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LONGITUDINAL WAKEFIELD STUDY IN SLAC ROTATABLE COLLIMATOR DESIGN FOR THE LHC PHASE II UPGRADE

L. Xiao, S. Lundgren, T. Markiewicz, C. Ng, J. Smith, SLAC, Menlo Park, CA 94025, U.S.A.

Abstract

SLAC proposed a rotatable collimator design for the LHC Phase II collimation upgrade. There are 20 facet faces on each cylindrical jaw surface and two jaws are rotatable in order to introduce a clean surface in case of a beam hitting a jaw during operation. When the beam crosses the collimator, it will excite broad-band and narrow-band modes. The longitudinal modes can contribute to beam energy loss and power dissipation on the vacuum chamber wall. In this paper, the parallel finite element eigensolver Omega3P is used to search for all the longitudinal trapped modes in the SLAC collimator design. The power dissipation generated by the beam in collimators with different vacuum chamber and RF contact designs is discussed. It is found that a wider RF foil connecting the jaw and the vacuum flange can reduce efficiently the beam heating caused by the longitudinal modes.

SLAC ROTATABLE COLLIMATOR

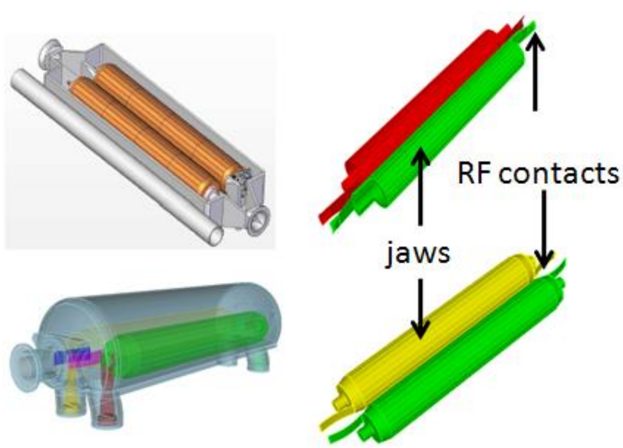

Figure 1: 3D solid models (top/bottom left) and rotatable jaws with RF contacts (top/bottom right) for SLAC previous/current collimator designs.

The LHC Phase II upgrade requires a robust collimator design that can absorb high heating power and is recoverable from an accident scenario during operation. The SLAC rotatable collimator design as shown in Figure 1 is one of the options under consideration for the upgrade through the US LHC accelerator research program (LARP) [1].

The rectangular vacuum chamber collimator design was first proposed for the LHC operation. The RF contacts are 250 micron thick beryllium-copper sheets which connect the jaw end flat tapers with the vacuum flanges, providing a smooth geometrical transition and thus reducing beam impedance. There is a sliding contact between the rotating jaw and the fixed RF foil. The partial-circular vacuum chamber design with half-domed end plates is currently adopted for its easier fabrication and better vacuum pumping. The simple EM foils are used to connect the jaws and the vacuum flanges without the taper transitions.

For both designs, there are 20 facet faces on each cylindrical jaw surface and the two jaws are rotatable and will move in and out during operating.

In the SLAC rotatable collimator design, the beam can excite significantly trapped modes in the vacuum chamber. The longitudinal trapped modes cause power heating which might dissipate at unwanted locations such as the RF foils. In this paper, we will focus on the longitudinal trapped mode heating study by using the parallel finite-element eigensolver Omega3P [2]. The effects of different vacuum chamber and transition part designs on the longitudinal trapped mode impedances are discussed in the following sections.

PREVIOUS COLLIMATOR DESIGN

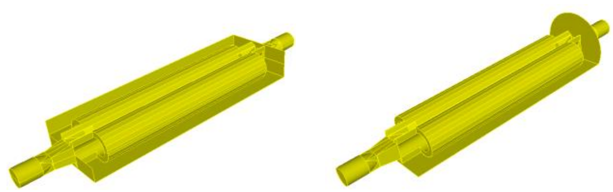

Figure 2: Rectangular (left) and partial-circular (right) vacuum chamber collimator simulation models with the previous jaw end and RF contact designs.

