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HIGH RELIABILITY MULTISTAGE MINE DEWATERING PUMPSETS(*)

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INTRODUCTION

Since mining began there was always been problem of water percolating into mining workings, which needs to be removed to ensure the safety of operating personnel and to safeguard the investment in capital plant. The majority of mines have therefore been wholly dependent upon pumps to ensure their effective continuing operation and to provide the various auxiliary services.

As with all installed safety related equipment, whether it be in a central electricity generating station, a petrochemical plant or within a mining complex, it is of paramount importance that the equipment selected be of high reliability.

Today centrifugal pumps, either single or multiple stage, are selected to provide the save, reliable and economic solution to the vast majority of pumping needs within mines.

This paper reviews the principal factors which normally govern the selection of the various types of multiple stage pump arrangements, which are used in main mine dewatering applications. Aspects are then presented of the engineering development programme of one of those product types, in which reliability of the pumpset range has been further improved.

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PUMP TYPES CRITERIA FOR SELECTION

There are three principal types of multiple stage centrifugal pump, Figure 1, each of which theoretically compete for a share in the total market demand in mine dewatering applications. In practice, however, local conditions often limit this choice either because of access restrictions, risk of local flooding and/or the availability of the skilled maintenance personnel. Local experience in the operation of the various pump types, which are normally subject to exacting demands in a hostile environment, frequently influence the style of pumpset chosen.

These pump types are as follows:

Horizontal Ring Section Type

This is the common style of pump used worldwide for the primary requirement of mine dewatering and has been developed to a high level of reliability by the principal pump suppliers which serve the industry. This pump whilst being generically similar to that which is used for other applications such as boiler feed service and water transportation is nevertheless specially engineered to permit the handling of minewaters which may be acidic in nature and are often abrasive, through the suspension of sands and grit. Special attention is normally given to the design of the sump and pump intake, to minimise the carry over of these abrasive particles into the pump, which otherwise will inevitably reduce both the operating efficiency of the unit and the time interval between major overhauls.

Long experience with this type of unit has shown that it can be readly installed and efficiently operated by the mine personnel, providing that due care is taken to ensure that the pump remains fully primed and that the shaft glands are adequately protected against loss of lubrication.

Where operating and maintenance personnel are readily available at or close to the installed pumps then this type of pump, manually started and monitored, is often considered to be the most cost effective selection. The conversion, however, for thistype of pump from manual to fully automatic control, requires particular care, when arranged to operate under suction lift conditions.

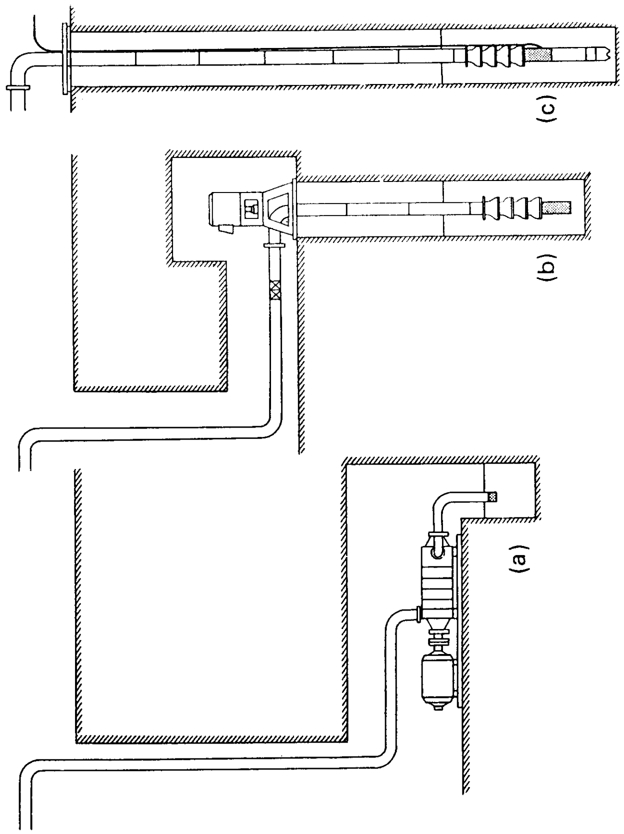


Figure 1 Multistage centrifugal mine dewatering pumpsets

Vertical Turbine Type

Whilst the vertical turbine type pump is less frequently used than the horizontal rig section type pump, mainly because of space restrictions at or access to the optimum sump site, it is worthwhile to note that it is comparable in operating efficiency and offers the further advantage of being suitably primed at all times. This unit is therefore more suited than the horizontal unit to automatic control, where the sump water is below the level at which the motor is to be mounted.

