SIMULATION OF A NEW BEAM CURRENT MONITOR UNDER HEAVY HEAT LOAD*

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Abstract

At the Paul Scherrer Institute (PSI), the High Intensity Proton Accelerator (HIPA) feeds a pion and muon source target with protons. A beam current monitor, called MHC5, installed 8 meters downstream from the target is heated by the scattered particles from the target. This thermal load on the monitor causes the resonance frequency to drift much more than expected.

A novel new beam current monitor using graphite has been developed. In order to have a good understanding of its performance, the simulation software ANSYS has been used to carry out thermal and high frequency simulations. With this software, it was possible to perform a detailed design of the thermal self-compensation scheme and to check the structural stability of the whole system. In this paper, simulation results show that frequency drift can be reduced to only 8 kHz from previous 730 kHz when expected operating conditions are assumed.

INTRODUCTION

The proton beam current monitor, MHC5, has been operated for several years in the PSI 590 MeV proton cyclotron. The scattered particles and their secondaries from the target 8 meters upstream cause the resonance frequency of the current monitor to drift due to radiation heating. The originally designed MHC5 made of aluminium showed its operational limits with the increased beam intensity of the last few years. A newer version presently in operation still has large system gain variations caused by the frequency drift even with an active cooling system [1, 2].

To have a good understanding of the MHC5 performance and its limitations, simulations for an old prototype and for the MHC5 version in operation have been carried out using ANSYS.

FUNDAMENTAL BEHAVIOUR OF THE MONITOR

The MHC5 is a coaxial resonator tuned at 101.26 MHz, the 2nd harmonic of the proton beam pulse frequency. The size of the capacity gap, as shown the red ellipse in Figure 1, is a critical parameter influence the resonance frequency. Figure 2 shows the relationship between the size of capacity gap and the resonance frequency of MHC5. As the capacity gap increases, the resonance frequency of the monitor is increasing non-linearly.

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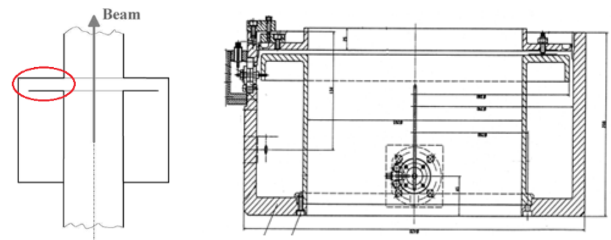

Figure 1: Schematic (left) and section view (right) of the MHC5.

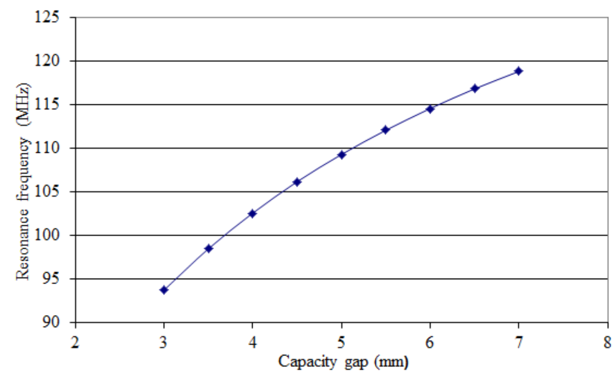

Figure 2: Resonance frequency changing with capacity gap.

Scattered particles from the target deposited on the MHC5 heat up the monitor and provoke frequency drift. Figure 3 shows the resonance frequency drift with increasing temperature on the monitor.

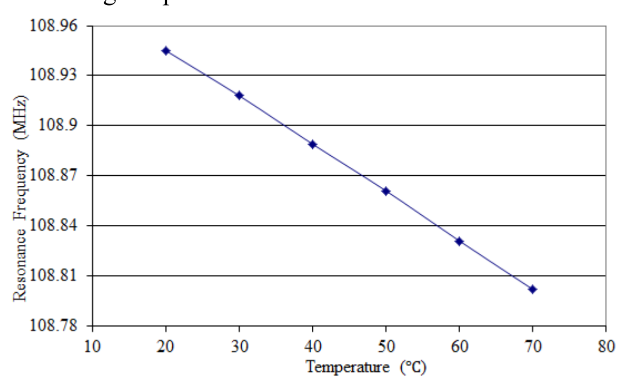

Figure 3: Resonance frequency drifting trend.

The monitor needed to be divided to 7 segments in simulation, since the distribution of the scattered particles is Gaussian in transverse plane, which means each segment has different power deposition.

