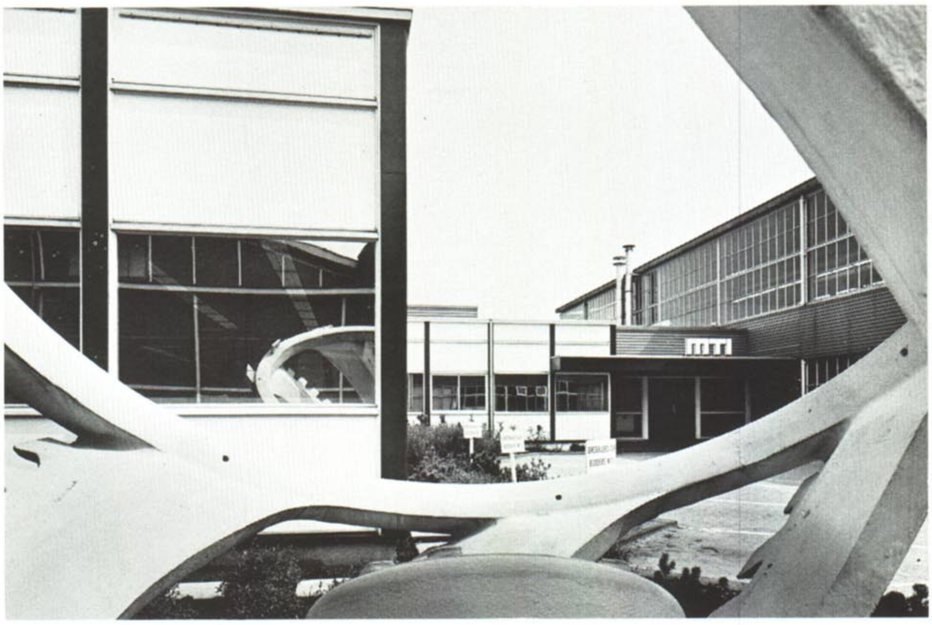
Centrifugal Dredgepumps 9

By
Ir. S. E. M. de Bree



This article is the ninth 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, 85, 86 and 87.

Introduction

The previous article dealt with the effect of using two or more pumps connected in series. The considerations were based on a multi-pump installation in the dredger.

We now come to the use of intermediate, or booster, stations in the delivery pipeline. The effect of introducing such a unit will not differ in principle from that of employing a multi-pump, series-connected installation in the vessel. After all, a booster station is in fact a pumping installation which operates in series with the vessel's pump or pumps. There are, however, significant problems associated with the use of a booster, e.g. its position in the delivery pipeline, the effect of this when working at alternately short and long delivery distances, and the matter of controlling the booster during the dredging process.

Excessive delivery distances

Generally speaking, there exists for a given pumping installation, transporting a given type of soil through a pipeline of steadily increasing length, a maximum distance over which all material offered to the suction inlet can be pumped. Until this is reached, the output of the installation is limited only by the pit supply and, in the case of coherent soil, by the output of the cutting device ahead of the suction inlet.

Once the maximum delivery distance is reached, other factors come into play. The maximum delivery distance corresponds to the lower limit of the working range of the pumping installation in the Q-H diagram (see Fig. 1). This generally coincides with the flowrate corresponding to the critical velocity of the mixture being transported through the pipeline.

If it is necessary to deliver over an excessive distance (see Fig. 2, working point A), steps must be taken to prevent sedimentation. A sub-critical situation exists, and there is thus a high risk of blockage of the pipeline, particularly if material with a medium-fine to coarse grain is being transported. The only means by which sub-critical operation with the pumping installation considered can be

