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ELECTRODYNAMIC MERCURY PUMP

by A. Vary

Lewis Research Center

Cleveland, Ohio

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SUMMARY

Problems associated with high-pressure, electromagnetic pumping of mercury were investigated. Electromagnetic pressure development with mercury was difficult to achieve because of two factors: first, mercury wetting of the flow passage surface was not readily attained; second, induction heating of the mercury resulted in vapor formation in the pump flow channel causing loss of developed pressure. Satisfactory results were obtained by chemical and thermal conditioning techniques developed to induce mercury wetting. The problem of overheating was resolved by means of a novel pump cell design that assured better electrical continuity and efficient heat removal. The resultant pump cell had a developed pressure capability of approximately 500 pounds per square inch and was able to meet the following design requirements: output pressure, 350 pounds per square inch; mercury flow rate, 150 pounds per hour; and operating temperature, 600° F. The pump was operated for over 400 hours of which over 200 hours were accumulated in a two-phase corrosion loop under SNAP-8 conditions of pressure and temperature.

INTRODUCTION

An electrodynamic rotating-magnet induction pump was studied in a two-phase mercury loop involved in an investigation of mercury corrosion and mass transport effects with various candidate materials for the SNAP-8 space power system.

Herein, the application of an electrodynamic pump used for high-pressure pump ing of mercury is described. Specifically, this study was restricted to certain critical aspects of the pump associated with surface effects that have a bearing on performance and efficiency. Although electrodynamic induction pumps have been used successfully with sodium, sodium-potassium, and potassium, application to mercury presented problems not previously encountered.

One design problem arose because mercury unlike the alkali metals does not readily wet the flow passage surface. In particular, the various high-temperature alloys con-

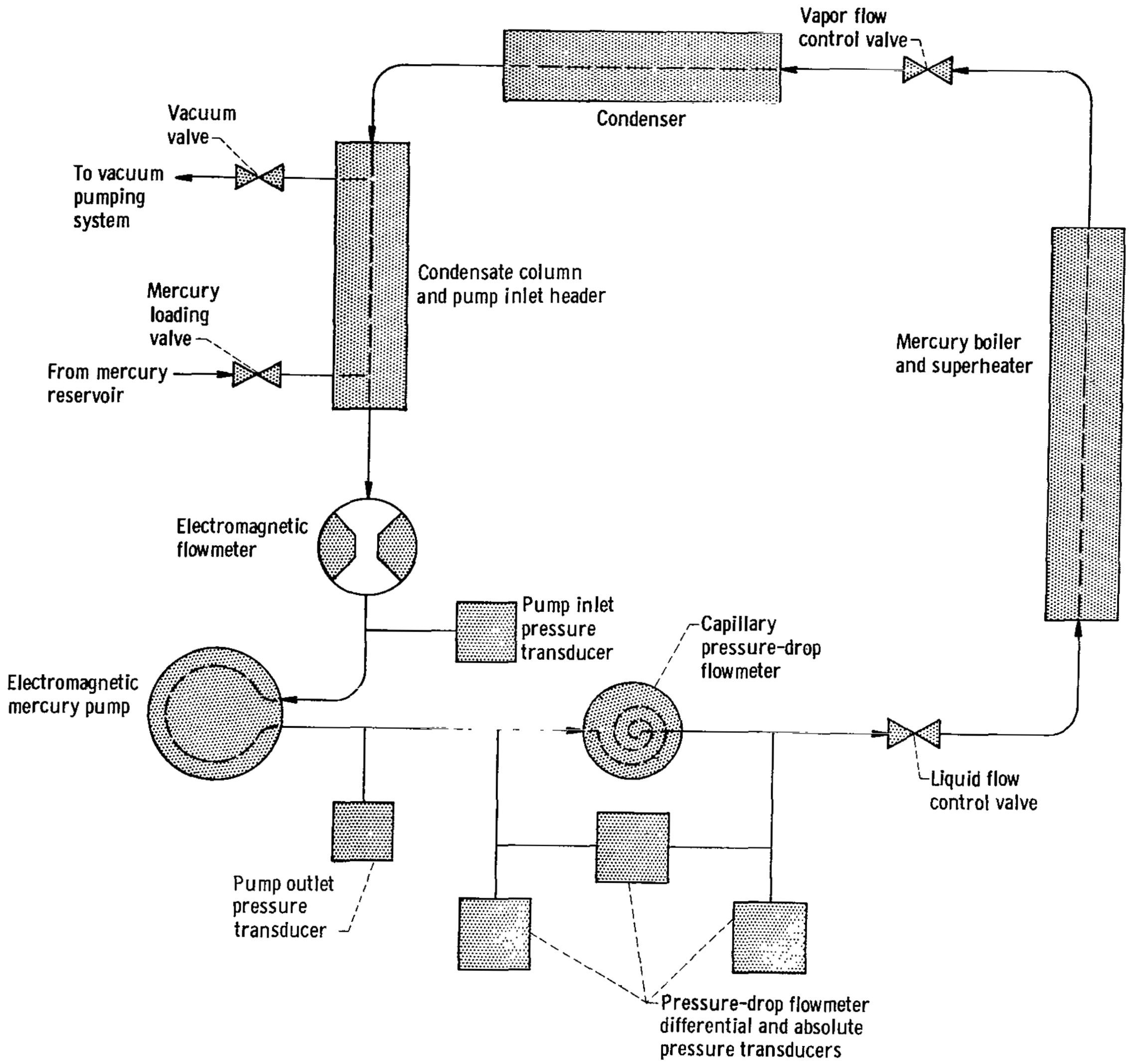


Figure 1. - Flow diagram of two-phase mercury loop.

templated for the loop and pump flow passage resist mercury wetting. Pump performance is strongly affected by this factor. The use of wetting agents such as magnesium or rubidium or the deposition of wettable metals such as copper on the channel surface were specifically avoided because such measures were inimical to the use to which the pump was to be applied.

A second problem arose because of a feature common to all electromagnetic pumps, the high rate of heat generation associated with the large electric currents existing in the pump cell and fluid. This could be particularly detrimental in an electromagnetic mercury pump because of the high vapor pressure of mercury at elevated temperatures. The tendency toward boiling and consequent loss of head is therefore quite strong in an electromagnetic mercury pump.

