COLLIMATORS AND BEAM ABSORBERS FOR CLEANING AND MACHINE PROTECTION

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Abstract

An inventory of all collimators and beam absorbers in the LHC ring is presented. The required settings of the various devices are discussed, the roles in beam cleaning and machine protection are explained and limitations in phase space coverage are explored. A basic strategy for commissioning of all collimators and absorbers is explained. The required cleaning performance and protection is discussed as a function of beam energy and various required steps in commissioning of collimators and absorbers are presented.

THE LHC COLLIMATION SYSTEM

At 7 TeV a single proton beam in the LHC will store up to 360 MJ of energy for many hours. This stored beam energy is about a factor of 200 above the present records in storage rings and is potentially highly destructive. At the same time the super-conducting magnets in the LHC are sensitive to small levels of energy deposition. If a small fraction of the stored beam energy (1 out of 1 billion protons) is lost in an uncontrolled way then the magnets can loose their super-conducting state ("quench") and LHC operation will be interrupted for several hours. The LHC collimators are designed to intercept the unavoidable beam losses. Collimators are located in two cleaning insertions per ring and form a beam cleaning system that absorbs the lost beam energy and protects the cold aperture. In addition to their cleaning functionality, the collimators provide a limited passive machine protection. Abnormal beam losses at the collimators are detected with beam loss monitors and the beam is quickly extracted onto the beam dump [1]. The LHC collimators are complemented by a number of collimator-like objects, called beam absorbers and diluters. Some of these only have a role for machine protection.

The LHC collimation project is working since 2003 across several CERN departments on finalizing the design of the collimation system and on constructing and testing the key components. There are a number of collimator-like objects that are not part of the collimation project. They are included in this paper.

CLASSES OF COLLIMATOR-LIKE OBJECTS IN THE LHC

The various collimators perform different tasks in the LHC collimation system and their hardware design is adapted for their specific purpose. A collimator-like object is defined as an object that presents one or two movable pieces of material (jaws) to the beam inside the machine vacuum. Four classes of collimator-like objects should be distinguished in the LHC.

Class 1: Collimators (TCP, TCSG)

Collimators are cleaning devices and interact with the primary, secondary or tertiary beam halo. The jaws are designed to act as scattering devices for spoiling and inducing inelastic interactions of protons that are lost from the beam. Collimators are precise devices with two low-Z fiber-reinforced graphite (CFC) jaws and are used for efficient beam cleaning but also have a secondary function for machine protection. They must achieve small gaps (down to 2 mm) and must respect stringent tolerances to ensure multi-stage cleaning. Due to the low-Z jaw design, collimators absorb little energy and are the most robust devices in the LHC rings in what concerns beam loss during accidents. Per beam a total number of 20 collimators are employed for the LHC start-up, with an additional 15 collimators (TCSM) to be installed during a phase 2 of LHC collimation.

Class 2: Movable Absorbers (TCT, TCLA, TCLP)

Movable absorbers fulfil a central role for beam cleaning. They have a very similar design to the collimators, but employ high-Z jaw material. Their jaws interact with the tertiary beam halo and the shower products from p-p and p-collimator interactions. The absorbers are designed to absorb a maximum of energy and are located in the cleaning insertions and the experimental insertions. With their high-Z jaw material they are very delicate and can easily be damaged by beam loss. This is avoided by keeping absorbers in the shadow of the more robust collimators and diluters. The larger gaps lead to relaxed operational tolerances. The movable absorbers in front of the experimental triplets have additional important machine protection functionality (protection of triplets against mis-kicked beam). There are about 20 movable absorbers per beam in the LHC (exact numbers being finalized).

Class 3: Diluters (TDI, TCLI, TCDQ, TCDI)

Diluters are mainly machine protection devices and have the primary purpose to interact with mis-kicked beam as it can originate from irregular beam dumps or injections. The mis-kicked beam will impact on the low-Z jaws of the diluters, which induce partial energy absorption and a strong emittance increase (dilution). The energy that escapes the diluters is sufficiently diluted that downstream elements are protected against beam-induced damage. Several of these devices have been optimized in order to also avoid quenches of downstream elements for more frequent injection and dump errors. In the LHC ring there are 4 diluters per beam. This is complemented by 7 diluters in each transfer line.

