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High Voltage Submersible Mine Dewatering Pumps for Extremely High Lifts

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ABSTRACT

After a short description of design of submersible motor pumps (s.m.p.) some examples will be given of application. Above all, the advantages of water-filled motors will be shown. Thanks to its water fill and to the fact that in operates totally submerged in water, the submersible motor is flameproofed (firedamp-proofed) in ideal fashion.

Though the s.m.p. has a wide range of application the present paper will confine itself to the mining industry.

Pumps with 1000 m total and capacities up to 5000 m³/h are available. Motors with ratings of 2000 kW have now been operating successfully. Ratings of 3000 kW are in the development stage at the present time.

For larger ratings up to 1000 kW low voltage is used; for ratings up to 1000 kW, high tension of 3 kV is adupted, and for even higher ratings, 10 kV.

1. Introduction

The submersible motor pump owes its development to the requirement for a pump set capable of operating reliably in the fully submerged state, and consequently totally without maintenance.

An important aspect of submersible motor pumps is the physical fact that the suction lift of a pump operating in open circuit is limited by the barometric pressure. The submersible motor pump, on the other hand, operates totally submerged in most applications, so that the question of an adequate NPSH does not arise, apart from a few exceptional cases.

The main fields of application for the submersible motor pump are:

- Groundwater winning from deep wells, and water drainage in mines, civil engineering projects and tunnel construction etc.
- Pumping of hydrocarbons from underground storage caverns
- Used as cooling water, ballast and firefighting pumps on drilling and production platforms

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The present paper will confine itself to the application of submersible motor pumps in the mining industry, a field of application which has made an outstanding contribution to the present-day stage of development of these pumps, because of the stringent requirements involved.

2. Description of Design

2.1 Submersible Pump

The main feature of this pump is its slim shape, which facilitates its installation in narrow and deep boreholes.

Figure 1 illustrates two s.m.p.'s in cross-section, with the motor shown in shortened form. Because of the relatively small diameter of the pump, a large number of stages (impellers and diffusers) is usually required to achieve the desired total head.

Total heads in excess of 1000 m (3300 ft) are attainable, and if the pumps are fitted with mixed flow impellers (Figure 1, left-hand side), rates of flow (capacities) in excess of 3000 cu.m/hr (13200 USGPM) can be achieved.

Most submersible pumps are of the single flow or single entry type, on condition that the axial thrust generated is capable of being absorbed by the thrust bearing arranged in the motor.

Figure 2 illustrates a double entry pump with its associated driving motor. The hydraulic axial thrust in this case is balanced almost completely, and the thrust bearing arranged at the lower end of the motor is only required to absorb the rotor weights of the pump and motor.

The radial forces of the pump are absorbed by plain bearings arranged in the suction casing and discharge casing respectively. Because the liquid pumped acts as lubricant, the bearings are designed in such a way that the solid particles entrained with the liquid are prevented as far as possible from penetrating inside the bearings; this is particularly relevant in the case of mining applications. However the ingress of abrasive solid particles into the bearings cannot be entirely prevented, and abrasion-resistant bearing materials have therefore to be adopted. All the throttling clearance gaps through which the fluid flows contribute to the guidance of the shaft. This results in exceptionally quiet running characteristics even in the case of badly worn pumps, because of the multistage design and relatively small impeller diameters of submersible pumps. In addition, the submersible pump has a longer service life than conventional mine drainage pumps.

2.2 Submersible Motor

The submersible motor is regidly coupled to the pump. There have been a large number and variety of developments of this type of motor, but only three of these are of real significance:

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a) the oil-filled motor

This type of motor must be fitted with an absolutely reliable and leak-tight shaft seal. The dissipation of the heat losses and the thermal expansion require special attention and a correspondingly high expenditure, because of the lower thermal conductivity of oil as compared with water. Compared with water, oil has the disadvantage of a higher fluid friction, but on the other hand it permits the adoption of antifriction bearings, in so far as the service life requirements of the bearings allow it. Antifriction bearings are not generally regarded with great favour for mining applications.

b) the semi-wet submersible motor (canned motor)

The stator compartment and stator winding of this type of motor are sealed off from the water-filled rotor compartment by a can. In order to improve heat dissipation, the winding space is filled with casting resin poured into it.

This type of motor has an inferior efficiency and is usually adopted only for low ratings up to 30 kW approx.

c) the wet or water-filled motor

Whereas developments in the USA centered mainly around the oil-filled motor, developments in Europe were concentrated on the water-filled motor. This type of motor is completely filled with water, i. e. the winding is immersed in water, and the plain bearings are water-lubricated (Figures 1 and 2). These water-lubricated bearings have reached such an advanced stage of development that they offer complete and absolute operational reliability and a very long service life even under heavy loadings.

The remarkable increase in output ratings of the water-filled motor during the past 20 years, and its proven reliability in service point to this type of motor as the most likely solution for the future. Motors with ratings of 2000 kW have now been operating successfully over a period of several years, and ratings of 3000 kW are in the development stage at the present time. One feature of decisive importance in this development has been the progress made in the field of waterproof and pressure-tight plastic insulating materials for the winding wires. The quality of the plastic materials and the processing technology have improved continuously, with the result that present-day winding wire insulations are capable of withstanding very high electrical, thermal and mechanical loadings.

The normally selected supply voltage for motor ratings up to 300 kW approx. is low voltage (low tension); for ratings up to 1000 kW, high tension of 3 kV is adopted, and for even higher ratings, 6 kV.

