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, mashed 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 co-ordinating 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

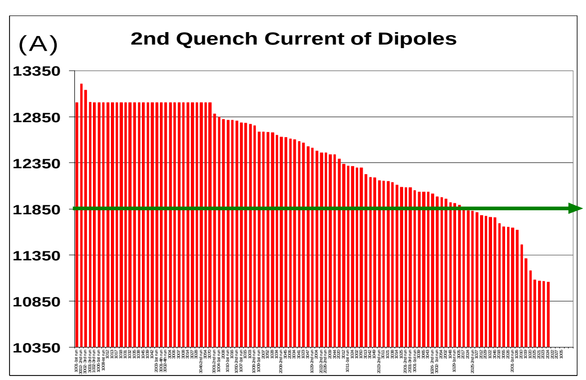

Figure 1: 2^{nd} Quench current of dipoles till Dec 2003

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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

Magnet	300-80K (Hours)	80-4.2K (Hours)	4.2-1.9K (Hours)	1.9-300K (Hours)
Dipole	16	10	4	15
Quadrupole	8	7	3	12
Special SSS	8	7	3	12

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

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.

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 5 Cool Down)	TBA1	127.67	8
13 - WARM UP TO 300 [K] since 10h 31' (PT 12 Warm Up)	TBA2	273.51	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 3: Typical cryogenic priority allocation

1	A2	2393	285		90	A2	C1	C1
2	D1	S317	276			F2	C2	A2
3	F2	2374	104		88	A1	A2	D1
4	C2	s339	4.6			D1	D1	F2
5	C1	s360	1.9			C2	F2	C2
6	E2	2357	297			C1	E2	E2
7	B2	s353	297			E2	B2	B2
8	A1	1373	107	83		B2	A1	A1
9	E1	2389	298			E1	E1	E1
10	F1	2381	296			F1	F1	F1
11	B1	s518	297			B1	D2	D2
12	D2	S515	296			D2	B1	B1

LHe DEWAR LEVEL: 71 %
LN2 DEWAR LEVEL: 72 %
BALLON VOLUME: 72 m^3
1.9 [K] Pumping Resources: 1(WPU1) + 4(WPU2) = 5 [g/s]
TOTAL HELIUM FLOW THRU CWS: 274 [g/s]

Figure 4: Resource allocation after priority change

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 (1or 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 stand-by 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].

Magnet Appraisal & Perf sheet (MAPS)

Goodness Evaluation

Magnet Name	SSS531
Bench Name	TBB2
Date of Arrival	Wednesday, January 31, 2007
Departure Date	Tuesday, February 13, 2007

#	Test	In SMTMS	Result	MTF
1	WP04	Not found	?	not transferred
2	CDW1 HV	-	OK	transferred
3	CDBP HV	-	OK	transferred
-	Shafts	No		
4	Training 1	12093.7A		
-	Training 2	12667.2A		
-	Not Trained in	3 training		
-	Maximum current	12808.1A		
5	CDAP HV	-	OK	transferred
6	CDR or CQR	-	OK	transferred
7	WP07 HV	Not found	?	transferred
#	**Test**	**In SMTMS**	**Result**	
8	PT 14 Magnet MAPS	-	Stand By	
#	**Comments**			
10	NC in Corrector Powering (PT 5.4)			

Figure 5: MAPS sheet of a standby magnet

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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