SOFTWARE FOR DC ELECTROMAGNETIC PUMP SIMULATION - BEMC-1

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Abstract. *The cooling system of high-density thermo power device requires fluids of high thermal conductivity, such as liquid metals. Electromagnetic pumps are used to control liquid metal fluid flow in cooling loops. The principle of operation of electromagnetic pump used to control fluid flow is based on Lorentz's force. This is obtained by interaction of the magnetic field and the current intensities, both imposed and adjusted by two independent electric power sources. In this work the operational principles, development scheme, type of pump studied are presented. The computational program BEMC-1 is presented, too. This program was developed for design and performance evaluation of DC electromagnetic pumps. The program results are compared with the experimental data for magnetic induction, static pressure and fluid flow operation in a mercury dynamic loop. The experimental results agree fairly well with the results predicted by the program. The BEMC-1 program can be considered validated and optimized to be used in the evaluations and projects of the DC electromagnetic pump.*

Keywords*. electromagnetic pump, computational simulation, experimental evaluation, liquid metal, fluid flow control.*

1. Introduction

Systems of cooling that use liquid metal as working fluid can remove high energy densities.

The electromagnetic pumps do not have movable parts, they are completely stamped, they present high reliability and they allow the use of radioactive fluid at high temperature. These characteristics make them interesting to be used in fast nuclear reactor cores cooled by liquid metal, as in the EBR-II (Lentz, et all, 1985), in the PRISM (Kwant, et all, 1988) and in the REARA (Borges, et all, 1994).

In the Institute for Advanced Studies (IEAv-CTA), the first Brazilian continuous current (DC) electromagnetic pump was projected, built and evaluated. It worked satisfactorily in static and dynamic operations, with mercury, in closed loops especially developed for those purposes (Borges, et all, 1995).

The computational program BEMC-1 was elaborated with the objective to study each stage of the development of DC electromagnetic pumps.

BEMC-1 is quite versatile, it facilitates the evaluation of deviations between calculated and experimental data, and it allows the use of correction factors, in a way to minimize these errors in the project of DC electromagnetic pumps.

This work presents the principle of operation of an electromagnetic pump, its basic equations, comparison among the theoretical and experimental data of magnetic field, static pressure and mercury fluid flow, for different values of main currents and magnetic field currents supplied, validating the BEMC-1 program.

2. The principle of operation of a DC electromagnetic pump

In a DC electromagnetic pump the Lorentz's force defines the intensity and the direction of the force applied in the conductive fluid under influence of the main electric current and the magnetic field imposed.

The magnetic field and the main electric current are controlled by two independent electric power sources.

Figure (1) shows the principle of operation of a DC electromagnetic pump.

Where: "a" is the height of the channel of the pump, "b" is the width of the channel, "c" is the useful length and "d" is the iron-break or air gap length.

These parameters and others are used to the pump performance evaluation (Borges, 1991).

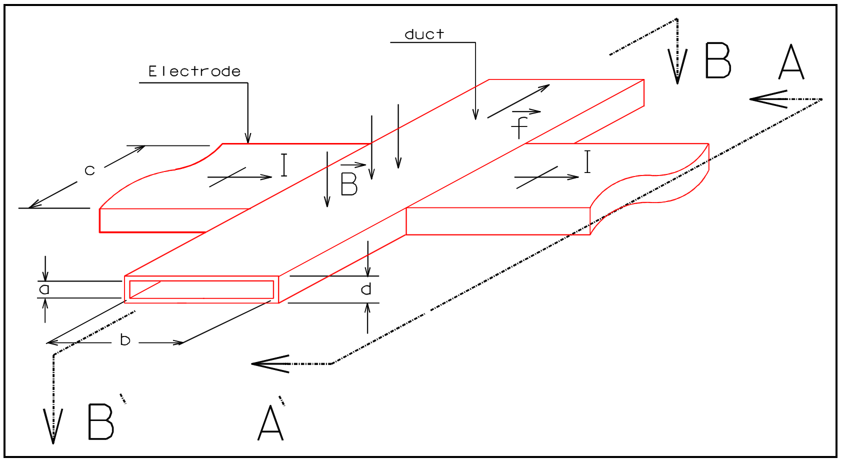

Figure 1. The principle of operation of a DC electromagnetic pump.

