Centrifugal Dredgepumps

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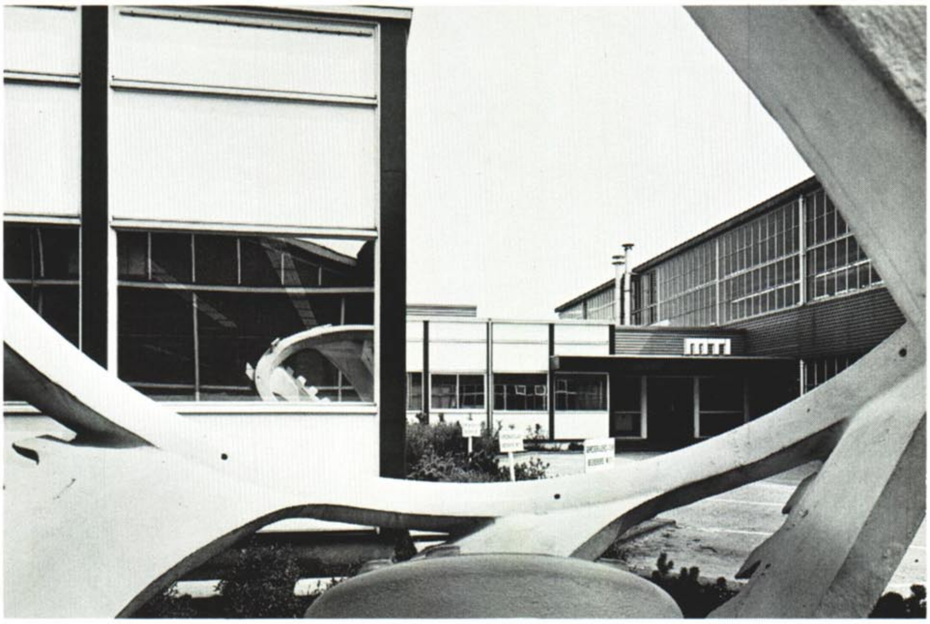

As stated in a previous article in this series, the most common prime mover in dredgepump installations is the diesel engine.

The characteristic of the diesel engine is repeated in Fig. 1. In this we distinguish between:

- the governor range, within which the engine load is below the nominal full torque point and the speed in principle remains constant when the load decreases.

  In this range, the speed in fact increases slightly as the load drops. The magnitude of the increase depends upon the type of governor. Where the actual characteristic of the engine concerned is not known in detail, the speed in the governor range is assumed to be constant.

- the nominal full torque point (A). This is the point at which the nominal load and the nominal running speed coincide. It is the design and specification point of the engine.

- the full fuel flow range. This is the range in which the engine operates when more power is demanded than is can nominally deliver. When this situation is reached, the engine speed diminishes.

The full fuel flow range is also referred to as the constant torque

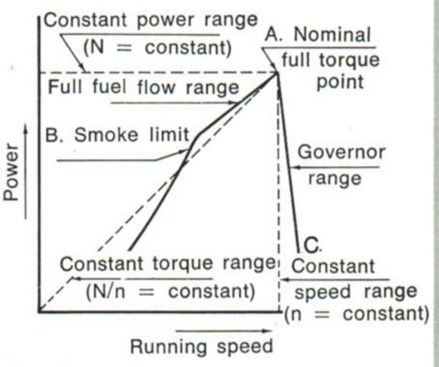

Fig. 1

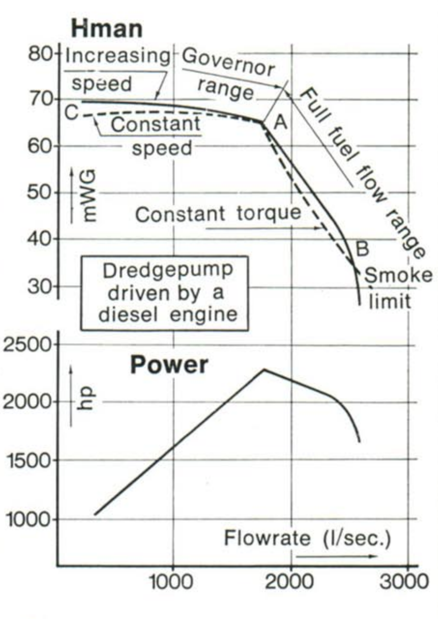

Fig. 2

range, because here the torque delivered by the engine remains virtually constant.

