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ARGONNE NATIONAL LABORATORY

Argonne, Illinois

SODIUM PUMPING - PUMP PROBLEMS

(Pompage du Sodium. Problemes Recontres dans les Pompes Mecaniques)

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General design of sodium pumps

Generalizations

One of the principal advantages of sodium in the cooling of nuclear reactors is its very high boiling point (880^{o}C under atmospheric pressure), a property which, contrary to other liquid or gaseous thermal conductor fluids used in the nuclear domain, enables it to be employed at levels free from the constraints of atmospheric pressure. Apart from the fact that this capability greatly reduces the price of the primary containment of the reactor, the possibility of free levels of sodium or of a thermal conductor fluid at low pressures appreciably simplifies pump technology as well as that of other reactor components.

Actually, the problem of a tight seal at the pump shaft outlet, as well as at the outlet of every other movable part (control rods, for example), becomes a rotating or sliding seal problem between the cooling gas and the surrounding air. Attempts have been made to implement rotating seals in sodium in which, at the shaft outlet point, the sodium is cooled sufficiently to ensure its solidification, thereby creating a tight seal by itself. Sodium which is relatively soft does not greatly impede the shaft rotation but, under the influence of pressure, it has a tendency to flow towards the exterior, a condition which is unacceptable in the case of a radioactive circuit. We will not, therefore, dwell upon this type of apparatus which does not appear to have a great future; rather we will limit ourselves to pumps with free sodium levels.

Ring pumps

The design of these pumps is always very similar to that shown in Figure 1. The "pump" in the strict sense (impeller and diffuser) is situated at the lower extremity of a structure which keeps it completely submerged in sodium. The impeller is turned by a fairly long shaft supported at its upper end by a bearing. The seal attachment mentioned earlier is found directly below the bearing which, therefore, functions in air. The distance between impeller and the bearing is tied to a certain number of constraints, such as the eventual variations in the level of sodium, the thermal protection of the top part of the pump, and the biological protection of the primary pump.

A shaft of such length demands the use of a control bearing at its lower extremity, that is, immersed in sodium. This shaft length poses the problem of the critical velocity of bending. This second problem can be resolved either by the use of a relatively expensive tubular shaft or by the use of an intermediary bearing in sodium. This second solution is used infrequently due to the additional mechanical risks which it presents.

The pump thus conceived is lodged in a sodium tank. The sodium inlet of the pump is lateral and the outlet is axial. The inverse of this placement is sometimes adopted. Each of these solutions has its advantages and disadvantages.

The primary circuit of nuclear reactors is always equipped with several pumps connected in a parallel manner. They are often equipped with a gate valve, designed to eliminate their reversal and a loss of useable output. This gate valve is generally integral with the pump and is located at the outlet. The entire pump-valve apparatus is removable by simply hoisting. The tank is soldered to the piping; the juncture between pump and circuit is made by a slip joint placed on the lower tip of the gate valve or of the diffuser.

Pool reactor pumps

The quest for greater safety led fast reactor project leaders to conceive a type of reactor in which the entire primary circuit is contained in a tank in which the core, the pumps (see Figure 2) and the intermediate heat exchangers are situated together.

Though this arrangement may ensure a reduction in the risks of radioactive contamination, at the same time it imposes new constraints on the primary pumps which are difficult to meet. The integration of all of the primary components in the reactor tank considerably increases its size; of course, the pump designers were asked to achieve the maximum reduction in the radial room required by the pumps.

The most effective way to attain this result is evidently to increase all of the velocities. Such outputs will greatly alter the customary noise level in the pumps. In other words, if the second generation fast reactors are employed as industrial prototypes, they will still be research tools. Their characteristics are greatly taxed and there exists a notable danger of local boiling of the sodium in the core.

The temperatures reached on the one hand, and the opacity of the sodium on the other hand, make acoustical observation practically the only useable study technique. It is easily seen that a cavitation in the pump can mask the phenomenon under study. Research on the correlations between the conditions for the appearance of cavitation in water and in sodium has unfortunately not progressed to the point where it is possible to predict with certitude the operating limits in sodium without cavitatation. Designers are only able to create a pump capable of very high output in water.

Special care was given to the study of the pump environment, in terms of the ingress of gas into the fluid, as well as to the choice of the space between the impeller and the diffuser, for the following reasons: to avoid hydroelastic phenomena from being created in the upper or lower structures of the pump; to ensure that the fluctuations in pressure at the exit of the impeller do not place a radial load on the hydrostatic bearing.

