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на тему

ПРОБЛЕМЫ ГИДРАВЛИЧЕСКИХ ТУРБОМАШИН

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MACIEJ ZARZYCKI, JERZY ROKITA

Instytut Maszyn i Urządzeń Energetycznych Politechniki Śląskiej, Gliwice (Institute of Power Machinery and Equipment of the Technical University of Silesia, Gliwice)

ZYGMUNT FROEHLKE

Ośrodek Badawczo-Rozwojowy Pomp Przemysłowych, Warszawa (Research and Development Centre of Industrial Pumps, Warsaw)

Constructional and Technological Problems of Pumps for Thermal Power Engineering

The aim of this paper is to draw attention to the pump problem in thermal power engineering, and especially to the boiler feed pumps, the importance of which rises with introducing ever larger power units into the Polish power plants. The remarks result from an analysis of the world trends as well as the experience gained when designing, constructing and operating the pumps for 200 MW power units mainly used in the Polish power engineering. Besides, the problem of pumps for long-distance hydraulic transport of ash and slag is also discussed in the paper. This problem is connected with the increasing distances to the places of ash and slag storage and therefore the need for working out multistage centrifugal impeller pumps for water mixtures of ash and slag. Some designs of such pumps have been analysed by the authors. The remarks contained in the paper should be helpful for designing and constructing boiler feed pumps for power units of large output and for long-distance hydraulic transport of water mixtures of ash and slag.

1. Introduction

A variety of pumps of diverse application is used in thermal power engineering. Depending on application, these machines differ from each other in respect of design, technology and working parameters. Currently the domestic industry provides in principle all pumps necessary for equipping power units up to 200 MW. However, the problem arose of providing pumps for power units of 360 MW and those of greater output in the future. In addition, due to increasing distances to places of ash and slag storage the problem of long-distance hydraulic transport of such waste also appeared. Therefore, basing on the analysis of the present state of the pump problem in thermal power engineering, this paper deals only with the problems of boiler feed pumps for larger power units and with pumps for long-distance hydraulic transport of water mixtures of ash and slag.

2. Trends in Development of Boiler Feed Pumps

Constant and rapid growth of the Polish thermal power engineering and increase of power unit output affects essentially the design solutions and technological development of boiler feed pumps. Outputs of generators increase from 200 MW to 360 MW and 500 MW. In the future these power outputs of conventional and nuclear thermal power plants will keep increasing. Progress in constructing power plants manifests itself also in changing the medium circulation. As a result the pumps can work under different conditions which also results in changing the design features. The pumps used in these pump systems will have to be characterized by high efficiency and reliability of operation as well as short standstill periods.

The changes which are being introduced into the structure of boiler feed pumps and the problems which should be taken into account in new solutions, are best considered on the example of particular pump subassemblies and components [1, 2, 3, 4, 5].

2.1. Pump casings and tie bolts

Feed pumps for supply of steam boilers are built with the following casings:
— divided in planes perpendicular to the pump axis (sectional casing) (Fig. 1 and 2),
— divided in horizontal plane passing through the pump axis (Fig. 3),
— non-sectional, (Fig. 4 and 5).

The sectional casings are cast with a larger wall thickness or are made as castings with walls of small thickness and strengthened with suitable rings. The pumps are also built with sectional casings divided into low- and high-pressure parts. Pumps with casings divided in the horizontal plane are used in pump systems in which the pressure does not exceed $p = 10$ MPa. Pumps with non-sectional casings have several design variations depending on the method of compensating the internal clearances and mounting the inner components: they can be mounted separately or may constitute a subassembly which can be inserted or taken out as a whole during the assembly or disassembly of the machine.

