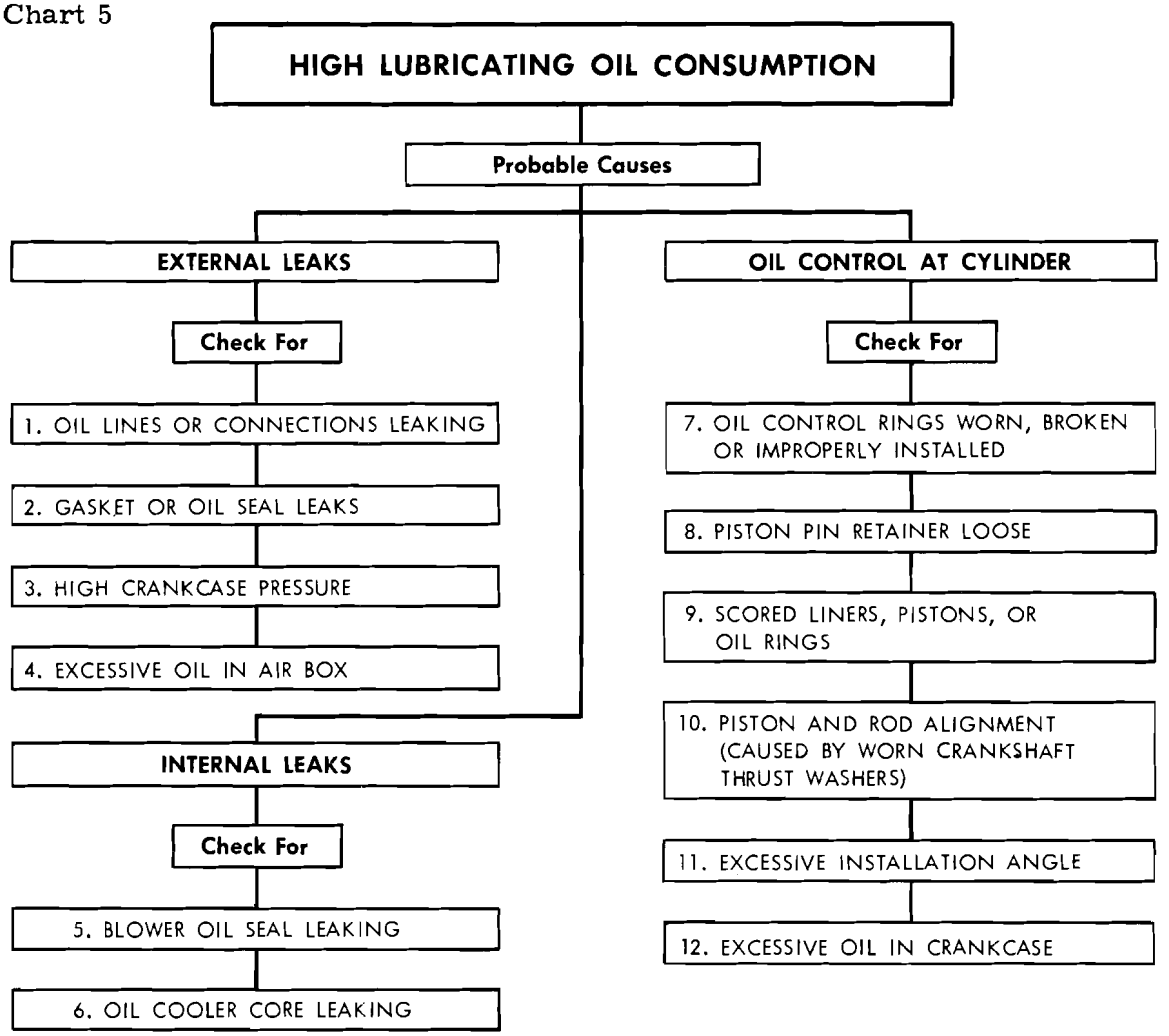
13. Replace with larger tank to unit fuel lines when fuel supply is remotely mounted from unit.

14. Replace restricted fitting in return line.

15. See that valve is installed in line correctly; arrow should be on top of valve assembly or pointing upward. Reposition valve if necessary. If valve is inoperative, replace with new valve assembly.

16. Check engine fuel spill back temperature. The return fuel temperature must not exceed 150°F. or a loss in horsepower will occur. This condition may be corrected by installing larger lines, relocating fuel return line in fuel tank (farther from suction line), or install a larger fuel tank.

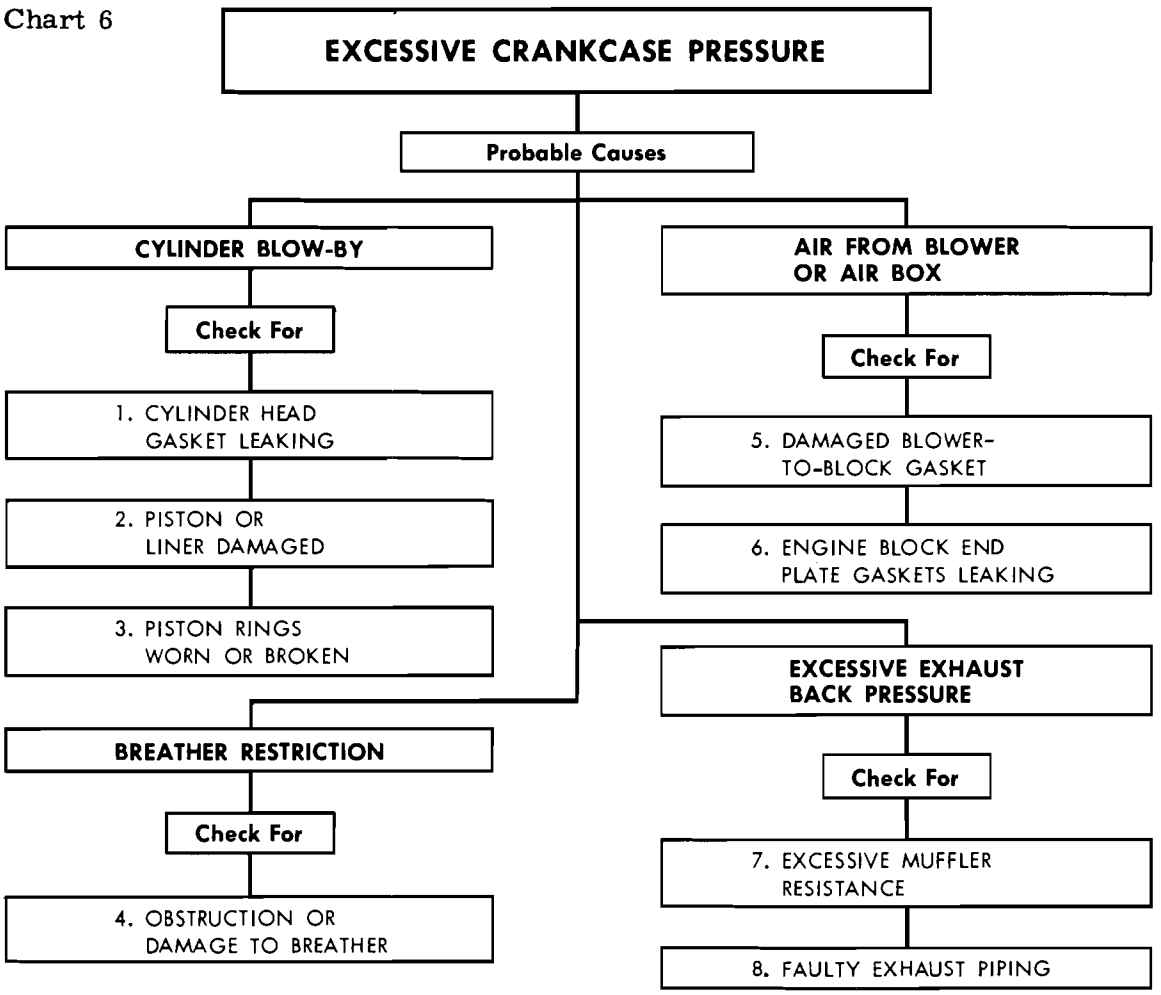
Chart 5



SUGGESTED REMEDY

1. Tighten or replace defective parts.
2. Replace defective gaskets or oil seals.
3. See chart "High Crankcase Pressure".
4. See chart "Abnormal Engine Operation".
5. Remove air inlet horn and inspect blower end plates while engine is operating. If oil is seen on end plate radiating away from oil seal, overhaul blower.
6. Inspect engine coolant for oil; if found, replace oil cooler core. Then use a good grade of cooling system cleaner to remove oil from cooling system.
7. Replace oil control rings on piston.
8. Replace piston pin retainer and defective parts.
9. Remove and replace defective parts.
10. Replace worn and defective parts.
11. Decrease installation angle.
12. Fill crankcase to full mark on dipstick.

Chart 6



SUGGESTED REMEDY

1. Check compression pressure and if only one cylinder has low compression remove cylinder head and replace cylinder head gaskets.
2. Inspect piston and liner and replace damaged parts.
3. Inspect piston for worn or broken piston rings and replace necessary items.
4. Clean, repair or replace breather assembly.
5. Remove blower-to-block gasket and replace with new gasket.
6. Replace block end plate gaskets with new gaskets.
7. Check exhaust back pressure and repair or replace muffler if an obstruction is in muffler.
8. Check exhaust back pressure and install larger piping if it is determined that the piping is too small, too long or has too many bends. If street elbows have been used they should be replaced with pipe elbows and if possible reduce the number of bends in the exhaust pipe.