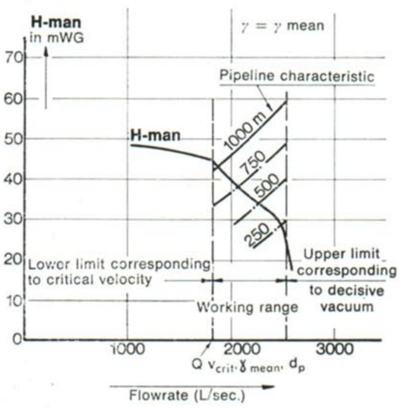


Fig. 1

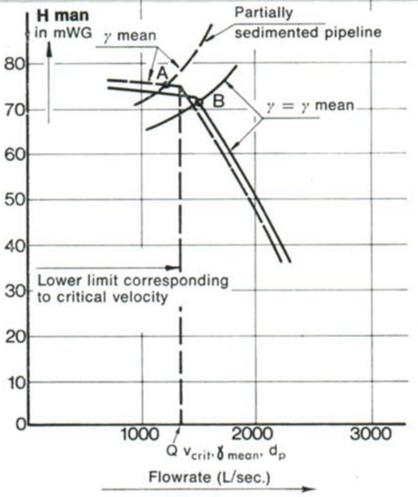


Fig. 2

prevented when working in soil of the type described is to reduce the specific gravity of the mixture by admitting plain water, thereby diluting the mixture to the point where the installation is operating just in the supercritical range (see Fig. 2, working point B). Lowering the specific gravity implies that the output, in terms of the quantity of solids transported, is lower than the figure attainable on the basis of the pit supply, or the attainable cutter output in the case of a dredger equipped with a cutting tool ahead of the suction inlet. This explains the reference to excessive delivery distances.

The extent to which the specific gravity can be lowered by the admission of water in order to gain delivery distance is limited (see line III in the output graph in Fig. 3). The reason for this is that the output falls sharply with increasing delivery distance. If it is only necessary to exceed the maximum delivery distance for a short period, the loss of output will often be accepted as inevitable. Where it is not a temporary expedient, an obvious solution lies in incorporating a booster station in the delivery pipeline.

It will be clear from the foregoing that delivery into a pipeline of more than the theoretical maximum length does not automatically necessitate the use of a booster station. The total duration of the job, the total output to be achieved at the excessive distance, the extent to which this is excessive and the difference in output with and without a booster all play a role in determining whether or not there is a need for one.

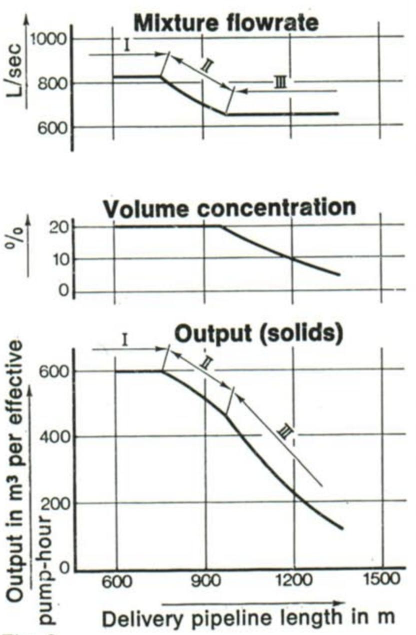


Fig. 3

In deciding this, it is necessary to include the comparative costs in relation to output and, moreover, to do so for those delivery distances of which the corresponding pipeline curves intersect the pump curves of the existing installation alone, i.e. without a booster, and the total pump curves of the combined installation, i.e. with a booster connected in series. In comparing costs, not only must the fixed costs and those relating to the operation of the booster be taken into account, but also the greater wear caused by the higher throughput of solid material per unit of time at a given delivery distance as a result of the presence of the booster.

In many instances, the delivery distance will prove to be so much greater than the maximum distance attainable when operating the installation that introducing one or more boosters in the delivery pipeline will be the sole means of arriving at a realistic output.

Types of booster

Boosters can be either of the land-based or floating type. Floating booster stations can be positioned in the floating pipeline or in the shore pipeline, according to the circumstances; in the latter case, the pipeline must happen to cross a canal, river or lake at a convenient point. It is usual to position a floating booster at the end of the floating pipeline. In many cases, a suitably modified suction dredger is used for the purpose.

Most land-based booster stations comprise a pump and driving mechanism mounted on a frame. Such frames are often designed in the form of a sledge; in a few cases, involving small-capacity installations, the unit is mobile.

It is common practice to house boosters of this type in a shelter, e.g. a Nissen hut, to protect them from the weather. Land boosters are sometimes mounted on a pontoon and used afloat.

Choosing a booster station

In choosing a booster for installation in the delivery pipeline, the characteristics of the pump installation in the dredger, with which it will operate, form the starting point. It is important that the two installations should be compatible, and five factors are of importance in this respect:

1) the characteristics of the pumps;
2) the suction and delivery pipeline connexions;
3) the passages of the two pumps;
4) the position of the booster in the delivery pipeline;
5) the control of the booster.

Re 1, 2 and 3

A good multi-pump installation is designed in such a manner that the pumps are fully matched to each other in terms of operating characteristics and also passages. Many installations of this type employ identical pumps.

If, for example, a booster is hired, it is almost certain that the pumping installation will differ from that in the dredger with which it is required to operate. It is then necessary to consider what modifications to the booster are necessary in order to match it to the dredger. These may, for instance, involve fitting a different impeller, or even replacing the pump in the booster.

