CAVITATION IN CENTRIFUGAL PUMPS

by

LIEUTENANT (E) C. H. HUMBY, R.N.

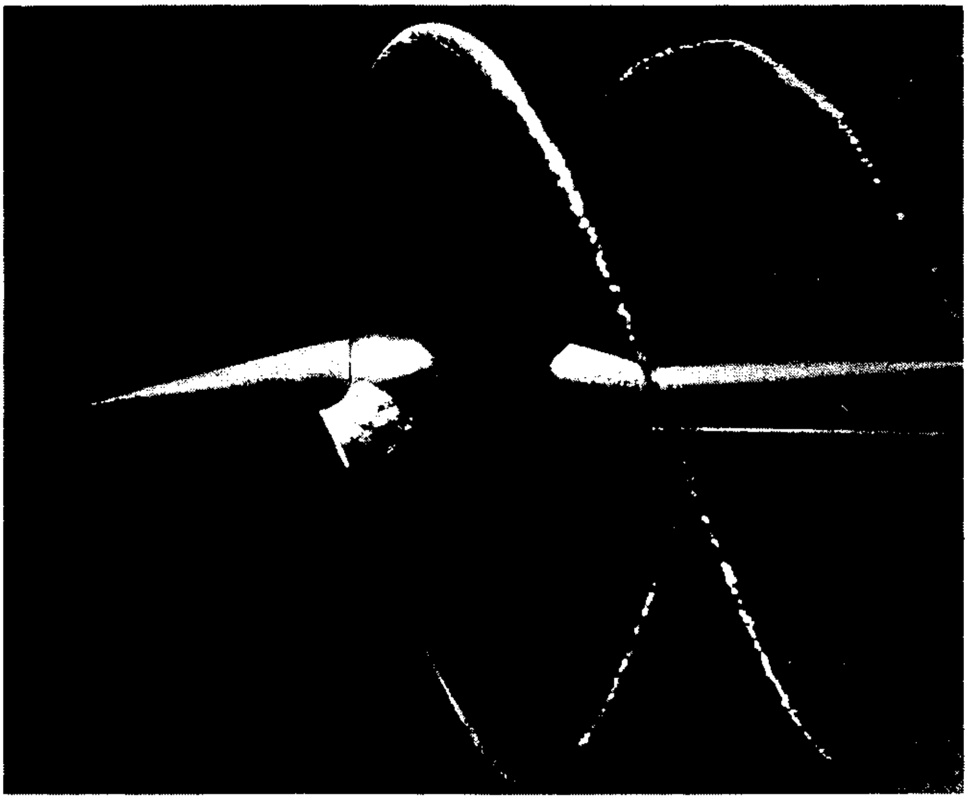

FIG. 1.—VAPOUR BUBBLES FORMING AT PROPELLER BLADE TIPS

Cavitation is a well-known term in connection with the operation of the propellers of ships. It is one of the deciding factors in the design of a propeller and, indeed, of the whole main engine unit as it limits the tip speed of the propeller. Exceeding the maximum allowable tip speed (210 ft/sec.) results in erosion of the propeller due to cavitation. The propellers of high-speed motor-boats, however, run above this maximum tip speed but their speed is so high that a surface of vapour is built up on the astern face, which possibly protects it from erosion. Fig. 1 shows vapour bubbles that have formed at the blade tips.

Cavitation can also occur in centrifugal and axial-flow pumps, and when serious will soon cause extremely severe erosion of the impeller. Fig. 2, which is a photograph taken looking into the eye of the impeller, shows an example of severe erosion of the leading edges of the impeller vanes and of the entrance to the passages through the impeller. Fig 3 shows the characteristic form of slight erosion of impeller vanes.

The Mechanism of Cavitation

In order to appreciate the causes of cavitation in centrifugal pump impellers it is necessary to describe the mechanism of cavitation. The theory accepted at present is that when water flows past a vane in its path and is either accelerated