Two pump cells were evaluated: the first was a standard cell designed and adapted for use with mercury by the pump manufacturer; the second was a modified version based on experience gained with the first.

DESCRIPTION OF EQUIPMENT

Description of Loop

The electrodynamic induction pump was incorporated into a two-phase mercury loop having the components depicted schematically in figure 1. Although designed for the purpose of investigating mercury corrosion and mass transport effects under SNAP-8 conditions, the loop served as a test rig for the pump. The loop consisted of a tubular flow circuit in which the major components were the pump, an electrically heated boiler and superheater, an air-cooled condenser, liquid and vapor throttle valves, and a pump inlet header.

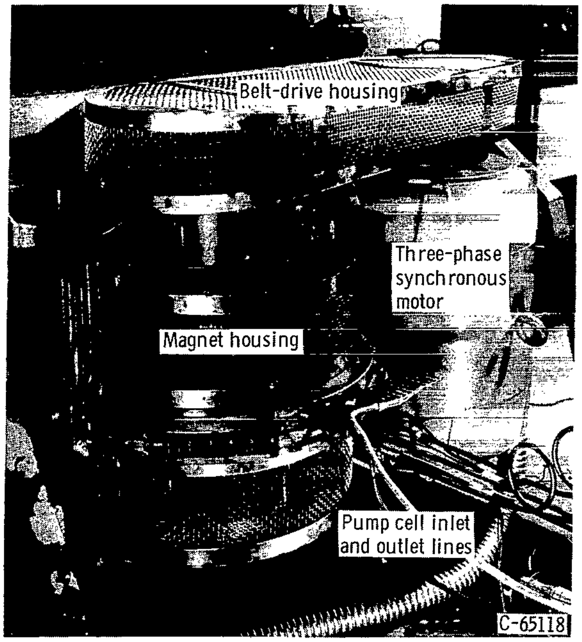
All loop components were welded together to provide a high-pressure, high-temperature vacuum-tight enclosure. The material used for construction was HS-25 (also known as L-605), a cobalt-base alloy.

Pump output pressure, flow rate, and operating temperature were set in accordance with loop requirements. These requirements called for a developed head of about 350 psi at a mercury flow rate of 150 pounds per hour and a mercury temperature of approximately 600° F in the pump flow passage.

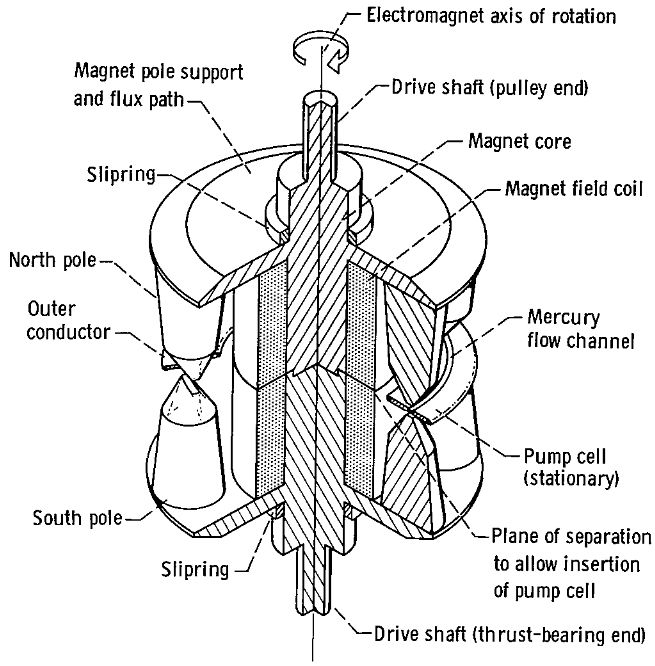
Pump inlet and outlet pressures were measured by means of strain gage pressure transducers. Mercury flow rates were determined by two separate devices. The first was an electromagnetic flowmeter located between the pump header and the inlet. The second device, located downstream of the pump, consisted of a calibrated length of small-bore tubing across which the pressure difference corresponded to the flow rate. This double check of flow was useful because of the low flow rates involved; the maximum flow rate was approximately 200 pounds per hour, or 0.03 gallon per minute.

Description of Pump

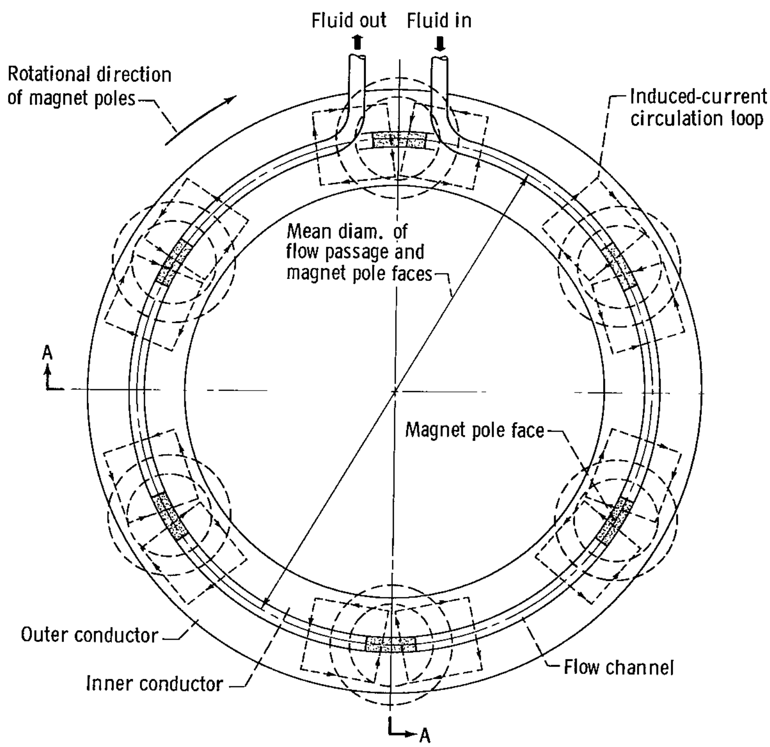
The pump consisted of three major components: the drive motor, the rotating electromagnet, and the pump cell (fig. 2). The electromagnet had six pole pairs that rotated with respect to the pump cell which was fixed to the magnet housing by means of four support lugs. A three-phase, synchronous motor rotated the electromagnet at a nominal speed of about 1750 revolutions per minute. The pump performance and component



(a) Magnet housing and drive motor.



