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SURVEY OF
SODIUM PUMP TECHNOLOGY
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Prepared for the New York Operations Office
U. S. Atomic Energy Commission
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June, 1963

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ABSTRACT

This report reviews the current status of sodium pump development as related to nuclear power applications. The report includes a description of the design features and performance characteristics of the more important types of sodium and sodium-potassium alloy (NaK) pumps. Some requirements for sodium pumps for future large liquid metal reactor systems are presented with some preliminary consideration of the potential of various pump types to meet these requirements.

ABBREVIATIONS

REACTOR OR PROJECTS

ANP	Aircraft Nuclear Propulsion
BR-5	Breeder Reactor (No. 4)
DFR	Dounreay Fast Reactor
EBR I	Experimental Breeder Reactor (No. 1)
EBR II	Experimental Breeder Reactor (No. 2)
EFAPP	Enrico Fermi Atomic Power Plant
HNPF	Hallam Nuclear Power Facility
LAMPRE	Los Alamos Molten Plutonium Reactor Experiment
SCT	Sodium Components Testing (facility)
SGR	Sodium Graphite Reactor
SRE	Sodium Reactor Experiment

ORGANIZATIONS

AC	Allis-Chalmers Manufacturing Company
AEA	United Kingdom Atomic Energy Authority
AEC	United States Atomic Energy Commission
AERE	Atomic Energy Research Establishment (Harwell)
AI	Atomics International
BJ	Byron Jackson Pumps, Incorporated
CEA	Commissariat à l'Energie Atomique
GE	General Electric Company
KAPL	Knolls Atomic Power Laboratory
LASL	Los Alamos Scientific Laboratory
MSA	Mine Safety Appliance Company
NAA	North American Aviation, Incorporated
NRTS	National Reactor Test Station
ORNL	Oak Ridge National Laboratory
PRDC	Power Reactor Development Corporation
PWAC	Pratt and Whitney Aircraft
USN	United States Navy
ANL	Argonne National Laboratory
CPPD	Consumers Public Power District

TECHNICAL

HP	Horsepower
GPM	Gallons per minute
NPSH	Net Positive Suction Head
MWt	Megawatts (thermal)
MWe	Megawatts (electrical)
Na	Sodium
NaK	Sodium-Potassium alloy

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D. R. Nixon

C. C. Randall

1.0 SUMMARY

The current status of sodium pump technology as related to use in the nuclear power industry may be summarized as follows:

- A. Over 75 mechanical liquid sodium pumps have been constructed as of March, 1963. The fluid horsepower ratings range from 2-1000 HP with capacities up to 13,000 GPM. Over half of these units employ oil lubricated mechanical face type gas shaft seals. Maximum efficiency obtained is 77%.
- B. Over 400 electromagnetic sodium pumps have been constructed as of March, 1963. The fluid horsepower ratings range from less than 1-440 HP with capacities up to 10,000 GPM. More than half of these units are small (less than 2 FHP) AC conduction pumps. Efficiencies up to 43% have been obtained on large AC linear induction and DC conduction pumps.
- C. A mechanical-electromagnetic (helical rotor) liquid sodium pump, rated at 1000 fluid HP, has been constructed for circulating 3000 GPM with an efficiency of 28%. Efficiencies of 44% have been estimated for larger units of this design.

Future requirements of the nuclear power systems are estimated to include pumps of over 100,000 GPM with fluid horsepower requirements of up to 8200 HP. Based on the review of current technology the only pump types that appear to be economically and technically feasible in sizes larger than approximately 50,000 GPM are the following:

- 1. Free surface mechanical shaft seal.
- 2. Canned rotor.
- 3. Canned motor (totally enclosed).

2.0 INTRODUCTION

This report reviews the existing status of sodium pump developments which are related to use in nuclear power systems. The work reported herein was performed as part of an initial phase of a study for the Atomic Energy Commission under Contract AT(30-1)-3123, which covers a conceptual design of a sodium pump test facility, and a sodium pump development program.

This report includes a summary of the design features, technical specifications and performance characteristics of the more important sodium and NaK pumps. The report was compiled from a review of the unclassified literature, supplemented by private communications and discussions with individuals and organizations currently or recently active in the development of sodium pumps or systems utilizing sodium pumps.

The body of the report is organized according to pump design type. All pertinent information on a single type is grouped within a single section.

3.0 BACKGROUND

3.1 SODIUM PUMP DEVELOPMENTS

Over the past 15 years, the pumps for circulating liquid metals for reactor cooling have been designed and built as the needs arose. For initial experimental reactor and heat transfer work, pumps of various designs were provided, but only a minimum of emphasis was placed on their design requirements. As reactor technology progressed, so did the need for larger and more reliable liquid metal pumps. In response to these requirements both mechanical and electromagnetic pumps with capacities up to 10,000 GPM have already been built for the reactors listed in Table 1. The general requirements which have affected the design of sodium pumps for these reactor plants are:

1. High temperature
2. Leakless or near leakless operation
3. Low maintenance
4. Good efficiency
5. Adequate NPSH
6. Size, weight and pump location
7. Reliability

3.2 SODIUM PUMP TYPES

From a purely hydraulic standpoint, the mechanical pumping of sodium is similar to pumping water. In addition, the good electrical conductivity and permeability of liquid metals makes it possible to pump sodium by electromagnetic means.

Sodium pumps may be classified by types as shown in Fig. 1. The subsequent sections of this report will deal with various types in accordance with the classification.

The mechanical pumps are usually centrifugal units with a suitable rotating drive equipped with either a shaft seal or an enclosed motor to prevent sodium or inert cover gas leakage.

Electromagnetic pumps are units which produce a pumping force by the interaction of a current produced in the liquid metal and a magnetic field. They have no moving parts other than the flowing liquid and are completely hermetic.

Mechanical electromagnetic pumps combine both mechanical and electromagnetic principles by mechanically moving a magnetic field in the proximity of a conductive liquid. The field travels through the liquid and induces eddy currents within the liquid which interact with the magnetic field to produce a force on the liquid.

SODIUM COOLED REACTORS

Date	Reactor	Location	Operator	Type	Power (MW) t/e	Coolant Temp. Max.	Pumps	
							Primary	Secondary
1951	EBR-I	ANL	AEC	Test	1.5/ -	NaK 662 °F	1 DC EM	-----
1955	SIG	West Milton	KAPL	Sub Proto	-----	Na	()	()
1956	S2G	Seawolf	USN	Sub Prop.	-----	Na	()	()
1957	SRE	Santa Susana, Calif.	AEC/AI	Power	20/6	Na 960 °F	2-Mech Freeze Seal	2-Mech Freeze Seal
1957	BR-5	Obninsk	(Russia)	Test	5/ -	Na	-----	-----
1959	SNAP 2	-----	AI	-----	-----	Na	Perm. Magnet EM Pumps	
1959	DRF	Dounreay, England	AEA	Power	60/15	NaK 662 °F	24-AC EM	24-AC EM
1959	BN-50	Ulyanovski	(Russia)	Power	-/ 50	Na	-----	-----
1961	EFAPP	Detroit	PRDC	Power	300/100	Na 800 °F	3-Mech Free Surface Gas Seal	3-Mech - Gas Seal
1961	EBR-II	NRTS	AEC	Power	62/ 20	Na 900 °F	2-Canned Motor. Totally Enclosed	1-AC EM
1961	Lampre I	LASL	AEC	Test	1/ -	Na 900 °F	2-EM	-----
1962	HNPF	Hallam, Nebr.	CPPD	Power	240/ 76	Na 945 °F	3-Mech Gas Seal	3-Mech Gas Seal
1963	Rapsodie	Cadarache, France	CEA	Test	10/ -	Na 645 °F	-----	-----

TABLE 1

FIG. 1 PUMP TYPES

4.0 MECHANICAL PUMPS WITH SHAFT SEALS

Mechanical pumps with some form of shaft seal are a widely used and efficient means of pumping liquid sodium. The most commonly used design consists of a vertical centrifugal pump operating with a "free surface" of sodium in the pump casing. A mechanical shaft seal separates a low pressure inert gas covering the surface of the sodium from the normal atmosphere.