2.1. Problem formulation

The magnetic field can be calculated with the Ampere's law:

$$B = \mu\ N\ I_{field}\ /\ d\ . \tag{1}$$

The magnetic loss in the iron-break (d) is greater than the one in the magnet.

The magnetic permeability (μ) to a liquid metal is the same to one of the vacuum.

The Eq. (1) relates the intensities of magnetic field (B) around a closed path, where N is the total number of spires and I_{field} is the magnetic field current supplied.

Considering the magnetic field perpendicular to the main electric current (I) and the direction of the fluid flow, the force (F) resulting from the interaction between magnetic field and main electric current can be calculated as a function of the useful electric current (I_e) by:

$$F = B\ I_e\ b\ . \tag{2}$$

The head pump (P) can be defined by:

$$P = F\ /\ (a\ b)\ . \tag{3}$$

Substituting the Eq. (3) in Eq. (2), comes to:

$$P = B\ I_e\ /\ a\ ,\ \text{in}\ [N\ /\ m^2]\ ;\ \text{and} \tag{4}$$

$$P = B\ I_e\ /\ (a\ 1360)\ ,\ \text{in}\ [\text{cm Hg}]\ . \tag{5}$$

The electric tension of the pump is given by:

$$V = I_e\ R_e + E_c = I\ R_t\ . \tag{6}$$

Where: R_t is the equivalent electric resistance of the circuit and E_c is the electro-countermove force resulting from the fluid moving in the magnetic field. This induced voltage is:

$$E_c = B\ W\ /\ a\ . \tag{7}$$

The useful electric current (I_e) can be calculated as a function of the: main current (I), electro-countermove force (E_c) and electric resistances R_e , R_w and R_b. These electric resistances are respectively, of the fluid in the channel of the pump, of the wall and the "bypass" or escape. The last is related with the geometry of the pump, and it is calculated multiplying the useful electric resistance (R_e) by an empiric correction factor.

The useful electric current (I_e) is a function of the volumetric fluid flow (W). Therefore, in the static pressure case (without fluid flow) the last term is null, where as in the dynamic pressure case (with fluid flow) this term is not.

$$I_e = \frac{I}{1 + R_e\left(\frac{R_w + R_b}{R_w R_b}\right)} - \frac{E_c}{R_e + \frac{R_w\ R_b}{R_w + R_b}} \,. \tag{8}$$

Figure (2) shows the equivalent electric circuit of the DC electromagnetic pump.

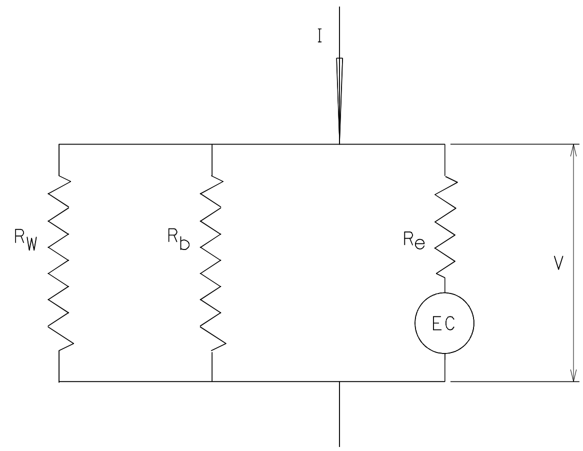

Figure 2. Equivalent electric circuit of the DC electromagnetic pump.

3. The BEMC-1 program

The fundamental stages of the project of an electromagnetic pump are the evaluation of magnetic field, static pressure and dynamic fluid flow data.

The BEMC-1 was developed in C++ language. It was created with the objective to evaluate each stage of the development of a DC electromagnetic pump. With this program it is possible to change all the important parameters of the pump.

The pumped fluid properties, as well as, the geometry and materials of the channel data, are used to calculate the electric resistances. These parameters are used in Eq. (6).

A very important parameter is the magnetic field. This can be calculated by the field equation Eq. (1), in function of the air gap length and of the magnetic field current. If necessary the program permits that the magnetic field to be corrected by an appropriate correction factor.

The head pump, calculated by Eq. (4) and Eq. (5), depends on the magnetic field, the duct geometry and the useful electric current. The last one is a function of the main current, the electric resistances and the fluid flow, in the Eq. (7) and Eq. (8).