The major differences between the previous and current designs are the vacuum chamber cross sections and transition pieces. In this section, the collimators with the previous jaw ends and RF contacts but different vacuum chamber designs as shown in Figure 2 are investigated for studying the effect of vacuum chamber shape on the longitudinal trapped mode impedances. For the LHC operation, the jaws opening is 2mm and 42mm for fully inserted and fully retracted jaws, respectively. The beam pipe radius is 42mm.

Due to symmetry of the collimators, only a quarter and half of the structures are used to simulate the rectangular and partial-circular vacuum chamber collimators, respectively. Setting magnetic boundary conditions at the symmetry planes, longitudinal trapped modes with Ez components on the beam axis are determined using Omega3P. The mode RF parameters are plotted in Figure 3 assuming the vacuum wall being made of stainless steel and the jaws of copper in the SLAC rotatable collimator design.

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In Figure 3, the left plot shows that the longitudinal trapped mode R/Q's in the two vacuum chamber designs are similar for the same jaws opening. But the longitudinal trapped modes have higher R/Q's for fully retracted jaws than for fully inserted jaws. The right plot shows that the longitudinal trapped modes have higher Qs in the partial-circular vacuum chamber design than in the rectangular one. However, the jaws opening does not affect the mode Qs much. In the rectangular vacuum chamber design, the most dangerous mode is localized between the jaws and between the jaw surface and the chamber wall, which has lower Q [3]. In the partial-circular vacuum chamber design, the dangerous mode is localized between the jaw surface and base plate as well as spreads around the jaws as shown in Figure 4. The mode is cavity-like and has higher Q.

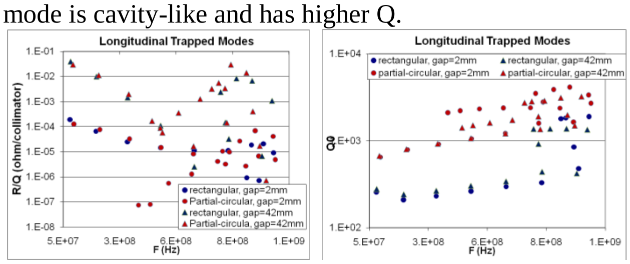

Figure 3: Longitudinal trapped mode R/Q's (left) and Qs (right) with the previous jaw end and RF contact designs in the different vacuum chamber collimators.

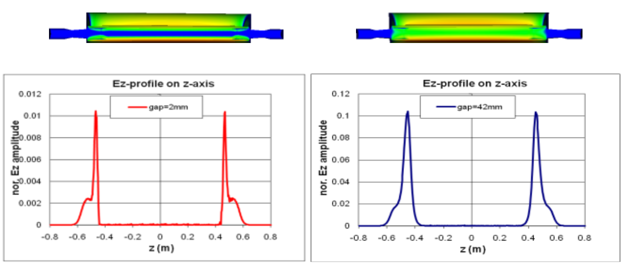

Figure 4: Lowest longitudinal trapped mode E-fields and Ez-profiles along the z-axis for fully inserted jaws (top/bottom left) and fully retracted jaws (top/bottom right) in partial-circular vacuum chamber collimator.

The Ez-components of these modes concentrate in the transition regions as shown in Figure 4. With larger jaws opening, there are more Ez-fields in the transition regions and thus the modes have larger R/Q's.

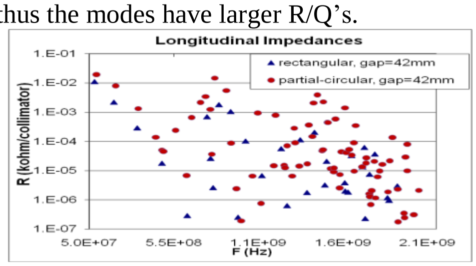

Figure 5: The longitudinal trapped mode impedances for fully retracted jaws in rectangular and partial-circular vacuum chamber collimator designs with previous jaw end and RF contact designs. Form-factors for the beam spectrum are included using 7.55cm bunch length.

