IMPEDANCE STUDIES FOR VMTSA MODULE OF LHC EQUIPPED WITH RF FINGERS

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Abstract

During the 2011 LHC run it was found that beam-induced heating causes many issues for accelerator components. Particularly some of the double-bellow modules, called VMTSA modules, were found to have deformed RF fingers and a broken spring, which had ensured good contact between them and a central insert. Impedance studies have been performed for different types of nonconformities. It was found that even a small gap between the fingers and a central insert could be fatal for the VMTSA operation. Results of this study were an input for the further thermal analysis.

INTRODUCTION

Beam-induced heating has been observed in several accelerator components during the 2011 LHC run. In particular eight bellows, out of the ten double-bellows modules (called VMTSA) present in the machine, were found with the spring, which should keep the RF fingers in good electrical contact with the central insert, broken, see Fig. 1. Sliding contacts in these modules were designed to allow a lateral movement of several millimetres for the nearby two-beam collimators.

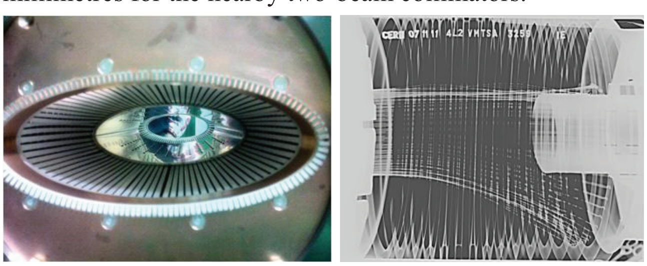

Figure 1: Conforming RF fingers as installed in the VMTSA module (view from beam-pipe at left) and X-ray image of the deformed fingers (right).

In 2012 all the VMTSA's have been replaced with the ones equipped with shorter RF fingers (see Fig. 2) and there are plans to remove all of them after the LHC long shutdown in 2013-2014 along with the 2 beam collimators. At the same time the LHC RF fingers task-force has been established to review the design of all components of the LHC equipped with RF fingers [1]. In particular, as the follow-up to the VMTSA issues, impedance studies presented in this paper have been performed for the module.

GEOMETRY AND 3D MODEL

Simplified VMTSA models have been recreated in CST [2] based on the mechanical drawings for the old (longer) and new (shorter) RF fingers, see Fig. 2.

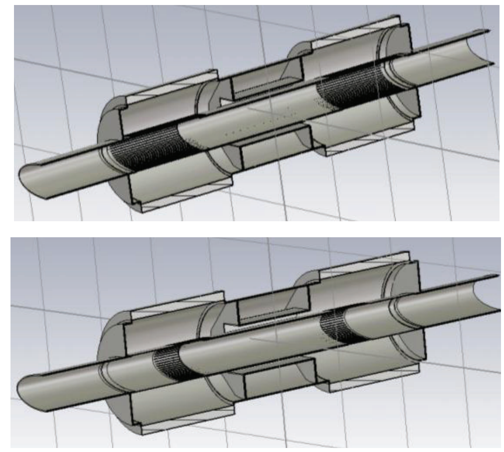

Figure 2: Longitudinal sections of the VMTSA module equipped with the longer RF fingers (top) and shorter RF fingers (bottom). Conforming case.

There are many different ways to model loss of a contact between the finger and a central insert. A quick way to do that was a slight deformation of the bottom part of the elliptical beam-pipe so that the attached fingers do not touch the central insert anymore, see Fig. 3 bottom. A more advanced way is to introduce a gap rotating each finger separately around the edge, see Fig. 3 top, so that the gap size and shape are comparable with what we could see on the X-ray image in Fig. 1.

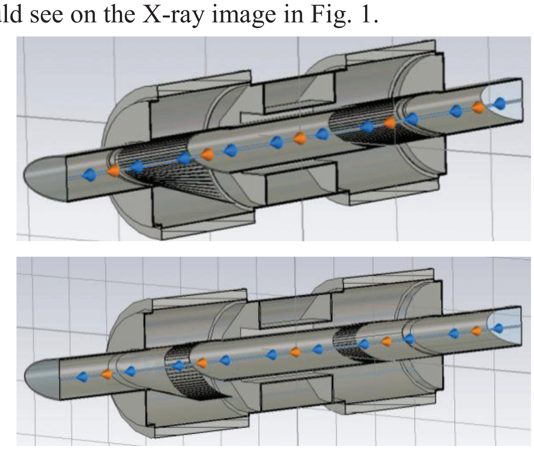

Figure 3: Longitudinal sections of the VMTSA module equipped with the longer RF fingers (top) and shorter RF fingers (bottom). Loss of contact.