The static pressure is the operational limit of the pump. It is calculated with the last term of Eq. (8) set to null.

The BEMC-1 program can evaluate the fluid flow and the head supplied by the pump operating in closed circuits, calculating the loss of the loop, as a function of the fluid flow, the channel diameter and the equivalent length of the loop.

The BEMC-1 program allows for the project and the optimization of a DC electromagnetic pump, by changing data and parameters to analysis a new condition of performance of the pump, as well as, geometric data of the pump and of the loop.

4. The DC electromagnetic pump

The DC electromagnetic pump builted is a C-type magnet and field coil with 2000 spires. The magnet is made in steel 1020, with area 60 x 70 mm and air gap length with 20 mm. The channel of the pump is defined by: the duct height “a” (10 mm), the width “b” (30 mm) and the useful length “c” (70 mm). In (Borges, et all, 1995) are presented detailed geometric data of the pump.

Figure (3) shows the cross section of the DC electromagnetic pump with C-type magnet studied.

The magnetic field and the main electric current are controlled by two independent electric power sources. A electric power source of continuous current HP-6030A supplies the field current. This travels the 2000 spires and adjusts the magnetic field in air gap. Other power source of continuous current ADELCO supplies the main electric current until 800 Amperes.

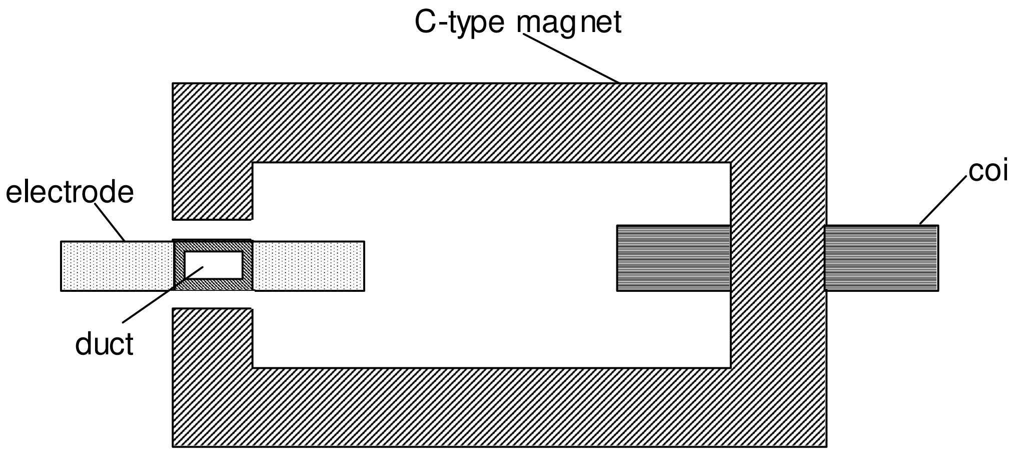

Figure 3. Cross section of the DC electromagnetic pump with C-type magnet.

5. Evaluation

The experimental and theoretical data of magnetic field, head pump and fluid flow, supplied by the EM pump, should be compared in order to define the adjustment factors and validate of the BEMC-1 program.

5.1. Magnetic field

The DC electromagnetic pump studied is a C-type magnet and field coil with 2000 spires and air gap length with 20 mm.

Figure (4) shows data of theoretical magnetic field, calculated by Eq. (1), and the average experimental magnetic field, in the center of the air gap, as a function of the magnetic field current imposed to the coil.