Pumps of this design are characterized by conventional centrifugal pump hydraulic performance and efficiency and utilize conventional drive mechanisms.

The disadvantages associated with this type of pump for reactor service are primarily the restriction on location and attitude required to maintain a "free surface" in the casing and the inherent limitations of flow control by conventional variable speed drive systems.

Maintenance requirements are primarily those associated with the shaft seals. For oil lubricated face type seals, six months to a year of service life without maintenance is typical.

4.1 MECHANICAL SHAFT SEALS

When using an inert gas blanket, i.e. "free surface" design, the seal materials are not attacked by hot liquid metal and the seal surfaces can then be oil, gas or dry lubricated. The majority of seals used with this type of design have been oil lubricated face type seals. Attempts made to seal the liquid metal directly have resulted in excessive leakage because of oxide formation on the seal faces, lack of lubrication by liquid metals, and chemical attack.

FIG. 2 MECHANICAL SHAFT SEAL PUMP

Approximate Maximum Overall Pump
Efficiency -80%

Special Auxiliary Systems Required

Inert gas supply to "free surface"
Oil supply to seal

Advantages

High overall efficiency
Conventional motor drive

Disadvantages

Attitude limitations imposed by
"free surface" design
Seal maintenance

Applications

See pages 9 and 10 for Table 2.

References

Byron Jackson, Allis Chalmers, General Electric and ORNL have had the bulk of the manufacturing and test experience with oil lubricated shaft sealed liquid metal pumps. The HNPF and EFAPP pumps are equipped with these seals.

- (1) Reactor Auxiliary Systems Unit V-12 Liquid Metal Pumps, Personnel Training Manual for Enrico Fermi Atomic Power Plant Prepared by Commonwealth Associates, Inc., Jackson, Mich., 1960.
- (2) NAA-Sr-4336 Performance of HNPF Prototype Free-Surface Sodium Pump by R. W. Atz, 1960.
- (3) KAPL-635 Mechanical Liquid Metal Pumps in the Alplaus (Genie) Heat Transfer System by P. M. Clark, 1951.
- (4) Pumps for High Temperature Liquid Systems by H. W. Savage & A. S. Grindell, 1961. ARS Space-Nuclear Conference, May 1961 at Gatlinburg, Tenn.

MECHANICAL SHAFT SEAL PUMPS TYPICAL APPLICATIONS

Installation	Mfgr. Date	Customer	No. Built	Type Seal	Type Bearings In Liquid Metal	Fluid HP	GPM	Head Ft.	RPM	Temp. Of Liquid	Eff.	Type Drive	Speed Control	Operations & Repairs
EFAPP Primary	B-J 1960	APDA PRDC	3	Double Mech. Oil Lubricated	Two Press. Hydrostatic Radial Bearings	925	11,800	310	900	1000 °F Sodium	77% O'All	Wound Rotor Induct. Motor	Liquid Rheostats	10,000 hrs. total for temp. up to 600°F, some seal problems initially some slight seal leakage (3-63)
CANEL Project	B-J (1959)	Pratt-Whitney	2	Mech. Seal Oil Filled Motor	None	615	4,000	610	2,450	1300 °F Sodium		Elec. Motor	Vary Freq.	
EFAPP Secondary	B-J	APDA	3	Double Mech. Seal Oil Lubricated	One Press. Hydrostatic Radial Bearing	330	13,000	100	825	950 °F Sodium		Induct. Motor	Eddy Cur. Coupling	One pump run 660 hrs. others never oprd. (3-63)
CANEL Project	B-J (1958)	Pratt-Whitney	2	Mech. Seal Oil Filled Motor	None	310	2,000	610	3,200	1400 °F Sodium		Elec. Motor	Vary Freq.	
HNPF Primary	B-J (1960)	AI	3	Double Mech. Seal Oil Lubricated	Press. Hydrostatic Radial Bearing	290	7,200	160	870	1000 °F Sodium		Induct. Motor	Eddy Cur. Coupling	Over 2000 hrs. each pump; no failures
HNPF Secondary	B-J (1960)	AI	3	Double Mech. Seal Oil Lubricated	Press. Hydrostatic Radial Bearing	290	7,200	160	870	1000 °F Sodium		Induct. Motor	Eddy Cur. Coupling	Over 2000 hrs. each pump; no failures
HNPF Prototype	Allis Chalm. (1959)	AI	1	Oil Lubricated Mech. Shaft Seal	Press. Hydrostatic Pad Radial Bearing on Supplier	270	7,200	150	1,110	945 °F Sodium	Approx. 73% O'All	Induct. Motor	Eddy Cur. Coupling	Over 800 Hours Alignment problems Initially
CANEL Project	B-J (1958)	Pratt-Whitney	2	Oil Filled Motor	None	230	2,000	460	3,200	1500 °F Sodium		Elec. Motor	Vary Freq.	
GAAA	B-J (1962)	Pompes Guinard	1	Double Mech. Seal Oil Lubricated	Press. Hydrostatic Radial Bearing	240	3,170	302	1,450	1200 °F Sodium		Elec. Motor		
SCT I Primary Loop	B-J (1962)	AI	1	Double Mech. Seal Oil Lubricated	Press. Hydrostatic Radial Bearing	160	4,000	160	1,750	1200 °F Sodium		Elec. Motor		
PKP	ORNL	ORNL	4	Oil Lubricated Type Mech. Shaft Seal	None	145	1,500	380	3,500	Sodium		Elec. Motor		Over 30,000 hrs. total operation