Where the correct characteristic of a given engine is not known, it is assumed that the torque curve in the full fuel flow range is constant.

- the smoke limit (B), the lower extremity of the full fuel flow range, at which the torque falls away sharply.

An engine should not be operated below the smoke limit, where combustion is incomplete and smoke and pollution are produced. The risk of damage to an engine which continues to operate below this limit is very great.

The characteristic of a dredgepump driven by a diesel engine is reproduced in Fig. 2. Relating to the location of the working points of a dredgepump with diesel direct drive two possible situations can be distinguished (see Fig. 3), namely:

a) the intersection of the pump and pipeline characteristics (point D), the working point, lies within the full fuel flow range (line AB), in which the torque is virtually constant;

b) the intersection of the pump and pipeline characteristics (point E), the working point, lies within the so-called governor range (line AC), in which the speed is virtually constant.

Working points within the full fuel flow range
The situation in which the points of intersection of the pump and pipeline characteristics lie within the full fuel flow range is reproduced in Fig. 4. This is based on a given dredger in a given operating situation. Depending upon the type of soil, the pipeline length and the mean attainable specific gravity γ_{mean} of the mixture, the mean working point is found from the intersection of the relevant pump and pipeline resistance curves.

Assuming that, when delivering through a normal pipeline, the resistance curve and the pump curve for the mean attainable mixture s.g. γ_{mean} intersect at point A, the flowrate and the pressure head can be represented by Q_A and H_A respectively. If the pipeline becomes partially blocked as a result, say, of momentary sedimentation caused by the local presence of coarser particles, or by large lumps of material, the resistance curve can be represented by the broken line which intersects the constant torque curve of the pump at point B. The corresponding flowrate and head will be Q_B and H_B. If mixture of a higher specific gravity is temporarily pumped, we arrive at point C, with which flowrate Q_C and head H_C correspond.

If a coarser type of soil is pumped, while the mixture s.g. remains the same, we arrive at point D, with which flowrate Q_D and pressure head H_D correspond.

Q_B, Q_C and Q_D are of some smaller magnitude than Q_A, while H_B, H_C and H_D are of significantly greater magnitude than H_A.

It is thus clear that, when operating within the full fuel flow range, the mixture velocity varies as a result of changes in the pipeline resistance caused by partial blockage, or changes in the type of soil and/or the mixture s.g., but that the variation will be accompanied by a relatively large change in pressure. We are now in the stable operating range of the dredgepump installation, and therefore points of intersection with the pipeline characteristics should lie within this range.

The design point of a dredgepump installation is the so-called nominal full torque point. For a given layout and under given operating conditions, this is based on the mean attainable mixture s.g. for the type of soil involved and the maximum pipeline length required. At the mean attainable mixture s.g., the characteristic of the longest pipeline — which will thus have the greatest resistance — should intersect the pump curve just below the nominal full torque point. Just below it, because the mean attainable mixture s.g. formed the starting point. The portion of the steep characteristic in the full fuel flow range, up to the nominal full torque point, must be kept in reserve to meet momentary surges in resistance caused by fluctuations about the mean situation. The critical flowrate in the pipeline at the mean attainable mixture s.g. γ_{mean} will constitute the left-hand flowrate limit of the working range of the pump curve in the Q-H diagram.