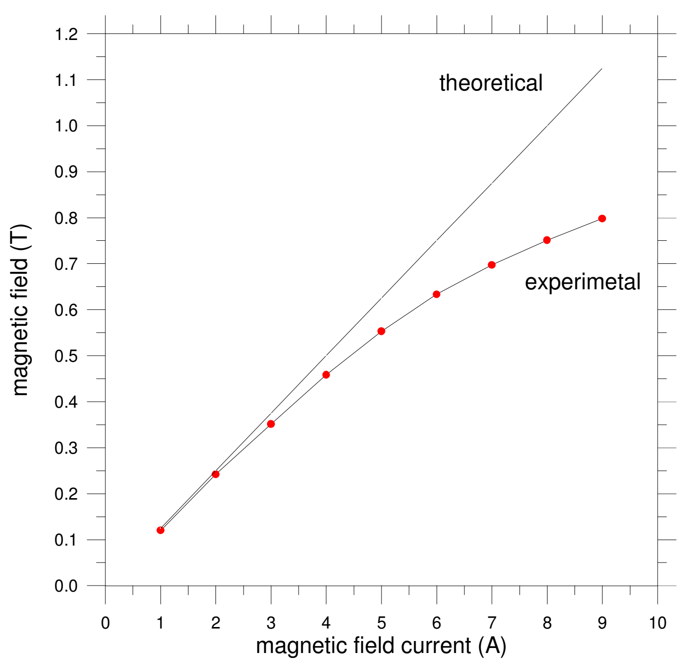

Figure 4. Magnetic field in the center of the air gap of the C-type magnet.

It is observed that for growing values of magnetic field currents, the difference among the theoretical and experimental data is increased, due to saturation of the magnet. For the simulation to reproduce the experimental data, there is, the need of using adjustment factors, in the calculation of magnetic field in the program BEMC-1, as a function of the magnetic field current. This was made and in the subsequent calculations the BEMC-1 uses the corrected field.

5.2. Static pressure of the DC electromagnetic pump

The theoretical pressure static data are obtained as a function of the useful electric current, the channel geometry and the magnetic field.

Figures (5) and (6) show, respectively, the theoretical and the experimental data of static pressure of the DC electromagnetic pump with the C-type magnet, as function of the main current and the magnetic field currents.

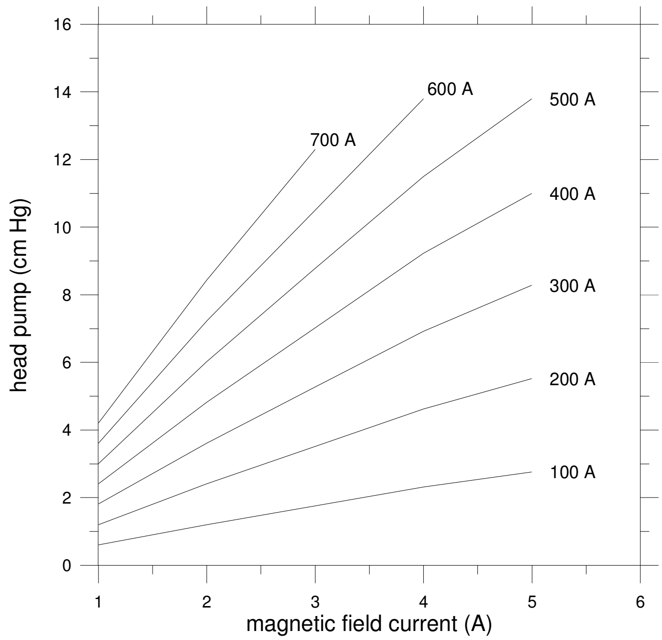

Figure 5. BEMC-1 theoretical static pressure data of the DC electromagnetic pump.

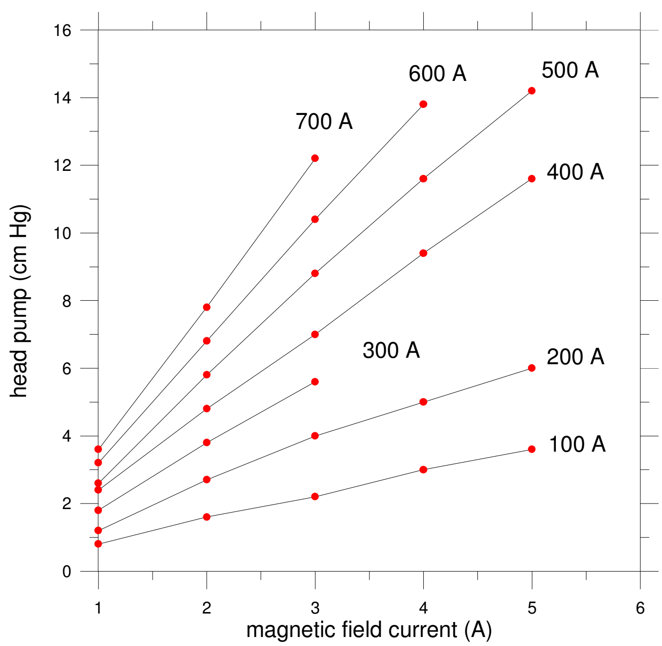

Figure 6. Experimental static pressure data of the DC electromagnetic pump.

