

CRYOGENIC MAGNET TESTS FOR THE LHC: PROCESS OPERATION USING WEB-BASED TOOLS AND FACILITIES

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ABSTRACT

For the Large Hadron Collider under construction at CERN, an essential requirement is the acceptance test of its 1706 Cryo-magnets in cryogenic conditions in a purpose-built facility at CERN. Several teams ensure the proper operation of the infrastructure on a round the clock basis. The cold test part is one of the key elements amongst many other essential activities requiring magnet transport and connections/disconnections, cryogenic preparation and pumping, cooling down to 1.9 K as well warm up before disconnection & removal. All these operations involve multi-tasking and usage of 12 test benches with nominal turn-round time per dipole magnet of 120 hours. It also involves multiple teams of industrial contractors, a support contract for cryogenics operation, CERN staff in magnet testing Operation, aided by a large external collaboration of visiting staff for round the clock operation. This paper gives a flavour of the operation and exposes the software tools that were necessary, designed and developed to run the magnets test facility in the most structured way, both from the global teams' interaction point of view as well as for the cryogenic, electrical and magnetic tests management over the tests life-cycle. It explains how the complexity and the volume of tests are managed in the most automated way by our control systems and web-based management tools, using backbone database applications helping the different operation teams to work together efficiently and in harmony to meet the tight tests schedule for the LHC.

INTRODUCTION

The LHC requires [1] 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 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 the SM18 Test facility was built at CERN.

All the 1706 LHC cryomagnets are planned to be tested in a 3-year period. The standard operation of the acceptance tests has been developed and we started to implement the tools described here in parallel with the construction & assembly of more than half of the benches of the SM18 Tests Facility. This challenging objective led CERN to set-up industrial methods and support structure where applicable. A peak test capacity of up to 16-18 cryomagnets per week has been achieved. This paper describes briefly the typical test process cycle and how the web-based systems have helped to improve the functioning of the facility in terms of operation and management.

WORK CONTEXT & HARDWARE /SOFTWARE INFRASTRUCTURE

The following paragraphs describe the overall work context and the typical process overview. The cryogenic supervision system is described in somewhat greater detail than the magnet tests system because it has not been dealt with in earlier ICALEPCS conferences. Overall, the process is broadly split in 3 parts shared between three different teams.

1. Mechanical tasks: connection and disconnection of cryomagnets.
2. Cryogenic aspects covering magnet cool down, running at 1.9 K and warm up.
3. Testing and Measurement at warm and under cryogenic conditions.

The 12 test benches facility is arranged in 6 clusters. Each cluster is equipped to accept 2 magnets at the same time but sharing the measurement electronics equipment and power supply. 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 has its constraints in warming, cooling and the number of quenches permitted in real time for the available benches. All these requirements therefore impose priority settings & continual sequencing in the testing regime with multiple benches under operation for all 3 sub-processes.

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

Nominal times to test a magnet are:

- Connection :12 hours
 - Vacuum pump-down :12 hours
 - Cool down: 26 hours
 - Cold magnet tests: 36 hours
 - Warm up :12 hours
 - Disconnection: 10 hours
- Total time for one cyodipole is ~ 108 hours

Fig 1: Typical situation on 12 benches

Cryogenic plant & Controls

The control system is designed and built in an industrial manner [2] with PLC units and Supervisory Control (SCADA) applications running on PC's. A network of PLC's linked together by TCP/IP and Profibus™ protocols control the cryogenic processes. This system of PLC's hosts ~850 analog inputs, ~1650 digital inputs, ~350 analog outputs and ~1200 digital outputs. The PLC system is the first logical level of control; it handles all the real-time tasks, runs the ~380 PID's control loops of all regulated objects, assures the safety and the reliability of the installation through program sequences and background processes. Using the TCP/IP protocol, the PLC system transmits the status and physical measurements values to the second layer, namely the SCADA system. The latter displays the animated synoptics, trends & alarms windows and transmits all the control parameters and the operator commands. An exhaustive set of flags and alarms centralized and summarized per system helps the operator in diagnosing process deviation or possible equipment malfunction. The majority of the program parameters are custom-tailored through the SCADA application to permit the tuning of any process. The SCADA applications are running on 8 PC's, 6 for the 6 clusters (6 pairs of Cryo-feed boxes, CFB's) and 2 for the general utilities of the cryogenic plant.

Magnet Test Benches & Controls

The magnet tests and measurement control systems have been amply described elsewhere [3]. It suffices here to say that the hardware infrastructure is based on SUN workstations linked to VME crates by MXI bus for the low level acquisition. For the higher level, we have SUN workstations in the control room. For the 6 pairs of test benches, there are 6 independent tests systems, i.e., the tests on any one magnet are carried out by independent labview based applications without coupling with other magnets and tests applications on other benches. In that sense, each test bench has its own labview based system with one-to-one correspondence to one of the 6 workstation consoles in the control room.

There is a mix between commercial and CERN produced software, but contrary to the accelerator control room, the applications have not been written or specified by the tests operation team.