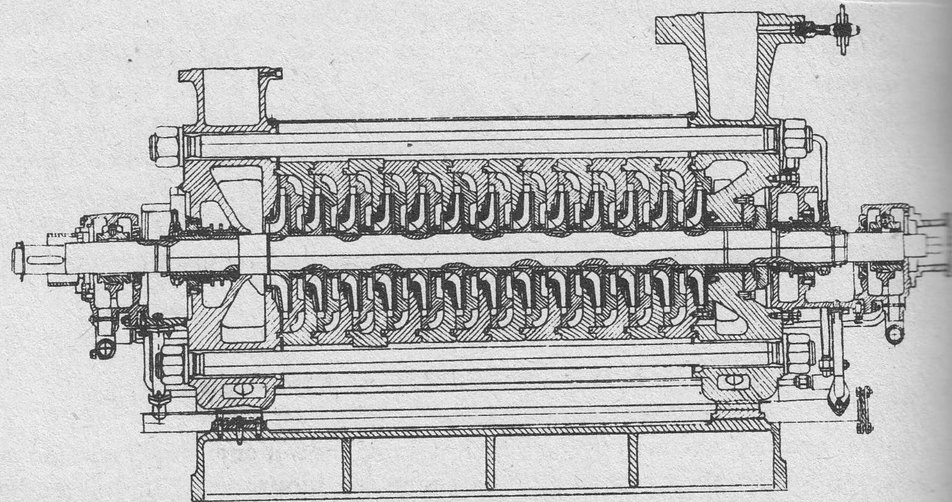


Fig. 1. Type PE250-180 (USSR) impeller pump with sectional casing

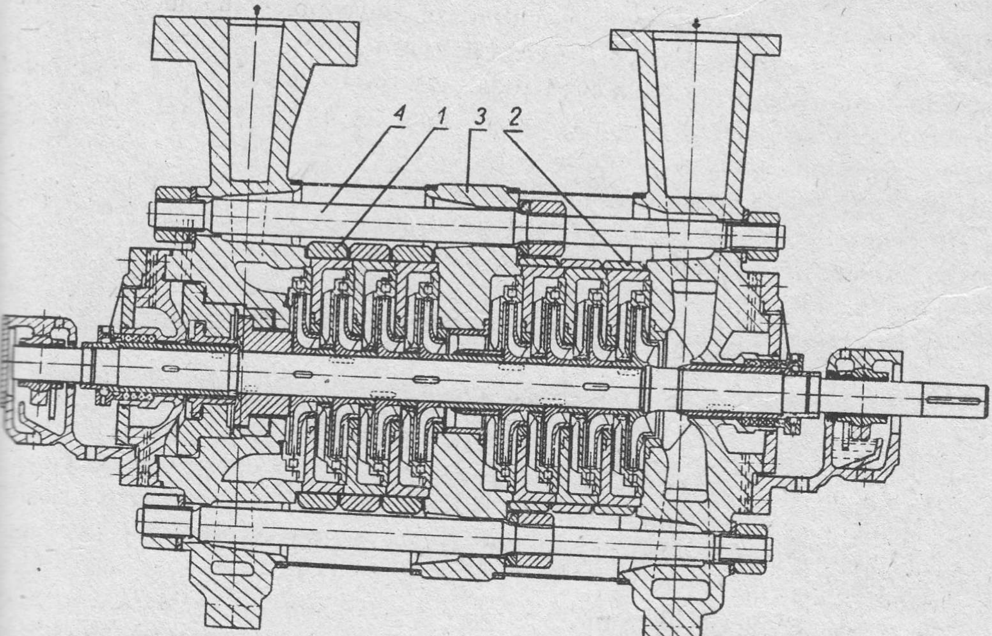
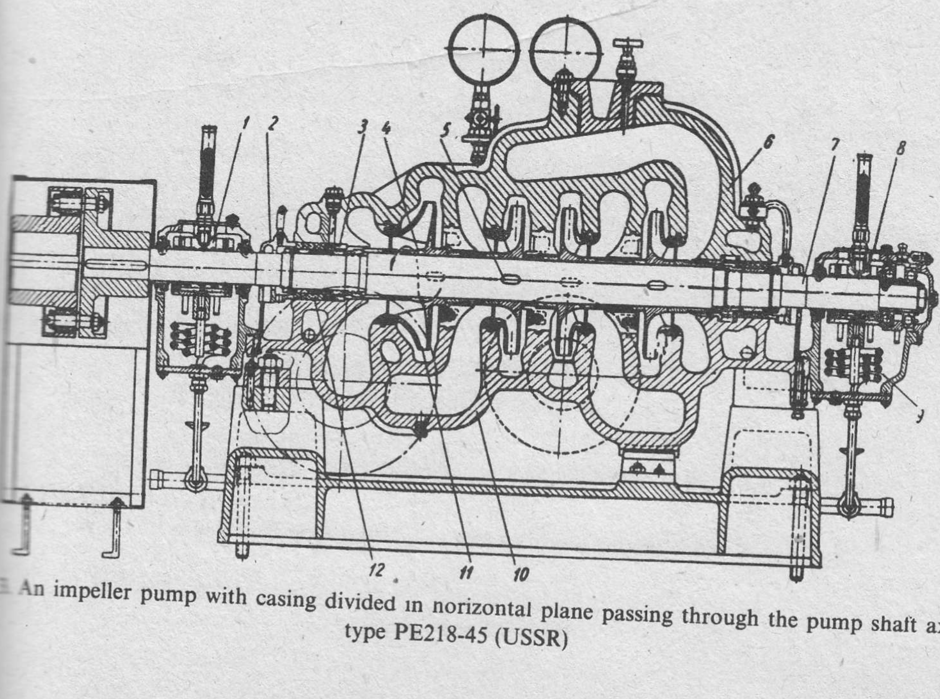