A 10 kV motor has been operating for the last 5 years without any trouble (see Figure 2).

Basically the design of the water-filled submersible motor does not differ from that of conventional three phase squirrel cage rotor motors, i. e. the construction is simple and sturdy. The salient points of the design are the slim shape and the fact that the motor

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is completely filled with water. The following data tabulation relating to a series of submersible motors proves conclusively that high efficiencies are attainable with this type of motor:

Rated output kW	Voltage V	Length/O.D. mm	At 50 Hz Rot.speed r.p.m.	Efficiency %
1800	6000	4025/680	1450	91
1600	6000	3925/680	1450	91
1200	6000	3425/680	1450	90
1000	3000	3380/614	1450	90
800	3000	2960/614	2900	90
500	3000	2864/450	2900	90
300	500	2470/343	2900	90
150	380	2010/282	2900	88
100	380	1730/361	2900	87
50	380	1490/226	2900	87
10	380	920/180	2900	83
1	220	420/141	2900	70

The motor is filled with conventional drinking water shortly before final installation.

The advantages of the water fill are:

- Water is an excellent conductor of heat. Heat dissipation can be improved even further by auxiliary devices such as a special paddle wheel to circulate the water, making it possible to operate the motor at high ambient temperatures if necessary, such as those which frequently occur in mines.

- There is no need for absolute leak-tightness, only for the prevention of an exchange of fluid; should there be a leak, or should a seal fail, the ingress of fluid pumped will not result in failure of the motor.

In order to achieve a long service life, special attention must be paid to the prevention of an exchange of fluid and to protection against the ingress of dirt in submersible motors for mining applications. The adoption of mechanical seals has proved unsatisfactory for a considerable time already, because these seals are very sensitive to sediments which are frequently present in mine waters. It has needed a long and painstaking series of experiments and trials under conditions simulating practical mining applications to arrive at a final solution which functions satisfactorily even under the most arduous operating conditions.

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The rotor is guided in two radial bearings. The thrust bearing is mounted at the lower end of the rotor shaft, and it rotates against a ring of tilting pads which are stationary in the peripheral direction, but which are otherwise free to tilt in all directions.

Figure 3 shows how the weight per unit of output has decreased over the years from 1950 to 1978. This graph illustrates very clearly the continuous further development and improvement of the submersible motor over the years.

3. Examples of applications in the Mining Industry

Because water-filled electric motors which operate completely submerged do not require any special explosion proofness (firedamp proofness), the entire range of submersible motors (i.e. the complete range of outputs) used for other purposes is equally suitable for the mining industry in its basic form.

It is only necessary to know the operating data and conditions in each specific application, such as the nature and condition of the medium pumped (temperature, chemical properties, solids content), and the mode of installation and operation (mode of starting, switching frequency (number of stops and starts per hour), and length of downtimes (shutdown periods)).

3.1 Opencast Mining, e.g. Brown Coal (Lignite) Opencast Mining

Submersible motor pumps have been used in opencast mining applications for many years now, in the world's largest opencast coal mining operation, the Rhineland soft coal basin near Cologne. Figure 4 illustrates such an opencast mining operation sectionally. The ground water table is indicated diagrammatically, and the purpose of the submersible motor pumps installed below the deepest bed level is to lower this ground water table. At present, some 2500 submersible motor pumps in all, with a combined capacity of over 150 000 m^3/h are installed at the Rhineland Soft Coal Mines. These submersible motor pumps are installed in wells with borehole diameters up to 800 mm and at depths down to 500 m. (1)

Figure 5 illustrates a section through a deep well with a submersible motor pump.

The largest submersible motor in this coal field has a rating of 1600 kW. Special attention has been devoted to the problem of abrasive wear, because most deep wells contain sand in the water, to a lesser or greater extent.

Because the hydraulics of a mixed flow pump are characterized by more gradual changes of direction of flow than those of the equivalent radial flow pump, the mixed flow pump will be less prone to abrasive wear and erosion than the equivalent radial flow pump under similar operation conditions.

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Figure 6 illustrates the conventional mode of installation in a deep well. As a general rule, a non-return valve is mounted directly above the pump discharge nozzle, to prevent the rising main from running empty every time the pump is switched off. In addition, the reflux of liquid from the rising main would cause the pump to "windmill", i.e. run as a turbine.

Finally the problem of pressure surges (water hammer) which can occur in the rising main when the pump sets are switched on and switched off must be mentioned. Calculations and experimental measurements point to the fact that these pressure surges can present a serious hazard to the safe operation of the pump sets and installation (1). On condition that the necessary data are made available to us, it is a relatively easy matter to ascertain whether pressure surges will in fact occur, and to take suitable preventive measures.

3.2 Underground Mining (Hard Coal and Ore Mining)

Submersible motor pumps are installed in collieries and ore mines for drainage duties, i.e. to remove the water which collects in the individual bottoms. The water concerned arises from natural affluxes, and in certain cases from hydraulic stowing operations.

Depending on the depth of the bottom on which the submersible motor pumps are installed, they will pump the water either direct above ground, or from a bottom deeper down to the drainage facility of a bottom situated higher up, whence it is pumped above ground. In most cases, the submersible motor pumps are suspended in a sump on the bottom concerned.

A diagrammatic representation of a mine drainage installation of this type is shown in Figure 7; it has been in operation since 1960. Hartmann and Guillaume (2) have described this installation in detail in a paper, and have demonstrated the submersible motor pump in the most suitable and even essential item of equipment for the automation of the complete installation.