(b) Section (A-A).



(c) Pump cell with projections of magnet pole faces; magnetic flux is normal to and out of plane of page.

Figure 2. - Electrodynamic mercury pump.

TABLE I. - ELECTRODYNAMIC MERCURY PUMP SPECIFICATIONS

Performance	
Nominal mercury flow rate, lb/hr	150
Maximum developed pressure, psi	500
Operating temperature, $^{\circ}F$	600
Flow channel	
Material	HS-25
Mean diameter (cold), in.	11.937
Cross-sectional shape	Approx. elliptical
Major outside diameter, in.	0.31
Minor outside diameter, in.	0.125
Wall thickness, in.	0.015
Electromagnet	
Type	dc
Number of pole pairs	6
Nominal saturated flux, G	10 000
Nominal rotational speed, rpm	1750
Mean diameter pole circle, in.	12
Dimensions of pole faces, in.	1.5 by 0.25
Air gap between poles, in.	0.294
Room-temperature field-coil resistance, ohm	1.5
Drive motor	
Power rating, hp	30
Type	Synchronous 3 phase, 60 cycle
Voltage rating, V	220 to 440
Nominal speed, rpm	1765

specifications are presented in table I.

The mercury flow channel of the pump cell was formed from 0.25-inch outside diameter by 0.015-inch wall HS-25 tubing that was bent into a planar, circular loop and flattened slightly to produce an elliptical channel cross section 1/8 by 3/8 inch, approximately. The flow channel had a mean overall diameter of 11.94 inches at room temperature, which increased to 12 inches, the mean diameter of the pole face circle, at 600° F.

Two pump cells, each having identical flow channels were used. The cells differed in the form and the mode of attachment of the conductors, which consisted in each pump cell of two annular members attached to the inner and outer perimeters of the flow channel. In the first pump cell the conductors were formed of silver castings (fig. 3, p. 6). Tubular copper conductors silver soldered to the flow channel were used in the second pump cell (fig. 4, p. 7).

In the cast-silver-conductor pump cell, silver was vacuum-cast in metallic shells welded to the inner and outer peripheries of the flow channel (cross section in fig. 3). Formed from 3/4-inch outside diameter by 0.015-inch wall HS-25 tubing, the two shells had elongated, nearly elliptical cross sections with major diameters of 1 inch and minor

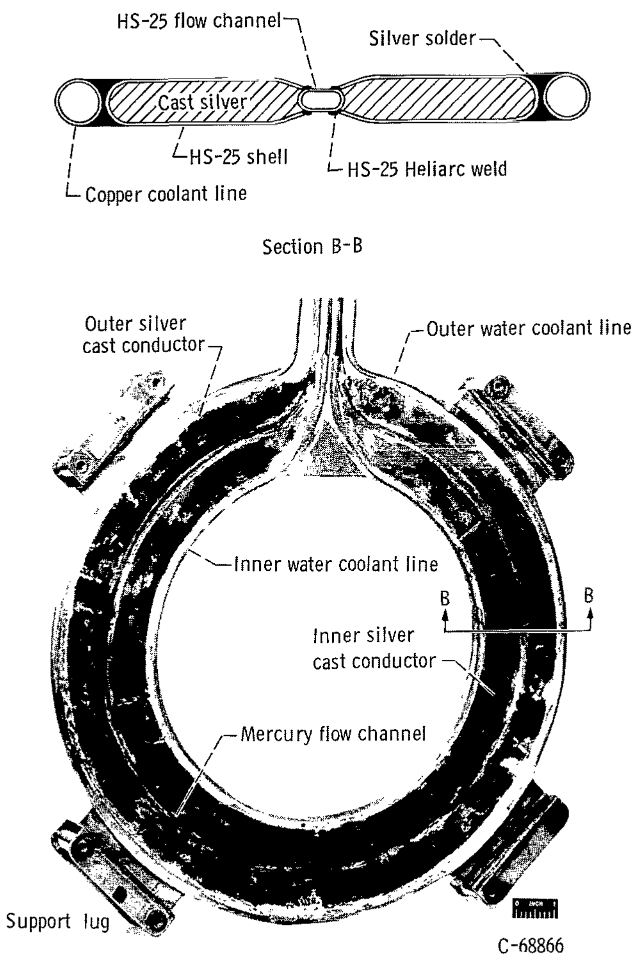


Figure 3. - Cast silver pump cell.

diameters of 1/4 inch, approximately. The shells were split and welded to the flow channel prior to being filled with silver so that the silver made direct contact with the flow channel surface. Copper tubing to be used for water cooling the pump cell was silver soldered to the conductors.

The second pump cell had tubular conductors formed from 5/8-inch outside diameter by 1/16-inch wall annealed copper tubing and silver soldered to the inner and outer perimeters of the flow channel (cross section in fig. 4). In addition to serving as conductors these tubular members also provided a channel for cooling water. The conductors had an approximately triangular cross section for which the base measured approximately 1/2 inch and the height measured approximately 3/4 inch. Prior to the attachment of the tubular conductors, the HS-25 flow-channel tubing was solution heat-treated under vacuum for about 10 minutes at 2250° F.

