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BEARING AND SEAL REQUIREMENTS FOR LARGE
LIQUID-METAL COOLED REACTOR SYSTEMS*

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SUMMARY

Bearing and seal technology is well advanced in the components to which it has been applied. So far, it has been concentrated primarily in the mechanical sodium pumps; an order of magnitude extrapolation in pumping capacity will be required for prospective plants, which in turn requires technology extrapolation and extensive tests to assure satisfactory performance. Some additional applications of bearings and seals are possible if they are economically justified, although at least partially satisfactory substitutes are currently available.

INTRODUCTION

Fast breeder reactors of power levels of 1000 Mwe or greater are presently considered to be necessary for the continued conservation of nuclear resources in an expanding nuclear power economy. Component requirements in the large future systems transcend any experience now available; the largest sodium cooled reactor built to date has a design power of 300 Mwt, with components sized to meet this power generation capability. Therefore, an order of magnitude extrapolation in component size for power generation at about 2500 Mwt is a near term objective.

Sodium, because of its high chemical reactivity, and its rather poor lubricating qualities is not suitable for anti-friction bearings. Consequently, sodium systems have demanded bearings lubricated by the

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working fluid and rotating seals to retain inert gas over the sodium wherever mechanical shafting had to be introduced into the heat transfer systems, almost since the inception of sodium cooled reactors. Sodium also becomes highly radioactive in the primary circuit. While this does not affect the bearing performance, it does introduce stringent requirements for reliability, accessibility and repairability. In small plants, the requirements could sometimes be dodged by devices such as frozen sodium shaft seals which permitted conventional bearings to be used outside the sodium, with varying degrees of success. However, with the advent of even the moderately large plants constructed to date, it has become apparent that at least for pumps the impeller and shaft must be stabilized by sodium lubricated bearings. This automatically requires the use of a rotating shaft seal to retain inert gas over the sodium in the pump casing; we are faced again with a large extrapolation from current practice.

CURRENT APPLICATIONS

Bearings

The largest sodium pumps built to date have been installed in the Enrico Fermi Fast Breeder Reactor, with a capacity of approximately 11,000 gpm. These have been operated quite satisfactorily, indicating that the principle of sodium lubricated bearings is a sound one. The bearing dimensions for these pumps are 12-in. diameter and 14-in. length. The six pumps installed at the Hallam Nuclear Power Facility, of 7500 gpm capacity and identical bearing size, have operated equally satisfactorily for a total of 70,000 hours on all pumps.

The bearings in sodium main circulating pumps to date have been hydrostatic, supporting only the radial loads imposed on the shaft. High pressure sodium supplied to the "pads" is furnished from the discharge of the pump, with 1 to 4% of the total pump flow being bypassed through the bearing to the suction side of the pump. Bearing sodium is relieved into the free surface volume of the sodium above the pump impeller and flows back to the suction side of the pump through an overflow line and

pressure balancing "weep holes" in the impeller. Radial loads of up to 120 lb force have been sustained by these bearings, which operate in the turbulent regime. No attempt has been made as yet to sustain thrust loads by such bearings; these are typically absorbed by roller or duplex ball bearings located above the rotating inert gas seal, where they are available for inspection and receive ordinary oil lubrication. Journal surfaces are hard faced to prevent galling during startup and shutdown with evident success; in the case of the Hallam pumps, inspection after 250 starts and stops showed no measurable wear and only slight polishing of the surfaces. Experimental evidence has been adduced which indicates that bearing stabilization and "lift off" from the rubbing surfaces takes place after less than one revolution of the shaft. Because of the success of this design on the pumps constructed to date, this type of bearing will undoubtedly be at least one of the reference designs for the 60,000 to 120,000 gpm pumps now under consideration. There are, however, obvious unknowns in extrapolating this bearing performance to the rather larger shaft sizes envisioned. The design parameters of these larger pumps have not yet been firmly fixed. It is reasonable to expect, however, that bearing journal diameters of at least 20-in. will be required. Shaft rotating speeds will probably not be substantially different from the 500-1500 rpm commonly utilized now, but it is obvious that the lineal velocity at the bearing surface will be substantially higher due to the increased bearing diameter. These pumps will be used in commercial power plants, where any loss of efficiency means an increase in parasitic plant load, which in turn means internal consumption of power which cannot be sold at a profit. Efficiency is thus a matter of great interest, particularly when one is considering pump drivers of 5-10 Mw in power. Bearing design thus assumes one of the critical roles in plant design and pump selection, which must be done on the basis of economics and reliability. A high bypass flow and/or a high bearing drag will contribute a significant efficiency loss to the plant with a measurable economic penalty. There are other types of pumps which can be utilized for moving sodium which are currently less efficient than mechanical pumps, but whose other potential advantages may prevail should the mechanical pump efficiency fall undesirably low. Therefore, it should not be assumed that

free surface mechanical pumps with sodium lubricated bearings are the only possible choice regardless of their mechanical design and efficiency. For instance, small canned motor pumps have been used in sodium to a limited degree; these utilize hydrodynamic bearings and have apparently been satisfactory although their cost has been quite high compared to shaft sealed overhung impeller pumps which can perform the same service. Bearings are probably not the key to reducing cost in this case; electrical insulation is a more likely candidate for cost reduction.