The trend during the last ten years has been towards the direct pumping from the deepest bottom to a level above ground by means of a single pump, which is capable of generating the necessary total head. In the hard coal mines of Germany, this requires total heads of up to 1000 m and driver ratings of up to 1800 kW. In mining circles, a conservative approach and considerations of safety are paramount, and consequently two requirements are imposed in the case of machines with higher ratings:

1) A 4 pole motor, i.e. a rotational speed of 1450 or 1700 r.p.m. respectively

2) A pump of double entry type (double suction design)

Whereas the first of these two requirements will only occasionally meet with any objections from the viewpoint of the pump manufacturer, there can only be one single valid argument in favour of the second requirement, viz.:

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The balancing of the hydraulic thrust in the eventuality that the thrust bearing is incapable of absorbing the thrust of a single entry pump. Other axial thrust balancing devices not only dissipate power but also lose their effectiveness as a result of abrasive wear, and consequently they can only be adopted in the case of pumped media which do not contain any solid particles. This can never be achieved fully in any mining operation.

The double entry pump design is, however, unsatisfactory in the case of very low rates of flow in relation to the total head. The flow channels become very narrow and the efficiency of the pump deteriorates as a result.

The decision as to whether a two pole or a four pole motor is the better solution cannot be made by the pump manufacturer alone. There is no doubt that a two pole motor pumping set is the more economic solution for pumping water containing only a very small percentage of solids (less than 25 ppm). Pumping sets with two pole driving motors of 600 kW rating have been built and have proved themselves in service.

These pumps are designed for the following operating data:

$Q = 300\ m^3/h$

$H = 450\ m$

Elevated temperatures of the liquid pumped

Whilst the operating conditions in brown coal open cast mines usually deal with cold water of less than 25°C handled by the pump, the water pumped out of underground collieries is warm in most cases (40 to 50°C). This makes the dissipation of the motor heat losses more difficult, and special measures have to be taken, such as the use of a plastic insulating material for the winding wires resistant to elevated temperatures, and the additional incorporation of a cooling jacket. The cooling jacket stretches from the top edge of the pump inlet body (where it is closed) to the bottom edge of the motor (where it is open); consequently the water aspirated by the pump is forced to enter the pump via the bottom end of the cooling jacket. The water thus pumped is obliged to flow around the outer surface of the motor casing at a predetermined velocity, and carriers off the motor heat losses quite satisfactorily. Here again, motor designs which incorporate an auxiliary paddle wheel can be adopted if necessary, to circulate the motor fill water via cooling ducts in countercurrent to the pumped water, in order to improve the cooling action still further.

The protection of the winding against excessive overheating is ensured by means of a so-called thermomonitor embedded in each of the two winding ends of the motor; these monitors automatically switch off the motor via a special control current line (trip line) as soon as a given pre-set limit temperature has been attained, which is below the temperature which might damage the winding.

The cooling jacket has the added advantage of preventing the motor casing from becoming caked up with solids (sludge) when the sub-

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mersible motor pump operates e.g. in a sump. Such a coating of sludge on the motor would impede the efficient dissipation of the motor heat losses. The presence of the cooling jacket, which also acts as a suction jacket, ensures that the solids are entrained by the pump.

Special importance in hard coal underground mining operations is attached to the flameproofing(firedamp-proofing) of all electrical equipment used underground, and this includes the submersible motor. Thanks to its water fill and to the fact that it operates totally submerged in water, the submersible motor is flameproofed (firedamp-proofed) in ideal fashion. The cable leading out of the motor is led into a pressure-tight, firedamp-proof and explosion-proof cable junction box. When the submersible motor pump is installed, the power supply cable from the distribution is also connected inside this junction box. The box is then sealed water-tight with a cover. In cases where a second cable is required, a second cable junction box must be provided, and similarly a third box must be provided for the control current cable of the thermomonitor. These cable junction boxes are attached to a special rising main pipe which is connected to the non-return valve on the pump, and which constitutes a component part of the submersible motor pump. The pump execution illustrated in Figure 8 has been approved as firedamp-proof (flameproof) by the German Bureau of Mines.

A smaller size submersible motor pump of firedamp-proof execution for horizontal installation is illustrated in Figure 9; it was developed for the special purpose of roadway (drift) dewatering. Its motor is sealed by means of a metal carbide mechanical seal. It is filled with water and vented via two pipes. The motor is supported in relation to the cooling and suction jacket via a series of setscrews. The jacket is vented at the top through a hole fitted with a screwed plug; it is also fitted with two skids to facilitate transport in the mine, and with two sturdy carrying stirrups. The cable junction box is mounted on the jacket.

An orifice plate is fitted downstream of the non-return valve and upstream of the discharge line, which can be altered or removed completely according to requirements. The submersible motor pump is switched on and off automatically in function of the upper and lower water levels via two electrodes which are adjustable on a rail.

This particular submersible motor pump is a compact and sturdy pumping set, easy to handle in the mine. Its principal data (with the orifice plate removed) are as follows:

Capacity	3,8 m^3/h
Total head	51 m
Pump efficiency	60 %
Motor rating	1,5 %
Motor efficiency	71 %
Motor speed	2870 r.p.m.
Operating voltage	500 V

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Materials

Reference has been made to the problem of abrasive wear on page This problem can be attacked by the use of specially abrasion-resistant materials, apart from low rotational speeds and various design measures. The chemical quality of the water is another important aspect in the selection of the most suitable materials, and this is of particular importance in mining applications. Because of the great variety of requirements, it is often difficult to say in advance which materials will be the most suitable ones.

