Centrifugal Dredgepumps
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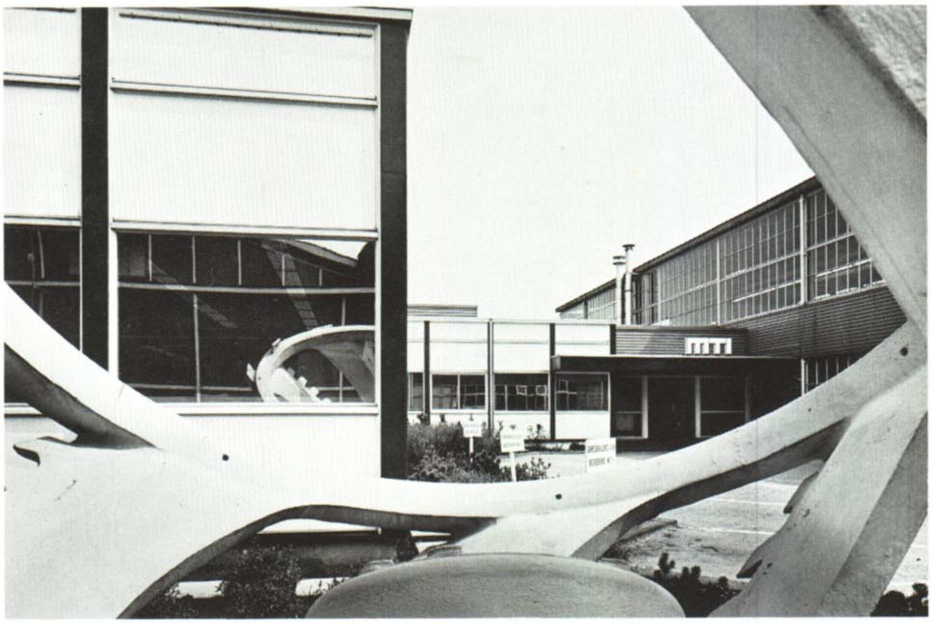
By
Ir. S. E. M. de Bree



This article is the seventh in a series written by Ir. S. E. M. de Bree, Head of the Mineral Technological Institute, the development laboratory of the Dredger Division of IHC Holland.

The earlier articles appeared in issues 77, 78, 80, 82, 84 and 85 of this publication.

The following is a revised version of an address entitled "The theory of the submerged dredgepump, its applications and the design of compact, electrically-driven units" presented by the author at the "Oriëntatiedag voor de Baggerindustrie" organized by IHC Holland on 14th March 1975 for the benefit of Dutch and Belgian dredging contractors.

Introduction

As the title of the address indicates, the subject, the submerged dredgepump, will be examined from three points of view. These are:

a) the theory of the submerged dredgepump;

b) the applications for this dredger component;

c) a new design of submerged dredgepump which IHC Holland will introduce this year and which will be known as the ISS (Integral Suction System) pump.

In view of the fact that this article is a revised version of the address referred to, it is impossible to deal exhaustively with the subject here.

