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FRATT & WHITNEY AIRCRAFT
DIVISION OF UNITED AIRCRAFT CORPORATION

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IN NUCLEAR SCIENCE ABSTRACTS

CHAM-5354
Specification For High Frequency Linear
Induction Electromagnetic Pump

November 11, 1963

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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1.0 General

All areas of work not specifically covered herein shall be in accordance with and subject to the terms and conditions of United's purchase order in which this specification is incorporated.

2.0 Scope

This specification sets forth the requirements for the design and fabrication of a linear induction electromagnetic pump for a NaK-316 stainless system. This pump is planned to be used as an experimental unit for evaluation of light weight high frequency electromagnetic pumps. This specification covers procurement of the pump unit only; the auxiliary coolant system and the control system will be furnished by United.

3.0 Proposal

3.1 Proposals shall be submitted within four (4) weeks after receipt of United's request. The proposal shall be in strict accordance with this specification and shall bear a statement to this effect. If exceptions are taken, they shall be clearly defined and itemized separately. Sufficient information shall be submitted with the proposal to allow proper evaluation by United. This information shall include the following:

- a. Complete description of the component.
- b. Complete bill of materials.
- c. Circuit diagram
- d. Outline drawing(s).
- e. Predicted performance curves and operating characteristics.
- f. Estimated weight.
- g. Design stress levels in pump duct cells and pertinent mechanical and physical property data used in establishing these design stress levels.
- h. Delivery date and list of major milestones along with target date.
- i. Price.

3.2 In addition, a separate proposal shall be submitted covering performance testing. This proposal shall be based on testing the pump using NaK in a stainless steel system at a temperature of 1000F. The test results shall be presented in a test report. All records, data, charts, etc., resulting from the test shall become the property of United.

4.0 Proposal Evaluation and Vendor Selection

It should be recognized at the onset of this procurement that the power factors and efficiencies are the minimum values necessary for the feasibility of this concept. Therefore, the Vendor should make every effort to improve these values and, in addition, obtain a lightweight design. The engineering performance of this unit with respect to improvement over these minimum criteria will be weighed heavily in the evaluation of proposals in addition to the normal cost evaluation.

5.0 Design Approval

5.1 The Vendor shall submit four (4) copies of all drawings covering the complete design and fabrication of the unit. The time period required to complete these drawings shall be submitted as part of the proposal.

5.2 Within two weeks after receipt of the above drawings and other required information, United will return one (1) set individually signed and marked:

1. Approved
2. Approved with corrections as noted
3. Returned for corrections

Prints in category 1 or 2 authorize the vendor to proceed; items under category 3 shall be resubmitted for approval.

5.3 Within two (2) weeks after receipt of approved drawings, the Vendor shall furnish four (4) complete sets of certified construction drawings covering the complete equipment.

5.4 The applicable United Specification number and purchase order number shall be marked on each drawing, preferably in the title block.

5.5 Checking and/or approval of drawings, material lists, etc., by United shall not relieve the vendor of the responsibility of errors. Approval by United shall not be construed as waiving any part of this specification unless the approval includes a specific written statement to that effect.

5.6 Any proposed variation from these specifications, any proposed changes after design approval has been given, shall be reduced to writing by the Vendor and submitted to United for consideration. No change shall be put into effect until written approval has been granted by United.

5.7 No drawings or other information submitted to United shall contain "proprietary" clauses. Drawings containing such clauses shall be returned to the vendor for deletion or waiver of the same prior to any action by United. Any delays caused by the above shall not relieve the Vendor of the responsibilities to meet all schedules pertaining to the work.

6.0 Correspondence

- 6.1 All correspondence pertaining to the equipment furnished by the Vendor under this specification shall bear reference to this specification and to the applicable United purchase order number.
- 6.2 The minutes of any meeting between the Vendor and United shall be reduced to writing by the Vendor with three copies to United.

7.0 Identification

The complete assembly shall bear a nameplate stating the Vendor's name, model number, serial number, operating limits, United's purchase order number and the specification number.

8.0 Delivery and Schedules

- 8.1 Delivery of the system shall be made to CANEL, River Road, Middletown, Connecticut.
- 8.2 The Vendor shall submit a complete design, procurement and fabrication schedule to United within two weeks after receipt of order. The Vendor shall formally report status of this schedule every two weeks. Any deviation from this schedule must be completely and, in United's opinion, adequately justified.

9.0 Intended Use

- 9.1 The unit specified herein will pump NaK at 1000F and will operate in an air environment. Experimental evaluation of this pump concept over a range of head and flows is planned. Continuous runs of up to 10,000 hours are contemplated.

10.0 Engineering Requirements

The pump shall be designed to meet the following conditions and requirements:

10.1 Design Specifications

10.1.1	Rated Capacity	15 lb./sec.
10.1.2	Head Rise at Rated Capacity	20 psi
10.1.3	Inlet Pressure at Rated Conditions	15 psia
10.1.4	Inlet Temperature at Rated Conditions	1000F
10.1.5	Pumped Fluid	NaK (78% - K)
10.1.6	Rated Voltage	200 Volts

10.1.7	Number of Phases	3
10.1.8	Frequency	400 cps
10.1.9	Ambient Temperature	150F
10.1.10	Coolant	Water
10.1.11	Design Life	10,000 hours continuous
10.1.12	Electrical Insulation	Class H or better
10.1.13	Power Factor at Rated Conditions	0.25 minimum uncorrected
10.1.14	Overall Pump Efficiency at Rated Conditions	15% minimum
10.1.15	Weight	Minimum practicable
10.1.16	Operating Environment	Air
- 10.2 Duct Design Requirements
- 10.2.1 Material - 316 Stainless Steel - AMS 5573, AMS 5524 or AMS 5648.
 - 10.2.2 End Connections - butt welding - tube size to be determined.
- 10.3 Maintenance
- 10.3.1 Maintenance is limited to that which can be performed with the unit operating. Maximum continuous operation is up to 10,000 hours.
 - 10.3.2 The stator shall be bolted for easy accessibility and shall be capable of replacement without disturbing the pump duct.
- 10.4 Mounting
- 10.4.1 Pump design shall be suitable for mounting with duct axis either horizontal or vertical.
 - 10.4.2 United will supply mating attachments for pump mounting.
- 10.5 Thermocouples - chromel/alumel wired to separate terminal posts shall be provided to sense the following temperatures:

- 10.5.1 Pump Cell, four (4) locations along longitudinal axis, three (3) thermocouples spaced transversely at each location for a total of twelve (12).
 - 10.5.2 Stator Conductors, four (4) locations, three (3) thermocouples at each location for a total of twelve (12). Locations to correspond to 10.5.1.
 - 10.5.3 Core Iron, four (4) locations, three (3) thermocouples at each location for a total of twelve (12). Locations to correspond to 10.5.1.
 - 10.5.4 Stator End Turns, three (3) locations, two (2) thermocouples at each location for a total of six (6).
 - 10.5.5 Responsibility for readout equipment and its connection to terminal board to be assumed by United. Locations of thermocouples to be specified by United.
- 10.6 Cooling
- 10.6.1 Cooling System - Vendor shall design pump to utilize water at a minimum inlet temperature of 150F.
 - 10.6.2 Alternate Cooling System - If water cooling is found to be unacceptable from a design standpoint, alternate cooling methods may be proposed.
- 10.7 Applicable Specifications
- 10.7.1 The detail pump duct design shall incorporate the latest issue of the following specifications:
 - CS-120 - General Procedure Inert-Gas-Shielded Tungsten Arc Welding
 - CS-309 Class II - Cleaning and Preservation of Components and Systems
 - CS-140 - Procedure for Inspection of Welds
 - 10.7.2 The thermocouples shall conform to the latest issue of the following specifications:
 - CSP-1927 (Class II with Grounded Junction) - Thermocouple - AMS 5573 Clad Cap Welded Chromel/Alumel.
- United will consider exceptions to these specifications.

