N93-19407

1992 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

STUDY AND DEVELOPMENT OF AN AIR CONDITIONING SYSTEM
OPERATING ON A MAGNETIC HEAT PUMP CYCLE
(DESIGN AND TESTING OF FLOW DIRECTORS)

PREPARED BY:	Mr. Pao-lien Wang
ACADEMIC RANK:	Associate Professor
UNIVERSITY AND DEPARTMENT:	University of North Carolina at Charlotte Department of Engineering Technology
NASA/KSC	
DIVISION:	Mechanical Engineering
BRANCH:	Special Project
NASA COLLEAGUE:	Frank S. Howard
DATE:	August 7, 1992
CONTRACT NUMBER:	University of Central Florida NASA-NGT-60002 Supplement: 8

ACKNOWLEDGMENTS

I would like to thank NASA/ASEE Summer Faculty Fellowship Program, Mr. Willis Crumpler and Dr. Gary Lin of the Kennedy Space Center, Dr. Loren Anderson of the University of Central Florida, for giving me with the opportunity to work on this challenging and rewarding project. Special thanks should be extended to my KSC colleague Mr. Frank Howard for his help, guidance, and encouragement throughout the project. Also my thanks to Mr. Johnny Gay of the Development Testing Laboratory for his support in fabricating and testing of the prototype, without his help I would not be able to complete successfully this summer project. Ms. Kari Stiles's assistance and helpfulness also very much appreciated.

ABSTRACT

This report describes the fabrication, design of flow director, fluid flow direction analysis and testing of flow director of a magnetic heat pump.

The objectives of the project are: (a) to fabricate a demonstration magnetic heat pump prototype with flow directors installed. (b) analysis and testing of flow director and to make sure working fluid loops flow through correct directions with minor mixing.

The prototype was fabricated and tested at the Development Testing Laboratory of Kennedy Space Center. The magnetic heat pump uses rear earth metal plates rotate in and out of a magnetic field in a clear plastic housing with water flowing through the rotor plates to provide temperature lift. Obtaining the proper water flow direction has been a problem. Flow directors were installed as flow barriers between separating point of two parallel loops. Function of flow directors were proven to be excellent both analytically and experimentally.

SUMMARY

The heat pump consists of a rotor turning through four magnetic field area created by permanent magnets. Gadolinium was selected as the working material for this prototype. Rotor was designed to be constructed of flat parallel disks of working material with very small space in between. The rotor rotates in and out of the magnetic field in a clear plastic housing. Water flowing through the rotor plates in the opposite direction to provide heating and cooling effect. It is necessary to divide the fluid flow separately into a cold loop and a hot loop. Separation of fluid loops has been a problem in the model development. Flow directors were installed between two loops at their points of separation to develop enough restriction and properly guide fluid flow through correct path. Both the experimental and computational results prove the validity of the design of the flow director.

For testing and demonstration of flow director performance, magnets were not installed, and rotor plates were constructed with clear plastic instead of gadolinium.

TABLE OF CONTENTS

I INTRODUCTION

The use of Freon gas-cycle to provide refrigeration and space heating has broad application in industry and for domestic in this country. Research has shown that the release of Freon into the atmosphere will deteriorate the ozone layer in the Earth's atmosphere. As a result, research has begun to try to limit or eliminate the use of Freon for refrigeration purposes. One alternative to consider is the magnetic heat pump.

NASA Kennedy Space Center initiated the development of an air conditioning system operating on a magnetic heat pump cycle. The project is being managed by Mr. Frank S. Howard of DM-MED-11. The preliminary study of a laboratory scale demonstration prototype has been completed. The design and engineering drawings were completed during the 1991 NASA/ASEE Summer Faculty Fellowship Program. Fabrication and testing of flow directors of the heat pump are the major tasks for the 1992 summer project.

II DESCRIPTION

2.1 Concept

The rotating magnetic heat pump consists of a rotor of magnetic working material with flow passages to allow heat transfer fluid to move through the rotor in good contact with the magnetic material. The rotor moves in a clear plastic housing with flow ports positioned at the transition between magnetic field change for fluid to enter and exit the housing as shown in Fig. 1. The cycle executed as follows:

(1) Fluid is pumped into the housing at point 1 where the rotor approaching the magnetic field and flows to point 2.

