Construction and Characterization of a Multi-Sections Solenoid for Power Microwave Tubes

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ABSTRACT — **The construction and the characterization of a multi-sections solenoid to be used as a magnetic focusing structure of a TWT is reported in this paper. Using copper sheet as electric conductor, the developed solenoid is able to produce a magnetic density flux of 175 mT on axis with 10 A and electrical power of 2.2 kW. Electrical, magnetic and thermal characterizations of the device are presented. Comparison between theoretical and experimental results are shown and discussed.**

Index Terms **— Magnetic electron beam focusing, Solenoids, PPM focusing.**

I. INTRODUCTION

Power microwave tubes such as TWT (traveling- wave tube) need high current density electron beams to work. However, these electron beams will certainly present space charge effects and the beam spreading can be so large that a focusing system must be used to ensure the correct operation of the tube.

Electron beam focusing is possible by means of electric or magnetic fields. Pierce [1] indicated that the former is sensitive to electric breakdowns at high fields, what becomes this system not attractive to be utilized.

Magnetic fields are obtained from solenoids or permanent magnets. The first can usually present one of the following drawbacks: excessive weight, need of a power source, and a cooling system. However, if one wants to design a PPM (Periodic-Permanent Magnet) focusing structure, a solenoid is a useful device to determine experimentally the magnetic flux density to focus a given electron beam before working with magnets due to a better focusing adjustment [2].

In this research it is presented the results from the construction and the characterization of a copper sheet multi-sections solenoid that will aid the design of a PPM to focus the electron beam of a TWT under investigation at CTMSP. The constructed device uses a thin metallic copper sheet instead of wire because it is reported that this kind of conductor provides better axial field symmetry [3]. The design of the multi-sections solenoid is reported in the literature [4].

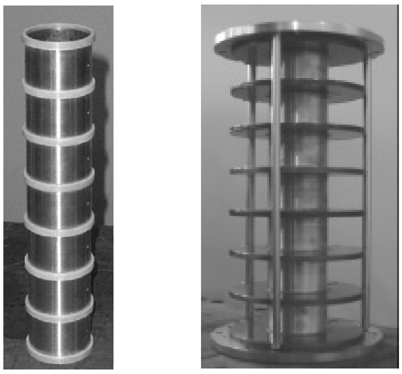
This paper is organized as follows: in Section II is presented the experimetnal setup used during this research. Section III shows and discusses the results of the investigations carried out and Section IV relates the conclusions.

II. EXPERIMENTAL SETUP

A. Solenoid construction

First of all, seven circular end opened pipes of ASTM 120 brass alloy were assembled and electrically isolated from each other using fiber glass. The brass pipes will support mechanically the windings and are the first ohmic contact of each section to allow the polarization. The second ohmic contact is located on the end of each winding when it is finished.

After that, eight varnished copper plates have been used as spacers between the sections (positioned on fiber glass). These spacers make possible the solenoid cooling by means of internal channels where a liquid flows during solenoid working. Fig. 1(a) shows the mechanical assembly without the copper plates and Fig. 1(b) presents complete solenoid without windings.



(a) (b)

Fig. 1. Solenoid brass base. (a) Without copper plates. (b) With copper plates.

Each section has 680 turns to obtain the desired magnetic density flux [4]. Between overllaped copper turns, a polyester sheet of 12 m thickness was added to avoid electric short-circuit.

Next, the device was vacuum dried using a metallic chamber connected to a rotary vane vacuum pump. After that, the chamber was filled out with the varnish SÃO MARCO ISALPHEN P-056 and then the solenoid was put to a furnace FANEN 320SE to dry at 130ºC during 24 hours.

B. Solenoid characterization

Experimental data of the axial magnetic density flux component B_z on axis of symmetry (=0) has been obtained from a Hall probe GLOBALMAG TMAG-01T assembled on a 2-D precision table. The B_z was measured with step of 1 mm. The developed system which allows the sensor motion at and *z* axes is presented in Fig. 2. Tests with all sections connected were carried out without cooling system and, because of this, it was used electric currents of 0.85A and 1.00 A.