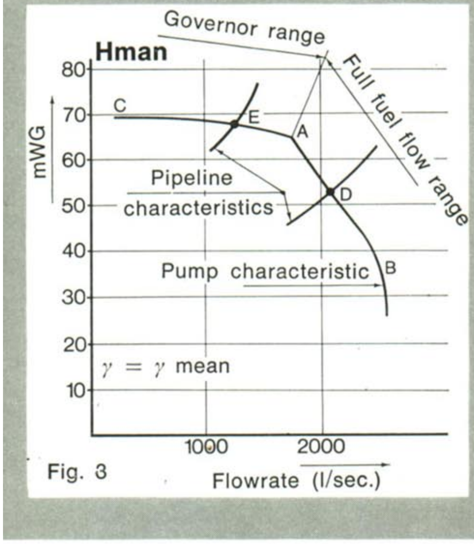

Fig. 3

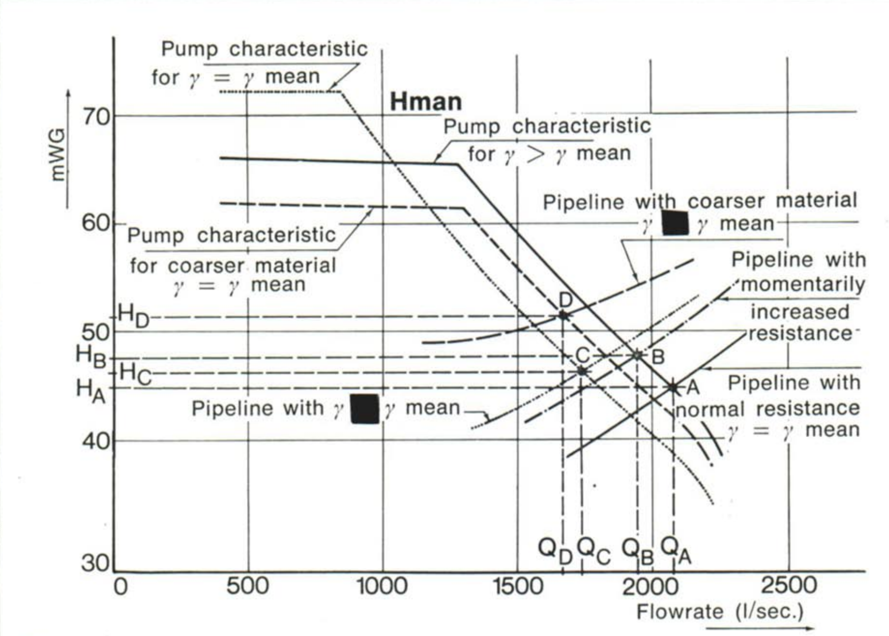

Fig. 4

When designing a dredgepump to handle one specific type of soil, the aim should be to match as closely as possible the flowrate at the full torque point and the flowrate corresponding to the critical velocity of the material to be transported (see Fig. 5). Most installations, however, are required to handle not one, but a whole range of different types of soil, and to meet this it is necessary to strike a compromise in terms of design point. As this compromise can only be described after the whole subject of the characteristic of a dredgepump has been dealt with, it will perforce have to await a later opportunity.

If the pipeline is of less than the maximum length, the working point in the full fuel flow range moves in the direction of greater flowrates. The shorter the pipeline, the lower will be the working point in the full fuel flow range. The speed of the pump also undergoes a downward shift, and there is a risk at a given moment it will become so low that the smoke limit is reached and the engine "stalls."

A solution lies in fitting an impeller of smaller diameter (see Fig. 6) or one with less blades (see Fig. 7). The effect of this is to move the working point from A to B; this coincides with a higher pump speed. By allowing the speed of the engine to rise, either of these measures enables its rated output to be better utilized. The torque remains virtually constant, thus increasing the power absorbed by the pump. The flowrate also increases, as does the pressure head, and as long as the limit of the decisive vacuum of the dredgepump installation and/or the limit of the pit supply is not reached, the output of solids will rise.

As stated in the fifth article in this series, which appeared in issue 84 of *Ports and Dredging & Oil Report,* the diameter of the impeller can be reduced by machining or flame-cutting the blades. However, from the point of view of flow technology, which in this context is synonymous with efficiency, it is preferable to construct and fit a new impeller with blades of suitable shape.

