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**AN ELECTRO - MAGNETIC PUMP AND HEATING TRANSFORMER
FOR HIGH TEMPERATURE LIQUID METALS**

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U N I T E D S T A T E S A T O M I C E N E R G Y C O M M I S S I O N

AN ELECTRO-MAGNETIC PUMP AND HEATING TRANSFORMER
FOR HIGH TEMPERATURE LIQUID METALS

by

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ABSTRACT

Details of a linear electro-magnetic induction pump and heating transformer for circulating Mg-Th alloy at 1000°C are given.

I. INTRODUCTION

The purpose of the experiment was to circulate a liquid metal at temperatures up to 1000°C in an inner envelope material which could not tolerate atmospheric gases at this elevated temperature.

Since static corrosion tests indicated that tantalum might be a suitable container for Mg-Th alloy, this combination was selected for the first attempt.

II. LOOP DESIGN

The final loop design incorporated an inner envelope of 0.030 in. thick tantalum and an outer envelope of one-eighth inch inconel. Fig. 1 shows the size and construction of the loop.

All tantalum welds were made under a helium atmosphere and no filler rod was used. A heliarc torch with tungsten electrode and argon was used at 90 amp direct current, for the tantalum welding.

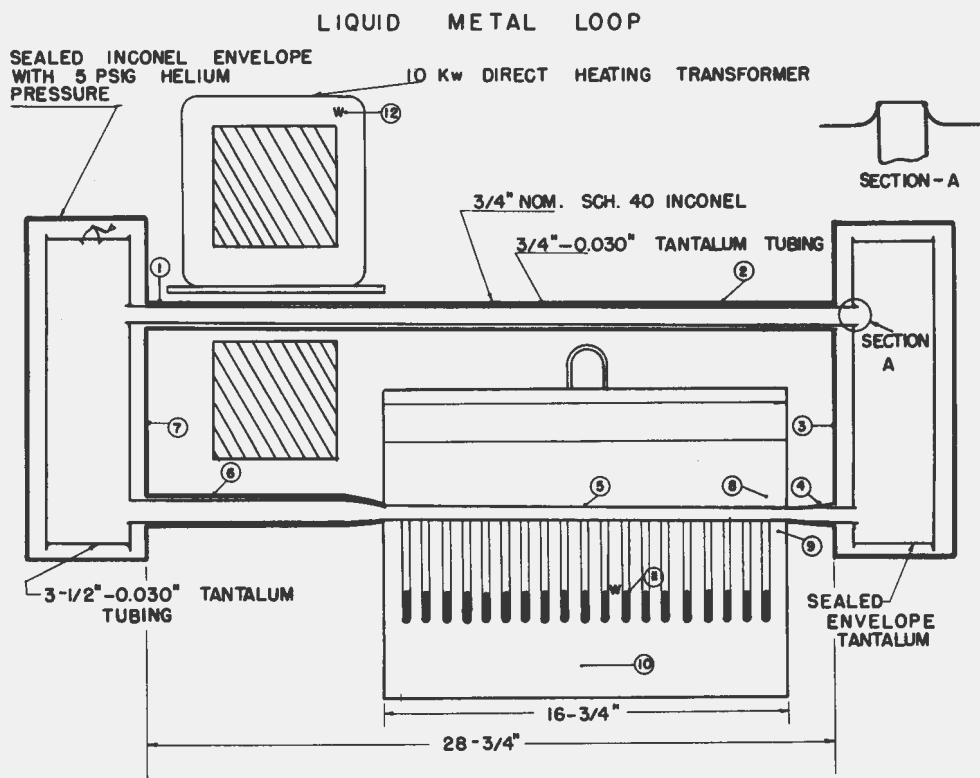


Fig. 1

The welded joints were all mechanically formed to give mating edges which could be fused together with no filler rod required. Insert A in Fig. 1 shows a tantalum weld.

The tantalum envelope was evacuated after charging with alloy and the system sealed with 3 psia of helium.

The outer inconel envelope was heliarc welded and leak tested. It was equipped with a remote pressure gauge and a second remote evacuating lead-in tube. The system was designed to contain a static charge of helium at 5 psig.

III. ELECTRO-MAGNETIC PUMP DESIGN

Inasmuch as the viscosity and electrical properties of the liquid alloy at elevated temperatures were not known, no accurate predictions of pump performance could be made.