Fig. 2. AKSB (FRG) impeller pump with sectional casing fitted with stiff partition



...3 An impeller pump with casing divided in norizontal plane passing through the pump shaft axis, type PE218-45 (USSR)

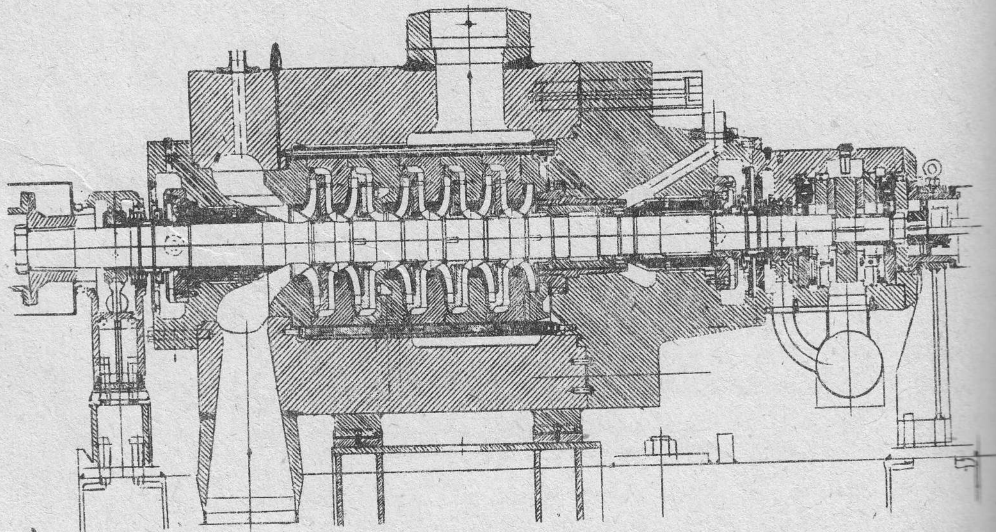


Fig. 4. Sulzer (Switzerland) impeller pump of the HPT type with non-sectional casing

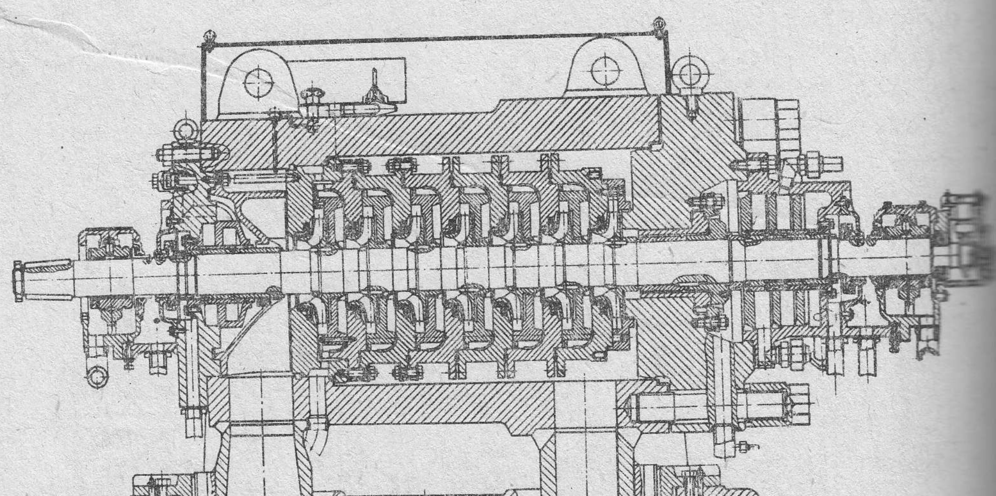


Fig. 5. An impeller pump with non-sectional casing, type PE600-300-3 (USSR)

The design of the casing is determined by the internal pressure and thermal stresses. For this reason sectional casings are generally used when the working medium temperature does not exceed $T = 423$ K (150°C), whereas within the temperature range $T = 423$ to 533 K (150° to 260°C) and higher non-sectional casings are used. Such casings are forged from steel. Presently they are also cast. The cost of cast casings, including the manufacture of a model, is lower by 12% than the cost of forged casings made for the same pump. If the model is used for making e.g. four castings, the cost of making a pump casing is decreased to about 30% [5]. It should be emphasized that cast casings can be designed more correctly from the viewpoint of strength requirements.

