SUBMERSIBLE MOTOR PUMPS FOR MINE DRAINAGE APPLICATIONS

Dieter-Heinz Hellmann, Dr.Ing.
Detlef Tams, Dipl. Ing.
Klein, Schanzlin & Becker AG
Frankenthal (Pfalz)
West Germany
Homburg/Saar Works

ABSTRACT

After briefly describing the basic design of the submersible motor pump and listing advantages it offers for mining applications, the latest developments for meeting the, in many cases, extreme demands relating to safety, erosion, corrosion, temperature, motor rating, high voltage, head and axial thrust are dealt with. The practical aspect of these main areas of development is illustrated by the use of two examples.

Introduction

Irrespective of the function of a pump in a particular installation, its selection must be made both on the basis of specified technical parameters and according to economic criteria. A satisfactory solution is achieved when the technical requirement for high availability is in a viable relation to the total investment and operating costs.

It is precisely this combination of technical sophistication and cost-effectiveness which has made submersible motor pumps an indispensable feature of the mining industry.

The consistent utilization of the technical features inherent in the design of the submersible motor pump, which have been specifically developed in recent years, means that in many applications the submersible motor pumps represents an attractive alternative to conventional pump types, from both a technical as well as an economic point of view.

The basic design of the submersible motor pump

The basic design (Fig. 1) of the submersible motor pump, in this case with a water-filled motor, has changed little since it was first conceived. The pump and motor constitute a compact unit operating in the product, thereby forming a section of the pipeline, or inside the pipeline. The pump's geometry has been specially adapted to that of the borehole, i. e. the practically unlimited length available is fully utilized so as to keep the outer diameter to a minimum.

The pump itself is of the conventional multistage type which offers the advantage of being easily integrated into a pipeline with a minimal outer diameter. The pump thus forms a section of the pipeline. The use of product-lubricated plain bearings means that the pump requires no maintenance.

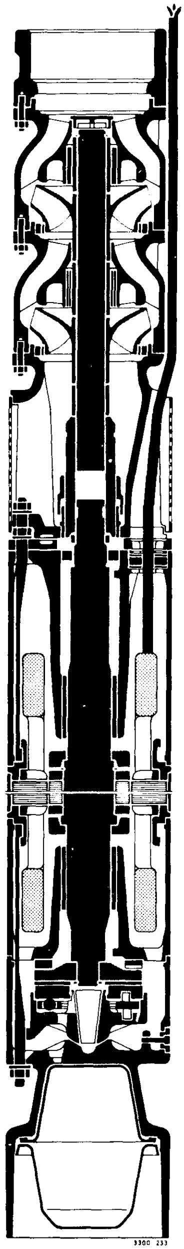
The electric motor which is close-coupled with the pump in an asynchronous squirrel cage motor filled with clean water. The motor fill water lubricates the radial plain bearings and the thrust bearing which takes the axial thrust and the weight of the rotor. It also serves to cool the winding which is insulated against water and pressure.

In any temperature condition of the motor a pressure-balancing system at the bottom of the motor automatically adapts the pressure to ambient at any depth under water.