Chart 7

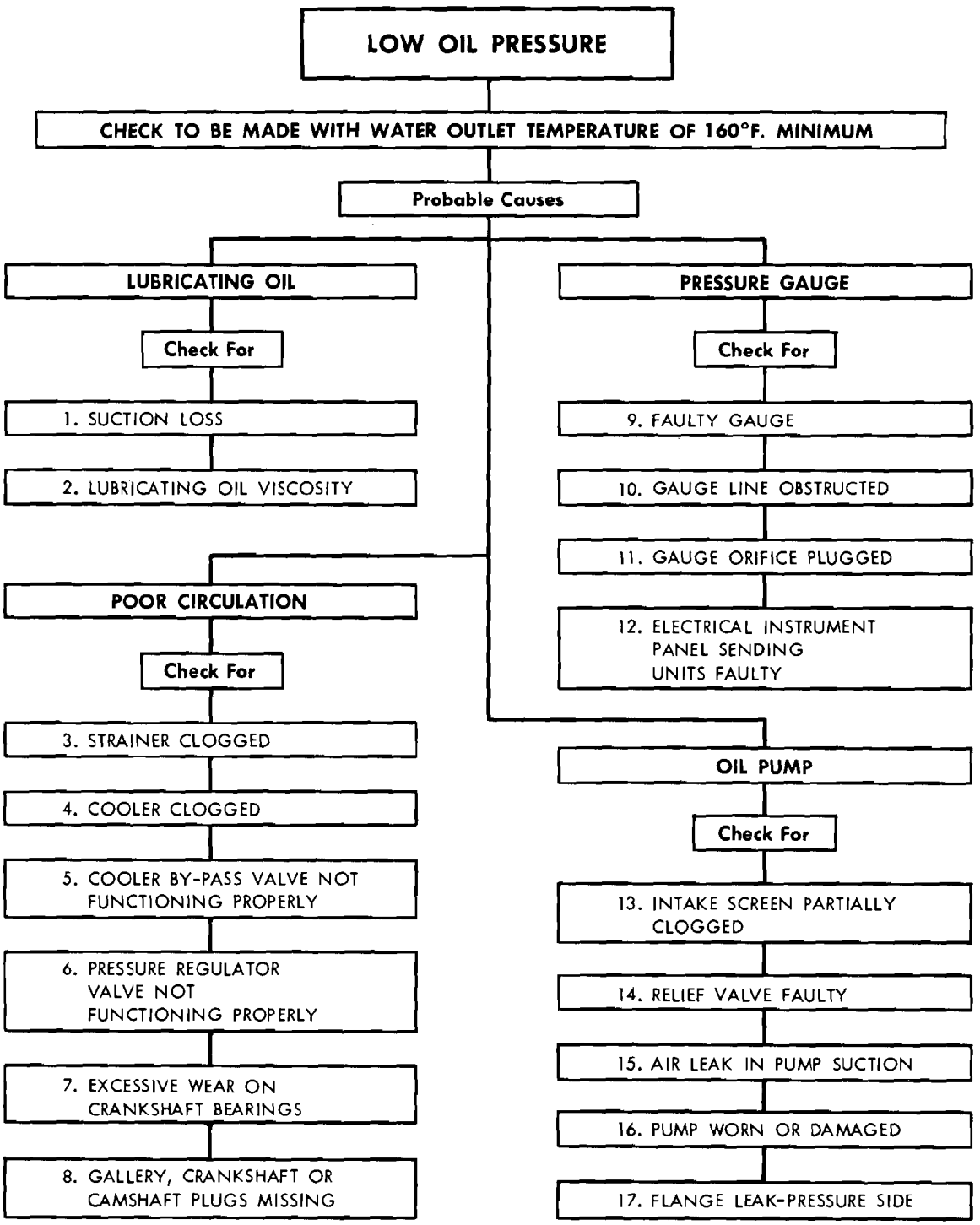

LOW OIL PRESSURE
CHECK TO BE MADE WITH WATER OUTLET TEMPERATURE OF 160°F. MINIMUM
Probable Causes
LUBRICATING OIL
Check For
1. SUCTION LOSS
2. LUBRICATING OIL VISCOSITY
POOR CIRCULATION
Check For
3. STRAINER CLOGGED
4. COOLER CLOGGED
5. COOLER BY-PASS VALVE NOT FUNCTIONING PROPERLY
6. PRESSURE REGULATOR VALVE NOT FUNCTIONING PROPERLY
7. EXCESSIVE WEAR ON CRANKSHAFT BEARINGS
8. GALLERY, CRANKSHAFT OR CAMSHAFT PLUGS MISSING
PRESSURE GAUGE
Check For
9. FAULTY GAUGE
10. GAUGE LINE OBSTRUCTED
11. GAUGE ORIFICE PLUGGED
12. ELECTRICAL INSTRUMENT PANEL SENDING UNITS FAULTY
OIL PUMP
Check For
13. INTAKE SCREEN PARTIALLY CLOGGED
14. RELIEF VALVE FAULTY
15. AIR LEAK IN PUMP SUCTION
16. PUMP WORN OR DAMAGED
17. FLANGE LEAK-PRESSURE SIDE

Chart 7(Cont'd.)

LOW OIL PRESSURE (Cont'd.)

SUGGESTED REMEDY

1. Check oil level and bring to FULL mark on dipstick or correct installation angle.

2. Wrong viscosity of lubricating oil being used; consult "Lubricating Oil Specifications".

   Plugged oil cooler is indicated by excessively high lubricating oil temperature. The oil cooler core should be removed and cleaned.

   Check for fuel leaks at injector seal ring and fuel jumper line connections. Leaks at these points will cause fuel oil dilution.

3. Remove oil strainer and clean.

4. Remove oil cooler and clean by the use of steam and circulation of fuel oil.

5. Remove by-pass valve, clean valve and valve seat and inspect valve spring. Replace defective parts.

6. Remove pressure regulator valve, clean valve and valve seat and inspect valve spring. Replace defective parts.

7. Change engine bearings, clean oil pan, consult "Lubricating Oil Specifications" for proper grade of oil to use and change oil filters.

8. Replace missing plugs.

9. Check oil pressure with a reliable gauge and replace engine gauge if found faulty.

10. Remove and clean gauge line, replace if necessary.

11. Remove and clean gauge orifice.

12. Repair or replace defective equipment.

13. Remove oil pan and oil intake screen, clean pan and intake screen, consult "Lubricating Oil Specifications" for the proper grade of oil to use and change oil filters.

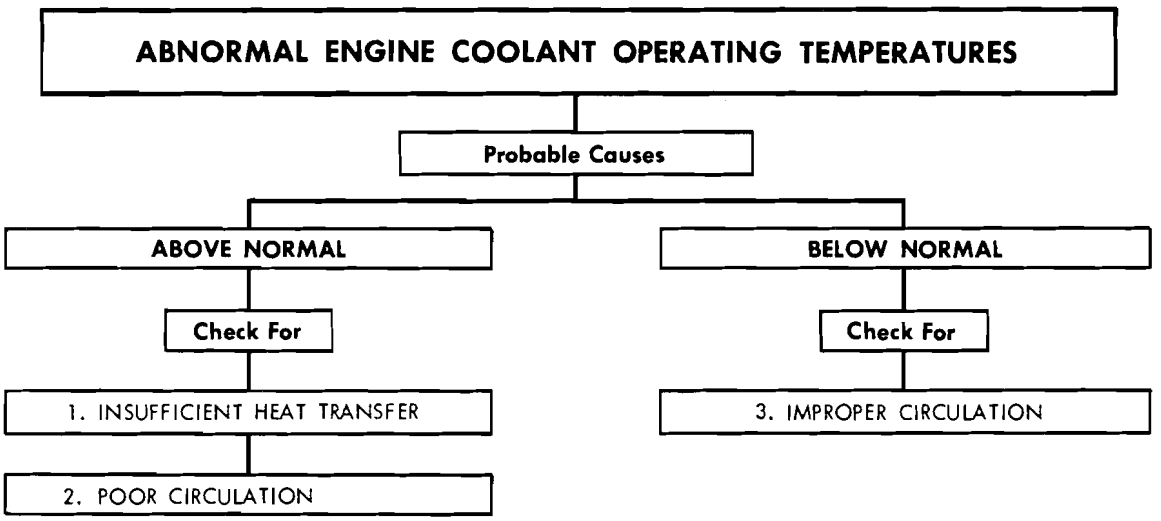
14. Remove and inspect valve, valve bore and spring, replacing faulty parts.

15. Disassemble piping and install new gaskets.

16. Remove pump, clean and replace defective parts.

17. Remove flange and replace gasket.

Chart 8



SUGGESTED REMEDY

1. Cooling system should be cleaned with a good cooling system cleaner and thoroughly flushed to remove scale deposits.

   The exterior of the radiator core should be cleaned to open plugged passages permitting normal air flow.

   Loose fan belts should be adjusted to proper tension to prevent slippage.

   Check installation of engine for improper size radiator or inadequate shrouding.

2. Check coolant level and fill to filler neck if coolant is low.

   Inspect for collapsed or disintegrated hoses. Replace all hoses found faulty.

   Thermostat may be inoperative. Remove, inspect, test and replace if found faulty.

   Check water pump for loose impeller. If loose, replace impeller and pin impeller to shaft.

   Check flow of water through radiator. A clogged radiator will cause an inadequate supply of water on the suction side of the pump. Clean inside radiator core.