Seals

An inert gas blanket must be maintained over the sodium pool within the free surface pumps. This gas is normally argon, in fast reactors, which is maintained at 1 to 5 psi over atmospheric pressure, to permit outleakage of argon rather than inleakage of air in case of seal failure. In addition to minimum inert gas leakage, the rotating seal must not permit any contaminants to enter the sodium stream. Oil lubricated face type seals must be carefully designed so that the lubricant is trapped before it can leak down the pump shaft, and the oil volume should be arranged such that the traps can contain any conceivable amount of leakage. Carbon is quite deleterious to sodium systems, carburizing and embrittling thin stainless steel sections such as fuel cladding, and its introduction into a sodium system must therefore be avoided. It is possible to find non-carbon bearing lubricants; the effects of their decomposition products in sodium has not, to my knowledge, been completely explored. The simplest course is therefore to assure that potential contaminants cannot escape from the seal into the sodium.

Rotating seals utilized in large mechanical sodium pumps to date have been carbon faced, oil lubricated, operating on shafts up to 6-in. in diameter. Again, a substantial extension of technology is required when considering this type of seal for shafts up to 10-in. in diameter. Present seal technology is demonstrated at lineal speeds up to about 30,000 inches per minute; whether this experience, technology and manufacturing practice for flatness, finish, etc., can be extended by factors of 2 to 3 satisfactorily has not been established. Complete reliability for at least

10,000 hours of operation at speeds of 1500 rpm is required, as the seal is essential to pump operation, and the reactor system cannot operate without pumps. It will be necessary to perform both analysis and extensive tests to ensure that this critical component meets the requirements of economy, reliability, and tightness to gas and lubricant leakage which are required for performance in the central station fast breeder reactors of the future.

POTENTIAL APPLICATIONS OF BEARINGS AND SEALS

Bearings

Some possible additional applications of sodium lubricated bearings come to mind, providing the technology permits. It should be understood that these are not necessarily recommended applications, and that reasonably suitable equipment now exists. The examples cited must offer significantly improved reliability and/or cost advantages to be seriously considered. The first of these is in turbine type flowmeters, completely immersed in the sodium stream. These are not now practical primarily because of the bearings, which cannot be lubricated by anything but sodium. There is no source of high pressure sodium for these small bearings as in the pump case; a hydrodynamic bearing might possibly be suitable if the cost and complexity can be reduced to where such a flowmeter would be competitive with the electromagnetic type (which suffers from lack of accuracy in large pipes) and the differential pressure type (which suffers from lack of accuracy due to imperfect pressure measurement). A considerable amount of ingenuity will also be required in the electrical insulation and connections to a turbine flowmeter in sodium, even if the bearing problem is solved.

It is also possible to conceive control and safety mechanisms which could operate at reasonably high speeds in sodium, providing adequate bearings were available. As it is, all bearing surfaces are normally kept out of sodium and sodium vapor atmosphere, with the possible exception of surfaces which slide or roll quite slowly over one another. Sliding and rubbing under sodium, or in sodium vapor, has proven to be most unrewarding to date, although development along this field is

continuing. A "canned motor" drive with sodium lubricated bearings is conceivable, although many other problems such as electrical insulation would face the designer.

Seals

Any time a sodium system is penetrated, it is necessary to utilize a seal. Normally, the seal must retain inert gases containing sodium vapor. The main sodium coolant pumps are the prime examples. Control rod drive mechanisms, which usually penetrate the top of the shield, are excellent candidates for improved seals. Currently, the problem is sometimes dodged by isolating the operating mechanisms from the reactor atmosphere by a bellows which operates only in (vertical) linear motion. This is not always desirable, due to the questionable integrity and lifetime of thin-walled bellows with large extension ratios. This problem has also been dodged by containing the whole control mechanism, including the absorber column, in a "thimble" thus isolating the complete unit from sodium and cover gas. This is wasteful of neutrons, and is often rather clumsy in a small, high power density, reactor core. Therefore, a reliable rotating seal, operating at modest speeds up to perhaps 100 rpm, which can be depended upon to permit the escape of cover gas containing radioactive sodium vapor and maintaining close alignment throughout its lifetime, may well find application in drive and safety mechanisms for sodium cooled reactors.

So far, sealing against sodium directly has been most successfully accomplished by a frozen sodium annulus, such as in valve stems. Cooling is either by air or a liquid jacket. This method of sealing does introduce a necessity for periodically exercising the valve stems to break up sodium oxide deposits which may form. Also, of course, some small amount of sodium oxide is deposited on the shaft each time the valve is operated, thus making operating force erratic. So far, this has not proven difficult to handle, requiring only a sufficiently energetic valve operator. These are normally electro-mechanical or pneumatic. An economical seal, with constant force characteristics and which can be depended upon to reliably seal high temperature sodium from the atmosphere in translation and/or rotation would be highly desirable.