The influence of varying numbers of impeller blades on the pump characteristics is shown in Fig. 8. This relates to a diesel-driven pump fitted with impellers having 5, 4 and 3 blades respectively.

Fitting an impeller with a smaller number of blades results in a smaller pressure head. As the number of blades decreases, the curves in the governor range become somewhat steeper, while the flowrate decreases. Fitting an impeller with a smaller number of blades causes the nominal full torque point to move towards larger flowrates and lower pressure heads.

The maximum efficiency of a soundly constructed dredgepump fitted with a well-designed 3- or 4-bladed impeller need not differ appreciably from that of a dredgepump with a 5-bladed impeller. One advantage of a smaller number of blades is that the passage is somewhat larger, with the result that the pump is less susceptible to blockage by debris and large pieces of stone. As mentioned in the first of

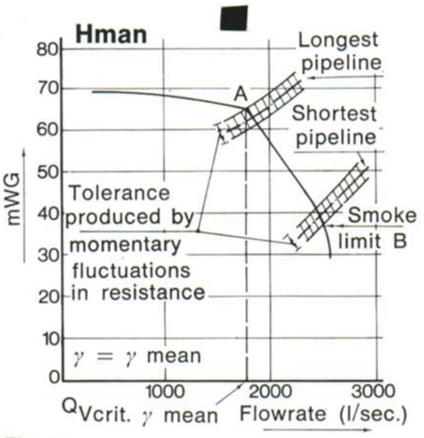

Fig. 5

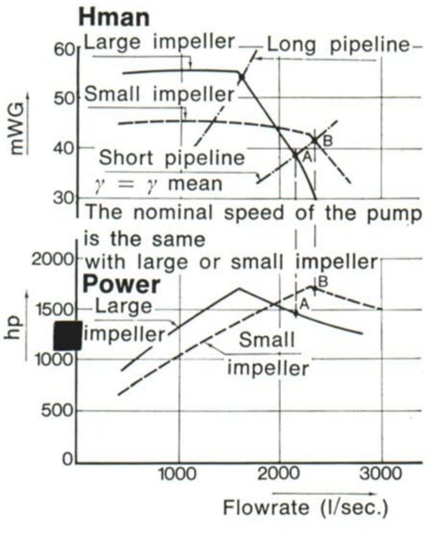

Fig. 6

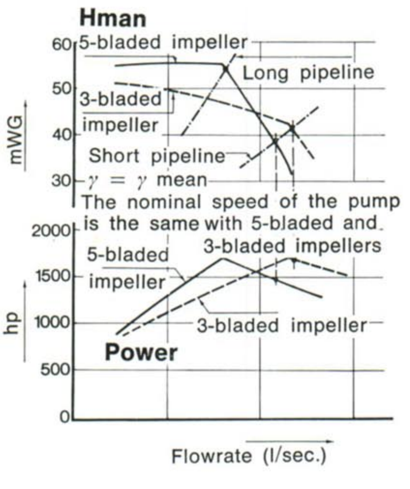

Fig. 7

these articles (issue 77 of *Ports and Dredging)*, an aperture of one-third of the impeller inlet diameter is the accepted minimum. In view of this, it is seldom feasible to exceed five blades, and this explains why 5-bladed impellers are the most common.

The reduction in the pressure of a pump with a 4-bladed impeller, compared with a 5-bladed impeller, is in most cases too small to have any practical consequences. Moreover, in a diesel-direct system, the use of a 4-bladed impeller can result in difficulty: the even number of blades, in conjunction with an even number of engine cylinders, can give rise to undesirable resonances. Where a diesel-driven dredgepump supplied with a 5-bladed impeller is subsequently fitted with a 4-bladed type, due regard must be paid to this hazard.

The upshot of this situation is that most dredgepumps are in practice equipped with a 5-bladed impeller, while in many cases a 3 bladed unit is also available.