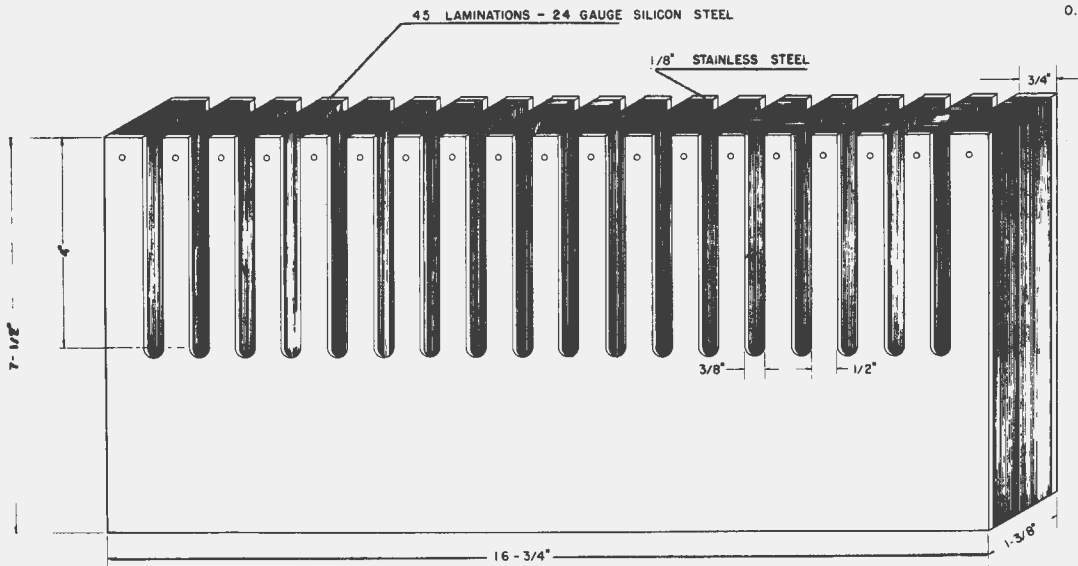
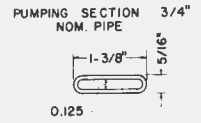
An appropriate field velocity with respect to efficiency was selected and the compromise of heat removal from the poles against an increased air gap for insulation, resulted in a 7 1/2-in. deep core, 16 3/4-in. long.

The size of tantalum tubing selected was 3/4-in. OD and this dimension fixed the thickness of the pump at 1 3/8-in. Fig. 2 shows the core before winding.

Following are the specifications:

- 2 pole - 3 phase - 3 slots/phase
- 18 coils - two layer winding
- 30 turns/coil - No. 12 Formvar wire
- 8/9 pitch - Y connected
- Rated voltage - 208 v - 60 cycles

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LINEAR ELECTRO-MAGNETIC INDUCTION PUMP STATOR CORE 2 POLES - 60 CYCLES - 3 SLOTS/PHASE - 3 PHASE ARMATURE GRADE STEEL

Fig. 2

Rated power - 1000 w max.

Maximum air gap - 1/2-in.

Armature grade silicon steel core - laminated - 24 gauge

Approximate field velocity - 80 ft/sec.

Fig. 3 shows the wiring diagram of the pump windings and Fig. 4 is a detailed drawing of the core iron cap.

The pumping section is 3/4-in. nominal schedule 40 inconel pipe with an internal liner of 0.030 in. tantalum 3/4-in. OD tubing. The double envelope is rolled flat to a finished inside dimension of 0.125-in. by 1.125-in. The rolling process involves the use of a bending alloy and soft copper tubing in the section as it is rolled to allow for the decrease in cross-sectional area as the rolling progresses.