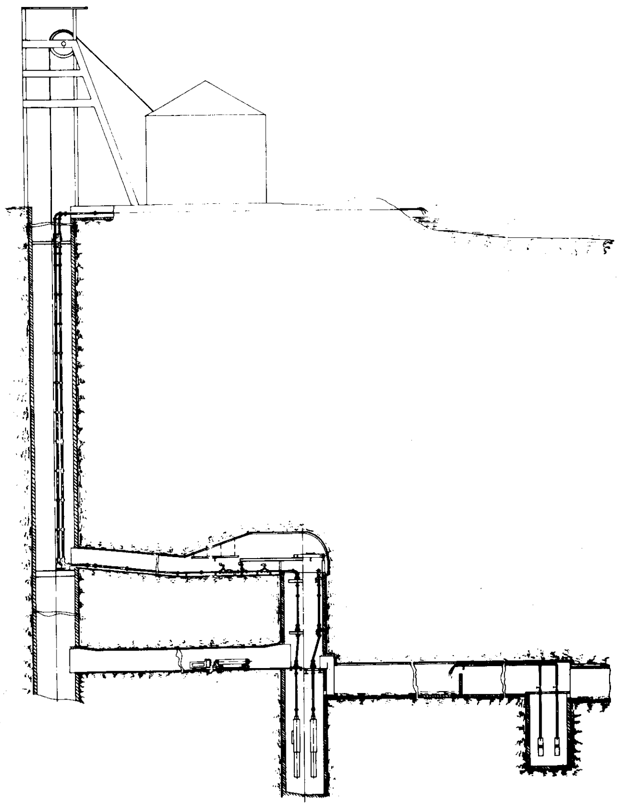
An interchange of the motor fill water and product water is prevented by the fitting of a mechanical seal, for example, in the upper part of the motor.

Owing to its simple, sturdy construction and the use of water-lubricated plain bearings the motor is also maintenance-free.

Since the motor, pump and pipe section form one unit the construction work and expenditure required for installation of the submersible motor pump is identical to that of the delivery pipe (Fig. 2).



1. Submersible motor pumps (type UPA)



2. Submersible motor pumps
- easy to install -

Advantages inherent in the design of the submersible motor pump for mine drainage applications

Since, as described, the motor, pump and delivery pipe form a single unit which is designed for operation immersed in the product, the outlay required for pump installation is comparable to that for installation of the delivery pipe.

This type of pump requires no special pumping stations below ground so that there are savings on the outlay for these constructions and consequently on the installation and maintenance of the equipment normally required.

This is possible primarily because in applications using submersible motor pumps:

- the torque required to drive the pump is generated at the pump itself with the aid of the submersible motor and only the energy actually required for this irrespective of the head is transmitted reliably and efficiently;
- cooling is effected by the product, i. e. the heat generated by the motor is carried to the surface by the product (no additional ventilation is required);
- the drainage process can be started, controlled and monitored from the surface;
- no anti-flooding protection is required.

On the contrary the desired flooding means that

- a high degree of explosion protection is provided and
- the units require no maintenance.

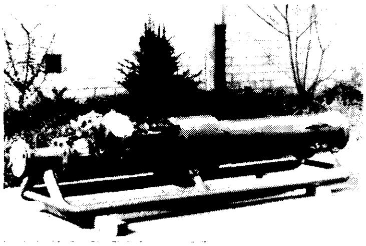
The state of the art of submersible motor pumps for mine drainage duties

The submersible motor pumps used in underground mines for drainage and dewatering duties often have to meet stringent demands as regards safety, erosion, corrosion, temperature, output, high voltage and head.

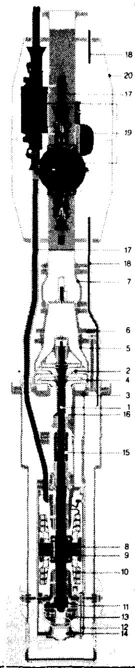
As any one of the above may constitute the criterion for selecting this pump type, these demands are dealt with in detail below.

Safety (explosion protection)

The demand for a high level of safety is the one most easily met by the design of the submersible motor pump, as the pumpset operates totally immersed and the motor is filled with water. Pressure-tight, explosion-proof terminal boxes are provided for connection of the cables outside the motor (Fig. 3).



3. Flame-proofing



1 Pump shaft
2 Impeller
3 Suction casing
4 Stage casing
5 Discharge casing
6 Adaptor
7 Non-return valve
8 Rotor
9 Stator
10 Winding
11 Thrust bearing plate
12 Thrust bearing housing
13 Thrust bearing
14 Diaphragm
15 Sleeve coupling
16 Sand guard
17 Motor cable
18 Control cable
19 Flameproof, pressure-tight junction box
20 Split shroud

Erosion and corrosion

To achieve satisfactory resistance to erosion and corrosion submersible motor pumps are made from the latest available materials. These represent a compromise between hardness, strength, malleability and economy.