Re 4

To prevent excessive terminal pressure, the dredger and the booster must be kept a certain distance apart. The aim will be to limit the pressure at the inlet of the booster – and thus the delivery or terminal pressure – in order to avoid the need for a special pump or specially-designed components such as special gate valves, line pipe, etc. This implies that the resistance, and thus the distance between dredger and booster, must at all times be sufficient to ensure a low inlet pressure and a reasonable terminal pressure.

At the same time, the inlet pressure must not be too low, since the booster pump must not be allowed to perform a suction function if the already irregular dredging process is not to

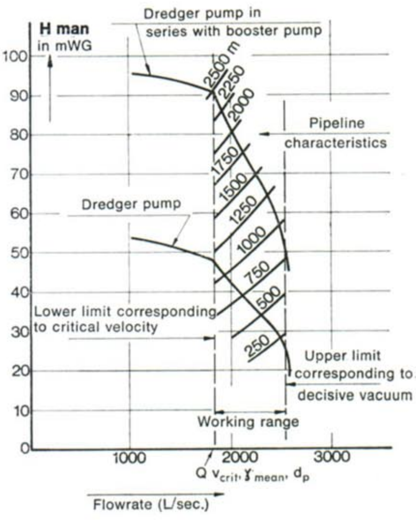


Fig. 4

be further complicated by water hammer, with all its deleterious consequences.

Re 5

As interruptions occur in the flow of mixture from the dredger to the booster, as a result of the suction process before and in the suction inlet, it is necessary to regulate the speed of the booster during the pumping process. If this were not done, a fall in the supply of mixture could lead to suctioning action by the booster and the occurrence of a vacuum in the pipeline before this pump. This, in turn, would result in accelerations in the mass of mixture before the pump and, if a serious shortage of mixture existed, to vacuous spaces, producing deceleration of the mixture in the pipeline beyond the pump. Upon the resumption of the normal flow, major accelerations would occur in the mixture before the booster, producing heavy impact between the mass and the steel components in areas where the flow is diverting, i.e. at branches, bends, in the booster pump itself, and so on. In addition, severe water hammer could occur at the point where the accelerating incoming flow and the decelerating outgoing flow meet.

When starting up or shutting down the complete installation, and pumping water, it is similarly necessary to regulate the speed of the booster, or to adopt a certain procedure, in order to prevent water hammer.

Possible consequences of impact and water hammer include the destruction of the delivery pipeline and booster installation, and also damage to the surrounding area as a result of the escape of the soil and water mixture A number of components, instruments and control devices for installation in the dredger and the booster are available to prevent disasters of this type. Where more than one booster is used in a delivery pipeline, positioning and control become more complicated.

Pump characteristics of a dredger-plus-booster installation

As earlier explained in connexion with the operation of two pumps in series (see *Ports & Dredging and Oil Report* No. 87), the characteristics of the existing dredgepump and the booster pump at identical flowrates must be summated in order to assess the installation as a whole. The new pump characteristic, or curve, thus obtained is imaginary and serves as an aid in calculating the theoretical output. But it constitutes a basic factor for determining the working points of the individual pumps and the position of the booster in the delivery pipeline.

With this imaginary pump curve it is possible to find, within the working range in the Q-H diagram, points of intersection with the total resistance curve (representing suction and delivery pipelines) corresponding to substantially greater delivery distances (see Fig. 4). Furthermore, where a booster is employed, it is seen that the points of intersection of the imaginary curve and the pipeline resistance curves correspond to a higher flowrate than is attainable over the same delivery distances with the dredger-mounted pump alone. It is thus clear that, provided the upper limit corresponding to the intersection of the curve representing the decisive vacuum of the suction pump and the suction line curve is not exceeded, the use of a booster affords a significantly higher mixture velocity.

The imaginary working points calculated from the intersections of the pump and pipeline curves may only be used to determine the mixture flowrate and solids output of the installation and the position of the booster station in the pipeline. The inlet pressure (and thus also the delivery pressure) of the booster pump is governed by the overall pipeline layout and the geodetic height, the delivery pressure of the pump in the dredger, and the layout and geodetic height of the section of pipeline linking the booster with the dredger.

Owing to losses in the pipeline before the booster, the delivery pressure of this unit is always lower than the total (imaginary) manometric head of the two pumps working in series.

The output curves of a dredger alone, with one booster and with two boosters are shown in Fig. 5 as a function of the delivery distance. All three curves fall into the three zones referred to in an earlier article.