10.8 Electrical Connections

The two (2) leads from each of the three (3) phases for each of the two stators shall be brought out separately to a terminal board. These shall be connected at the terminal board in such a manner to facilitate phase-to-phase and phase-to-ground resistance measurements with a minimum disconnection of wires.

11.0 Inspection and Testing

11.1 The complete pumping system shall be installed in a NaK/stainless system and performance tested. The test shall be conducted at temperatures not less than 1000F. Certified reports of the test shall be submitted in which all data is reproduced. (As noted under Paragraph 3.2, the proposal for testing should be covered separately. United, at its option, may choose to perform these tests at CANEL as part of the evaluation program).

11.2 United reserves the right to witness any tests performed by the Vendor on these units. The Vendor shall notify United at least 48 hours prior to the beginning of testing.

12.0 Installation

The Vendor shall furnish, at CANEL, Middletown, Connecticut, one representative to inspect and certify the correctness of the complete installation of the pump system.

13.0 Performance, Reliability, and Warranty

Because of the experimental nature of this pump unit, a certain latitude must be allowed with regard to performance. Therefore, the Vendor shall state the tolerance limits within which his design will meet the design head and flow requirements. Following installation, and after inspection by the Vendor and acceptance by United, the Vendor agrees that for 1,000 operating hours or 6 months, whichever occurs first, he will, at no cost to United, immediately correct any failure in the equipment which is attributable to faulty material, workmanship, or which results from a deficiency in design. The Vendor shall clearly indicate in his operating manual, design limits which may not be exceeded for the warranty to remain in effect.

14.0 Design and Operating Manual

Twelve (12) copies of a Design and Operating Manual which shall include but not be limited to the following information shall be provided for the pump.

14.1 Design Information

- 14.1.1 Performance curves indicating calculated heads, efficiencies, power factors for flows up to maximum at design voltage.
- 14.1.2 Operation limits of pump, i.e., maximum cell pressure, cell temperature, iron temperature, insulation temperature, winding temperature, coolant temperature, maximum rate of temperature rise in pump cell, maximum rate of temperature rise in windings, maximum rate of power increase at startup.
- 14.1.3 Design Parameters at Rated Condition
 - a. Average liquid metal velocity in pump cell.
 - b. Maximum liquid metal velocity in pump cell
 - c. Pump cell stresses.
 - d. Average current density in stator winding
 - e. Maximum and average flux density in pump cell.
 - f. Maximum and average flux density in the stator teeth.
- 14.1.4 Step-by-step description of the installation and normal operating procedures.
- 14.1.5 Complete parts list.
- 14.1.6 Operational, inspection and preventative maintenance requirements.
- 14.1.7 Complete set of as-built electrical and mechanical drawings including one reproducible copy of each drawing for United's use.
- 14.1.8 Recommended electrical control circuit diagram.

PRATT & WHITNEY AIRCRAFT
DIVISION OF UNITED AIRCRAFT CORPORATION

CANEL

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CHIM-5354
Supplement 1
Specification for High Frequency Linear
Induction Electromagnetic Pump

February 11, 1964

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UNCLASSIFIED
Classification

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2/13/64
Date

Introduction

This supplement provides a specification for the two part procurement of a linear induction electromagnetic pump. Only paragraphs containing changes (additions, corrections, or deletions) to CNIM-5354 dated November 11, 1963, are covered by this supplement. All remaining clauses are as stated in the original specification.

2.0 Scope

This specification sets forth the requirements for a two phase effort covering procurement of a linear induction electromagnetic pump for a NaK/316 S.S. system. This pump is planned to be used as an experimental unit for evaluation of light weight high frequency electromagnetic pumps. The specification covers only the pump unit procurement; controls, cooling, and other auxiliaries will be furnished by United. Phase I of this specification covers the analytical design, drawings, and the completed design report. Phase II is the fabrication and delivery of actual hardware. The results of Phase I will be used to determine the advisability of the continued fabrication effort.

Upon completion of Phase I, United may, at its sole option, elect not to proceed with Phase II without any obligation to the Vendor beyond Phase I.

3.0 Proposal

3.1 h. Delivery date for (1) Design drawings and report and (2) completed pump including list of major milestones with target dates.

5.0 Design Approval

5.1 Within 12 weeks after receipt of order, the vendor shall submit to United four (4) copies of all drawings, curves, pertinent analysis, and reasoning for the final selection. These shall be submitted as a design report, with the drawings suitable for use in Phase II of the contract. These drawings shall include, but are not necessarily limited to:

1. Pump Assembly Drawing with important sections
2. Outline and Mounting Drawing
3. Connection Diagrams, Hydraulic and Electric
4. Pump Duct Drawings
5. Typical Stator Punching
6. Insulation Scheme, Thermal and Electrical

Drawings specifically required for the Vendor's internal shop fabrication procedures and which do not cover significant pump details not shown on drawings listed above do not require design approval or submittal to United.

5.2 Within two (2) weeks after receipt of all the above drawings and required information, United will return one (1) set individually signed and marked:

1. Approved
2. Approved with corrections as noted
3. Returned for corrections

Prints in category 1 or 2 authorize the Vendor to proceed only if specifically authorized by written notification from United. Items under category 3 shall be resubmitted for approval.

- 5.3 Within four (4) weeks after authorization to proceed, the Vendor shall furnish four (4) complete sets of certified fabrication drawings covering the complete equipment.
- 5.4 The applicable United Specification Number and Purchase Order Number shall be marked on each layout or assembly drawing, preferably in the title block.

8.0 Delivery, Schedules, and Termination

- 8.2 The Vendor shall submit a complete design, procurement, and fabrication schedule to United within three weeks after receipt of order. The Vendor shall formally report the status of this schedule every two weeks. Any deviation from this schedule must be completely and, in United's opinion, adequately justified.
- 8.3 Delivery and subsequent approval of the design drawings, reports, and analysis as specified under paragraphs 5.1 and 5.2 complete Phase I under the scope of work.

10.0 Engineering Requirements

10.1 Design Specifications

10.1.10	Coolant	Water and/or NaK-78	
10.1.13	Power Factor at Rated Conditions	.25 Min	.30 Target
10.1.14	Overall Efficiency at Rated Conditions	12% Min.	15% Target
10.1.15	Weight	110 lbs. Max.	< 100 lbs.

10.2 Duct Design Requirements

- 10.2.2 End connections - butt welding - tube size to be determined, using straight through transition pieces.
- 10.2.3 Duct shall be internally stayed or braced as necessary to withstand 15 psi external pressure in addition to fluid condition requirements stated under paragraph 10.1.

10.6 Cooling

- 10.6.1 Cooling System - Vendor shall design pump to utilize either coolant at a minimum inlet temperature of 150F. Direct slot cooling may be used.

10.7 Applicable Specifications

- 10.7.2 The thermocouples shall conform to the latest issue of the following specifications:

CSP-1927 (Class II with Grounded Junction) - Thermocouple -
AMS-5573 Clad cap welded Chromel/Alumel expected in
the windings where ungrounded junctions shall be used.