(2) Between points 1 and 2 working material becomes magnetized and heats up. Fluid flowing between 1 and 2, removes most of the heat of magnetization of the working material and transferred to the load (heating loop).

(3) Fluid is pumped into the housing at point 3 flows through the rotor to point 4.

(4) Between points 3 and 4, working material demagnetizes and cooled down. Fluid flowing between 3 and 4, giving away heat to the cold working material and flow to the cooling load (cooling loop).

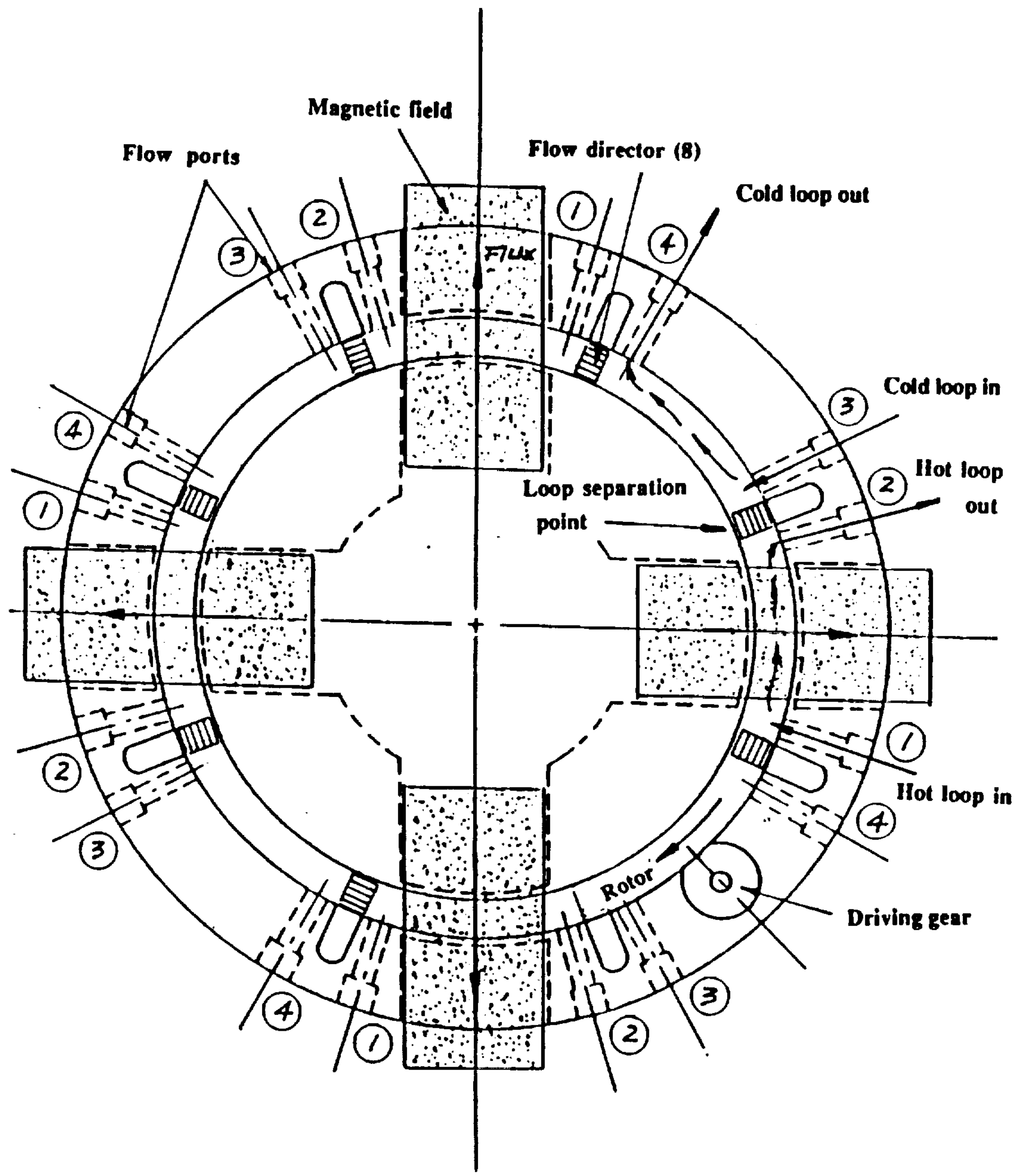


Fig. 1 Housing Assembly

It is necessary to divide the fluid flow into two separate loops, but it was found to be a problem in development of the prototype. To solve the problem, comb shaped flow directors were installed at the separation point between loops, to obtaining proper flow direction.