Class 4: Scrapers (TCHS)

Scrapers are only used in special circumstances for beam and halo diagnostic or for beam shaping. They are thin one-sided objects. The detailed hardware design remains to be worked out. For phase 1 of LHC collimation there will be 3 scrapers per beam.

Overview on Phasing, Design, Numbers, Locations and Usage

It would go beyond the scope of this paper to give a detailed list of all 162 possible elements and their detailed locations. This is available from the LHC layout database. Instead, Table 1 provides a summary of the different collimator-like movable objects in the LHC. This list may be used to get a basic understanding of the different collimation-like elements in the LHC, their phasing, their material and length, the area where they will be installed, their basic use and purpose.

It is seen that a total of 162 collimator-like objects can be installed in the two LHC rings and the transfer lines for the purpose of beam cleaning and machine protection. Out of these, 104 objects are part of phase 1 of LHC collimation and must be installed for the 2007 start-up of the LHC machine or shortly after.

It is noted that in total about 330 m of machine length have been reserved for collimator-like objects. About half of this length represents active jaw length, the rest is required for flanges and vacuum interconnects.

In the ring at injection about 34 collimator-like objects must be set ***per beam*** and for phase 1. An additional 7 collimator-like objects must be set for injection per transfer line. At top energy up to 39 collimator-like objects must be set ***per beam*** and during phase 1. The required settings will be discussed in the next sections.

Table 1: List of all collimator-like movable objects in the LHC. The information provided includes the acronym, the phase in which equipment will be installed, the material of the jaws, the flat top length of the jaws, the total number of elements for both rings, the locations, the use at injection or top energy and a short description of their purpose.

Class & Acronym	**Phase**	**Material**	**Length [m]**	**Number**	**Location**	**Use at injection**	**Use at top energy**	**Purpose**
Collimators								
TCP	1	CFC	0.2-0.6	8	IR3, IR7	Yes	Yes	Primary collimators for beam cleaning. Additional functionality for protection.
TCSG	1	CFC	1.0	30	IR3, IR7	Yes	Yes	Secondary collimators for beam cleaning. Additional functionality for protection.
TCSG	1	CFC	1.0	2	IR6	Yes	Yes	TCDQ set-up help.
TCSM	2	tbd	1.0	30	IR3, IR7	-	Yes	Hybrid secondary collimators for beam cleaning.
Phase 4	4	tbd	1.0	22	IR3, IR7	Yes	Yes	Space reservations for a possible phase 4 (maximum cleaning efficiency).
Movable absorbers								
TCT	1	Cu/W	1.0	16	IR1, IR2, IR5, IR8	-	Yes	Cleaning and protection at the experimental triplets.
TCLP	1 + 3	Cu	1.0	8	IR1, IR5	-	Yes	Cleaning at IP of secondary particles from p-p collisions.
TCLA	1	Cu	1.0	~ 16	IR3, IR7	Yes	Yes	Cleaning of secondary particles from collimators.
Diluters								
TDI	1	Sandwich	4.2	2	IR2, IR8	Yes	-	Injection protection.
TCLI	1	CFC	1.0	4	IR2, IR8	Yes	-	Injection protection.
TCDI	1	C	1.2	14	TI2, TI8	Yes	-	Injection protection.
TCDQ	1	CFC	6.0	2	IR6	Yes	Yes	Dump protection.
Scrapers								
TCHS	1 + 2	tbd	tbd	8	IR3, IR7	Yes	Yes	Beam scraping.

SETTINGS FOR CLEANING AND MACHINE PROTECTION

All objects listed in Table 1 are movable and must be set to the right distance from the beam in order to be fully effective for beam cleaning and machine protection.