Electro-submersible Type

Experience has shown that the water filled electro-submersible motor driven pump, first manufactured some 50 years ago and progressively developed since then, can satisfy all but the most severe pumping conditions in mine dewatering, providing that due care has been taken to match the pumpset to the system and to the conditions which exist in the particular dewatering location. This type of unit has since the 1960's taken its place immediately behind that of horizontal ring section type pump as a well established pumpset for use in mine drainage applications.

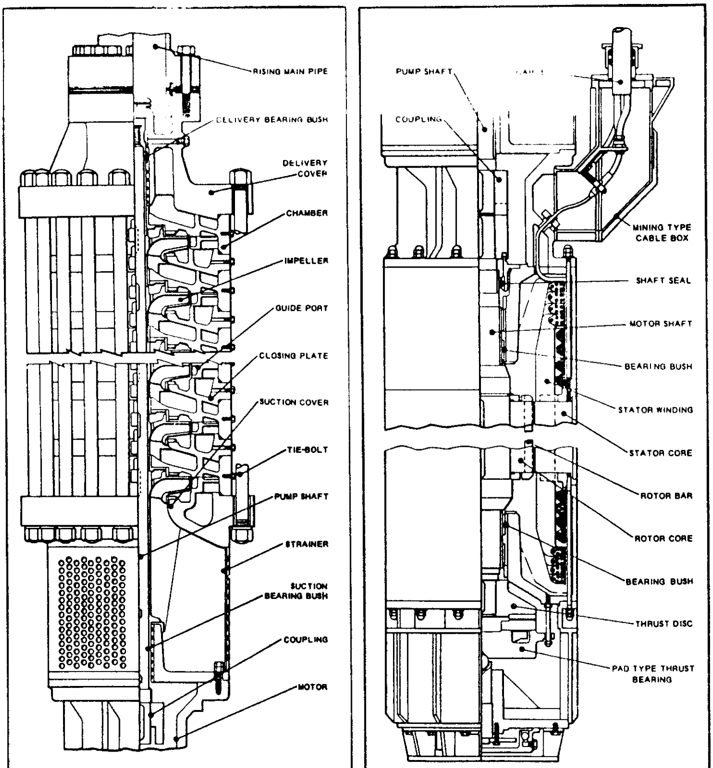
The submersible pumpset, however, whilst attractive to most operators in terms of its relative ease of installation and suitability for use under automatic control, has generally suffered a setback in much wider usage, through its historical reputation for premature failure in difficult mining installations.

Later sections of this paper discuss various aspects in a programme of further development of electro-submersible motors, specifically set out to raise the standard of operating reliability in medium and high powered mine drainage pumpsets.

Leading manufacturers of this plant have carefully studied the failure analysis data across a broad range of the equipment and have further developed pumpsets reduce the likelihood of premature failure, resulting from the identified causes and, thus achieve an higher degree of reliability.

Typical Submersible Pumpset

The construction of a typical submersible pumpset used today for main mine dewatering is generally as shown in Figure 2, comprising a multiple stage ring section type pump which is close connected to its electro-submersible motor. I the majority of



(a) **Sectional Arrangement of 1500 G.P.M. 11 Stage, 1880 Feet Head, Submersible Pump.**

(b) **Sectional Arrangement of Submersible Squirrel-Cage Induction Motor of 1150 B.H.P. Rating, 3 PH. 50 Hz., 3300 Volts, 1470 R.P.M.**

Figure 2 Typical submersible pumpset

applications the pumpset is installed vertically, suspended on its discharge main either fro the surface or from some other convenient level within the mine, with the motor fitted below the pump. Where units are to be installed either as inclined or horizontal pumpsets, particular care must be exercised to ensure that the pump and motor are maintained in good alignment and that the motors are properly filled.

The submersible pump is comprised basically of a rotor assembly including pump shaft, impellers and sleeves supported in water lubricated journal bearings, fitted within the pump suction and discharge covers. The rotor assembly is contained within a ring section style casing which is fitted with guide ports and returnwater passages to ensure good recovery of kinetic head at impeller exit and to control the pumped flow between successive stages. The pump suction chamber serves to guide the well water efficiently to the first stage impeller, whilst providing the means for good pump to motor alignment, combined with offering protection to both the shaft coupling and to the shaft seal on the motor. A coarse mesh strainer is normally fitted at the pump inlet, thus protecting the pump against floating debris.