VALIDATION WITH PROTOTYPE

In order to validate the simulation results, a cross check between simulation and experiment is necessary. An old

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prototype made of aluminium was used to carry out some laboratory tests.

An old prototype was put into a climate chamber and heated from 20 ºC to 60 ºC. Figure 4 shows the frequency drift of the prototype was 24 kHz/10 ºC. A 2D model was set up in simulation. The frequency drift is 24.5 kHz/10 ºC in simulation. With the thermal expansion as shown in Figure 5, the diameter increased 0.394 mm and the height increased 0.197 mm, which show good agreement with the experiment results in Table 1.

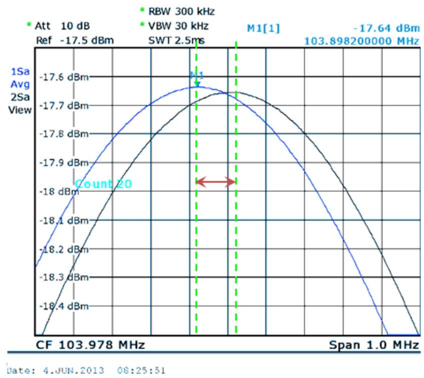

Figure 4: Sensitivity curves from 20 ºC (black) to 60 ºC (blue).

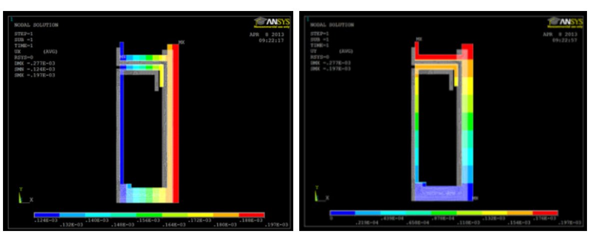

Figure 5: Simulations of the thermal expansion of the diameter (left) and the height (right).

Table 1 Measured and simulated thermal expansion for a temperature increase from 20 ºC to 60 ºC

	Measured	Simulated
Height (mm)	0.2	0.197
Diameter (mm)	0.4	0.394

SIMULATION AND VALIDATION WITH THE EXISTING OPERATIONAL MONITOR

Simulation

The MHC5 presently in operation is made of aluminium as well. Compared to the old prototype the present monitor has a water pipe mounted on the beam entry side to provide an active cooling. A 3D model was set up, as shown in Figure 6.

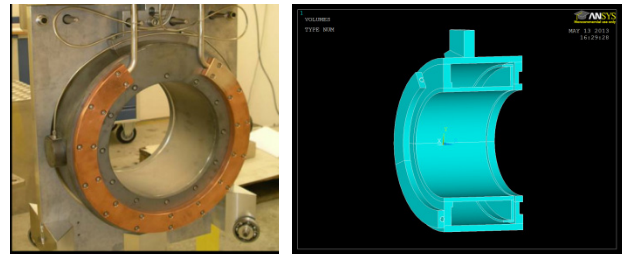

Figure 6: The MHC5 in operation, the water cooling pipe at the beam entry side (left), 3D model setup (right).

Normally the cooling efficiency will be increasing with the water velocity increasing. But once the turbulence is fully developed, the improvement of the cooling efficiency with increasing water inlet speed is marginal. Different water velocity was applied and the simulation results show in Figure 7. When the velocity of the water ups to 2 m/s, there is no significant improvement of the cooling efficiency to be expected, just as earlier simulation shows [3].

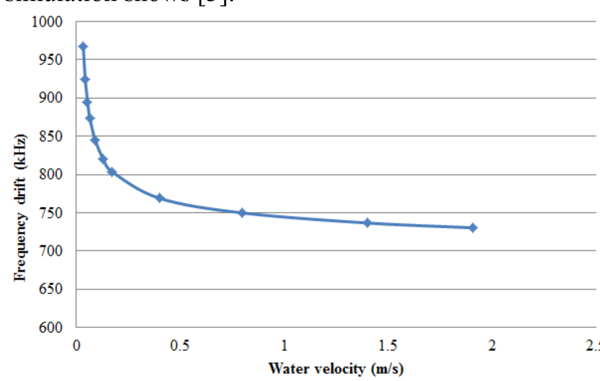

Figure 7: Frequency drifts dependent water velocity.

Validation

The temperature of the monitor presently in operation can be controlled by modulating the cooling water speed using a valve. In the routine operation the velocity of the cooling water is 1.91 m/s, the temperature of the water is around 48 ºC. Through simulation the frequency drift of the MHC5 in operation is 730 kHz when 3 mA proton beams is applied.