Basic Strategy for Settings

The strategy for setting these elements is as follows:

1. The **LHC ring aperture $\mathbf{a}_{\mathbf{ring}}$** [2] must be protected against regular and irregular beam losses. It sets the basic reference for all settings.
2. The **protection devices** (“diluters”) must protect the ring aperture and their setting $\mathbf{a}_{\mathbf{prot}}$ must therefore be tighter than the ring aperture: $\mathbf{a}_{\mathbf{prot}} < \mathbf{a}_{\mathbf{ring}}$.
3. The **secondary collimators** must have a tighter setting $\mathbf{a}_{\mathbf{sec}}$ than the protection devices in order to ensure a well-defined two-stage cleaning only in the cleaning insertions: $\mathbf{a}_{\mathbf{sec}} < \mathbf{a}_{\mathbf{prot}}$.
4. The **primary collimators** must be the tightest aperture restrictions in the LHC beam. In particular their setting $\mathbf{a}_{\mathbf{prim}}$ must be tighter than the setting of the secondary collimators: $\mathbf{a}_{\mathbf{prim}} < \mathbf{a}_{\mathbf{sec}}$.

These conditions must always be fulfilled in order to guarantee the proper functioning of two-stage cleaning and protection. Other movable elements (e.g. movable absorbers) must be set to compatible beam distances, as defined later.

The setting **a**, used above, should be understood as **half aperture** in normalized terms. Though it is sufficient to normalize by the square root of the beta function, **a** is often expressed in terms of the beam size $\sigma = (\varepsilon\beta)^{½}$. For example, a horizontal collimator gap would be expressed in horizontal beam sigmas at its location:

$$a_x(\sigma) = \frac{\tilde{a}_x(\mathrm{m})}{\sqrt{\beta_x(\mathrm{m})\ \varepsilon_x(\mathrm{m})}} \quad .$$

It is noted that this definition is quite handy in terms of the settings obtained (for example, primary collimators are set to a beam-size normalized 6 σ instead of a beta-normalized distance of $1.2\times10^{-4}\ \sqrt{\mathrm{m}}$). However, care must be taken for a proper definition of the normalization. In this paper the settings are normalized to the design values of the beta function and the design value of emittance at a given energy. Several assumptions are noted:

1. The settings **a** are normalized only to the betatron beam size. The dispersive part of the beam size is not included. For example, momentum collimators seem to be wide open in betatron space. However, they limit the aperture in momentum space once energy spread and dispersion are taken into account.
2. Settings are only valid for the energy for which they are defined. In particular, a specification of settings in beam sigmas at injection does not mean that the collimators are closed during the ramp to maintain this normalized setting (while the geometric emittance is decreasing in the energy ramp).

Settings During Injection

The settings for movable collimator-like devices have been worked out for injection. They are summarized in Table 2. All the various movable collimator-like elements in the LHC rings and the transfer lines have been included and the nomenclature of various setting parameters **a** have been expanded accordingly. It is noted that the transfer line collimators have been fixed to 4.5 σ in order to achieve a ring protection at 6.9 σ [3].

Differences in settings are small and a central, strict and precise control of settings for the various collimators, absorbers and diluters in the LHC is clearly mandatory. Tolerances are at the 0.1 σ level. To achieve and guarantee these settings during the whole injection process will be a clear challenge for the operation of the LHC. Once the injection process is completed, the injection protection elements can be opened.

It is noted that the primary and secondary collimators must be put very close to the beam in order to be compatible with the tight LHC aperture. As the setting for the primary collimator has to be below 6 σ, collimator-induced problems with beam lifetime cannot be excluded. In particular, there is no significant room for emittance blow-up or strong beta-beat during the injection process.

Table 2: Normalized settings of all movable collimators, absorbers and diluters during LHC injection. Some elements only act in a given plane. For these elements the collimation plane is indicated in brackets (H or V).