Besides, while designing a pump casing one should take into account loads coming from pipes, interaction of casing covers and thermal expansion differences at various points of the casing in transient states.

As it appears from measurements of operating parameters in different points of medium circulation in a power plant, pump casings operate under particularly difficult conditions. For example, for 100 MW power units the temperature difference on both sides of a boiler drum wall in a steam boiler amounts to about $T = 328$ K (55°C), whereas in a pump it can amount to $T = 428$ K (155°C). In transient states, the thermal shock in the pump reaches the value of 823 K/min (550°C/min), while in the boiler drum — only about 300 K/min (27°C/min). The pressure and temperature range for a pump from about $p = 14.0$ MPa to 19.0 MPa and from $T = 509$ to 544 K (236 to 271°C), respectively, while for a boiler drum $p = 11.0$ MPa and $T = 593$ K (320°C).

Irrespective of the above mentioned remarks, the pump design should ensure that the displacement of individual components during pump operation be not larger than several hundredth of millimetre.

In transient states, when the temperature changes rapidly, stresses in the casings are maintained within the permissible limit by adopting such a form of the casing in the area of pump inflow that it acts as an elastic element. The sealing surfaces and those washed with water flowing through at high velocity are protected with coats made of austenitic stainless steel. During pump manufacture, attention should be paid that places of stress concentration have no material flaws.

A separate important problem is the construction of tie bolts. They should be prestressed in order to obtain tightness of individual members of the casing. Selection of material for tie bolts is important in respect of strength, homogeneity of structure, thermal elongations relative to the casing elongation as well as selection of geometrical characteristics of the bolts. It should be borne in mind that during heating and cooling of the pump the temperature of tie bolts is different from the temperature of casing walls. The temperature of the casing upper part may differ from the lower part temperature [5, 2]. For these reasons pumps fitted with non-sectional casings and covers mounted at the pump outlet (discharge) side are predominant. For bolt prestressing hydraulic servo-motors or electric heaters are used. For a dozen or so years the "Weir Pumps Limited" works have been using an elastically strained ring in place of the cover fastening screws [6, 7].

2.2. Rotating unit

While studying the trends in development of boiler feed pumps one observes that the designs aim at increasingly compact and more reliably operating machines. The tendency is to decrease the number of pump stages by shortening the shaft with a simultaneous increase of its diameter. The shaft should have a small deflection and rotational speed lower than the first order critical speed.

Analysis indicates that at high efficiency a delivery head up to $H = 1200$ m can be obtained from one pump stage. However, the structure of a pump with such a high delivery head requires that sufficient distance is maintained between the impeller and the guide vane inflow edge. Such a solution is adopted because of the limitation of erosive effect of stream of liquid having a large flow velocity and a suitable inflow head in order to avoid cavitation. Optimum values of the dimensionless specific speed for impellers mounted on large diameter shafts amount to about $n_{sf} = 70$ to 100 [6].

Due to the large moment transferred by connection of the shaft with impeller two keys are used. The keys are shifted by 90° in each subsequent stage. In newer generations of boiler feed pumps of splined connections with involute tooth profile are used. A part of the impeller hub is hot-mounted in the shaft using some pressure to protect against penetration of liquid between the hub and shaft and to provide coaxiality of the connection. Axial forces are transferred via half-rings. The impeller hub is fitted with appropriate recesses in order to form a heat barrier when mounting and removing the impeller by means of gas burners.

In order to obtain high delivery heads from one stage and thus a small number of stages, high-speed engines or drives via gears are used for driving boiler feed pumps. In high-speed pumps in the diffuser channel there occur pressure oscillations of small amplitude and high frequency during pump operation. These oscillations cause noisy pump work. To decrease the noise level a larger radial clearance between the impeller and guide vanes should be foreseen when designing the pump and a smaller number of impeller and guide vanes should be used.

During the pump design attention should be also given to proper selection of structural materials for shafts and impellers. The structural material (cast chromium steel) should be characterized by high resistance to corrosion and erosion and by suitable thermal expansion coefficients. Statistical investigations indicate that pump failures occur in 74.3% due to the relief system and in 16.7% due to the shaft damage, 7.7% due to casing damage and 1.3% due to bearings [8]. For this reason, the present solutions of boiler feed pumps tend to eliminate axial clearances, increase radial clearances and provide proper shaft stiffness. Elimination of axial clearances in modern pumps for larger power units requires the use of relief drums instead of relief disks. The relief disk is a good solution provided that there is no fear that at low liquid pressure at the inflow (suction) side of the pump there may occur evaporation of water flowing out of the clearance between the disk and counter-disk and "dry" operation. Therefore relief drums are used in new solutions and leakages of liquid, increased in this case, are partly limited by using spiral grooves on the adjacent surfaces.

