

NEW METHOD FOR VALIDATION OF APERTURE MARGINS IN THE LHC TRIPLET*

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Abstract

Safety of LHC equipment including superconducting magnets depends not only on the proper functioning of the systems for machine protection, but also on the accurate adjustment of the protective devices such as collimators. In case of a failure of the extraction kicker magnets, which are part of the beam dumping system, it is important to ensure protection of the superconducting triplet magnets from missteered beam. The magnets are located to the right of Interaction Point 5 (IP5) and are protected by one set of collimators in the beam dumping insertion in IR6 and another set close to the triplet magnets. In this paper, a new method for verification of the correct collimator position with respect to the aperture is presented. It comprises the application of an extended orbit bump with identical trajectory as the beam trajectory after a deflection by the beam dump kickers. By further increasing the bump amplitude and successively moving in/out the collimators in the region of interest, the accurate positioning of the collimators can be validated. The effectiveness of the method for LHC IP5 and IP1 and both beams is discussed.

INTRODUCTION

Missteered beams could put in danger accelerator equipment by creating losses at unexpected locations, which could lead to quenches of the superconducting components or damage of the exposed parts in case of larger beam losses. One of the reasons for missteered beam in the LHC is the firing of all the 15 modules of the extraction kicker (MKD) non-synchronously with the abort gap [1]. In this case individual bunches will experience a kick of lower amplitude then needed to direct the beam into the beam dump channel. Missteered bunches should be intercepted by the TCDQ-TCSG assembly [2]. If this fails, the TCT collimators should intercept the beam. Figure 1 presents the collimators between the MKD and the triplet (MQX) as seen by Beam 2. However, if these collimators are not properly aligned other equipment will be in danger, depending on the optics, i.e. phase advance from the MKD. Asynchronous dumps are expected to occur at least once per year.

Such missteered clockwise (Beam 1) and counter-clockwise (Beam 2) beams might be harmful for the triplets in the interaction points IP1 and IP5, respectively. Checking the aperture margins is of particular relevance when operating with the collision optics and the ATS (Achromatic Telescopic Squeeze) beam optics [3], because in these cases the respective triplets will be the aperture bottlenecks if the collimators are not set properly.

For this reason it is crucial to assure the proper settings of collimators around the triplets that are also at risk in case of asynchronous beam dumps together with a wrong setting of other protection devices. This paper suggests an alternative method of checking the aperture margins of the collimators and the triplets.

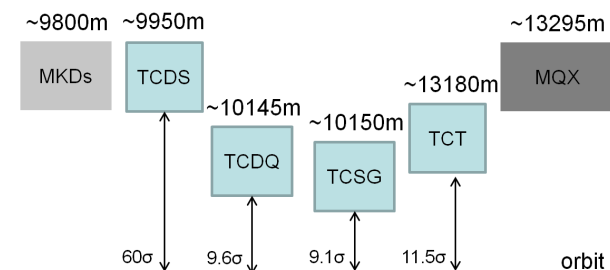


Figure 1: Scheme of collimators between the MKD and the MQX at IP5 [4] for Beam 2 (the zero of the coordinate system is at IP1). The longitudinal location of the component is shown (above) together with the retraction (below, expressed in beam σ -units) from the reference orbit.

METHOD

The proposed aperture-validation method is based on the fact that the beam trajectory of missteered beam can be reproduced by creating a 4-corrector orbit bump. The present study is devoted to the validation of the aperture margins around the MQX; therefore the global orbit bump is established around it. For beam 2, the bump starts before the MKD and closes after the IP5. Figure 2 shows a comparison of a trajectory of missteered beam and an orbit bump, corresponding to $1 \mu\text{rad}$ deflection angle at the MKD, calculated with ATS optics. The maximum of the orbit bump in both collision and ATS optics is observed in the triplet, for injection optics this is not the case.

The experimental measurements could be performed in two different ways: (1) by moving out the collimators, (2) by moving them in. For both approaches it is important to know the beam size, e.g. to cut the tails of the beam using primary collimators (TCP) in Sector 7.