TABLE 2

MECHANICAL SHAFT SEAL PUMPS TYPICAL APPLICATIONS

Installation	Mfg. Date	Customer	No. Built	Type Seal	Type Bearings In Liquid Metal	Fluid HP	GPM	Head Ft.	RPM	Temp. Of Liquid	Eff.	Type Drive	Speed Control	Operations & Repairs
Under Constr	B-J (1963)	LASL	1	Double Mech. Oil Lub. Face Gas Shaft Seal	Press. Hydrostatic Radial Bearings	27	660	164	1,400	1040 °F Na		40 HP Motor		Under Construction
SRE Prototype Test	B-J 1961	AI	1	Mech. Shaft Seal	Press. Hydrostatic Radial Bearings	25	1,200	80	1,160	1200 °F Na		Motor		
LASL	B-J	LASL	1	Double Mech. Oil Lub. Face Gas Shaft Seal	Sleeve	15	500	115	1,710	1200 °F Na		25 HP Motor		
Cal. Tech VPL	B-J	Cal. Tech	1	Double Mech. Oil Lub. Face Gas Shaft Seal	None	15	1,000	60	1,160	900 °F Nak		25 HP Motor		Numerous seal failures over 12,000 hrs. total operation
Alplaus Genie	Buffalo GE Pump	GE	2	Face Type Oil Lub. Shaft Seal (Gas)	None	13	400	126	1,750	800 °F Na/ Nak	50%	20 HP Amplidyne	Vary Voltage	
DANA	ORNL	ORNL	10	Oil Lub. Face Type Shaft Seal (Gas)	None	12	150	300	3,750	Sodium		Elec. Motor		
LASL 2000 Kw Na Test Facility	B-J (1961)	LASL	1	Double Mech. Oil Lub. Face Shaft Seal (Gas)	Sleeve	3	230	50	1,700	1100 °F Na		7.5 HP Motor	Eddy Current Coupling	Over 47,000 hrs. total Operations
EFAPP Service	B-J	APDA	1	Double Mech. Oil Lub. Face Shaft Seal (Gas)	None	7.5	300	100	2,300	1000 °F Na		15 HP Motor		
EFAPP Overflow	B-J (1960)	PRDC	2	Double Mech. Oil Lub. Face Shaft Seal (Gas)	Sleeve	2.5	100	100	870	1000 °F Na		15 HP Motor		
MF	ORNL	ORNL	3	Oil Lub. Face Type Shaft Seal (Gas)	None	9	700	50	3,000	Sodium		Elec. Motor		2-1/2 Years Operation. No Major Mech. Problems
LASL 2000 Kw Na Test Facility	B-J (1961)	LASL	1	Double Mech. Oil Face Shaft Seal (Gas)	Sleeve	6.5	230	110	1,700	1100 °F Na		10 HP Motor	Eddy Current Coupling	

TABLE 2 (Cont.)

4.2 FROZEN SHAFT SEAL

In this design, the motor and pump are separated and sealed from each other by a frozen annulus of sodium surrounding the shaft. The temperature in the seal region is kept below the freezing point of the sodium by means of forced cooling. Heat generated by shaft friction results in a thin film of molten sodium around the shaft. The film can withstand moderate pressures without being expelled. An inert gas is usually maintained above the frozen seal by means of a mechanical seal.

FIG. 3 FROZEN SHAFT SEAL PUMP

Approximate Maximum Overall
Efficiency -70%

Special Auxiliary Systems Required

Seal refrigerant system

Inert gas cover

Advantages

Attitude free

Good efficiency

Conventional drives

Disadvantages

High starting and running torque

Potential refrigerant leakage

Relatively high maintenance due
to wear from oxide accumulation

Applications

The frozen seal pumps listed below were manufactured for Atomics International by Byron Jackson. The **prototype** was manufactured in 1959 and the others in 1961.

	Fluid H. P.	GPM	Head Ft.	RPM	Temp. of Na °F	% Eff	Type Drive	Speed Control
HNPF Proto- Type	270	7200	150	830	1000	63	Electric Motor	Eddy Current Coupling
SRE Secondary	30	1200	97	1500	1200	-	50 HP DC Motor	Vary DC Motor Field Current
SRE Primary	11	1200	35	1500	1200	-	25 HP DC Motor	Vary DC Motor Field Current
SRE Auxiliary	4	300	-	1500	1200	-	5 HP DC Motor	Vary DC Motor Field Current

The prototype pump had over 960 hours of satisfactory operation and the other pumps have had over 3000 hours of satisfactory operation.

References

Byron Jackson⁵, Mine Safety Appliances⁶, and Atomics International^{5, 7} have performed development work on frozen sodium shaft seals. The pumps for the SRE²⁹ were of this type. Work is also being done in Russia^{8, 9} on a pump operating at 950°F.

- (5) NAA-SR-4387 Testing of HNPF Freeze-Seal Pump by R. W. Atz, 1960.
- (6) NP 7391 Performance of a Frozen Sodium Seal on a 120 GPM Durion Centrifugal Pump by V. K. Heckel & E. C. King, 1954.
- (7) NAA-SR-MEMO-4119 Performance Test of a Two-Coolant-Region Sodium Pump Shaft Freeze Seal by F. O. Streck, 1959.
- (8) Experience with Russian Liquid-Metal Pumps by P. L. Kirrilov & others, 1959. Engineers Digest, June, 1960, Vol. 21, No. 6.
- (9) The Design & Operation of Some Pumps for Sodium & Sodium-Potassium Alloys by P. L. Kirrilov & others, 1959. Atomic Energy, USSR.
- (29) Design & Development of the Coolant System for the Sodium Reactor Experiment by D. T. Eggen, A. M. Steele & M. Heisler of Atomics International, Canoga Park, California.

4.3 PACKED OR STUFFING BOX SHAFT SEALS

Shaft seals using packing to seal the liquid metal directly have not been found suitable. Many types of metallic packing and soft packings have been used in attempts to seal sodium without success. The problems of leakage, shaft wear, packing disintegration, and torque requirements have not been overcome for this service. Life of seals tested has been limited to 100 hours or less.

FIG. 4 PACKED OR STUFFING BOX SHAFT SEAL PUMP

Applications

No successful applications reported.

References

General Electric³ performed most of the original test work on packed type seals for sodium service.

- (3) KAPL-635 Mechanical Liquid Metal Pumps in the Alplaus (Genie) Heat Transfer System by P. M. Clark, 1951.

4.4 ELECTROMAGNETIC SHAFT SEALS

An electromagnetic shaft seal utilizes the same principle as an EM pump to contain the liquid metal in the annulus between the rotating shaft and the stationary housing of a mechanically driven pump. The pressure force of the liquid attempting to leak through the annulus is counteracted by the pressure force developed on the liquid metal by the electromagnetic action of the EM pump field. Operation is similar to that of an annular linear induction type electromagnetic pump.

FIG. 5 ELECTROMAGNETIC SHAFT SEAL PUMP

Estimated Maximum Overall
Efficiency -70%

Special Auxiliary Systems Required

EM power supply
Inert gas system

Advantages

Potentially capable of sealing high temperature liquid metal directly
Attitude Free
No Wear Parts
Good efficiency

Disadvantages

Low seal efficiency i.e. seal power consumption
Separate seal power supply

Applications

Development of a seal of this type was initiated by Allis Chalmers 12, 35 and a 4" shaft unit was built but not tested before project was suspended.

References

- (12) TID 5143 Development of Hermetically Sealed Centrifugal Pump Units for Liquid Metals. Final Report, Allis-Chalmers Manufacturing Co. , 1953.
- (35) E. E. Brill, Development of Special Pumps for Liquid Metals, ASME Paper Annual Meeting 1952, New York.

4.5 DYNAMIC SHAFT SEAL

A dynamic shaft seal was successfully developed for a gas turbine driven centrifugal sodium pump. The unit sealed primary sodium by maintaining a positive "liquid metal-to-inert gas" interface on a rotating vaned impeller by pressure balancing.

