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INTRODUCTION: CLASSIFICATION AND SELECTION OF PUMPS

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INTRODUCTION

Only the sail can contend with the pump for the title of the earliest invention for the conversion of natural energy to useful work, and it is doubtful that the sail takes precedence. Because the sail cannot, in any event, be classified as a machine, the pump stands essentially unchallenged as the earliest form of machine for substituting natural energy for human physical effort.

The earliest pumps we know of are variously known, depending on which culture recorded their description, as *Persian wheels*, *waterwheels*, or *norias*. These devices were all undershot waterwheels containing buckets that filled with water when they were submerged in a stream and that automatically emptied into a collecting trough as they were carried to their highest point by the rotating wheel. Similar waterwheels have continued in existence in parts of the Orient even into the twentieth century.

The best-known of the early pumps, the Archimedean screw, also persists into modern times. It is still being manufactured for low-head applications where the liquid is frequently laden with trash or other solids.

Perhaps most interesting, however, is the fact that with all the technological development that has occurred since ancient times, including the transformation from water power through other forms of energy all the way to nuclear fission, the pump remains probably the second most common machine in use, exceeded in numbers only by the electric motor.

Because pumps have existed for so long and are so widely used, it is hardly surprising that they are produced in a seemingly endless variety of sizes and types and are applied to an apparently equally endless variety of services. Although this variety has contributed to an extensive body of periodical literature, it has also tended to preclude the publication of comprehensive works. With the preparation of this handbook, an effort has been made to create just such a comprehensive source.

Even here, however, it has been necessary to impose a limitation on subject matter. It has been necessary to exclude material uniquely pertinent to certain types of auxiliary pumps that lose their identity to the basic machine they serve and where the user controls neither the specification, purchase, nor operation of the pump. Examples of such pumps would be those incorporated into automobiles or domestic appliances. Nevertheless, these pumps do fall within classifications and types covered in the handbook, and basic information on them may therefore be obtained herein after the type of pump has been identified. Only specific details of these highly proprietary applications are omitted.

Such extensive coverage has required the establishment of a systematic method of classifying pumps. Although some rare types may have been overlooked in spite of all precautions, and obsolete types that are no longer of practical importance have been deliberately omitted, principal classifications and subordinate types are covered in the following section.

CLASSIFICATION OF PUMPS

Pumps may be classified on the basis of the applications they serve, the materials from which they are constructed, the liquids they handle, and even their orientation in space. All such classifications, however, are limited in scope and tend to substantially overlap each other. A more basic system of classification, the one used in this handbook, first defines the principle by which energy is added to the fluid, goes on to identify the means by which this principle is implemented, and finally delineates specific geometries commonly employed. This system is therefore related to the pump itself and is unrelated to any consideration external to the pump or even to the materials from which it may be constructed.

Under this system, all pumps may be divided into two major categories: (1) dynamic, in which energy is continuously added to increase the fluid velocities within the machine

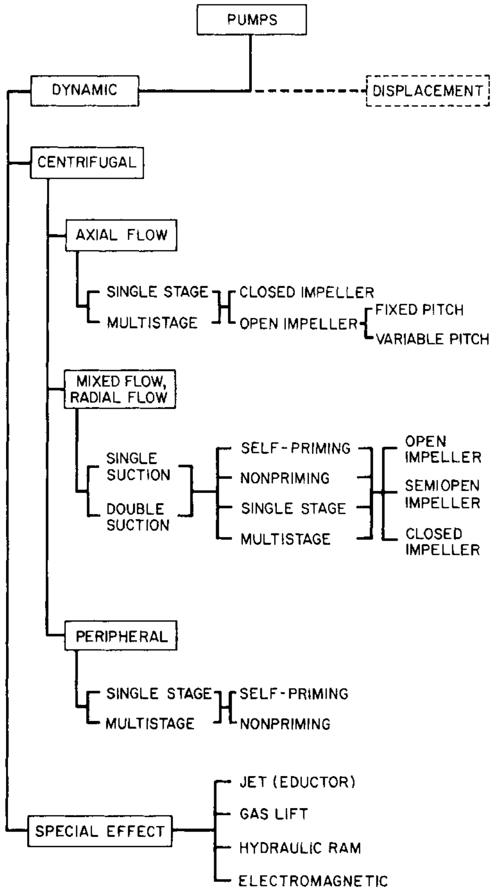

FIGURE 1 Classification of dynamic pumps

to values greater than those occurring at the discharge so subsequent velocity reduction within or beyond the pump produces a pressure increase, and (2) displacement, in which energy is periodically added by application of force to one or more movable boundaries of any desired number of enclosed, fluid-containing volumes, resulting in a direct increase in pressure up to the value required to move the fluid through valves or ports into the discharge line.

Dynamic pumps may be further subdivided into several varieties of centrifugal and other special-effect pumps. Figure 1 presents in outline form a summary of the significant classifications and subclassifications within this category.