Adoption of a relief drum (about 90%) and bearing with tilting pads (about 10%) in order to compensate for the axial thrust allows for failure-free "dry" operation of the pump. The diameter of the relief drum is selected so that tensile stress occurs in the shaft within the entire operating range of the pump.

2.3. Glands and bearings

The operating conditions of seals in boiler feed pumps become more and more difficult because the rotational speeds, shaft diameters and pressures acting on the seals increase. In order to improve the operating conditions of gland seals throttling sleeves preceding the seal and hydraulic locks with cold water supply are used. Water supply does not only reduce leakages but also decreases the temperature. Soft packing or — for smaller units — mechanical (sliding) seals [9] are used for seals in glands.

Glands for new generations of pumps tend to have seals shorter in the axial direction (by possible extension in transverse direction) in order to shorten the shaft length to maximum. In newer generations of supply pumps the shaft is sealed by means of floating rings which can work at considerably smaller clearances.

These rings are made of hardened stainless steel (about 17% Cr, 4% Ni) and co-operate with a sleeve covered with hard chromium coating superfinished to the depth $Ra = 0.0002$ mm. Nowadays some manufacturers use tightening seals which in case of pump stoppage considerably limit the water flow.

While designing slide bearings for boiler feed pumps overheating of bearings as well as the phenomenon of oil whirling should be avoided. Therefore in newer solutions bearings of small length (ensuring proper values of side leakages) and of increased clearances are used. In them the bearing bushings attenuate oil whirling [10]. While designing bearing housings attention should be paid to the frequency of housing free vibration and their stiffness in order to avoid the decrease of critical rotational speed of the shaft.

In newer solutions the bearing housing is fixed to the pump casing so that the thermal elongation of the casing may affect to a lesser degree the change of location of the rotating unit in relation to the pump casing.

2.4. Foundation frame

The structural component of the pump unit the importance of which is often underestimated is the foundation frame. Its load is very complex. The foundation frame is subjected to forces due to the driving motor, coupling, pump and possibly the transmission gear weights, forces exerted by pipelines as well as friction forces during shifting of supports (lugs) of the casing in relation to the frame, because of thermal expansion. While designing the foundation frame it should be borne in mind that the frame must be sufficiently stiff and should enable free elongation of the pump in longitudinal (axial) and transverse (radial) direction.

Therefore longitudinal and transverse keys for locating the casing supports in horizontal plane passing through the casing axis as well as possibly high symmetry of the machine casing in both main planes are foreseen. In order to reduce friction losses proper lubrication of friction faces should be provided.

To prevent expansion of foundation frames caused by temperature, frames in pumps for water of temperature over $T = 423$ K (150°C) are cooled.

The foundation frames are made of welded steel plates and then, prior to mechanical working, are subjected to stress relieving. Some of the recently applied solutions enable mounting the pump unit on reinforced concrete foundations with steel plates in the place where pump supports and set keys are mounted.

3. Present State of Production of Pumps for the Power Industry in Poland

At present all the pumps for the Polish conventional power industry are of Polish manufacture (50, 125, 200 MW units, pumps of 15Z28 × 7, HD150 × 5, Hm200 × 3, 15Z33 × 8 types), except for feed pumps for 360 MW units which have so far been imported from the Worthington Works in Italy [11]. In order to eliminate the import of boiler feed pumps for the 360 MW units the ZAMECH Mechanical Works in Elbląg have entered into co-operation with the "Weir Pumps Limited" (England). The production of pumps will be developed gradually until 100% of structural components is made in Poland.

Irrespective of the above the Warsaw Pump Factory in co-operation with the Research and Development Centre of Industrial Pumps in Warsaw have also started their own integrated research and development project concerning the structure and preparation for production of a series of types of supply pumps for large conventional power units (360, 500, 600 MW) and nuclear power units (440 and 1000 MW). The Warsaw Pump Factory is planning also to prepare and start production of a series of other types of pumps for nuclear power plants [12].

Besides, investigations and design and construction work on supply pumps for selected power units are carried out at the Hydraulic Machinery and Equipment Department of the Technical University of Silesia [13] and at the Power Machinery and Equipment Department of the Warsaw University of Science and Technology.