FIG. 6 DYNAMIC SHAFT SEAL PUMP

Estimated Maximum Overall
Efficiency -80%

Special Auxiliary Systems Required

Inert gas system

Pressure balancing system

Advantages

Conventional Drive

Compact

High Efficiency

Disadvantages

Liquid Level Control

Application

Pratt and Whitney Built and used a dynamic shaft seal pump for the ANP Project. The pump was designed for a load of 335 psi and a liquid metal temperature of 1300°F. The pump operated at 8000 RPM with a 3000 GPM flow. An air turbine drive was used in this single stage centrifugal in line pump.

References

Dynamic seals development for liquid metal service has been performed by both Pratt and Whitney¹⁰ and Worthington Pump Corporation.³⁶

- (10) PWAC-318 Development Tests of the TP-1 Liquid Metal Turbopump and Components by H. V. Marmon and others, 1961.
- (36) Personal Communication, C. A. Kennedy of Worthington Corporation.

5.0 MECHANICAL PUMPS WITHOUT SHAFT SEALS

Mechanical pumps without shaft seals have been built for liquid metal service in a variety of configurations. In general the pumped fluid and pump rotor is separated from the driving mechanisms by a membrane or "can". The drive is usually effected by electromagnetic coupling.

The advantages of this class of pumps are the complete absence of moving seals, relative compactness of design and independence of attitude limitations of the "free surface" designs.

This class of pumps has the disadvantage, in general, of somewhat lower efficiencies than shaft sealed pumps and requires special motor designs with inherently difficult speed control characteristics.

The lack of moving seals indicate a potentially favorable maintenance condition for this type of pump providing adequate bearing design life is achieved.

5.1 AC CANNED ROTOR (WET ROTOR)

The canned rotor designation refers to an induction motor driven pump having the motor stator bore lined with a metal can which is seal welded to and backed up by, the motor structure. Mechanical seals are eliminated by this design because the full system pressure is contained within the stator bore. The motor rotor operates in the pumped fluid and is usually enclosed in a similar can to permit the use of conventional rotor materials. The motor and pump bearings operate in the pumped fluid.

The fluid within the motor rotor space is isolated from the high temperature fluid in the pump casing by thermal barriers, and is usually circulated through a heat exchanger to cool the motor bearings.

FIG. 7 AC CANNED ROTOR PUMP

Approximate Maximum Overall
Efficiency -60%

Special Auxiliary Systems Required

Motor cooling heat exchanger and cold trap.

Advantages

Attitude free

Seal free

Good overall efficiency

Disadvantages

Special motor design

Thermal and radiation requirements on motor insulation.

Applications

See page 21 for Table 3.

References

Westinghouse¹¹ and Allis Chalmers¹² have built canned rotor units for sodium service and the English¹³ have performed some early development work.

- (11) High Temperature Mechanical "Canned Motor" Liquid Metal Pumps by O. P. Steele, 1958. Nuclear Engineering & Science Conference, Preprint 76, Session II, March 1958.
- (12) TID 5143 Development of Hermetically Sealed Centrifugal Pump Units for Liquid Metals. Final Report, Allis-Chalmers Manufacturing Co., 1953.
- (13) The Design of Totally Enclosed Mechanical Pumps by P. Fortescue, 1954. J. Nuclear Energy, 1954, Vol. 1, pp. 5-23.

AC CANNED ROTOR PUMPS TYPICAL APPLICATIONS

Installation	Mfr. Date	Customer	No. Built	Type Seal	Type Bearings In Liquid Metal	Fluid HP	GPM	Head Ft.	RPM	Temp./ Liquid	Eff.	Type Drive	Speed Control	Operations & Repairs
CANEL Project	Westinghouse (1959)	Pratt-Whitney	2	Canned Rotor	Two Hydrodynamic Radial. One Kingsbury Thrust	715	4,000	708	3,350	1500 °F/ NaK	65% O'All	Induct. Motor	Vary Freq.	Water tested only
CANEL Project	Westinghouse (1959)	Pratt-Whitney	2	Canned Rotor	Two Hydrodynamic Radial. One Kingsbury Thrust	155	1,000	616	3,350	1500 °F/ NaK	65% O'All	Induct. Motor	Vary Freq.	Satisfactory operation at temp. up to 1400°F 1350 hrs. for 1 unit
Developmental Testing	Byron Jackson	B & W	1	Canned Rotor	Sodium Lubricated Ball Bearings	155	3,625	126	900	900 °F Sodium	55% O'All	Induct. Motor	Vary Freq.	Unsatisfactory bearing life
Developmental Prototype	Allis Chalmers (1952)		1	Canned Rotor	Hydrostatic Radial Bearings	120	3,800	125	1,700	1500 °F/ NaK	50% O'All	Induct. Motor	Vary Freq.	Water tested satisfactorily
Allis Chalmers	Allis Chalmers		1	DC Canned Rotor	Ball to be replaced with pressurized LM Bearings	25	to 4,000	to 125	to 5,000	1100 °F/ Na or NaK	76% Gen.	DC Unipolar Motor		Run as a generator with promising results. Tests discontinued (1952)
Allis Chalmers Test	Allis Chalmers (1952)		1	Canned Rotor	Pressurized Hydrostatic (fluid piston)	15	725	80	1,700		48% O'All	Induct. Motor		Satisfactorily tested in kerosene
NSA Test Loop	Westinghouse (1957)	Westinghouse	1	Canned Rotor	2-Radial Hydrodynamic. 1 Kingsbury Thrust	11	150	280	3,600	1300 °F/ NaK	40%	Induct. Motor	Vary Freq.	Over 4000 hrs. satisfactory operation at temp up to 1300 °F. 400 starts

TABLE 3

5.2 DC CANNED ROTOR (WET ROTOR)

DC canned rotor pumps are of the unipolar motor type. The unipolar motor is so described because the field has the same polarity during the armature conductor's complete rotation. The armatures of unipolar motors can be essentially single conductors which have very low resistance requiring a low voltage and high current power supply. The unipolar principle has been generally abandoned for industrial use due to the problems involved in efficiently transferring current from rotating to stationary parts. However, in liquid metal systems, the liquid metal can be used to produce contact between rotary and stationary mechanisms instead of mechanical brushes. This use of liquid metal current collectors permits the design of unipolar machines with good efficiencies.

FIG. 8 DC CANNED ROTOR PUMP

Approximate Maximum Overall
Efficiency -40%

Special Auxiliaries Required

Unipolar generator power supply
Motor cooling system
Auxiliary cold trap

Advantages

Attitude free
Low voltage motor insulation
No seals
Good speed control characteristics

Disadvantages

Special motor
Special high current low voltage
power supply
Low overall efficiency

Application

A disk collector type unipolar motor was built and tested by Allis-Chalmers in 1952. The design called for 25 fluid horsepower to pump 4000 GPM at up to 125 ft. of head at 1100°F. The unit was operated successfully as a unipolar generator with efficiency of 76%. The test proved the adequacy of liquid metal current collectors. The tests were discontinued due to program cutbacks without further development of this type of pump.

Reference

- (12) TID 5143 Development of Hermetically Sealed Centrifugal Pump Units for Liquid Metals. Final Report, Allis-Chalmers Manufacturing Co., 1953.

