TESTING OF THE LHC MAGNETS IN CRYOGENIC CONDITIONS: OPERATION CHALLENGES, STATUS AND OUTLOOK

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Abstract

For the Large Hadron Collider under construction at CERN and the testing of its 1706 Cryo-magnets in cryogenic conditions, considerable challenges had to be overcome since 2002 to arrive at the situation of today, with semi-routine operation of the purpose built tests facility. With the setting up of an Operation Team comprising of few non-expert CERN Accelerator operation staff, and a large external collaboration, it was essential to develop the methodology of working in light of external collaboration limits and base it on CERN-known techniques and experience in accelerator running-in, commissioning and routine operation. A flavour of the operation tools that were necessary or developed will be given, i.e., web-based tests follow-up management & information systems, development of precisely defined 'to do list' of tests sequences, associated methods, procedures and strict check-lists, electronic logbooks and so forth. The presentation will briefly outline the tests operation programme and its context & constraints, give a summary of the accomplishments so far, together with the outlook for the successful completion of the whole programme within the project goals.

INTRODUCTION

The LHC requires [1] at least 1706 cryo-magnets to be tested at CERN: 1232 cryo-dipole bending magnets (with correctors) are the largest component of these. Secondly, 360 Short Straight Sections (SSS) integrated with arc quadrupoles are needed for the standard focusing / defocusing lattice functions. Lastly, 114 Matching & Dispersion Suppressor region magnets integrated in Special SSS (IR-SSS) also need testing. The testing of all these magnets at 1.9 K is a pre-requisite to their installation in the LHC tunnel. These tests are not feasible at the manufacturers; hence a facility was built at CERN (called SM18). The SM18 tests facility is structured as shown in figuratively below.

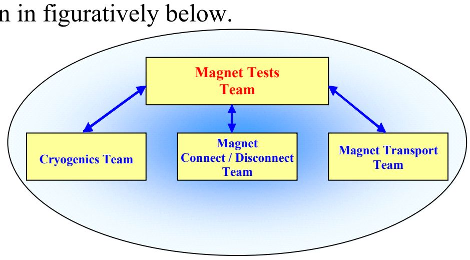

Figure 1: SM18 Functional Structure.

The key element of the structure is the Magnet Tests Team, which interacts with the other teams such as the Cryogenics, Mechanics and the Transport team to complete & complement the tests activity.

The tests activity on a magnet is broadly classified into 5 phases. These are Connect, Cool down, Cold tests, Warm up and Disconnect phases. The average time frame for these phases is shown in Fig 2, including the total reference time frame (108 hrs). The average phases' duration may even exceed the reference durations, as seen in Fig.2. The different colours indicate the various phases.

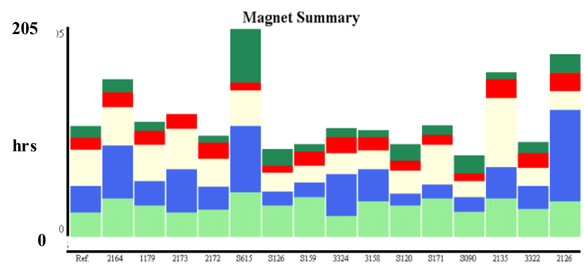

Figure 2: Performance for Week from 01 May 2005. The reference complete sequence is in the first histogram with its average estimated values per phase in parentheses below.

- Light green: Connect + Pump down (24 hr)
- Blue : Wait + Cool down (26 hr)
- Ivory: Tests at Cold at 1.9K (36 hr)
- Red : Wait + Warm up (12 hr)
- Dark Green: Disconnect (10 hr)

OPERATIONAL CHALLENGES

With financial restraints, it was considered that a testing facility of 12 test benches arranged in 6 clusters would be adequate to meet the project requirements [2], [3]. A cluster also shares common equipment & electronics systems. The consequence of this arrangement is that two magnets on a single cluster cannot be powered simultaneously. Additionally, the water capacity too is restricted to power 4 magnets at a time.

The cryogenics infrastructure capacity has increased in 2005, but still, it has its constraints in warming, cooling and the number of quenches permitted in real time for the available benches. All these requirements impose priority settings & continual sequencing in the testing regime with multiple benches under operation.

The operation team comprises of few CERN accelerator operation staff and a large external collaboration from Dept. of Atomic Energy, India. The Indian personnel are available only for fixed one-year periods. Hence, there is a constant rotation of personnel and inherent learning.