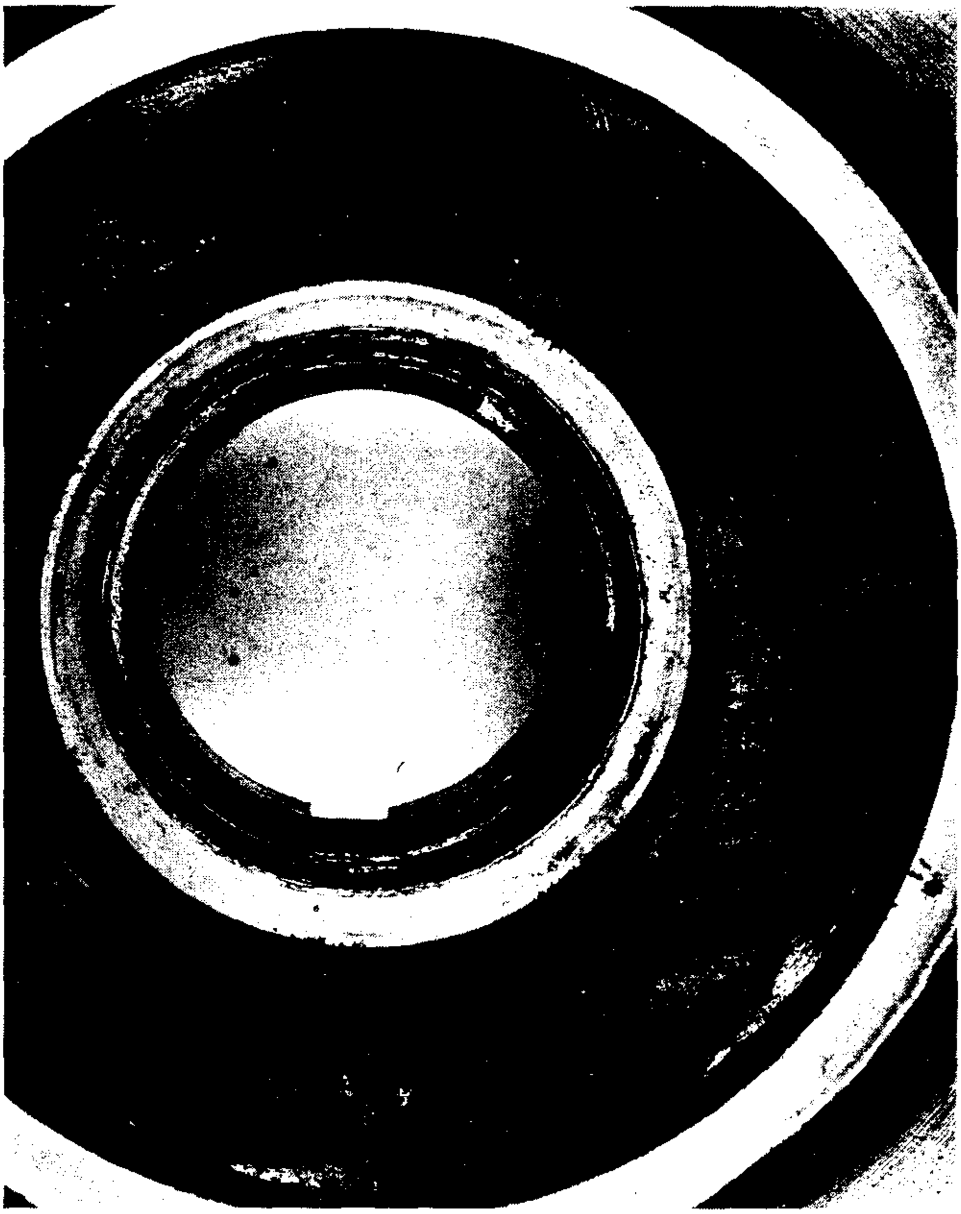

Fig. 2.—Severe erosion of a feed pump impeller

or decelerated the resulting speed-change produces a pressure change in the water. In Fig. 4, the streamlines are compressed below the vanes and the speed rises while the pressure falls ; thus there is a transverse force on the vane in the direction shown. The lower part of the figure indicates the pressure obtaining in way of the blade. From the figure it is apparent that on the suction side, near the forward edge of the vane, there is a rapid fall of pressure. Minute bubbles of water vapour form when the pressure is reduced below the vapour pressure and if there is air in the water these bubbles will contain air. When the bubbles move to a region of higher pressure where their existence is unstable, they collapse, and energy is liberated rapidly producing a pin-point blow in the order of 120 tons/sq. in. As the material may not stand this stress it results in heavy wear which has a typical eroded appearance.

It has been suggested that the presence of air dissolved in water can, in some cases, increase cavitation ; in fact, one authority states that the presence of air is essential for cavitation to take place. It seems likely that the air assists in the formation of bubbles and thus enhances the possibility of cavitation.

