PRACTICAL MARINE ENGINEERING

SECOND EDITION

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Preface

This book deals with the basic elements which make up a marine steam power plant. Primarily the treatment is from the point of view of the man who operates the plant. In addition to marine plant operating personnel, shore-side stationary and supervisory engineers will find this book of great value as a reference; students enrolled in technical courses in Mechanical and Marine Engineering will welcome it as a supplement to their theoretical texts; designers of marine power plants and equipment may well be guided by the operating techniques discussed.

Practical Marine Engineering is the outgrowth of many lectures given to applicants for Merchant Marine Engineering-Officer licenses. The examinations which such applicants must pass are basic and fundamental, and the subject matter covered in this text is patterned along similar lines. Each chapter covers a particular phase of the required material and is, in itself, a complete study unit. Many of the questions at the end of each chapter are so fundamental in nature that they repeatedly appear on U. S. Coast Guard examinations for Marine Engineers and on Civil Service Examinations for Stationary Engineers.

Many applicants for Merchant Marine Engineering-Officer licenses have not had the advantage of formal training in basic science or in mathematics. Problems which appear on U. S. Coast Guard examinations require a knowledge of simple arithmetic on, perhaps, the junior high-school level; however, these problems deal with many different types of physical situations. In order to satisfy the requirement of knowledge of fundamental arithmetic on the part of those applicants with little or no formal training, and in order to give all applicants practice and review in problems of the type presented in the examination room, this second edition contains a chapter on Engine-Room Mathematics. Here one is shown how to multiply, how to divide, how to extract a square root, and many similar operations. Also included, and described in detail, is a system by which the applicant may check his work. Illustrative problems are completely worked out, and form models by which the subsequent practice problems may be solved; answers are given to all of the practice problems.

The chapter on Fire-Fighting Equipment has been completely rewritten so that it is in conformity with most recent U. S. Coast Guard Rules and Regulations.

The text covers refrigeration and electrical systems, deck machinery, and numerous other auxiliaries accessory to the modern marine power plant. It contains many sketches and illustrations which add immeasurably to the clarity which is so essential for self-study.

R.C.K. jr.

Contents

CHAPTER 1

Introduction to the Marine Power Plant

Past Development

Present-day merchant vessels of the United States differ so greatly from ships of a hundred years ago that the two are not subject to comparison. Not only would the mechanically propelled and well-instrumented modern vessel appear fantastic to a master of a clipper ship of a century ago, but the type of men who today follow the sea for a livelihood would strike him as unbelievable. In those days, ships were manned by social castaways; today, the well-organized and efficiently operated vessels of the American Merchant Marine are monuments to the intelligent and liberty-loving Americans who "go down to the sea in ships." It is to those men who desire to continue their chosen vocation and elevate its standards that this book is addressed.

The first steamships were driven by reciprocating engines to which fire-tube boilers supplied steam. Engines manufactured in the days of James Watt were not much different from those in use today. Watt resorted to compounding of engines, developed valve motions, and invented the engine indicator. Probably the most noticeable advance since Watt's time is the improved method and material of piston packing. The boilers on early steam vessels, designed to use sea water and to burn coal as a fuel, were inefficient and their principal aim was to keep steam pressure up.

Present Trends

1. High Pressures. World War I saw the emergence of a large fleet of turbine-driven vessels. These turbines operated on steam pressure which was fairly low and which was supplied by water-tube boilers. The superiority of turbine drive over reciprocating-engine drive was so pronounced that, until the building of the emergency Liberty[1] fleet, the majority of ocean-going ships were designed with turbine drive.

Studies of the economy of modern, marine power plants dictate the use of higher steam pressures and temperatures. So, hand in hand with the development of higher-pressure steam turbines has come improvement in boiler design. Boilers for shoreside plants have been built for pressures up to 2600 pounds per square inch, one designed for 4500 pounds per square inch pressure is scheduled for 1956 operation, and several 1500-pound-per-square-inch boilers are now in use aboard American vessels.