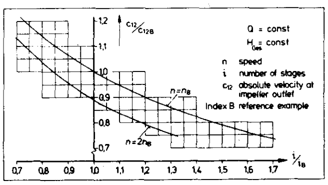
When the surfaces in contact with the product are exposed to extreme erosion in the form of cutting and impact wear, the wear rate can often only be reduced by decreasing the flow velocity in the pump (wear $\sim c^{2.5}$). The flow velocity is determined by the absolute velocity at the impeller outlet.

Fig. 4 shows the change in absolute velocity at the impeller outlet as a function of the number of stages and the speed at a constant flow rate and a constant total head.

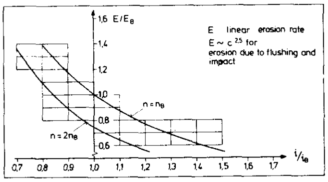
Increasing the number of stages which is easily achieved in submersible motor pumps because of their basic design, and also increasing the speed in consideration of the number of stages which is generally technically feasible on submersible motor pumps because of the absence of cavitation problems and is also expendient for cost reasons, provide a simple means of reducing erosion due to cutting and impact wear.

Corresponding to the statement $E \sim c^{2.5}$ ($E \hat{=}$ intensity of erosion) Fig.5 shows the change in intensity of wear related to the number of stages and the speed as indicated in Fig. 4.

The erosion in the plan bearings of the pump (grinding wear) which is subject to other, even more extreme physical laws, can, in the case of the extreme loading already assumed, only be reduced or prevented by the use of special materials.



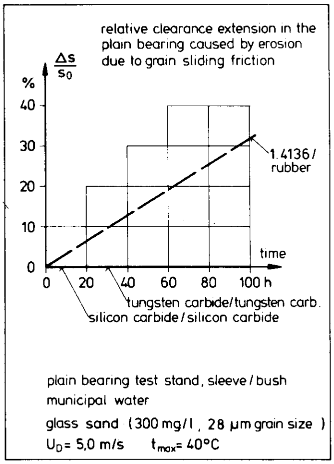
4. Change of the absolute velocity at the impeller outlet



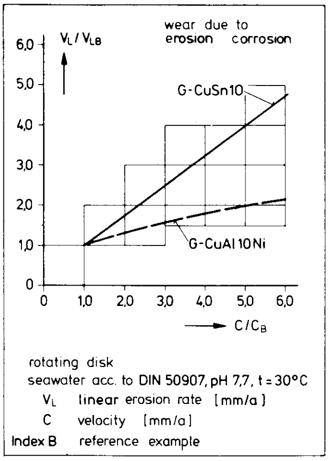
5. Change of the erosion intensity (please also refer to Fig. 4)

Fig 6 shows the increase in the clearances caused by silica sand as a function of time for the bearing material combinations chrome steel (1.4136)/rubber, tungsten carbide/tungsten carbide and silicon carbide/ silicon carbide.

As well as the wear caused by erosion, corrosion is of decisive importance as regards availability. As in the case of erosion, the wear caused by so-called erosion-corrosion is also dependent on the velocity in the pump (see Fig. 4) and/or the solids content of the product. All materials whose resistance to corrosion depends on surface layers may be subject to wear by erosion corrosion. Stainless steel, for example, produces surface layers in the form of passive films, whereas cast iron and steel produce reactive layers. If the surface layer is destroyed and not restored then, depending on the aggressivness of the surrounding medium, considerable corrosion damage may occur.



6. Relative clearance extension



7. Erosion, corrosion

Fig. 7 shows the influence of the velocity on the destruction of the surface layer and consequently on the erosion rate of bronze (G-CuSn 10) and aluminium bronze (G-CuAl10 Ni) in clean, synthetic seawater.