Comparing the static pressure data, it is noticed that (using the appropriated magnetic field correction and “bypass” factors) the BEMC-1 program reproduces the experimental data, validating the methodology used in the BEMC-1 program. Without the use of the magnetic field correction factors, the errors arrive up to 20% (Borges, et all, 1998).

5.3. Dynamic performance of the DC electromagnetic pump

Figure (7) shows the theoretical pressure loss data in the dynamic loop with mercury (internal diameter is 0.0122 meters and equivalent length is 3.8 meters), as a function of the fluid flow, obtained with the program BEMC-1.

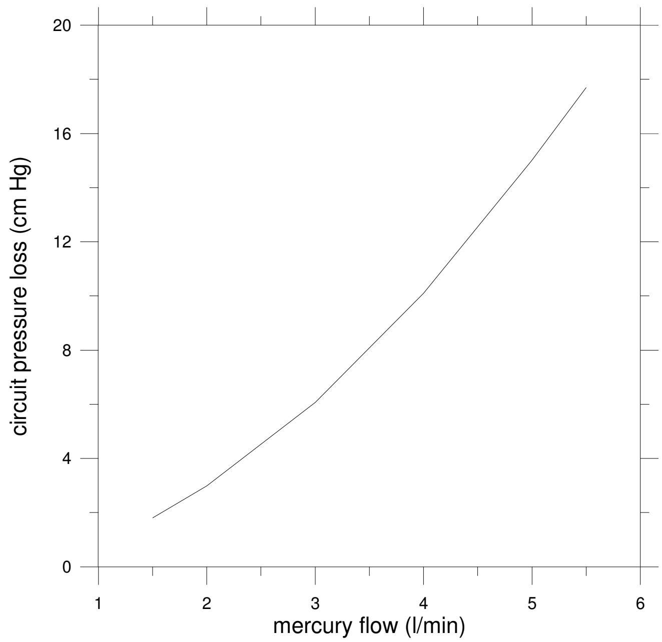

Figure 7. BEMC-1 theoretical loop pressure loss data.

Figure (8) shows the experimental fluid flow data of the DC electromagnetic pump with C-type magnet, in the dynamic loop with mercury.

The mercury fluid flow supplied by the DC electromagnetic pump depends directly on the values of the magnetic field and main currents. The maximum mercury fluid flow is nearly 6.0 l/min. This value is associated to the limitations of the current sources used.

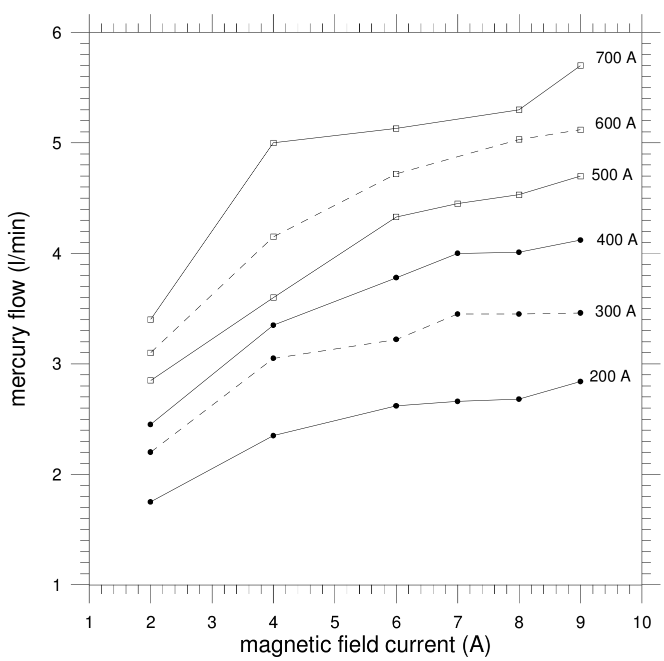

Figure 8. Experimental fluid flow data of the DC electromagnetic pump.

The theoretical performance of a DC electromagnetic pump depends on geometric data, the electric currents supplied, and the pressure loss data in the loop.

Figure (9) shows the theoretical fluid flow data of the DC electromagnetic pump with C-type magnet, for the dynamic loop with mercury, calculated by the BEMC-1 program.