Summary of processes in a magnet test cycle

The cryomagnets are cryostated and configured for stand-alone testing (i.e., equipped with a cryogenic return box – mainly return loops pipes - and with two anti-cryostats when magnetic measurement are required). They are then transported by the means of a special wire-guided transport vehicle to the selected test bench in the test hall. They are further positioned, aligned and levelled on the supporting structure of the CFB. The cryomagnet 12 kA connections are *in-situ* soldered and mechanically secured. The retractable sleeves housing the electrical joints are stretched out and locked in closed position. The six flanged hydraulic connections are tightly bolted. An automatic helium leak check of the just-connected hydraulic circuits is performed to ensure the correct tightness. The dismountable thermal shield and the multilayer insulation (MLI) blanket surrounding the connection area are fitted. Lastly, the vacuum sleeve is pulled out and tightly bolted. At this stage, the magnet instrumentation cables are connected and electrical measurement & protection circuits checked for conformity at room temperature. Then, the vacuum enclosure is roughly pumped down (by means of a vane pump) to ~1 Pa and rinsed 3 times with dry nitrogen to extract as much as possible the moisture trapped in the cryostat. The secondary pumping then begins to arrive at ~0.1 Pa and a global helium leak rate measurement is done on the cryostat. The cooldown to ~90 K is done by means of helium circulated at 80 K. Subsequent cooldown to ~4.5 K

and filling is done through a 2-phase helium distribution, and lastly, the cool-down to superfluid helium temperature carried out by means of the 1.9 K pumping facility.

The cryomagnet coils are maintained at 1.9 K throughout the power tests and magnetic measurements when requested. The coils are cooled back to 1.9 K after training quenches (resistive transitions) in typically 5 hours. A thermal cycle to room temperature is applied for magnets requiring long training. At the end of magnets tests, the magnet is ramped up to nominal current for sustainability and finally, quenched forcibly at a lower energy to assist the helium emptying in the cryomagnet. The cryomagnet is subsequently warmed up to 295 K over several hours and the vacuum enclosure is pressurized up to atmospheric pressure with nitrogen gas. Then the vacuum sleeve is pulled away, the MLI & thermal shield are removed and the helium circuits that are to be disconnected are automatically purged with nitrogen gas. The hydraulic and electrical interfaces are disconnected after a last high-voltage test. The tested cryomagnet is then transported back for stripping off (removal of test configuration in cryomagnet). A typical summary of 12 concurrent test processes running in the so-called “cog wheeling” fashion over 12 test benches is shown in Fig.2.

Work Teams & human Interaction

For the complex and numerous jobs repeatedly required to be carried out to complete the tests of the LHC cryomagnets, CERN has taken the approach of splitting the tasks by areas of expertise: mechanics, cryogenics and magnetic & electrical measurements, hence, 3 separate teams. For the mechanical tasks, mostly those of (dis)connection of cryomagnet electro-mechanics interfaces, the activities are outsourced via an industrial contract, in the framework of results oriented Work Packages (WP). Each WP is described in an engineering specification document in which the details of the tasks as well as those of the quality control are exhaustively set. The operation of magnetic & electrical measurements, which has to comply with strict procedures, is conducted by CERN staff and supported through a collaboration agreement for highly qualified personnel from India. Last but not least, the operation of cryogenics, which relies on predefined procedures for acting on modular or shared infrastructure, is also outsourced within the framework of a dedicated resource-oriented contract. In addition, CERN ensures the training and on-the-job transfer of know-how for the round the clock operation staff of the 3 teams, thus leading to guarantee the accurate execution of the WP's and the correct application of the procedures as applicable.

This division by nature of the tasks has lead us to design software tools to monitor and improve, and to some extent formalize, the communication between the 3 teams involved in the execution of the interleaved tasks of the whole process, in order to enable the respective teams to work together in the most efficient way.

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	✗	1	4	10-09	26h	26h	27h	6h	-	85 h.
2	TBA2	MBAL3402	✗	1	0	11-09	22h	20h	-	-	-	42 h.
3	TBB1	MBAL1230	✗	2	2	12-09	0h	16h	12h	3h	-	31 h.
4	TBB2	MBBL1197	✗	1	0	10-09	29h	37h	3h	-	-	69 h.
5	TBC1	MBBL1217	✗	1	3	09-09	54h	54h	94h	16h	0h	112 h.
6	TBC2	MBAL2138	✗	1	0	10-09	35h	31h	-	-	-	66 h.
7	TBD1	SSS293	✗	1	0	10-09	68h	-	-	-	-	68 h.
8	TBD2	SSS606	✗	2	15	08-09	0h	19h	96h	-	-	115 h.
9	TBE1	MBAL1087	✗	1	0	13-09	11h	-	-	-	-	11 h.
10	TBE2	MBBL2188	✗	1	3	08-09	46h	26h	29h	17h	7h	125 h.
11	TBF1	MBAL2177	✗	1	4	09-09	29h	21h	20h	16h	1h	91 h.
12	TBF2	MBBL2143	✗	2	0	11-09	29h	11h	-	-	-	40 h.

