EYETS RECOVERY

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Abstract
During the winter 2016/2017 the LHC will undertake a period of maintenance, the so-called Extended Year Stop (EYETS). Many activities will be performed during this period to solve issues as well as to increase the LHC performance. One of the main activities is the exchange of a weak magnet in sector 12. This involves warm up of the sector, magnet exchange, cool down and subsequent recommissioning, including magnet re-training. The delicate phase of recovery from the long stop and recommissioning the LHC after all interventions will be discussed.

THE TRAINING CAMPAIGN

Due to the excellent year of operation, at the end of 2016 it was decided to perform a training campaign on some of the dipole circuits. This operation was meant to increase knowledge on the process, thus enabling correct estimate of the required effort to operate the LHC at 7 TeV. The two allocated weeks were foreseen just before the Extended Year Technical Stop (EYETS). An analysis performed on historical data [1] allowed to identify sector 34 and sector 45 as the best candidates for this exercise. Besides, it estimated the number of required quench to 25 and 24 respectively. The uncertainty on these numbers is nevertheless high as the knowledge on the process is still limited.
The target for the training exercise was set to 12 kA (nominal current for 7 TeV operation is 11850 A) and the training campaign was carried out between December 4th and 15th; between 2 and 3 quenches per day were performed. The final results of the training campaign are shown in Tab.1.
One of the key ingredient of the success was the performance of the cryogenic system. Due to the secondary quench effect, each test resulted in an average of 13 MJoule injected in the system. Despite the high energy, the cryogenic system managed to cool down the magnets and re-establish nominal condition in less than 8 hours.

	Current	Equivalent E	#quenches
S34	11415 A	6.74 TeV	8
S45	11535 A	6.82 TeV	24

Table 1: Results of training campaign

Short to ground in RB.A34

Looking at the results shown in Tab.1, a large difference in the test performed between the two sectors is clearly visible. This is due to a problem occurred on the dipole circuit RB.A34, which resulted in a stop of the training campaign for this sector. Just after a quench occurred on C12L4, the power converter detected an earth fault in the circuit. Dedicated electrical permanent showed a permanent short-to-ground on the anode lead of the cold diode of MB.C12L4, very likely at the half-moon connection. Moreover, an X-ray scan was performed (Fig.1), showing metallic debris at the level of the diode lead.

Fig.1 X-rays of the diode lead at the level of the half-moon connection for magnet C12L4, showing the presence of metallic debris.

This event is very similar to the one occurred in March 2015 during the first training campaign. As consequence, the same method was applied and the short was removed by means of a capacity current discharge. After that a test involving all circuits of the sector was carried out to verify that the quality was not compromised, but the time allocated for the training campaign was already over.

THE EYETS

After the training campaign, the Extended Year End Technical Stop (EYETS) will take place. Many activities have to be performed in a few months to allow a safe and reliable operation of the LHC in 2017. A solid baseline for the YETSs was established in 2015/2016 with the cryogenic system securing the conditions during the stop and Electrical Quality Assurance (ElQA) measurements to be performed before powering tests are carried out. Uninterruptable Power Source (UPS) and *Arrêt Urgence Generale* (AUG) tests are also in the frame of the YETS, as these tests proved to be crucial for ensuring safe operation.

Besides the main frame, many activities will be performed during the EYETS. The most critical one is the exchange of the dipole magnet in A31L2, due to a probable inter-turn short. This operation is delicate as it defines the critical path and it involves many teams. Beam Loss Monitors have to be dismounted and 17 vacuum sub-sectors open, before the magnet can be removed. Due to this operation, the entire sector will be warmed up to room temperature. This condition is very interesting as the powering tests will give information on the capability of the magnets to keep memory of the performed quenches after a thermal cycle. This knowledge is crucial to plan operation for the years to come.

Besides the magnet exchange, a large set of smaller interventions will be performed with non-negligible impact on the various systems and on machine operation.

THE RECOVERY

In order to re-qualify the superconducting circuits for operation, a large set of powering tests is foreseen. As for the YETS activities, also in this case a solid baseline has been established and a clear program of powering tests defined. The only exception will be sector 12 where the full set of powering tests will be performed to re-qualify the circuits after the thermal cycle. A total of 2 weeks has been allocated at the end of April for testing all superconducting circuits, plus an additional week for sector 12. About 6500 tests will have to be executed and analyzed during this period, making this operation challenging.