The pump is lodged in the ring-like space defined by the main tank and the primary tank of the reactor. Sodium comes from two heat exchangers placed on both sides of the pump. Under these conditions, the detection of a homogeneous discharge at the entrance of the impeller is impossible without certain precautions. The collection of sodium at the bottom of the tank by a means of skirt with a vertical axis which constitutes a converging canal from top to bottom is an effective solution which furthermore prevents cold sodium from collecting in the bottom of the reactor.

Finally, the operating staff of a primary pump make great demands when it comes to the risk of the ingress of argon gas by vortex-rings which can appear on the free surface. This phenomenon is dangerous for the reactor because the passage of a gas bubble in contact with the fuel pin cladding provokes a discontinuation of cooling sufficiently major to cause local melting. Protection from such an eventuality is afforded in part by ensuring that the pump inlet remains sufficiently immersed during all of the operating conditions of the reactor, but also by limiting as much as possible the ring-shaped space included between the pump and the fixed structures situated above the inlet. This approach is limited nevertheless by the fact that the pump and these structures are affected by relative displacements due to the differences in the radial expansion of the reactor cover and of the girder.

Superposed on this purely radial displacement is a rotation of the pump axis which does not remain vertical. The reactor slab on which the pump motor rests actually is deformed to an appreciable extent from the state corresponding to a cold start-up to the nominal configuration in which it bears the mass of the core, of sodium, and the components that are supported by it.

Added to these horizontal displacements are the vertical displacements which originate the same way along with other displacements due to the movement of the structures.

At the level of the tip of the pump outlet, the total of these displacements reaches several centimeters and presents the problem of the hydraulic linking of the pump to the pump outlet piping. On certain reactors this problem is resolved by the presence of a flexible member but this solution could lead to vibrations of the structures. The oscillating sleeve with which the pump is equipped, represented in Figure 2, makes it possible to eliminate this risk.

Secondary pumps (see Figures 3 and 4)

The secondary pumps each installed in the expansion reservoir of its corresponding loop also pose problems of good hydraulic feeding that are nearly as delicate as those previously studied.

These secondary tanks actually function not only as expansion reservoirs and gas ingress basins for the pumps but they also serve as members for the absorption of high pressures in the circuit which can be the result of accidental sodium-water reactions in the steam generator. The steep high pressure pulses that are the result, then the low-pressure pulses steeper yet which follow the rupture of the shield walls must not, at all costs, propagate through the secondary pumps to the intermediate heat exchangers which are not prepared to handle them. This fact has influenced the geometry of the entire environment of the pumps inside the secondary tank and led to requiring the discharge flow to pass near the free surface before entering the pump. This logic accounts for the positioning of the pump. This proximity to the free surface can induce the fear of dragging in argon, a phenomenon to be avoided for proper functioning of the hydrostatic bearing. A hydraulic test on a scaled down model of the entire tank structure has enabled the elimination of this risk.

It is very evident that the function of absorbing the high pressures which the secondary tank provides could have been fulfilled by another structure at the free level placed at the exit of the steam generator, such as is done, as a matter of fact, at its other end. Above all, it was with the purpose of simplifying the circuit that this function was relegated to the pump environment.

Diverse Technological Problems linked to the Presence of Sodium

Sodium bearings

Thanks to the vertical placement of the pumps, the pressures withstood under normal operating conditions are small. They can nevertheless reach high values in the case of an earthquake.

Attempts have been made to devise classic bearings of a hydrodynamic type, but hydrostatic bearings meanwhile are in use everywhere. This fact is easy to understand if we remember that the viscosity of sodium at the temperatures under consideration is on the order of 50 to 100 times weaker than that of a flowing lubricating oil. Under these conditions, the creation of a hydrodynamic film capable of a substantial lift would lead to the use of very large shafts. Moreover, because the risk of friction at start-up implies the use of costly cladding, it appears that a hydrostatic bearing constitutes a more rational solution. The lift of this bearing is assured by the outlet pressure of the pump. It is evidently very small at start-up, but the technology is available today to produce relatively small bearings which reach a stable operating state at less than 10% of the nominal speed of the pump.

Swivel joints of the oscillating annulus

The development of swivel joints capable of absorbing a displacement simultaneously angular and axial while assuring a very small leakage under several bars of pressure is a good example of the problems that the presence of sodium makes particularly difficult to resolve. Actually, in this fluid no plastic material used can be counted upon and metal to metal contact, which under operating conditions occurs with a very high friction level, can cause uprooting, a phenomenon which must be avoided at all costs since one of the seal mechanisms is located in the reactor. Thanks to the joint utilization of extra strong cladding and very precise manufacturing tolerances, these mechanisms were able to be perfected.