The resonance frequency was measured with two different cooling water speeds, as shown in Figure 8, the blue line is the sensitive curve under 51.8 ºC and the green line is under 74.1 ºC. From this figure the frequency drifts between 51.8 ºC and 74.1 ºC can be estimated around 100 kHz. Table 2 compares the results from experiment and simulation.

Table 2 Frequency drifts comparison

	Temperature	Frequency drift
Experiment	51.8 ~ 74.1 ºC	~ 100 kHz
Simulation	52 ~ 74.1 ºC	~ 110 kHz

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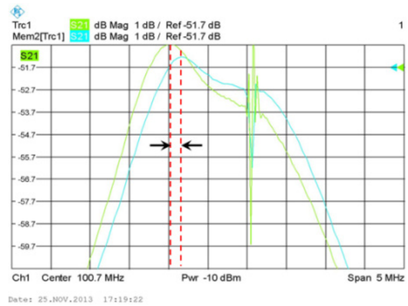

Figure 8: Sensitivity curves from measurement. The blue curve is for 51.8 ºC, the green curve is for 74.1 ºC.

DESIGN OPTIMIZATION

Through the simulations described before, the origin of frequency drift is caused by the thermal expansion and the thermal gradient between inner parts and outer parts. Graphite is proposed instead of aluminium to make the new monitor, since it has a lower thermal expansion coefficient and a very high emissivity. As a result, the active cooling is no more required and the thermal gradient can also be strongly reduced.

Improvement in Geometry

A simplified model of graphite without the water cooling pipe is shown in Figure 9. The power deposition in this structure is 400 W [4].

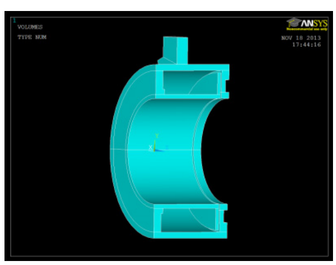

Figure 9: Simplified model without water pipe.

In order to decrease the power deposition, the inner diameter of the MHC5 is increased from 255 mm to 280 mm, the corresponding power deposition is decreased from 400 W down to 169 W. But the capacity gap has to be reduced from 4.5mm to 2.5mm to keep the same resonance frequency. This makes the manufacture more difficult, since the resonance frequency is very sensitive to the size of the capacity gap.

Improvement and Compensation of the Capacity Gap

To relax the mechanical tolerance, ceramic is used to fill partially the capacity gap. Since the capacity between two plates is directly proportional to the permittivity ε of the material filling the gap, a larger permittivity (typically 10) allows a larger the capacity gap.

A 6.1 mm thick ceramic ring can be inserted between the capacitor plates and to give the same resonance frequency.

In addition, a 2 mm thick aluminium shim is used to compensate the capacitance increase due to the thermal expansion. The shim is placed so that its thermal expansion leads to an increase of the capacitor gap. The thermal expansion coefficient of aluminium is about 8 times higher than graphite so by calculating the thickness of the shim proportionally, the capacitance can be kept approximately constant.

Figure 10 shows the final design of the new MHC5. The frequency drift of this model under 3 mA proton beams is only 8 kHz in simulation, much lower than the unit in operation.

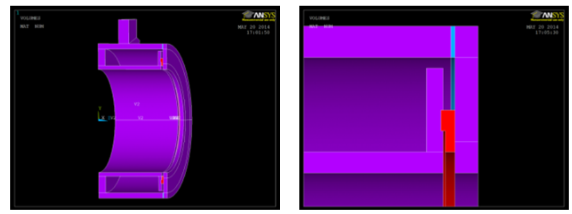

Figure 10: Final design of the new MHC5 with aluminium shim and ceramic ring.

Tuning Method

Eight M20 size screws are distributed on the beam exit side for the fine tuning, as shown in Figure 11. The tuning capability of these screws is [0, -2.2 MHz].

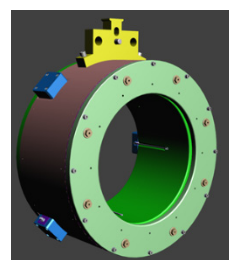

Figure 11: Eight screws for fine tuning on the beam exit side.

CONCLUSION

Simulation study has been carried out for the design of a new current monitor. First the simulation has been validated by comparing experimental and simulated results using existing current monitor. The simulation has then been used to test the design and the improvements of the new current monitor. According to these simulations, the frequency drifts of the new design can be ideally reduced to 8 kHz from the previous value of 730 kHz.

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