Before operating the machine, the so-called machine check-out has also to be performed. This includes individual system tests, plus verification of the communication and check of the control system infrastructure. Many tests of machine protection will also be performed to ensure safe operation with high energy beam. The machine check-out will start in parallel with the last part of powering tests.

2017 LHC OPERATION

With increasing demand of performance for the LHC, the operation team is working on improving the design of the cycle. Mainly two ideas are being considered.

Combined Ramp & Squeeze

The possibility to combine the energy ramp and the betatron squeeze has been addressed through systematic studies at CERN since 2011 [2,3], then proposed [4] and implemented for 2016 operation. This operation was performed about 300 times in 2016, resulting in an overall gain of about 30 hours of operation, without compromising the quality. It is then clear that a further extension of this process is very interesting from a performance point of view. The enhanced quality of dynamic optics measurements made it possible to envisage a scenario when the beams are squeezed to less than 3 meters beta* in the high luminosity points during the energy ramp. For such reason two scenarios are at the moment under investigation:

- Squeeze to 1.2 meter beta*, resulting in a gain of 257 seconds per squeeze

- Squeeze to 1 meter beta*, resulting in a gain of 306 seconds per squeeze.

Furthermore, a Machine Development study has been proposed to try to squeeze a pilot beam until 40 cm beta* during the energy ramp.

The PPLP ramp

The present energy ramp of the LHC (so-called PELP) is composed of four parts [5]:

- **Parabolic** to smoothly passed through the snapback phase;
- **Exponential** to minimize non-linear field imperfections;
- **Linear**;
- **Parabolic** to settle up.

With increase knowledge of the powering and magnetic system and thanks to the high quality of the magnetic field in the LHC, a review of this process is proposed. Some studies, in fact, are being carried out to evaluate the possibility of increasing the speed of the ramp in view of using the LHC as injector in the FCC era. A new ramp is then proposed to be used for 2017 operation. This new ramp (so called PPLP) will have the first parabolic phase untouched to smoothly transit across the snapback. The first parabola will then match a second faster parabola to get into the linear phase. Finally, the settling parabola will be slightly more aggressive than the present one. This new design would result in a gain of 10% in the ramp length (see Fig.2).

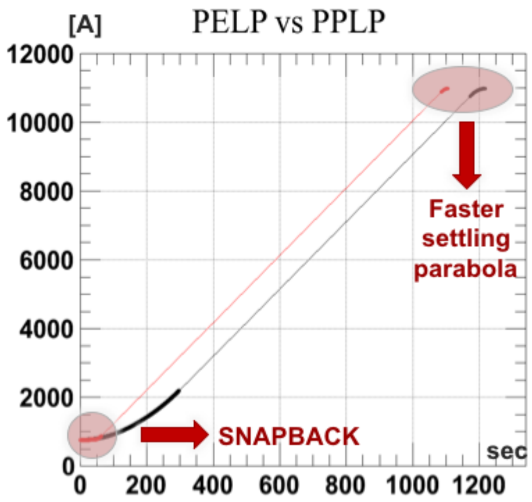

Fig.2 Present LHC energy ramp (PELP) versus new proposed design (PPLP)

CONCLUSIONS

The training quench campaign was an extremely useful exercise and gave clear indication on the effort needed to operate the LHC at 7 TeV. Some magnets have experienced an unexpected re-training and also due to the amount of secondary quench, preliminary analysis shows a long way to reliably operate the dipole circuits at their design energy. Sector 34 was also very useful; despite of the non-completed campaign, in fact, the experience gained in removing the fault is extremely valuable. Similar event can happen art any quench and it is important to establish a method to quickly remove the short.

Many activities will be carried out during the EYETS, including a complete warm-up of a sector and a magnet exchange. Many tests will have to be performed to ensure safe operation of the LHC in a short time. The recovery from the EYETS will be challenging.

Operation in 2017 will benefit of some improvements being studied.

ACKNOWLEDGMENT

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