As the quantity of the soil to be dealt with — the so-called pit supply — is constantly changing, the situation during dredging operations is seldom static.

The variation in the working points which results from changes in the pit supply and thus in the mixture s.g. is reflected in Fig. 9. This shows the pump curves relating to mixtures of various specific gravities and the pipeline curves relating to a specific layout and a given type of soil. The points of intersection of the pump and pipeline characteristics are in all cases within the stable operating range, namely the full fuel flow range. In this range, variations in the mixture flowrate produce fairly large fluctuations in pressure. The tolerance with respect to fluctuations in the pipeline resistance is indicated around the resistance lines. From the intersections of the limits of the areas of tolerance of the resistance lines and the pump curve, other lines — of which there is one for each mixture s.g. — emerge; somewhere along these lies the working point of the pump.

By joining all the upper and lower limits of the lines representing the various mixtures s.g.'s, we obtain a banana-shaped working range for the dredgepump installation with the given pipeline layout and soil type. Within this range, the working point moves under the influence of changes in the pit supply, i.e. changes in the mixture s.g. A characteristic feature of the diagram of fig. 9 is that variations in the flowrate produced by changes in the specific gravity are accompanied by relatively large variations in pressure.

Working points within the governor range

Fig. 10 again shows the pump and pipeline characteristics relating to a diesel-driven dredgepump. This diagram assumes an average situation in terms of soil type and pipeline, and a specific gravity corresponding to the mean attainable s.g. γ_{mean}.