4. Trends in Development of Pumps for Hydraulic Transport of Ash and Slag

The analysis carried out indicates that there exists generally a sufficient number of design variations and sizes [14] as regards low-pressure pumps for hydraulic transport of ash and slag. These are single-stage centrifugal impeller pumps made at the Mining Machine Factory POWEN in Zabrze, types PH(PZ), as well as type MF pumps manufactured at the Industrial Equipment Factory in Świdnica.

At present, however, multi-stage centrifugal impeller pumps are not manufactured and it is necessary to fill this gap as quickly as possible, since the distances of transport from a power station to a waste setting tank (for ash and slag) become increasingly longer. These pumps are expected: to reach considerable delivery head (at rotational speed not exceeding $n = 1450\ \text{min}^{-1}$, and more advisible about $n = 980\ \text{min}^{-1}$), to attain considerable durability and operational reliability as well as to pass solid bodies of required grain size. The above conditions limit the delivery head which can be obtained from one pump stage as well as the assumed pump discharge.

While constructing multi-stage centrifugal impeller pumps additional difficulties arise in comparison with single-stage centrifugal impeller pumps:
— large axial thrust which results in the necessity of using designs compensating the longitudinal forces,
— large pressure drop in glands and flow of abrasive mixtures through the gaps.

Multi-stage centrifugal impeller pumps for hydraulic transport are constructed with a few typical flow systems:
— pump with stage systems in two groups, reversed in respect to each other by 180°, connected in a series (Fig. 6),
— pump with stage systems in two groups, reversed in respect to each other by 180°, parallelly connected (Fig. 7),
— pump with tandem stage system, with a gland after the last stage on the high-pressure side and with relief disk in a separate chamber supplied with pure liquid by the pump (Fig. 8).

Pumps of the first type can have several different structural solutions. They are characterized by balanced axial thrust, which is achieved by dividing the stages into two groups reversed with respect to one another, but the series connection of these groups causes that both the gland at inflow side of the second group and the gland in the centre of the pump between the groups of both stages, must operate at high pressure.

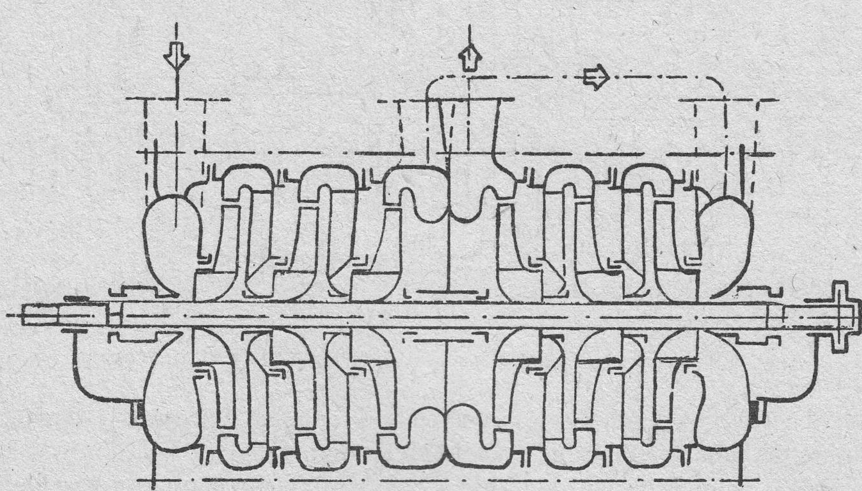


Fig. 6. Diagram of an impeller pump with two groups of impellers, in connected series