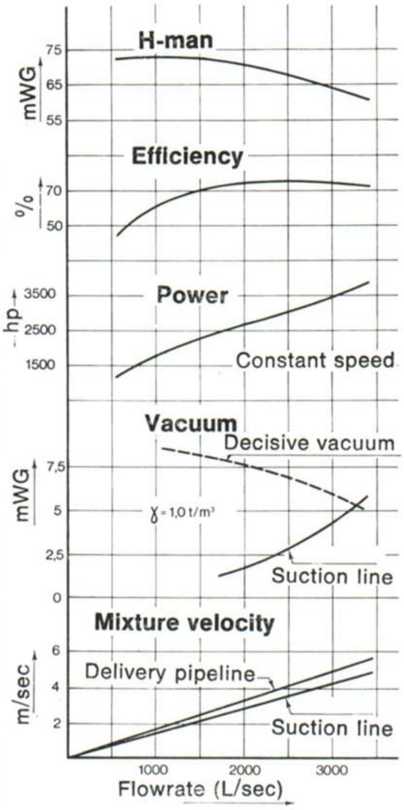


Fig. 1

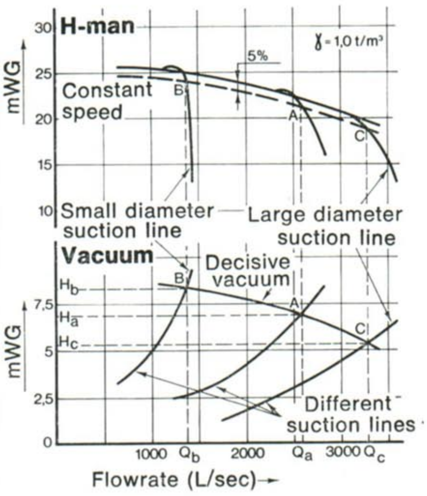


Fig. 2

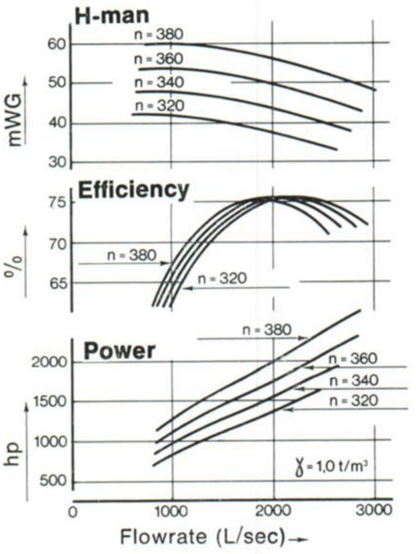


Fig. 3

Accordingly, a number of aspects will be examined in greater detail in subsequent articles.

Theory of the operation of a dredgepump

Before proceeding to the three specific aspects referred to above, it is necessary to reiterate some of the theoretical principles dealt with in earlier articles, by way of introduction to the theoretical principles of the submerging of a dredgepump.

Fig. 1 shows the characteristics of a dredgepump when pumping plain water. In this, the suction head, the efficiency (η), the power, the vacuum in the suction pipe and the decisive vacuum of the pump, and the mixture velocity in the suction and delivery lines are all plotted against the flowrate.

The curve representing the decisive vacuum indicates the threshold of cavitation (see Fig. 2).

At the onset of cavitation, the delivery pressure deviates from the Q-H curve.

Further excursion into the area of cavitation leads to a steady fall in the delivery pressure, ending in total collapse. The pump chokes. The efficiency falls away with the delivery pressure and the flowrate rapidly drops to zero.

The decisive vacuum is deemed to be the vacuum at which, at a given pump speed, the suction head during cavitation differs by 5% from the normal suction head.

The effect of increasing the speed of the pump in question is shown in Fig. 3. As a general rule it may be assumed that, where the variation in speed is not of very large magnitude, the flowrate is proportional to the speed, and the pressure proportional to the square of the speed. The power absorbed by the pump is thus proportional to the cube of the speed.

Here it is assumed that the efficiency η remains virtually constant.

The virtual absence of laws makes it very difficult to predict changes in the decisive vacuum as a result of increases of the pump speed. It is, however, known that on pumps which are designed for a particular maximum speed, a drastic fall in the decisive vacuum occurs if this maximum is exceeded. Nowadays nearly all pumps are designed to operate at maximum speed because no one wishes to install a larger unit than is necessary, in view of the high initial cost.

Generally speaking, the pumping of mixtures has an adverse influence on the cavitation pattern. This is attributable to the presence of coarse and fine soil grains and foreign matter.

These disturb the homogeneity of the fluid vehicle and encourage cavitation.

Accordingly, the value of the decisive vacuum will be substantially lower when transporting a mixture than when pumping water.

The characteristics of a given pump when pumping water and when transporting mixture are shown in Fig. 4. In this, the mixture is assumed to have a specific gravity γ of 1.2 ton/m³ and to contain sand with a d_{50} of 200 μm. The diagram also contains a number of resistance curves relating to delivery pipelines of various lengths, viz. 100, 500 and 1,250 metres, with an assumed, constant layout.

The points of intersection of the pipeline characteristics and the corresponding pump characteristics constitute the working points of the pump.

It is clear from this diagram that a dredgepump does not operate at a fixed working point, but can have a working range consisting of a number of working points.

The working range in the Q-H diagram of a dredgepump (see Fig. 5) lies between:

a) a lower limit at low flowrates which correspond to the critical velocity;

b) an upper limit at high flowrates which correspond to the decisive vacuum of the pumping installation, which is itself a limiting factor.