In the first of these zones (I in Fig. 5), the factor which limits output is the decisive vacuum of the suction pump in the dredger. In this zone, the introduction of a booster in the delivery pipeline can never result in higher output, since it does not influence the decisive vacuum of the suction pump. It does, however, enable the

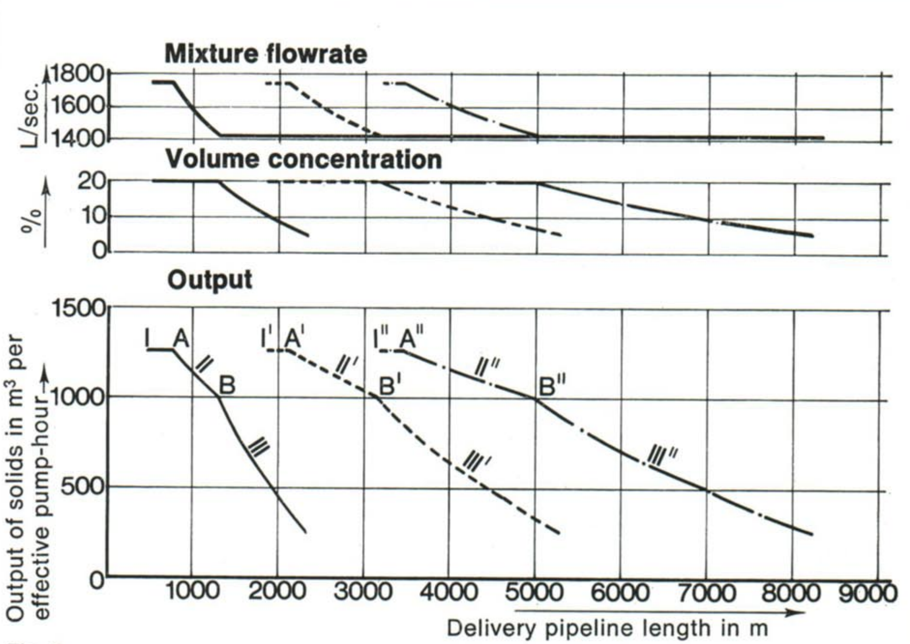


Fig. 5

same volume of material to be transported over a considerably greater distance (I′). The original bend A in the output curve of the dredger, operating alone, has moved to A′, corresponding to a greater delivery distance, as the result of introducing a booster. If two are used, a further shift to A″ (an even greater delivery distance) occurs.

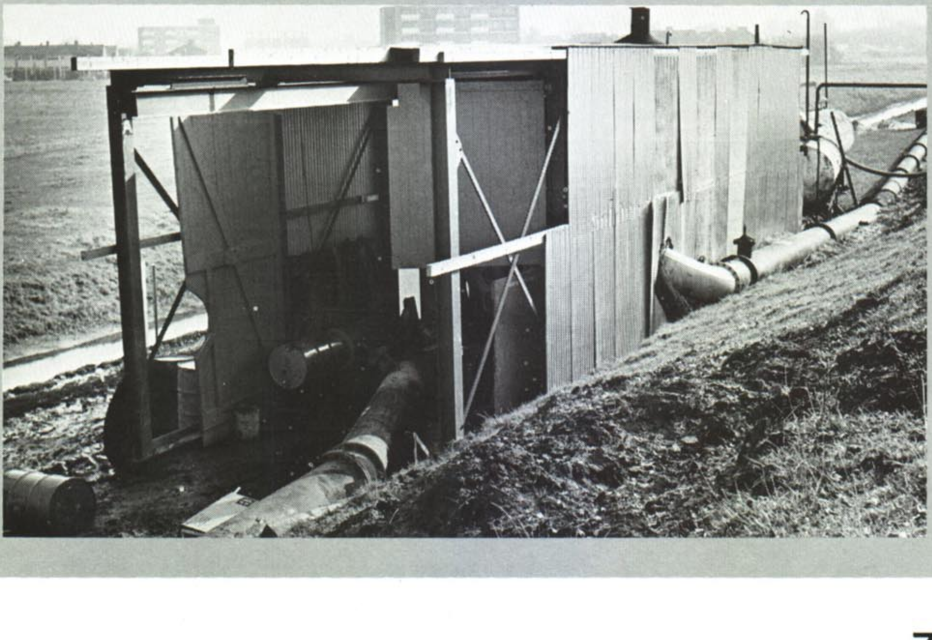
The second zone (II in Fig. 5) corresponds to the actual operating range of the installation. The introduction of a booster greatly enlarges the range and shifts it towards greater delivery distances (II′). The second bend in the output curve (B) also shifts to a greater delivery distance (B′). If two boosters are used, these effects are even more pronounced (distance II″ and bend B″).