Under normal circumstances, the pipeline resistance curve intersects

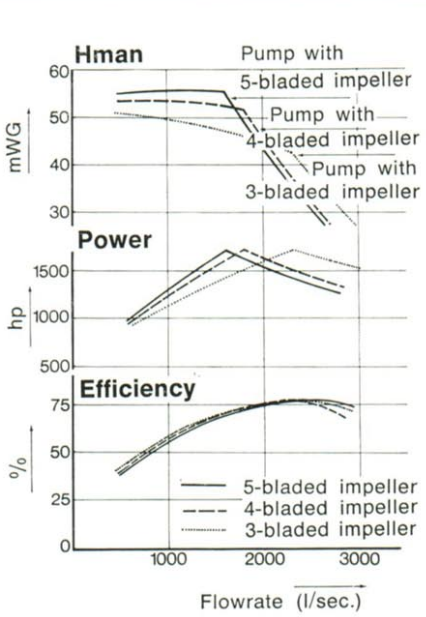

Fig. 8

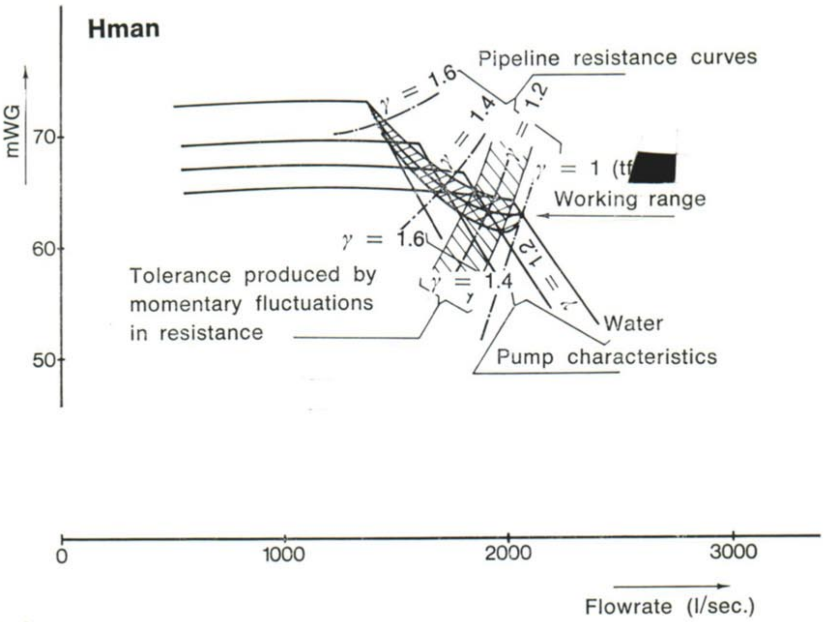

Fig. 9

the pump curve in the governor range, i.e. at point A. The corresponding flowrate and pressure head at this point are Q_A and H_A respectively. If the resistance in the pipeline were to increase as a result, say, of momentary sedimentation, the pipeline resistance curve would intersect the pump curve corresponding to the constant speed of the pump at point B, which implies that the flowrate and the pressure head would then become Q_B and H_B. The pressures H_A and H_B are virtually identical, but flowrate Q_B is considerably smaller than flowrate Q_A. This means that the velocity of the mixture in the pipeline has fallen sharply. The reduction in velocity increases the danger of the largest pieces of stone and the coarsest particles of gravel settling in the pipeline, reducing the effective bore and so increasing the resistance. This, in turn, produces a further drop in the flowrate, and if unchecked, could lead to complete blockage of the pipeline. This may be a very rapid process! It is thus clear that variations in the flowrate introduced by e.g. momentary sedimentation under otherwise average conditions already imply a serious threat of sedimentation.

Such a situation, however, can be avoided by timely measures such as raising the suction pipe slightly, or reducing the speed of the hauling winch of a cutter suction dredger, so that plain water or a weaker mixture is drawn in to flush the pipeline. Many installations embody a controllable valve on the suction pipe, via which water can be admitted for this purpose.

As we are all aware, the constant changes in the quantity of the soil which we are called upon to deal with mean that there is no such thing as a stationary situation in dredging. If the pump curves of a dredgepump installation and the pipeline curves for a specific layout are drawn for a given type of soil and for various mixture s.g.'s, we obtain a diagram such as appears in Fig. 11. The situation chosen is such that the points of intersection of the pump and pipeline curves fall within the governor range.

If we again proceed from a tolerance area around the pipeline resistance curve, we find, as in the previous section, a line for each mixture s.g., somewhere along which the working point lies. Joining the upper and lower limits of these lines again produces an area valid for the given pipeline layout and soil type, within which the working point of the pumping installation moves under the influence of variations in the specific gravity of the mixture.

However, we find that, with the same variation in mixture s.g., the working range is much wider than that pertaining to the full fuel flow range when operating here in similar way (compare Figs. 9 and 11). The reason is that we are now working in the flat section of the pump curve, the governor range. The movement of the working points in response to variations in the specific gravity now produces significant changes in the flowrate. The pressure displays little variation.

Once the working point is found to be in the governor range, another

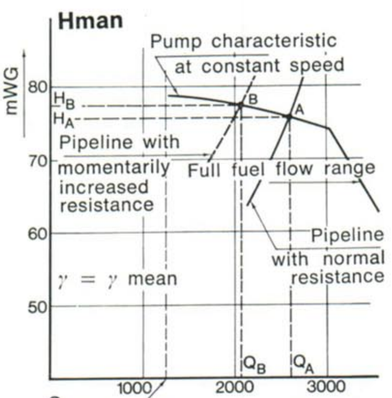

Fig. 10

modus operandi which leads back to stable pump behaviour can be employed. In describing this, we shall proceed from the position described above and illustrated in Fig. 10.

In this situation, the engine throttle is eased back sufficiently to produce a reduced torque curve which intersects the pipeline curves in the diagram. Reducing the volume of fuel injected results in the engine delivering constant torque, but of a smaller magnitude than the nominal torque at full fuel volume. The result is a new pump characteristic. The reduced torque point H replaces the nominal full torque point G. The pump curve bends at H and the existing portion of the former governor curve (now, however, from point H to the no-load point) functions as the governor curve for the new situation, while the full fuel flow range is replaced by the reduced fuel flow range. As a result, the constant torque portion of the pump curve will move to the left, i.e. towards lower flowrates.