5.3 CANNED ROTOR (DRY ROTOR)

In this design, the rotor, pump shaft and bearings are enclosed in a hermetically sealed can. Inert gas fills the inside of the canned area and covers the liquid metal. Conventional bearings are usually used on the motor end and precautions are taken to prevent the diffusion of liquid metal vapor into the bearings. The pump end of the shaft extends through a shaft housing into the pump casing where liquid metal lubricated bearings are used to carry the radial load of the overhung pump shaft.

FIG. 9 CANNED ROTOR (DRY ROTOR) PUMP

Approximate Maximum Overall
Efficiency -65%

Special Auxiliary Systems Required

Inert Gas System
Level Control System
Gas Cooling System

Advantages

Sealeless
Removable Stator
Conventional Motor Bearings
Good Overall Efficiency

Disadvantages

Special Motor Design
Level Control Requirements

Application

A motor of this type was designed and built by Westinghouse for bismuth service at BNL.

References

5.4 CANNED MOTOR (TOTALLY ENCLOSED)

In this design, the pump casing is welded to a liquid level tank above which an inert gas atmosphere is contained. The tank is connected to the motor by a gas tight shafthousing, in which a long, close clearance, labyrinth is installed. The entire motor is enclosed in an outer housing and connections to the motor are provided with suitable seal welds. Equalization of the pressure between the motor and liquid tank eliminates the need for mechanical seals. Motor bearings are conventionally lubricated and a liquid metal lubricated bearing is usually used to support the pump end of the long overhung shaft.

FIG. 10 CANNED MOTOR (TOTALLY ENCLOSED) PUMP

Approximate Maximum Overall
Efficiency -80%

Special Auxiliary Systems Required

Motor cooling
Inert gas supply
Liquid level control

Advantages

High efficiency
Sealless
Conventional motor

Disadvantages

Level control
Speed control
Motor cooling

Application

See page 28 for Table 4.

References

The EBR II prototype manufactured by Allis-Chalmers¹⁷ and the two EBR II primary pumps manufactured by Byron Jackson are totally enclosed canned motor units.

- (17) Characteristics & Performance of 5000 GPM AC Linear Induction & Mechanical Centrifugal Sodium Pumps by O. Seim & R. Jaross, Geneva Conference, 1955. P/2158.
- (19) Reactor Handbook, Engineering, 1955, Chapter 2.7, by J. F. Cage & S. D. Collins.

CANNED MOTOR PUMP TYPICAL APPLICATION

Installation	Mfgr. Date	Customer	No. Built	Type Seal	Type Bearings In Liquid Metal	Fluid HP	GPM	Head Ft.	RPM	Temp. Of Liquid	Eff.	Type Drive	Operations & Repairs
EBR-II Prototype	Allis Chalmers (1960)	ANL	1	Totally Enclosed Motor	Press. Hydrostatic Radial Bearing	135	5,000	107	1,750	900 °F Sodium	76% Pump eff @ Des. Pt	150 HP 440 V 2 Speed	Over 16,100 hrs. satisfactory Operation
EBR-II Primary	Byron Jackson	ANL	2	Totally Enclosed Canned Motor	Press. Hydrostatic Radial Bearing	280	5,500	200	1,075	800 °F Sodium	-----	Elec. Motor	50 hrs. water test only installed - not operated yet
Russian Test	Russia (1959)	-----	2	Totally Enclosed Motor	One be-bronze Radial Bearing	9	450	75	1,450	750 °F Sodium	40% @ 990 rpm	13 HP Motor	9000 hrs. operating with 200°C Na Windings damaged by Na vapor
EBR-I	ANL	ANL	1	Canned Motor	None	7	500	53	1,750	500 °F Sodium	54%	Induct. Motor	Liquid level indicator & controller

TABLE 4

5.5 NUTATING DRIVE

Nutating type drives have been used successfully on low speed applications with conventionally lubricated bearings. This type of drive utilizes a bellows or flexible diaphragm through which a crank rod or drive shaft passes. With this arrangement, circular motion is transmitted by nutating the ends of the drive shaft, without rotating the shaft on its own centerline. The bellows or diaphragm is subjected to a rocking or tilting motion through 360° for each revolution of the drive.

FIG. 11 NUTATING DRIVE PUMP

Advantages

Hermetic seal

Disadvantages

Constant flexing of unsupported bellows or diaphragm

Applications

None for high speed pumps in nuclear plants

References

TID 5143 Development of Hermetically Sealed Centrifugal Pump Units for Liquid Metals. Final Report, Allis-Chalmers Manufacturing Co., 1953.

5.6 MAGNETIC COUPLING

A magnetically coupled drive transmits rotation to the driven member using the same principle as an induction motor, except that the rotation of the magnetic field which produce eddy currents in the driven member, and the eddy currents react with the magnetic field to produce motor action. By placing a leak tight barrier between the driving rotor, a hermetically sealed drive results²⁷.

FIG. 12 MAGNETIC COUPLING PUMP

Approximate Maximum Overall
Efficiency -60%

Special Auxiliary Systems Required

Cooling medium

Advantages

Good efficiency

Conventional drives

Disadvantages

Thin wall barrier

Added component equivalent
in size (HP) to drive

Application

Development work on small canned magnetic couplings was performed by Allis-Chalmers¹², and a test unit transmitted 44 HP at 1500 rpm with an efficiency of 74%.

References

- (12) TID 5143 Development of Hermetically Sealed Centrifugal Pump Units for Liquid Metals. Final Report, Allis-Chalmers Manufacturing Co. , 1953.
- (27) Magnetic Drive Pumps, C & E News, May 26, 1952.

6.0 ELECTROMAGNETIC PUMPS (EM)*

The good electrical conductivity and permeability of liquid metals makes it possible to pump these materials by electromagnetic means. A large number of types and configurations of electromagnetic pumps have been designed and constructed for sodium service, including both induction and conduction types utilizing both AC and DC.

In general, the EM pumps provide a means of achieving direct flow control, hermetically sealed flow systems, freedom from attitude limitations, and systems without moving parts.

In practice, these advantages have been attained at the expense of relatively low efficiency, heavy bulky units, and frequently very special power supply systems.

Maintenance of EM systems is quite low but thermal and radiation damage to electrical insulation are significant problems.

*Electromagnetic

6.1 DC OR FARADAY CONDUCTION PUMP

This is the simplest form of EM pump. It consists of a duct into and out of which the liquid metal is fed from the main pipe work. Copper bus bars are attached to two opposite sides of the duct through which large currents are fed through the liquid metal. Magnetic poles are placed adjacent to the other pairs of sides in order to produce a magnetic field at right angles to the current.

FIG. 13 DC CONDUCTION PUMP

Approximate Maximum Overall
Efficiency -50%

Special Auxiliary Systems Required

Unipolar generator power supply

Advantages

Hermetic
Ease of Control
Low voltage insulation
Good efficiency
No moving parts

Disadvantages

High current power supply
Bulky configuration

Applications

Approximately thirty different DC electromagnetic pump designs have been employed by the Argonne National Laboratory ranging in capacity from 5 to 10,000 GPM. The 10,000 GPM, 75 psi, 50% efficiency design developed by ANL for the EBR II pumping test program is the largest DC-EM pumping unit constructed. However, it did not meet design conditions and was not used in the EBR II reactor plant. In tests, it provided only 25 psi and approximately 25% efficiency.