In zone III′ of the output curve (Fig. 5) the output is limited by the total available manometric head of the two pumps in series, corresponding to the critical velocity of the mixture being pumped through the pipeline concerned. In this zone, one is in fact operating at excessive delivery distances, at which the mixture must be diluted by the admission of water in order to sustain a supercritical situation. In spite of the addition of a booster station, the output is now less than the maximum as determined by the pit supply and the output of the cutting device on the dredger. One method of achieving higher output (zone III″) at these delivery distances (zone III′) than is possible with one booster, is to employ two boosters. At even greater distances, it is the only way to achieve a realistic level of output.

Suction and delivery connexions

The dimensions of the connexions on the booster pump, on both the suction and delivery sides, must be such that no undue restriction occurs. This is necessary in order to prevent excessive local wear and a significant local pressure drop. As a rule, the bore of the pump inlet should be of the same, or slightly greater, diameter than the delivery pipeline. The bore on the delivery side should be slightly smaller than, or the same as, the pipeline diameter.

The matching on the suction side is of particular importance in this context. Too small a bore will result in excessive mixture velocities at the inlet and an unsatisfactory flow pattern in the impeller and the housing, the effect of which is to reduce the efficiency of the pump and increase wear on the components, particularly the rear impeller shield, by a significant or very significant margin. The shape of the impeller hub nose is of importance in this respect. In many cases this is positioned as near to the shaft side as possible in the interests of a large inlet; but from the point of view of the flow – and thus also wear – it is decidedly better for the nose to be more towards the suction side.



Naturally, the impeller inlet must then be more rounded axially and the blades be extended into the inlet, the latter to obviate loss of blade length as a result of the more axially rounded impeller inlet.

From the fabrication angle, however, this solution is more difficult, certainly with welded impellers and to a lesser extent with cast types; it also has consequences for the construction of the cover.

If the proposed booster and the installation in the dredger correspond in terms of the working range of the pumps, the diameter of the suction inlet of the booster pump will generally be slightly larger than the delivery pipeline in which it is to be positioned. The difference is then bridged with a flared adaptor, the taper angle of which should not exceed 5° or so in order to preserve a smooth flow and prevent undue turbulence and wear. If the diameter of the pump outlet is on the small side in relation to the delivery pipeline, a flared adaptor – which again should have a maximum angle of about 5° – should be inserted.

Passage of the booster pump

In terms of passage, the booster pump must conform to the requirements laid down for a multi-pump installation in a dredger (see *Ports & Dredging and Oil Report* No. 87), but with the proviso that the minimum passage of the booster will in most cases have to be slightly larger than those of the pumps in the dredger in order to minimize interruptions and downtime. It is clearly preferable that lumps of material or debris should be removed before they reach the dredgepump, or if necessary from it, than that they should reach the booster pump, with the added risk of partial or, if pumping continues, complete sedimentation in the pipeline linking dredger and booster.

This requirement with regard to the passage in the booster pump is, of course, largely governed by the mixture transported though the installation. The nature of the soil plays a decisive role.

If, for example, pure sand is being transported, the requirement can be ignored. If, on the other hand, a lot of debris is present – as is the case in maintenance dredging – the booster pump must have a considerably larger passage than the pumps in the dredger in order to allow angular and oblong objects which manage to get through the first pumps to pass without causing blockage.

As far as the impeller is concerned, the passage of a pump is determined by the minimum distance between two successive blades and the internal width. In the volute itself, the distance between the impeller and the cutwater is a decisive factor.

In an attempt to prevent very large pieces of material being drawn in where the passage of the booster pump is smaller than that of the dredgepump, it is common practice to fit rods or a grille to the suction inlet or to the cutter. This can result in a greater loss of output than the use of a booster pump with a larger passage.

The passage of a booster pump can also be enlarged by fitting an impeller with a smaller number of blades. This, however, alters the characteristic of the pump and with it the rate of delivery of the installation. The value of this method must be judged on the basis of a number of factors including the characteristics of the pumps in the installation.

Position of the booster in the pipeline

From the transport point of view, the position of the booster in the delivery pipeline is not critical, provided that the inlet pressure remains adequate and the delivery pressure does not become excessive.

The inlet pressure must be above atmospheric under all circumstances, that is to say, when pumping water containing little soil, or a mixture with a high specific gravity; when pumping the finest or coarsest material on the site; and when delivering over the shortest or longest distance.

The existence of a vacuum at the inlet of the booster pump can result in an irregular process or, worse still, water hammer with all its consequences.

If the resistance, including the geodetic head, in the suction and delivery pipes up to the inlet of the booster is too great, a vacuum will be produced at this point. The situation which then exists is reproduced in Fig. 6. In this, the pump in the dredger is assumed to be driven by a diesel engine, and the booster pump by non-synchronous electric motors fed from the mains supply.