The low erosion rate of aluminium bronze which is also achieved and surpassed by high-grade steels is due to the greater strength of the surface layers.

Wherever there is the danger of erosion corrosion, i. e. when pumping aggressive water with a high solids content, highgrade steels are preferred.

An important member of this group of materials is Noridur ® 9.4460, an austenitic-ferritic cast stainless steel developed and patented by KSB.

The aim in developing this material was to achieve improved resistance to wear by corrosive and abrasive media.

Noridur's® resistance to corrosion by numerous corrosive agents is far superior to that of the usual types of austenitic chrome molydenum cast steel, such as 1.4408. The same is true of its resistance to abrasion

Austenitic - ferritic
Cast Stainless Steel
Noridur 9.4460

Material	Loss [g/m³h]
1.4408 G-X6CrNiMo 18 10	300
1.4462 G-X40CrNiMo 27 5	155
1.4138 G-X120CrMo 29 2	100
9.4460 Noridur	76,6

Model test under abrasive conditions

Medium : silica sand-water, ratio 1:1
grain size 0,9 - 1,2 mm
Speed : 3000 1/min
Test duration: 2 hours

Table 1: Abrasion resistance of Noridur ® 9.4460

In a model wear test under purely abrasive conditions in a silica sand/water mixture the wear rates of Noridur ® 9.4460 were determined in comparison with other types of austenitic, austenitic-ferritic and ferritic-carbide cast steels. (Table 1).

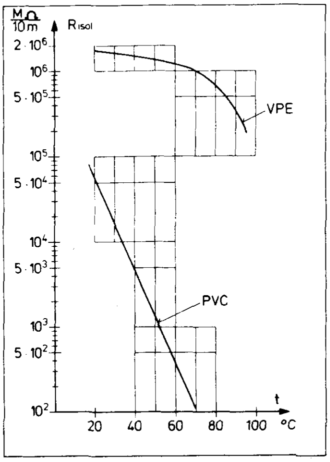
The wear rate of Noridur ® 9.4460 was only 76.6 g/m²h as compared with 300 g/m²h for 1.4408 under the same conditions.

The successful use of this material in numerous pumps for mine drainage applications serves to confirm laboratory test results.

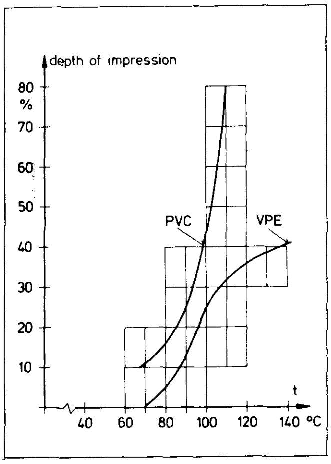
Temperature

The heat rise above ambient temperature occurring in the fill water due to the losses in the motor, which is dependent on the rating, the speed and the internal cooling system can lead to a relatively high internal motor temperature as regards the insulation materials used in submersible motor pumps. For this reason it is necessary to consider the effect of the temperature on the electrical and thermo-mechanical properties of the insulating materials (winding wire, cables, connection points).

Using the examples of standard insulation materials PVC (polyvinyl chloride) and VPE (cross linked polyethylene) the effect of the temperature on the insulation resistance (Fig. 8) and the impression depth (Fig. 9) is shown.



8. Insulating resistance as a function of the temperature



9. Depth of impression as a function of the temperature

For the polyethylene insulation, for example, the internationally accepted constant temperature is 90°C. As the maximum temperature inside the motor is approx. 20 - 40°C above ambient, depending on the rating, the speed and the internal cooling system an ambient temperature of between 50°C and 70°C is permissible as the constant temperature.

