COLD AND HIGH POWER TEST OF LARGE SIZE MAGNETIC ALLOY CORE FOR XiPAF'S SYNCHROTRON

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Abstract

A compact magnetic alloy (MA) loaded cavity is under development for XiPAF's synchrotron. The cavity contains 6 large size MA cores, each is independently coupled with solid state power amplifier. Two types of MA core are proposed for the project. We have developed a single core model cavity to verify the impedance model and to test the properties of MA cores under high power state. The high power test results are presented and discussed.

INTRODUCTION

Xi'an Proton Application Facility (XiPAF), under construction in Xi'an, China, is dedicated to radiation applications like proton therapy, single event effects (SEE) study [1]. XiPAF's accelerator complex is composed of a 7 MeV Linac, a compact synchrotron (7~230 MeV) and two application beam lines. The synchrotron works in slow cycling mode and can accelerate proton beam from 7 MeV to 230 MeV in 0.5 s.

We propose to use a compact MA loaded cavity for beam acceleration because: 1. MA material has the property of wide band, thus we can use a single cavity to cover the large frequency range of our machine. This property can also simplified the control system compared to ferrite loaded cavity; 2. For slow cycling operation of our machine, a voltage of several hundred volts is enough, so the cooling of MA loaded cavity would not cause serious problem.

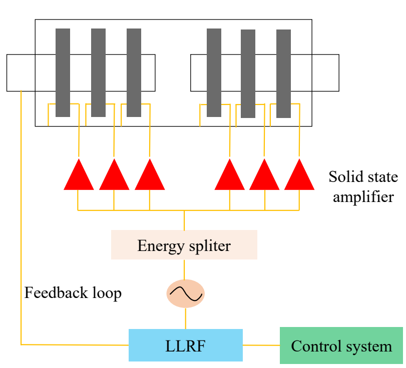

Figure 1: MA loaded RF system for XiPAF's synchroton.

The schematic design of our MA loaded cavity is shown in Fig. 1. The cavity contains 6 large size MA cores. The impedance of each core will be designed close to 50 Ω, so they can be independently coupled with solid state power amplifier without special impedance match. The main parameters of the cavity are listed in Table. 1.

Table 1: Parameters of the MA Loaded Cavity

Parameter	Value	Unit
Frequency range	1~7	MHz
Harmonic number	1	
Max. Voltage	800	V
Core number	6	
Shunt impedance per core	~80	Ω
Max. power dissipation per core	~110	W
Q value	~0.5	
Core outer diameter	450	mm
Core inner diameter	300	mm
Core thickness	25	mm

Two local company in China have provided two types of large size MA core (see Fig. 2):

- Type A: The material of ribbon is 1K107 produced by AT&M[1]. The thickness of ribbon is 18 μm. The core is solidified with epoxy resin.
- Type B: The material of ribbon is FT-3M, which is the most widely used material in this area. The thickness of ribbon is 18 μm. The core is solidified with silica gel.

We have carried out several experiments of both low power and high power to test the performance of large size MA cores.

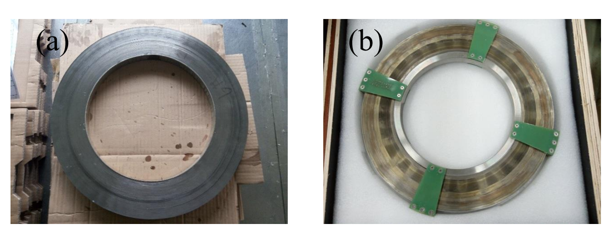

Figure 2: Large size MA cores, (a) Type A, (b) Type B.

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[1] http://www.atmcn.com/

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RESULTS OF COLD TEST

The shunt impedance R_p of each core can be written as [2]

$$R_p = (\mu'_p Q f) t \ln\left(\frac{R_o}{R_i}\right) \tag{1}$$

$$\mu'_p = \mu'_s\left(1 + \frac{1}{Q^2}\right) \tag{2}$$

where R_o, R_i and t are the outer diameter, inner diameter and thickness of the core, Q is defined as μ'_s/μ''_s, $\mu'_s - j\mu''_s$ is the complex permeability of the material. The product $(\mu'_p Q f)$ is independent of the size of core and is used to evaluate magnetic material.

We have measured the complex impedance of the MA cores through a vector network analyzer and deduced their $(\mu'_p Q f)$ and Q. The measured results are shown in Fig. 3. Cold test results show that 1K107 and FT-3M material have similar performance. The cores made of FT-3M have better $(\mu'_p Q f)$ when the frequency reaches several MHz. Their $(\mu'_p Q f)$ ranges from 4 GHz to 9 GHz in the frequency range of 1~7 MHz. With the size of the core, the shunt impedance ranges from about 50 Ω to 120 Ω in the frequency range of 1~7 MHz. A single core model cavity is built to further

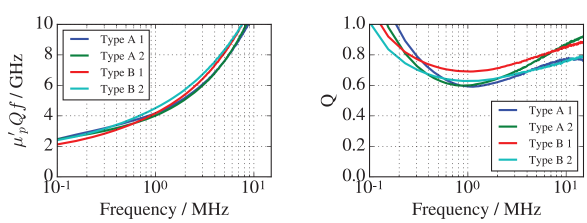

Figure 3: $(\mu'_p Q f)$ and Q value of large size MA core.

Figure 4: Single core test cavity.

test the MA cores (see Fig. 4). A tunable capacitance is installed on the cavity to adjust the resonant frequency. We measure the impedance through the couple loop as shown in Fig. 5. The measured results show the cavity has good wide band property, the standing wave ratio stays below 1.7 in the frequency range of 1~7 MHz. However, the measured result is not well consistent with the theory result. Here, the theory complex impedance is calculated as $Z_{\text{core}}//\frac{1}{j\omega C}$, where Z_{core} is the measured impedance of MA core without cavity. We infer that the distributed inductance is the main reason of the difference, because the image part of measured impedance grows much faster than the image part of theory impedance.