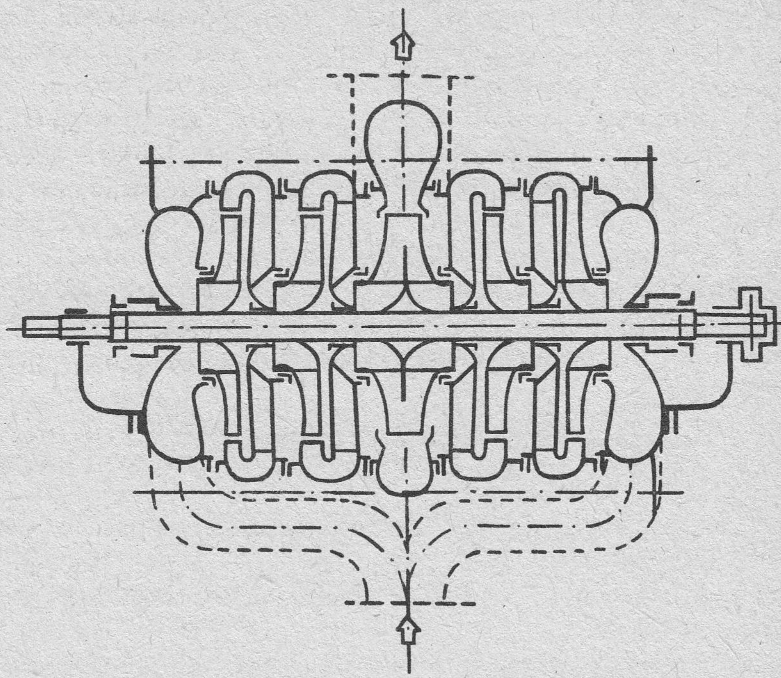


Fig. 7. Diagram of an impeller pump with two groups of impellers, parallelly connected

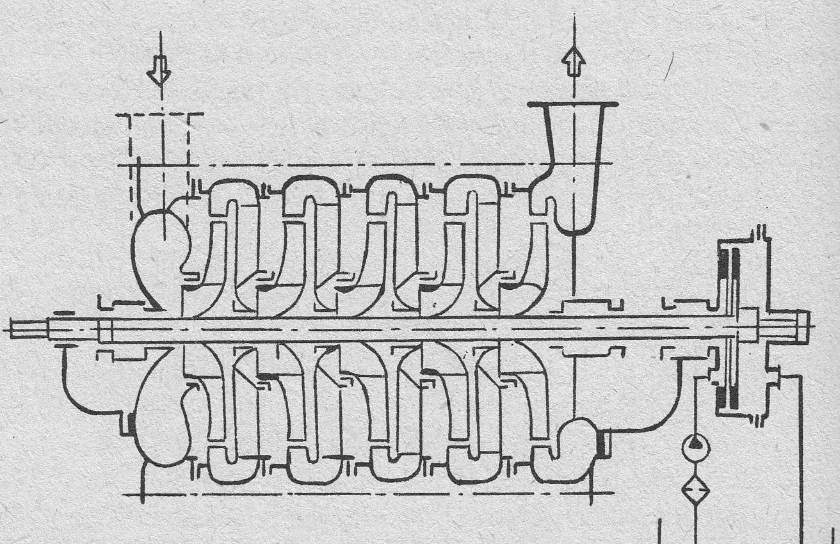


Fig. 8. Diagram of an impeller pump with relief disk in a separate casing

While the external gland can be observed and repaired, if necessary, damage to the gland inside the pump requires disassembling the pump. Such a solution was adopted in type WWB pumps designed at the Coal Mining Construction-Mechanization Works (now KOMAG) at Gliwice and at the Technical University of Silesia in Gliwice

These pumps were built by the Mining Machines Factory POWEN in Zabrze [15]. The experience gained during investigations and operation of these machines is now taken advantage of while designing newer generations of pumps for long-distance hydraulic transport of solid bodies.

The advantage of the designs of the second kind consists in balancing the axial thrust by the symmetry of flow system and the need of using low-pressure glands only. This is the simplest solution. Pumps of this type were worked out at the Chief Institute of Mining in Katowice in co-operation with the Mining Machines Factory POWEN in Zabrze [16].

The advantage of pumps of the third design is the relief disk working in a separate casing and supplied with pure liquid (oil), and hence not exposed to erosion. However, the complicated structure and the necessity of using a gland at the outflow (discharge) side of the high-pressure pump are shortcomings of that design.

At present a pump has been designed according to the third solution and a prototype is being manufactured. Hitherto gained experience suggests that the last design gives good promise of fulfilling the requirements posed before high-pressure impeller pumps for long-distance hydraulic transport systems.

It would be advisable to prepare in the nearest future and implement such pumps with discharges ranging from $Q = 100$ to 500 m^3/h and of $H = 250$ to 300 m delivery head.

5. Notes and Conclusions

Summing up the results of the review and analysis of world trends in the development of construction of boiler feed pumps for larger power units as well as pumps for long-distance hydraulic transport of ash and slag one can determine the main directions of activities as regards working out suitable pumps for the next years.

5.1. Boiler feed pumps for larger power units

Within the range of boiler feed pumps the following recommendations can be suggested:

a) Irrespective of the actually started production of feed pumps for 360 MW power units by the ZAMECH Mechanical Works in Elbląg in co-operation with the "Weir Pumps Limited" in England it is advisable to continue work on independent designs of feed pumps for 360 MW and larger power units foreseen for manufacturing in Poland.