13.0 Performance, Reliability, and Warranty

Because of the experimental nature of this pump unit, a certain latitude must be allowed with regard to performance. Following installation, and after inspection by the Vendor and acceptance by United, the Vendor agrees that for 1000 operating hours or 6 months, or 36 months from delivery, whichever occurs first, he will, at no cost to United within a reasonable time correct any failure in the equipment which is attributable to faulty material, workmanship, or which results from a deficiency in design. The Vendor shall clearly indicate in his operating manual design limits which may not be exceeded for the warranty to remain in effect.

14.0 Design Report - Phase I

14.1 Four copies of the Design Report shall be provided as required under paragraph 5.1. The following information is required:

14.1.1 Performance curves at 400 cps and 200 cps indicating predicted heads, efficiencies, and power factors for flows up to maximum at design and half design voltage.

14.1.2 Operation limits of pump, i.e., maximum duct pressure, duct temperature, iron temperature, insulation temperature, winding temperature, coolant temperature, maximum rate of temperature rise in pump duct, maximum rate of temperature rise in windings, maximum rate of power increase at startup, coolant flow rates.

14.1.3 Design Parameters at Rated Condition

- a. Average liquid metal velocity in pump duct
- b. Maximum liquid metal velocity in pump duct
- c. Pump duct stresses
- d. Average current density in stator winding
- e. Maximum and average flux density in pump duct
- f. Maximum and average flux density in the stator teeth.

14.1.4 A discussion of the effects of variations on this particular unit in:

- a. Air gap width and height
- b. Fluid velocity, slip, and pole pitch
- c. Number of coils/phase

14.1.5 Electrical equivalent circuit of the specific unit.

15.1 Operational Information - Phase II

15.1.1 Performance curves indicating calculated heads, efficiencies, power factors for flows up to maximum at design voltage.

15.1.2 Operation limits of pump, i.e., maximum cell pressure, cell temperature, iron temperature, insulation temperature, winding temperature, coolant temperature, maximum rate of temperature rise in pump cell, maximum rate of temperature rise in windings, maximum rate of power increase at startup, coolant flow rates.

15.1.3 Design Parameters at Rated Condition

- a. Average liquid metal velocity in pump cell
- b. Maximum liquid metal velocity in pump cell
- c. Pump cell stresses
- d. Average current density in stator winding
- e. Maximum and average flux density in pump cell
- f. Maximum and average flux density in the stator teeth

15.1.4 Step-by-step description of the installation and normal operating procedures.

15.1.5 Complete parts list.

15.1.6 Operational, inspection, and preventative maintenance requirements.

15.1.7 Complete set of as-built electrical and mechanical drawings including one reproducible copy of each drawing for United's use.

15.1.8 Recommended electrical control circuit diagram.

CNLM 53547 Suppl 2

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DESIGN REPORT

for

LINEAR INDUCTION ELECTROMAGNETIC PUMP

MODEL 5KY414AA1

Prepared by: J. W. Gahan

Atomic Motor Products Section
Large Generator & Motor Dept.
General Electric Co.
Schenectady, New York

Abstract

The design of a lightweight 400 cps linear induction electromagnetic pump which meets very stringent performance specifications, in particular, efficiency, power factor and weight requirements, is presented. The design was developed for Pratt & Whitney Aircraft - CANEL Operations as Phase I - Engineering Study, of Purchase Order AEC-79672 (G.E. Req. 301-82996). The proposed design meets the specification requirements as follows:

	<u>Required by Spec</u>	<u>Proposed Design (calc)</u>
Weight	110 pounds maximum	92 pounds
Efficiency	12% Minimum	12.3%
Power Factor	25% Minimum	31.9%

It is recommended that an experimental unit be built and tested.

June 26, 1964

TABLE OF CONTENTS

	<u>Page</u>
I Introduction	1
II Results and Conclusions - Final Design	2
III Discussion and Evaluation of Design	
A. Design Description	3
B. Design Performance	7
C. Performance Effects of Various Parameters	11
IV Analysis of Design	
A. Performance Calculations - Equivalent Circuit	15
B. Thermal Calculations	18
V References	21

LIST OF ILLUSTRATIONS

Figures

- Figure 1 General Configuration for Flat Linear EM Pump
- Figure 2 Generalized Duct Section
- Figure 3 EM Pump Design Layout - View 1
- Figure 4 EM Pump Design Layout - View 2
- Figure 5 EM Pump Design Layout - View 3
- Figure 6 Equivalent Circuit for Linear EM Pump

Performance Curves

- 149HA984 Performance at Rated Voltage & Frequency (180^V & 400 cps resp.)
- 149HA985 Performance at 90^V and 400 cps
- 149HA986 Performance at 63^V and 200 cps
- 149HA987 Performance at 31.5^V and 200 cps

Drawings

- 525D775 Pump Assembly Drawing
- 525D776 Pump Outline Drawing

I Introduction

The Atomic Motor Products Section of the Large Generator and Motor Department was requested by Pratt & Whitney Aircraft - CANEL Operation - to design and build a 400 cps linear EM pump which met some very stringent performance requirements. In particular, efficiency, power factor and weight were the principal performance parameters which had to meet certain specified values. A formal proposal, which indicated the need for considerable engineering effort, was made to Pratt & Whitney for developing and building a design to meet their specifications. Purchase Order AEC-79672 (G.E. Req. 301-82996), which was subsequently placed by Pratt & Whitney, was divided into two phases.

Phase I - Engineering Study - Pump Development and Design

Phase II - Manufacture one experimental unit for extensive testing upon Pratt & Whitney's approval of Phase I.

This report presents the results of Phase I - Engineering Study. The design requirements are contained in Pratt & Whitney Specification CNLM-5354 and CNLM-5354 Supplement 1. In particular, the specific performance requirements were as follows:

Fluid	NaK (78%)
Temperature	1000F
Frequency	400 cps
Voltage, Design	200 volts
Flow	145 gal/min (15 lb/sec)
Developed pressure	20 psi
Suction pressure	15 psia
Efficiency	12% Min; 15% target
Power Factor	25% Min; 30% target
Weight	110 pounds max; 100 pounds target
Cooling	NaK or water @ 150F inlet temperature
Duct Material	316 Stainless Steel
External pressure	Capability for 15 psi

Performance curves, assembly and outline drawings, and a description and evaluation of the final EM pump design as well as supporting analysis and calculations are included in this report.

II Results and Conclusions

The final design reported and described herein meets the performance requirements specified by the customer. Complete performance curves for the pump are shown in drawings 149HA984, 149HA985, 149HA986, 149HA987.

The most important calculated performance for the final design at the rated point of 145 gpm, 20 psi, 1000°F NaK is as follows:

Total Weight of pump = 92 pounds

Efficiency = 12.3%

Power Factor = 31.9%

Power Input = 10.3 KW

KVA Input = 32.3 KVA

Applied Voltage = 180 Volts

Line Current = 104 Amps

Some of the overall dimensions for the pump are:

Duct (incl. inlet/outlet pipes)	.235" high x 6.2" wide X 21.3" long (overall)
Stator Iron	1.9" high X 5.8" wide X 14.75" long
Complete Pump Assembly	7.3" high X 21.3" long X 13.4" wide

More specific design details are covered in later sections of this report. In addition, the proposed design is delineated in General Electric Co. Assembly Drawing 526D775 and Outline Drawing 526D776.

Since the proposed design meets the specification requirements, it is recommended that a prototype or experimental unit be built and tested by Pratt & Whitney Aircraft (CANEL Operations) according to Phase II of the purchase order.

III Discussion and Evaluation

A. Description of Design

Induction EM pumps can be designed in several different configurations. This particular design is a flat, linear induction EM pump which is well suited for this application. The term "flat" refers to the general form of the liquid metal containing (duct) portion of the pump. The term "linear" (or "axial") refers to the direction of flow of the liquid through the pump. Figure 1 illustrates the general configuration for this pump.