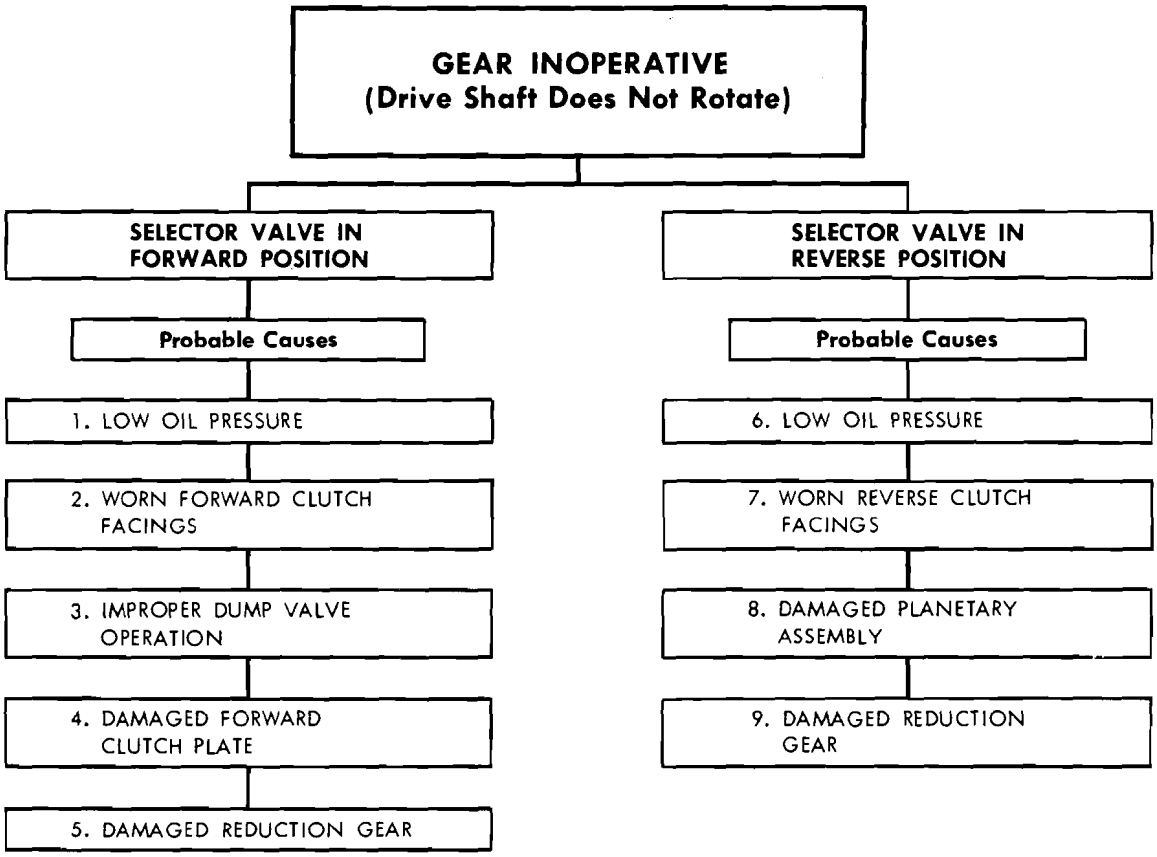
   Remove radiator cap and operate engine, checking for combustion gases in cooling system. The cylinder head must be removed and inspected for cracks and head gaskets replaced if combustion gases are entering cooling system.

   Check for air leak on suction side of fresh water pump and replace defective parts.

3. Thermostat vent valve, if used, may be open or not seating. Remove vent valve and clean up valve and seat in housing and reassemble.

   The thermostat may not be closing. Remove, inspect, and test thermostat. Install new thermostat if necessary.

Chart 9



SUGGESTED REMEDY

1. Consult chart "Low Oil Pressure" for the probable causes of low oil pressure.
2. Inspect clutch facings and replace if found excessively worn.
3. Check dump valves for varnish or other foreign material that would cause poor seating or restrict their movement.
4. Inspect clutch plate for damage. Clutch plate may be sheared or loose on hub and require replacing.
5. Examine reduction gears and bearings for damage. Replace damaged parts found.
6. Consult chart "Low Oil Pressure" for the probable causes of low oil pressure.
7. Inspect clutch facings and replace if found excessively worn.
8. Examine planetary assembly. Disassemble and repair with new parts.
9. Examine reduction gears and bearings for damage. Replace damaged parts found.

Chart 10

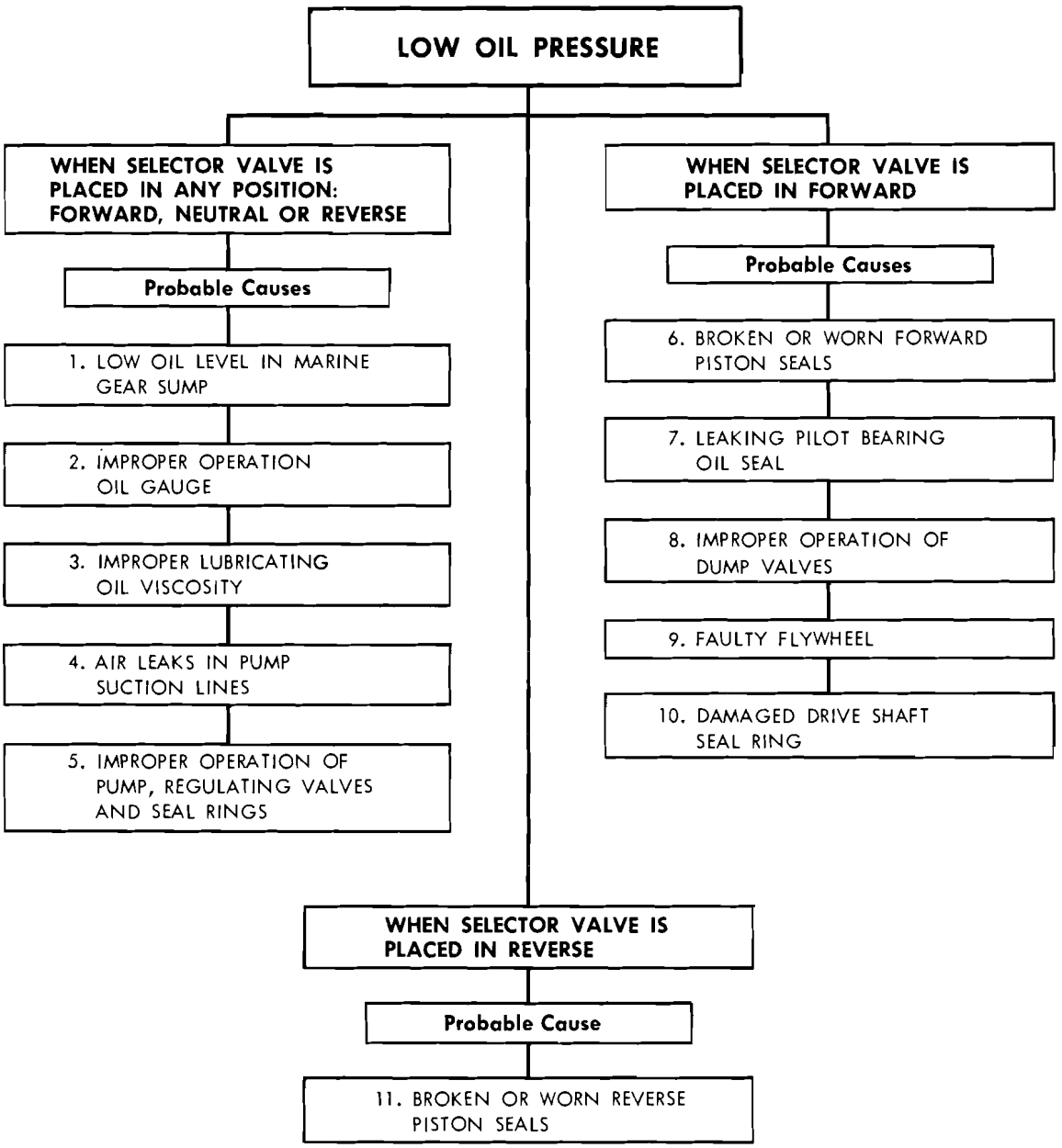

LOW OIL PRESSURE
WHEN SELECTOR VALVE IS PLACED IN ANY POSITION: FORWARD, NEUTRAL OR REVERSE
Probable Causes
1. LOW OIL LEVEL IN MARINE GEAR SUMP
2. IMPROPER OPERATION OIL GAUGE
3. IMPROPER LUBRICATING OIL VISCOSITY
4. AIR LEAKS IN PUMP SUCTION LINES
5. IMPROPER OPERATION OF PUMP, REGULATING VALVES AND SEAL RINGS
WHEN SELECTOR VALVE IS PLACED IN FORWARD
Probable Causes
6. BROKEN OR WORN FORWARD PISTON SEALS
7. LEAKING PILOT BEARING OIL SEAL
8. IMPROPER OPERATION OF DUMP VALVES
9. FAULTY FLYWHEEL
10. DAMAGED DRIVE SHAFT SEAL RING
WHEN SELECTOR VALVE IS PLACED IN REVERSE
Probable Cause
11. BROKEN OR WORN REVERSE PISTON SEALS

Chart 10 (Cont'd.)

LOW OIL PRESSURE (Cont'd.)