Design features to note on the submersible pump which distinguish it as a mining pump, includes its particularly robust construction, generous flow passages minimising the risk of pump blockage and the detailed attention which has been given to chamber bushes and wear rings to ensure long in service life. Materials of construction are normally selected from a knowledge of the quality of the water to be pumped,. these may range from high quality bronze impellers fitted within a cast iron, carbon steel and bronze casing to the use of high alloy stainless steels for high pressure units handling aggressive waters.

The electro-submersible motor is of the squirrel cage induction type and of the form generally referred to as 'wet' since the motor windings are in intimate contact with the water fill of the unit. The stator of the motor comprises a stack of laminations, secured with a heavy section steel cylindrical outer casing having tunnel type slots into which the PVD and XLP insulated stator winding are fitted. Dependent upon application or preference, the stator windings can be connected to the main supply cable within a mining type cable as shown, or directly to trailing cables which are normally supplied suitable for connection to the main supply cable, above the level of the pump discharge flange. Attached to the stator are the bearing support frames housing the replaceable water lubricated journal bearing bushes and tilting pad axial thrust bearing assembly, which supports both the pump and motor rotors and accommodates any residual hydraulic thrusts which may be transmitted from the pump. The motor is fitted with a suitable rotary seal, local to the pump/motor coupling, to prevent ingress of minewater into the motor casing.

To achieve a higher level of operating reliability any engineering system it is first of all necessary to establish the principal modes of failure which occur in existing plant and to understand the primary reasons for these occurrences. It is then necessary to determine a corrective action which will reduce the risk of such failures occurring, taking due care to ensure that such action will not stimulate an alternative mode of failure.

The concept of achieving higher levels of reliability through the analysis of failures is as old as the engineering profession itself, and cases can be cited there the technique has been used to good effect in the design and construction of cathedrals and bridges, over several centuries, and within modern times to both aircraft and nuclear power plant. This technique involves the study of equipment operating both with and without incident, within real and simulated environment conditions, throughout all predicted modes of operation. The prime objectives of such studies are to identify all potential failure mechanisms and their probable causes, together with an assessment of the probability and frequency of such occurrences. The provision of quality feed back of this nature to the equipment designer is essential, if higher reliability is to be achieved.

In the early stages of development programme a significant quantity of reported electro-submersible pumpset failure data across a number of market sectors, including mining, was collected and studied. Figure 3 shows a summary of mining industry data used, which was considered to be generally representative of the wider set of data which has been analysed. This data indicated that almost 90% of all submersible pumpset failures were attributed to failures within the submersible motor and that 70% of all failures were reported as windings faults. Bearing failures were registered as another principle cause of pumpset failure with almost 80% of these failures occurring within the submersible motor.

The failure reports indicate that the windings faults occurred mainly due to a general overheating of the motor but that loss of motor fluid causing failure of the motor top end windings and damage to the motor bearings was also a contributory factor.

WINDINGS FAULTS (MAINLY OVERHEATING)	**70·3%**
THRUST BEARINGS	**9·8%**
WORN BEARINGS	**6·5%**
SEIZED BEARINGS	**6·5%**
OTHER CAUSES	**6·9%**

Figure 3 Submersible pumpset failure analysis summary (mining Industry

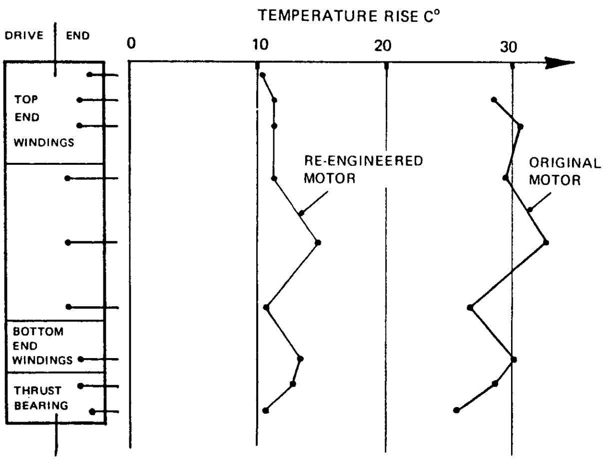


Figure 4 Submersible motor temperature profile

Analysis of such conditions and detailed inspection of units in which they have occurred indicates that vapour cavities within the motor casing can and do occur, which may be transient in nature. The presence of such cavities if they occur either within the bearings or local to the surface of the motor windings may cause degradation and premature failure of these component.