Large quantities of air tend to reduce cavitation due to a cushioning effect. It has also been shown that cavitation is assisted by the presence of nuclei on which the bubbles can form.

Every endeavour must therefore be made firstly to reduce the air content of the water to a minimum and secondly to avoid sudden pressure changes. The reduction of pressure may take place over the whole system or may only occur *locally without a general change of* pressure. A general pressure drop may be produced by :—

(i) an increase in the static lift of the centrifugal pump

(ii) a decrease in the absolute pressure of the system as when pumping from a compartment under vacuum, or

(iii) an increase in the temperature of the liquid being pumped.

A local decrease in the pressure can be caused by one of the following means :—

(i) an increase of velocity on the suction side by speeding up the pump

(ii) a result of separation, or

(iii) a deviation of the streamlines from their normal path as occurs in a turn.

Detection of Cavitation

Cavitation can be detected by the following signs :—

(i) *Noise and vibration.* These are caused by the sudden collapse of vapour bubbles as soon as they reach the high pressure zone in the pump. Such signs of cavitation may appear in the normal operating range of *the pump if the suction head* is insufficient to suppress cavitation. However, noise

FIG. 3.—EROSION ON FEED PUMP IMPELLER VANES

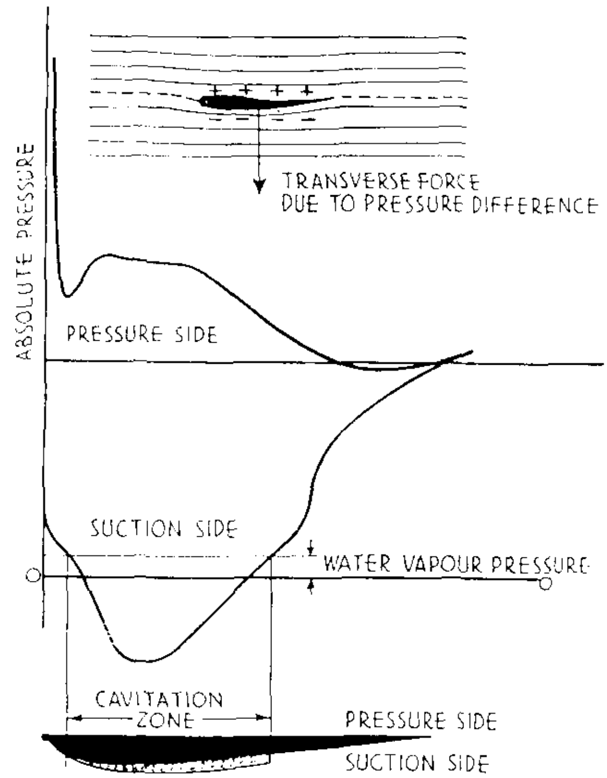

FIG. 4.—THE MECHANISM OF CAVITATION

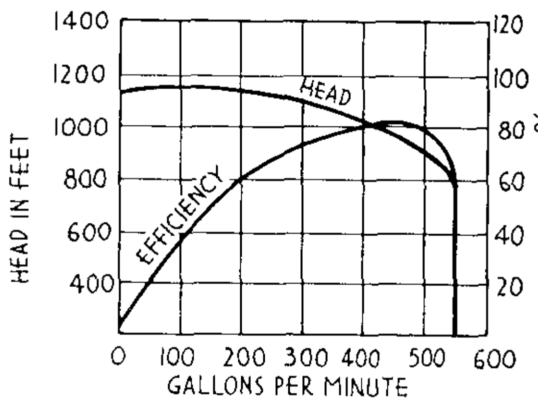

FIG. 5.—FOR CENTRIFUGAL PUMP

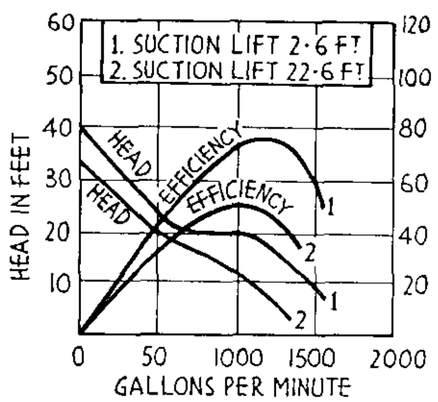

FIG. 6.—FOR AXIAL-FLOW PUMP

and vibration are present to a varying degree in all pumps when operated at points far removed from maximum efficiency, due to a bad angle of attack at the impeller eye. In some shore installations, more particularly in hydraulic turbines, air admission in small amounts is resorted to in order to give a cushioning effect.

