LHC MAGNET TESTS: A CHALLENGE FOR AN OPERATIONS TEAM

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Abstract

In 2002 it was decided that the Accelerator Operations group would assist in the testing of the LHC magnets, which at the time was the major bottleneck in the LHC project. For Operations, this was a great challenge, not least because the team set up for this task was highly heterogeneous. Operations group persons were mixed with staff from other departments and with external contractors; furthermore, the core of the staff for the operation work was coming from India, as part of a CERN-India collaboration. This multi-cultural team and the tight schedule pushed the tests operation team to develop various innovative techniques, particularly since late 2003, in order to complete the superconductor magnet tests by early of 2007. These techniques, which were rigorously applied to ensure the successful and timely completion of the tests, are described.

INTRODUCTION

The LHC required [1] 1706 cryo-magnets to be tested at CERN. These magnets were the 1232 cryo-dipole bending magnets (with correctors), the 360 Short Straight Sections (SSS) integrated with arc quadrupoles needed for the standard FODO lattice functions, and the 114 Matching & Dispersion Suppressor region magnets integrated into Special SSS [2]. Testing all these magnets at 1.9 K was a pre-requisite to their installation in the LHC tunnel. These tests were not feasible at the manufacturers' factories, due to lack of cryogenic and powering facilities; hence, the SM18 Test Facility was built at CERN.

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. For the complex and numerous jobs repeatedly required to perform the complete tests of LHC cryo-magnets, CERN had taken the approach of splitting the tasks by area of expertise, namely, mechanical aspects, cryogenics and electrical/magnetic measurements, in 3 distinct teams. For the mechanical tasks, mostly those of connection and disconnection of magnet electro-mechanical interfaces and transport, the activities were outsourced to an industrial contractor. The operation of magnetic & electrical measurements, which had to comply with strict procedures, was conducted by CERN and supported through a collaboration programme with India. Last but not least, the operation of cryogenics was also part of another industrial contract in the field of cryogenics. To accomplish the massive and time-bound objective, some effective management principles had to be addressed, necessary supporting tools and strategies developed, and a a certain level of operator empowerment had to be efficiently implemented. This paper describes some of the innovative operational tools and strategies developed by the SM18 operation team, which played a crucial role in the successful completion of these magnet tests.

WEB SERVICES

At the beginning of the magnet tests program in November 2002, the situation in SM18 was critical. Only one prototype test cluster was operational, the nature of the tests to be performed was not clearly established and the software tools to run the facility were not finalized. The first thing that operation team tried to set up was an agreement on a "To-Do-List" [3] that described the minimum set of tests to be performed on a magnet. This in turn led us to set up the tools able to generate specific paper templates obeying the "To-Do-List" – the so called Magnet Test Report (MTR) where all the test results per magnet were manually logged. However, when more benches came into service, the need for a global view of the facility became evident. The second point where operation has played a crucial role from the beginning was to identify bottlenecks in the test procedures. Everybody knew that the facility was late in meeting the foreseen schedule but few people understood exactly why that was so. By defining rigorously each test and publicizing the time that it took [4], displaying on screens around the facility the team responsible, as well as through automatic generation of statistics, we were able to put in the effort where it was necessary. All those tools were centralized on a web site called SM18 Test Management System (SMTMS) [5]. SMTMS gives tremendous flexibility for statistical analysis and presentation of test data, and served as the hub of the so called tests & results repository. Web tools were also developed to link this database with the official CERN magnets database called MTF. In parallel, a tool called e-traveller was also developed. The latter can be summarized for each team as "what one has to do, when and where".

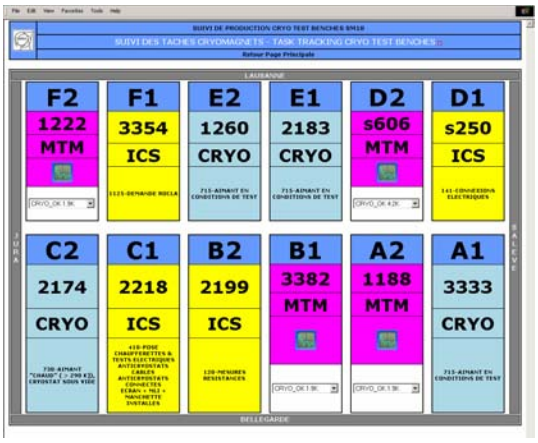

Figure 1: Electronic Traveller

This adage is translated graphically on a web page symbolizing the 12 test benches as 12 blocks (Figure.1) displaying the following information: the tag of the test bench, the designation/name of the cryo-magnet on which the test sequence is running, the team involved in the current operation (3 colours for 3 teams) and a short sentence explaining the currently ongoing task.