FIG.1 General Configuration

As shown, windings are placed on both sides of the duct and hence, we can think of the flat pump as having two stators. Each stator is equivalent to a cylindrical induction motor stator which has been cut axially and laid out flat. The windings are supplied with three phase power, the same as an induction motor, to produce a traveling sinusoidally distributed, magnetic field. The motion of the field is linear (in a straight line) rather than circular (revolving) as in a motor. The velocity of the field is determined by the pole pitch of the stator windings and the frequency. The rotor of the conventional motor is replaced by a layer of conducting fluid confined in a metal envelope (duct) located in the magnetic field between the two stators.

The duct is rectangular in cross-section. Voltages are induced in the fluid by the traveling magnetic field, causing current to flow. The interaction of the currents in the fluid with the magnetic field produces a body force on the liquid metal. The integrated effect along the axial length of the duct is the pressure developed by the pump. The two stators are connected electrically so that the fields produced are additive.

Figures 3, 4 and 5 illustrate the specific design layout for this pump. The important geometric parameters are indicated in these figures. From these figures and selected materials, a set of manufacturing drawings can be made and the manufacturing details determined. General Electric Co. Assembly drawing 526D775 and Outline drawing 526D776 give a completed picture of the pump. The pump itself is composed of two major sub-assemblies; the pump duct and the two stators.

The pump duct assembly consists of the flat duct section, the transition pieces at each end and the inlet/outlet sections. All parts of the duct assembly are made of 316 stainless steel.

The duct section is approximately .235" X 6" in cross-section by 14.75" long. The wall thickness is .0175". The duct is provided with internal supports (shaped like I-beams) which prevent its collapse when evacuated. It is not self-supporting when pressurized internally but is supported by the stators when in position.

The transition pieces are shaped to provide minimum hydraulic loss when transforming the flow from the rectangular duct cross-section through a 90° bend to the circular inlet/outlet pipe cross-section.

Each stator assembly consists of a laminated punching stack, form wound coils, coolant tubes, structural stator support beams and metallic thermal insulation.

The laminated punching stack provides a low reluctance path for the magnetic flux as in a conventional induction motor stator. The laminations are .014" thick silicon steel. They are roughly 14.75" long X 1.9" high(overall), and contain 41 slots. Slot and lamination dimensions are partially indicated in design layout, figure 4.

The coolant tubes are expanded into holes running through the punching stack. The tubes are .5 O.D. X .4 I.D. spaced on 1.34" centers. Each stator contains 10 tubes. Each tube is connected to the adjacent tube by 180° welded return bends at alternate ends of the punching stack. The tubes are 316 stainless steel.

The form wound coils are very similar to the form wound coils used in large conventional induction motors except that these are considerably smaller, and the two coil sides lie in parallel planes since the slots in the punchings are parallel. The coils are arranged to form a six pole magnetic field with a linear synchronous speed of 140 ft/sec.

The coil cross-section is shown in figure 4. Each coil consists of six turns of rectangular copper wire .061 X .170" insulated with approximately .0025" of enamel (trade name* "ML"). The entire coil is insulated with glass-backed silicone-bonded mica tape approximately .020" total on a side.

The complete winding on each stator consists of 36 coils, each coil spanning 5 teeth thereby giving a 5/6 pitch. The first 5 slots contain

one coil side, the next 31 contain two coil sides, and the last 5 contain one coil side. Electrically, each stator is connected as a one circuit, 3-phase delta connection. The two stators, when in operation, are to be connected in parallel thereby giving a 2-circuit delta connection to the complete pump. The complete wound stator is vacuum pressure impregnated with silicone varnish and then baked to provide a well insulated, tight wound stator.

The punching stack is held together by two I-beams welded across the back of the laminations. In addition, there is a weld bead across the back of the stator in the spaces between the coolant tubes as indicated in figure 4. The I-beams provide the external structural restraint for the stator and pump duct. The two stators are mechanically positioned and held relative to one another by four studs, one at each corner. These studs are fastened to the I-beams through small structural angles at each end of the I-beams.

The thermal insulation, located between the duct and punching stack, provides a thermal barrier between the windings and hot liquid metal to limit the heat load from the duct to the stator. It consists of alternate layers of .012", 28 x 28 mesh stainless steel screen and narrow strips of .005" stainless steel foil. Three layers each of screen and foil are used making the complete thermal insulation approximately .05" thick.

Thermal insulation should be placed around the inlet/outlet pipes and the transition sections after the duct is welded into the loop. This can be just a continuation of the insulation used on the customer's piping.

III B. Design Performance

Complete performance curves are shown in drawings 149HA984, 149HA985, 149HA986 and 149HA987. These curves plot developed pressure, power input, efficiency and power factor vs. flow at 400 cps and 200 cps for both rated voltage and half-rated voltage. The rated point of operation is indicated on the performance curves which apply at rated voltage. These rated points are as follows:

145 gpm @ 20 psi for 400 cps, rated voltage (180V)

72.5 gpm @ 5 psi for 200 cps, rated voltage (63V)

The basic rating of the pump is 145 gpm, 20 psi developed pressure, 1000F Nak, 180 volts.

The performance of the pump is calculated through the use of an equivalent circuit which is explained in Section IV, the solution of which has been programmed for an IBM 650 Computer. This equivalent circuit and the computer program utilizes well established equations and concepts relating to induction motor and EM pump theory. However, in calculating losses, the computer program is based on a hydraulic loss through the duct of one velocity head. The duct has been designed to minimize this loss as much as practical, but because the diffusion through the transition piece at inlet and outlet takes place over a relatively short length, the entrance and exit loss is significant. The best calculations indicate that the total hydraulic loss through the entire pump could be larger than one velocity head, possibly being on the order of one to approximately 1.3 velocity heads.

One velocity head represents approximately 8.4 psi and a loss in the fluid of approximately .5 kw. Additional hydraulic loss would

naturally increase the total losses and thereby reduce efficiency slightly, while requiring slightly higher voltage (approximately 4%), but this cannot be determined or predicted precisely until a unit is built and carefully tested.

At the rated point, the complete calculated performance and important design parameters as determined by the computer as well as by some hand calculations, can be tabulated as follows:

1. Electrical Performance

a. Stator winding current density	=	2896 amps/in ²
b. Stator tooth peak flux density	=	62.1 kilo lines/in ²
c. Stator yoke peak flux density	=	34.5 kilo lines/in ²
d. Gap peak flux density	=	13.5 kilo lines/in ²
e. Pump losses & power requirements		
Stator winding I ² R	=	.95 kw
Iron loss	=	.28 kw
Duct loss	=	1.64 kw
Hydraulic loss		
(for 1 velocity head)	=	.51 kw
Secondary I ² R	=	<u>5.66 kw</u>
	Total losses	= 9.04 kw
	Output	= 1.26 kw
	Input	= 10.30 kw
f. Slip	=	.707
g. Efficiency	=	12.3%
h. Power factor	=	31.9%
i. KVA input	=	32.3 kva
j. Line current	=	104 amps
k. Applied Voltage	=	180 volts

2. Thermal (Coolant and winding)

a. Winding hot spot temperature rise	=	159°C
b. Winding average temperature rise	=	106°C
c. Heat load through duct walls	=	6.5 kw
d. Total heat load to coolant	=	8.0 kw
e. Coolant flow per stator	{	4 gpm water
	or	10 gpm Nak
f. Coolant inlet temperature	=	150 F
g. Coolant temperature rise	{	14°F for water
	or	31°F for Nak
h. Coolant pressure drop	{	5.2 psi for water
(for 2 stators hydraulically in series)	or	26 psi for Nak
i. Total heat generated in duct + fluid	=	9 kw