Operation at these temperatures does not increase the technical risks or reduce the service life of the pumpset. Since the temperature of the water (i. e. the ambient temperature of the motor) handled in mine drainage applications is generally well below 50° - 70°C, the difference between this and the internal motor temperature permitted by the insulation material can be utilised by selecting a motor with a higher rating (investment costs) or be regarded as a safety margin.

A safety margin may be necessary when for example, the water to be pumped exhibits a tendency to form heavy deposits and the deposits on the motor cause an increase in the internal motor temperature. In these cases a temperature probe is used to monitor the temperature inside the motor and the maximum permissible temperature set as a limit value.

High voltage, high rating

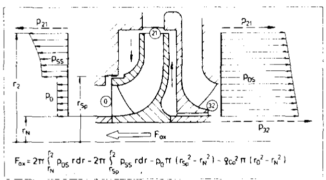
The use of submersible motors at great working depths (e. g. in a mine pump at a depth of 1000 m) and/or with high ratings (3500 kW as standard) is both feasible and acceptable from the point of view of investment and operating costs, by the use of high-voltage motors.

The reduction in electrical power losses achieved by high-voltage motors and the possibility of connecting a motor for 10 000 V, for example, without an integrated transformer directly to the bus ar means that there are no economic limits to these applications.

To demonstrate the functional efficiency of the insulation system even at 10 000 Va submersible motor pump with 10 000 V operating voltage was operated successfully in an open-cast mine as long ago as 1972. The experiments preceding the field test and the field test itself (approx. 80 000 h) have shown that provided the thickness, materials and configuration of the insulation is suitable there is reason why the 3000 or 6000 V operating voltages previously used should represent the technically feasible limit (see Fig. 4).

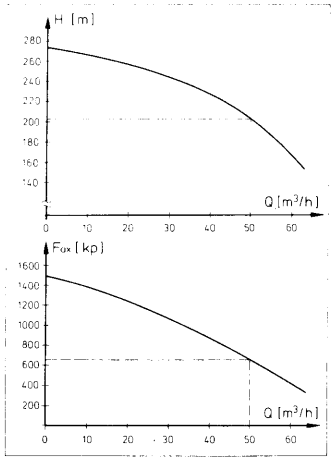
Head and Axial thrust

The pump section of the submersible motor pump is a conventional multistage pump. The total head of the pump is the sum of the heads generated by the individual stages. Each stage comprises an impeller and return section (i. e. casing) (Fig. 10) arranged one behind the other.



10. Pressure distribution on the impeller shroud at the section side (SS) and on the discharge side (DS) of multistage pumps

The head generated by a stage produces an axial thrust on the impeller. This axial thrust results from the distribution of pressure around the impeller and the impulse forces at the inlet and outlet cross-sections of the impeller. Reference points of the pressure distribution are the



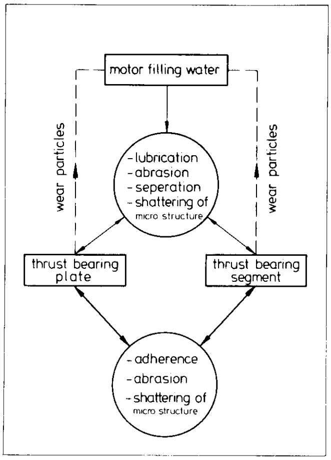
11. Typical influence of pump capacity on axial thrust

static pressure at the pressure outlet and that at the impeller inlet (Fig. 10), the difference between the two results from the work performed in the impeller and is thus closely related to the stage head. Fig. 11 shows a typical axial thrust curve.

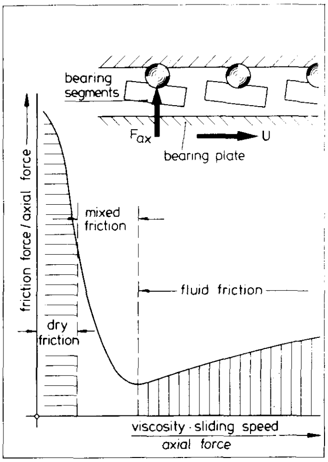
The axial thrust increases as operation moves towards the part-load range. This is due to the fact that the static pressure at the impeller outlet increases with the head towards the part-load range and the impulse force ($Q \sim Co$) decreases.