Although the pump manufacturer is always anxious to standardize his material executions as far as possible and for every possible individual component, it is clear that the requirements of the mining industry are so diverse that new adaptations and adjustments have constantly to be made.

The "Noridur" and "Norihard" alloys have been specially developed by KSB itself for use in contact with chemically aggressive and abrasive media pumped. Please refer to our special leaflets for details on these alloys.

Summary

1. Advantages of submersible motor pumps in comparison with conventional pump designs for mine drainage:

   - No NPSH problems, because pump is completely submerged
   - Direct connection without necessity for a booster pump, i.e. always ready for instant start-up, easy to automate
     Can be controlled from above ground if required
   - Maintenance-free
   - Can be installed in the sump, no sump room required
   - Small diameter, low peripheral speed, reduced rate of wear if the water contains solids

2. Advantages of the water-filled motor in comparison with the oil-filled motor and the canned motor

   - No special seal required (only prevention of liquid exchange)
   - All the required ratings and voltages are available and have been proven in service

Capacities up to	5000 m^3/h
Total heads up to	1200 m
Motor ratings up to	3000 kW
Voltages up to	10000 V

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- Exceptionally good cooling, can therefore be used to pump warm media if required
- Exceptionally quiet running and plain bearings with a long service life
- Firedamp proofness (flame proofness) requirements are easy to meet

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List of Figures

References

1 Blank, R.: Der Einsatz von Unterwassermotorpumpen zur Vorentwässerung der Tagebaue der Rheinischen Braunkohlenwerke AG.(RBW) Braunkohle (1965) 7, S. 270/282

2 Hartmann, G. und Guillaume, F.: Die Automatisierung der Hauptwasserhaltung und der Zubringerwasserhaltung auf der Saargrube Reden Glückauf (1962), S. 1299/1311

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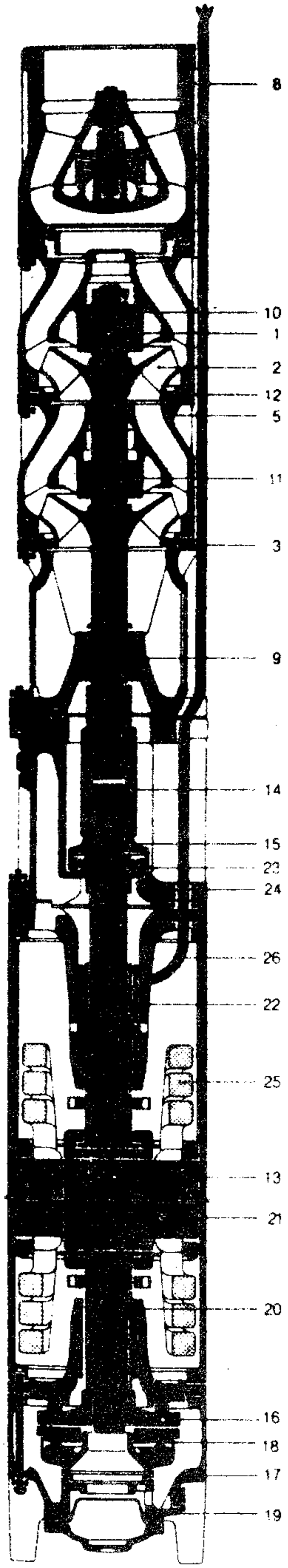

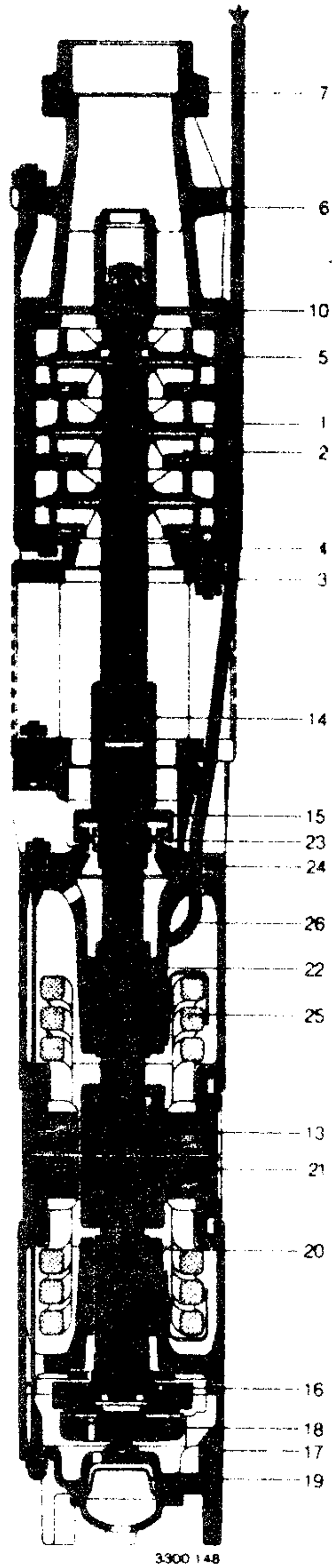

1 Pump shaft
2 Impeller
3 Suction casing
4 Inlet ring
5 Stage casing
6 Discharge casing
7 Reducer
8 Non-return valve
9 Bearing bush
10 Bearing bush
11 Bearing bush
12 Casing wear ring
13 Rotor
14 Sleeve coupling
15 Sand guard
16 Thrust bearing plate
17 Thrust bearing housing
18 Thrust bearing
19 Diaphragm
20 Bearing bush
21 Stator
22 Bearing bush
23 Radial seal ring
24 Connecting piece
25 Winding
26 Cable