SUGGESTED REMEDY

1. Check oil level in marine gear and fill, if oil level is low, to full mark on dipstick. Use the same type of lubricating oil and viscosity in the marine gear as is used in the engine. The recommended viscosity of the oil varies the same as the engine oil with the changes in ambient temperature.

2. Inspect oil gauge and replace if found faulty. If oil gauge is slow to register, clean out oil gauge line by bleeding to remove entrapped air or obstruction.

3. Check oil temperature and if found abnormally high remove and clean both internally and externally the marine gear oil cooler. Replace cooler if necessary.

   Clean oil strainer with fuel oil and replace.

4. Inspect pump suction lines and strainer cap and gaskets for air leaks. Repair or replace lines and fittings that are leaking.

5. Check operation of charging pump. Overhaul pump, replacing leaking seals and cleaning oil pressure regulating valves.

   Examine seal rings on drive shaft and replace if found worn or damaged.

6. Remove and replace forward piston seal rings.

7. Remove and replace pilot bearing oil seal.

8. Remove dump valves, clean and inspect seating surfaces. Replace damaged parts. On units using a piston type valve, remove the piston and spring. Clean and inspect parts, replacing as necessary. When reassembling use a new gasket on the valve cover.

9. Inspect flywheel and replace loose or missing passage plugs.

   Check emergency engagement bolts for tightness. Tighten loose bolts.

10. Inspect seal rings on drive shaft and replace if found worn or damaged.

11. Remove and replace reverse piston seal rings.

Chart 11

GEAR DRAGGING
(Drive Shaft Rotates With Selector Valve in Neutral)

AFTER MOVING SELECTOR VALVE FROM FORWARD TO NEUTRAL

Probable Causes

1. STICKING FORWARD CLUTCH PLATE
2. DAMAGED FORWARD CLUTCH PLATE
3. DAMAGED FORWARD PISTON DRIVE PIN
4. DAMAGED FORWARD PISTON
5. BINDING PLANETARY ASSY.
6. STICKING DUMP VALVES
7. FAULTY SEAL RINGS

AFTER MOVING SELECTOR VALVE FROM REVERSE TO NEUTRAL

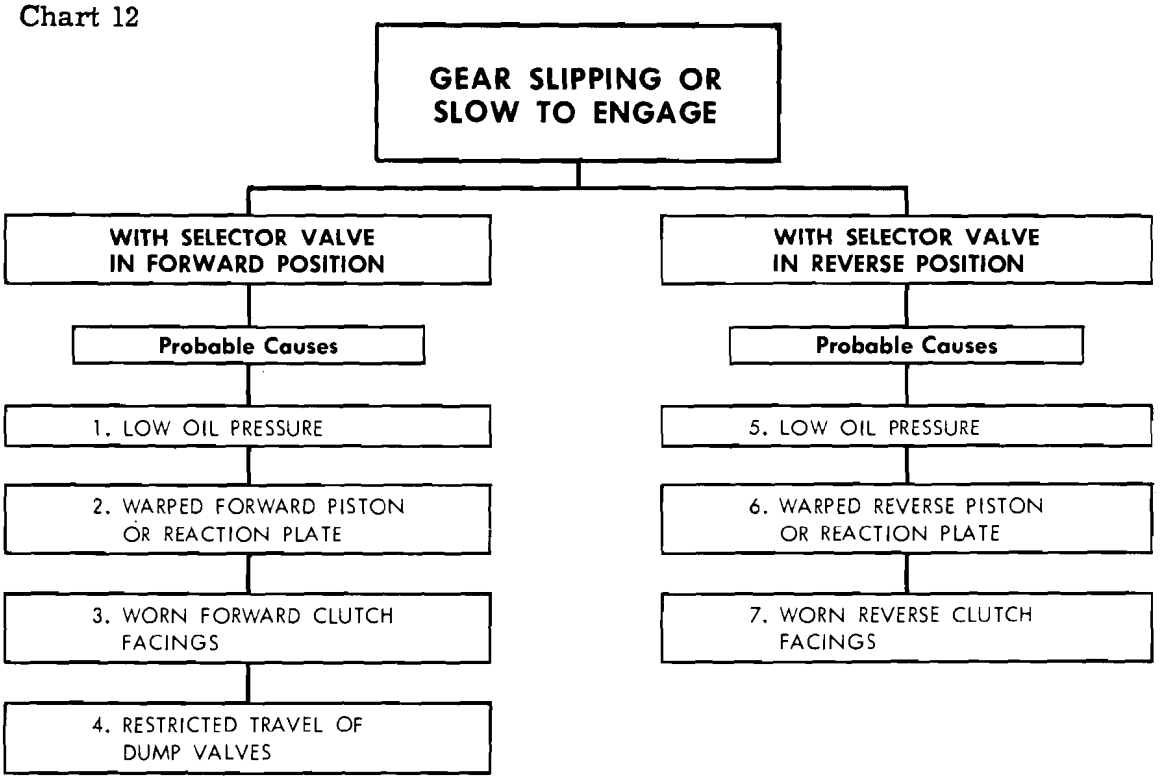
Probable Causes

8. STICKING REVERSE CLUTCH PLATE
9. DAMAGED REVERSE CLUTCH PLATE
10. DAMAGED REVERSE PISTON DRIVE PINS
11. DAMAGED REVERSE PISTON
12. BINDING PLANETARY ASSEMBLY

SUGGESTED REMEDY

1. Inspect clutch plate for wear, if facings have worn smooth the clutch plate should be replaced.
2. Check clutch plate for broken or loose facing material. This material may lodge between clutch plate and piston or reaction plate.
3. Inspect piston drive pins for burrs that could prevent the piston from moving into the disengaged position. Burred pins should be replaced with new pins.
4. Check flatness of forward piston and replace if warped.
5. Inspect planetary assembly for binds. Overhaul and replace damaged parts.
6. Inspect dump valves for varnish or foreign material that may prevent valves from seating properly. Clean or replace damaged parts.
7. Inspect seal rings on drive shaft for wear or breakage. Replace faulty parts.
8. See item 1 for remedy.
9. See item 2 for remedy.
10. See item 3 for remedy.
11. See item 4 for remedy.
12. See item 5 for remedy.

Chart 12



SUGGESTED REMEDY

1. Consult chart "Low Oil Pressure" for the probable causes of low oil pressure.
2. Check flatness of forward piston and reaction plate and replace if badly warped.
3. Inspect clutch facings for wear, if facings are badly worn the clutch plate should be replaced.
4. Inspect dump valves for varnish or foreign material that may prevent valves from seating properly. Clean or replace damaged parts.
5. Consult chart "Low Oil Pressure" for the probable causes of low oil pressure.
6. Check flatness of forward piston and reaction plate and replace if badly warped.
7. Inspect clutch facings for wear, if facings are badly worn the clutch plate should be replaced.

CHECKING ELECTRICAL STARTING SYSTEM

The following quick checks can be made to determine whether or not the units in the electrical system are operating properly. If not operating properly, the checking will indicate whether the generator or regulator is at fault, then proper corrective measures may be taken.

In analyzing generator-regulator operation, check for one of the five following conditions.

1. A fully charged battery and low charging rate indicates normal generator and regulator operation.

2. A low battery and high charging rate indicates normal generator-regulator operation.

3. A fully charged battery and a high charging rate indicates the voltage regulator is not reducing the generator output as it should and will damage the battery. This condition may be caused by improper voltage regulator setting, defective regulator unit, short circuit or poor connection in generator or regulator wiring or high battery temperature.

4. A low battery and low or no charging rate indicates improper or no regulator operation. This may be due to loose connections, damaged wires, low voltage or current regulator setting, oxidized contact points or a defective generator.

5. Excessive arcing at contact points may be due to oxidized or misaligned contact points, defective regulator winding, poor cable connections or other causes.

Chart 13

LOW CONVERTER CHARGING PRESSURE

Probable Causes

1. LOW OIL SUPPLY
2. OIL LINE LEAKAGE
3. DEFECTIVE OIL PUMP
4. EXCESSIVE OIL FLOW TO TRANSMISSION
5. PLUGGED INLET LINE OR SCREEN
6. SUCTION SCREEN UNCOVERED
7. OIL FOAMING

SUGGESTED REMEDY

1. Add oil. Refer to Lubrication and Preventive Maintenance Chart.
2. Check for air leaks in suction lines and oil leaks in pressure lines.
3. Check for wear in oil pump. Check for high stall speed (See specific Torqmatic Converter Maintenance Manual).
4. Check operation of selector valve, check valve, bypass valve and transmission driven pump. (Series 400 through 900 converters).
5. Check inlet line and screen. Clean if necessary. (Series 400 through 900 converters).
6. Low oil level or improper installation of screen. (Series 400 through 600 converters).
7. Oil return line not below oil level in sump.