Displacement pumps are essentially divided into reciprocating and rotary types, depending on the nature of movement of the pressure-producing members. Each of these major classifications may be further subdivided into several specific types of commercial importance, as indicated in Figure 2.

Definitions of the terms employed in Figures 1 and 2, where they are not self-evident, and illustrations and further information on classifications shown are contained in the appropriate sections of this book.

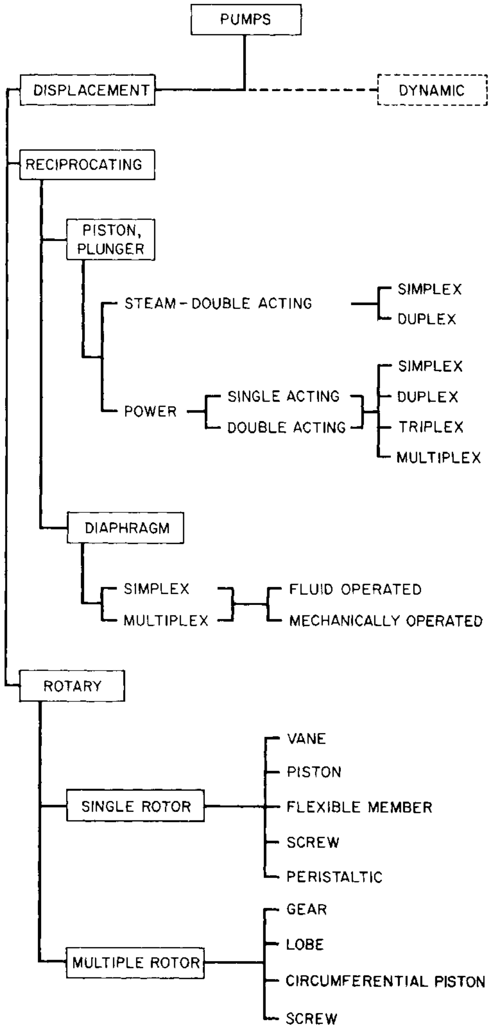

FIGURE 2 Classification of displacement pumps

OPTIMUM GEOMETRY VERSUS SPECIFIC SPEED

Optimum geometry of pump rotors is primarily influenced by the specific speed N_S or Ω_S, defined as shown in Figure 3. This parameter is one of the dimensionless groups that emerges from an analysis of the complete physical equation for pump performance. In this equation, performance quantities such as efficiency η and head ΔH (or just H) are stated to be functions of the volume flow rate Q, rotative speed N or angular speed Ω, rotor diameter D or radius r, viscosity, *NPSHA,* and a few quantities that have lesser influence. For low viscosity (high Reynolds number) and *NPSHA* that exceeds what the pump requires (namely *NPSHR*), the performance in terms of the head coefficient $\psi = g\Delta H/(\Omega^2 r^2)$ is influenced only by the flow coefficient or "specific flow" $Q_s = Q/(\Omega r^3)$. Now, if one divides $Q_s^{1/2}$ by $\psi^{3/4}$, the rotor

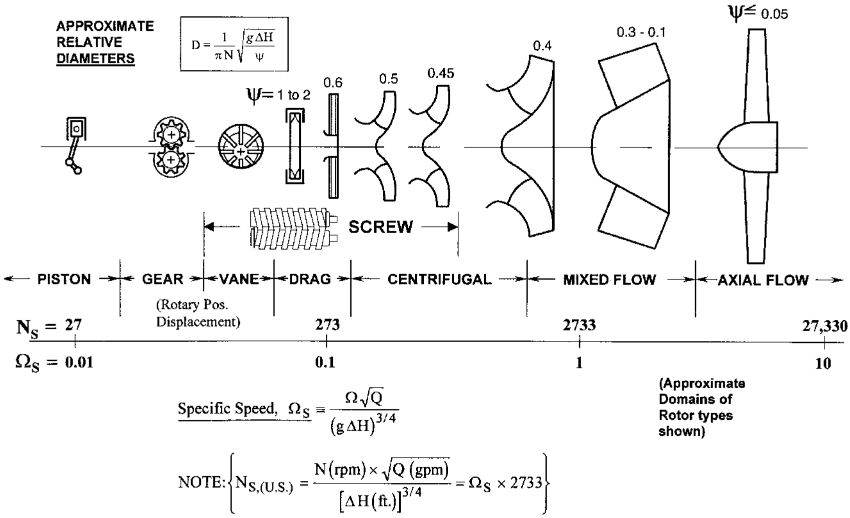

FIGURE 3 Optimum geometry as a function of BEP specific speed (for single stage rotors).

radius r (= D/2) drops out (which is convenient because we don't usually know it ahead of time), and we get the universal specific speed Ω_S as the major dependent variable—in terms of which the hydraulic design is optimized for maximum efficiency, as shown in Figure 3.

This optimum geometry carries with it an associated unique value of the head coefficient ψ, thereby effectively sizing the rotor. For "rotodynamic" or impeller pumps, imagining speed N and head ΔH to be constant over the N_S-range shown yields increasing optimum impeller diameter as shown. This size progression shows that the optimum head coefficient ψ decreases with increasing specific speed.