3. Hydraulic (duct & main fluid)

- a. Temperature rise of Nak through duct assuming no heat loss (conservative) = 27°F
- b. Temperature rise of Nak through duct using heat load loss of item 2c above = 100°F
- c. Fluid velocity in duct = 41 ft/sec.
- d. Velocity head of fluid in duct = 8.4 psi

4. Mechanical Performance and Parameters

- a. Duct stress (across slot opening) = 6700 psi
- b. Duct stress (@ transition piece) = 8200 psi
- c. Outlet Pipe stress (@ transition piece) = 3500 psi
- d. Thermal expansion of duct (axially) 70F-1000F = .143"
- e. Peak stress in I-Beams behind stator = 14100 psi
- f. Peak stress in stator yoke = 25500 psi
- g. Peak stress in shoulder studs between stators
 - Direct stress = 8000 psi
- h. Peak stress in shoulder studs between stators
 - Bending stress = 37000 psi

5. Weight Tabulation

Duct	8 pounds
Stator Iron	41 pounds
Winding	31 pounds
Structural, coolant tubes, and Misc.	<u>12 pounds</u>
Total Weight 92 pounds	

The total pump weight of 92 pounds is based on an inlet/outlet pipe length of about 9.5". This has been extended approximately 4" for convenience of connection to the customer's loop. However, the weight due to this additional 4" is not included as part of pump weight since it represents loop piping.

In addition to the above values for various performance parameters, certain operational limits must be imposed to insure satisfactory operation throughout the pump's life. These operational limits are as follows:

- 1. Duct temperature = 1100°F max.
- 2. Winding & insulation temperature = 240°C max.
- 3. Stator Coolant flow - water = 4 gpm min.
- 4. Stator Coolant flow - Nak = 10 gpm min.
- 5. Duct Pressure = 25 psia max.

The duct temperature limit is based on judgement taking into account such things as allowable stress in the duct, temperature rise of the fluid in passing through the duct, possible local variations of temperature throughout the duct and possible variations in incoming fluid temperature. The design is based on normal operation at 1000F liquid metal.

The winding and insulation temperature is limited primarily by the temperature at which copper exhibits rapid oxidation. The insulation will give long life at 240C based on past experience and tests. However, it is well recognized by various authorities that above 250C copper begins to show considerable oxidation. Therefore, the winding and insulation temperature limit is established at 240C. As tabulated above, the expected hot spot temperature rise of the winding is 159C which gives a normal operating hot spot temperature of approximately 224C for a 65C (150F) coolant temperature. The corresponding average winding temperature is only 171C.

The coolant flow limitations are based on limiting the temperature rise of the coolant to reasonable values. The duct pressure is limited by allowable stress.

In addition, the voltage should not exceed 200 volts since this may cause some of the other limits to be exceeded. Certain operational limits to be observed during start-up will be based on the preheat procedures to be used and will be covered in the instruction manual for the specific unit built to this design.

C. Performance Effects of Various Parameters

Fundamentally, this pump as well as most induction EM pumps is a low flux density machine due to the relatively large air gap as compared to conventional induction motors. Large magnetizing currents become necessary to establish the required flux levels in the gap. This in turn results in relatively low power factors. Hence, it is desirable to make the total gap between stators as small as possible. This is accomplished by keeping the thermal insulation thin, the duct walls thin and the fluid passage height small. This reduces magnetizing current which improves power factor and also reduces I^2R losses in the stator winding.

In this design, the thermal insulation is .050" thick which is large enough to limit the heat load from the duct to a tolerable level. The duct walls are only .0175" which keeps the duct I^2R losses to a reasonably low level and also helps to keep the total gap to a minimum. Duct I^2R losses can be expressed as

$$W_D = I_D^2 R_D = \frac{V_{indD}^2}{R_D} = \frac{K}{\ell/A_D} = K^1 t_D$$

where K^1 = a constant
 t_D = duct wall thickness

Thus, duct losses are directly proportional to thickness for a given induced voltage in the duct and therefore, the duct wall is designed as thin as the structural integrity and manufacture of the duct permit.

A fluid height of 0.2" was selected. Smaller values for fluid height are impractical for several reasons. If the width is not increased when the height is decreased, the fluid velocity eventually becomes

too large thereby creating excessive hydraulic losses. Even if the width is increased to maintain constant velocity, the hydraulic diameter is decreased which increases hydraulic losses, and in addition, the stator stack length becomes greater resulting in increased weight of copper and iron. Fluid heights less than 0.2" may also introduce operational problems such as plugging.

Fluid velocity is also a very important parameter. It is interrelated with slip, pole pitch and frequency. Slip, and thereby fluid velocity, has a great effect on efficiency since the secondary I^2R losses, which are the largest contributor to total losses, depend directly on slip. Mathematically:

$$\left. \begin{aligned} \text{Power transferred to fluid} &= I_f^2 R_f / s \\ \text{Power Output} &= I_f^2 R_f \frac{(1-s)}{s} \\ \text{Fluid loss} &= I_f^2 R_f^2 \end{aligned} \right\} \begin{array}{l} \text{Induction} \\ \text{Motor Analogy} \end{array}$$

Then, fluid loss in terms of output is:

$$W_f = W_o \frac{s}{(1-s)} = W_o \left[\frac{1}{\frac{1}{s} - 1} \right] \quad \text{where } s = \text{slip}$$

This clearly shows that, for constant output, the loss in the fluid decreases with decreasing slip. For a given frequency and velocity, slip is determined by pole pitch. Slip can be related to velocity, pole pitch and frequency by the expression

$$S = \frac{v_s - v}{v_s} = 1 - \frac{v}{v_s} = 1 - \frac{v}{2f\lambda}$$

where v_s = synchronous velocity
 v = fluid velocity
 f = frequency
 λ = pole pitch

To meet the specification requirements for this design, the best balance of slip, velocity and pole pitch at a frequency of 400 cps was found to be:

$$\begin{aligned}s &= .707 \\ \lambda &= 2.1 \text{ inches} \\ v &= 41. \text{ft/sec.}\end{aligned}$$

Fluid velocity is determined by duct geometry and required flow. Lower fluid velocities yield lower hydraulic losses, but result in higher slips and hence higher I^2R losses in the fluid. A pole pitch less than about 2.1" is impractical, and a fluid velocity much greater than 41 ft/sec appears to increase the hydraulic losses too much.

The winding and magnetic material also influence performance. The magnetic material cross-section was made adequate to keep the flux density in the iron relatively low, since at 400 cps the eddy current portion of iron losses can become very appreciable. This is also counteracted by using an iron lamination thickness of only .014". The winding consists of 2 coils per pole per phase with 5/6 pitch.

Although 1 coil per pole per phase with 100% pitch could be used, the 5/6 pitch eliminates the possibility of 5th and 7th phase belt harmonic content in the winding mmf, and hence, appears to be a better winding arrangement.

In trying to determine the best EM pump design to meet a set of specification requirements such as these, it becomes quite clear very early in the design phase that no sharp optimum point exists. Because of the interrelation among all variables, there are several designs which

meet the specification requirements, any one of which may be considered optimum by various individuals. It is the author's opinion that the design described in this report is an optimum design for the given specification requirements. Slight variations in some of the parameters could certainly produce a design which also meets the requirements and which may be equally as good as the one presented here. However, the differences in performance would not be significant. The most important parameters have been fairly well optimized in this design.