All these conditions therefore pose formidable challenges to set up and run the tests facility.

[1]On Behalf of the CERN SM18 Operation Team

THROUGHPUT STRATEGIES

To achieve the strategic objectives it was necessary to plan, schedule and track the progress of the magnet tests. Secondly, a "follow up management" scheme had to be developed to check the technical and numeric throughput of the facility. Operational practices have been continuously modified to achieve the project objectives.

The streamlining of the operations was initiated by creating a "To Do List", which described the minimum sets of tests that had to be performed on a magnet. It was agreed that the additional tests would be carried out only if requested in advance.

To collate tests results and produce summaries, the SM18 Tests Management System (SMTMS) was developed [4]. It extensively uses the CERN network backbone in providing Web based services as well as the features of the ACCESS database. With this tool, it was also possible to keep track of times taken during the various phases in magnet preparation for the tests, cryogenic connections, cool down, warm up and so forth. As it is web based, all persons directly concerned could keep track of the progress from varied geographical locations in CERN & outside as well as from the tests hall. Fig 3 shows an example of the real time information available in SMTMS.

LHC SM18 Magnet Test Facility

6	A1	MBBL3235	PT 6.3 Training 3	1.90
5	A2	MBAL2129	Prep 5 Pumping + Cool Down	137.39
1	B1	SSS601	Prep 5 Pumping + Cool Down	181.11
9	B2	MBAL2156	Prep 5 Pumping + Cool Down	251.89
2	C1	MBBL1196	PT 12 Warm Up	262.94
3	C2	MBAL2150	Prep 5 Pumping + Cool Down	93.26
8	D1	SSS100	PT 5.2 1.5 KA Quench HF	1.91
10	D2	SSS019	ICS 3 Traveller after warm test	290.71
4	E1	MBBL2147	PT 12 Warm Up	234.95
12	E2	MBBL2137	Prep 5 Pumping + Cool Down	291.87
7	F1	MBBL1199	PT 6.5 Training 5	4.69
11	F2	MBAL2154	Prep 3 CDW1 HV	290.53

3/3/2005 4:13:43 PM Temperature data are taken from TBSM18 site

Figure 3: Real time information on Tests.

As shown in fig. 1, interaction between the various teams is required during the different stages of preparation before testing could begin or, at the end of the tests. A computer based tool in the form of an Electronic-Workflow manifest was also created [5]. The interface of this tool with mobile phones alerts & informs relevant teams (via short message service) of the need for their services on a particular magnet.

Graphical displays to highlight the status of the various resources (water, power and cryogenics) are generated by providing an interface with software programs running under different operating systems. Hence the real time information on resources is available on a single window to the operation team. This enables the operation crew to optimise resource usage and prevent resource conflicts from arising. The resource display is shown in Fig. 4.

The Electronic Faults Logbook is extensively used to keep track of faults in the various tests systems. This logbook helps in categorizing faults that occur. Availability of statistical distribution of faults helps in the identification of commonly occurring faults, leading to improvements and elimination or reduction of these.

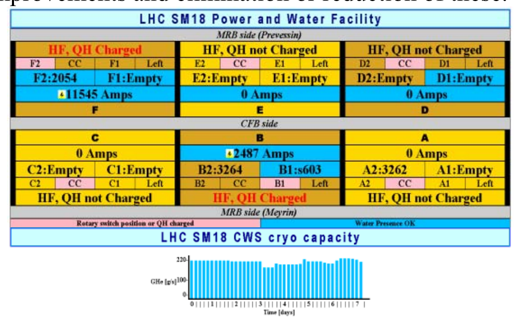

Figure 4: Power, Water & Helium flow [g/s]

Routine error-free operation is only possible by means of organised methods and procedures. A documentation strategy has been developed which facilitates easy integration of rotating staff to the tests operation. The documentation consists of several levels of complexities from a single sheet "Tests made easy" to a brief but complete description of each test, further example trouble shooting aids as well as full checklist of the work to be carried out in the form of step by step test reporting sheets. These documents are written by the operation staff for use in operation, after consultation with the experts. A specific website has been designed and implemented for this purpose.

One of the most important factors that influence the success in operation is the follow-up management. A weekly operation review meeting is held with the aim of discussing the problems encountered & the milestones achieved during the preceding week. Plans for the following week are also discussed. The forum is used extensively to address issues raised by the operation and support teams.