Outside the N_S range shown in Figure 3 for each type of rotor, the efficiency becomes unsatisfactory in comparison to that achievable with the configuration shown for this N_S. Rotary positive displacement machines such as vane pumps, gear pumps, and a variety of screw pump configurations are more appropriate for the lower values of N_S, the lowest N_S-values requiring reciprocating (piston or plunger) positive displacement pumps.

Regarding units for these relationships, the rotative speed N is in revolutions per second (rps) unless stated to be in rpm because the quantity of $g\Delta H$ usually has the units of length squared per second squared. The diameter D has the same length unit as the head; for example, in the rotor size equation, head in feet would imply diameter in feet. The universal specific speed Ω_S has the same value for any combination of consistent units, and similarly shaped turbine and compressor wheels have similar values of Ω_S—making it truly "universal." Note that for the unit of time of seconds, Ω is given as radians per second [= N(rpm) × π/30], where radians are unitless.

SELECTION OF PUMPS

Given the variety of pumps that is evident from the foregoing system of classification, it is conceivable that an inexperienced person might well become somewhat bewildered in trying to determine the particular type to use in meeting most effectively the requirements for a given installation. Recognizing this, the editors have incorporated in Chapter 11, "Selecting and Purchasing Pumps," a guide that provides the reader with reasonable familiarity regarding the details that must be established by or on behalf of the user in order to assure an adequate match between system and pump.

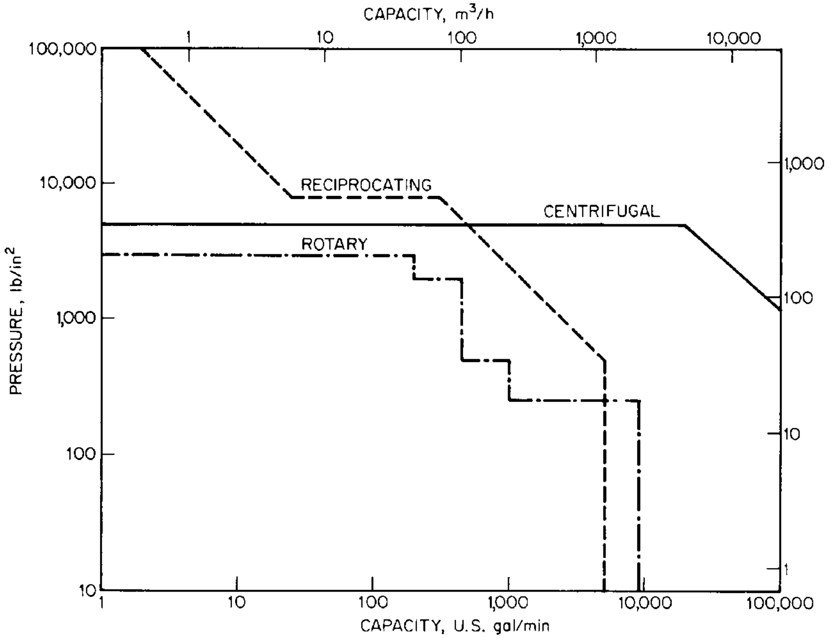

FIGURE 4 Approximate upper limit of pressure and capacity by pump class

Supplementing the information contained in Chapter 11, the sections on centrifugal, rotary, and reciprocating pumps also provide valuable insights into the capabilities and limitations of each of these classes. None of these, however, provide a concise comparison between the various types, and Figure 4 has been included here to do just that, at least for the basic criteria of pressure and capacity.

The lines plotted in Figure 4 for each of the three pump classes represent the upper limits of pressure and capacity currently available commercially throughout the world. At or close to the limits shown, only a few sources may be available, and pumps may well be specially engineered to meet performance requirements. At lower values of pressure and capacity, well within the envelopes of coverage, pumps may be available from dozens of sources as pre-engineered, or standard, products. Note also that reciprocating pumps run off the pressure scale, whereas centrifugals run off the capacity scale. For the former, some highly specialized units are obtainable at least up to 150,000 lb/in^2 (10,350 bar)[1] and perhaps slightly higher. For the latter, custom-engineered pumps would probably be available up to about 3,000,000 U.S. gal/min (680,000 m^3/h), at least for pressures below 10 lb/in^2 (0.69 bar).

Given that the liquid can be handled by any of the three basic types and given conditions within the coverage areas of all three, the most economic order of consideration for a given set of conditions would generally be centrifugal, rotary, and reciprocating, in that order. In many cases, however, either the liquid may not be suitable for all three or other considerations—such as self-priming or air-handling capabilities, abrasion resistance, control requirements, or variations in flow—may preclude the use of certain pumps and limit freedom of choice. Nevertheless, it is hoped that the information in Figure 4 will be a useful adjunct to that contained elsewhere in this volume.

[1] 1 bar = 10^5 Pa. For a discussion of bar, see "SI Units—A Commentary" in the front matter.