Principle of Operation

As in other electromagnetic pumps, pressure development in a rotating-magnet induction pump is derived from interacting mutually orthogonal components of electric and magnetic fields. When rotating with respect to the pump cell, each of the six pole pairs of the electromagnet induces an electric current that circulates in a closed loop and passes through the inner and outer conductors and the pumped fluid, as depicted in figure 2(c) (p. 4). Each of the loops or circulation loci moves along the pump cell with the rotational speed of the electromagnet. That portion of the current in each loop that passes through the fluid in the flow channel interacts with the magnetic field existing between the poles. The interaction results in a force on the fluid elements through which

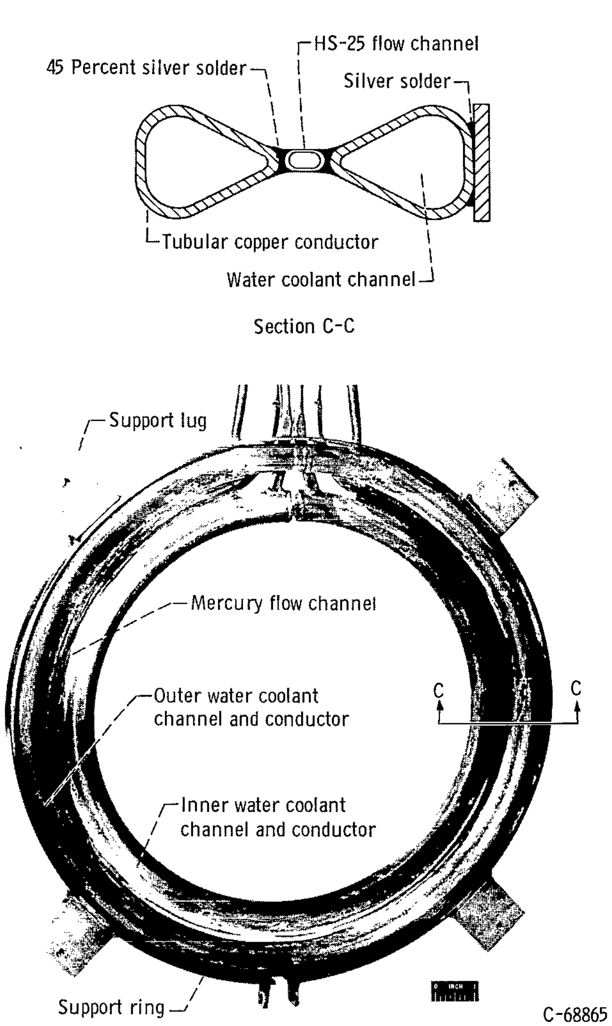


Figure 4. - Tubular copper conductor pump cell.

the current is momentarily passing; pressure development and consequent fluid motion arises as a reaction to the force. The electromagnetic interaction of the fields that arises in the vicinity of each pole "links" the fluid to the magnet so that the magnet tends to drag the fluid along as it rotates. The strength of the induced currents, and hence the amount of linkage or interaction, is dependent on both the electrical continuity within the pump cell and the strength of the electromagnet field current. For a given throttle valve setting the pump pressure can be controlled solely by varying the field current, all other factors such as the rotational speed being essentially fixed.

PROCEDURE AND RESULTS

Preliminary Considerations

Efficient pressure development in any electromagnetic pump and specifically in the electrodynamic mercury pump described herein depends on three principle factors:

(1) Good electrical conductance must exist between the fluid and the flow channel and between the flow channel and the conductors. Particularly, interfaces between the different materials involved should offer the least possible electrical resistance. To effect pumping, high electric currents (on the order of 1000 A/sq in.) pass in a radial direction to the fluid flow channel, and even relatively low resistances (on the order of 0.001 ohm) may pose a serious problem if the high rate of ohmic (I^2R) heat generation is considered. Therefore, good metallurgical bonding between the flow channel and the conductor annuli and optimum wetting by mercury of the flow channel surface are required.

(2) Low shunt resistance parallel to the flow channel must be provided by the conductor annuli, which are affixed to each side of the flow channel. The conductors are

required to provide the means for excluding nonradial portions of the induced currents from the pumped fluid in which they would produce useless transverse pressure gradients. Exceptionally good electrical conducting materials such as silver, nickel, or copper in conjunction with appropriately large cross-sectional areas are therefore needed for the conductor annuli to provide effective shunting.

(3) A means to efficiently remove the electrically generated heat in the pump cell must be provided to avoid overheating the fluid, to avoid adverse thermal stresses, and to maintain the required operating temperature. (The rate of heat generation under design conditions is roughly 10 kilowatts over the length of the flow passage of the pump.) This factor requires water-cooling channels to be directly on the conductor annuli for effective heat removal.

Test and Fabrication Procedure

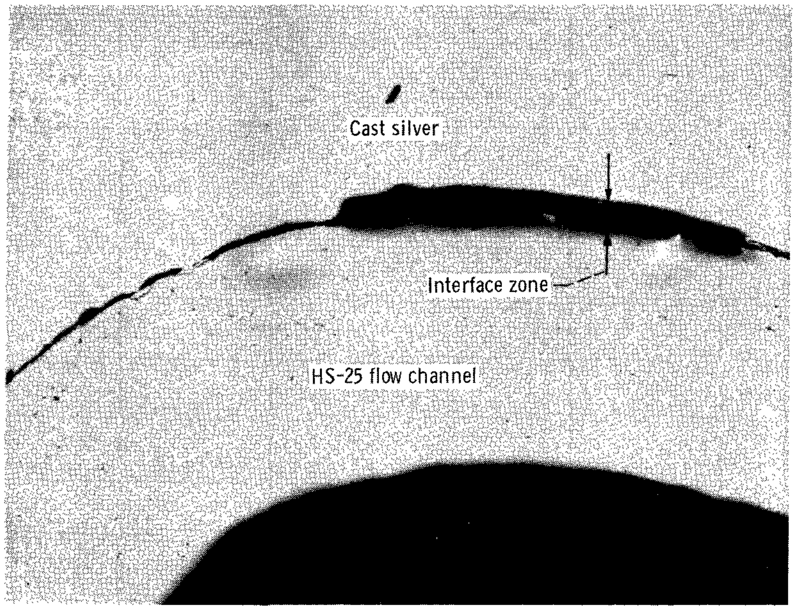
Preliminary operation of the pump with the cast-silver-conductor pump cell supplied by the manufacturer yielded unsatisfactory results because of overheating, inadequate head development, and boiling in the flow channel. Boiling was inferred from pressure traces and observation of boiling in the loop under similar conditions of temperature and pressure. These problems appeared traceable primarily to excessive ohmic heat generation, ineffective cooling, and inadequate mercury wetting of the flow channel.