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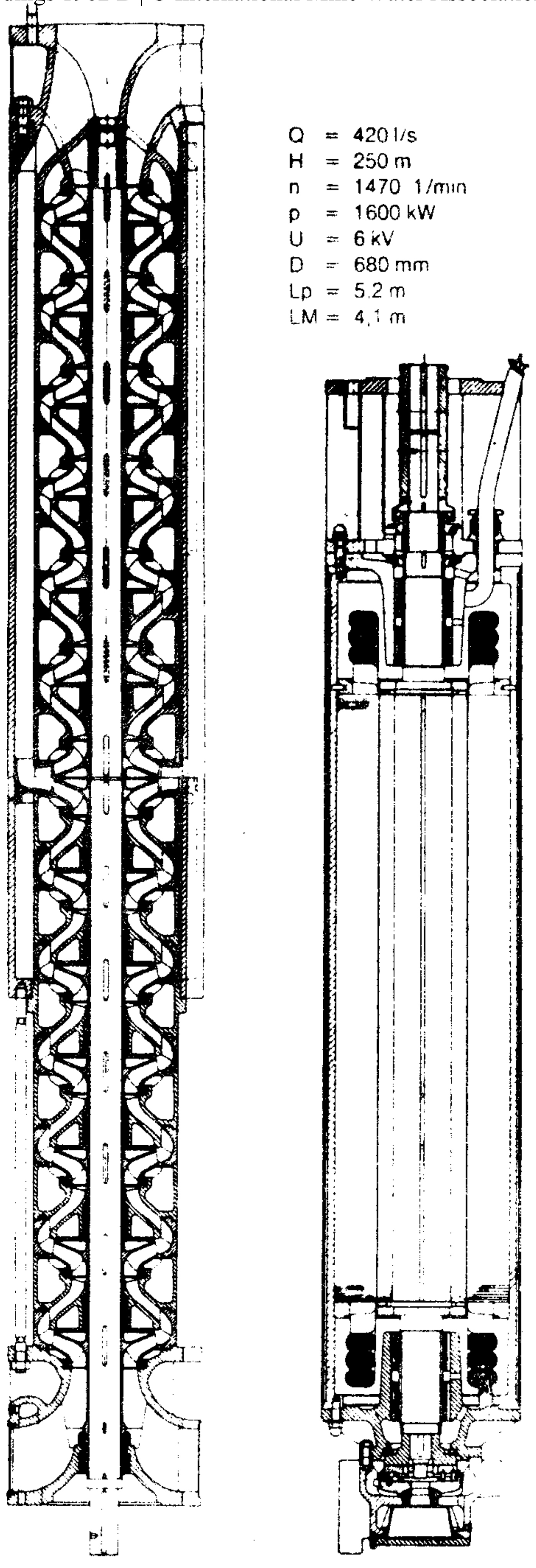

Fig.2: Submersible motor pump

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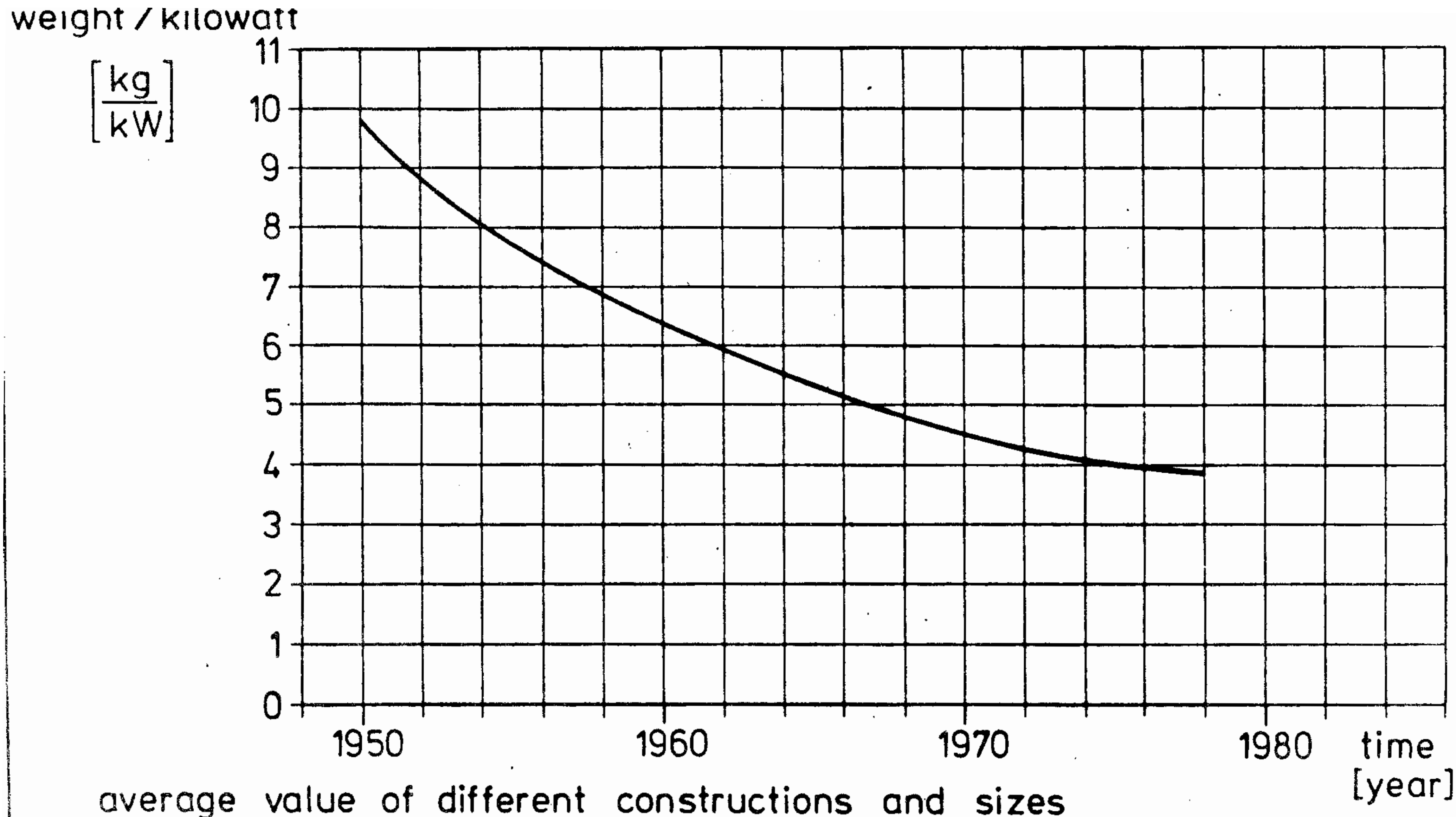