Summary of design parameters

Core Material: GDTC293
Working fluid: Water
Core Type: Plate
Rotor OD: 0.2159m
Rotor ID: 0.1905m
Core Hight: 0.0397m
Plate Thickness: 0.00159m
Plate Spacing: 0.003175m
High Field: 1 Tesla
Low Field: 0
Rotation Time: 8 Sec/Rev.
Cycle/Revolution: 4

For detail of prototype design, see Ref. 1 and 2

2.2 Flow Director Design

The system demands that fluid flowing in and out of the housing (with rotor rotates in it) must follow two separated loops without mixing. It is very difficult to separate fluid into two loops within the same housing without being mixing (Fig. 1). To solve this problem, Mr. Frank S. Howard suggested to install a comb shaped pieces(called flow director in this report) fitted between the thin rotor plates at the loop separation point (Fig. 2a and 2b), enough restriction would be developed by the comb shaped pieces to properly direct the fluid flow. Calculations from the Darcy's equation indicates that the introduction of Flow Director provides adequate resistance to guide the fluid flow through correct directions with very little mixing.

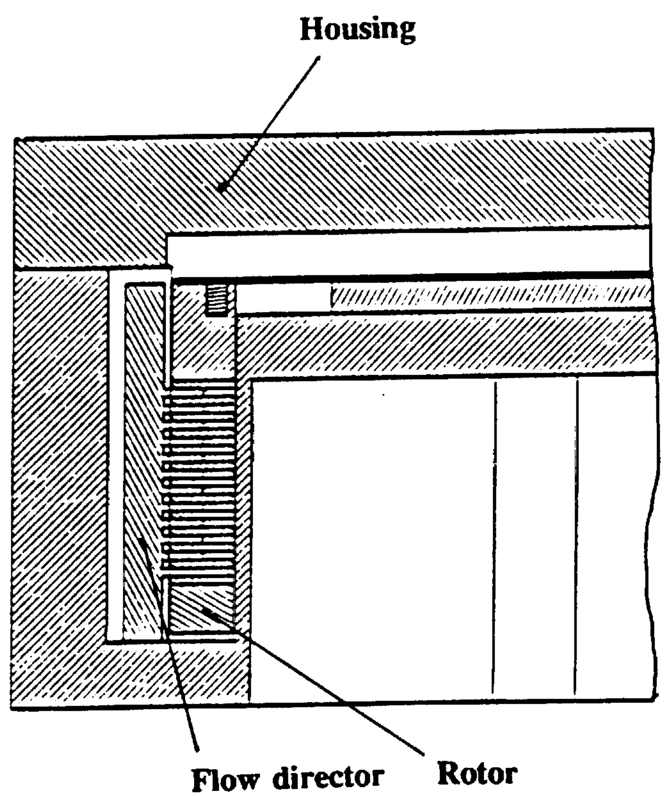


Fig. 2a Flow director assembly

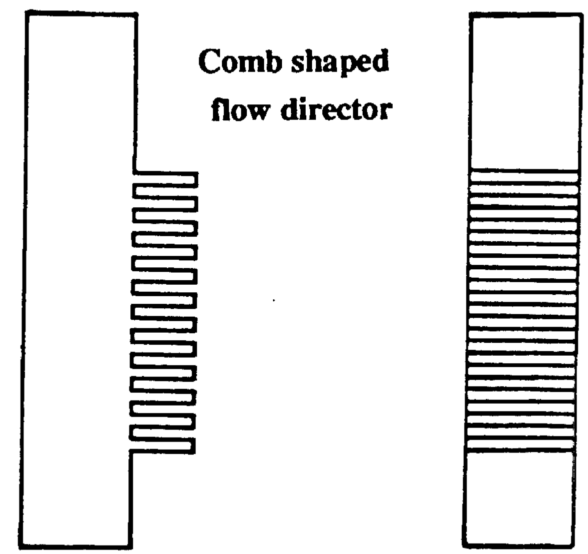


Fig. 2b Flow director

2.3 Calculation of Performance

