LHC MAGNET TESTS: OPERATIONAL TECHNIQUES AND 
EMPOWERMENT FOR SUCCESSFUL COMPLETION

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Abstract

The LHC magnet tests operation team developed various innovative techniques, particularly since early 
2004, to complete the superconductor magnet tests by Feb. 2007. Overall and cryogenic priority handling, rapid 
on-bench thermal cycling, rule-based goodness evaluation on round-the-clock basis, multiple, meshed web systems 
are some of these techniques applied with rigour for successful tests completion in time. This paper highlights 
these operation empowerment tools which had a pivotal role for success. A priority handling method was put in 
place to enable maximum throughput from twelve test benches, having many different constraints. For the 
cryogenics infrastructure, it implied judicious allocation of limited resources to the benches. Rapid On-Bench 
Thermal Cycle was a key strategy to accelerate magnets tests throughput, saving time and simplifying logistics. 
First level magnet appraisal was developed for 24 hr decision making so as to prepare a magnet further for 
LHC or keep it on standby. Web based systems (Tests Management and E-Traveller) were other essential ideas 
to track & coordinate various stages of tests handled by different teams.

INTRODUCTION

The SM18 magnet test facility was assembled at CERN to accomplish the goal of testing the 1706 cold masses 
produced in Europe since 2001 for the LHC [1]. These cold masses, majority operating at 1.9 K, consist of twin- 
aperture, superconducting 8.3 T dipoles and quadrupoles. All were successfully tested by early 2007. 

Testing, training and qualification of these magnets under cryogenic conditions, which is a prerequisite to 
their installation in the machine, was not feasible at the manufacturers’ premises. The SM18 facility consists of 
12 test benches arranged in 6 clusters. Each test bench is fed independently with a cryogenic feed box, and 
electronics and power resources are shared between the benches within a cluster. A round-the-clock operation 
coordinating three different teams namely tests operation, magnet connection/disconnection, and cryogenics teams, 
was implemented in SM18, creating a semi-industrial environment within an essentially physics laboratory like 
CERN. To accomplish the massive and time-bound objective, some effective management principles had to 
be addressed, necessary supporting tools and strategies developed, and certain level of operator empowerment 
had to be efficiently implemented. This paper describes some of the innovative operational tools and strategies 
developed by the tests operation team which played crucial roles in the successful completion of magnet tests.

SMTMS & E-TRAVELLER

All the tests results were being manually logged into a paper log called magnet test report (MTR), which follows 
the “To-Do-List” [2] that described the minimum set of tests to be performed on a magnet. However, verifying 
and assessing the test results entered in the MTR was a tedious task. This demanded the development of an 
electronic repository of test results pertaining to each magnet. A web based SM18 Test Management System 
(SMTMS) was developed by the operation team as a tool to link the tests results with other management tools [3]. 
SMTMS gives tremendous flexibility for statistical analysis and presentation of test data, and served as the hub of the so called tests & results repository. 

During the initial phase of testing, there were considerable problems originating from the difficult 
communication and co-ordination between the various teams involved in SM18 activities. For example, a major issue was that the magnet tests operation team consisting of mainly Indian associates spoke exclusively English while the other teams were largely French speaking. To overcome this situation, the operation team in conjunction with certain cryogenic team experts put forward the idea of a web-based tool called e-traveller. This kept track of an electronic, signature-based information exchange and maintained an automatic time-stamped log of tests activities. Each team responsible for specific tasks was supposed to sign the e-traveller after the completion of their part of work. This informed the next team which is supposed to follow-up the task through an automatic cell

Figure 1: 2nd Quench current of dipoles till Dec 2003
phone message as well as a colour change in the domain status of the e-traveller interface display. Video display screens put all over the SM18 premises broadcast any change in domain status, informing all teams simultaneously in the appropriate language, without recourse to verbal communication.

SMTMS and e-traveller, being synchronous, mashed web systems, permit day to day activities like keeping track of tests phases in time, generation of quench performance reports, verification of all sequences of tests performed on any magnet and generally giving history of any magnet ever tested in SM18.

**MAGNET TRAINING CRITERIA**

Earlier, each dipole was trained to reach its ultimate field (9 T or 12850 A). This was a significant time consuming activity, especially since it required typically 3-4 hours recovery time in between two successive quenches. A major breakthrough in magnet testing rate was the introduction of modified training rules, by which all the magnets were not required to be trained up to their ultimate current. A statistical study conducted on quench performance of early magnets revealed that ~80% of ‘good’ magnets cross the nominal field (8.33T or 11850 A) in two training quenches (Fig.1) [4]. Based on this, a new training rule named the ‘Two-Quench Rule’ was accepted by the magnet experts, under which it was recommended to do only two training quenches in each magnet provided it crossed the nominal field with a small margin. Later on, this was complemented by the ‘Three-quench rule’ whereby the magnet is also accepted if it crosses a field of 8.66 T (12250 A) in the third quench even if it has not passed the preceding rule [2].