2. The Uniflow Engine. For vessels of horsepowers up to about 3000, the uniflow-type engine gives excellent service, but for vessels of much larger horsepower, the trend is definitely toward high-pressure turbines. The operating economies possible with a well-designed large-horsepower turbine results in a higher over-all plant efficiency.

3. Gear Drive vs. Electric Drive. High-speed turbines may either drive the propeller through reduction gearing or they may drive an electric generator that supplies electrical power to propulsion motors. The reduction gearing is of the single type for low-speed turbines and of the double type for high-speed units. Electric drive is fitted normally only on installations of 2000 shaft horsepower and above.

The advantages of electric drive are more rapid maneuverability, a more flexible arrangement of machinery, full power available for astern travel, and the omission of an astern element. The disadvantages of electric drive include greater cost and, sometimes, greater weight; auxiliary air-cooling equipment; need for specially trained engineers; and a lower efficiency. It thus appears that the modern steam vessel of the future will be driven by a high-pressure reduction-geared turbine.

Steam and Diesel Drives Compared

4. Selection of Prime Mover. In selecting a prime mover for installation aboard ship, there are at least six factors to be considered:

1. Total weight of engine and everything needed to make it operate (steam boiler, and so forth).
2. Total space occupied by machinery.

[1] Here, the emphasis was on speed of production, the aim being to provide the greatest number of ships in the least possible time. The turbine- and gear-building capacity of the nation was not prepared to undertake a task of such magnitude at such short notice. Also, the training needed for the large influx of new men would have been more of a problem for turbine-driven vessels.

3. Original cost of complete plant.
4. Operating costs of plant.
5. Amount of time lost in maintenance and repairs.
6. Maneuverability.

1. *Weight.* The following table[2] gives a clear picture of the total weights of various machinery in pounds per shaft horsepower:

Low-pressure steam, reciprocating engines, scotch boilers	500
High-pressure steam, turbines, water-tube boilers	240
Diesel engines, two-stroke cycle, single-acting, or four-stroke cycle supercharged	400
Diesel engines, two-stroke cycle, double-acting	350
Diesel engines, geared, with transmission clutch	300

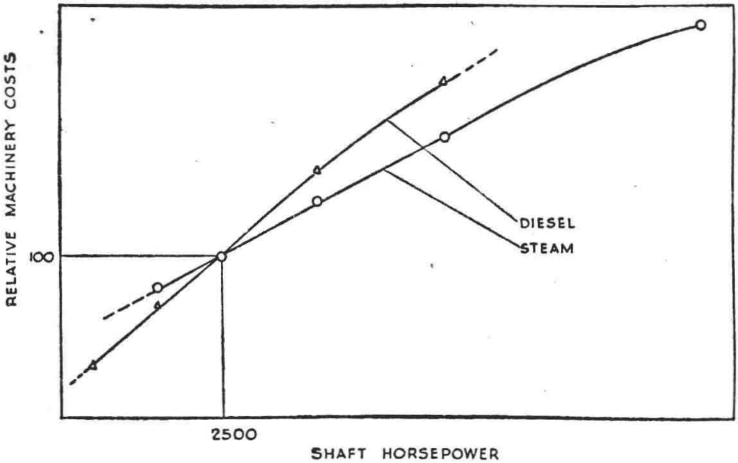

FIG. 1-1. Diesel and steam costs compared.

Since unit weight of the total machinery installation increases with a decrease in total shaft horsepower, small craft, such as tugboats and harbor craft, find Diesel drive very acceptable. However, for ocean-going vessels, the total weight of a Diesel installation is about 25 per cent higher than that of a steam plant.

2. *Space.* The machinery installation of a steam plant includes boilers, auxiliary machinery, and main propulsion unit. As such, the space occupied will be greater than that required for a Diesel installa-

[2] Freeman, Sterry, *Transactions of the Institute of Naval Architects*, 1939

tion. This is of considerable importance for ships that are designed for the purpose of making very long voyages.