The former approach starts with moving in the collimators to the initial positions. When increasing the amplitude of the bump one will start seeing losses by the Beam Loss Monitors (BLMs) at the TCDQ and the TCSG since their offsets from the centre of the vacuum chamber (in beam- σ units) are smaller than for the TCT. Knowing the beam size and the amplitude of the orbit bump (deflection angle at the MKD) it is possible to evaluate the offset of the collimators once the losses are registered. Before proceeding with the measurements of the aperture

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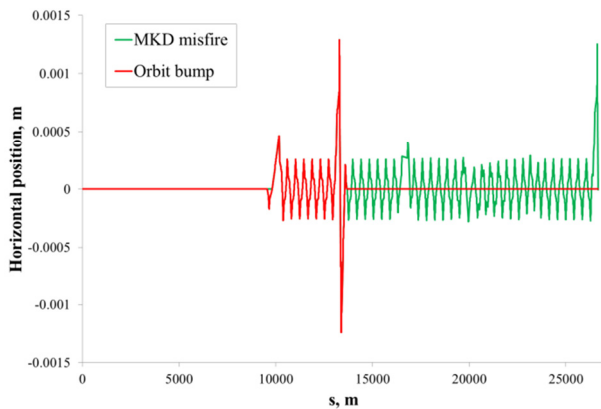


Figure 2: Comparison of the beam 2 trajectories calculated for ATS optics, in case of a MKD misfire giving $1 \mu\text{rad}$ deflection angle and in case of a 4-corrector orbit bump with respective amplitude.

in the TCT, the settings for the TCDQ and the TCSG will be recorded and both collimators put in parking position. The aperture in the TCT is measured the same way – by further increasing the bump amplitude and registering the losses. In this approach it is essential to slowly increase the orbit bump amplitude in order to reduce the uncertainties in measurements, which occur due to the scraping of the beam. Alternatively, the measurements could be done with two different bunches. In this case the first bunch is blown up and further scraped with the primary collimators to know its profile in σ -units. Then the measurements proceed as described above for the TCDQ and TCSG. For measuring the aperture in the TCT the other bunch should be blown up and scraped, respectively, when the two other collimators are at parking position.

The latter approach starts with all collimators in the parking positions. A bunch is blown up and scraped with the TCP to know its profile in σ -units, which will increase the precision of the further aperture measurements. Following this, the amplitude of the orbit bump is increased until the first losses are observed in the triplet; afterwards the amplitude of the bump is slightly decreased. The bunch should be blown up and scraped again in order to repopulate the tails that were cut by the triplet. After this the TCT is moved in until the losses are observed, this will indicate that the TCT has the same aperture (in σ) as the MQX. For setting the TCT at a certain offset, the bump amplitude should be decreased respectively, also taking into account the beam size. The TCT is moved in until the beam losses are observed by the BLMs, this indicates that the TCT is exactly at the desired offset. The bunch should be blown up and scraped with the TCP each time after the losses occur and the amplitude of the orbit bump is changed. Once the TCT is set in such a way that no losses are observed in the triplet, the adjustment of the TCDQ and TCSG are done in similar way: setting the bump amplitude to the desired offset minus the beam radius. Moving in the collimators and observing the BLM signals allows concluding that

they have certain retraction from the centre of the vacuum chamber.

RESULTS

The simulations were performed using MAD-X [5]. Beam 2 was tracked for one turn, starting at IP1 and going counter-clockwise. Normalized beam emittance was $3.5 \text{ mm}\cdot\text{mrad}$ at energy 7 TeV . The calculations were done with the ATS optics, and zero crossing angles at the experiments. The amplitudes of the orbit bump corresponded to MKD kick angles between 1 and $10 \mu\text{rad}$. A deflection of such small angles lets part of the beam pass through the first collimators without being fully intercepted, which happens at higher deflection angles.

The studies started with baseline configuration for 2015 [4]. The nominal settings are defined as following: TCDQ and TCSG retractions are 9.6σ , TCT retraction is 11.5σ . The distribution of lost particles at different MKD deflection angles for these settings is shown in Fig. 3. When the MKD deflects the beam by $1 \mu\text{rad}$ the beam is only partly lost in one turn and the losses are distributed between TCDQ and TCSG. When increasing the angle between 2 and $8 \mu\text{rad}$ the beam is fully lost in TCDQ, whereas further increase up to $10 \mu\text{rad}$ leads to the losses in TCDS, which is the absorber protecting the septum.

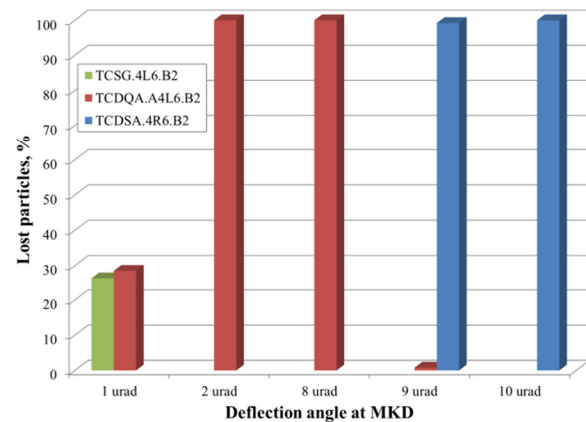


Figure 3: Losses in the TCSG, TCDQ and TCDS for different angles of MKD misfire in case of nominal settings of TCDQ/TCSG and TCT.