ACCOMPLISHMENTS

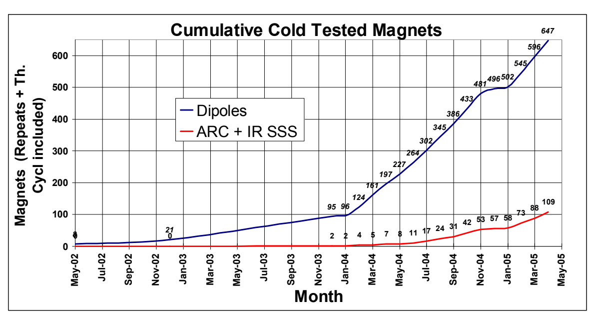

Figure 5: Cumulative Cold Tested magnets.

The implementation of focused tests rules, better operational practices and the commissioning of all the 12 test benches in 2004 assisted in increasing the throughput. The rate of the cold tests of the dipole and quadrupole magnets was considerably higher during 2004 compared to the preceding year [6]. This is shown in Fig. 5, together with a Table 1.

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In 2004 a total of 401 Dipoles, 52 Arc-SSS and 3 IR-SSS were tested. Tests rate of ~ 55 magnets per month was achieved.

Table 1: Summary of Tests

	Dipole Tests	Dipoles Repeated	Arc-SSS	Arc-SSS Repeated	IR-SSS
Year 2003	95	Not Applicable	2	Not Applicable	Not Applicable
Year 2004	356	45 (~11%)	49	3 (~ 6%)	3
Year till April 2005	134	17	43	5	4
TOTAL 2004	401 Includes Rejects & Repeats		52 Includes Rejects & Repeats		3
Cumulative Total	647		102		7

OUTLOOK

Although the number of cryo-magnets to be tested is 1706, the number of tests will be higher, due to the retests. From the present operational experience, it is estimated that finally ~1900 magnet tests will be needed, assuming a retest figure of ~11%. This leads to ~69 magnet tests per month to terminate the testing activity by end 2006, as shown in Fig. 6 [7].

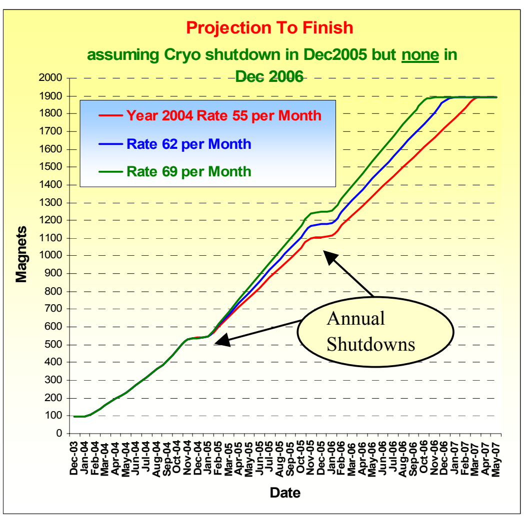

Figure 6: Estimates on a simple magnet count basis.

In early 2005, a course of action was decided upon to enhance the throughput, without compromising the test objectives. It was estimated that the bench occupancy time for dipoles would reduce from ~ 137 hours to ~120 hrs. A drastic reduction in testing time of the Arc SSS's was also foreseen, leading to ~ 137 hrs compared to ~ 209 hrs in 2004.

It is estimated that these tests times would translate to 52 dipoles & 16 Arc-SSS tested per month. The bench configuration assumed for these figures is 8 and 3 benches dedicated to dipoles and Arc-SSS respectively. One bench would be reserved for the testing of IR-SSS. The most notable assumption made in these projections is that the appropriate magnets would be available for testing purposes as and when required.

The results from 2005 so far confirm that the estimates have not been off the mark, with a test rate of 72 magnets per month, achieved in April. Considering that the LHC project is unique in many ways, there is still some unknown and novelty component that may arise with implications for the magnet tests. Hence one has to be prepared to carry out the additional tests in the wider sense of the project. However, with current experience, one can still be reasonably confident to meet the project deadlines for the tests activity.

CONCLUSION

Despite CERN's financial constraints in 2000, late delivery of tests benches and related equipment, and certain under capacity in cryogenics till last year, the cryo magnet testing programme is now fully on schedule to meet the project deadlines.

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