(ii) *Drop in Characteristic and Efficiency Curves.* In a pure centrifugal pump the head-output, efficiency, and power characteristics drop off suddenly when cavitation is reached as shown in Fig. 5. In axial-flow pumps, however, there is a general drop of the characteristics over the whole range, the drop in efficiency being the most reliable indication of cavitation (Fig. 6). The difference is due to the fact that in a centrifugal pump the formation of vapour in the eye completely stops delivery whereas in an axial-flow pump, due to the channel between the vanes being shorter, wider, and not overlapping, there are always parts of the channel where the pressure remains above the vapour pressure.

(iii) *Cavitation Erosion.* If a pump is operated under cavitating conditions for a sufficient time, erosion takes place as a form of pitting, the amount of metal lost depending on the material used and the degree of cavitation. The pitting produced is due solely to the mechanical action of the collapsing bubbles.

Examples of Cavitation Erosion

The minimum pressure in pumps of normal design occurs on the back of the impeller vane slightly beyond the suction edge. Pitting appears further downstream where the vapour bubbles collapse. If the pump is operating continuously above normal output, pitting may occur on the front side of the vane at the suction edge (Fig. 7).

Local high velocity through the blade tip clearance, in conjunction with separation due to a sudden change in direction, produces the so-called " marginal " cavitation and pitting. Rounding off the discharge side corners of the vanes eliminates the pitting but produces increased leakage through the clearance.

Fig. 7 (*d*) shows the position of pitting at the cut-water of the discharge casing which occurs when a pump operates continuously at capacities above normal.

Fig. 2 showed the severe erosion that has taken place in an impeller of an auxiliary feed pump of one of the 1942 Light Fleet carriers. Most of these