Setting			**Explanation**
$\mathbf{a}_{\mathbf{abs}}$	≈	10.0 σ	Movable absorbers in IR3 and IR7
$\mathbf{a}_{\mathbf{sec}\delta}$	=	9.3 σ	Secondary momentum collimators in IR3 (H)
$\mathbf{a}_{\mathbf{prim}\delta}$	=	8.0 σ	Primary momentum collimators in IR3 (H)
$\mathbf{a}_{\mathbf{ring}}$	=	7.5 σ	Available transverse cold aperture in the ring
$\mathbf{a}_{\mathbf{prot}}$	≥	7.0 σ	TCDQ dump protection (H)
$\mathbf{a}_{\mathbf{prot}}$	=	6.8 σ	TDI, TCLI injection protection (V)
$\mathbf{a}_{\mathbf{sec}}$	=	6.7 σ	Secondary betatron collimators
$\mathbf{a}_{\mathbf{prim}}$	=	5.7 σ	Primary betatron collimators
$\mathbf{a}_{\mathbf{TL}}$	=	4.5 σ	Transfer line collimators

The settings that are listed in Table 2 can be combined with the information on the collimator locations in order to estimate the phase space coverage that is provided by the overall collimation system. The resulting phase space coverage is illustrated in Figure 1 for the horizontal plane.

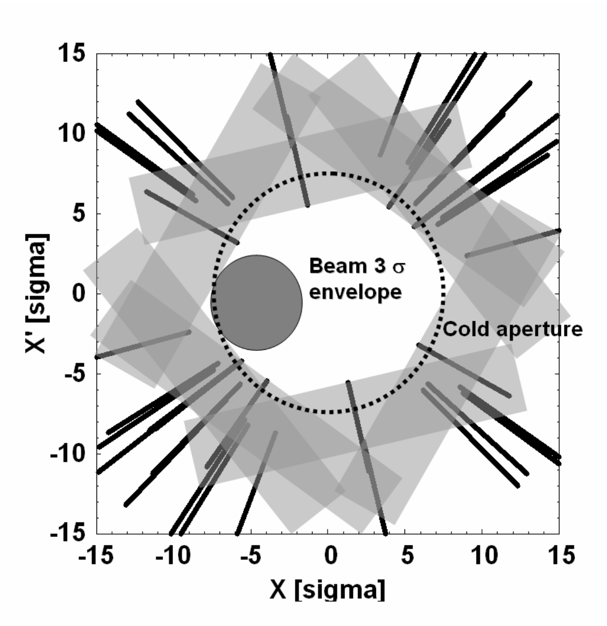

Figure 1: Normalized phase space coverage in the horizontal plane that is provided by all collimators, absorbers and diluters at their nominal injection settings.

Each movable collimator, absorber or diluter is represented by one or two black lines. Each black line represents a single jaw. The lines are perpendicular to the collimator jaw and their endpoint closest to the origin gives the distance of the collimator jaw from the nominal beam which runs through the 0,0 point. For the most critical aperture restrictions the extensions of the jaws have been illustrated in order to visualize the phase space coverage (free white space around the origin). For comparison both the cold aperture (circle) and the 3 σ envelope of a mis-kicked beam touching the aperture are illustrated. It is seen that the collimators provide for most phases a good coverage in the sense that any beam loss will first occur at a collimator jaw. However, there are two betatron phases that are just not covered, as illustrated in Figure 1. The 3 σ enevelope seems to first touch the cold aperture.

It is concluded that most irregular beam losses in the horizontal plane at injection can be detected first at the collimators. However, the phase space coverage is not fully complete and it is strongly supported to complement the machine protection based on losses at collimators with other independent measures [1].

Settings at top energy with collision optics

The settings at the LHC top energy (7 TeV) have been worked out for the nominal collision optics with a β^* of 0.55 m. They are summarized in Table 3. The settings are slightly relaxed with respect to the settings at injection, if the normalized settings are considered. For example, it is possible to set the primary collimators to 6 σ while still protecting the cold aperture. However, the beam size at top energy is 4 times smaller than at injection and tolerances are much more difficult for operation at 7 TeV.

Table 3: Normalized settings of all movable collimators, absorbers and diluters at top energy and for nominal collision optics. Some elements only act in a given plane. For these elements the collimation plane is indicated in brackets (H or V).