Fig.3. Reduction of the weight/kilowatt value of submersible motors from 1950 until 1978

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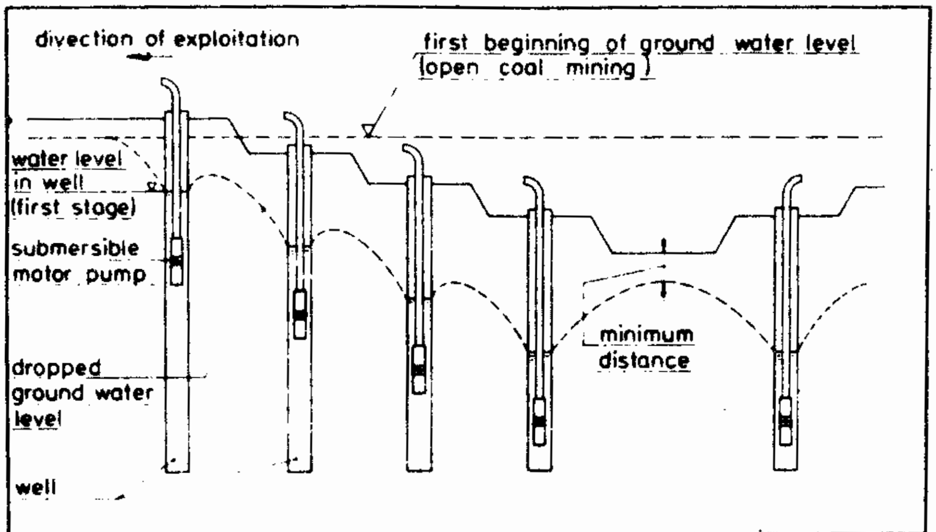

figure 4 | Section through an open coal mine | R906 a

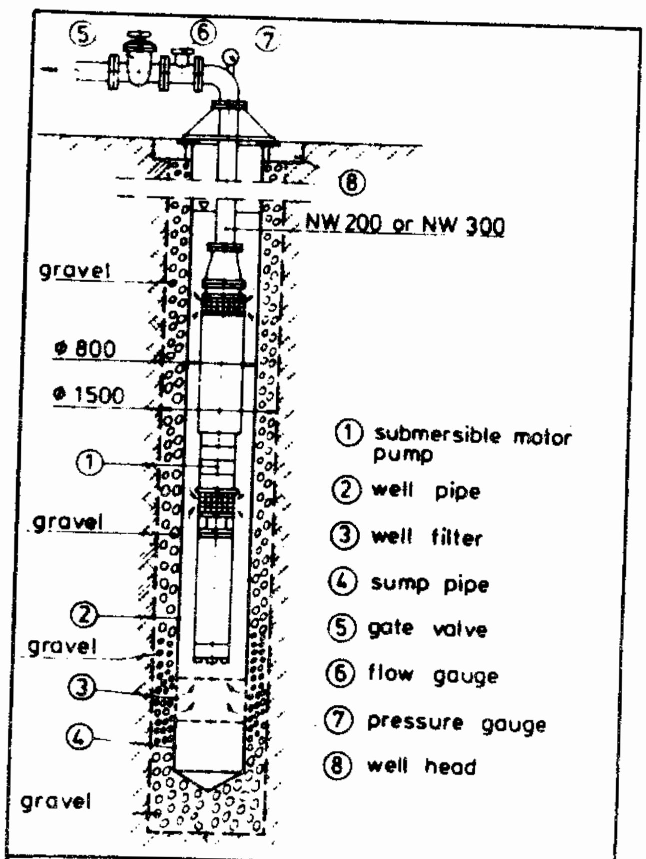

figure 5 | Section through an deep well with submersible motor pump | R 907 a

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Fig. 6: submersible motor pump
mode of installation