TIME DOMAIN SIMULATIONS

CST Particle Studio [2] was used to perform simulations in time domain. Since we're mostly interested in the power losses in the module we set a magnetic

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boundary condition on the symmetry plane, open boundary at the both ends of the beam-pipe and finite conductivity condition (copper) for the outer walls, see Fig. 4. We also set up a particle source exactly in the middle of the beam-pipe.

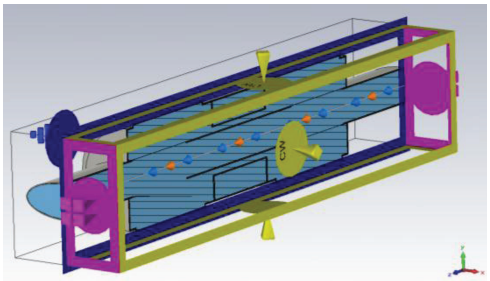

Figure 4: Time domain simulation setup of VMTSA equipped with the longer deformed RF fingers.

Results of the simulations are presented in Figs. 5 and 6. It is demonstrated that conforming longer RF fingers have almost no impedance for the beam while the gap of 30 mm introduces several dangerous modes below 1.5 GHz.

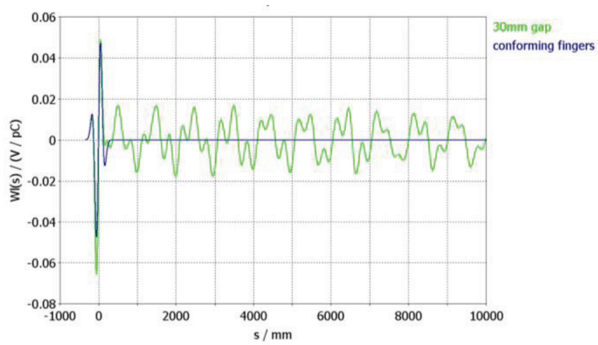

Figure 5: Longitudinal wake potential for conforming fingers (blue) and 30mm deformation (green).

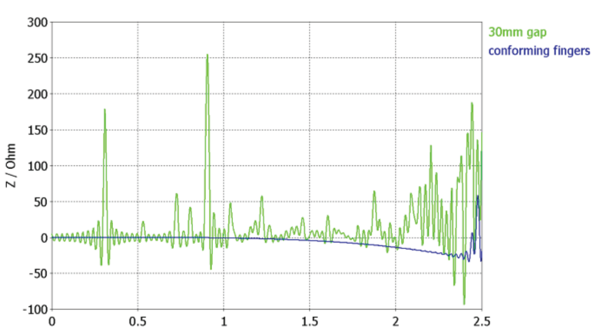

Figure 6: Longitudinal wake impedance for conforming fingers (blue) and 30mm deformation (green).

In order to calculate the power losses coming from the modes a dedicated impedance study has been performed in the frequency domain and the formula presented in the next section has been used.

POWER LOSS CALCULATION

Based on the general formula from [3] we derived the one for a sharp resonance [4] to estimate the power losses:

$$P_{loss}(f_r) = (MN_b e f_{rev})^2 * 2R_l * 10^{\frac{P_{dB}(f_r)}{10}} \qquad (1)$$

where f_r – resonance frequency, M – number of bunches in the LHC ring, N_b – bunch population, f_{rev} – revolution frequency, R_l – longitudinal shunt impedance of the structure, P_{dB} – measured bunch power spectrum. It should be mentioned here that the spectrum changes significantly from beam 1 to beam 2, from fill to fill and also during a fill, so we consider a bunch power spectrum which is shown below in Fig. 7 just as a typical option.

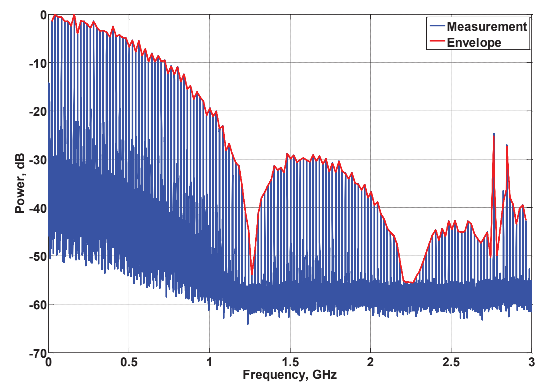

Figure 7: Example of power spectrum measured in LHC in 2012.

The 20 MHz distance between the coupled bunch lines (blue spikes in Fig. 7) is determined by the 50 ns bunch spacing in the beam. Calculating the power losses by means of (1) red envelope from Fig. 7 is used so that considering the worst case we don't underestimate the power spectrum.