The lower limit of the working range is the minimum flowrate commensurate with the maximum length of delivery pipeline for which the installation is designed. If this length is exceeded, the velocity will become

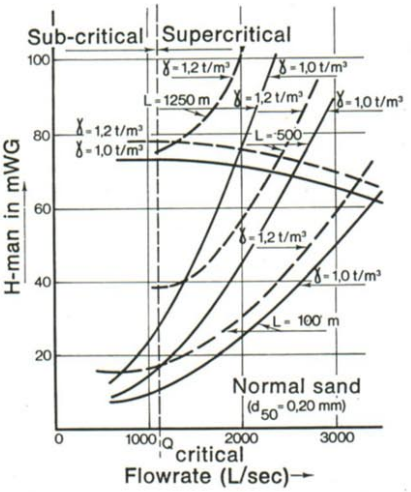


Fig. 4

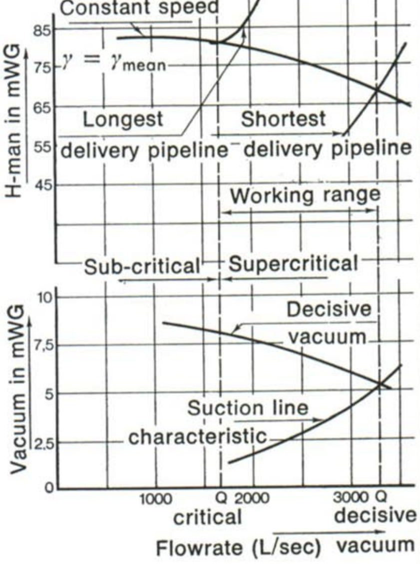


Fig. 5

sub-critical, resulting in sedimentation in the pipeline and a high risk of total blockage.

The upper limit of the working range is the threshold of cavitation. If the pump is to operate satisfactorily, cavitation must be prevented as far as possible.

In the high flowrate area, the working range of a pump is limited by the flowrate at which the level of vacuum in the suction pipe is equal to the decisive vacuum for the installation.

Where this is so, the pump commences to cavitate. This upper limit corresponds to the minimum delivery distance at maximum flowrate.

In a complete installation, comprising dredgepump, prime mover and suction and delivery pipelines, the working point of the pump is determined by the point at which the pump characteristic, as determined by the pump and its drive system, and the pipeline characteristic intersect in the Q-H diagram (Fig. 6). Where an installation is designed for a given pipeline layout and a given pit supply based on the nature of the soil and the operating circumstances, the only variable factor in calculating the output of solids is the length of the delivery pipeline.

The mean output which may be expected from a dredger can be calculated from the mean working point of the installation. This is the mean point of intersection of the pump and pipeline characteristics at the mean attainable specific gravity of the mixture.

By calculating the mean outputs for a number of pipeline lengths, a graph can be produced showing the output as a function of the pipeline length. In compiling this, the existence of a set number of known, additional obstructions in the delivery pipeline, such as bifurcations, gate valves, etc., will usually be assumed. A typical output graph for a dredgepump installation is shown in Fig. 7. In the majority of cases, the curve will bend sharply at two points, effectively dividing the graph into three zones.

These correspond to:

1) short, or too short, delivery distances (I).
   In this zone, the speed of the pump must be reduced sufficiently to prevent cavitation;

2) delivery distances corresponding to the normal working range of the pump (II);

3) long, or too long, delivery distances (III).
   In this zone, the mixture concentration must be reduced to a point where the flowrate is just above the critical limit.

The theory of the submerged dredgepump

The effect produced by lowering the position of the dredgepump is principally a result of a drastic change in the suction conditions of the installation.

The level of vacuum required immediately before the pump in order to transport the mixture from the bottom to the pump inlet, via a suction pipe (see Fig. 8), consists of:

1) The velocity height, i.e. the pressure required to accelerate the mixture in preparation for entering the suction pipe.
   This is expressed in the equation:

$$\frac{v_s^2}{2g}\cdot\gamma_m$$

2) Losses occurring at the suction inlet.
   These are expressed in the equation:

$$\alpha\cdot\frac{v_s^2}{2g}\cdot\gamma_m$$

   in which α is governed by, among other things:
   a) the shape of the suction inlet;
   b) the nature of the soil;
   c) the degree of penetration of the suction pipe.