Fluid entering the housing at point 1 is free to flow through the rotor in either direction to 2 and 4. If there is no barrier at 2, fluid will flow from 2 to 3 and mix with the other loop. Due to the installation of a flow director (comb shaped barrier) between 2 and 3, flow resistance between 1 and 2 is much less than 2 and 3. Thus, most fluid entering at 1 flows to 4 which is the proper direction (see Fig. 3). Calculation indicated that the pressure difference between point 2 and 3 is much greater than between 1 and 2. Most of the fluid entering at 1 flows to the exit port at 4. There are some trace of fluid flow cross the flow director from point 2 to 3 and mix with the adjacent loop, but the quantity was calculated to be very small (only about 6.63 x 10^{-5} ft^3/s/port).

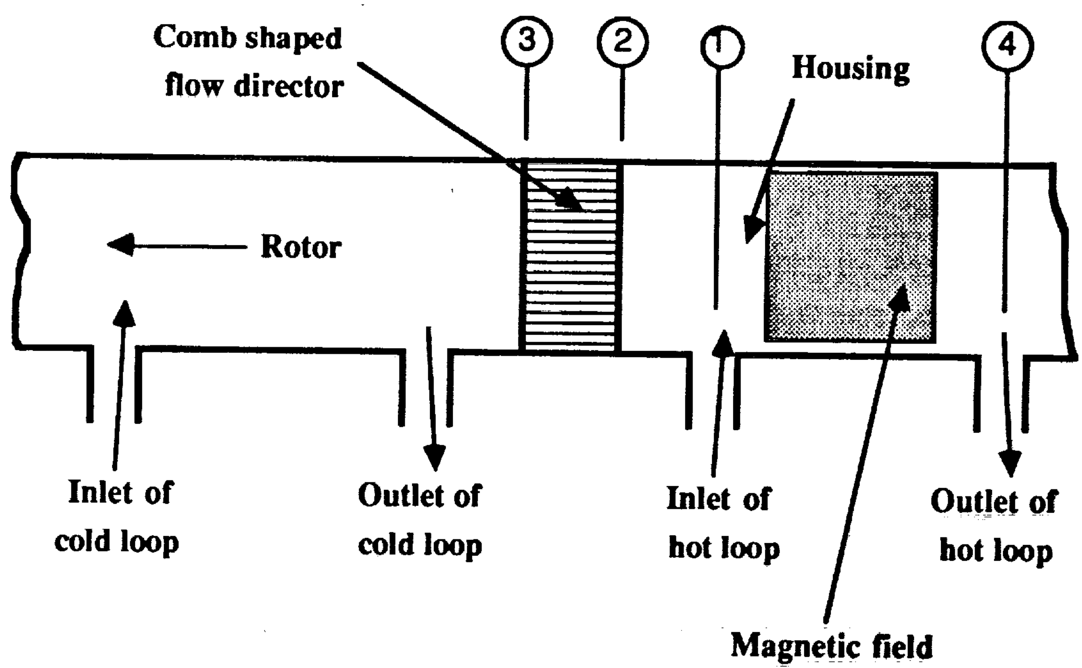


Fig. 3 Schematic for flow director position and loop separation

Calculations are made by using the Darcy formula for laminar flow (Ref. 3)
Reynolds number = 1383 (Laminar flow)

$$\Delta P = 0\ 000668 \frac{\mu L v}{d^2} = 0.1225 \frac{\mu L q}{d^2}$$

For non-circular sections $d = 48\ R_H$, where R_H is the Hydraulic Radius

Where:
- ΔP - Pressure difference between two points (lb/in^2)
- μ - Dynamic viscosity (centipoise)
- R_H - Hydraulic radius (ft)
- L - Length of passage (ft)
- v - Velocity of flow (ft/s)
- q - Rate of flow (ft^3/s)

Pressure differences ΔP and the flow rate through the flow directors q were computed by the ratio of hydraulic radius.

Detailed computations are presented in the Appendix.