3. *First Cost.* Fig. 1-1 is based on figures given by John Burkhardt in the *Transactions of the Institute of Naval Architects,* 1938. At about 2500 shaft horsepower, the cost of a Diesel plant is the same as that of a steam turbine plant. For values below 2500 horsepower, a Diesel plant would be cheaper, and for values above 2500 horsepower, a high-pressure, steam turbine plant would be less expensive.

4. *Operating Costs.* The number of engine-room personnel is generally smaller on Diesel-driven vessels than on steam vessels. Fuel consumption in pounds per shaft horsepower-hour will approximate 0.55 for steam drive and about 0.4 for Diesel drive. However, cost of Diesel fuel and lubricating oil is higher than that for a steam installation, and the operating costs tend to balance each other. An important point in favor of Diesels is that, for long voyages, the decrease in fuel storage space allows a greater cargo-carrying capacity.

5. *Maintenance.* One of the greatest disadvantages in Diesel plants of the past was the amount of time spent in overhauling the engine and making repairs. Modern Diesels are being built so that time spent in repairs is about the same as that required for steam vessels.

6. *Maneuverability.* Steam reciprocating engines and turbines can throttle down to a very low speed. On Diesel engines, if speed is reduced more than 70 to 75 per cent below full speed, the engine will often cease to operate. In maneuvering, the ability to run at low speeds is very important.

Geared turbines require about 60 seconds to go from full ahead to full astern. Electric-drive Diesels, electric-drive steam turbines, direct-drive Diesels, and reciprocating steam engines can change from full ahead to full astern in from 10 to 20 seconds. This reversibility is another point in favor of Diesel drive for use in harbor craft, where speed in reversing is very important.

The Gas Turbine

5. Development. The idea of the gas turbine is by no means new. A patent covering a gas turbine was granted to John Barber by the English government in 1791. Development of a practical gas turbine was retarded for many years because of two factors: first, the compressor used in conjunction with early models was the inefficient reciprocating type and, second, much experimentation was necessary to develop blading with sufficient heat-resisting qualities to withstand the extremely high temperatures so necessary for efficient operation.

Efficient multistage axial compressors have now been developed to a high degree of efficiency. Blading material to withstand as much as 1500° F has been discovered. There is no great barrier to prevent the gas turbine from becoming popular for marine as well as for industrial use. As this book is being prepared, tests are being run on gas-turbine, marine power plants. The chief advantages of the gas turbine are:

1. It eliminates necessity for steam boilers and attendant auxiliary apparatus.
2. Weight per shaft horsepower would be much less than that required for a high-pressure, geared steam turbine plant.
3. Space occupied would be less than that required for either a Diesel or steam turbine plant.
4. Thermal efficiency would be slightly higher than that of a steam or Diesel plant.

6. Essential Elements. Figure 1-2 shows the essential elements of a gas turbine designed for marine service. Fuel is burned in the firebox F_1. Combustion products pass through the various stages of the high-pressure gas turbine T_1. Exhaust gases from this turbine pass through the firebox F_2, where they mingle with combustion products and so increase in temperature. Hot exhaust gases then pass through the various stages of a low-pressure gas turbine T_2 and exhaust through a regenerator (air heater) R, and then out the smoke stack. Air enters at the upper, right-hand corner of the diagram and passes through a centrifugal compressor A_1. This intermediate pressure air is passed through an intercooler I because it has been found that intercooling between stages of compression increases efficiency by some 5 per cent. The air then passes through the high-pressure air compressor A_2 and then through the regenerator R. Note that the air does not come into direct contact with the exhaust gases from T_2. The high-pressure air supports combustion in firebox F_1, and this combination of heat and pressure is the force that drives the turbines.

Note that the centrifugal compressors are driven by the turbines. Thus, a very large portion of total turbine power is consumed *internally* within the cycle. Yet enough power is left over to make the gas turbine more efficient than either the steam or Diesel cycles.