Setting			**Explanation**
$\mathbf{a}_{\mathbf{abs}}$	$\approx$	20.0 σ	Movable absorbers in IR3
$\mathbf{a}_{\mathbf{sec}\delta}$	$=$	18.0 σ	Secondary momentum collimators in IR3 (H)
$\mathbf{a}_{\mathbf{prim}\delta}$	$=$	15.0 σ	Primary momentum collimators in IR3 (H)
$\mathbf{a}_{\mathbf{abs}}$	$\approx$	10.0 σ	Movable absorbers in IR7
$\mathbf{a}_{\mathbf{ring}}$	$=$	8.4 σ	Triplet cold aperture
$\mathbf{a}_{\mathbf{prot}}$	$=$	8.3 σ	Local cleaning and protection at the experimental triplets (TCT)
$\mathbf{a}_{\mathbf{prot}}$	$\geq$	7.5 σ	TCDQ dump protection (H)
$\mathbf{a}_{\mathbf{sec}}$	$=$	7.0 σ	Secondary betatron collimators
$\mathbf{a}_{\mathbf{prim}}$	$=$	6.0 σ	Primary betatron collimators

The settings at top energy can be relaxed (larger gaps) by operating the LHC with increased β^* in IR1 and IR5. This will provide an excellent possibility for a gradual learning curve. It is noted that this possibility for relaxing requirements does not exist at injection.

Settings During the Energy Ramp

The optics of the LHC machine is kept constant during the energy ramp in the present baseline. It is planned to perform the beta squeeze after the plateau at top energy has been reached. In this case there is no change in the available LHC aperture during the energy ramp, if tight tolerances on transient orbit and beta beat changes are achieved. The collimators, absorbers and diluters can then in principle be kept at their injection settings ("CONSTANT"). However, in this case the normalized beam deflection can reach many sigmas before any beam is intercepted at a collimator. Erroneous field changes per time (e.g. quenches) usually become rapidly larger with time. Therefore there is some concern about compromising machine protection if collimators are kept constant. The other extreme approach is to close the collimators, absorbers, and diluters proportional to $\sqrt{\gamma}$, such that they remain at the same normalized settings as at injection ("SCALED").

The two cases are compared in Figure 2. It is seen that both for constant and scaled settings the cleaning inefficiency improves during the energy ramp. This is a design feature of the collimation system ("optimization for top energy") and was chosen in order to mimic the decrease in the relative quench limit of the magnets during the ramp. The scaled case provides, however, an even better inefficiency and might be preferable if limits in the

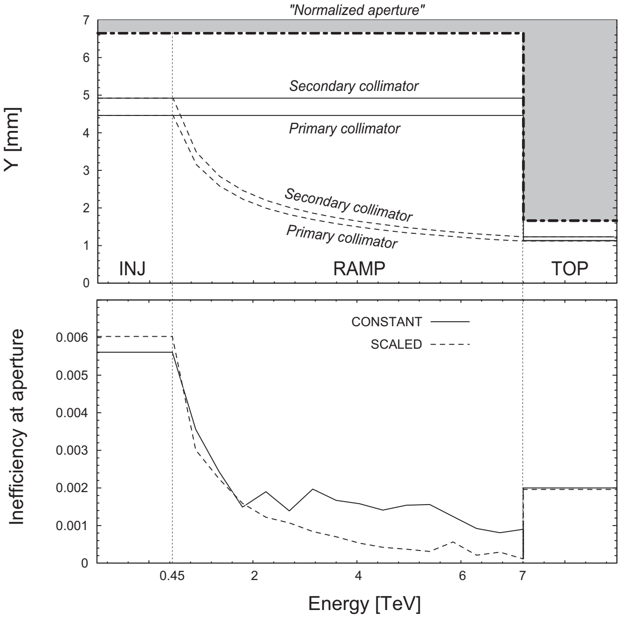

Figure 2: Possible primary and secondary collimator settings (vertical plane) during injection, ramp and top energy (top). The case of "constant" (solid line) and "scaled" settings (dashed line) are distinguished. The minimum cold aperture in the ring (transformed to the location of the primary collimator) is illustrated. The cleaning inefficiency was evaluated for both cases at the aperture limit (bottom). The energy scale is not linear and ends below 0.45 GeV and above 7 TeV!

cleaning efficiency are encountered during the ramp.