Chart 14

MANUAL INPUT DISCONNECT CLUTCH SLIPPAGE

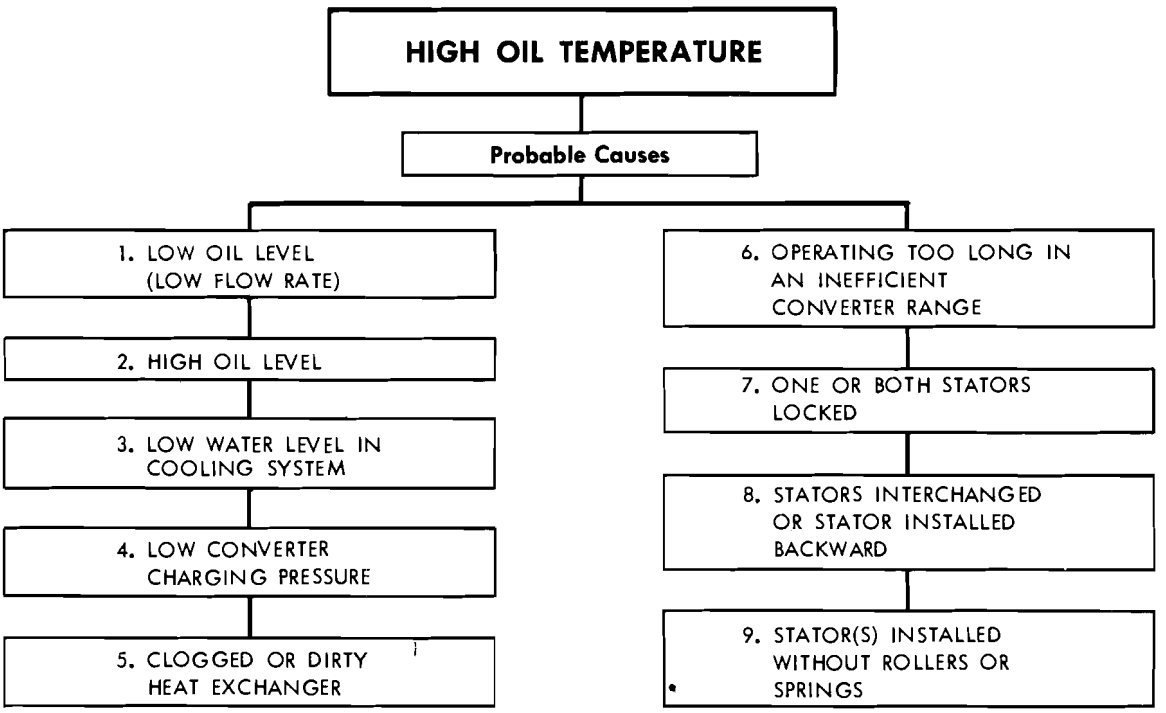
Probable Causes

1. CLUTCH FACING WEAR

SUGGESTED REMEDY

1. Adjust clutch.

Chart 15



SUGGESTED REMEDY

1. Add oil. Refer to Lubrication and Preventive Maintenance Chart.

2. Drain oil to FULL mark.

3. Add water. Check for leaks.

4. Refer to Chart 13.

5. Clean or replace as necessary.

6. Readjust work cycle to allow operation in an efficient converter range.

7. Check for low maximum speed of operating equipment.

   The maximum converter "OUT" oil temperature is 250°F.

   If it should become necessary to check for locked stator(s) by observing temperature drop rate, increase converter "OUT" temperature to 230°F. by stalling converter output shaft at full throttle. Release the converter output shaft and immediately check rate of temperature drop with no load on converter and maximum input r.p.m. Temperature should start to drop after 15 seconds.

   A slow temperature drop rate probably indicates locked stator(s). A rapid temperature drop rate indicates normal stator operation.

8. Check for lack of power at converter stall. Refer to Chart 13.

   Disassemble converter and check stators (refer to specific Torqmatic Converter Maintenance Manual).

9. Disassemble converter and install rollers and/or springs (see item 4 in charts 16 and 17).

Chart 16

HIGH ENGINE SPEED AT CONVERTER STALL

Probable Causes

1. LOW OIL SUPPLY
2. LOW CONVERTER CHARGING PRESSURE
3. HIGH OIL TEMPERATURE
4. STATOR(S) INSTALLED WITHOUT ROLLERS (SERIES 200-300 CONVERTERS)

SUGGESTED REMEDY

1. Add oil. Refer to Lubrication and Preventive Maintenance Chart.
2. Refer to chart 13.
3. Refer to Chart 15.
4. Disassemble converter and install rollers (refer to specific Torqmatic Converter Maintenance Manual).

Chart 17

LOW ENGINE SPEED AT CONVERTER STALL

Probable Causes

1. LOW ENGINE OUTPUT TORQUE
2. CONVERTER ELEMENT INTERFERENCE
3. STATORS INTERCHANGED OR STATOR INSTALLED BACKWARD
4. STATORS INSTALLED WITHOUT ROLLERS (SERIES 400 THROUGH 900 CONVERTERS)

SUGGESTED REMEDY

1. Tune engine and check output.
2. Check for noise at stall. Overhaul converter if necessary.
3. Check for lack of power at converter stall (see specific Torqmatic Converter Maintenance Manual).

   Disassemble converter and check stators.
4. Disassemble converter and install rollers.

Chart 18

LOSS OF POWER

Probable Causes

1. STATORS INTERCHANGED (SERIES 300 THROUGH 900)
2. STATOR INSTALLED BACKWARD (SERIES 200)
3. STATOR(S) INSTALLED WITHOUT ROLLERS (HIGH STALL SPEED, SERIES 200; LOW STALL SPEED, SERIES 300 THROUGH 900)
4. LOW CONVERTER CHARGING PRESSURE
5. LOW ENGINE SPEED, AT CONVERTER STALL

SUGGESTED REMEDY

1. Check for lack of power at stall (see specific Torqmatic Converter Maintenance Manual).

   Disassemble converter and check stators.
2. Check for lack of power at stall.

   Disassemble converter and check stator.
3. Disassemble converter and install rollers.
4. Refer to Chart 13.
5. Refer to Chart 17.

Chart 19

LOW LOCK-UP CLUTCH PRESSURE

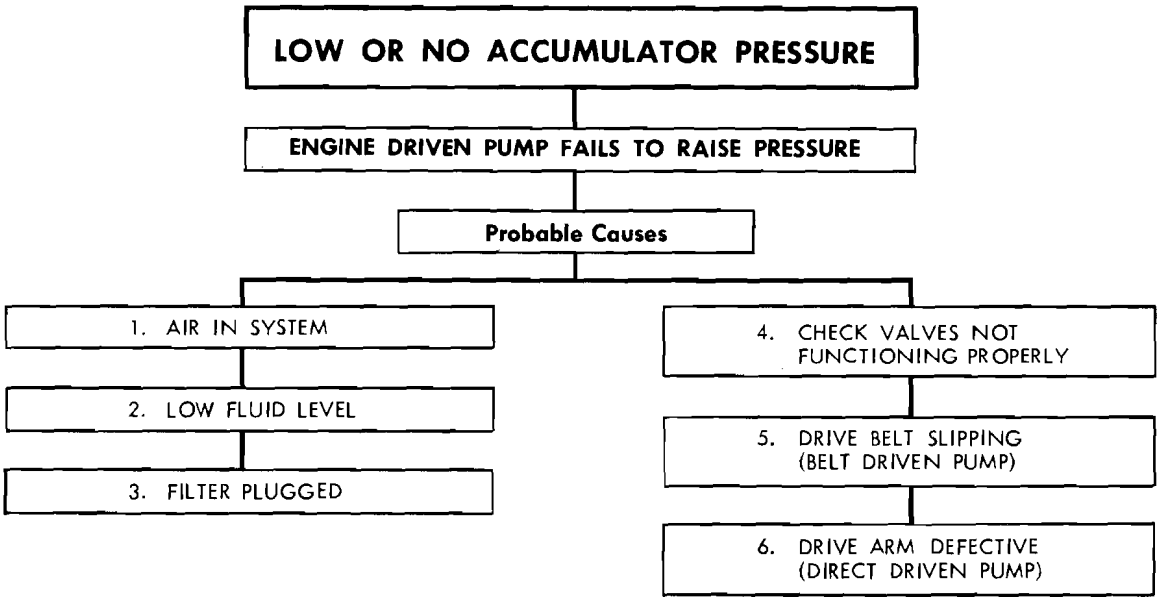
Probable Causes

1. FAULTY LOCK-UP CLUTCH LINKAGE ADJUSTMENT
2. LOCK-UP CLUTCH SELECTOR VALVE NOT WORKING PROPERLY
3. FAILED OR WORN SEAL RINGS
4. STOPPAGE IN PASSAGE FROM OIL PUMP TO LOCK-UP PISTON

SUGGESTED REMEDY

1. Adjust linkage.
2. Remove charging oil pump cover and check clutch selector valve.
3. Disassemble converter. Replace failed or worn seal rings.
4. Disassemble converter and clean passage. Inspect converter for dirt.

Chart 20



SUGGESTED REMEDY

1. To purge engine driven pump of air:

   a. Operate engine at maximum no-load engine speed.

   b. Break hose connection at discharge side of engine driven pump until a full stream of oil is discharged from pump.

   c. Connect hose to pump and alternately loosen and tighten swivel fitting on discharge hose until oil leaking out, when fitting is loose, appears free of air bubbles.

   d. Tighten fitting securely and observe pressure gauge.

   Pressure should rise rapidly to accumulator precharge pressure (1250 p.s.i. at 70°F.) then increase slowly to 2900 to 3300 p.s.i. in 6 to 10 minutes depending upon size of the particular accumulator.

   If accumulator pressure does not rise, make certain hand pump relief valve is closed after pressure is released and repeat above purging procedure.

2. The fluid level in the reservoir should be sufficient to completely cover the filter at bottom of tank after the accumulator is charged and the engine driven pump is bypassing a full stream of fluid to the reservoir.

3. Remove and clean reservoir filter and flush out reservoir tank, also clean filter located in supply line between reservoir and engine driven pump.

4. Open relief valve on side of hand pump, while engine is running, to permit engine driven pump to wash check valves free from particles.