From the curve thus produced it could appear that the pump was being driven by a smaller diesel engine with the same nominal running speed and a lower nominal output — namely the output corresponding to point H. This is revealed in Fig. 12. The line which passes through points E and F is the pump curve pertaining to the reduced torque of the engine in the throttled-down situation. The point of intersection of the maximum speed pump curve and the throttled-down constant torque curve should be just before point B. The working point — the intersection of the normal pipeline curve and the throttled-down pump curve — will now lie at point F.

Should momentary sedimentation occur, increasing the resistance in the pipeline, the working point will shift to E.

The working point is now in a more stable region and a reserve of pressure head is available. In this situation, the flowrate is influenced to a much smaller extent by momentary fluctuations in the pipeline resistance. The risk of sudden sedimentation is therefore less. The attainable flowrate is lower than in the situation previously described. However, the stability thus ensured enables the same or even a greater output of solids to be achieved than is possible by operating in the governor range with an unthrottled engine.

Nominal full torque point

The design point of the installation is the nominal full torque point. This is so chosen that the flowrate corresponding to the nominal full torque point is virtually identical to the flowrate corresponding to the critical velocity of the mixture of water and the type of soil concerned at the mean attainable specific gravity under the operating conditions. In most cases the pump will not be operated in the governor range, which in the circumstances described is the area of sub-critical flowrates at which sedimentation occurs in the pipeline.

There may, however, be occasions on which it is necessary to operate in the governor range — for example, if the pipeline is longer than had been anticipated for the type of soil to be transported. This can result from enforced modification of the layout to meet practical requirements. A similar situation can arise if the pit supply is greater than had been expected and the pipeline is of the maximum length. The specific gravity will then be higher than had been forecast. There are also occasions on which the risk of sub-critical operation is deliberately accepted, e.g. as a temporary expedient when pumping to the farthest point of the reclamation area.

Sub-critical operation implies going below the flowrate corresponding to the critical velocity and the mean attainable specific gravity in the type of soil envisaged — in other words, the flowrate corresponding to the nominal full torque point. Where this situation arises, the choice lies between working with a partially sedimented pipeline, and reducing the specific gravity of the mixture somewhat, thereby lowering the resistance in the pipeline and also the critical velocity. This situation is reproduced in Fig. 13.

At an attainable mixture s.g. γ_{mean} and with a long pipeline, the pump and pipeline curves will then intersect at point A, which is within the governor range of the pump and corresponds to a flowrate lower than the critical figure for the material being transported. The pipeline will accordingly be partially sedimented, and the risk of total blockage may be very great. Just how great this is depends in part on the nature of the pumped soil. Generally speaking, fine soils carry less risk of sedimentation than coarser types.