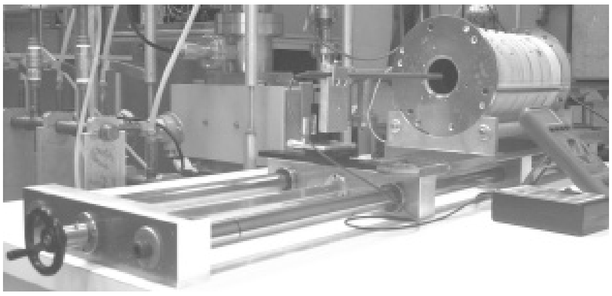


Fig. 2. Developed system used to magnetic characterization of the multi-sections solenoid. It is also presented the Hall probe located at the entrance of the device.

Thermal characterization has been carried out from measurements of water temperature that cools the solenoid and circulates through a heat exchanger. Using two temperature sensors, one at the entrance and other at the exit of the solenoid, it was possible to evaluate the parameter ΔT. These tests were performed for each section individually using a current of 10A and water flux of about 50 L/h, where using these values a thermal balance can be stablished.

III. RESULTS AND DISCUSSION

A. Electrical and magnetic characterization

The copper sheet ohmic resistance values obtained during the solenoid construction using a multimeter WAVETEK DM27XT to each 100 turns in every section during its fabrication are presented in Table I. R_1 denotes the resistance for the section 1, R_2 for section 2 and so on. It is possible to notice that the resistance measurements showed very similar to each other, which shows that the developed methodology is reproducible.

TABLE 1

MEASUREMENTS OF RESISTANCE FOR EACH SECTION.

	Section (error = ±0.05Ω)						
Turns	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_4 (Ω)	R_5 (Ω)	R_6 (Ω)	R_7 (Ω)
100	0,4	0.3	0.3	0.3	0.4	0.4	0.4
200	0.7	0.7	0.7	0.7	0.7	0.7	0.7
300	1.0	1.0	1.0	1.1	1.1	1.1	1.1
400	1.5	1.5	1.5	1.5	1.5	1.5	1.5
500	1.9	2.0	2.0	2.0	2.0	2.0	2.0
600	2.4	2.5	2.5	2.6	2.6	2.6	2.5
680	2.7	3.0	2.9	3.1	3.1	3.0	2.9

Experimental magnetic characterization of the solenoid when all sections were connected is presented in Fig. 3. The profile of the curve is similar to that presented in [4] and the variation of the field with the current change was linear. When B_Z profile using (1.00±0.05)A is compared with the one obtained theoretically, it is noticed that exists a discrepancy at the ends of the curves. This can be attributed to the presence of the ferromagnetic plates that support mechanically the solenoid, as presented in Fig. 1(b). When the maximum intensities of both profiles are compared, the discrepancy is 5.2%.

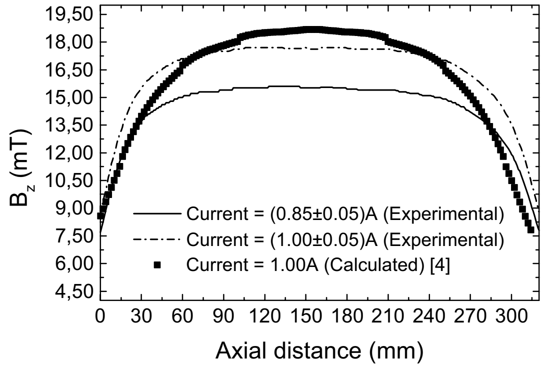


Fig. 3. Experimental axial magnetic density flux on axis of symmetry for two different electrical currents with all seven sections connected. It is also presented the calculated profile of B_Z for $I = 1.00$A [4].