Thermal shock loads

Thermal shocks occur in all types of reactors when the control rods fall. They are more violent in the case of fast reactors in sodium by the fact that the temperatures at the core outlet and the corresponding ΔT are clearly higher than in water reactors and, furthermore, the thermal diffusity of sodium is much greater than that of water (on the order of 500 times). The number of these thermal shocks is evaluated by function of the number of incidents estimated during the life of the reactor. It is up to the designer to take adequate precautions so that the pump can withstand them. There are two types of steps to be taken: first, the greatest symmetry possible is desirable in the pump because it permits it to be free of distortions; secondly, the diminution of the thicknesses leads to a reduction of the thermal stresses.

This second measure becomes difficult to respect, however, with the rapid increase in the size of the pumps. Particularly, for the large foundry parts, it is not only difficult to retain small thicknesses, but also to obtain parts which are completely free of defects which the internal stresses caused by thermal shock loads multiply until the parts rupture.

Conclusion

The first generation of sodium pumps put into operation on experimental reactors has shown (when rightfully it must be noted that a higher frequency of incidents was expected) that the pumps achieved a very satisfactory rate of availability. Excluding incidents of an electrical origin, the availability surpassed 99% for the pumps of the Rapsodie reactor.

Their endurance is confirmed every day since certain pumps have attained 40,000 operating hours and after this length of service their essential parts are still in excellent shape.

This good behaviour well permits the prediction of usage of the second pump generation on which tests in sodium will take place during the course of 1972.

The experience acquired during the course of these studies and during the creation of these pumps has already enabled us to define the essential traits of pumps destined for the future 1000MWe reactor and to evaluate the major difficulties which their creation may present.

These pumps which represent, in comparison to the pumps of the Phénix reactor an extrapolation of a factor on the order 3 in the amount of output, will be characterized by a slightly different design which will be capable at the same time of solving the problems previously described and of responding to the economic imperatives which will be of prime importance for future power reactors.