The maximum longitudinal trapped mode impedances up to 2GHz are plotted in Figure 5. The excited wakefields with spectral components above 2GHz are negligible for the LHC long bunches. In the SLAC rotatable collimator design, the dangerous longitudinal mode shunt impedance is less than 20Ω which is similar to the CERN Phase I collimator design [4] [5], and is within the longitudinal impedance budget. The beam heating of this mode is also acceptable.

CURRENT COLLIMATOR DESIGN

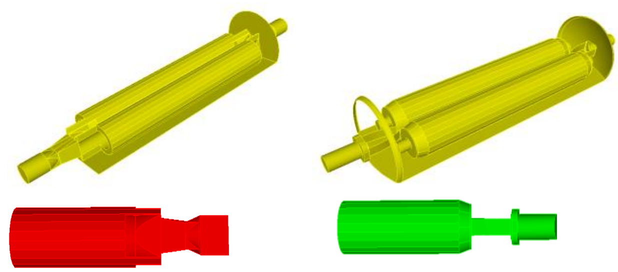

Figure 6: EM simulation models for the partial-circular vacuum chamber collimator with previous (top/bottom right) and current (top/bottom right) jaw end and RF contact designs.

The current collimator design is scheduled to be installed and tested in the SPS in 2010. For the SPS testing, the jaws opening is 2mm and 60mm for fully inserted and fully retracted jaws, respectively. The beam pipe radius is 30.5mm. In the current design, the transition pieces are simplified without the tapers.

Both the previous and current transition designs with the similar partial-circular vacuum chambers are shown in Figure 6. The longitudinal trapped mode results in these two designs are plotted in Figure 7 for fully inserted jaws with 2mm jaws opening.

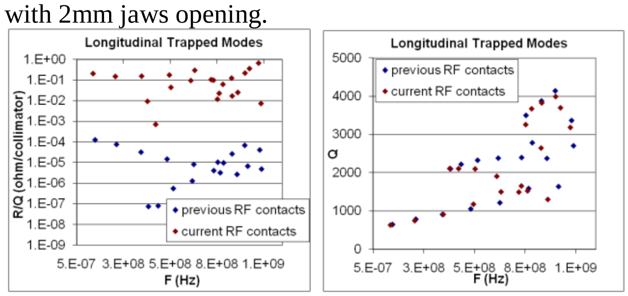

Figure 7: Longitudinal trapped mode R/Q's (left) and Qs (right) in the partial-circular vacuum chamber collimators with different RF contact designs.

As shown in Figure 7, the longitudinal trapped modes in both designs have similar Qs because of their similar vacuum chambers. The transition pieces do not affect the mode Qs very much. However, the longitudinal trapped modes have much larger R/Q's using the current RF contact design than the previous one.

Figure 8 illustrates the Ez-profiles for the lowest trapped modes in the two designs. For fully inserted jaws, the maximum Ez amplitude is two orders of magnitude higher using the current transition design than that of the previous one. The reason is that the mode fields can pass through the narrow region between the EM foils and thus cause stronger Ez components on the beam axis.

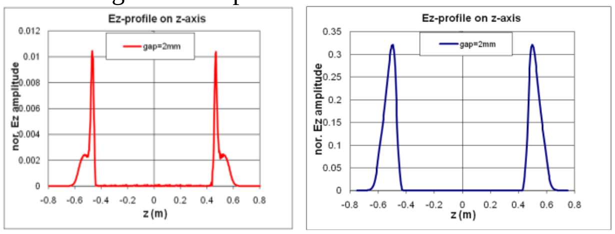

Figure 8: Lowest longitudinal trapped mode Ez-profiles along the z-axis using the previous (left) and the current (right) transition designs.