III TEST OF FLOW DIRECTORS

3.1 Components and Procedure

The testing prototype consists of the following primary components (Fig. 4);
(1) The housing (with inlet and exit flow ports)
(2) The rotor (with rotor material plates)
(3) Gear driving device and driving motor
(4) Fluid pump and tank for each cold and hot loop
(5) Tygon tubing connecting flow ports to fluid pumps and tanks

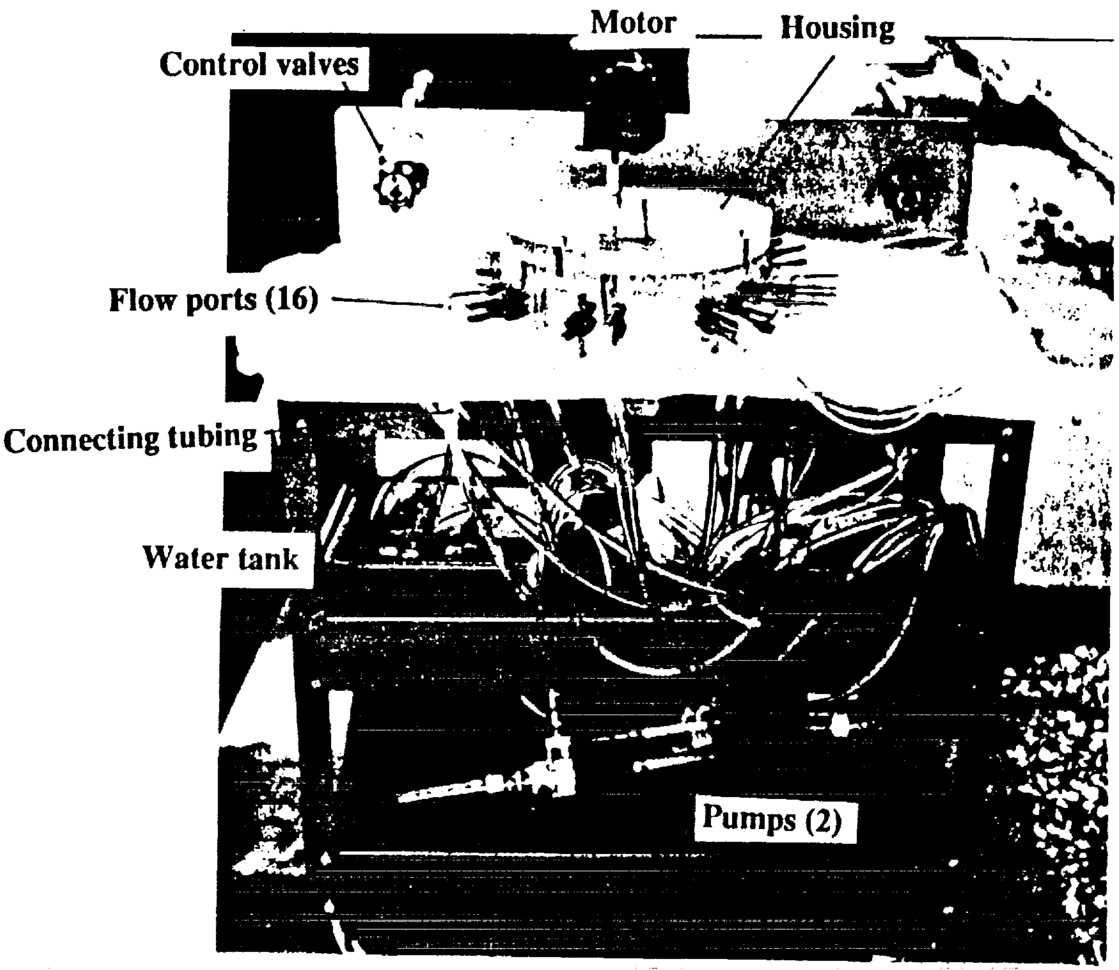


Fig. 4 Photograph of test prototype

Testing procedure:

(1) Turn gear drive motor on, and measure rotor speed in RPM.
(2) Fill fluid tanks with clear water.
(3) Turn pump power on let water run for 15 minutes until water fills housing.
(4) Adjust flow control valves until flow rate of both loops are approximately equal.
(5) Measure flow rate per port with a stop watch and a grade fluid beaker, record flow rate.
(6) Add color fluid into one of the two fluid tank.
(7) Visually inspect path and direction of colored fluid flow, and make sure fluid flow through two separate loops (a clear water loop and a colored water loop).
(8) Exam if any colored water cross Flow Director.
(9) Video tape fluid flow pattern.
(10) Shout down system.

3.2 Result

Analytical Result

1. Computation indicates that the pressure difference between section 2 and 3 is much greater than pressure difference between section 1 and 2. Most of the inlet flow will eventually flow from 1 to 4.