As the thrust bearing of the submersible motor pump is integrated in the motor, in the vertical installation the thrust bearing must first and foremost take up the axial thrust of the pump (sum of the stage axial thrusts) as well as taking the weight of the rotor.

The thrust bearing is arranged in the motor so that its reliability is not affected by the material properties of the product in addition to being subject to the factors shown in Fig. 12.



12. Characteristic factors which influence life time of axial thrust plain bearings



13. Friction conditions of an axial plain bearing (STRIBECK curve)

As we use the excellent tried and tested tilting pad thrust bearings (Michel type) for the motor fill water lubricated thrust bearing fluid friction must occur during continuous operating (Fig. 13).

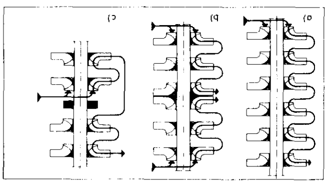
As can be seen in Fig. 13, a thrust bearing sized to take the axial thrust occuring in the normal operating range of the pump would, during operation in the part-load range and the consequent increase in axial thrust (Fig. 11), move from the range of fluid friction to mixed friction.

The same effect would also occur if, with the external conditions remaining the same, an identical thrust bearing were used but further stages added, thereby increasing the head and thus the axial thrust. To prevent this effect which would then lead to dry friction and ultimately to destruction of the bearing, the bearing must be relieved of the axial thrust of the pump when this reaches the maximum level acceptable to the bearing.

For submersible motor pumps this becomes necessary at the latest when heads of over 500 m are to be realised. With very high flow rates this necessity may arise at only 200 m head.

Of the balancing possibilities available in pump engineering, the back-to-back arrangement of the stages has proved the most successful in mine drainage applications.

As an aid to understanding this balancing method Fig. 14 shows the classic multistage pump arrangement where the axial thrust of the stages are added together as well as two possible back-to-back arrangements of pump stages where the axial thrusts of the pump stages cancel each other out.



The selection of the particular back-to-back arrangement depends on the specific application.

14. a) single flow impeller arrangement, all impellers facing the same way
    b) double flow impeller arrangement, with back-to-back impellers
    c) single flow impeller arrangement, with back-to-back impellers

Examples

To ensure that the method of describing submersible motor pumps for mine drainage duties used here does not make us lose sight of the practical aspects of these applications let us conclude by looking at two examples of these pumps in use in actual mining installations. The units used in both cases are double entry pumps with impellers in back-to-back arrangements in the Noridur® version.

15. One of the submersible motor pumps for main drainage duties in a German mine

The principal operating data are:

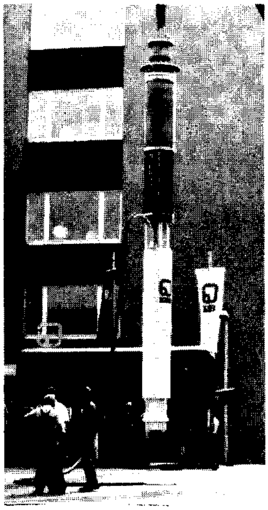
$Q = 480\ m^3/h\ (8\ m^3/min)$

$H = 1050\ m$

$n = 1450\ 1/min$

$P = 2000\ kW$

$U = 5\ kV$



16. One of the submersible motor pumps for shaft dewatering in a Chinese mine

The main operating data are:

$Q = 1000\ m^3/h\ (16{,}7\ m^3/min)$

$H = 650\ m$

$n = 1450\ 1/min$

$P = 2600\ kW$

$U = 6\ kV$