At flowrate Q_A, the pipeline resistance curve intersects the two pump curves at the imaginary working point A. The total resistance curve of the suction and delivery pipes up to the booster is also shown in the diagram. At flowrate Q_A, the manometric head corresponding to point A′ is required to transport the mixture to the booster. The manometric head provided by the pump in the dredger is less than this (point A″) and therefore the mixture is at a negative pressure – shown by line A′-A″ in the diagram – when it reaches the booster. This will then commence to suction. To continue pumping with the installation, it is necessary to reduce the flowrate of the mixture.

Among the methods of achieving this is to reduce the diameter of the booster impeller and to run the pump at the same speed (the same effect could be obtained by reducing the pump speed if a variable-speed drive system were employed). The flowrate has to be reduced sufficiently to transform the vacuum at the booster into a positive pressure. The effect of this, however, is to reduce the total available manometric head. The new imaginary point of intersection of the pump and pipeline curves B, now shifts to a lower flowrate, Q_B. The manometric head generated by the pump in the dredger (B′) is now greater than the head required to transport the mixture to the inlet of the booster pump (B″). Line B′-B″ represents the positive pressure now existing at the booster inlet.

The same effects can be obtained by another method, although this is only feasible where the booster pump is driven by a diesel engine. This involves reducing the supply of fuel to the engine. Very simply achieved, this is less critical, affords a reserve of pressure to deal with lumps of material, and can more easily be adapted to changing delivery distances. The situation resulting from throttling down the engine is reproduced in Fig. 7.

If one is already in the vicinity of the lower limit of the working range (the critical velocity), it is, moreover, necessary to reduce the pipeline resistance by lowering the specific gravity of the mixture; this is achieved by admitting more water to the system. Reducing the flowrate diminishes output, and lowering the specific gravity does so to an even greater degree (see Fig. 3). Therefore positioning the booster too far from the dredger means a loss of output at shorter delivery distances.

A booster inlet pressure of approximately 1 kgf/cm² is generally regarded as the minimum. In choosing the position of the booster, care must be taken to ensure that the pressure does not become too great under conditions which differ from those to which the minimum value applies. The maximum permissible pressure in and after the booster pump must be borne in mind in this context.

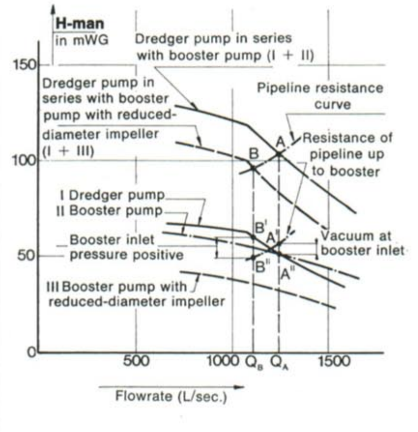


Fig. 6

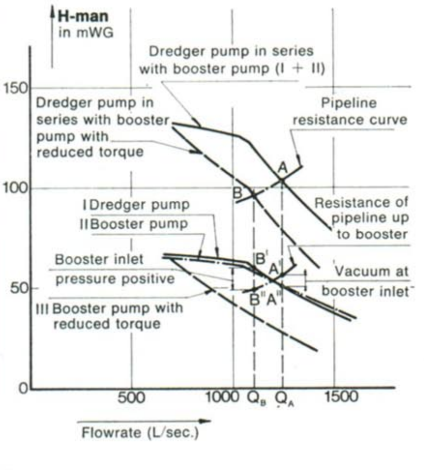
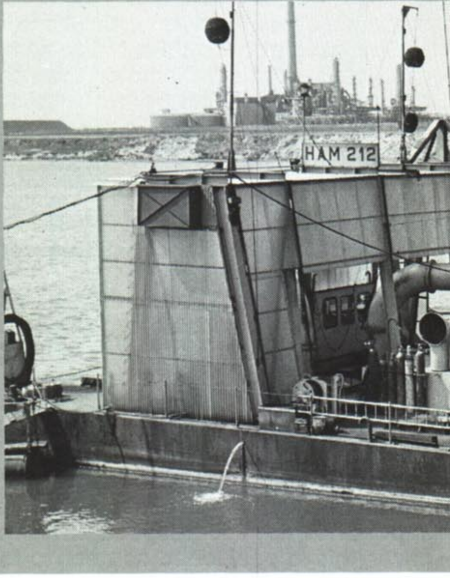


Fig. 7



Generally speaking, the maximum design pressure for these pumps is of the order of 10-14 kgf/cm². If the total pressure were to exceed this level, all manner of special constructions, e.g. reinforced pump housings and covers, highly unconventional seals, special gate valves, etc. would be required. Furthermore, at the higher delivery pressures, the removal of components for repair or replacement would coincide with a greater residual wall thickness.