   If accumulator can be charged with hand pump but not with the engine driven pump, then a check valve in the engine pump is defective. Replace faulty check valve assembly.

5. Adjust or replace if necessary.

6. Replace arm.

Chart 21

CRANKING SPEED TOO LOW

Probable Causes

1. HYDROSTARTER SYSTEM FLUID TOO HEAVY
2. ENGINE OIL TOO HEAVY
3. CONTROL VALVE NOT FULLY OPEN

SUGGESTED REMEDY

1. Check mixture of fluid in system. Use fluid consisting of 75% Diesel fuel and 25% SAE 10 or 30 lube oil.
2. Replace oil with proper viscosity grade. Refer to the Engine Lubrication Oil Specifications.
3. Check travel of control valve located on side of starter. Minimum travel is 1-1/16". Remove any obstruction preventing sufficient control valve or control lever handle travel.

Chart 22

LOSS OF FLUID FROM RESERVOIR

Probable Causes

1. EXTERNAL LEAKS
2. WORN STARTER SHAFT SEAL
3. DEFECTIVE GASKET UNDER STARTER COVER
4. WORN SHAFT SEAL (BELT DRIVEN PUMP)
5. WORN SHAFT SEAL (DIRECT DRIVEN PUMP)

SUGGESTED REMEDY

1. With pressure in system, check all hoses and fittings for leaks. Tighten or replace fittings and any defective parts.
2. Remove starter after releasing system pressure and observe inside of clutch housing. If evidence of system fluid is found replace shaft seal.
3. Operate the starter. During the cranking cycle watch closely for fluid leaking around the cover or any of the bolts which retain it.
4. While pump is by-passing at full system pressure examine shaft for evidence of leakage. Replace defective seal.
5. After pump has been by-passing at full system pressure, remove pump from flywheel housing and examine back of mounting plate near seal for evidence of leakage. Replace shaft seal.

Chart 23

LOSS OF FLUID PRESSURE WHEN ENGINE IS NOT RUNNING

Probable Causes

1. AMBIENT TEMPERATURE DECREASE
2. ENGINE DRIVEN PUMP CHECK VALVES. NOT HOLDING
3. HAND PUMP VALVES NOT HOLDING
4. DAMAGED SEAL RING IN STARTER CONTROL VALVE SHOWN BY EXTERNAL LEAKAGE
5. DAMAGED MIDDLE SEAL RING IN STARTER CONTROL VALVE, NO VISIBLE EXTERNAL LEAKAGE
6. EXTERNAL LEAKAGE IN SYSTEM
7. STARTER CONTROL VALVE OUT OF TIME - BENT SHIFTING FORK
8. LOSS OF ACCUMULATOR PRE-CHARGE (NITROGEN)

SUGGESTED REMEDY

1. A drop in temperature will decrease the nitrogen pressure. Adjust as needed for cranking requirements by use of hand pump.

2. Disconnect return line and inlet line from engine driven pump. Leakage from inlet fitting means that both check valves are defective. Leakage at return fitting only means that outlet check valve is defective. Replace defective check valve assembly(s).

3. Disconnect inlet line from hand pump. Leakage from inlet fitting means that either the relief valve alone or both the inlet and outlet check valves are defective. Stone and clean ball seats in pump body and replace balls and springs if necessary.

4. Remove control valve from starter and replace seal ring.

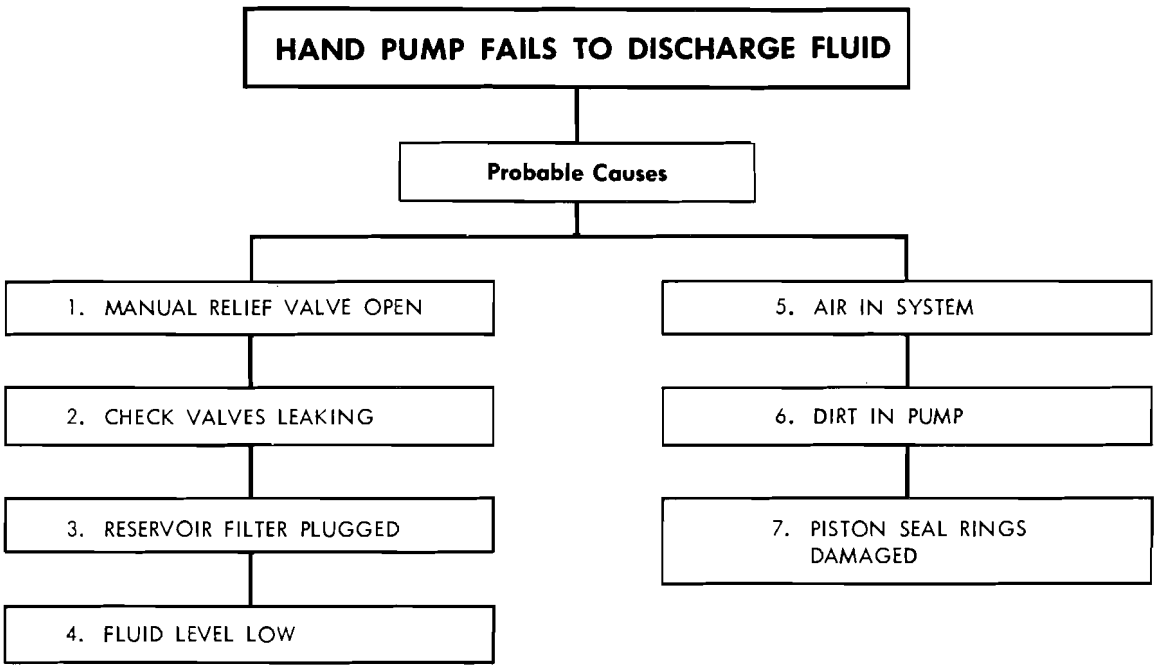
5. Disconnect return line from starter. Use hand pump to raise pressure if necessary. If fluid leaks from return fitting when control valve is closed, the middle seal ring is damaged. Remove control valve. Replace seal ring.

6. Examine all hoses and fittings for leaks. Tighten or replace fittings and any defective parts.

7. With control valve closed, check length of piston protruding beyond valve body. Correct length should be $7/8'' \pm 1/32$. If length is incorrect, shifting fork may be bent or nylon yoke between fork and clutch collar may be damaged. Replace faulty parts.

8. See Chart 26.

Chart 24



SUGGESTED REMEDY

1. Close relief valve.
2. If caused by dirt, open relief valve, and operate hand pump slowly for a few minutes to wash particles out of check valves. If this is unsuccessful, stone and clean ball seats in pump body and replace balls and springs if necessary.
3. Remove and clean reservoir filter, flush reservoir tank and reassemble.
4. See Chart 20, item 2.
5. To purge hand pump of air:
   a. Relieve any system pressure, then disconnect outlet line from hand pump.
   b. Close manual relief valve and operate pump until fluid is discharged when stroking both directions.
   c. Reconnect outlet line.
6. See item 2.
7. Replace seal rings.

Chart 25

STARTER TURNS BUT ENGINE DOES NOT

Probable Causes

1. PINION NOT ENGAGING FLYWHEEL RING GEAR
2. PINION CLUTCH SLIPPING (COLD WEATHER OR HEAVY LUBRICANT)
3. OVERRUNNING CLUTCH BURNED OUT
4. STARTER ASSEMBLED WRONG

SUGGESTED REMEDY

1. Check shifting fork. If bent replace.
2. Wash out heavy lube oil and replace with SAE 5W or SAE 10 lube oil.
3. Replace clutch. If mechanical linkage is attached to control lever, add sufficient spring force to assure clutch is withdrawn from engagement, and that the control valve is returned to shut off position. If no mechanical linkage is used operator should disengage starter as soon as engine starts. Prolonging the period during which clutch overruns will reduce clutch life.
4. Starter may be assembled for LH rotation but with an RH overrunning clutch. Remove and assemble correctly.

Chart 26

LOSS OF ACCUMULATOR PRECHARGE (NITROGEN)

Probable Causes

1. DAMAGED SEAL RING ON PISTON
2. DEFECTIVE AIR VALVE
3. DAMAGED SEAL RING BETWEEN TUBE AND END CAP

SUGGESTED REMEDY

1. With some nitrogen precharge but no fluid pressure in system, bubbles and foaming in the reservoir indicate nitrogen is leaking past the seal ring on the accumulator piston. Overhaul the accumulator.
2. Release pressure in system by opening relief valve on side of hand pump. Then loosen hex lock nut on nitrogen valve approximately 3/4 turn to release remaining precharge before attempting to remove valve from accumulator. Replace air valve.
3. Apply light oil on threaded end of accumulator at end of cap. Bubbling of oil indicates a leak past end cap seal. Release nitrogen precharge before removing cap to replace seals.

Chart 27

HIGH PRESSURE IN SYSTEM (3500 p.s.i. or above)

Probable Causes

1. DEFECTIVE GAUGE
2. ENGINE DRIVEN PUMP UNLOADING VALVE NOT OPERATING PROPERLY

SUGGESTED REMEDY

1. Replace gauge.
2. Overhaul pump.

Chart 28

FLUID EMERGES FROM THE RESERVOIR FILLER CAP WHEN STARTER IS USED

Probable Causes

1. FILTER ELEMENT IN FILLER CAP LOADED WITH DIRT
2. NITROGEN IN FLUID RETURNED TO RESERVOIR
3. EXCESS FLUID IN RESERVOIR

SUGGESTED REMEDY

1. Rinse filler cap thoroughly in fuel oil, blow dry with compressed air.
2. Overhaul accumulator. See Chart 26, item 1.
3. Check fluid level after the accumulator is charged and the engine driven pump is by-passing a full stream of oil to the reservoir. The fluid level should be sufficient to completely cover filter in bottom of tank.