3) The resistance produced by straight sections of the suction pipe.
   This is expressed in the equation:

$$\frac{L_s}{100}\cdot W_{100}$$

   in which L_s is the length of the straight sections and W_{100} the resistance encountered by the pumped mixture per 100 metres of straight suction line of the given diameter, at the given velocity v_s and mixture s.g.

4) Resistance produced by other components of the suction line.
   This is expressed in the equation:

$$\xi_s\,\frac{v_s^2}{2g}\cdot\gamma_m$$

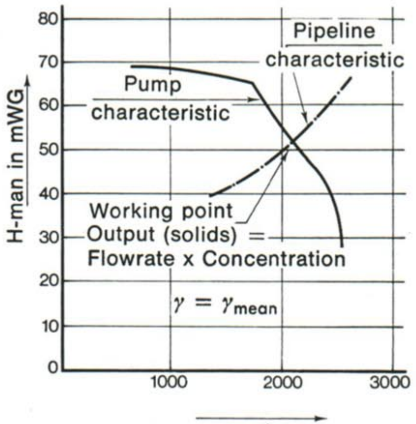


Fig. 6

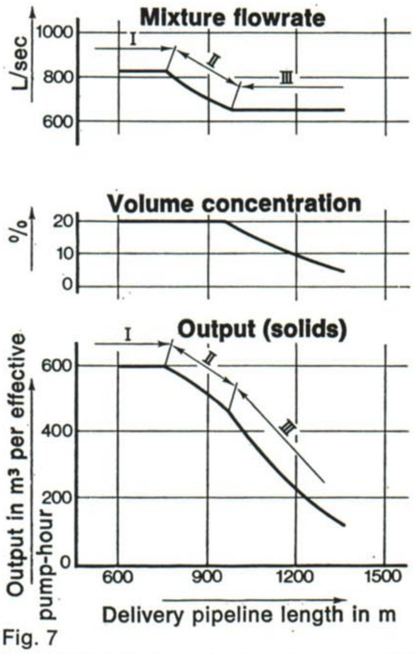


Fig. 7

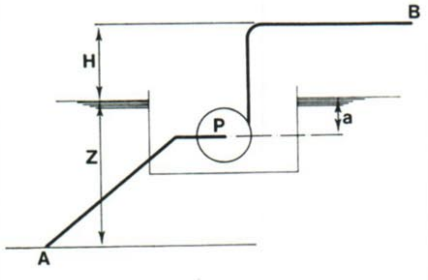


Fig. 8

in which ξ_s is the sum of the loss factors attributable to bends, hoses, restrictions, stone traps, etc.

5) The static head.
To raise the mixture from the dredging point to the pump requires a static head of

$$(Z\text{-}a) \times (\gamma_m\text{-}1)$$

in which Z is the geodetic suction depth, a the vertical distance from the surface of the water to the centre of the pump shaft, and γ_m the mean attainable mixture s.g.

As Fig. 8 shows, there exists at the suction inlet a pressure (a), which is the water pressure at the level of submersion of the pump, plus the decisive vacuum which the pump can generate ($H_{s\ dec}$).

$$H_{s\ available} = a + H_{s\ dec}$$

As stated earlier, the pressure required to transport the mixture through the suction pipe may not exceed the pressure available at the pump inlet. When the two are equal, the result is the decisive vacuum, i.e. the upper limit of the working range, which corresponds to the maximum flowrate.

The situation of equilibrium is expressed in the following equation:

$$(1 + \alpha + \xi_s).\ \frac{v_s^2}{2g}\ .\gamma_m + \frac{L_s}{100}\ .W_{100} + (Z\text{-}a)\ .\ (\gamma_m\text{-}1) = a + H_{s\ dec}$$

The term on the left of the equals sign is the pressure required to transport the mixture from the dredging point to the pump.

The term on the right of the equals sign is the pressure available at the pump inlet.

It will be clear from the equation that, for a given dredger with a given decisive vacuum, operating under constant conditions, with a fixed pipeline layout and transporting mixture of a given specific gravity, there is only one maximum dredging depth.

It will also be seen that the water pressure above a pump situated below the water level represents additional pressure on the suction side of the system. All other circumstances being equal, therefore, the deeper the pump is submerged, the lower will be the vacuum.