FREQUENCY DOMAIN SIMULATIONS

To calculate eigenmodes, corresponding *Q*-factors and shunt impedances HFSS Eigensolver [5] and CST Microwave Studio [2] are used.

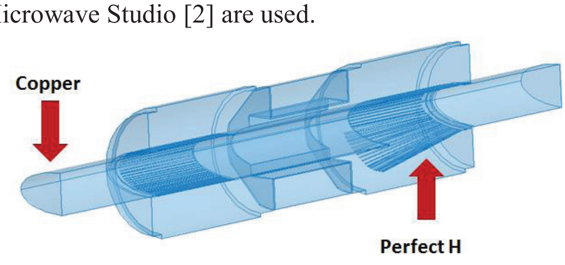

Figure 8: HFSS eigenmode simulation setup.

We simulate ½ of the VMTSA module applying a magnetic boundary condition on the longitudinal section and specifying a copper outer boundary, see Fig. 8.

The case of the conforming long RF fingers was studied at first. No modes which could deposit significant amount of power were identified, see Table 1.

Table 1: Eigenmodes of VMTSA Equipped with the Conforming Long RF Fingers.

Mode	Frequency [MHz]	Q-factor	Shunt Impedance [Ω]	Power Loss [W]
1	550	7640	0.24	0.01
2	550	7660	0.003	~0
3	753	5290	6.2	0.08
4	753	5280	7	0.1

For a gap of 40 mm, comparable with what has been identified by the X-rays scan in Fig. 1 (right), the power losses became significantly larger, see Table 2.

Table 2: Eigenmodes of VMTSA Equipped with the Longer RF Fingers and 40mm Gap

Mode	Frequency [MHz]	Q-factor	Shunt Impedance [Ω]	Power Loss [W]
1	279	455	10050.5	652.8
2	342	211	192.6	12.5
3	370	163	7.5	0.6
4	383	134	1.7	0.1
5	390	114	0.6	0.04

Electric field distribution and a surface loss density is illustrated in Fig. 9 for the most dangerous mode identified at 279 MHz.

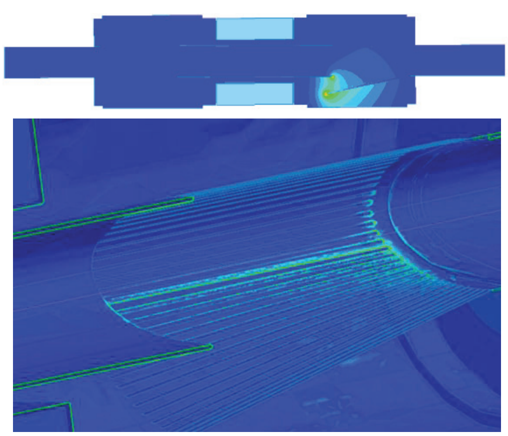

Figure 9: Electric field distribution in VMTSA (top) and surface loss density (bottom, log scale) on the longer fingers for the eigenmode at 279 MHz and 40mm gap.

Dedicated simulation studies and measurements for a wire excitation in VMTSA have also confirmed an existence of the dangerous mode around 300 MHz [6].

Different gap sizes have also been studied for the case of the short RF Fingers and the summary is presented in Fig. 10. It can clearly be seen that even a small gap of 0.5 mm could result in the kW losses and be fatal [7] for the VMTSA operation since this device has no active cooling attached.

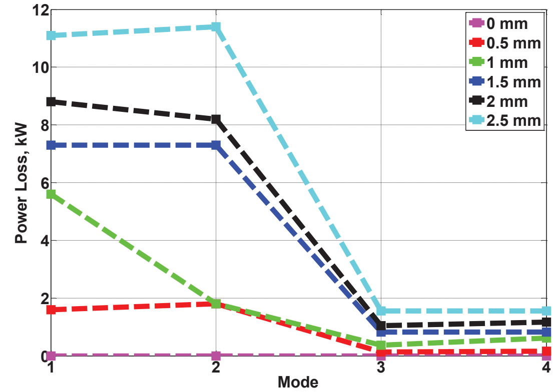

Figure 10: Power loss dependence on the gap size for the the VMTSA module equipped with the short RF fingers.

A possibility to install Philips 8C11 ferrites [8] on the entry and exit plates of the bellow to damp the modes caused by the loss of contact has also been considered in [7]. It was found however that in this position they do not affect the gap modes and therefore do not provide any beneficial effect.

CONCLUSIONS

Time and frequency domain impedance studies have been accomplished for the VMTSA module equipped with RF fingers. It was found that even a small gap of 0.5 mm could lead to huge power losses which then are all concentrated on the fingers and could lead to the device failure. Ferrites might be used as a backup solution to damp the modes caused by the gap, however a dedicated electromagnetic study is required to identify the optimal location.

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