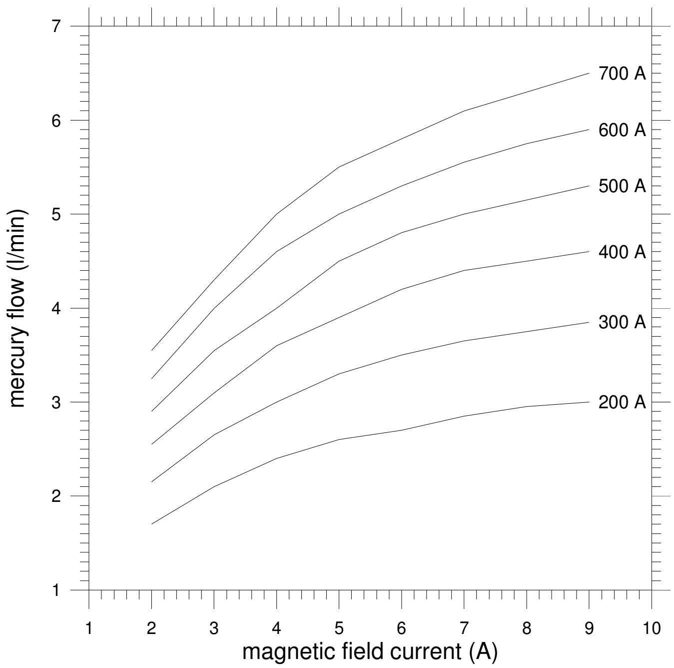

Figure 9. BEMC-1 theoretical fluid flow data of the DC electromagnetic pump.

The theoretical data of fluid flow and head pump are correlated. Therefore, the head pump is calculated as a function of the fluid flow.

Figure (10) shows the theoretical head pump, obtained with the BEMC-1 program.

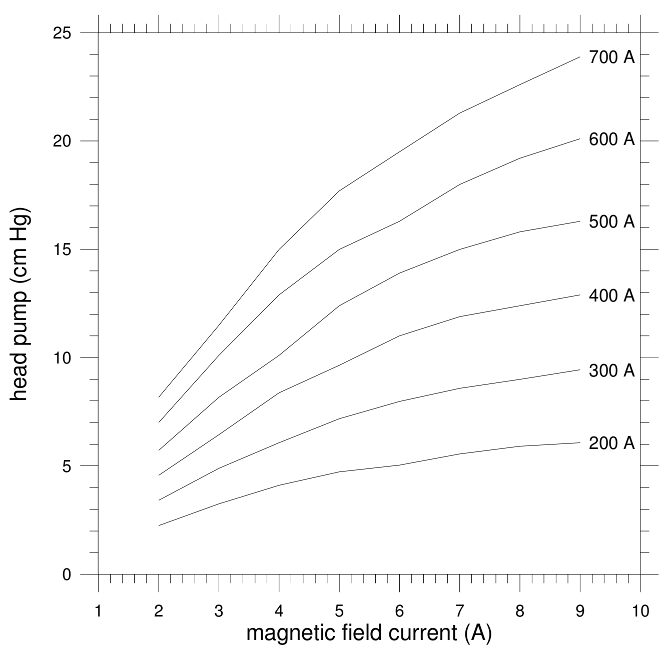

Figure 10. BEMC-1 theoretical dynamic head pump.

The dynamic head pump data in Fig. (10) is always smaller than the static pressure data in Fig. (5), for the same magnetic field and main currents supplied, and it has been compatible with the pressure loss data of the loop.

6. Conclusion

The analysis of the data obtained in the evaluations demonstrated the importance of developing specific mathematical models for each studied phenomena and the need of the development of the BEMC-1 program.

Comparing the theoretical and experimental data of magnetic field, it is observed that for data of growing magnetic field currents, the difference among them increases, due to saturation of the magnet. There is, therefore, the need of using adjustment factors, in the calculation of magnetic field in the program BEMC-1, as a function of the magnetic field current.

Comparing the static pressure data, it is noticed that (using the appropriated magnetic field correction and “bypass” factors) the BEMC-1 program reproduces the experimental data, validating the methodology used in the BEMC-1 program. Without the use of the magnetic field correction factors, the errors arrive up to 20%.

The BEMC-1 program can be considered validated and optimized to be used in the evaluations and projects of the DC electromagnetic pump.

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