In determining the position of the booster, the decisive factor is the pressure drop in the pipeline linking dredger and booster. This implies that in general the minimum distance between them is governed by the shortest total distance over which the coarsest material encountered has to be transported at the highest attainable mixture s.g. As explained in a previous article (see *Ports & Dredging and Oil Report* No. 82), the geodetic head plays a role in the overall pressure drop.

The distance between the dredger and the booster may be less than the minimum referred to. The inlet and delivery pressures of the booster pump will then rise proportionally with the decrease in the total resistance of the pipeline linking dredger and booster and the decrease in geodetic head between dredger and booster obtained by placing the booster close to the dredger. A distance less than the minimum may be employed provided that this does not lead to the pressures in and after the booster pump exceeding the maximum value for the installation concerned.

As stated earlier, it is usually difficult to arrive at a booster station which meets the first three criteria of compatibility with the pump in the dredger, namely pump characteristics, suction and delivery connexions, and passages.

For a job which spans a number of years and requires one or more boosters, it is usual to have suitable units built.

On most jobs, however, booster capacity is needed only for a relatively short period. In terms of the quantities of mixture to be pumped, dredgers and boosters are usually designed for a particular working range and for mean soil conditions, i.e. average types of soil. Corresponding to these average soil types and these quantities are mean suction and delivery pipe diameters, between which, in turn, a relatively constant relationship exists. In terms of passage at the inlet and in the impeller, the constructional design of the pump is dimensioned principally on the basis of the suction pipe diameter (d_z).

If the suction and delivery diameters of the dredger and booster pumps differ appreciably – say, by more than 100 mm – it will usually be necessary to modify the booster pump(s). Available booster units often prove to be considerably too small or considerably too large.

Undersize booster pump

If an available booster unit proves to be too small, the pump can be fitted with an impeller with a larger bore (a suitably modified cover being fitted also). This, however, is seldom sufficient. As stated, the characteristic of the booster pump must be matched to that of the pump in the dredger.

In most cases the nominal full-torque point of an undersize booster pump will correspond to a lower flowrate than that of the dredger-mounted pump (see Fig. 8). To overcome this problem, it is necessary to reduce the outlet diameter of the booster pump impeller. As the outlet diameter has to be reduced and the inlet diameter enlarged, the blade length will be considerably reduced, and this can result in a significant loss of pump efficiency. To obtain an adequate blade length, it is necessary to fabricate a new impeller having blades which are fairly flat and have a substantial overlap (see Fig. 9).

With the larger bore and smaller outlet diameter, the passage of the pump in terms of the bore and the space between the impeller and the volute is more in keeping with that of the pump in the dredger. But now the flatter blades impede the free passage (see Fig. 9). The final answer in many cases lies in a compromise between reducing the diameter of the impeller and maintaining an adequate passage.

It will be clear that modifications of this sort can be realized only within a limited range. If reduction of the impeller diameter is carried too far, the efficiency of the pump declines and the booster has little effect. If the blades are too flat, the bore is so small that it is repeatedly necessary to stop the pump to remove stones and debris with the same end result: little extra output and only then at

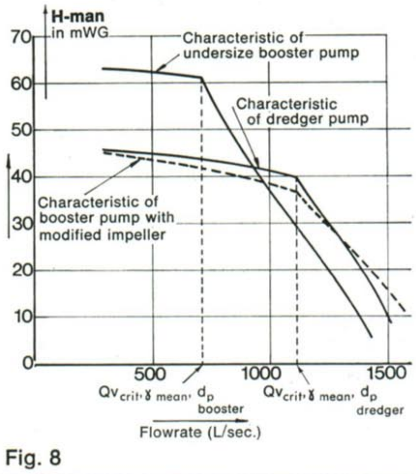


Fig. 8

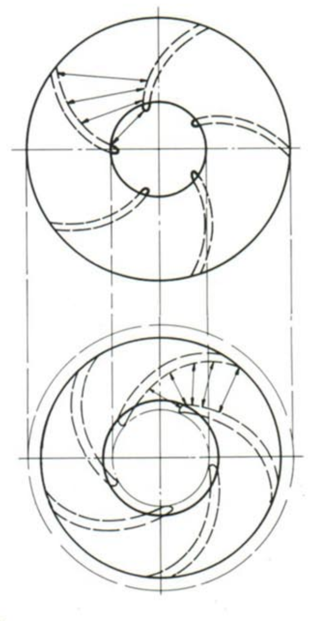


Fig. 9

relatively high cost per unit of time. The only dimension of the impeller still to be matched to the higher flowrate is the width. Not modifying this, results in appreciably higher wear, notably on the shields at the back of the blades on the outlet side. This can be combatted by using impellers of more wear resistant material. If this is not sufficient, another, wider, pump must be employed.