FINAL COLLIMATOR PROTOTYPE

As we have known that the dangerous longitudinal trapped mode concentrates in the transition regions. Reducing the distance between the EM foils as well as increasing their widths can suppress the RF fields in the transition regions along the beam path. The RF contacts are modified in the final collimator design as shown in Figure 9 [6]. The maximum shunt impedance in the final prototype is less than 10Ω/collimator and the collimator can be used for the LHC operation.

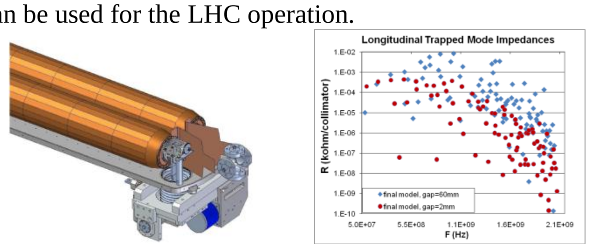

Figure 9: Final collimator (left) and the longitudinal trapped mode impedances (right).

There are two kinds of heating effects, transient and resonant. The transient heating effect normally causes no problem for structures with good thermal conduction [3]. The resonant heating happens in the worst case that all bunches are in phase with all these trapped modes. The heating power transferred by the beam into these trapped modes is

$$P = I^2 \sum (\frac{R}{Q})_i e^{-\omega_i^2 \sigma^2 / c^2} * Q_i$$

Table 1: Maximum Trapped Mode Heating

< 2GHz	Max. Power at the worst case	Jaw gap=42mm	Jaw gap=60mm
Collimator for the LHC operation with previous transition design (I=0.582A)	Rectangular vacuum chamber	**6.7 W**	
	Partial-circular vacuum chamber	**38 W**	
Collimator for the SPS testing with current transition design (I=0.23A)	Partial-circular vacuum with narrow EM foils		**127 W**
Final collimator design (I=0.582A)	Partial-circular vacuum with wider EM foils	**< 25 W**	**25 W**

Table 1 lists the maximum trapped mode heating power on the vacuum chamber walls of different designs. The power heating in the final collimator prototype for the LHC normal operation is acceptable.

SUMMARY

We have investigated the longitudinal trapped modes in the SLAC rotatable collimators with different vacuum chambers and transition designs. We found that the vacuum chamber shape can affect the longitudinal mode Qs, and the transition piece can change the longitudinal mode R/Q's. The most dangerous longitudinal mode has its fields concentrated in the jaw transition region. With wider EM foils, the longitudinal trapped mode impedances in the final SLAC rotatable collimator design are within the impedance budget for the LHC operation.

The transverse modes can cause coupled bunch instability. The study of the transverse trapped modes is underway.

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REFERENCES

[1] Smith, J. *et al.*, "Design of a Rotatable Copper Collimator for the LHC Phase II Collimation Upgrade", Proceedings of EPAC08, MOPC096, (2008).

[2] Lie-Quan Lee, *et al.*, "Omega3P: A Parallel Finite-Element Eigenmode Analysis Code for Accelerator Cavities, SLAC-PUB-13529, (2009).

[3] Liling Xiao, *et al*., "Trapped Modes Study for a Rotatable Collimator Design for the LHC Upgrade", Proceedings of EPAC08, TH5PFP089, (2008)

[4] A. Grudiev, "Simulation of Longitudinal and Transverse Impedance of Trapped Modes in LHC Secondary Collimator", AB-Note-2005-042 RF, CERN

[5] Sergio Calatroni, *et al.*, "RF contacts for the LHC collimators", NIM,A 566 (2006) 205-211

[6] Smith, J. *et al*., "Construction and Bench Testing of a Rotatable Collimator for the LHC Collimation Upgrade", Proceedings of IPAC10 TUPEB078 (2010)