The problem of overheating was not soluble without radical reconstruction of the pump cell; thus the problem of wetting was investigated first. A method for improving mercury wetting involving a sequence of chemical and thermal conditioning steps was developed. Performance of the cast silver cell was greatly improved by the application of the conditioning technique, which produced a high degree of wetting as evidenced by the higher developed pressures attained.

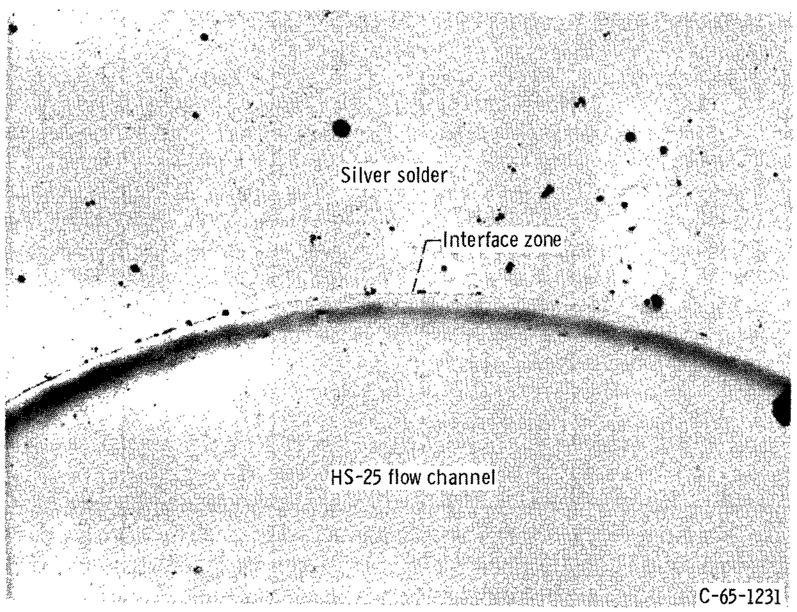
Operations with the cast silver cell were terminated, and the cell was sectioned to examine the regions in which excessive electrical heat generation was suspected. Microscopic examination of the silver-to-flow-channel interface revealed poor bonding and a high proportion of voids (fig. 5(a)). It is likely, therefore, that overheating of the flow channel was caused primarily by a lack of sufficient electrical continuity and the presence of high interface resistance resulting from unsatisfactory metallurgical bonding between the silver and the HS-25. The problem of overheating was probably intensified by the lack of effective heat removal by the water-coolant channels on the pump cell.

The poor bond between the silver and the HS-25 is probably inherent to the casting method used. Differences in the thermal expansion properties of the two materials result in high interfacial stresses upon solidification of the cast silver.

Another drawback inherent in the cast silver mode of pump cell construction is ex-



(a) Channel joint for cast-silver-conductor pump cell.



(b) Channel joint for tubular-copper-conductor pump cell.

Figure 5. - Microphotographic sections through conductor-to-flow channel joint for cast-silver-conductor and tubular-copper-conductor pump cells. X100.

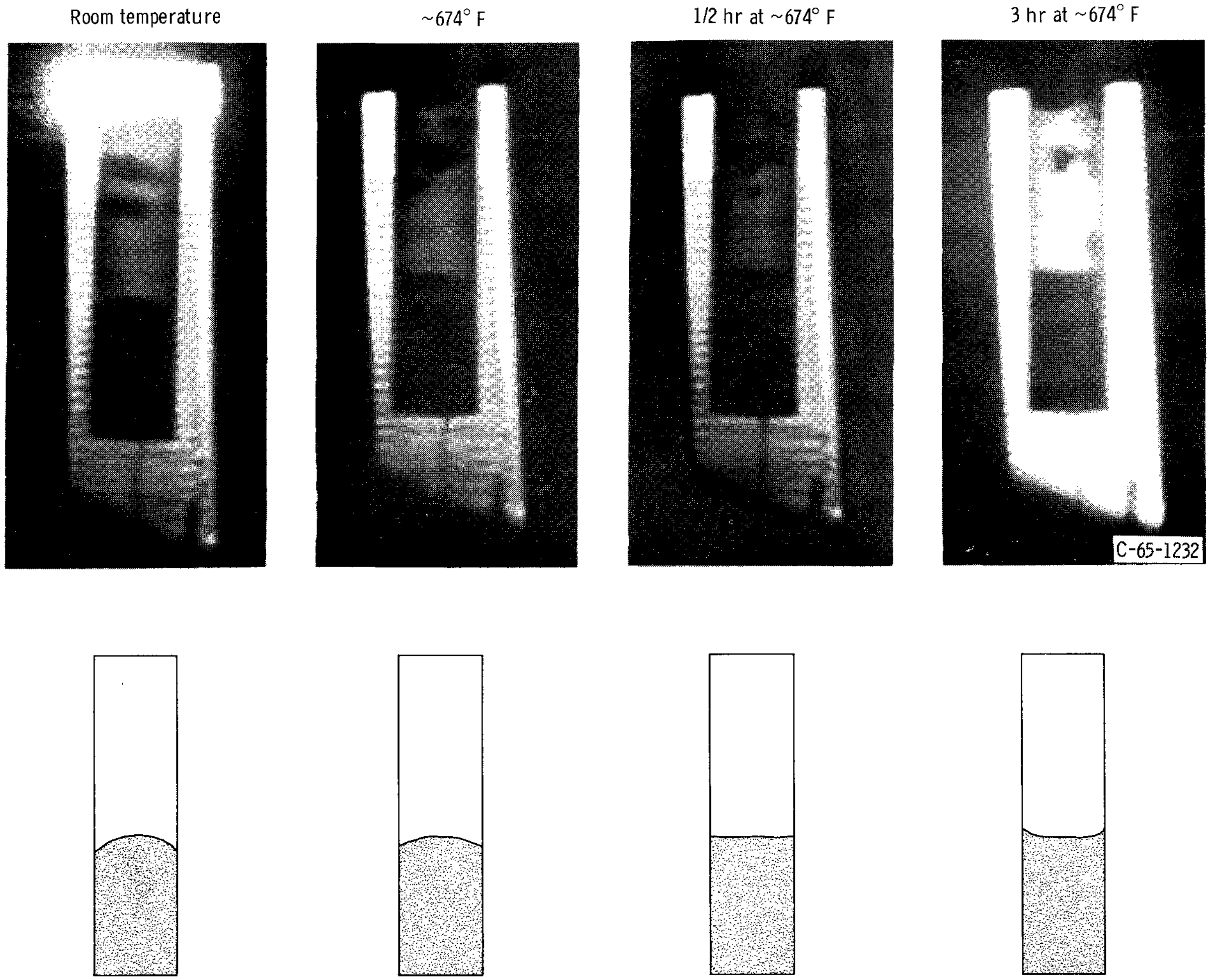
cessive hardening of the HS-25 material at the casting temperature. Although this factor did not affect pump performance, it was believed to shorten the pump cell life. (One reason for terminating the use of the cast silver cell was the appearance of a leak resulting from a crack in the flow channel.)