The column of water above the pump acts as it were as a "pretension", counterbalancing the vacuum occurring on the suction side of the pump. Furthermore, since placing the pump below the waterline implies that the distance over which the mixture has to be raised at a given dredging depth will be less, the suction pipe will be shorter and the resistance loss on the suction side smaller.

The effect of positioning the pump farther below the waterline

Submerged dredgepumps are by no means solely used in order to achieve greater dredging depths.

The effect of positioning the pump farther below the waterline is threefold, viz.

1) greater maximum dredging depth

2) higher attainable mixture s.g.

3) greater uniformity of the process.

Let us examine these in turn.

Fig. 9 shows the curve representing the decisive vacuum for a given, conventional pumping installation operating at a given speed, and the same curve after the application of a small increase in pressure a_1 caused by placing the pump a short distance below the waterline. This is the pressure available before the pump. The graph also shows the maximum suction depth as calculated on the basis of the available pressure and a constant mixture s.g. Where the speed remains constant, placing the pump farther beneath the waterline (a_2) does not produce any change in the decisive vacuum. The curve representing the pressure before the pump, however, does change: it moves upwards by an amount corresponding to the increase in the depth of the pump below the waterline. If we again plot the maximum suction depth for the given mixture s.g., we find that this is now appreciably greater.

Where additional suction depth is not the primary aim, locating the dredgepump farther beneath the waterline enables a considerably higher mixture s.g. to be attained. This is illustrated in Fig. 10. Here, too, the comparison is between a conventional installation and one in which the pump is placed farther below the waterline. Maintaining a constant suction depth, we can, with the aid of the pressure available before the pump, calculate the maximum attain-

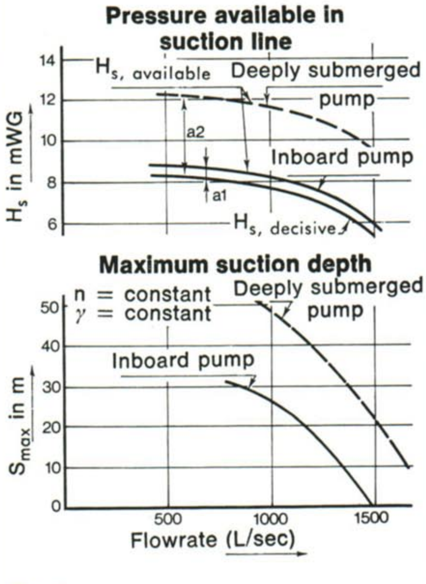


Fig. 9

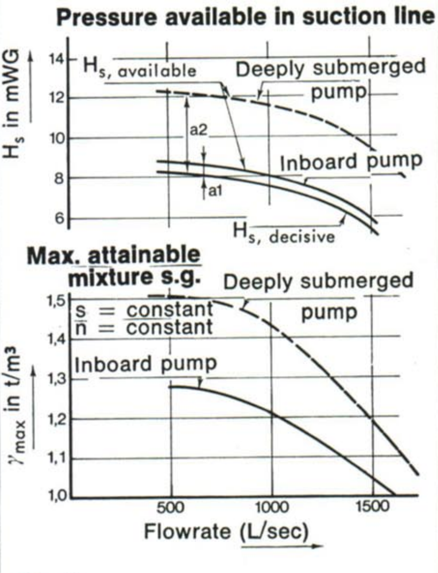


Fig. 10

able mixture s.g. for a conventionally positioned pump and one situated deep below the waterline. The result shows that the submerged pump is capable of transporting a substantially heavier mixture.

The power available to drive the pumping installation must, of course, be adequate for transportation by means of pressure, and the pit supply must be such that the higher specific gravity can be obtained. The pit supply can be improved significantly by placing the pump farther below the waterline. The improvement stems in part from the effect of submersion on the soil entering the suction inlet. The losses at this point are not governed solely by the shape of the inlet, but also by factors relating to the soil in situ. Submerging the pump results in a higher pressure differential at the point where the soil and water mixture enters the inlet, with the result that the soil is more easily dislodged and ingested.

Thus, the additional pressure obtained by placing the pump farther below the waterline will serve partly to increase the supply of solids to the suction inlet and partly to transport the heavier mixture through the pipe to the pump inlet.