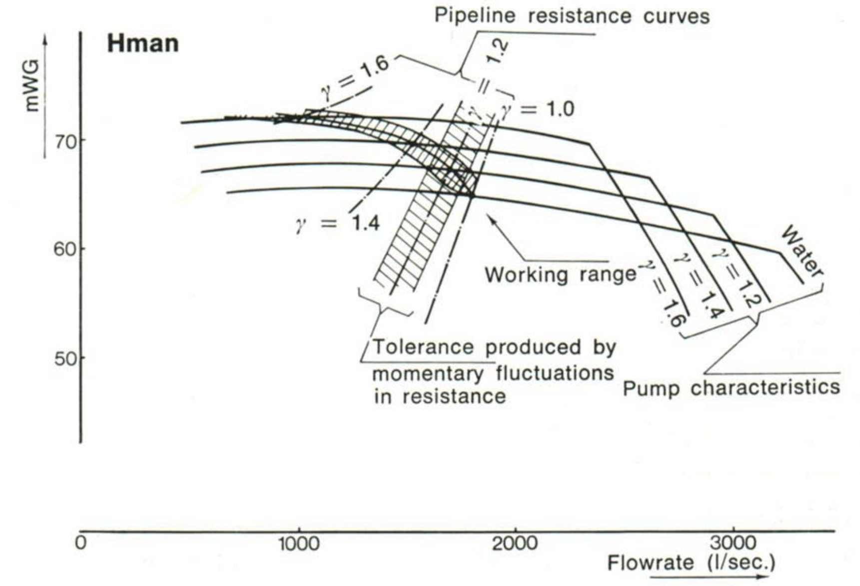

Fig. 11

Lowering the specific gravity of the mixture — by reducing the speed of the hauling winch on a cutter suction dredger, or raising the suction pipe, or admitting water to the suction pipe via a controllable valve on this pipe — will reduce the resistance in the pipeline, enabling the working point to move to a position corresponding to a higher flowrate which is in the supercritical area (point B in the full fuel flow range).

Choice of pumping installation

As stated earlier, there is another facet which plays a very important role in the design of a pumping installation. In most cases, installations of this sort are not designed to deal with one specific type of soil. Often the type of soil envisaged at the design stage proves to differ from that encountered in practice. Moreover, the contractor desires a tool which can deal with a wide range of soils, ideally everything from clay to stone. This, of course, is not feasible, but the designer must nevertheless think in terms of the widest possible range. Needless to say, the installation must be matched to the soil types and operating conditions most likely to be encountered.

The related investment and the compatibility of the pumping installation with all other parts of the vessel's dredging installation — e.g. the cutter installation in the case of a cutter suction dredger — also play a major role. And because there will always be a number of conflicting desires and demands, it is in all cases necessary to accept a compromise. The factors which determine the choice of a dredgepump installation and the design criteria involved will form the subject of a future article. It will be clear from the foregoing that the majority of dredgepump installations are designed to handle coarse sand or gravel. As a result, the working points lie in the governor range when such installations are used to transport fine-grain material over long distances. Experience has shown that, with due care, it is possible to transport soil having a critical flowrate substantially below that of the type of soil for which the installation was designed, while still operating within the constant speed range. This, however, depends upon the fineness of the grain and the steepness of the grain distribution curve relating to the material to be transported, the degree of fluctuation in the nature of the material and the position of the pump and pipeline curves. Broadly speaking, it can be achieved with soils of such fine grain that their critical velocity is low or very low. In all other circumstances it is preferable to operate with the engine throttled down, because this produces a stable operating area in which there is no risk of blockage of the pipeline.

If a soil whose critical velocity is substantially higher than that of the design type is to be pumped, the resistance losses in the pipeline will be greater. The operating situation will then be similar to that indicated in Fig. 13.

Water should then be admitted to the pipeline to reduce the specific gravity of the mixture and restore a supercritical condition.

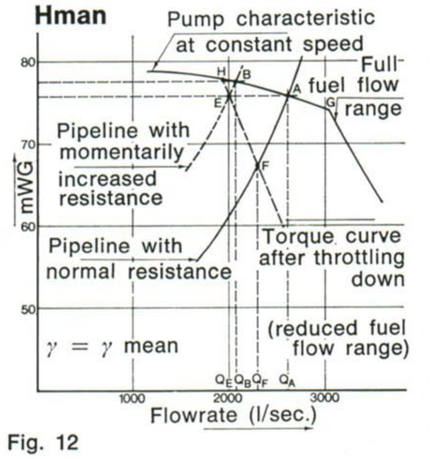

Fig. 12

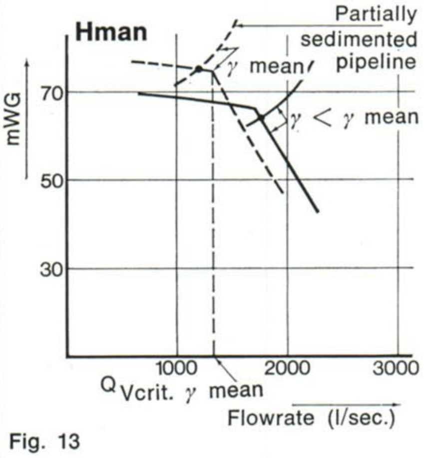

Fig. 13