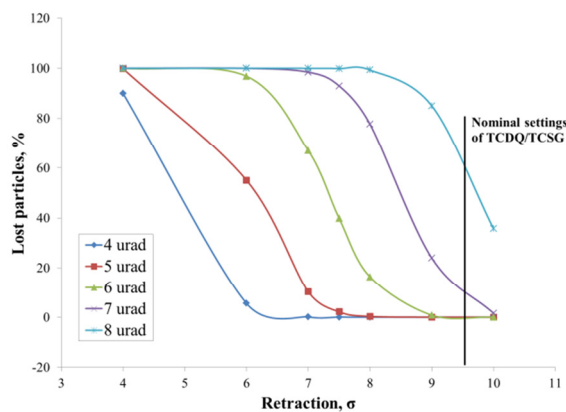


Figure 4: Losses in TCDQ for different angles of MKD mis-fire vs retraction of TCDQ/TCSG.

Different retractions of TCDQ, TCSG and TCT from the centre of the vacuum chamber were checked (TCDQ and TCSG were moved out simultaneously). The percent of circulating particles lost in TCDQ at different retraction settings is shown in Fig. 4 for different MKD-kick angles. The losses in the TCT as a function of the retraction of TCDQ/TCSG are shown in Fig. 5. For the beginning of the Run 2 the TCDQ and TCSG are both set to 9.6σ .

When moving out the TCT (with TCDQ and TCSG in parking position) and keeping the deflection angle small ($1\pm 10\mu\text{rad}$), the TCT stops intercepting the beam and the beam circulates further without being lost (Fig. 6).

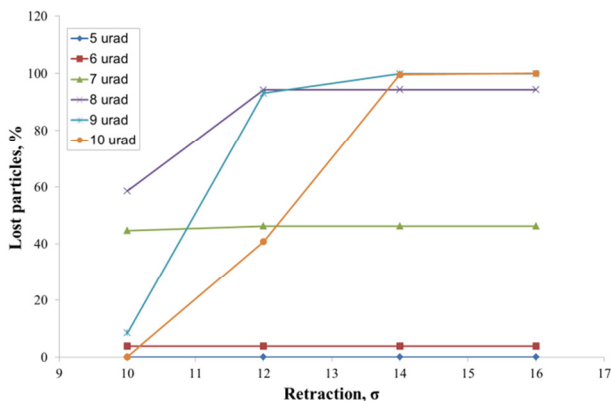


Figure 5: Losses in TCT for different angles of MKD mis-fire vs retraction of TCDQ/TCSG (TCT at 8.3σ).

The method also works for Beam 1 and the triplet in IP1 when operating with collision or ATS optics. However in case of missteered Beam 1 the triplet in IP1 is protected by the collimation system located in Sector 7, therefore this method is of less relevance for Beam 1.

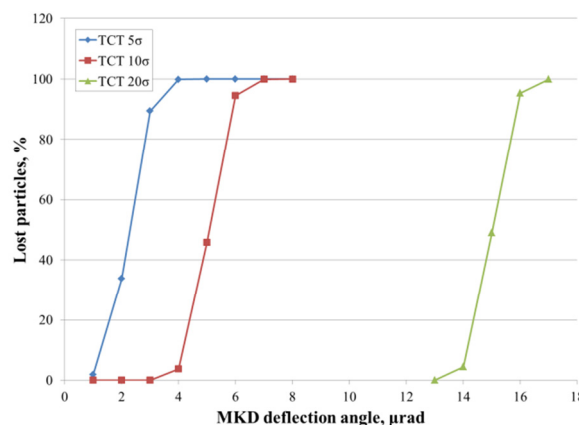


Figure 6: Losses in TCT for different angles of MKD mis-fire vs retraction of TCT (TCDQ and TCSG in parking position).

CONCLUSIONS

A new method for the validation of aperture margins is demonstrated. It is based on the fact that the trajectories of the beam in case of the MKD misfire and an orbit bump are similar. Two different approaches of measuring the aperture margins experimentally are described.

The beam optics plays an important role in this case, i.e. for injection optics the triplet will not be an aperture bottleneck in case of the MKD firing, whereas in case of collision and ATS optics this will be an issue.

When the MKD kick is strong, Beam 2 is fully intercepted by TCDS. When the kick is weak the beam is lost in TCDQ/TCSG or TCT, depending on their retractions.

The suggested method has an experimental advantage with respect to other methods since it can be performed with circulating beam. There is no need to dump the beam after each MKD firing, which allows studying the aperture margins in greater details.

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