The increase in the attainable mixture s.g. which results from submerging the pump also manifests itself in the output curves. Fig. 11 shows the curves relating to the pumping installation previously referred to. Here again the first curve relates to a conventionally located (inboard) pump and the second to a pump located well below the waterline.

Submerging the pump affords a more uniform dredging process. Fig. 12 shows the pump characteristic of the same unit, together with the suction line characteristic. The pipeline layout and the operating conditions are as before, and the diagram is again based on conventionally positioned and submerged pumps.

Submerging the pump results in a marked downward shift in the suction line characteristic, which then intersects the decisive vacuum curve at a point corresponding to a substantially greater flowrate. Thus, the extension of the upper limit of the operating range to embrace a higher flowrate has the effect of enlarging the whole range substantially. Naturally, this implies an increase in the power required to drive the installation.

The wider spacing of the suction line characteristic and the curve representing the decisive vacuum, which results from placing the pump farther below the waterline, has reduced the risk of the pump cavitating or choking as a result of fluctuations in the process.

Optimal positioning of the pump below the waterline

From the foregoing it can be deduced, and calculated, that, from the point of view of transport technology, there is an optimum depth at which a pump must be located in order to draw up a given type of soil in a mixture of predetermined specific gravity from a given maximum depth and transport it through a pipeline of a given layout.

From the point of view of dredging technology, there is no objection to the pump being positioned at a depth greater than this; on the contrary. The lower the pump, the lower is the vacuum and the smaller the risk of cavitation, choking and loss of output as a result of fluctuations in the process.

This affords an additional, "solid" bonus. Moreover, with most types of soil, submerging the pump results in a more ample pit supply, thereby increasing the specific gravity of the mixture.

Because dredgers are very seldom purchased for a single job, and because the nature of the soil and the operating conditions seldom remain constant on any job, it is anything but simple to arrive at the optimal depth for a submerged dredgepump. It is therefore usual to choose a depth somewhat greater than that calculated on the basis of transport technology.

Reducing the size of the pumping installation by placing the dredgepump under water

It will be clear from what has been said that the contribution made by the decisive vacuum to the pressure in the suction pipe before the pump decreases progressively with the submersion of the pump. This implies that, in a given situation, a pump with a smaller than normal decisive vacuum can be used, provided that it is

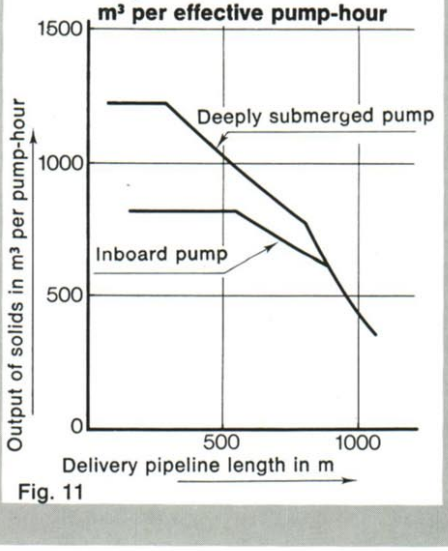


Fig. 11

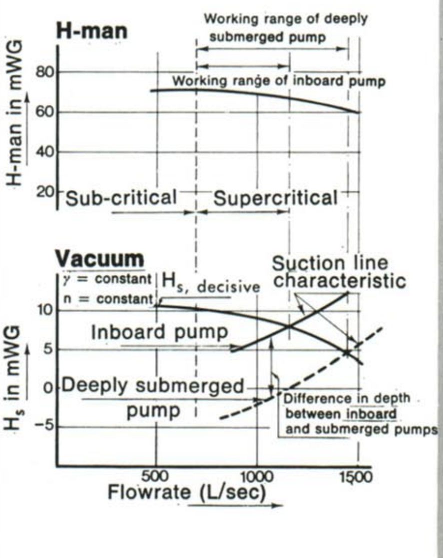


Fig. 12

located sufficiently far below the waterline, i.e. sufficiently close to the suction inlet. This, in turn, means that considerably smaller, faster-running pumps can be used for submerged applications, affording substantial reductions in weight and initial cost.

These considerations led IHC Holland to develop a pump for incorporation in the suction pipe. A cross-sectional view of this unit is given in Fig. 13.

The ISS (Integral Suction System) pump marks a departure from conventional practice, in which the pump and its bearings are mounted on a ladder and driven from above the waterline, in many cases by an electric motor, via a long shaft, or by a hydraulic motor. The most up to date method of driving submerged pumps employs non-synchronous motors.