Chart 29

FLUID EMERGES AROUND RUBBER BOOT ON HAND PUMP

Probable Cause

1. DAMAGED PISTON SEAL RINGS

SUGGESTED REMEDY

1. Replace seal rings and leather back-up rings on pump piston.

Chart 30

FLUID EMERGES FROM ENDS OF STARTER CONTROL VALVE WHEN STARTER IS OPERATED

Probable Causes

1. DAMAGED FRONT CONTROL VALVE SEAL RING
2. BENT SHIFTING FORK CAUSING END OF CONTROL VALVE TO MOVE PAST THE REAR SEAL RING

SUGGESTED REMEDY

1. Operate starter, if fluid emerges around front end of control valve, seal ring is damaged.
2. See Chart 23: 6 Also operate starter. If fluid emerges from cap on rear of control valve, fork is bent and seal ring may be damaged.

Chart 31

FAULTY OPERATION

CLUTCH SLIPS

Check For

1. IMPROPER ADJUSTMENT
2. GREASE OR OIL ON FACINGS
3. FACINGS WORN
4. OVERLOADING

OUTPUT SHAFT DAMAGE

Check For

11. MISALIGNMENT
12. BELT LOADING ABNORMALLY HIGH
13. DRIVE SHAFT BEARINGS WORN OR DAMAGED

CLUTCH DOES NOT RELEASE

Check For

5. LINKAGE WORN
6. CLUTCH RELEASE AND CLUTCH SEPARATOR SPRINGS WEAK OR BROKEN
7. MISALIGNMENT
8. PILOT BEARING DAMAGED

CLUTCH FACING TEETH WEAR

Check For

14. MISALIGNMENT

PILOT BEARING FAILURE

Check For

9. LACK OF LUBRICANT
10. MISALIGNMENT

OVERHEATING

Check For

15. TAPERED ROLLER BEARINGS OVERHEATED
16. CLUTCH FACINGS OVERHEATED

SUGGESTED REMEDY

1. Adjust clutch. The clutch should be adjusted before slippage occurs for longest clutch life. Check tension on end of handle and whenever tension drops below the figures specified in the following chart readjust clutch.

Clutch	Pounds*
8" Dia. Clutch Front PTO (35 HP)	40 lbs.
10" Dia. Clutch Rear PTO	60 lbs.
11-1/2" Dia. Clutch Rear PTO	50 lbs.
11-1/2" Dia. Clutch Front PTO (60 HP)	60 lbs.
14" Dia. Clutch Rear PTO	75 lbs.
18" Dia. Clutch Rear PTO	90 lbs.

*Pounds pull on end of handle to engage clutch.

Chart 31 (Cont'd.)

FAULTY OPERATION (Cont'd.)

SUGGESTED REMEDY

2. Disassemble clutch assembly and remove excessive grease and oil from clutch operating linkage. Remove all grease and oil from pressure plates and facings. Replace facings if badly saturated.

3. Measure thickness of facings. Replace when worn to 1/4'' on 8''; 5/16'' on 10'' and 11 1/2''; or 3/8'' on 14'' and 18'' diameter clutches.

4. Check installation and reduce operating load on units as much as practical, also shock loads and unnecessary belt loading should be reduced to a minimum. If possible, install a higher capacity clutch.

5. When the linkage is badly worn and the clutch is adjusted as outlined in Item 1, the clutch may not disengage. Replace worn linkage.

6. Broken or weak release and/or clutch separator springs may cause a dragging clutch. Disassemble clutch and replace damaged parts.

7. Misalignment is caused by overloading the output shaft, shock loads, incorrect shimming of the outboard bearing (if used) or out of round of the flywheel housing.

Inspect installation and determine if load on output shaft is excessive. This condition may be corrected by referring to Item 4.

Inspect outboard bearing and adjust by the use of shims and a dial indicator. With pillow block attaching bolts loose, mount dial indicator to unit base and rest pointer on outboard end of shaft. Tighten attaching bolts to recommended torque and read dial indicator. If the shaft is within .002'' of the nominal center line and rotates freely by hand without any perceptible bind after assembly of pillow block to support the alignment is satisfactory. If necessary, readjust, using shims as required.

The out-of-round (concentricity) and the run-out of a flywheel housing can be checked by attaching a dial indicator to the crankshaft and having the pointer ride first the bore and then the attaching face of the housing. Maximum out-of-round is .013'' and maximum attaching face run-out is .013''. If necessary, loosen housing attaching bolts and retighten to specified torque in proper sequence.

8. Damage to pilot bearing is usually the result of misalignment, see Item 7; lack of lubricant see Item 9; or faulty adjustment of taper roller bearings.

Adjust taper roller bearings after disassembling clutch and cleaning bearings of grease. Lubricate bearings with engine oil and reassemble to clutch housing, then support drive shaft in a vertical position with a chain fall attached to clutch housing and a dial indicator on drive shaft with the pointer on clutch housing. Note reading on dial indicator, then lower drive shaft onto floor and note reading. The end play should be within the limits shown on the clutch name plate. Readjust the bearing retainer until end play is correct. Complete the assembly of the clutch and lubricate the taper roller bearings with all purpose grease, see Item 15.

9. Pilot bearings may fail because of lack of lubricant. Remove pilot bearing and check for lubricant. Roller type pilot bearing should have the crankshaft cavity 1/3 (Max.) full of ALL PURPOSE grease. Ball pilot bearings should have the proper wick and felt assemblies required by the particular unit. The wick assembly should protrude into the bore of the output shaft sufficiently to transfer the oil, but not to char. Replace damaged pilot bearing following recommendations installations.

10. Pilot bearings that are overloaded may fail. This condition may be corrected by referring to Item 7.

11. The output shaft may be damaged by misalignment, refer to Item 7.

12. Belt load abnormally high may cause damaged to the output shaft refer to Item 7.

13. Drive shaft bearings that are badly worn or damaged may damage the output shaft. Replace worn bearing and adjust to proper end play.

14. Misalignment will place undue wear on the teeth of the clutch facings, resulting in rapid wear, refer to Item 7.

15. If inspection of the taper roller bearings shows evidence of abnormal overheating, the bearings should be replaced. Abnormal overheating is the result of insufficient lubrication and is caused by lack of lubricant or improper lubricant. Bearings should be lubricated with an all purpose grease. Properly lubricated bearings will have a small ridge of grease on the shaft next to the clutch housing.

NOTE: An overlubricated taper roller bearing will adjust itself by operating slightly not causing the grease to flow out around the drive shaft.

16. If inspection of the clutch facings reveal evidence of overheating, it is the result of clutch slippage. Refer to Item 1 to correct this condition.

ITEM 1

Check oil level daily with engine stopped and replenish to FULL mark on dipstick.

Select proper viscosity grade of oil in accordance with the instructions given in "Lubricating Oil Specifications" in Section 13.3.

It is recommended that new engines be started with 100 hour oil change periods. The interval may be gradually increased following the recommendations of the oil supplier (based on his analysis of the drained engine oil) until the most practical oil change period has been established.

ITEM 2

Install new oil filter element and gaskets every time the engine oil is changed. Check for oil leaks after starting engine.

ITEM 3

Check engine oil temperature at 1000 hour intervals or sooner if overheating is suspected by inserting a steel jacketed thermometer in dipstick opening immediately after stopping the hot, loaded engine. If the oil temperature exceeds the normal coolant temperature 160°F.-185°F. by more than 60° and other conditions are normal, the cooler may be plugged necessitating its removal and cleaning.

ITEM 4

Check coolant level daily and maintain to near top of heat exchanger tank or radiator upper tank. Clean cooling system every 1000 hours using a good radiator cleaning compound in accordance with instructions given on the compound container. After cleaning, rinse thoroughly with fresh water. Use soft water with a good grade of rust inhibitor or high boiling point type anti-freeze. Make sure all drain cocks or valves are closed and vent valve, if used, is open when filling cooling system. Open vent valve, if used, when draining system.

ITEM 5

Remove zinc electrode at inlet side of raw water pump and heat exchanger every 500 hours and clean with wire brush or, if worn excessively, replace with new electrodes. When checking electrodes, strike the electrodes sharply on a hard surface to determine their fitness for future use. This is the only way to determine the condition of the electrode core. Drain water from heat exchanger raw water inlet and outlet tubes prior to removing electrodes.

ITEM 6

Inspect hoses of cooling system at least once every 500 hours for signs of deterioration and replace if necessary.

ITEM 7

Inspect outside of radiator core every 200 hours, if necessary, clean with fuel oil and compressed air. It may be necessary to clean the radiator more frequently where air is exceptionally dirty.

ITEM 8

Keep fuel tank filled thereby reducing condensation to a minimum. Select proper grade of fuel in accordance with "FUEL OIL SPECIFICATIONS". Open drain at bottom of fuel tank every 500 hours to drain off any water or sediment.

ITEM 9

Drain approximately one-fourth pint of fuel and sediment from strainer and filter daily. Install new elements every 300 hours.

ITEM 10

Inspect blower screen, if used, every 1000 hours and if it contains foreign material, clean the screen in fuel oil and dry with compressed air.