The EBR-I primary pump was a DC conduction pump with approximately 7 fluid horsepower, 500 GPM, and a head of 25 psi.

Westinghouse manufactured a 2-fluid horsepower conduction pump for the MSA test loop. This pump had a 70 ft. head and operated at 1400°F.

6.2 AC CONDUCTION ELECTROMAGNETIC PUMP

AC conduction pumps have been developed in order to avoid the difficulty involved with DC power supplies. In principle, it performs like the DC type pumps, except the field and current supplies come from a transformer.

In most cases, the transformer is combined with the pump to make the unit as compact as possible¹⁵. The efficiency of this type pump is lower than the DC type for both large and small units owing to eddy currents and skin effects.

FIG. 14 AC CONDUCTION PUMP

Approximate Maximum Overall
Efficiency -20%

Special Auxiliary Systems Required

None

Advantages

Hermetic

No moving parts

Normal power supply

No auxiliaries

Disadvantages

Low efficiency

Low power factor

Applications

A standard line of AC conduction pumps¹⁵ is available in sizes from 200 GPM at 20 psi to 1/2 GPM at 150 psi for liquid metals at temperatures up to 1600°F.

Four AC conduction pumps have been manufactured for PRDC by MSA for the EFAPP. These pumps are designed to operate at 1200°F with a 60 foot head and have auto transformer flow control. Two of the pumps used for Na cooling have approximately a .6 fluid horsepower, 40 gallons per minute flow and are operated with 60 amp, 480 volt, 4 single phase power input. The other two pumps have approximately a 1.5 fluid horsepower, 100 gallons per minute flow and are operated with a 350 amp, 480 volt and single phase power input.

Reference

- (15) The Electromagnetic Pumping of Liquid Metals-2, by J. Hilditch, April, 1958, Atomic & Nuclear Energy, pp. 125-127.

6.3 AC LINEAR INDUCTION

Flat linear induction pumps (FLIP) consist basically of a thin walled duct connected to the liquid metal system piping. Polyphase induction windings are located adjacent to two opposite sides of the duct in slots of laminated magnetic structure. When energized, the windings produce a traveling magnetic field which induces eddy currents in the conductive liquid. Interaction by the magnetic field and the induced currents produces the pumping force on the liquid.

FIG. 15 FLAT LINEAR INDUCTION PUMP

Approximate Maximum Overall
Efficiency -50%

Special Auxiliary Systems Required

Cooling

Advantages

Hermetic

No moving parts

Good efficiency

No auxiliaries

Disadvantages

Temperature limitations of
insulation

Low power factor

6.3 AC LINEAR INDUCTION (Cont.)

Annular linear induction pumps (ALIP) operate on the same "traveling magnetic field" principle as the FLIP pumps, except in these units, the liquid flows in an annular duct between inner and outer core sections. The outer cylindrical core contains a system of toroidal coils connected so as to produce a polyphase traveling field. Although this type of pump has received considerable attention since its conception by Einstein and Szilard, fabrication difficulties have retarded its development and little operating experience has been gained to date.

FIG. 16 ANNULAR LINEAR INDUCTION PUMP

Application

See page 40 for Table 5.

References

The largest AC linear induction pumps (FLIP) have been built by General Electric. The EBR II secondary pumps represent the state of the art in AC electromagnetic pumping, circulating 6500 GPM at 65 psi heads.^{16, 17}

- (16) ANL-5719 Hazard Summary Report, Experimental Breeder Reactor II (EBR II) by L. J. Koch and others, 1957.
- (17) Characteristics & Performances of 5000 GPM AC Linear Induction and Mechanical Centrifugal Sodium Pumps by O. Seim & R. Jaross, Geneva Conference, 1955. P/2158.

AC INDUCTION PUMP TYPICAL APPLICATION

Installation	Mfgr. Date	Customer	No. Built	Type Seal	Approx. Fluid H P	GPM	Head	Temp. Liquid	Power Requirements	Flow Control	Size Weight	Eff.	Cooling	Remarks
EBR-II Secondary	GE	AEC	1	AC Linear Induction	250	6,500	65 psi	Na	-----	-----	-----	-----	-----	-----
EBR-II Sec. Proto	GE	AEC	1	AC Linear Induction	115	5,000	40 psi	850 °F Na	220kw, 480v, 780a	Vary Voltage	8'x4'x3' 8,500 lbs.	43%	Water	7000 hrs. SaL Oper. at 454 °C
----	GE	AEC	1	AC Linear Induction	80	8,000	40 ft.	1,000 °F Na	-----	-----	-----	-----	-----	-----
KAPL	GE	Test	1	AC Linear Induction	50	2,500	100 ft.	850 °F Na	130kw, 440v, 60n	-----	-----	-----	-----	-----
KAPL	GE	Test	1	AC Linear Induction	35	1,200	110 ft.	850 °F Na	300v, 288a, 60	Vary Voltage	6,400 lbs.	37%	Air	-----
----	GE		6	AC Linear Induction	20	400	200 ft.	1,000 °F Na.	-----	-----	-----	-----	-----	-----
DFFR Pri-Sec.	Eng. Elec. Co.	AEA	43	AC Linear Induction	5	300	25 psi	200 °C NaK	15w, 410v, 50	Vary Voltage	-----	24%NaK 32%Na	None	-----
AI Test	AI	AI	60	AC Induction	to 4	to 340	to 120 ft.	Na	-----	-----	-----	10%	-----	-----
AI Test Fac.	AI (1959)	AI	1	AC Linear Induction (Wrap Around)	1.3	340	15 ft.	600 °F Na.	90a, 540v, 3 Phase 60cy. Auto trans-former	Auto-trans-former	24"x23" 30"1100 lbs	5%	Air	Tested Satisfactorily

TABLE 5

6.4 AC SPIRAL INDUCTION

Helical or spiral flow induction pumps (SIP) are similar to the linear induction pumps in principle. The liquid metal is contained in a hollow cylindrical duct between the stator coils and a stationary cylindrical pole piece. A helical fin spiralling down the stationary pole piece changes the rotary motion of the liquid metal to an axial motion.

FIG. 17 SPIRAL INDUCTION PUMP

Estimated Maximum Overall
Efficiency -20%

Special Auxiliary Systems Required

Low frequency power supply

Stator cooling

Advantages

Hermetic

No moving parts

Compact

High head

Disadvantages

Low efficiency

Low capacity

Applications

General Electric has constructed and tested a spiral flow pump with capacity of 6 Fluid HP, 400 GPM at 54 foot head operating at 28 kilowatts, 200 volts, 25 cycles at efficiency of 20%.

References

- (15) The electromagnetic Pumping of Liquid Metals-2, by J. Hilditch, April, 1958, Atomic & Nuclear Energy, pp. 125-127.
- (19) Reactor Handbook, Engineering, 1955, Chapter 2.7, by J. F. Cage and S. D. Collins.

7.0 MECHANICAL ELECTROMAGNETIC PUMPS (M-EM)

A number of novel designs have been investigated that utilize some aspects of both the mechanical type pumps and the electromagnetic pumping principle. These designs have been attempts to incorporate the better features of each type of pump.