**OVERALL & CRYO PRIORITY HANDLING**

Overall priority allocation becomes critical for maximising the throughput from a constrained system with limited resources. In this context, operation team empowerment for deciding and setting the overall and cryo priorities has played a crucial role in maximising the throughput through effective and clash-free resource management.

The limited cryogenics infrastructure [5] in SM18 can support only 6 magnets at a time out of the total 12 that could be in the cooling-down, warming-up or cold test phase. To effectively utilize even this 50% capacity, the operation team has to make careful priority decisions keeping in mind the average time requirement for cooling down/warming up of the particular type of magnet (see Fig. 2) along with the constraints in the number of magnets that can co-exist simultaneously within each cryo regime, such as:

- 3 to 5 magnets at 1.9 K.
- Up to 2 magnets in 300 K to 80 K phase.
- Up to 2 magnets in warm up phase.
- 2 magnets in 80 K to 4 K phase.
- Maximum 3 magnets simultaneously in cool down and warm up phases put together.
- Minimum of 20 minutes delay between two quenches.

<table>
<thead>
<tr>
<th>Magnet</th>
<th>300-80K (Hours)</th>
<th>80-42K (Hours)</th>
<th>4.2-1.9K (Hours)</th>
<th>1.9-300K (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole</td>
<td>16</td>
<td>10</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>8</td>
<td>7</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Special SSS</td>
<td>8</td>
<td>7</td>
<td>3</td>
<td>12</td>
</tr>
</tbody>
</table>

Figure 2: Average cooling and warm-up times - 2005

The operation team initiated a priority change based on the following broad guidelines [6]:

- A magnet under warm-up phase shall be assigned highest priority (1 or 2), allowing it to go out as fast as possible.
- Due consideration shall be given to a cooling down magnet assessing the overall situation for the next 12 hours.
- Magnets already at 1.9 K shall be given next higher priority (2 to 5) with maximum of 3 magnets getting the major share of cryo cool-down/warm-up resources (85 g/s for each magnet out of the total 300 g/s gaseous helium) and a fourth one with the remaining resources.
- Priority numbers 6 to 8 can be assigned amongst the magnets cooling from 80 K down to 4.4 K.
- The remaining priorities were allotted to the other magnets considering their exact status and the time that would elapse before they require the resources.
A typical cryogenic priority assignment scenario is shown in Fig.3. After the assignment, the system status and resources allocation displayed through SMTMS is shown in Fig.4.

**ROBTC**

Until mid 2005, the existing strategy was to remove a magnet with ‘poor’ training performance from the test bench, equip it with anticryostats to house quench localisation devices, and eventually bring it back at a later date to the test bench for another run of a complete test sequence. This process where the magnet undergoes a ‘delayed thermal cycle’ was time consuming due to additional disconnection, connection, cryogenic pump down and leak tests as well as preparatory cold tests for the next run. However, operational experience revealed that the performance of the magnets improves after a thermal cycle and the installation of quench localisation devices was not always necessary, nor did it give much additional information. This led to the introduction of a strategy called Rapid On-Bench Thermal Cycle (ROBTC) by the operation team. Under this strategy, a magnet with poor performance is subjected to a rapid thermal cycle without disconnecting or removing it from the bench; an additional sequence of minimal power tests is performed to qualify the magnet, thereby saving a considerable amount of preparatory tests time and connection/disconnection time [7].

**MAPS**

Based on the test results, a magnet would either be accepted for installation in the tunnel or sent to the standby buffer for further action such as repair/retest. Earlier all magnets were sent to standby buffer irrespective of test results and the decision for acceptance was taken at a later date by the magnet experts. This led to a need for a large storage of standby magnets in SM18 region, a situation which was not tolerable since it hampered the throughput from the test hall. In order to tackle this issue, the operation team was empowered for round the clock decision taking on the first level of goodness evaluation, based on the test results. This empowerment and progression of first-level responsibility away from equipment specialists was a crucial, time-saving necessity; a tool to generate a single-page report of the rule-based magnet goodness evaluation called Magnet Appraisal & Performance Sheet (MAPS) (Fig.5) was developed by the operation team to facilitate this task. MAPS summarizes the major test results and the quench performance of the magnet. This proved to be a very efficient tool to aid in rapid decision taking, thereby to mitigate the issues of magnet storage logistics locally [8].

**CONCLUDING REMARKS**

LHC magnet series tests which began in 2001 were completed almost within the schedule, by mid Feb. 2007. Significance of the operational tools and strategies in successful completion of the magnet tests may be visualized from the sharp rise in throughput since early 2004 [2], [7]. This success reinforces the notion that for any large project with stringent infrastructure and other limitations, much may be accomplished through effective experience-based feedback, appropriate implementation of innovative strategies & tools as well as effective empowerment of staff directly concerned in the process flow.

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