It is noted that the cleaning inefficiency becomes worse after the beta squeeze. This is explained by the reduction in the cold aperture during squeeze and cannot be avoided.

If the collimators are uniformly closed during the ramp then tolerances on collimator settings will decrease with $1/\sqrt{\gamma}$. This might present an unacceptable difficulty for the operation of the LHC. Therefore it is proposed to implement an optimized setting during the ramp that features the following properties:

1. The primary collimators are closed with beam energy such that they remain at their constant normalized setting from injection (5.7 σ). This assures better phase space coverage for protection purposes.
2. The absolute distance between settings of primary and secondary collimators is kept constant. Secondary collimators are closed in absolute gap but their normalized setting increases during the energy ramp. This assures that setting tolerances for two-stage cleaning remain constant.
3. The TCDQ for dump protection follows the secondary collimators with a constant absolute distance.

The open phase space will shrink during the energy ramp without inducing more stringent tolerances on settings. The optimized approach would also provide a much improved safety against emittance blow-up. Orbit errors will in most cases be detected much earlier and the dB/dt of a magnet error will in general not be as steep at the detection time. The cleaning performance is expected to be in between the two results shown in Figure 2.

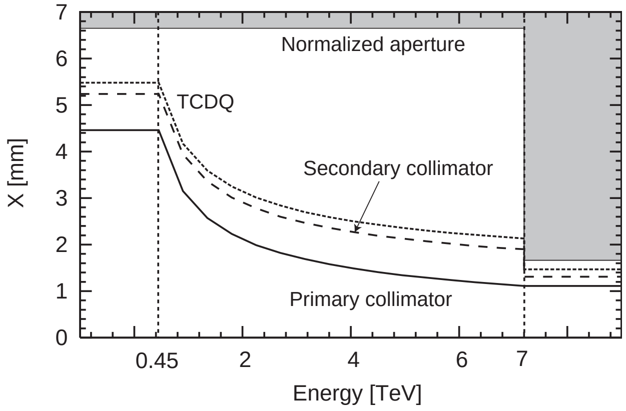

Figure 3: Possible "optimized" settings of primary and secondary collimator and TCDQ (horizontal plane) during injection, ramp and top energy (top). The minimum cold aperture in the ring (transformed to the location of the primary collimator) is illustrated. The energy scale is not linear and ends below 0.45 GeV and above 7 TeV!

FIRST IDEAS ON CONTROLS OF COLLIMATOR-LIKE OBJECTS

The large number of different elements, the tight settings and the possibility to quickly adjust the different collimators, absorbers and diluters necessitates a powerful control system. Work towards a detailed control system of collimator-like objects in the LHC is still in its starting blocks. However, basic requirements and a baseline concept have been defined [4].

Requirement 1: The control system must allow advanced and automatic collimator control algorithms as they are being used at TEVATRON and RHIC:

1. BLM-based settings must be possible, e.g. "move until BLM #i reads a value of X".
2. Automatic movements for fast beam-based alignment and rapid operational changes (e.g. during the squeeze) require the use of functions or equivalent.
3. A powerful interface to machine control and machine protection is required, while a maximum degree of flexibility must be preserved for empirical optimization of the cleaning performance.

Requirement 2: The complete collimator controls system must be broken into manageable packages that can be commissioned in phases, if required. Preliminary ideas for the sub-systems are:

1. A **Central Control Application (CCA)** generates simple or complicated functions and provides dump and warning levels.
2. A **Motor Drive Control (MDC)** should be a system that is as simple as possible. It provides the minimally required control (single motor