The ISS pump is an electrically-driven unit in which pump, bearings and driving motor are contained in a compact housing. This is mounted in the suction pipe and requires no separate supporting construction.

The compactness and low weight of the unit are of particular importance.

The principal applications for the ISS pump lie in trailing dredgers, profile dredgers and stationary reclamation dredgers delivering into a pipeline.

For trailing dredgers, the compact nature of the unit is especially important from the points of view of resistance and vulnerability. Naturally, there is an application for the unit on cutter suction dredgers, albeit it will then usually be mounted on the existing ladder.

The construction of the ISS pump

The constructional details of the ISS pump are shown in Fig. 13. The unit comprises a housing with the electric motor at one end and the actual pump at the other. The aim was to arrive at a "pancake" motor with a diameter as close as possible to that of the pump and of minimum length. The pump housing is a reinforced, open frame of steel plate and incorporates an inner housing. The impeller is secured by means of a Ringspannset.

For pumps in the higher power range, the drive system will consist of a diesel engine in conjunction with an "electric shaft." The electric motor section has been developed in collaboration with Smit Slikkerveer.

The non-synchronous electric motor has pre-assembled laminations. The housing is filled with a special type of oil. The bearing arrangements, which are of a new design, consist of two large bearings and a small axial support bearing, making the whole extremely compact. The large axial roller bearing absorbs both radial and axial loads.

The section housing the motor incorporates a compensation vessel with means for regulating the pressure of the oil in accordance with the pressure of the outside water. The oil in the housing is kept at a pressure sligthly above that of the outside water. The oil for this purpose was chosen only after close consultation between IHC Holland, S.K.F. Nederland, Smit Slikkerveer and Shell Nederland Verkoop Mij., a necessary procedure in view of the fact that it is required to possess both insulating and lubricating properties at the operating temperatures encountered.

The pump and motor sections are separated by an "open" intermediate section, which is in contact with the surrounding water, and each has its own sealing arrangements. The water chamber of the pump is flushed by means of a gland pump.

Conditions of the use of a submerged dredgepump

Where a submerged pump is used, it is necessary to provide adequate protection against choking of the pump. This applies especially where small, fast-running pumps with their lower decisive vacuum are operated at relatively shallow suction depths, where the "pretension" provided by the water above the centreline of the pump is limited.

To prevent choking of the pump, refined, automatic process control apparatus – which also improves the solids yield – is available. Where a submerged pump is operated in series with a pump on board the dredger, the latter must also be provided with means to prevent choking.

The apparatus for this purpose will be dealt with in subsequent articles.

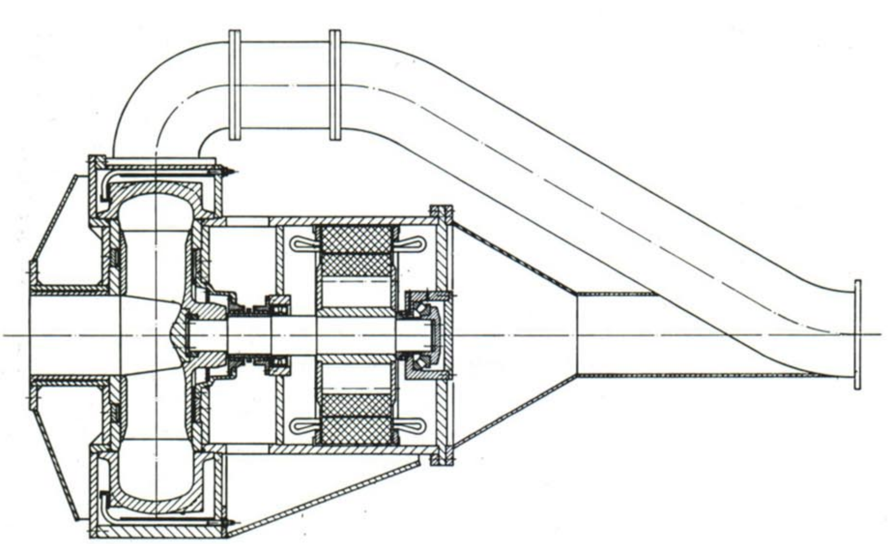


Fig. 13