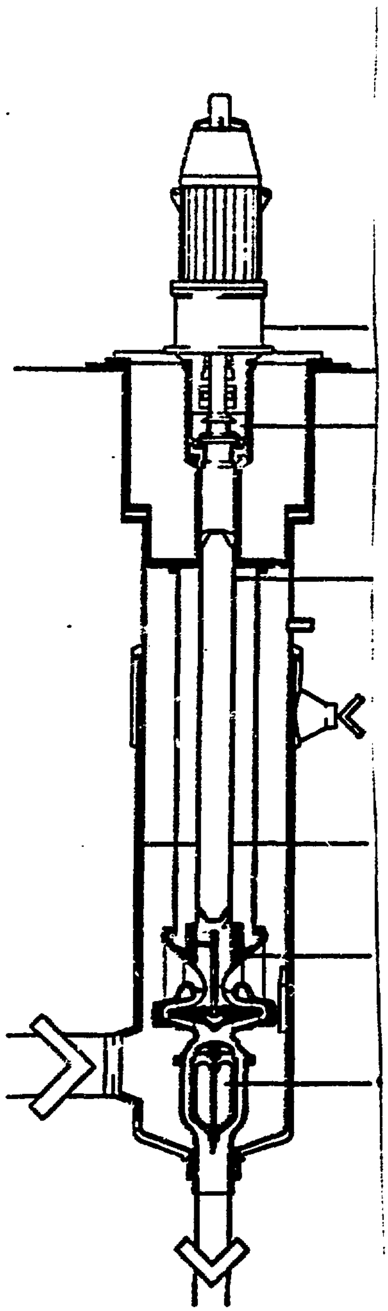


Fig. 1. Cross-section of a Rapsodie Type Primary Pump

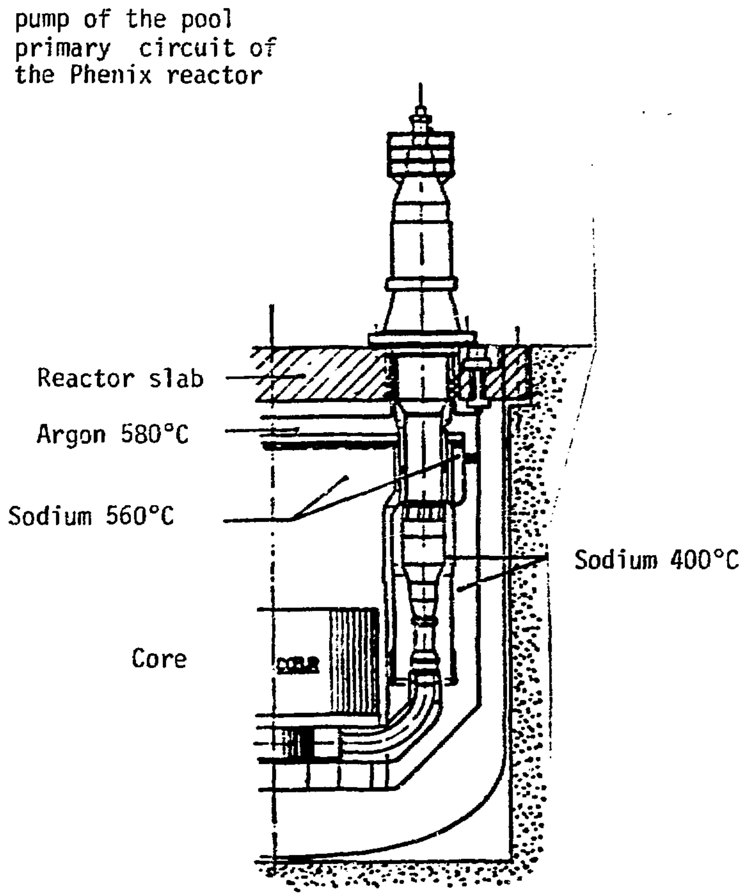
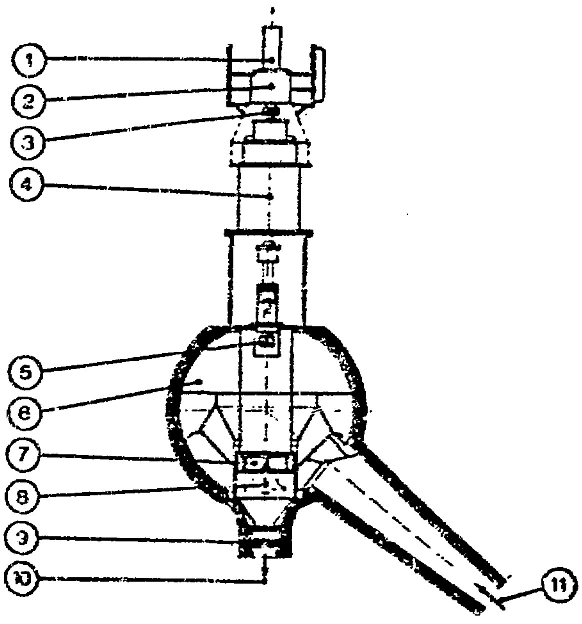


Fig. 2. Positioning in the Reactor of a Phenix Type Pool Pump



1. Auxiliary Motor
2. Reduction Gear
3. Clutch
4. Main motor
5. Butee et Joints Tournant
6. Expansion Vessel
7. Pump inlet
8. Impeller
9. Seal
10. Sodium outlet
11. Sodium inlet

Fig. 3. Expansion Reservoir and Secondary Pump

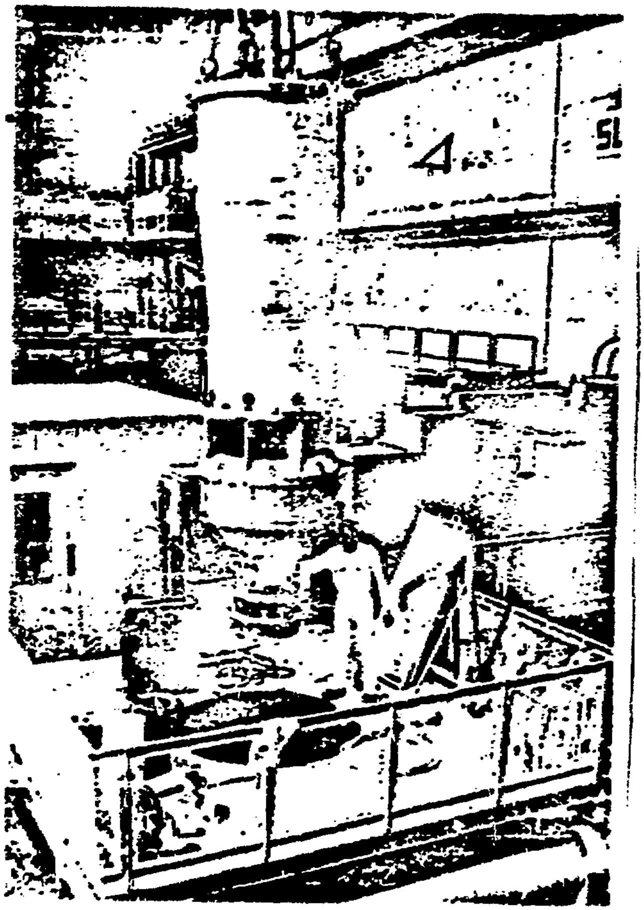


Fig. 4. Phenix type Secondary Pump