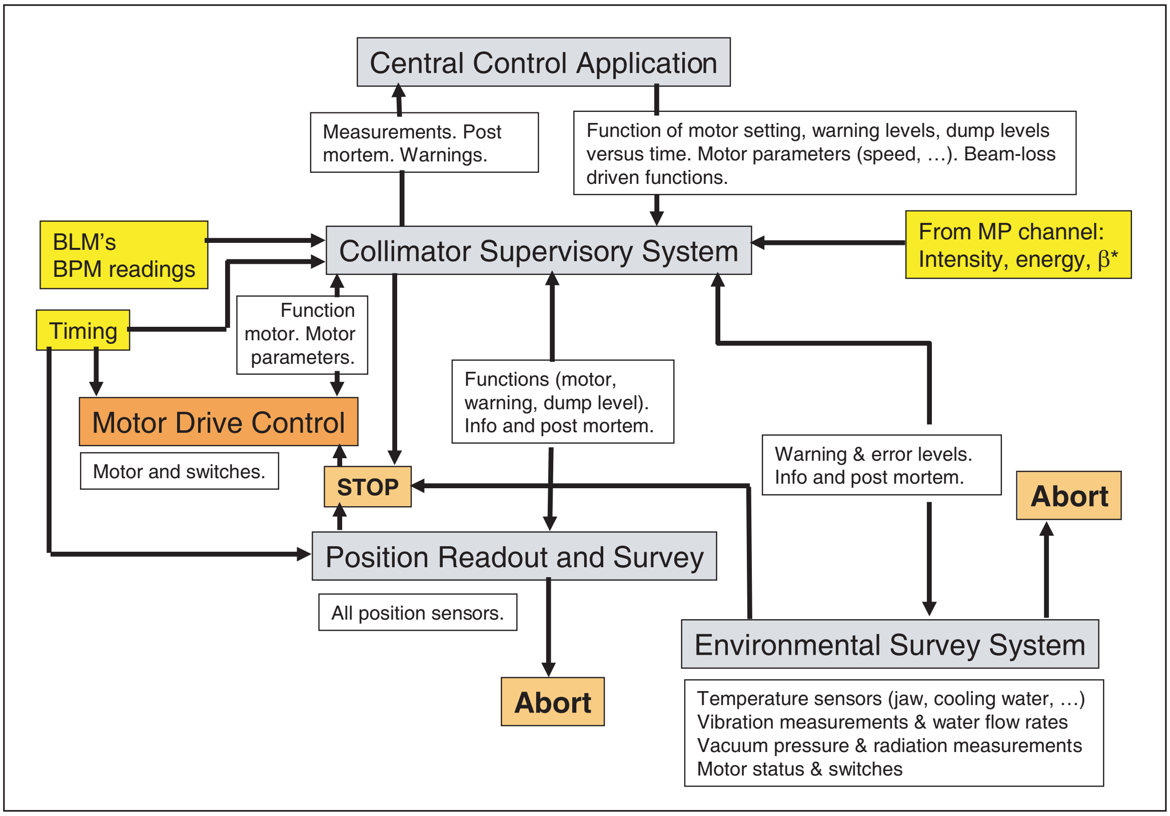

Figure 4: Preliminary ideas about the architecture of the controls system for movable collimator-like objects in the LHC. The overall control system is broken down in five separate packages covering low-level, middle-level and top-level controls. This approach is based on discussions between M. Jonker, M. Lamont and R. Assmann [4].

movement) and has no machine protection functionality. This sub-system must be ready for 2007!

3. A **Position Readout & Survey system (PRS)** and an **Environmental Survey System (ESS)** provide independent checks from various sensors that are installed on the collimators. It ensures continuous position verification, control of jaw temperatures and other key parameters. The two sub-systems incorporate the major machine protection functionality based on collimator settings.
4. A **Collimator Supervisory System (CSS)** interfaces with low and top level controls. There will be 1-2 CSS systems per interaction region, each system interfacing to many collimators. This system will provide advanced functionality, e.g. by including information from the Beam Loss Measurement system, the orbit feedback or other sources.

The preliminary concept and the most important interconnections between different sub-systems is illustrated in Figure 4. Further work will be performed in 2005 between AB/CO, AB/ATB, AB/ABP and AB/OP with the aim to arrive at the final definition of a powerful collimator control system for the LHC.

COMMISSIONING OF THE COLLIMATION SYSTEM

The commissioning of the beam cleaning and collimator-based protection system will strongly depend on the intensities in the rings and on the state of the machine orbit and optics. A detailed commissioning program can only be developed once the steps in beam intensity have been specified and scenarios of imperfections have been generated for each step. Imperfections of interest include maximum loss rates, maximum orbit offsets, maximum beta beat and estimates of transient errors during injection, ramping and squeeze. In absence of this information only basic ideas for collimator commissioning can be developed.