Once its current task is completed, the respective team has to acknowledge it by signing it in the e-traveller. The display is then incremented to the following task. If the next task has to be performed by the same team, the web page is just refreshed with the new task. If the next task must be completed by another team, the system also notifies the next team by a mobile phone text message (SMS) and/or an e-mail that it is time to perform a specific action on a specific bench. By these means, every team receives automatically information on what it has to do and where. Finer processes were also implemented: some task signatures trigger additional or pre-warning messages and special SMS messages are dispatched to the team managers, to help them to optimize the process. Using SMS and colours, language sensitivities due to French speaking staff and Indian Collaboration personnel were automatically catered for, easing communication enormously.

SMTMS and E-Traveller, being synchronous, mashed web systems, permitted 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 the history of any magnet ever tested in SM18.

LHC SM18 Magnet Test Facility				
12	A1	MBBR3316	ICS 4 Final connection	294.55
4	A2	MBAL1205	PT 12 Warm Up	258.03
3	B1	SSS132	PT 6.2 Training 2	11.99
6	B2	SSS010	PT 12 Warm Up	74.28
7	C1	MBBL3636	Thermal Cycle	2.35
1	C2	MBAL2168	PT 6.2 Training 2	5.13
2	D1	SSS151	PT 6.2 Training 2	1.90
8	D2	SSS095	Thermal Cycle	15.67
10	E1	MBAL1177	Prep 5 Cool Down	92.61
5	E2	MBAL1208	PT 12 Warm Up	253.65
9	F1	MBAR3303	Prep 5 Cool Down	4.61 HV
11	F2	MBAL3162	ICS 4 Final connection	293.65

Figure 2: Video Display

REAL TIME DISPLAYS

To help the various teams in this environment evolving rapidly in terms of workload and changing priorities, it was decided to make the information easily and widely available through displays. Among those displays are the e-traveller and a video display showing on a single page different information coming from different web sites such as the priority of the magnet, its name, the last test completed and the temperature (Figure 2). Showing permanently this screen in the control room allowed each visitor to understand at a glance precisely where we were in the test flow.

To reinforce this view, another display was also set up showing the time taken by each phase of the test (Figure 3).This was a very challenging task because everyone had to agree on the time boundaries. Hence, a lot of background programs had to be written to ensure that the various databases used for this project shared the same series of test and time stamps.

Magnets under Test on 13-09 3:25:35 PM

-	Bench	Magnet	Sh.	Tested	Quench	Start	Connect <24h	Cooling <26h	Cold Test <36h	Warming <12h	Disconnect <12h	Total
1	TBA1	MBAL3391	X	1	4	10-09	26h	26h	27h	6h	-	85 h.
2	TBA2	MBAL3402	X	1	0	11-09	22h	20h	-	-	-	42 h.
3	TBB1	MBAL1230	X	2	2	12-09	0h	16h	12h	3h	-	31 h.
4	TBB2	MBBL1197	X	1	0	10-09	29h	37h	3h	-	-	69 h.
5	TBC1	MBBL1217	X	1	3	09-09	54h	-54h	94h	16h	0h	112 h.
6	TBC2	MBAL2138	X	1	0	10-09	35h	31h	-	-	-	66 h.
7	TBD1	SSS293	X	1	0	10-09	68h	-	-	-	-	68 h.
8	TBD2	SSS606	X	2	15	08-09	0h	19h	96h	-	-	115 h.
9	TBE1	MBAL1087	X	1	0	13-09	11h	-	-	-	-	11 h.
10	TBE2	MBBL2188	X	1	3	08-09	46h	26h	29h	17h	7h	125 h.
11	TBF1	MBAL2177	X	1	4	09-09	29h	21h	20h	16h	1h	91 h.
12	TBF2	MBBL2143	X	2	0	11-09	29h	11h	-	-	-	40 h.

Figure 3: Time Tracking Display

MAGNET TRAINING CRITERIA

Another side effect of the statistics availability was the possibility to extract interesting facts about the magnets. This permitted the introduction of modified training rules, in order to gain time. In this scheme, 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 [6]. Based on this, a new training rule named the 'Two-Quench Rule' was accepted by the magnet experts, under which it was recommended to carry out 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 was also accepted if it crossed a field of 8.66 T (12250 A) in the third quench, even if it has not passed the preceding rule [3].