Generally these types incorporate the closed sodium liquid system and an electromagnetic pumping with the use of a mechanically progressed magnetic field driven by a conventional motor drive.

Results to date indicate that moderate efficiencies can be attained in pumps that have no moving parts in contact with sodium and which do not require unusual power supplies.

Disadvantages include the requirement of a thin membrane for containment of the pump sodium and problems of thermal protection of electrical systems.

7.1 EM CENTRIFUGAL PUMP

The pumping force of an EM centrifugal pump is generated by rotating a group of alternate north and south magnetic poles alongside a thin annulus containing liquid metal. The magnetic flux passes from a pole through the annulus into stationary back-up iron. From there, the flux passes back through the annulus into the opposite adjoining pole piece. When the magnetic field is rotated, a voltage and current is induced in the liquid metal which reacts with the applied field to move the liquid metal. The liquid metal is accelerated tangentially within the annulus and then passes into a standard pump volute.

FIG. 18 EM CENTRIFUGAL PUMP

Approximate Maximum Overall
Efficiency -20%

Special Auxiliary Systems Required

Advantages

- Hermetic
- Conventional drive
- Easy flow control

Disadvantages

- Low efficiency

Applications

A 275 GPM, 4 fluid HP, 55 foot head EM centrifugal pump with an efficiency of 17% was manufactured by Allis Chalmers²¹ for a 1000 kw heat transfer loop at MSA²². Permanent magnet EM centrifugal pumps are being developed by Atomics International for the SNAP programs.^{23, 24}

References

- (21) EM Centrifugal Pump by E. F. Brill, Mech. Eng. 75 No. 5, 369 (1953).
- (22) TID 5227 Liquid Metals Handbook, Sodium-NaK Supplement 1955.
- (23) NAA-SR-5244 SNAP 2 Reactor Pump Development Program (Radial Gap Permanent-Magnet Pump) by S. Sudar, 1961.
- (24) NAA-SR-6300 The SNAP 2 Power Corrosion System Topical Report No. 10, Sodium Pump Design and Testing by B. Snoke & J. Tiltins, 1960.

7.2 HELICAL ROTOR PUMP

The helical rotor design incorporates a helical shaped magnetic field or a helical magnetic return path which, when rotated (mechanically), imparts an axial motion to the liquid metal contained in an annulus surrounding the rotor. Any conventional drive can be used to rotate the rotor.

FIG. 19 HELICAL ROTOR PUMP

Approximate Maximum Overall
Efficiency -40%

Special Auxiliary Systems Required

Advantages

- Hermetic
- Conventional drive
- Ease of flow control

Disadvantages

- Low efficiency
- Unsupported thin walled sodium conduit
- Radiation damage to electrical insulation

Applications

Atomics International has developed the helical rotor EM pump for possible large reactor applications. A 3000 GPM 60 psi unit is now on test (1963). Computer solutions indicate that pumps of this design are capable of circulating over 50,000 GPM with efficiencies up to 48%.

References

(26) NAA-SR 7400 Annual Progress Report, Atomics International, 1961.

8.0 MATERIALS

Materials selection for these pumps has been based on information obtained from extensive compatibility studies carried out during the past decade. Thermal shock and standard high temperature properties governed the choice of materials for sodium systems to some degree, but from a standpoint of materials engineering, liquid metal corrosion has posed the greatest problem.

Information obtained from the Liquid Metals Handbook has probably guided materials selection for pumps and other sodium systems components more than any other single publication.

Austenitic stainless steels have been used for pump structural parts, contacted by sodium, in the majority of pumps built to date. They have performed satisfactorily for long periods of time at temperatures up to 1100°F and they are not particularly sensitive to oxygen attack in cold trapped systems (less than 50 ppm oxygen).

Ferritic steels have been found to be less satisfactory than austenitic steels because they are more sensitive to oxygen contamination.

Non-ferrous materials such as titanium, zirconium, chromium, vanadium, niobium, tantalum, molybdenum and tungsten have been used in liquid sodium systems, but their satisfactory performance depends more critically on oxygen level than the stainless steels. Many of these materials corrode appreciably in cold trapped circuits of 20-30 ppm oxygen and it is essential to reduce the oxygen level below 20 ppm by hot trapping.

Copper, magnesium, aluminum and alloys based on them are not suitable for long term use in sodium or sodium-potassium alloy.

A number of the superalloys and refractory metals have been found to be as resistant to corrosion in sodium as any of the austenitic stainless steels. Cobalt base alloys, nickel base alloys and pure nickel perform satisfactorily in 1000°F sodium.

Tungsten, titanium and chromium carbides bound with either nickel or cobalt have shown excellent resistance to attack in sodium and much work has been done with these materials for bearings and journals.

Ceramics such as alumina, beryllia, magnesia, titania, zirconia, etc., are unaffected by exposure to sodium. However, since most ceramic bodies are not 100% dense they tend to absorb sodium and crack under subsequent thermal cycling. Many of the binders, especially silicates react with sodium and will cause crumbling. The dense-fired pure oxides perform most satisfactorily.

8.0 MATERIALS (Cont.)

Graphite is wet by sodium above 850°F and there is absorption of the sodium into the graphite pores by capillary action. Since sodium wets graphite and has a relatively high thermal conductivity, hot graphite immersed into cooler sodium may be fractured by thermal shock.

9.0 MAINTENANCE

The requirement of "low maintenance" has been a major consideration for all of the liquid metal pumps developed for use in reactor power plants. While several prototype designs have been operated satisfactorily for over 10,000 hours, none of the more significant large pumps (EFAPP, HNPF, EBR II and CANEL) have been operated for more than a few thousand hours. Until more hours (10-20,000) are accumulated on these units, no meaningful data on future maintenance requirements can be obtained from them. Operation of prototype and other smaller units has indicated that the design approaches taken on the pumps for these projects, should yield at least a year of maintenance free operation.

Since EM pumps have no moving parts, the maintenance requirements on them are generally lower than on mechanical units containing bearings and seals. However, bearing operation on some test units has shown little or no wear with both hydrostatic and hydrodynamic type bearings which indicates that twenty year maintenance free bearing life can be obtained.

The large majority of mechanical sodium pumps built to date utilize the free surface approach so that shaft seals are needed only to prevent low pressure gas leakage. Most of these seals have been more or less standard mechanical oil lubricated face type seals. While six months to a year of maintenance free operation is typical for this type of seal, they do contain critical wear surfaces and present designs need periodic (1 to 2 year) maintenance (replacement or polishing).

Freeze seals have been used on sodium pumps (SRE), but maintenance requirements have been high due to wear caused by the oxide buildup.

From the experience gained to date in the liquid sodium pumping field, it may be said that unless one is willing to sacrifice efficiency and use EM or canned pumps, the maintenance requirements of liquid metal pumps are basically determined by bearing and seal performance. If bearing life is not adequate, EM or MEM pumps have to be used. If rotating seal life is not adequate, canned EM or MEM pumps are necessary. Five to ten year maintenance free operation using EM pumps and one to two year maintenance free operation using mechanical pumps appears to be available now. Future developments will undoubtedly reduce maintenance on both types.