Basic Rules for Commissioning of the Collimation System and Consequences

The collimator settings summarized in Tables 2 and 3 include a clear hierarchy of settings. Some basic rules for collimation set-up can be derived:

1. Beam-based set-up of collimators, absorbers and diluters is done at such a low intensity that the single-stage cleaning process during set-up will not quench any magnet. The intensity limits vary

depending on the particular type of object (jaw material) and its location.

2. Elements will be set-up from the most open jaw position in Tables 2 and 3 towards the smallest gap or distance to the beam.
3. Collimators in the cleaning insertions are commissioned from the back to the front of the cleaning insertion.
4. Once the low current set-up is complete, the beam intensity is raised until a first loss location approaches the quench limit. The collimator settings are then optimized empirically to achieve a better cleaning efficiency.

This process will profit from experience and stable machine operation. It is noted that this approach has the important consequence that the low current set-up must be applied at higher intensities without a chance for a new base set-up. The success will crucially depend on the machine stability and reproducibility from low to high beam intensities.

A Minimal Single-Stage Cleaning and Protection System

In general it is preferable to rather relax on the setting accuracy of collimators, absorbers and diluters instead of reducing the number of elements used. However, for early operation a minimal single-stage cleaning and protection system might be of interest. Such a system could be established for one ring in the following way:

1. At injection restrict intensity to about 5 nominal bunches.
2. In both IR3 and IR7 set each four movable absorbers to a coarse 9 σ position. This will shadow the SC arc aperture and capture debris from collimator-induced showers.
3. Set up the TCDQ for dump protection (~ 8 σ).
4. Set up the TDI and two TCLI for injection protection (~ 7 σ).
5. Three primary betatron collimators are set to a coarse 6 σ position. This will establish single-stage cleaning in the betatron insertion. One primary momentum collimator is set to 8.5 σ.
6. Accumulate and ramp.
7. At top energy set the eight movable absorbers at the experimental insertions to shadow the triplets, even before the first squeeze.

This system involves 22 movable elements per beam and provides a fully functional one-stage cleaning with injection and dump protection, as well as full protection of the triplets. The system would have an increased margin for set-up errors and transient beam changes (orbit and beta beat). At injection the total margin would be about 3 mm instead of 1 mm. At top energy the margin would be 0.6 mm instead of 0.2 mm.

Possible Cure of Beam Loss Limitations

In the case that beam loss limitations are encountered the following hierarchy of cures is proposed:

1. Increase the available aperture for the beam by working on the orbit and the beta beat.
2. Improve the stability of the machine which will result in lower loss rates.
3. Improve the cleaning efficiency by closing the collimators. However, at the same time operational tolerances are reduced, the impedance is increased and the overall machine operation becomes more difficult.
4. Decrease the beam intensity.

In the operational practice a combination of the various measures might be considered. However, only the successful work on all issues 1-3 will ensure that the LHC design performance can be reached.

CONCLUSIONS

The different classes of collimator-like objects in the LHC and their major functionality for beam cleaning and protection have been explained. The required settings of the different elements were specified for injection and top energy. Optimized collimator settings were proposed for the energy ramp, combining an improved cleaning efficiency, relatively relaxed operational tolerances and an enhanced machine protection.

Basic requirements for the control system of the collimation system were summarized and the possible system architecture was presented.

Basic rules for the commissioning of the LHC collimation system were discussed and a minimal one-stage cleaning and protection system was proposed for early commissioning.

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The summary on the various collimator-like objects strongly profited from the help by G. Robert-Demolaize. The settings of collimators, absorbers and diluters were defined together with B. Goddard, V. Kain and S. Redaelli. Many discussions with R. Schmidt “pushed” me towards considering the options during the energy ramp in more detail. The possible architecture of the control system was mainly worked out by M. Jonker and finalized in discussions with M. Lamont.

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