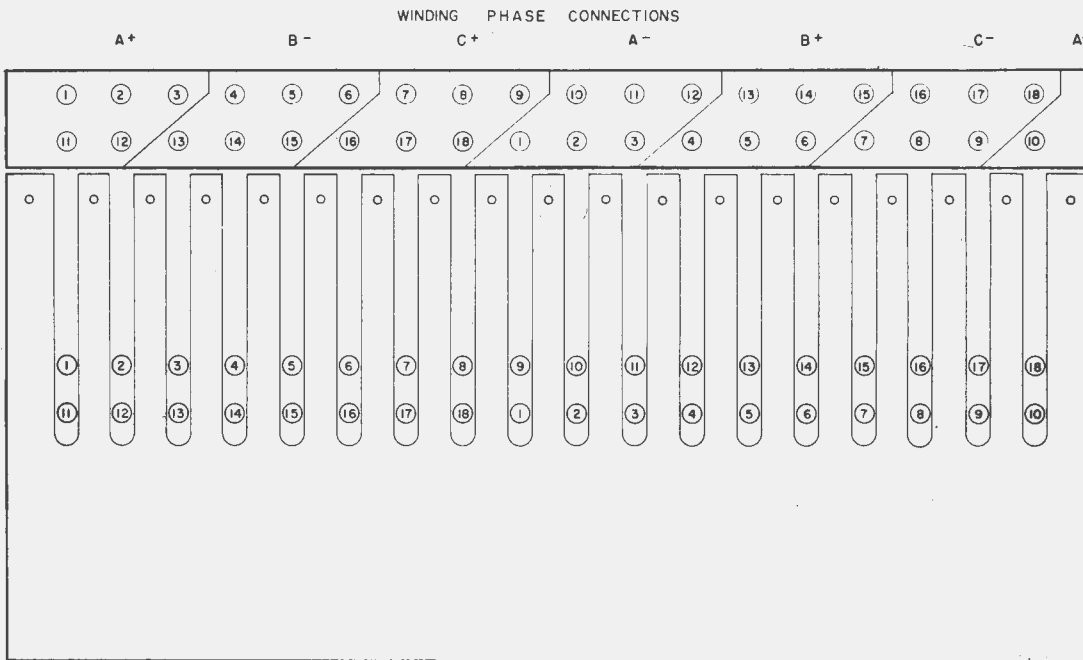
The pole extensions of the pump are cooled with 400 cfm of air, delivered through the winding slots and across the varnish-dipped windings. The core iron cap is cooled with approximately 20 cfm of air delivered by a small blower.

IV. HEATING TRANSFORMER DESIGN

The principle involved is different from most transformer designs, in that the liquid metal loop acts as a one-turn secondary winding which has a changing resistance with temperature change.

An approximate loop resistance was calculated from the information available on the separate metals involved.

A maximum secondary voltage of 6 was determined from the estimated heat loss from the system and the approximate resistance of the loop.



TWO LAYER WINDING 8/9 PITCH #12 WIRE - FORMVAR 30 TURNS / COIL U.S.S. ARMATURE GRADE SILICON STEEL
24 GAUGE. 220 VOLTS-60 CYCLES 3 PHASE-15 AMPS. AIR GAP 7/16" to 1/2".

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Fig. 3

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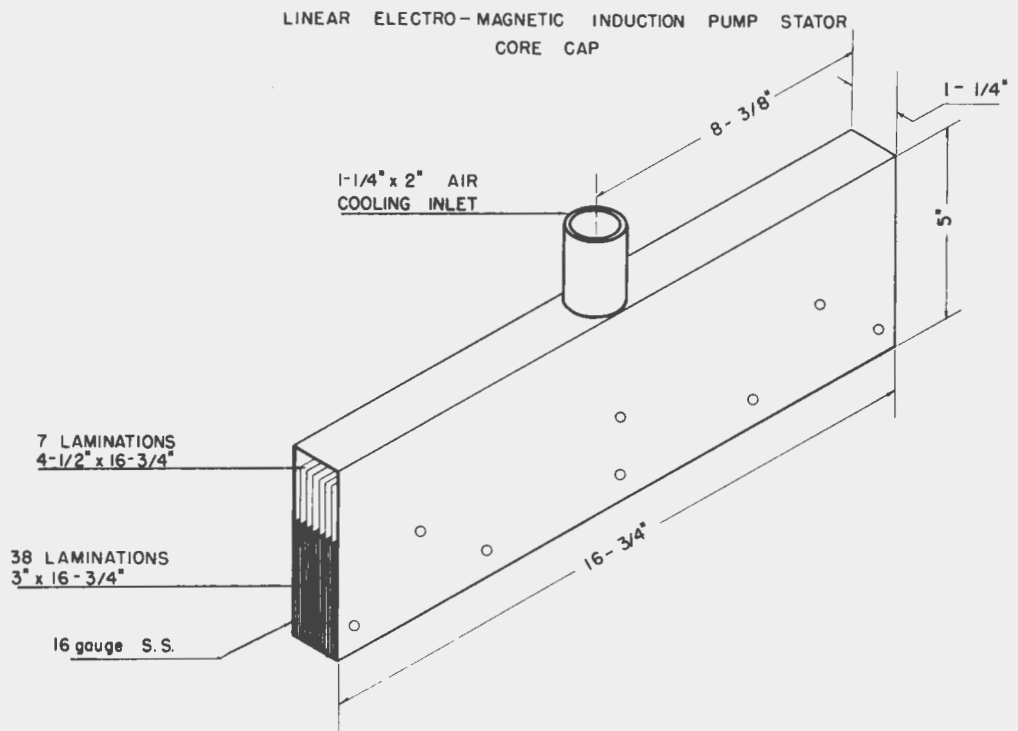