IV Analysis of Design

A. Performance Calculation

As mentioned previously, EM pumps develop pressure by virtue of the force exerted on a current carrying conductor in a magnetic field. The current carrying conductor is the liquid metal being pumped. This reaction between electric current and the magnetic field which produces a body force on the fluid is analogous to the force on a rotor of an induction motor. Fundamentally, the pressure developed in the fluid is proportional to the magnetic flux density, current density in the liquid metal and length of path of fluid in the magnetic field. Mathematically, this can be written as:

$$p = Bjc \quad (A1)$$

Where B = flux density
 j = current density
 c = length

A section of an EM pump duct is shown in figure 2 illustrating these quantities and their directions.

Figure 2
Generalized Duct Section

In addition, for this pump section, the volume flow q and power output W_o may be written as:

$$q = v(ab) \quad (A2)$$

$$W_o = pq = B j v (abc) \quad (A3)$$

Flux density and current density can be interrelated in the following manner. The voltage gradient (volts/inch) across the duct section in the x-direction is given by:

$$V = \rho_f j + Bv \quad (A4)$$

or

$$V = Bv_s \quad (A5)$$

where v_s is the synchronous velocity; i.e., the fluid velocity at which the current density is zero. This is equivalent to the synchronous speed of an induction motor. For the linear induction EM pump, synchronous velocity is given by:

$$v_s = 2f\lambda \quad (A6)$$

where f = frequency
 λ = pole pitch

Solving equations (A4) and (A5) for j yields

$$j = \frac{B(v_s - v)}{\rho_f} \quad (A7)$$

where ρ_f = fluid resistivity

Defining the slip of an induction pump as

$$S = \frac{v_s - v}{v_s} \quad (A8)$$

and substituting into A7 gives

$$j = \frac{Bsv_s}{\rho_f} \quad (A9)$$

Then equations (A1, 2 & 3) can be rewritten as

$$p = \frac{B^2 s v_s c}{\rho_f} \quad (A10)$$

$$q = v_s(1-s)ab \quad (A11)$$

$$W_o = \frac{B^2 v_s^2 s(1-s)}{\rho_f} \text{ (abc)} \quad (A12)$$

These last three equations describe the output characteristics of an EM pump. They could also be written in terms of current. To design and analyze a specific EM pump and calculate its complete performance, these expressions have to be related back to the stator structure and windings. In addition, other effects such as end effects, flux fringing, duct losses, iron losses, hydraulic losses, etc. must be properly taken into account. This is most readily done through the use of an equivalent circuit. The equivalent circuit for the linear flat induction EM pump is shown in figure 6. Its derivation and solution are analogous to that of an induction motor as presented in several classical texts such as reference 5. The solution of this circuit, along with expressions such as (A10, 11, 12) can be used to determine the performance of the flat linear induction pump. The calculation of the parameters, the solution of the circuit and the translation of the circuit solution into pump performance has been programmed for calculation on an IBM 650 Computer. For the final design of this pump, the equivalent circuit parameters in figure 6, are as follows: (per IBM 650 computer calculation)

R_1	= .088 ohms	X_m	= 2.3 ohms
X_1	= .87 ohms	I_m	= 54.3 amps
R_2	= 4.49 ohms	I_2	= 19.9 amps
R_D	= 30.4 ohms	I_1	= 60.1 amps
X_{PL}	= .073 ohms	R_4	= 346 ohms
X_2	= .154 ohms	V_1	= 180 volts

Some additional data used or generated in this study is as follows:

1. Liquid Nak @ 1000F

Resistivity	= 28.2 micro-ohm-inches
Density	= 46.5 pounds/in ³
Viscosity	= .4 pounds/hr-ft
Reynold's Number	= 560,000

2. 316 Stainless Steel duct @ 1000F

Resistivity = 42.7 micro-ohm-inches
Allowable stress = 14000 psi

B. Thermal Calculations

Temperature of the stator winding is one of the most important factors in limiting output. It is a function of liquid metal and duct temperature, current density, cooling system, and the geometry and thermal characteristics of the pump structure. Temperature rise of the winding is determined by establishing and solving an equivalent thermal circuit. The solution of the thermal circuit for a flat induction EM pump utilizing liquid cooling through tubes in the stator iron has been programmed on an IBM 650 as part of the electrical performance calculation described previously. The results of calculations using this program for this particular pump were as follows:

$$\theta_{et} = 159^{\circ}\text{C rise (hot spot - end turns)}$$

$$\theta_{ave} = 106^{\circ}\text{C rise (average)}$$

These results are temperature rises above the coolant inlet temperature. For a 150F coolant (65C) the hot spot winding temperature becomes 224°C and the average winding temperature is 171°C.

These results are based on assuming all heat flows through the stator iron to the cooling tubes which is conservative since some heat will be convected or radiated from the winding end turns. The accuracy of the above results is limited primarily by the accuracy of the thermal resistivities of the pump structure; in particular, the resistivity of the thermal insulation assembly between the duct and stator and the electrical insulation between the copper and stator iron. Based on

previous experience, the following values were used:

$$\rho_{\text{therm ins.}} = 200 \frac{^{\circ}\text{C in}}{\text{watt}}$$

$$\rho_{\text{elec ins.}} = 200 \frac{^{\circ}\text{C in}}{\text{watt}}$$

The total heat load transmitted to the cooling system consists of the stator losses plus the heat load through the thermal insulation.

Taking the iron temperature as approximately 350°F, the heat load through the thermal insulation is approximately

$$\begin{aligned} \text{HL}_1 &= \frac{\Delta T(\text{surface area})}{\rho_{\text{therm}} \times \text{length}} \\ &= \frac{(650 \times 5/9) (15 \times 6 \times 2)}{200 \times .05} = 6500 \text{ watts} = 6.5 \text{ kw} \end{aligned}$$

Adding the stator winding and iron losses, we get

$$\begin{aligned} \text{H.L.T} &= \text{HL}_1 + \text{KW}_1 + \text{KW}_H \\ &= 6.5 + .95 + .28 \approx 8 \text{ kw (conservatively)} \end{aligned}$$

This is the total heat load to the coolant. The coolant temperature rise is given by

$$\Delta T = \frac{3413(\text{HL}_T)}{\text{Cp } Q}$$

where Cp = specific heat in $\frac{\text{Btu}}{\text{# } ^{\circ}\text{F}}$

Q = coolant flow in #/hr

For water @ 150F inlet temperature with 4 gpm flowing (≈ 2000 #/hr), the coolant temperature rise is

$$\Delta T_{\text{coolant}} = \frac{3413(8)}{(1)(2000)} = 14^{\circ}\text{F for 4 gpm of water}$$

For Nak @ 150F inlet temperature with 10 gpm flowing (≈ 4280 #/hr), the coolant temperature rise is

$$\Delta T_{\text{coolant}} = \frac{3413(8)}{(.208)(4280)} = 31^{\circ}\text{F for 10 gpm of Nak}$$

The coolant pressure drop for these flows can be calculated as follows:

For water @ 4 gpm:

$$\text{velocity, } v = 4 \times \frac{1}{60} \times \frac{1}{7.48} \times \frac{144}{\frac{\pi}{4} (.4)^2} = 10.2 \text{ ft/sec}$$

$$\text{velocity head} = \frac{\rho v^2}{2g} = .705 \text{ psi}$$

$$\text{Reynolds number, } N_R = \frac{\rho v D}{\mu} = 95700$$

For this Reynolds number the friction factor, δ , is approximately .0046 which will give a pressure drop of

$$\Delta P = 4\delta \left(\frac{L}{D} \right) \left(\frac{\rho v^2}{2g} \right) = 5.19 \text{ psi}$$

Performing similar calculations for Nak @ 10 gpm yields:

$$v = 25.6 \text{ ft/sec}$$

$$\frac{\rho v^2}{2g} = 3.76 \text{ psi}$$

$$N_R = 131,000$$

$$\delta = .0043$$

$$\Delta P = 25.9 \text{ psi}$$

These calculations are based on having the cooling tubes for the two stators connected in series. If the two sets of cooling tubes are connected in parallel hydraulically, then for the entire cooling system, the above flows will double, the pressure drops will be halved and the temperature rise of the coolant will be halved.