The design and construction work should be carried out on the basis of experience obtained from the hitherto produced pumps or imported pumps operating in Polish power stations. Experience gained during testing of pumps at the ZAMECH Mechanical Works should also be applied.

b) In order to ensure an adequate performance of the pumps manufactured it is necessary to carry out systematical theoretical and experimental (fundamental and applied) investigations, especially within the following scope:
— new methods of calculating and designing flow spaces of pumps, taking into account the three-dimensional state of real liquid flow,
— development of methods of pump components strength calculation,
— improvement of methods of determining logitudinal and transverse (radial) forces,
— investigations of dynamics of rotating systems and pump noise,
— further investigations of cavitation,
— investigations of durability and reliability of pumps and their components under laboratory and service conditions,
— improvement of pump construction from the efficiency point of view,
— automation of pump unit operation.

c) In order to prepare and start production of new pumps for power engineering it is necessary to solve a series of technical problems, such as:
— working out and mastering new technologies of making precise castings of type LOH13N4M and LH18H9T cast steel, characterized by a high surface quality (C20) and dimensional accuracy (class II) as well as small number of surface and internal defects,
— mastering technologies of forged and "plated" pumps casings,
— improving the methods of casting,
— working out new and more efficient technologies for production of pump components,
— use of new structural materials.

5.2. Pumps for long-distance transport of ash and slag

As regards pumps for long-distance transport of water mixture of ash and slag the following notes and conclusions can be made:

a) The necessity of discharging wastes (ash and slag) to places of storage more and more distant from the power stations requires urgent implementation of production of multi-stage centrifugal impeller pumps for pumping ash and slag in a water mixture.

b) A series of pump types should comprise 3 sizes within the range of discharge $Q = 100$ to $500\ m^3/h$ and delivery head $H = 280$ to 300 m. It seems that the most appropriate design solution is the version with a relief disk located outside the flow system and supplied with oil under pressure.

c) It is necessary to intensify the research, design and construction work aimed at verifying in practice the prototype solution and working out subsequent sizes.

d) In order to ensure the adequate durability of pumps for hydraulic transport of wastes it is necessary to continue the research connected with structural materials resistant to erosive activity of pumped mixtures.

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Problemy konstrukcyjno-technologiczne pomp dla energetyki cieplnej

Streszczenie

Celem pracy jest zwrócenie uwagi na problem pomp w energetyce cieplnej, a zwłaszcza na pompy zasilające kotły parowe, w związku z wprowadzaniem do energetyki krajowej coraz większych bloków energetycznych. Uwagi wynikają z analizy trendów światowych oraz z doświadczeń uzyskanych przy projektowaniu, konstruowaniu i eksploatacji pomp dla bloków 200 MW głównie stosowanych w krajowej energetyce. Obok tej kwestii w pracy omówiono również problem pomp do dalekosiężnego transportu hydraulicznego popiołu i żużli. Zagadnienie to wiąże się z wzrastającymi odległościami usytuowania składowisk popiołów i żużli, a w związku z tym z potrzebą opracowania pomp wirowych odśrodkowych wielostopniowych do mieszanin wodnych popiołów i żużli. W pracy przeanalizowano niektóre rozwiązania tego typu pomp. Uwagi zawarte w publikacji powinny być pomocne przy projektowaniu i konstruowaniu pomp zasilających kotły dla bloków energetycznych o większej mocy oraz transportu hydraulicznego mieszanin wodnych popiołu i żużli na duże odległości.

Конструкционно-технологические проблемы насосов для теплоэнергетики

Резюме

Целью работы является обращение внимания на проблемы насосов в теплоэнергетике, а особенно на насосы питающие паровые котлы, в связи со стремлением к применению в польской энергетике всё больших энергетических блоков. Примечания следуют из анализа мировых стремлений, а также из опыта накоплённого в процессе проектирования, конструирования и эксплуатации насосов для блоков мощностью 200 Мвт, в основном применяемых в польской энергетике. Рядом с этим вопросом в работе обсуждается также проблема насосов для гидравлического транспорта золы и шлаки на большие расстояния.

Эта проблема связана с возрастающими расстояниями расположений хранилищ золы и шлаки, а в этой связи с необходимостью разработки центробежных многоступенчатых насосов для водных смесей золы и шлаки. В работе анализируются некоторые решения такого типа насосов. Примечания находящиеся в публикации должны исполнять роль пособия для проектирования и конструирования насосов питающих котлы для энергетических блоков большей мощности и для гидравлического транспорта водных смесей золы и шлаки на большие расстояния.