Oversize booster pump

If an oversize booster is connected in series to the dredger, the risk that it will act as a suction pump is considerably greater than with an undersize unit. The oversize booster will have been designed for a substantially higher nominal flowrate than the dredger pump, with the result that the booster will be operated in the governor range, in which the power of the prime mover is less than fully utilized. Because the dredging process is irregular, by reason of the fluctuation in the supply of soil, the booster pump will react to interruptions in the regular flow of mixture by attempting to absorb more power and restore the flow by suction. The only way in which this can be prevented is to throttle down the engine.

The situation which then exists is shown schematically in Fig. 10. The tolerance of the pipeline curves intersects the total curve of the diesel-driven dredgepump and booster pump (which, it will be remembered, is obtained by summating the individual curves) at imaginary working points A and B. The corresponding actual working point of the dredgepump lies between points A′ and B′, and that of the booster pump between C′ and D′. It is emphasized that the working points in Fig. 10 afford no indication of the delivery pressures for which the pumps must be designed. Fig. 10 shows that the working range of the dredger pump lies within the full fuel flow range of the engine which powers it. The engine of the (oversize) booster, however, is operating in the governor range, which implies that its output is not being fully utilized.

Throttling down the booster engine produces a new curve for the pump which it drives. This is represented by a broken line in Fig. 10. The tolerance of the pipeline resistance curve intersects the new (again summated) curve of the two pumps in series at points E and F. The working range of the booster now lies in a more stable area.

If it is desired to utilize the full power of the booster engine in order to deliver over a greater distance, the booster pump must be replaced by one with a larger impeller. The effect of this is to shift the nominal full-torque point of the pump curve to a smaller flowrate, thereby increasing the manometric head of the booster and thus the manometric head of the installation as a whole.

The situation which now exists is reproduced in Fig. 11. As in Fig. 10, the tolerance of the pipeline resistance curve intersects the summated, imaginary curve representing the dredger and booster pump at points A and B.

The corresponding working points of the individual pumps lie between A′ and B′ (dredger pump) and C′ and D′ (booster pump). By installing a larger pump in the booster, a new imaginary curve is obtained. This is shown by a broken line in Fig. 11. The tolerance of the pipeline resistance curve intersects this new imaginary pump curve at points E and F, which lie in the full fuel flow range of the prime movers. As the points of intersection correspond to a higher flowrate, it can be seen that the modification will also improve the output of the installation.

It should be noted that the gap between the dredger and the booster now requires to be reduced, since at the shortest delivery distance the booster now contributes more to the transport of the mixture over the total delivery distance and geodetic head than does the dredger.

The optimum position of the booster in the delivery pipeline is usually determined with the aid of a diagram based on the pump curves and the pressure pattern, including the geodetic head, throughout the delivery pipeline. This will be explained with the aid of examples in the following article.

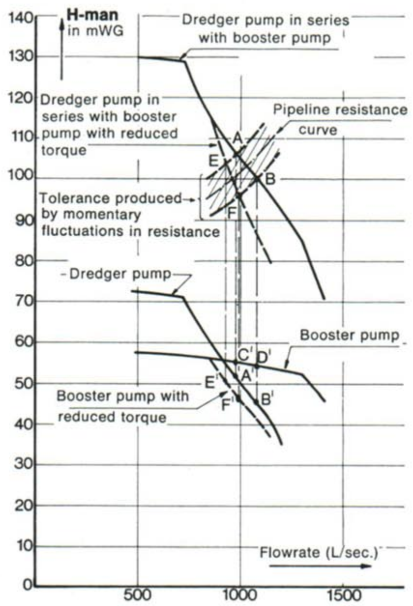


Fig. 10

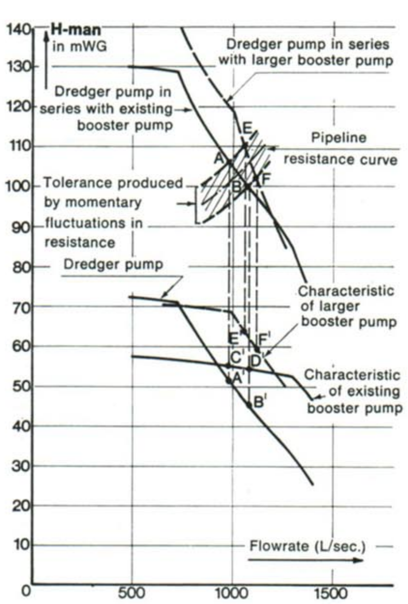


Fig. 11