SPACE REACTOR LITHIUM FLOW CONTROL VIABILITY BY DC ELECTROMAGNETIC PUMP

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ABSTRACT

In the Institute for Advanced Studies (IEAv), were developed, successfully, the first two direct current electromagnetic pumps (DC EM pumps) of Brazil. The first was built with C-type magnet and coils; and the second, with Samarium-Cobalt permanent magnets, for magnetic field generation. Both were tested and performed quite satisfactory. Experiments were run for measurements of magnetic field, static pressure and dynamic operation with Mercury. The electromagnetic pumps do not have mobile parts, are stamped, present high reliability and allow the flow control of liquid metals. These characteristics make them interesting to be used in space nuclear reactors cooled by liquid Lithium, as in the SP-100 project. The BEMC-1 code has been elaborated to study each stage of the development of a DC EM pump, the electromagnetic pump performance evaluation, and a new DC EM pump design. This work presents DC EM pumps studied, their operational principle, the Samarium-Cobalt permanent magnets electromagnetic pump performance evaluation, comparing theoretical and experimental data of static pressure and dynamic operation with Mercury, and study the space reactor Lithium flow control viability by DC EM pumps.

1. INTRODUCTION

The research on electromagnetic pumps at the Institute for Advanced Studies – IEAv is aimed to reach pumping capabilities to allow the development of liquid metal cooling systems to extract high heat densities, as it is necessary in nuclear fast reactors intended to be used in space.

This development started at IEAv in 1988, as part of the space reactor project called RESPA. At that time, for experimentation purpose, Mercury was chosen as working fluid because it is a liquid metal at room temperature and that would reduce the handling efforts. A laboratory to handle Mercury was installed then. Two direct current electromagnetic pumps (DC EM pumps) were designed, built and tested. The first pump was built using a “C” type electromagnet for magnetic field generation. The second was built using Samarium-Cobalt magnets for magnetic field generation. Both pumps presented satisfactory behavior with respect to the Mercury flow control [1, 2].

Electromagnetic pumps work based on Faraday’s principle, in which the electrical current (I) interacts with the magnetic field (B) generating the magnetic force (F). Therefore, this in turn controls the liquid metal flow (W) [3]. Figure 1 shows a schematic of the electromagnetic pump working principle. As may be noticed these pumps have no moving parts and they are completely sealed. They possess high reliability and allow the use of high temperature radioactive working fluid. These characteristics make them highly desirable to be used for...
flow control of liquid metal, such as Lithium in cooling systems for space reactor application, like for instance in the SP-100 space fast reactor [4, 5, 6]. Figure 2 presents the primary Lithium flow loop in the SP-100 design. In that design the Lithium flow is controlled by electromagnetic thermoelectric pump (EMTE) [3, 4].

Figure 1. Direct current electromagnetic pump working principle

Figure 2. SP-100 space fast reactor design
This work presents experimental evaluation data for a direct current electromagnetic pump that uses Samarium-Cobalt magnets and Mercury as a working fluid. It also presents the BEMC-1 [7] code that allows the design of new direct current electromagnetic pumps. And finally it provides a discussion on the use of DC EM pumps to Lithium flow control in space fast reactors applications.

2. SIMULATIONS

The BEMC-1 code was written in the C++ language. It was created with the objective to perform evaluation at each development step of a direct current electromagnetic pump, allowing for important design parameter variations. One may calculate the several electric resistances involved in the DC EM design by defining the working fluid and establishing its properties, the channel geometry and materials. Also, one may calculate the magnetic field and static pressure as a function of the main electrical current in the DC EM pump. With the BEMC-1 code can be calculated the system operating points, in other words, the fluid flow rate and the dynamic pressure give by the pump as it operates in a closed loop. The BEMC-1 code can calculate the dynamic pressure loss as a function of the fluid flow, and equivalent diameter and length of the loop.