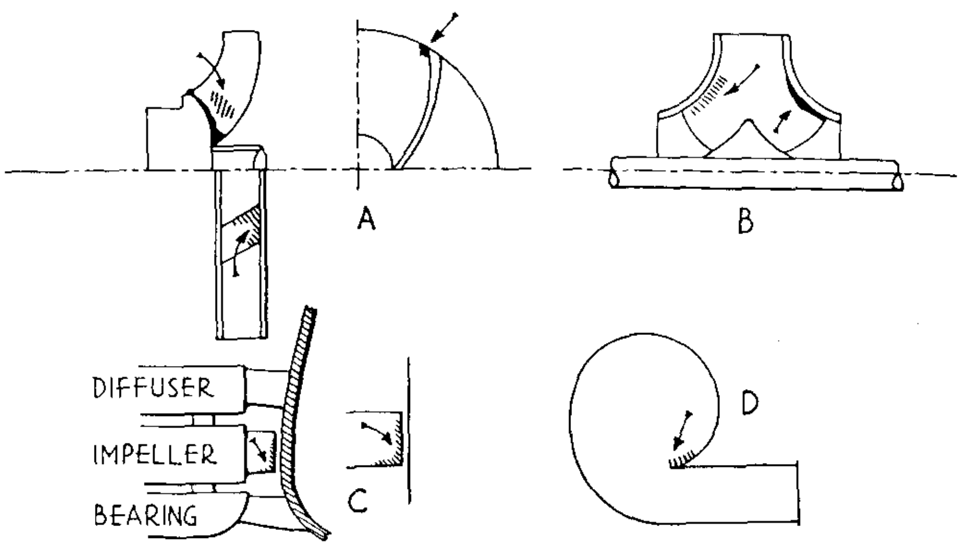

FIG. 7.—EXAMPLES OF CAVITATION

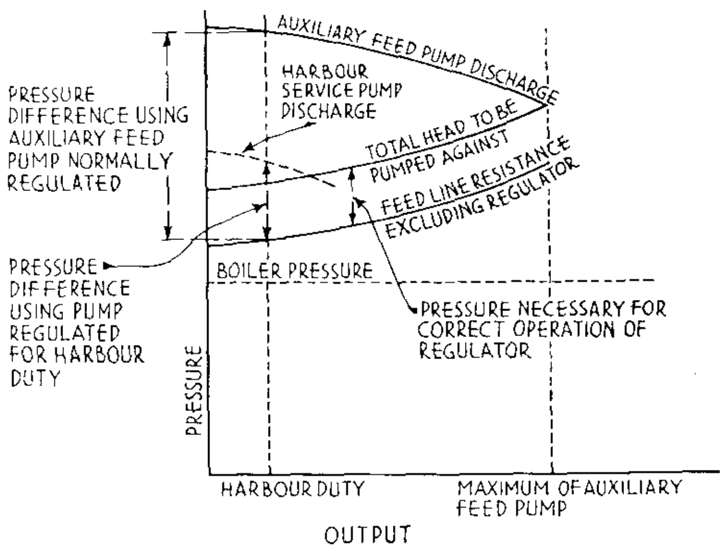

FIG. 8.—DIAGRAM SHOWING PRESSURE DROP ACROSS A FEED REGULATOR FOR HARBOUR SERVICE DUTY

ships have experienced this trouble. The auxiliary feed pump had to be used for harbour conditions as the ships were not fitted with harbour service feed pumps. The erosion was due to cavitation and it is considered that the likely causes were :—

(i) Insufficient output of the harbour service de-aerator thus leaving air in the feed water

(ii) Sudden accelerations and decelerations of flow through the impeller due to the opening and closing of the feed regulator.

A feed regulator must have a certain minimum pressure drop across it for correct operation, but too high a drop will cause it to hunt. As the auxiliary feed pump must be capable of feeding a boiler at high powers in comparison to the harbour duty it must be set to deliver at a pressure well in excess of the boiler pressure in order to overcome the resistance of the feed line at high powers and to provide a sufficient pressure drop across the feed regulator (Fig. 8). For harbour duty the

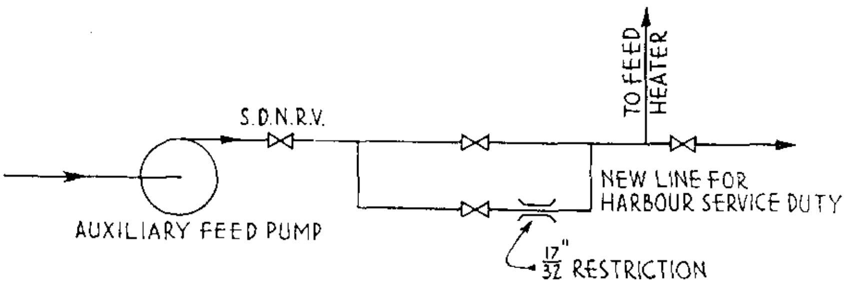

FIG. 9.—MODIFICATION TO FEED LINE IN 1942 LIGHT FLEET CARRIERS

high pressure drop between the feed and boiler pressures across the regulator will tend to produce hunting and hence accelerations and decelerations of flow of the feed water.

The remedy has been to fit a new line for harbour service with a $\frac{17}{32}$ inch diameter restriction in it in order to reduce the output of the pump (Fig. 9).

In general, anything producing a sudden decrease in pressure such as change in direction, alteration in area, or poor streamlining can produce local erosion if the suction pressure is reduced below a certain minimum. Erosion on the discharge side can occur when the pump pressure is not high enough to suppress cavitation.

Avoidance or Reduction of Cavitation

Cavitation should always be held in mind in designing centrifugal pumps. The following summary shows how it can be avoided or reduced :—

(i) When designed, full specifications of the suction conditions must be available. Reducing the losses in the suction pipe reduces the tendency towards cavitation

(ii) In high-specific-speed pumps (axial-flow type) an increase in the number of vanes, or in low-specific-speed pumps (pure centrifugal type) the removal of parts of the vanes and opening up the passages in the impeller eye, will increase the suction head for any given head-output conditions

(iii) An ample suction-approach area, without excessive swirl, and with better streamlining are essential for the greatest avoidance of cavitation

(iv) If cavitation conditions are unavoidable special materials to withstand the stresses produced should be used

(v) Noise and vibration caused by cavitation can be reduced by the admission of a small quantity of air to the pump suction.

Bibliography

(i) *Erosion due to Incipient Cavitation.* By W. T. Bottomley, Inst. Mech. Engrs., 1947.

(ii) *Cavitation in Centrifugal Pumps.* By A. J. Stepanoff, Trans. A.S.M.E., Oct., 1945.

(iii) *Theorie der Krieselpumpen und ihr Verhalten im Betriebe.* By K. Thannemann.