OVERALL & CRYO PRIORITY HANDLING

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

The limited cryogenics infrastructure [7] in SM18 could 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. Therefore, we used the web database to characterize each magnet, depending on the last test carried out and the associated cryogenic phase. A web page showed a grouping of the magnets that could be in concurrency for the same resources. Based on this information, the shift leader was able to choose which magnet should have the highest priority [8]. After assignment, the system status and resources allocation was displayed through SMTMS. (Figure 4)

Cold Tests	Bench	Temp.	Priority
10 - 1.9 [K] since 8h 56' (PT 3 QH Measure)	TBC1	1.90	5
Warming up or Cooling Down	**Bench**	**Temp.**	**Priority**
6 - COOLDOWN TO 80 [K] since 9h 36' (Prep 3 Cool Down)	TBA1	127.67	8
13 - WARM UP TO 300 [K] since 10h 31' (PT 12 Warm Up)	TBA2	273.31	1
13 - WARM UP TO 300 [K] since 58' (PT 12 Warm Up)	TBF2	69.49	3
Cooling 80 K to 4K	**Bench**	**Temp.**	**Priority**
Warm	**Bench**	**Temp.**	**Priority**
2 - CONNECTING MAGNET since 8h 10' (ICS 2 Connect Magnet (ICS))	TBB1	297.41	11
52 - OVC PURGE since 23' (ICS 4 Final connection)	TBB2	297.86	7
2 - CONNECTING MAGNET since 56h 6' (...)	TBD2	296.43	12
2 - CONNECTING MAGNET since 10h 47' (ICS 1 WP04 HV Test Warm)	TBE1	298.04	9
52 - OVC PURGE since 2h 33' (ICS 4 Final connection)	TBE2	296.79	6
16 - OVC AT ATM. since 13h 29' (PT 13.2 Resist. Meas.)	TBF1	296.88	10
Other	**Bench**	**Temp.**	**Priority**
9 - LHe FILLING since 2h 26' (PT 11.4 K Quench SSL)	TBC2	2.35	4
15 - MAGNET AT 300 [K] since 10h 27' (PT 13.2 Resist. Meas.)	TBD1	275.82	2

Figure 4: Priority Control

FURTHER STRATEGIES IN OPERATION EMPOWERMENT

Another important step towards reducing the overall magnet tests duration was the introduction by the operation team of a strategy called Rapid On-Bench Thermal Cycle (ROBTC). Under this strategy, a magnet with poor performance was subjected to a rapid thermal cycle without disconnecting or removing it from the bench; an additional sequence of minimal power tests was performed to qualify the magnet, thereby saving a considerable amount of preparatory tests time and connection / disconnection time [9]. Further time-saving came from the round-the-clock decision-making on the performance of a magnet by the operator, based on the results in the Magnet Appraisal and Performance Sheet, provided by the web-based SMTMS [10].

HUMAN RESOURCES AND BUILDING TEAM SPIRIT

The LHC magnet tests operation has also been a very successful example of a large scale collaborative effort in terms of human resources; over 90 persons from India have spent one year each at CERN since 2002 and hence, it is probably a unique example in international collaboration on that scale in the particle accelerator domain. The training and mentoring of the rapidly rotating, one-year stay Indian colleagues was a significant on- the-job challenge where, the web based tools and rigorous development and maintenance of the written procedures played an essential role. The collaboration and discussions with engineer-level Indian colleagues and refreshing Indian tea breaks during round-the-clock shifts made the tedium of repetitive and routine work more pleasurable. On their days off, the SM18 operation crews organised group visits to local tourist destinations. They also celebrated Indian cultural festivals and even formed teams for cricket matches.

CONCLUDING REMARKS

Although the work of testing magnets was essentially repetitive, it also presented a considerable mental challenge and carried considerable responsibility, largely due to the significant costs that these unique elements bear on the overall LHC Project. Operation crews therefore had the opportunity to perform various tasks in technical management and coordination of a large undertaking. The operation crew's pragmatism and tenacity, characteristic in an accelerator control room, played a major role; this can be visualized from the sharp rise in throughput since early 2004 [3]. For most of the people working in operation in SM18, those years were very challenging in terms of everyday stress in a situation of scarce resources. The team spirit developed in those days justified the efforts put in. This work has successfully met the LHC Project deadline, unlike many other subsequent activities where operation-like tasks are differently managed. The latter further emphasizes the point that the vision defended by the heterogeneous operation team for magnet tests since early 2003 was the right one.

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