V References

1. Specification for High Frequency Linear Induction Electromagnetic Pump, CNLM-5354 and CNLM-5354 Supplement 1, Pratt & Whitney Aircraft.
2. ASME Boiler Code, Section VII, Unfired Pressure Vessels, 1959 Edition
3. Liquid-Metals Handbook, Sodium-Nak Supplement, TID5277, July 1, 1955, AEC-Department of Navy
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5. "The Nature of Polyphase Induction Machines", P.L. Alger; John Wiley & Sons, 1951
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FIG. 3 E M PUMP DESIGN LAYOUT - VIEW 1

FIG. 4 E M PUMP DESIGN LAYOUT - VIEW 2

FIG. 5 E M PUMP DESIGN
LAYOUT - VIEW 3

Figure 6

Equivalent Circuit for Linear EM Pump

CALCULATED PERFORMANCE CURVES

149HA984

EM PUMP MODEL 5K144AA1

BASIC RATING 145 GPM, 20 PSI, 1000°F NAK

180 VOLTS, 3 PHASE, 400 CPS.

NOTE: THESE CURVES APPLY @ RATED VOLTAGE & FREQUENCY

GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
6-16-64 H.E. CASH

149HA984

CALCULATED PERFORMANCE CURVES

EM PUMP MODEL 5K1914001

BASIC RATING: 145 GPM, 20 PSI, 1000°F NAK

180 VOLTS, 3 PHASE, 400 CPS

NOTE: THESE CURVES APPLY @ HALF RATED VOLTAGE (90V)
@ RATED FREQUENCY (400 CPS) GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
6-16-64 J.E. CASH

149HA985

CALCULATED PERFORMANCE CURVES

149HA986

EM PUMP MODEL EK1414441

BASIC RATING: 145 GPM, 20 PSI, 1000°F NAK

180 VOLTS, 3 PHASE, 400 CPS.

NOTE: THESE CURVES APPLY @ 63 VOLTS & 200 CPS

(HALF RATED FLOW 72.5 GPM, QUARTER RATED PRESSURE - 5 PSI)

GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
6-16-64 NE 205M

149HA986

CALCULATED PERFORMANCE CURVES

EM PUMP MODEL 5K1444441

BASE RATING: 145 GPM, 20 PSI, 1000° F. WAK

180 VOLTS, 3 PHASE, 400 CPS

NOTE: THESE CURVES APPLY @ 31.5 VOLTS, 200 CPS

149HA987

GENERAL ELECTRIC CO.
SCHENECTADY, N.Y.
JUNE 16, 1968, H.E. LAM

149HA987

GENERAL ELECTRIC

PARTS LIST FOR

526 D775

CONT ON SHEET

SH NO.

[illegible]

CONT ON SHEET

SH NO.

PARTS LIST FOR
142B2170

PARTS LIST FOR

CONT ON SHEET

SH NO.

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED

① 250/ CUT EDGES
 MAT'L - AISI T.Y. 316 STN. STL. TO MEET THE
 REQUIREMENTS OF AMS 5573
 MAKE FROM 2" I.P.S. SCHEDULE 10 PIPE

APPLIED PRACTICES PER 945A700

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:		SIGNATURES		DATE	GENERAL ELECTRIC	
FRACTIONS	DECIMALS	±	±	±	L. G. & M. DEPT. LOC. SCHENECTADY	
ALL SURFACES	✓	DRAWN <i>W.C. Dyke</i>			TITLE PIPE	
MATL-GOVT OR COML	✓	CHECKED <i>W.C. Dyke</i>			CONTRACT NO.	
GE	✓	ISSUED <i>5 June 64</i>			CODE IDENT NO. 03569	
		ENGRG			SIZE B	
		MFG			DWG NO. 142B2169	
		MATLS			SCALE NTS	
					WT CALC ACTUAL	
					SHEET	

MAC-A SKY414AA1

FOLD

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
1	W C Dylas	JUNE 24, 1964

2 250/ CUT EDGES
MAT'L - AISI TY. 316 STN. STL. STRIP
TO MEET THE REQUIREMENTS
OF AMS 5524.

3 1/16 THK
250/ CUT EDGES
MAT'L - AISI TY. 316 STN. STL. STRIP
TO MEET THE REQUIREMENTS
OF AMS 5524

APPLIED PRACTICES PER 945A700

P. L. ISSUED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:		SIGNATURES		DATE	GENERAL ELECTRIC	
FRACTIONS DECIMALS ANGLES ± ± ±		DRAWN W C Dylas		2 June 64	L. G. & M. DEPT LOC. SCHENECTADY	
ALL SURFACES ✓		CHECKED		JUNE 24, 1964	TITLE BRACKET (PIPE SUPP.)	
MATL-GOVT OR COML		ISSUED			CONTRACT NO.	
GE		ENGRG			CODE IDENT NO. 03569	
		MFG			SIZE B	
		MATLS			DWG NO. 142B2170	
					SCALE NTS	
					WT CALC ACTUAL	
					SHEET	

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED

1 $\frac{125}{\checkmark}$ ALL OVER

MAT'L - AISI TY 316 STN. STL. BAR
TO MEET THE REQUIREMENTS
OF AMS-5648

APPLIED PRACTICES PER 945A700

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON: FRACTIONS DECIMALS ANGLES ± ± ± ALL SURFACES $\checkmark$ MATL GOVT OR COML. GE	SIGNATURES		DATE	GENERAL ELECTRIC L G & M DEPT. LOC SCHEENECTADY	
	DRAWN <i>W. C. Dylbas</i>		10 June 64	TITLE	
	CHECKED			SUPPORT RAIL	
	ISSUED		5 Nov 64	CONTRACT NO.	
	ENGRG			CODE IDENT NO.	
	MFG			SIZE	
	MATLS			DWG NO.	
				03569	
				A	
				175A3415	
			SCALE NTS		WT CALC ACTUAL -
					SHEET

↓ A 175A3414

SHEET

REV

0

REVISIONS

SYM	DESCRIPTION	DATE	APPROVED

125 ✓ ALL OVER

① MAT'L - AISI TY 316 STN. STL. BAR
TO MEET THE REQUIREMENTS
OF AMS 5648

APPLIED PRACTICES PER 945A700

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON:

FRACTIONS DECIMALS ANGLES

± ± ±
ALL SURFACES ✓

MATL GOVT OR COML

GE

SIGNATURES

DRAWN *W C Dylas*

CHECKED *W C Dylas*

ISSUED *W C Dylas*

ENGRG *W C Dylas*

MFG *W C Dylas*

MATLS *W C Dylas*

DATE

10 June 64

5 June 64

1964

GENERAL ELECTRIC
L G & M DEPT. LOC. SCHEENECTADY

TITLE END CHANNEL

CONTRACT NO.

CODE IDENT NO.

03569

SIZE

A

DWG NO.