10.0 CONTROL

For most of the liquid sodium cooled reactor applications, some degree of flow control is necessary. Loop flow can be controlled by throttling, varying pump speed, or in the case of EM or MEM pumps, by voltage or current control.

The relatively simple and inexpensive means of controlling flow when EM pumps are used has made them very appealing for many of the lower capacity systems where the low EM pump efficiency was not considered to be a major cost factor. However, on high capacity loops, high efficiency mechanical pumps are desirable and flow control valves or pump speed control are usually used. Sodium flow control valves have been built, but for the most part, operation of these valves has not been satisfactory and the trend is to do away with throttling valves and any other mechanisms in the loop flow path.

For high capacity loops pump speed control is the most direct approach. Some methods of speed control of liquid sodium pumps have been:

<u>Method</u>		<u>Application</u>
1. Eddy Current Couplings	-	HNPF, EFAPP (Secondary)
2. Wound Rotor Induction Motors	-	EFAPP (Primary)
3. Variable Freq. Power Supply	-	CANEL Project
4. Turbine Drives	-	ANP
5. DC Motor Drives	-	SRE

The method of speed control is dependent upon the type of pump selected and the degree of control required. Variable frequency power supplies can be used to vary the speed of an AC motor whether it is canned or conventional, but a variable speed drive and an alternate are required, which increase cost and reduce overall efficiency.

Eddy current couplings have been coupled to conventional motors to vary the pump shaft speed, but they cannot be used on canned motors. Conventional wound rotor AC induction motors and DC motors have been used to vary the speed of shaft sealed pumps. Turbines have also been used as variable speed drives, but again, they are limited to shaft sealed pump units.

The turbo pump developed by Pratt and Whitney provided a compact unit, but gas intake and exhaust requirements for a gas turbine drive in a land based plant would present major containment problems. However, a steam turbine driven centrifugal pump could be a practical unit since it would offer simple speed (flow) control.

10.0 CONTROL (Cont.)

All of the above methods of obtaining flow control have proved to be satisfactory and selection of one drive over another has been governed mostly by the pump type, cost and the degree of control required for the particular application.

11.0 DISCUSSION

11.1 SIGNIFICANT LARGE PUMP TYPES

Of all the pump types that have already been built and tested, the mechanical shaft seal type appears to have the best combination of efficiency, cost and reliability factors. Considering this, one would have to say that the EFAPP primary pumps represent the present state of the art of pumping liquid metal. However, the gas shaft seals used on these pumps still do not appear to be 100% reliable, and the free surface design does place certain limitations on reactor layout. Until the shaft seals approach 100% reliability, the hermetically sealed pumps cannot be disregarded. If low maintenance and reliability are to be stressed equally with cost and efficiency, the following are all potential pump types for large reactor power plants.

	Maximum Fluid HP Built as of 1963	<u>Application</u>
1. Mechanical Shaft Seal	925	EFAPP-Primary
2. Canned Rotor	715	CANEL- Loop
3. Canned Motor (Totally Enc.)	280	EBR-II-Primary
4. AC Linear Induction	250	EBR-II-Secondary
5. DC Conduction	440	EBR-II-Primary Prototype
6. Helical Rotor	100	Development

Over the past several years, the canned rotor pumps were not selected because of lack of experience with sodium lubricated bearings. However, both hydrostatic and hydrodynamic bearings now appear to be reliable. If the 10-15% reduction in efficiency caused by can and fluid friction losses can be outweighed by added reliability, low maintenance and ease of pump location within the reactor piping system, the canned rotor pumps must still be considered.

Canned motor pumps of the totally enclosed motor type were selected for the EBR-II primary pumps. Where efficiencies comparable to shaft seal units are desired, along with the increased reliability of a hermetic system, totally enclosed canned motors are practical. The only disadvantages of the totally enclosed units when compared to the shaft sealed units would be the gas cooling requirements and insulation and bearing problems if Na vapors get up into the motor end.

11.1 SIGNIFICANT LARGE PUMP TYPES (Cont.)

Both the linear induction and DC conduction EM pumps have demonstrated efficiencies approaching 50% in large units, and considerations of increased reliability could make them more practical than they appear when compared only on an efficiency basis.

The helical rotor design is in the same category as the EM pumps. It can be constructed in large sizes (50,000 GPM or over) with efficiencies of 40-50%. Reliability, ease of maintenance and ease of flow control make this type quite attractive.

11.2 FUTURE REQUIREMENTS

As part of the Sodium Graphite Reactor Program, a 300 MWe prototype plant is now being considered which may lead to a 1000 MWe plant in the future²⁸. Fast breeder reactor plants up to 1500 MWe are also being considered^{33, 34}. Typical pumping requirements for such proposed plants are listed below.

FUTURE PUMP REQUIREMENTS

	<u>Sodium Graphite</u>	<u>Fast Breeder</u>
	<u>Full Scale</u>	<u>Full Scale</u>
Reactor Size - MWe	1000-- 1500	1000 - 1500
Power/Loop MWt	660 - 1200	660 - 1200
Temp. Rise °F	400 - 500	250 - 350
Flow/Loop lb/hr x 10 ⁻⁶	15 - 34	22 - 46
GPM x 10 ⁻³	35 - 85	50 - 114
Head - Ft	150 - 200	250 - 350
Hydraulic HP/Loop	1200 - 3600	3200 - 8200

It can be seen that the trend is toward pumping capacities of 100,000 GPM and future requirements will be even higher.

11.3 LARGE PUMP DEVELOPMENT

Large liquid metal pump development will be guided by the application requirements and, therefore, no definite conclusion can be made as to the optimum size or type of pump without consideration of all aspects of plant design.

11.3 LARGE PUMP DEVELOPMENT (Cont.)

In all probability, future sodium pumps for capacities over 10,000 GPM will be of the mechanical centrifugal type, because of its cost and efficiency advantages. The successful application of these pumps will depend upon the development and demonstration of:

1. Large diameter sodium lubricated bearings.
2. Large diameter shaft seals.

Since facilities are now available to manufacture pumps with capacities of over 100,000 GPM and there are motor and turbine drives large enough to power them, it would appear that pump manufacturing capability is in pace with future reactor requirements.

Plant layout can put physical size limits on pumps and pump drives and so can economic considerations. In high capacity systems, a point can be reached when two half size units will be less expensive than one single unit. The size and cost of a centrifugal pump and drives can be reduced most effectively by increasing the operating speed. (In the low specific speed ranges doubling the speed achieves a four fold weight saving). However, as speed is increased so is the required suction head, to prevent cavitation. With presently used free surface designs the only way to increase available suction head is to locate the impeller further below the free surface and/or increase the gas blanket pressure. In order to locate the casing lower, in reference to the sodium surface, a longer shaft is necessary. To increase the blanket gas pressure the pump shaft seal design becomes more difficult along with increased wall thickness requirements on piping and vessels.

12.0 CONCLUSIONS

Current technology has developed satisfactory pumps in the 1000 fluid horsepower size range with flow capacities of up to 13,000 gallons per minute. Future requirements of over 5000 fluid horsepower and flow capacities of over 100,000 gallons per minute are estimated to be required for 1000-1500 MWe nuclear power plants. Pumps to meet these requirements appear to be attainable with additional development.

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