Fig. 4

Following are the transformer specifications:

Primary voltage - 210 V - 60 cycles

Secondary voltage - 6 v.

Armature grade silicon steel - 24 gauge design at 90,000 lines/sq. in.

35 turns

5 in. x 5 in. cross-section - 2 in. x 4 in. winding opening = 32 in. mean path

Volume = 760 cu. in. - Wt. = 212 lb.

Magnetizing Ampere-Turns = 768

Core loss = 720 w

Magnetizing current = 22 amp

Core loss current = 3.43 amp

Total primary current = 60 amp

Primary wire size = 1.5 in. x 0.030 in.

Secondary Current = (52.57)(35) = 1850 amp

Maximum Power output = (1850) (6) = 11 kw max

Transformer Design Calculation:

$$\phi_m = \frac{E}{4.44fN} = 0.00376 \frac{E}{N} = 0.0225 \text{ webers}$$

$$A = \frac{0.0225 \times 10^8}{90 \times 10^3} = 25 \text{ sq. in.}$$

The transformer core sheets were varnish-dipped and all through bolts were insulated from the core iron. Two 1/8-in. stainless steel plates were used on the outside to obtain as tight a packing density as possible.

Fig. 5 shows the transformer as constructed.

The throat of the transformer, through which the liquid metal loop passes, is cooled by 50 cfm of cooling air.

10 KW HEATING TRANSFORMER

PRIMARY

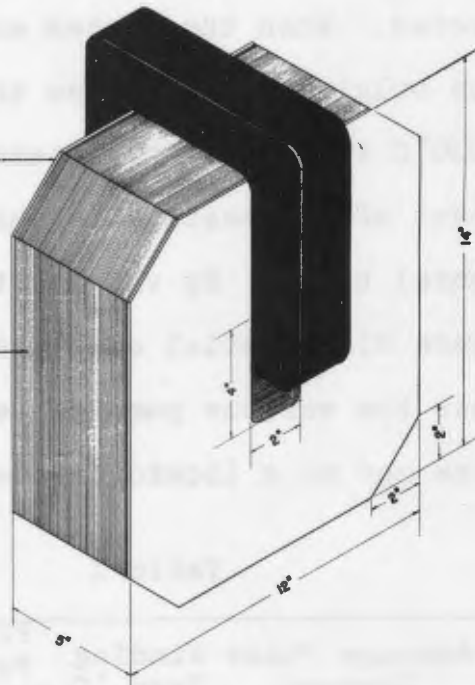
235 VOLTS 60 AMPS MAX. FLAT COPPER
WIRE 1.5" x 0.030" 33 TURNS.

SECONDARY

7 VOLTS 1800 AMPS MAX. LIQUID METAL
LOOP SECONDARY.

1/8" S.S. SIDE PLATES UNIT
BOLTED TOGETHER WITH 12
S.S. THROUGH BOLTS 3/16"
INSULATED FROM CORE MAT'L.

24 GAUGE USS. ARMATURE
GRADE SILICON STEEL
185 LAMINATIONS —
VARNISH DIPPED



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Fig. 5

V. SYSTEM PERFORMANCE

The complete system as described has operated for 2000 hours to date with no evidence of over-heating or failure of the components.

Fig. 6 shows the loop test stand.

Radiographs of the system, using iridium-192 as a source, showed bulging of the tantalum reservoir end plates at 800°C. The system was either overcharged or the vapor pressure of the alloy was higher than expected. When the system was operated at 840°C for 48 hours, the bulging increased so the operating temperature was reduced to 800°C to reduce the internal pressure.