175A3414

SCALE NTS

WT CALC ACTUAL

SHEET

PRINTS
TO

A E 6504

↑ MAC-A

5KY414AA1

SIZE
A

175A3417

SHEET

REV
D

REVISIONS

SYM	DESCRIPTION	DATE	APPROVED

LENGTH = $17 \frac{5}{8}$
MAT'L - ASTM-A371-53T
CLASS ER316 STN. STL.

APPLIED PRACTICE PER 945A700

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON:		SIGNATURES		DATE		GENERAL ELECTRIC	
FRACTIONS DECIMALS ANGLES		DRAWN <i>mb Rogers</i>		6/18/64		LOC. SCHEENECTADY	
± ± ±		CHECKED		ISSUED		TITLE	
ALL SURFACES ✓		MFG		ENGRG		INSERT, CONSUMABLE	
MATERIAL GOVT OR COML		MATLS		CONTRACT NO.		CODE IDENT NO.	
GE				03569		SIZE A	
				SCALE N.T.S.		DWG NO. 175A3417	
				WT. CALC. ACTUAL		SHEET	
PRINTS TO MF 650-1				MAC-A		5KY414AA1	

SIZE A 175A3416

SHEET

REV 0

REVISIONS

SYM	DESCRIPTION	DATE	APPROVED

① $\frac{1}{125}$ ALL OVER

MAT'L- AISI TY. 316 STN. STL. PLATE
TO MEET THE REQUIREMENTS
OF AMS-5524

APPLIED PRACTICES PER 945A700

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON:

FRACTIONS DECIMALS ANGLES

$\pm$ $\pm$ $\pm$
ALL SURFACES $\checkmark$

MATL GOVT OR COML

GE

SIGNATURES

DRAWN *we Dylro*

CHECKED

ISSUED

ENGRG

MFG

MATLS

DATE

2 June 64

507c32,
1964

GENERAL

ELECTRIC

L. G. & M.

DEPT.

LOC SCHENECTADY

TITLE

CAP

CONTRACT NO.

CODE IDENT NO.

03569

SIZE

A

DWG NO.

175A3416

SCALE NTS

WT CALC ACTUAL —

SHEET

PRINTS TO

MAC-A

SKY414AA1

SIZE
A

175A3418

SHEET

REV

0

REVISIONS

SYM	DESCRIPTION	DATE	APPROVED
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MAT'L: -ASTM A371-53T
CLASS ER 316 STN. STL.

PT. NO.	A DIA	APPROX. DEV. LG.
1	2 5/32	6 25/32

APPLIED PRACTICES PER 945A700

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES ON:

FRACTIONS DECIMALS ANGLES

± ± ±

ALL SURFACES ✓

MATL GOVT OR COML

GE

SIGNATURES

DRAWN *J. Rogers*

CHECKED

ISSUED

ENGRG

MFG

MATLS

DATE

6/18/64

JUN 22 1964

GENERAL ELECTRIC
L. G. & M. DEPT. LOC. SCHENECTADY

TITLE

INSERT, CONSUMABLE

CONTRACT NO.

CODE IDENT NO.

03569

SIZE

A

DWG NO.

175A3418

SCALE N.T.S.

WT CALC
ACTUAL

SHEET

PRINTS
TO MF 650-1

MAC-A 5KY44AA1

REVISIONS					
SYM	ZONE	DESCRIPTION		DATE	APPROVED

E E

1 125/ ALL OVER
MAT'L: AISI TY 316 STN. STL. BAR
TO MEET THE REQUIREMENTS
OF AMS 5648

APPLIED PRACTICES PER 945A700

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON: 2-PLACE DECIMALS ± 3-PLACE DECIMALS ± ANGLES ± ALL SURFACES ✓		SIGNATURES DRAWN <i>we Dyler</i> CHECKED ISSUED ENGRG MFG MATS		DATE 12 June 64 1964
MATERIAL— GOVT OR COML		GENERAL ELECTRIC L G S M DEPT LOC. SCHENECTADY		
GE		TITLE TRANSITION PIECE		
		CONTRACT NO.		
		CODE IDENT NO.	SIZE	DWG NO.
		03569	C	593C188
		SCALE NTS	WT. CALD. ACTUAL	SHEET OF
			MAC-A	5KY414AA1

NOTES

1. 180 VOLT, 3 PHASE, 400 CYCLE, 145 GPM, 20 PSI, 1000°F, NaK, 32.3 KVA
2. COOLANT REQUIREMENTS: WATER, 150°F APPROX 4 GPM PER STATOR, OR NaK, 150°F APPROX. 10 GPM PER STATOR. COOLANT TUBES FOR EACH STATOR MAY BE CONNECTED HYDRAULICALLY IN SERIES OR PARALLEL.
3. FOR NORMAL DIRECTION OF PUMPING CONNECT POWER AS SHOWN IN SCHEMATIC DIAGRAM WITH PHASE ROTATION L₁, L₂, L₃.
4. CALCULATED WEIGHT, TOTAL PUMP - 92 LBS.
5. THERMAL INSULATION SHOULD BE APPLIED BY CUSTOMER TO INLET/OUTLET PIPES AFTER INSTALLATION.

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE

SCHEMATIC CONNECTION DIAGRAM
(SEE NOTE 3)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON: 2 PLACE DECIMALS ± 3 PLACE DECIMALS ± ANGLES ± ALL SURFACES ✓ MATERIAL— GOVT OR COML— GE—		SIGNATURES DATE 22 JUN 54 30 MAR 54 1954		GENERAL ELECTRIC LG&M DEPT LOC SCH'DY TITLE OUTLINE EM PUMP CONTRACT NO. CODE IDENT NO. 03562 SIZE D DWG NO. 526D776 SCALE SHEET OF	
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REVISIONS				DATE	APPROVED
SYM	ZONE	DESCRIPTION			

- NOTES
1. FINISH I BEAMS, MOUNTING BRACKETS & NAME PLATE BRACKETS PER SE-18018-10-3
 2. THERMAL INSULATION OF ONE STATOR CAN BE BENT OUT SLIGHTLY TO FACILITATE ASM.

SECTION "B-B"

SECTION "A-A"

APPLIED PRACTICES PER 945/700

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES—
TOLERANCES ON:
2-PLACE DECIMALS ±
3-PLACE DECIMALS ±
ANGLES ±
ALL SURFACES ✓

MATERIAL—
GOVT OR COML
GE

SIGNATURES		DATE
DRAWN	CHECKED	
ISSUED	ENGRG	
MFG	MATLS	

GENERAL ELECTRIC LG&M DEPT LOC SCHDY	
TITLE ASSEMBLY E.M. PUMP	
CONTRACT NO.	
CODE IDENT NO.	03569
SIZE	D
DWG NO.	526D775
SCALE	
WT CALD ACTUAL	
SHEET	OF

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
I		W Dylas	JUN 30 1964

NOTES:
1. MASS SPECTROMETER LEAK TEST PER SI 16013-11.
2. CLEAN PER 507A 203

APPLIED PRACTICES PER 945A700

P.L. ISSUED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES— TOLERANCES ON: 3-PLACE DECIMALS ± 3-PLACE DECIMALS ± ANGLES ± ALL SURFACES ✓	SIGNATURES		DATE	GENERAL ELECTRIC	
	DRAWN CHECKED ISSUED ENGRS WFO MATES	6/17/64 6/17/64 6/17/64 6/17/64 6/17/64 6/17/64	6/17/64	L. N. & G. DEPT. LOC. SCHEMECTADY	
MATERIAL — GOVT OR COML				TITLE ASSEMBLY DUCT	
GE				CONTRACT NO.	
				CODE IDENT NO.	SIZE
				03569	D
				526 D 778	
				SCALE N.T.S.	WT CALD ACTUAL
				SHEET OF	