Other factors identified as causing pumpset outages include the harsh operating environment in which some units are required to operate, where corrosive and erosive conditions exist, or where solids in suspension are deposited on the outer surface of the motor, thus preventing the motor heat losses from being effectively discharged to the well water.

SUBMERSIBLE MOTOR RANGE DEVELOPMENT

Having recognised a requirement for a highly reliable submersible pumpset range to satisfy a number of capital intensive industries and heaving researched the failure modes in existing equipment, the authors company embarked upon a lengthy and rigorous development programme, which has designed to achieve a higher level of reliability , than that which currently available in the market place. The aim was to replace our established electro-submersible motor range with one which was engineered to satisfy the highest levels of unit reliability.

Within this development programme various motor engineering configurations were exhaustively tested, using three prototype pumpsets and covering a period of some 4 years. Thermal mapping and thermal gradient analysis techniques developed in conjunction with over power industry products, were utilised in the examination of the laboratory test results.

During the test programme up to 25 pressure and temperature sensors were fitted in a single motor, to measure both the local temperature and pressure gradients within the unit for all modes of operation.

Figure 4 shows graphically a 50% reduction in temperature rise achieved within one the prototype motors, for a given set of operating conditions, through the introduction of new engineering features. Data collected on the pressure distributions throughout this test series confirmed our views on the need to ensure its proper control, if partial evacuation of the motor fluid is to be minimised.

For the third prototype unit which was designed and constructed to incorporate the best combination of all features investigated, a duty was deliberately selected which was 180% of the rating of existing units, to demonstrate the margins of safety which are now being incorporated. This pumpset was installed by the Mines Drainage Unit of British Coal at Nunnerly Colliery, Barsley, ran without fault for a period of 12 months, after which it was returned for examination.

The product improvements for this development programme, which are now well proven both within the laboratory and field tested pumpsets and within refitted earlier models are now described.

MOTOR CONSTRUCTION AND FEATURES

The latest motor design, which is generally constructed as shown in Figure 5, has been engineered together with its associated pump ends, to ensure that the complete pumpset, as a unit, achieves the target levels of high reliability which were set. The principal features are as follows:

a) The improvement of the internal water flow circuit, to minimise local temperature gradients and to promote more effective heat rejection to the well water.

b) A carefully planned pressure filed throughout the motor to minimise partial motor evacuation under transient operating conditions and to provide a more suitable environment for both the windings and bearings.

c) Additional volume of motor fill above the motor top end windings, top eliminate the risk of windings failure which can occur , during transient conditions in which a a vapour cavity is created within the motor.

d) Detailed re engineering at the pump motor interface to reduce the risk of pumpset misalignment and distortion and the introduction of a most effective heat exchanger for the motor, whilst retaining a low hydraulic loss pump inlet section.

e) The heavy tabular casing feature of our existing large machines is now used throughout the motor range to

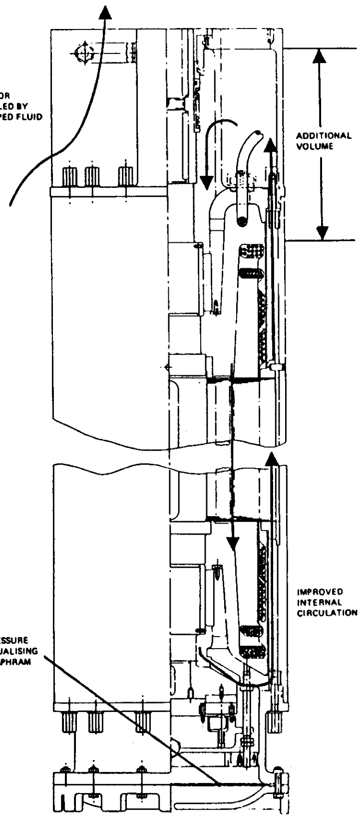


Figure 5 Re-engineered motor

ensure accurate journal bearing alignment at all times. This casing may be supplied either in carbon steel, stainless steel in in bronze dependent upon application.

f) The large area tilting pad thrust bearing with low specific loadings which is a feature of our earlier models has been retained, to ensure that hydrodynamic film conditions exist under all modes of operation.

Finally it cannot be overstated that the highest levels of reliability will not be achieved, unless the pumpset is well matched to the system in which it has to operate. It is therefore most important that extent of the deviation from the rated conditions, which may occur during the life of the pumpset, is well understood. Experience has shown that where supplier and user have worked closely together, to develop a better understanding of the operation of a unit within its system, the result has been improved reliability.