ITEM 11

Remove dirty oil and sludge from air cleaner cup and center tube of "heavy-duty" air cleaners every 8 hours, or less if operating conditions warrant. Wash cup and element in clean fuel oil and refill cup to level mark with same grade of HEAVY-DUTY oil as used in engine. Frequency of servicing may be varied to suit local dust conditions.

ITEM 12

With engine running, check for flow of air from air box drain tubes every 100 hours and, if tubes are clogged, remove, clean, and reinstall tubes. Air box drain tubes should be cleaned every 500 hours even though clogged condition is not apparent. If engine is equipped with air box drain tank, drain sediment periodically.

ITEM 13

Clean crankcase breather every 1000 hours. Remove crankcase breather from engine and wash in fuel oil and blow dry with compressed air. This cleaning period may be reduced or lengthened according to severity of service.

ITEM 14

The electrical cranking motor bearings are either lubricated by wick-type oilers or are permanently lubricated. The application of a few drops of engine oil on each wick at the time of engine overhaul provides sufficient lubrication. The pipe plugs used to plug the wick bores must, of course, be removed when oiling the wicks.

Remove cover band every 2000 hours, examine commutator and brushes and clean commutator, if necessary, with No. 00 sandpaper or brush seating stone. After cleaning, reseat brushes and blow out dust before installing cover band. Do not use emery cloth to clean commutator or seat brushes. A glazed or blue commutator does not indicate a condition requiring service, as this is a normal and satisfactory condition on a used motor. The brushes should be examined and replaced if shorter than 5/16". All electrical connections should be kept clean and tight.

ITEM 15

Remove cover band and inspect commutator and brushes every 500 hours for wear. Clean commutator every 2000 hours, if necessary, with No. "00" sandpaper or brush seating stone. After cleaning, reseat brushes and blow out dust before installing cover band.

ITEM 16

Check the specific gravity of the electrolyte in each cell of the battery every 100 hours. In warm weather, however, it should be checked more frequently due to a more rapid loss of water from the electrolyte. The electrolyte level should be maintained in accordance with the battery manufacturer's recommendations.

ITEM 17

Lubricate tachometer drive every 50 hours with all purpose grease at pressure fittings. Use No. 2 grade except in extremely cold temperatures, then use No. 1 grade.

ITEM 18

Lubricate throttle control mechanism pressure fittings, sparingly, with all purpose grease every 200 hours. Lubricate other control mechanisms as required with engine oil in hand oiler.

ITEM 19

Approximately 100 hours after the initial start and thereafter at 500 hour intervals and after an engine overhaul, check engine tune-up. See the engine "Tune-Up Procedures" in Section 14.

ITEM 20

Check drive belt tension every 500 hours and adjust, if necessary. Belts should be just tight enough to drive the moving parts without slipping. Too tight a belt is destructive to bearings of the driven part.

ITEM 21

Lubricate clutch throwout bearing sparingly through pressure fitting every 8 hours with short-fibre, high-grade bearing lubricant. Lubricate power take-off main bearing through pressure fitting every 50 hours with short-fibre, high-grade bearing lubricant. Remove inspection hole cover and apply engine oil sparingly to the clutch release lever and link pins and to bearing ends of clutch release shaft every 500 hours with hand oiler.

Check clutch facing for wear every 500 hours and adjust, if necessary.

ITEM 22

The transmission should be checked daily for proper oil level reading.

TORQMATIC MARINE GEAR

Check level of oil daily in Torqmatic marine gear and add as required to bring to FULL mark on dipstick. If single engine propulsion unit is set at an angle, the oil level should be 1/16" per degree of angularity above the FULL mark. Change oil every 200 hours.

Use oil of the same HEAVY-DUTY grade that is used in the engine and shown in the chart below.

Ambient Temperature	Viscosity
Above 32°F.	S.A.E. 30
0°F. to 32°F.	S.A.E. 20
Below 0°F.	S.A.E. 10

When refilling after an oil drain bring oil up to HIGH level on the gauge; then run engine at light load for three or four minutes, after which stop engine and check oil level again. Bring level up to HIGH mark on gauge.

Every time the marine gear oil is changed, remove oil strainer element, rinse thoroughly in fuel oil, blow dry with compressed air and reinstall.

TWIN DISC MARINE GEAR

A complete oil change every 500 hours is recommended. After removing the oil from the unit, the removable oil screen should be thoroughly cleaned before refilling the transmission with a straight grade Heavy Duty oil.

Use oil of the same HEAVY-DUTY grade that is used in engine and shown in chart below.

Ambient Temperature	Viscosity Grade
Above 32°F.	S.A.E. 30
0°F. to 32°F.	S.A.E. 20
Below 0°F.	S.A.E. 10

ITEM 23

On units equipped with a hydrostarter inspect the system periodically for leaks. Primarily examine the high pressure lines, connections, fittings and the control valve on the starter. Make certain that the oil level in the reservoir is sufficient to completely cover the filter element at the bottom of the tank. Make this check after the accumulator is charged and engine driven pump is by-passing oil to the reservoir.

Remove the hydrostarter from the engine every 2000 hours and apply a coating of Lubriplate, Type 130-AA or equivalent on the drive clutch pinion to ensure the clutch will slide freely while compressing the spring. Also apply Lubriplate or its equivalent on fingers of clutch and on spool of clutch yoke engaged by fork. This lubrication period may be reduced or lengthened according to severity of service.

Before removing the hydrostarter, release the pressure in the system using relief valve in hand pump then remove three bolts retaining starting motor to flywheel housing. Remove starter from flywheel housing without disconnecting hydraulic lines. This will prevent dirt and air from entering hydraulic system.

Remove pipe plug from starter drive housing, and saturate shaft oil wick with engine oil. Reinstall plug.

After lubricating, replace the starter and recharge the accumulator with the hand pump.

On units equipped with a hydraulic remote starting system, lubricate shaft in master cylinder through pressure fitting every 2000 hours.

Every 2,000 hours, or as conditions warrant, drain reservoir and remove filter from bottom of reservoir. Flush out reservoir, clean reservoir filter and reservoir filler cap.

Remove bowl and element from filter and wash both the element and the bowl in clean fuel oil and reassemble.

Drain remaining hydraulic fluid from system by disconnecting lines from hydrostarter components. Reconnect all hydraulic lines.

> **NOTE:** Make sure lines and fittings are clean before any connections are made. With the exception of the thread nearest the open end, Permatex No. 2 or its equivalent should be applied in a small amount to ONLY the male threads. Never apply Permatex to female threads. Work Permatex into threads and wipe off excess with a clean, lint-free cloth so that Permatex will not be washed into the system.

Fill hydrostarter system with new clean fluid (a mixture of 75% diesel fuel and 25% SAE10 or 30 lubricating oil), and purge hydrostarter system of air in accordance with prescribed procedure in Section 12.6.1.

ITEM 24

Install new viscous type vibration damper each time engine is overhauled or every 4000 hours or 100,000 miles of operation, whichever occurs first.

APPENDIX I

SPECIFICATIONS

The primary object of purchase specifications is to define the requirements that the engine builder can bid intelligently, offering the engine and machinery arrangement that will best meet the individual conditions. Essential items and information should be included, but unnecessary limitations or restrictions avoided.

Some or all of the following can be included:

Load and duty requirements, including plot (daily load curve) or figures showing amount and duration of loan, with special attention to the minimum and maximum loads.

Amount and character of momentary load variations.
Amount and character of seasonal load variations.
What is the altitude:
Type, size or capacity, speed, and make of driven machinery.
What is the means of transmission of power?
Size of vessel in marine work, its expected speed. Size of propeller. Is it of wood or steel construction? Any special maneuvering requirements? Include a drawing or sketch of the engine room space.
In stationary work describe the local conditions surrounding the engine room and the installation. What are the transportation facilities, the limitations of size of weight of engine pieces to be handled, the crane or facilities for installation? What height is available? What is the character of the subsoil?
What are the local ordinances or restrictions affecting the installation? Any special restrictions on noise of inlet or exhaust?
What are the analysis, quantity, source, pressure, and cost of cooling water available? Send sample.
If any particular type of cooling-water system is specified, all pertinent data should be given.
Can the engine waste heat be utilized?
Information may be requested in regard to:
Rated capacity and speed of engines offered.
Overload capacity and speed of engines offered.
Speed variation available.
Shipping weight.
Installed weight.
Weight and dimensions of heaviest pieces.
Fuel consumption.
Specifications of fuels that can be used.
Starting equipment.
Quantity and temperatures of cooling water.
Detailed descriptive specifications of engines.
Service records of similar engines in the same type of service.

LIST OF MANUFACTURERS

Allis Chalmers Manufacturing Company, Engine-Material Handling Division, Milwaukee 1, Wisconsin.

Atlantic Diesel Manufacturing, Incorporated, 4th and Maple Streets, Hamburg 7, Pennsylvania.

Detroit Diesel Engine Division, General Motors Corporation, 13400 W. Outer Drive, Detroit 23, Michigan.

International Harvester Company, 180 N. Michigan Avenue, Chicago 1, Illinois.

White Diesel Engine Division, The White Motor Company, 1409 Sheridan Avenue, Springfield, Ohio.

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2. Adams, Orville L., Sr. Elements of Diesel Engineering. The Norman W. Henley Publishing Co., New York, 1949.

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4. Armstrong, L. V. and J. B. Hartman. The Diesel Engine. The Macmillan Company New York, 1959.

5. Allen, Oliver Field. The Modern Diesel. Prentice-Hall, Inc., New York, 1947.

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8. United States Navy. Fundamentals of Diesel Engines. U. S. Government Printing Office, Washington, D. C. $1.25.

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