A magnetic field of 0.44 Wb/m$^2$ was measured for the Samarium-Cobalt magnets DC EM pump testing. A 800 A direct current electrical source is used to generate the main current. The main electrical current interacts with the magnetic field creating the magnetic force that acts over the fluid in the channel’s pump, controlling the fluid flow. The geometry of the channel’s pump is as follows: height $a = 10 \text{ mm}$, width $b = 30 \text{ mm}$ and useful length $c = 70 \text{ mm}$, where the letters $a$, $b$ and $c$ refers to Fig. 1. Given these data the BEMC-1 code can evaluate the DC EM pump theoretical performance, operating with liquid metal fluids of interest. Table 1 presents liquid metal properties of interest (Mercury and Lithium), that will be used in the simulations.

Figure 3 shows measurements for the static pressure of the Samarium-Cobalt magnets DC EM pump, operating with Mercury as a working fluid. The curves presented are for three, four and five magnet blocks, and as a function of the main electrical current. Also it is shown the theoretical result generated with the BEMC-1 code. The comparison of theoretical curves and measured data reveals good agreement.

Figure 4 shows measurement points of head pressure data to the Samarium-Cobalt magnets DC EM pump, as a function of the Mercury flow operating with a closed loop (called dynamic loop) with 3.8 m of length and 12.2 mm of internal diameter. Figure 4 also shows the theoretical pressure loss curve of dynamic loop, calculated with the BEMC-1 code.

<table>
<thead>
<tr>
<th>Property \ metal</th>
<th>Mercury</th>
<th>Lithium</th>
</tr>
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<tbody>
<tr>
<td>Temperature ($^\circ \text{C}$)</td>
<td>20</td>
<td>700</td>
</tr>
<tr>
<td>Electrical Resistivity (ohm.m)</td>
<td>9.3 e-7</td>
<td>4 e-7</td>
</tr>
<tr>
<td>Specific Mass (Kg/m$^3$)</td>
<td>13400</td>
<td>462</td>
</tr>
<tr>
<td>Dynamic Viscosity (N.s/m$^2$)</td>
<td>1.5 e-3</td>
<td>2.9 e-4</td>
</tr>
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</table>
Figures 3 and 4 present very good agreement between measured and calculated data using the BEMC-1 code. This fact gives validation to the results produced with the BEMC-1 computational program and allows for the use of the code for other liquid metals of interest.

Figure 5 shows the theoretical system operation points which are represented by the curves intersections. The intersections are produced by the DC EM pump theoretical performance
curve and the pressure loss theoretical curves for the dynamic loop, both calculated with the BEMC-1 code, considering Mercury as the working fluid. The DC EM pump performance curves are all parallel straight lines, that is due to the fact that the magnetic field, generated by the Samarium-Cobalt magnets, is constant and equal to 0.44 Wb/m².

Figure 6 shows the DC EM pump performance curves and the pressure loss in the dynamic loop, both calculated with the BEMC-1 code using Lithium as working fluid.

Figure 5. DC EM pump theoretical performance curves to Mercury as working fluid

Figure 6. DC EM pump theoretical performance curves to Lithium as working fluid
Table 2 presents the DC EM pump dynamic operation points, using as given parameters: the main electrical current (I) of 600 A and a magnetic field (B) of 0.44 Wb/m$^2$, considering Mercury and Lithium as working fluids as calculated by the BEMC-1 code.

<table>
<thead>
<tr>
<th>Parameter\Fluid</th>
<th>Mercury</th>
<th>Lithium</th>
</tr>
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<tbody>
<tr>
<td>Flow (l/min)</td>
<td>4.3</td>
<td>19.1</td>
</tr>
<tr>
<td>Pressure (N/m$^2$)</td>
<td>1.7 e 4</td>
<td>1.2 e 4</td>
</tr>
</tbody>
</table>

### 3. CONCLUSION

The operation points for the system pump/loop were obtained for the DC EM pump operating with both Mercury and Lithium as working fluids. The system operation points were obtained by the intersections produced by the dynamic pump curves with the pressure loss loop curves. An important observation is that the DC EM pump performance curves are parallel straight lines due to fact that the magnetic field, generated by the Samarium-Cobalt magnets, is a constant value and equals to 0.44 Wb/m$^2$.

The measured data compares quite nicely with the calculated results produced with the BEMC-1 code. That validates the calculation procedure performed by the program. The results presented here are of great value when one considers using DC EM pumps to Lithium flow control as part of the heat removal system in a space fast reactor.

### REFERENCES