The major part of the heating in the system takes place in the small horizontal tubes. By varying the pump power and direction, various temperature differential combinations can be achieved.

Table I shows the various pump temperatures at three different pump power inputs and at a liquid temperature of 800°C.

Table I

Power Watts	Voltage	Average Phase Current	Winding Temp. °C	Pole Face Temp. °C	Core Root Temp. °C	Cap Iron Temp. °C
300	150	6.9	50°	75°	70°	220°
600	200	9.6	60°	75°	88°	220°
900	230	11.3	70°	75°	94°	220°

The transformer winding temperature does not exceed 50°C.

LIQUID METAL LOOP TESTING SET-UP

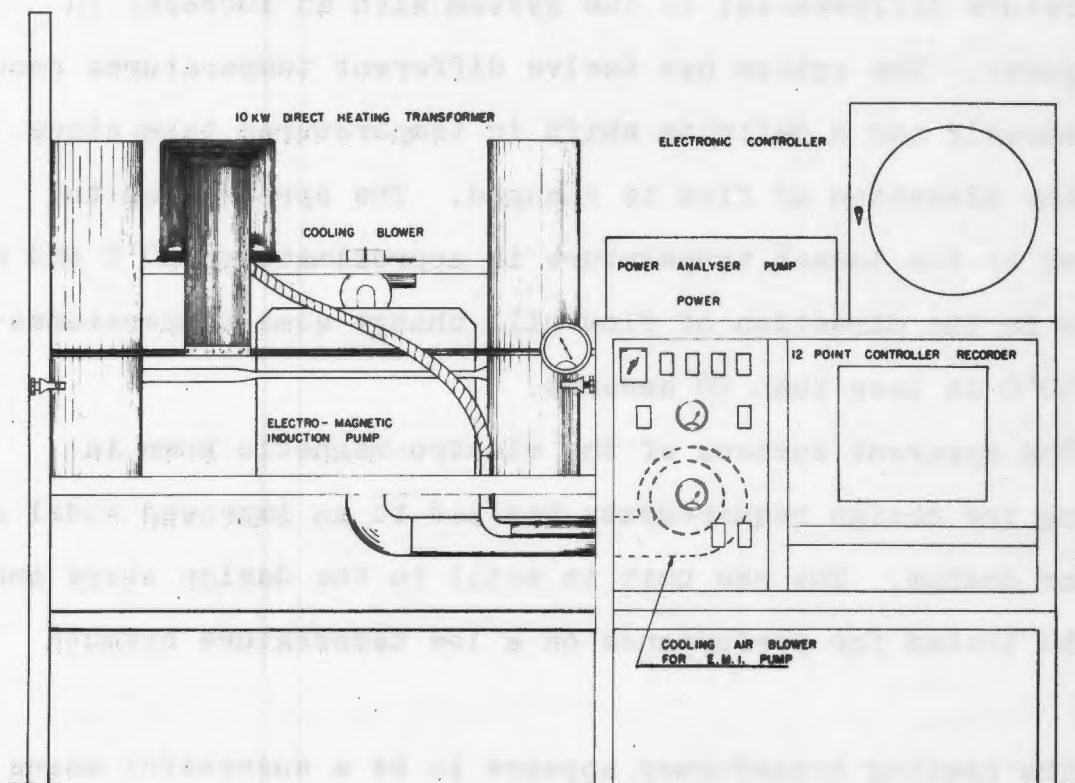


Fig. 6

Following are transformer performance readings:

Primary power - 4600 w

Primary voltage - 130 v

Primary current - 36 amp

Secondary current - 1200 amp

Approximate efficiency - 97%

An accurate determination of flow rate has not been made, but positive evidence of flow is noted by the reduction of the temperature differential in the system with an increase in pump power. The system has twelve different temperatures recorded continuously and a definite shift in temperatures takes place when the direction of flow is changed. The spread from the highest to the lowest temperature is approximately 120°C and a change in the direction of flow will change some temperatures over 50°C in less than 30 seconds.

The apparent success of the electro-magnetic pump in meeting the design requirements has led to an improved model of similar design. The new unit is still in the design stage and will be tested for performance on a low temperature bismuth loop.

The heating transformer appears to be a successful means of uniformly heating metals to temperatures above the range of conventional heating elements.