Tubular copper conductors silver-soldered to the flow channel, a design originated by Warren H. Lowdermilk of Lewis, appeared to resolve both the problem of securing good electrical continuity between the conductors and the flow channel and the problem of efficient heat removal. The tubular structure also allowed more thermal expansion thus minimizing the possibility of high stresses during the operation of the pump cell at elevated temperatures. Although annealed nickel was considered for the tubular conductors because of its superior oxidation resistance at high temperatures, nickel-plated copper tubing was selected because its conductance is greater by a factor of about 5.

Several methods for making the critical conductor-to-flow-passage joint were considered: arc welding with HS-25 and copper fillers, flame brazing with various silver solders, and furnace brazing. Furnace brazing was eliminated because the joint would have been weak and tenuous as a result of the differential expansion effects and the large spacing between the parts and because furnace brazing would involve temperature levels at which embrittlement of the flow-channel material is intensified. Evaluation and comparison of the results obtained by the welding and silver-soldering methods indicated that the best bonding was obtained with a 45-percent-silver solder alloy. This material was especially suitable because its "free-flow" temperature of 1145° F was well below the embrittlement temperature range of HS-25 while its "flow-start" temperature of 1125° F was sufficiently high to assure structural integrity at a pump-cell operating temperature of 600° F. When examined micrographically, the bonding was found superior to that observed in the cast silver cell (fig. 5(b)).

Tests performed with the tubular-copper-conductor pump cell indicated that the problems of electrical continuity, heat removal, and temperature control were resolved by the improved design and the mode of fabrication employed. Chemical and thermal conditioning techniques that evolved from the tests with the cast-silver-conductor pump cell were successfully employed to induce mercury wetting in the flow passage of the tubular-conductor pump cell. Pressure development and thermal characteristics of the tubular-conductor cell were investigated to determine the effectiveness of the wetting procedure, to determine factors that caused dewetting of the flow channel, and to determine the actual temperature levels at crucial points in the pump cell. These tests were accomplished under both flow and zero-flow conditions.

Over 200 hours of preliminary test operation of the tubular-conductor pump cell were accumulated. Afterwards, mercury was circulated for approximately 200 hours in the loop under two-phase, SNAP-8 conditions at the design pressure, flow rate, and temperature. No further changes in design appeared necessary, nor were any repairs or alterations required for the pump cell during shutdowns.



(a) Nonwetted condition. (b) Slight wetting. (c) Increased wetting. (d) Optimal wetting (no further change).

Figure 6. - HS-25 wetting capsule test results.

Surface Conditioning Procedure

The need for surface conditioning and the steps required to induce mercury wetting of the flow-channel material were demonstrated in a capsule experiment. The test capsule consisted of a small cylindrical container that could be capped and welded to form a vacuum-tight enclosure. After degreasing, ultrasonic chemical cleaning, and exposure to a 4-percent-sulfuric-acid - 4-percent-hydrochloric-acid solution, the capsule was partially filled with triple-distilled mercury and sealed by an electron-beam welder in a vacuum atmosphere of approximately 10^{-5} torr. The capsule was then placed in a specially designed furnace in which the capsule could be observed by means of an X-ray image amplification system. The initial form and changes of the mercury meniscus, which indicated the degree of wetting, were observed and radiographed at different levels of temperature.

Figure 6 (p. 11) illustrates the process as observed with an HS-25 capsule. The drawings in the figure are based on radiographs of the mercury meniscus. As seen in figure 6(a) the large contact angle of the meniscus indicated no immediate wetting as a direct result of chemical treatment and vacuum filling. Wetting ensued only after the temperature was raised to about 674° F (figs. 6(b) and (c)). (Although a temperature of 674° F is recorded, it had no particular significance because it was arbitrarily set.) Changes in the contact angle indicated improved wetting with prolonged heating at 674° F (fig. 6(d)). When heating was accomplished at temperatures below about 600° F no observable increase in wetting occurred even after 3 hours.

The wetting capsule data quoted above are unpublished preliminary results of an investigation being conducted by Kenneth J. Bowles of Lewis.

TABLE II. - TYPICAL CHEMICAL CLEANING SCHEDULE

Step	Cleaning solution or fluid	Duration, hr	Temperature, $^{\circ}$F	Purpose
1	Trichloroethylene	1/2	100	Degrease
2	Acetone	1/12	Room	Degrease and rinse
3	Distilled water	1/12	Room	Rinse
[a]4	[b]12 percent nitric acid-2 percent hydrofluoric-acid	1	Room	Descale
[a]5	[b]4 percent sulfuric acid-4 percent hydrochloric acid	1	150	Etch
[a]6	Distilled water	1/2	150	Neutralize and rinse
7	Argon	1/4	Room	Purge and dry out

[a]Circulated under ultrasonic vibration.

[b]Balance, distilled water.