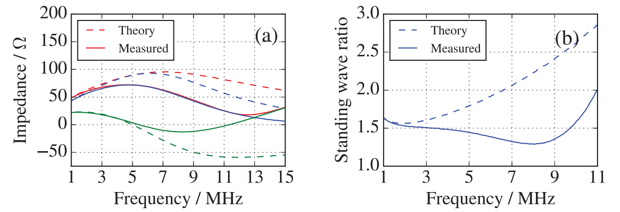

Figure 5: Imedance and standing wave ratio measured through the couple loop. In (a), the blue, green and red lines indicate the real part, image part and absolute value of complex impedance, the dashed lines stand for theory result, the solid lines stand for measured result.

RESULTS OF HIGH POWER TEST

We have carried some high power experiments to test the shunt impedance of MA core under strong field and high temperature. The shunt impedance of MA core is estimated by

$$R_p = \frac{V_C^2}{2P_{\text{in}}} \tag{3}$$

where V_C is the voltage across the capacitance, P_{in} is the input power from amplifier. A thermal camera is used to monitor the temperature distribution on the surface of MA core.

Instantaneous Experiment

The shunt impedance under strong field is evaluated through instantaneous experiment. The input power is ON only for a short time to avoid significant temperature rise. The test result is shown in Fig. 6. The maximum input power reaches about 2000 W, correspond to a average energy density of 1.4 W/cc. For both types of MA core, there is no sign shows the shunt impedance will decrease until this energy density.

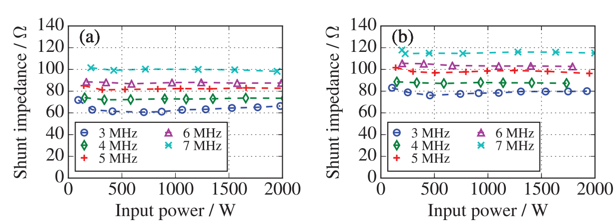

Figure 6: Shunt impedance of large size MA core under different input power, (a) Type A, (b) Type B.

Continuous Experiment

The MA cores are coupled with continuous 3 MHz RF power without special cooling to test their shunt impedance under high temperature.

For type A core, local damage happened when the input power is 800 W and the maximum surface temperature

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reaches 240 °C. The measured shunt impedance decrease slightly as shown in Fig. 7. There is epoxy resin leaking outside the core in some spots (see Fig. 8). The spots locate at the splints used to support the core which have made the heat dissipation more difficult. The local temperature should be higher than 240 °C that can not be observed by thermal camera. After the damage happened, we conducted high power test with input power of 300 W and 500 W. The measured shunt impedance reaches a balanced value after the temperature is stable and does not behave significant decrease compared with instantaneous test result. Local epoxy resin leakage seems not causing serious problem for the shunt impedance.

Figure 8: Local damage of type A MA core.

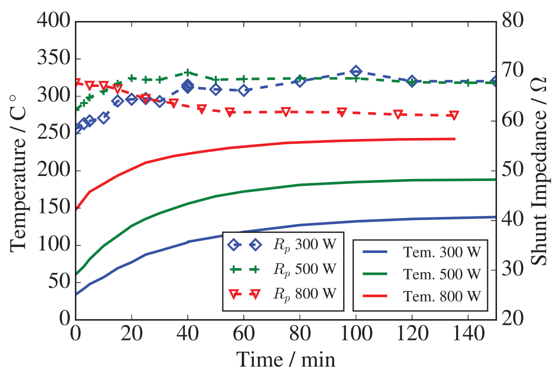

Figure 7: Long time high power test result of type A core. The 300 W and 500 W tests are conducted after 800 W test.

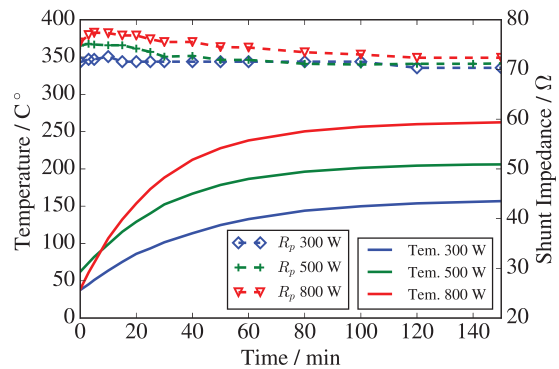

Figure 9: Long time high power test result of type B core.

For type B core, there is also damage when input power reaches 800 W, but no shunt impedance decrease as shown in Fig. 9. The damage way is different from type A core. There is local swell under the splint (see Fig. 10). The swell disappears after the core gets cooled. Under same input power, type B core's maximum surface temperature is a little higher than type B core's. We think this is due to the worse thermal conductivity of silica gel than epoxy resin.

Figure 10: Local damage of type B MA core.

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SUMMARY

Two types of large size MA core have been tested for XiPAF's MA loaded cavity project. Cold test shows the performance of 1K107 and FT-3M material are similar. Instantaneous high power test shows both type of MA core can sustain a average energy density of about 1.4 W/cc. In long time high power experiment, high temperature has caused local epoxy resin leakage for type A core (~240 °C) and slight shunt impedance decrease. For type B core, there is local swell under temperature ~260 °C, but no significant shunt impedance decrease. It seems that the difference comes from the material used for solidification.Silica gel has worse thermal conductivity, but it is more stable than epoxy resin under high temperature.

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