2. Calculation also indicates that the fluid flow through the flow director from 2 to 3 mixing with the adjacent loop quantitatively is very small (about 0.0000663 cubic feet per sec. per flow port).

Test Result

During laboratory testing operation, we found that fluid flow was channeled by the flow director clearly into two separate loops. It matched closely with analytical result (see Fig 5).

The analytical and testing results of the above match satisfactorily.

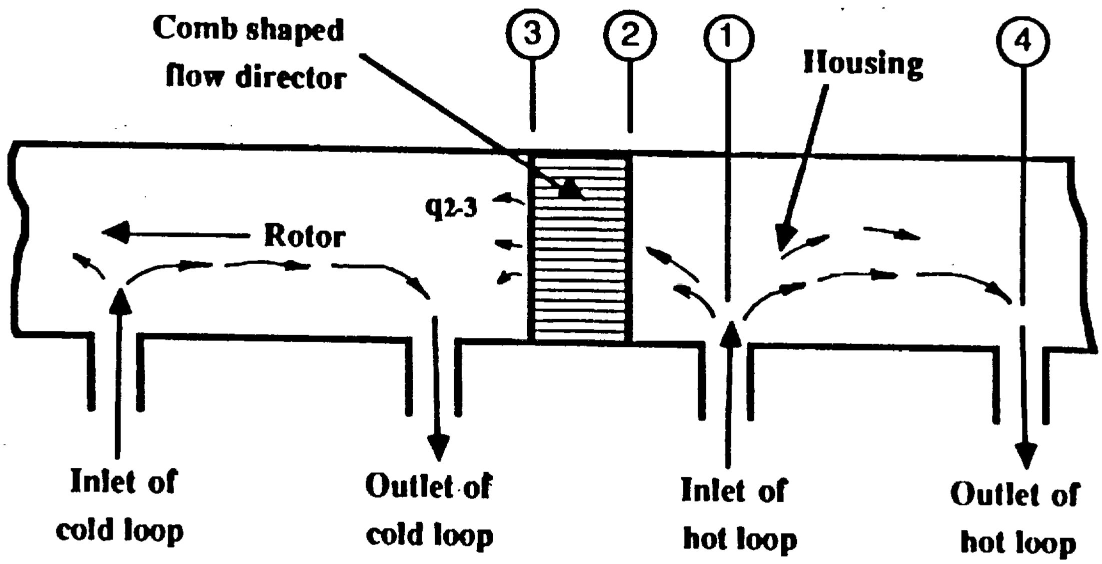
IV CONCLUSION AND FURTHER DEVELOPMENT

The agreement between analytical and experimental results proved that the project was carried out successfully. The introduction of flow director is a major break through of the magnetic heat pump project, and opened a new era for future research on this subject.

The future tasks for the KSC magnetic heat pump will be:
(1) fabricate rotor with gadolinium,
(2) install four permanent magnets, measuring instruments, and
(3) test for heat pump performance.

V APPENDIX

5.1 Calculations



Given (measured):

1. Flow area at section 1 $A1 = 8.64 \times 10^{-4}\ ft^2$
2. Flow area at section 2 $A2 = 2.20 \times 10^{-3}\ ft^2$
3. Wetted perimeter at section 1 $WP1 = 1.52\ ft$
4. Wetted perimeter at section 2 $WP2 = 0.86\ ft$
5. Hydraulic radius at section 1 $R_{H1} = 5.66 \times 10^{-4}\ ft$
6. Hydraulic radius at section 2 $R_{H2} = 2.56 \times 10^{-3} ft$
7. Flow rate /port $q = 5.3 \times 10^{-4}\ ft^3/sec$
8. Flow velocity at section 1 $v_{1\text{-}2} = 0.241\ ft/sec$
9. Flow velocity at section 2 $v_{2\text{-}3} = 0.616\ ft/sec$

Reynolds number

$$R_e = \frac{v(48R_H)}{\nu} = \frac{0.616\ (48)(5.66\times10^{-4})}{1.21\times10^{-5}} = 1383$$

Darcy's formula for laminar flow:

$$\Delta P = 0.000668 \frac{\mu L v}{d^2} = 0.1225 \frac{\mu L q}{d^4}$$

For non-circular flow area $d = 48\, R_H$

Then
$$\Delta P = 0.000668 \frac{\mu L v}{(48 R_H)^2} = 0.1225 \frac{\mu L v}{(48 R_H)^4}$$