On the basis of the capsule experiment a procedure for conditioning the surface at the pump-flow channel was developed. The first steps of the procedure consisted of a series of chemical cleaning treatments, as listed in table II. A sequence of degreasing rinses with trichloroethylene, acetone, and distilled water was used to eliminate oil films that may have deposited during previous processing or exposure to the atmosphere. Acid solutions were circulated through the channel under ultrasonic vibration to effect descaling and oxide-film removal from the channel surface. Following the cleaning procedure, the pump cell was secured to the pump framework, welded to the loop, and evacuated to about 10^{-4} torr. Triple-distilled mercury was then introduced into the flow channel and contiguous loop passages. Thermal conditioning was accomplished by induction-heating the mercury in the flow channel to about 700° F. The heating was accomplished by rotating the pump magnet and by appropriately adjusting the pump field current and flow rate of cooling water in the conductor coolant channels. While the mercury was heated in this manner for about 2 hours, mercury wetting of the channel progressively increased. Improved wetting was inferred from the rise in zero-flow developed pressure for a constant value of pump field current.

Although this method of thermal conditioning was believed to improve the wetting appreciably, it did not necessarily result in maximum wetting. Further increase in developed pressure was obtained by another mode of thermal conditioning that consisted of cycling the mercury temperature between 500° and 900° F at roughly 1 minute intervals

TABLE III. - PUMP FLOW CHANNEL CONDITIONING WITH TUBULAR CONDUCTOR PUMP CELL

Step	Conditioning applied	Developed pressure, psi (a)	Pressure trend[b]
1	Chemical cleaning under ultrasonic vibration	<200	No change
2	Thermal conditioning for 2 hr at 700° F, approx	~300	Increasing
3	Continued thermal conditioning at 700° F, approx	~350	Leveling
4	Thermal cycling between 500° and 900° F at 1 min intervals for 10 to 20 min, approx	~400	Increasing
5	Continued thermal cycling between 500° and 900° F at 1 min intervals, approx	>400	Leveling

[a]Obtained with zero-flow and field current of 3.0 amperes.

[b]If conditioning is terminated during or at the end of the step.

for 10 to 20 minutes. The thermal cycling was accomplished by setting the conductor cooling-water flow rate at a fixed level and then varying the pump field current between 0 and 3 amperes as the pump magnet rotated. In this manner mercury in the flow channel was alternately induction-heated and cooled. This mode of thermal conditioning resulted in a higher degree of wetting, as indicated by a further increase in developed pressure. Subsequent conditioning produced no pressure increase, and it was concluded that an "optimum" condition had been reached. The pump conditioning procedure is presented in table III (p. 13), where the sequence of steps and the pressure achieved as a result of each step are given.

To retain the optimum condition, it was necessary to maintain the flow-channel temperature at about 600° F or less. Had the temperature been allowed to remain above 800° F for more than a minute, boiling and resultant loss of developed pressure would have ensued. Boiling and other dewetting effects are discussed in the section entitled Mercury Dewetting Factors.

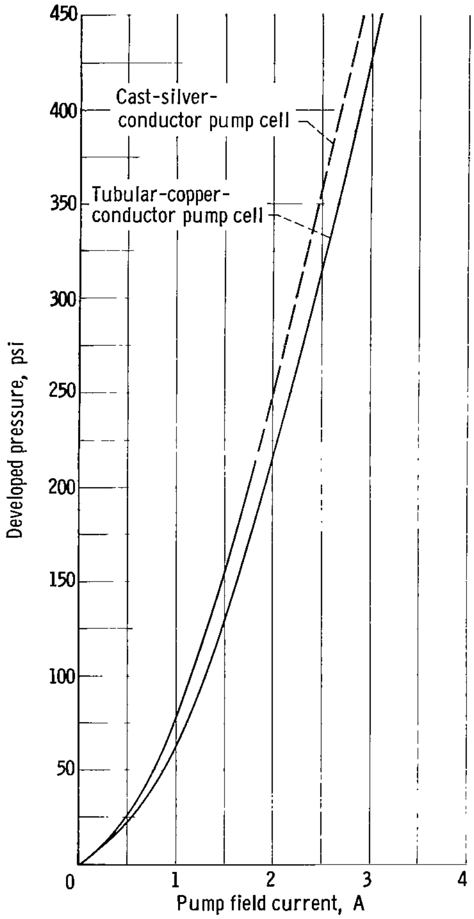


Figure 7. - Optimum, zero-flow developed pressure characteristics for cast-silver-conductor and tubular-copper-conductor pump cells.

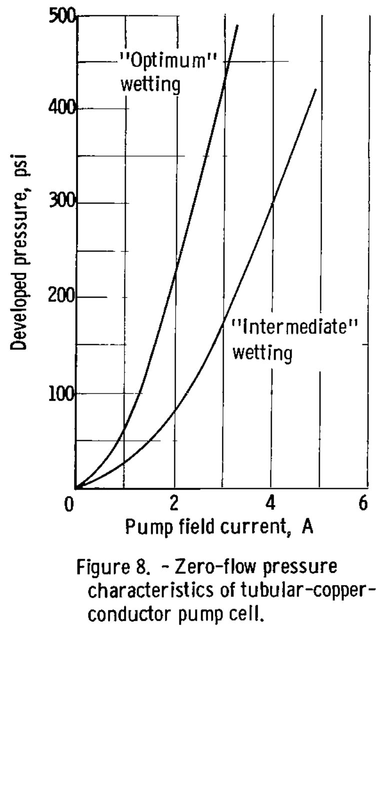


Figure 8. - Zero-flow pressure characteristics of tubular-copper-conductor pump cell.

Pressure Characteristics

A plot of optimum developed pressure against field current under zero-flow conditions is presented in figure 7 for the tubular-copper-conductor cell. A similar plot for the cast-silver-conductor cell is included for comparison. Although the cast silver cell produced a slightly better pressure characteristic, it could not be operated continuously with field currents greater than about 2 amperes because of overheating, which results in pressure degeneration.

Plots of developed pressure against field current obtained before and after thermal conditioning of the tubular-copper-conductor pump cell are presented in figure 8. The upper, optimum curve represents the best pressure characteristic obtained and is identical to that in figure 7. The optimum curve of figure 8 represents the highest degree of mercury wetting obtainable by the methods described in the preceding section. The lower, "intermediate" curve of figure 8 represents mercury wetting just after chemical cleaning and vacuum loading of mercury into the flow channel.