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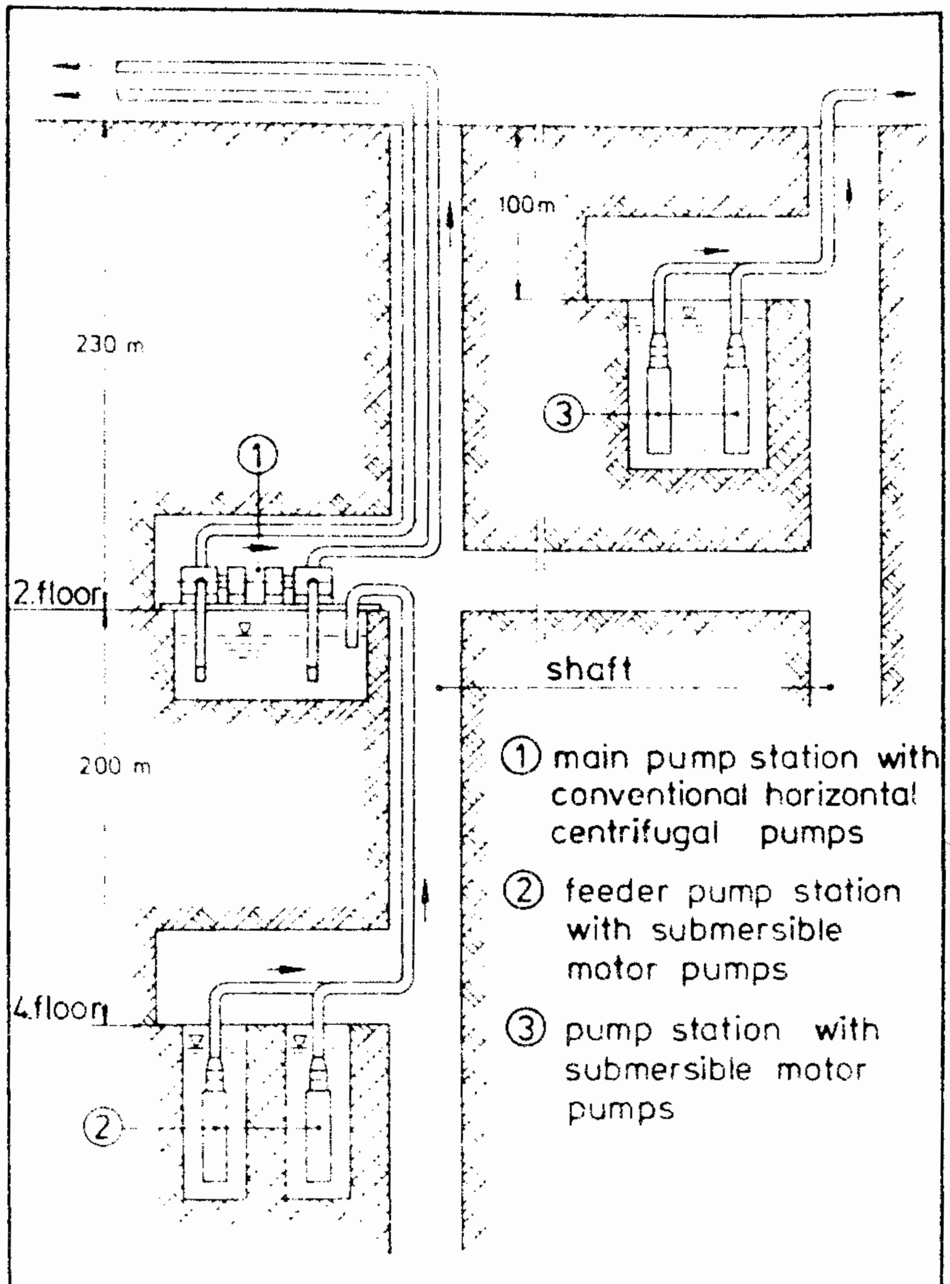