It was also obtained a periodic axial magnetic field with the multi-sections solenoid. Fig. 4 presents experimental and calculated B_Z profiles with three sections connected. One can notice that both graphs are coincident in the central measurement region, but there is a discrepancy at the ends, effect that can be explained exactly as the previous situation. Experimental profile does not become positive at near 80 mm because there are two magnetic field sources with field lines pointed in same direction acting on just one source of opposite field (the field direction depends on the electric current flow direction).

Another profile, with five sections, is presented in Fig. 5. The sections at the ends of this measurement configuration are negative and its field lines interact with the sections by your sides. The field lines from the middle section interacts mainly with sections by its side and, because of this, the second saddle point is lower than first or third. Once again, exists a good agreement between calculated and experimental data.

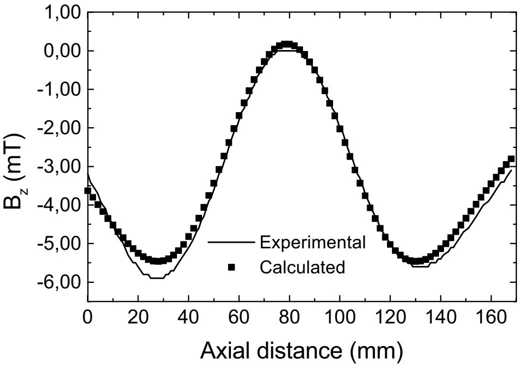


Fig. 4. Experimental and calculated axial magnetic density flux profile of three sections of opposite polarity for $I = 1.00$A.

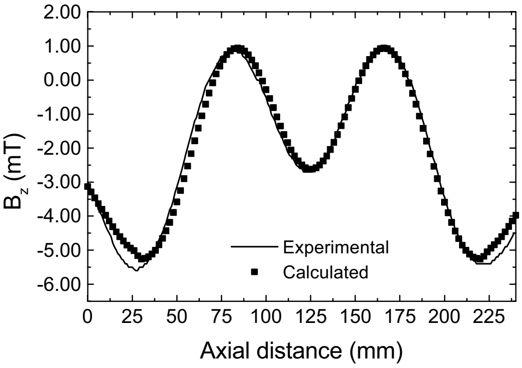


Fig. 5. Experimental and calculated axial magnetic density flux profile five sections of opposite polarity for $I = 1.00$A.

B. *Thermal characterization*

The typical behavior of the solenoid heating during the work is presented in Fig. 6. One can verify that the solenoid heating growths rapidly, following an exponential behavior and, passed about 50 minutes, ΔT becomes constant and the device reaches its thermal equilibrium. This is also the period of time necessary to stabilization of the magnetic field because there are no more variations of the conductor resistance originating from the Joule effect heating. At this moment, the electric power dissipated by just one section is about 315W and one can notice that if this value is multiplied by 7 (the section number), it is found 2.205 kW. There is a full conversion from electric to thermal energy, as expected.

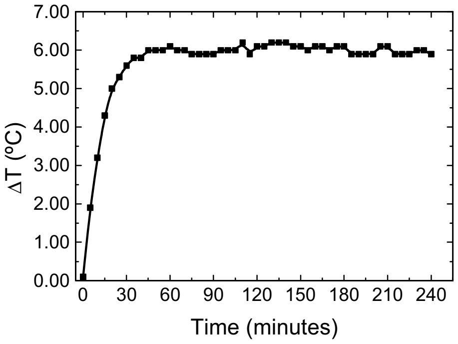


Fig. 6. Typical heating profile of the solenoid for $I = 10.00$ A.

V. CONCLUSION

In this paper it was presented construction and electrical, thermal and magnetic characterization of a solenoid which will be used as a power TWT focusing structure. Instead of copper wire, it was used a copper sheet and the experimental results were satisfactory. It was demonstrated that is also possible to obtain a periodic magnetic density flux profile with this multi-section solenoid.

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