The reader is cautioned that the optimum and intermediate curves are not to be interpreted as curves indicative of maximum or minimum wetting, respectively; rather, these curves represent reproducible initial and final sets of conditions achieved in the present investigation.

Investigation of the variation of developed pressure with respect to mercury flow rate was accomplished within a limited flow range, 0 to 200 pounds per hour. For the flow range surveyed the developed pressure was nearly constant as anticipated in lieu of the low flow rates involved.

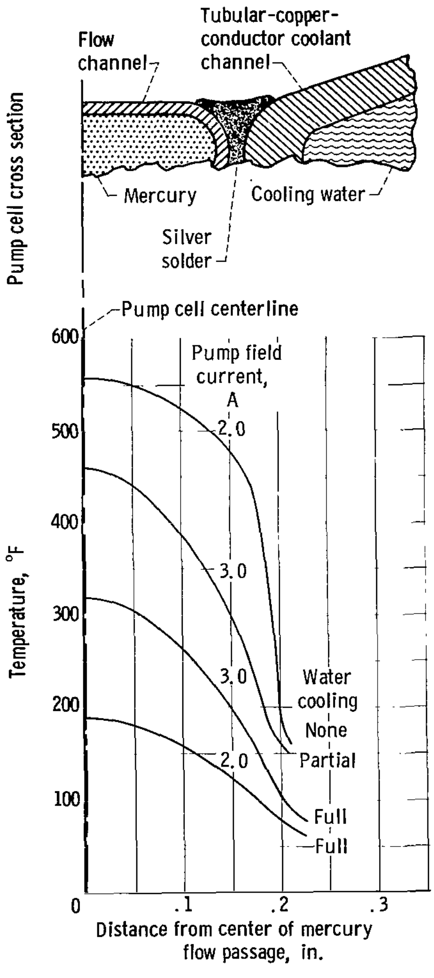


Figure 9. - Temperature profile in flow passage-to-conductor zone of tubular-copper-conductor pump cell.

Pump Cell Temperatures

Circumferential and radial temperature profiles of the pump cell were obtained with thermocouples spot-welded to the flow channel and conductor surfaces at various key locations. Several representative radial temperature profiles are presented in figure 9 with a cross-sectional sketch of the pump cell identifying the region involved. As evident from figure 9, the temperature level was controllable by adjustments in cooling-water flow rate and electromagnet pump field. Figure 9 represents surface thermocouple temperatures only; the actual temperature of mercury in the flow channel may have been 100° to 200° F higher.

Electromechanical Characteristics of Pump

An important factor that imposed an upper limit on the pump field current was the electromechanical linkage between the rotating electromagnet and the pump cell. This resulted in magnetic braking, which for a field current of 3 amperes dissipated approximately 15 horsepower. For a 6-ampere field current, approximately 35 horsepower were required to overcome magnetic braking, as determined by measurement of the motor power demand. Because of mechanical and stress considerations, a field current of about 3 amperes was selected as suitable for continuous pump operation, and a maximum field current of 4 amperes was selected for intermittent thermal conditioning of the cell.

Pump pressure was rather sensitive to small variations of voltage in the pump-field direct-current power supply. Small changes in field current effected relatively large changes in pressure, as borne out by the slopes of the plots of the developed pressure against field current in figure 7. For the tubular-copper-conductor pump cell, for instance, the slope was 250 pounds per square inch per ampere for field currents between about 2 to 4 amperes, the normal operating range. To minimize pressure variations caused by inadvertent drifting of the field current, it was necessary to employ a special, controlled direct-current power supply that limited field current variations to less than 0.01 ampere.

Mercury Dewetting Factors

Even after optimum mercury wetting in the pump flow channel was achieved, dewetting occasionally occurred during preliminary test runs, as evidenced by the loss of developed pressure. Dewetting appeared to be ascribable to three factors: first, boiling resulting from overheating; second, flow transport of oil or other contaminants into the flow channel; and third, oxidation or oxygen adsorption on the flow-channel surface.

Dewetting from boiling could be initiated simply by allowing the pump cell temperature to rise above about 800° F. Dewetting from overheating occurred in the cast-silver-conductor cell whenever the field current was raised above 2 amperes even with full cooling.

A thin film of oil adsorbed on mercury or a metallic surface will act as a barrier to wetting. Possible dewetting from oil contamination was minimized by chemical removal of oil residues from all loop components, the mercury reservoir, and the connecting tubing through which the loop was filled. Also, evacuation of the loop was accomplished by means of an oilless, cryogenic vacuum pump to eliminate oil back streaming usually associated with oil-diffusion or mechanical vacuum pumps.

The third dewetting factor prevailed during shutdowns when atmospheric oxygen was admitted into the loop and pump cell. Subsequently, the cell had to undergo thermal conditioning to reoptimize wetting for the next run. In this case dewetting was assumed to result from oxygen-film adsorption on the HS-25 surface, which because of its high chromium content has a particularly high affinity for oxygen.

SUMMARY OF RESULTS

The application of an electrodynamic induction pump to electromagnetic pumping of mercury was accomplished by resolving problems associated with the surface properties and high vapor pressure of mercury. Although electrodynamic pumps have been used successfully with alkali liquid metals, the properties of mercury are sufficiently different to entail considerable revision of the standard pump cell design and mode of fabrication.

A silver-soldering technique was used to establish good metallurgical bonding between the flow channel and the conductors to alleviate excessive electrical heat generation in that region of the pump cell. Tubular copper conductors serving as coolant channels were substituted for solid, silver conductors to provide more effective water cooling of the heat generating zone.

Surface-conditioning techniques were necessary to induce a high degree of mercury wetting of the pump flow channel, a prerequisite to effective pressure development. The first step of the surface-conditioning procedure involved a series of chemical treatments to eliminate contaminants that would form barriers to wetting. The second step involved thermal conditioning at elevated temperatures to increase the degree of wetting between the flow channel surface and the mercury.

This investigation resulted in a pump cell that was capable of producing mercury pressures on the order of 500 pounds per square inch at flow rates on the order of 100 to 200 pounds per hour. The pump was used to circulate mercury in a two-phase loop experiment for over 200 hours under SNAP-8 conditions of temperature and pressure.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 1, 1965.

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