figure 7	Section through an coal mining with submersible motor pumps	R910 a

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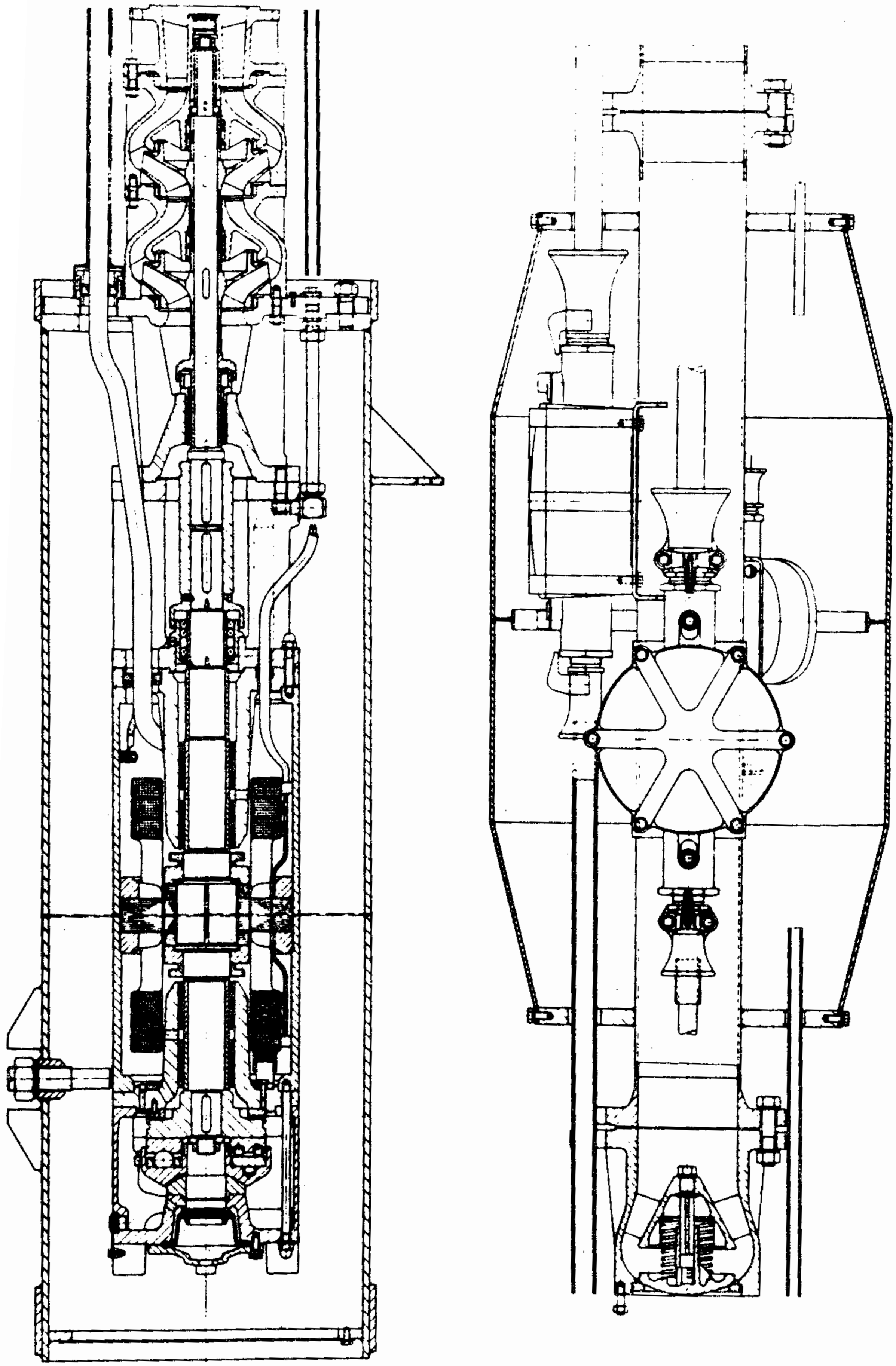

Fig. 8: Cut through a explosion-proof submersible unit, type BRI 435/6a + sIB 2503

Left: lower part with motor and pump
Right: upper part with cable connection box

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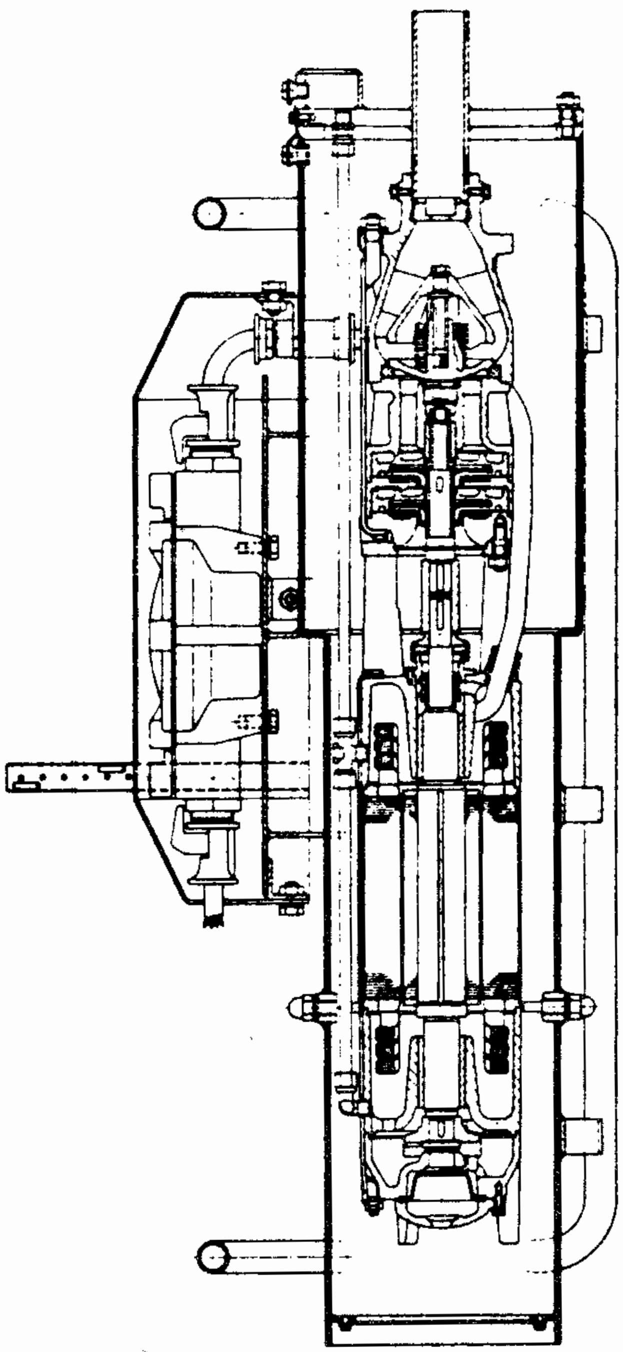

Fig. 9: Cut through a explosion-proof submersible unit, type UPD 62/6 + sDF 0203

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