Between section 1 and 2

(a) $$\Delta P_{1\text{-}2} = 0.000668 \frac{\mu L_{1\text{-}2} v_{1\text{-}2}}{(48 R_{H_{1\text{-}2}})^2}$$

Between section 2 and 3

(b) $$\Delta P_{2\text{-}3} = 0.000668 \frac{\mu L_{2\text{-}3} v_{2\text{-}3}}{(48 R_{H_{2\text{-}3}})^2}$$

Take (a) / (b) , we have

$$\frac{\Delta P_{1\text{-}2}}{\Delta P_{2\text{-}3}} = \frac{v_{1\text{-}2}}{v_{2\text{-}3}} \frac{(R_{H_{2\text{-}3}})^2}{(R_{H_{1\text{-}2}})^2}$$

$$= \frac{0.24}{0.616} \frac{(5.66 \times 10^{-4})^2}{(2.56 \times 10^{-3})^2}$$

$$= 0.3896 \times 4.89 \times 10^{-2} = 0.0191$$

$$\boxed{\Delta P_{1\text{-}2} = 0.0191\, \Delta P_{2\text{-}3}}$$

Thus, pressure difference between section 2-3 is much greater than pressure difference between section 1-2. Obviously, most fluid flows from section 1 to 4.

Also

$$\Delta P_{1\text{-}2} = 0.1225 \frac{\mu L_{1\text{-}2}\, q_{1\text{-}2}}{(48 R_{H_{1\text{-}2}})^4}$$

$$\Delta P_{2\text{-}3} = 0.1225 \frac{\mu L_{2\text{-}3}\, q_{2\text{-}3}}{(48 R_{H_{2\text{-}3}})^4}$$

Since

$$\Delta P_{1\text{-}2} = 0.0191\ \Delta P_{2\text{-}3}$$

$$0.1225 \frac{\mu L_{1\text{-}2}\, q_{1\text{-}2}}{(48 R_{H_{1\text{-}2}})^4} = 0.0191 \left[0.1225 \frac{\mu L_{2\text{-}3}\, q_{2\text{-}3}}{(48 R_{H_{2\text{-}3}})^4} \right]$$

Than

$$\frac{q_{1\text{-}2}}{(R_{H_{1\text{-}2}})^4} = 0.0191 \left[\frac{q_{2\text{-}3}}{(R_{H_{2\text{-}3}})^4} \right]$$

$$q_{2\text{-}3} = q_{1\text{-}2} \frac{(R_{H_{2\text{-}3}})^4}{0.0191 (R_{H_{1\text{-}2}})^4}$$

$$q_{2\text{-}3} = 5.3 \times 10^{-4}\ \frac{(5.66 \times 10^{-4})^4}{(2.56 \times 10^{-3})^4}$$

$$q_{2\text{-}3} = 5.3 \times 10^{-4}\ \frac{(5.66 \times 10^{-4})^4}{0.0191 (2.56 \times 10^{-3})^4}$$

$$= \frac{5.3 \times 10^{-4}}{1.91 \times 10^{-2}} \frac{(5.66 \times 10^{-4})^4}{(2.56 \times 10^{-3})^4}$$

$$\boxed{q_{2\text{-}3} = 6.63 \times 10^{-5}\ \frac{ft^3}{sec} \quad \text{per port}}$$

q2-3 is the quantity of fluid flowing through the flow director mixing with the other loop. It is found to be very small in this calculation.

All calculations are calculated per one flow port.

VI REFERENCE

1. P. L. Wang, "Laboratory Testing of a Supercritical Helium pump for a Magnetic Refrigerator," NASA/ASEE Summer Faculty Research Fellowship Program Research Report, John Kennedy Space Center, Florida, 1988. pp 412-439

2. P. L. Wang, "Study and Development of an Air Conditioning System Operating on a Magnetic Heat Pump Cycle," NASA/ASEE Summer Faculty Research Fellowship program Research Report, John Kennedy Space Center, Florida, 1991, pp 535-553.

3. Engineering Division, Crane Co. "Flow of Fluids through Valves, Fittings, and Pipe," Technical Paper No. 410, Crane Co., New York, 1979, pp 3-1, 3-5.