Fig 2

WEB BASED TOOLS & CONCEPTS

With many people from different teams working together, it became obvious that : (a) we needed a common reference system for tracking the current status of the test stations, (b) concurrent access to one common database to track the work done and above all, (c) the next task required to be done (magnet by magnet but also week by week). Given the fact that the magnet tests operation team on the ground had to face the problems and find ways to go forward without any obvious manpower support, we decided to find solutions by ourselves using the standard tools provided by CERN's IT Dept. to create, set up and run web based tracking & tests management systems.

The job was divided in 2 parts:

- a) TTS system (Task Tracking System) which gives the global bench overview with team responsibilities and showing us which team is working on which bench and the outstanding or pending task.
- b) SMTMS (SM18 Test Management System) with a magnet overview recording the sequence of tasks performed on each magnet.

The SMTMS was also foreseen as the tool for summarising and validating the magnet performance results at the end of the tests. It was not foreseen as a formal results database; rather, it is a tool to permit real-time transparency in tests results visibility to all within CERN as well as help in generating the results reports and facilitated upload of relevant files and data to the main LHC database called MTF. If required, the possibility exists to export this Microsoft Access based system to a more robust database (Oracle)

A significant part of this project was also the video distribution of various screens from the web sites and the placement of TV monitors all around the Tests hall and in the control room. This has eased the tests related work for all teams enormously.

TTS

An audit of the whole process was performed with all the involved teams to agree on a common and standard, well-defined process sequence. This led to the birth of the “Tasks Tracking System” (TTS). It consists of a web-based database which organizes the process in blocks of sequences of tasks to be completed by the 3 operation teams on shift.

The TTS can be summarized for each team as “what one has to do, when and where”. This adage is translated graphically on a web page symbolizing the 12 test benches as 12 tiles (Fig.3) displaying the following information: the tag of the test bench, the designation/name of the cryomagnet 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 current ongoing task.

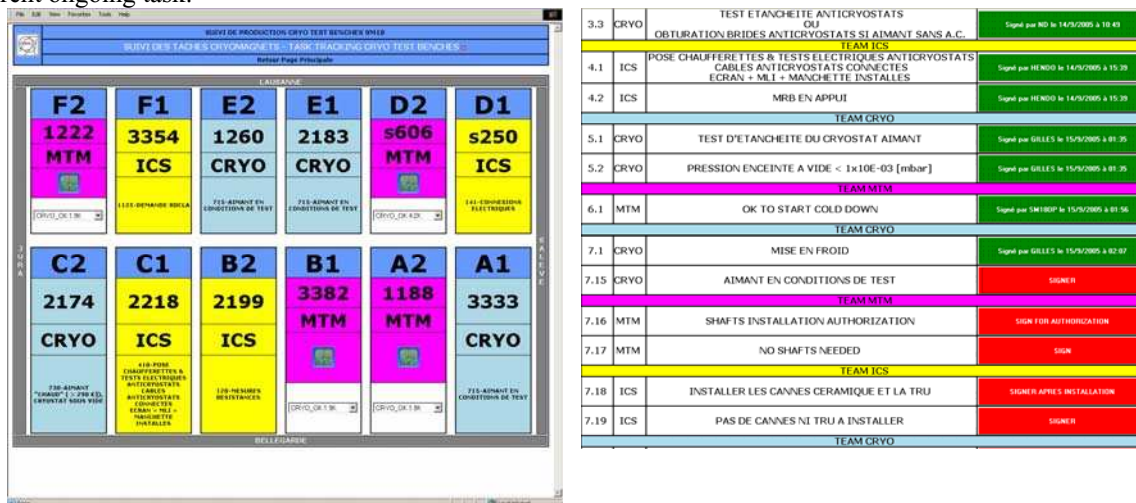


Fig 3

Once its current task is completed, the team has to acknowledge it by signing it. The TTS application then increments to the next 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 increments to the next task and notifies the next team by a mobile phone text message (SMS) and an e-mail that it is time to do a specific action on a specific bench. By these means, every team receives automatically what it has to do and where. Finer processes are also implemented: some task signatures trigger additional or pre-warning messages and special SMS's are dispatched to the team managers to help them to optimize the process. Using SMS's and colours, language sensitivities due to WP contract staff and Indian Collaboration personnel are automatically catered for, easing communication enormously.

The TTS database includes reporting capabilities. Each week, process & production reports may be extracted. Task times are compared with standard ones and deviations are examined carefully. This helps to predict equipment failure or malfunction, to improve operation procedures and to reduce the bottlenecks.

SMTMS

SMTMS (SM18 Magnet Tests Management System) is a web-based database system designed to record the tests undergone by the magnets. It is the only tool giving a global view of the magnet tests carried out at the facility. We used a web service due to its numerous advantages:

- No duplication of work (Earlier, Operation team was asked to fill the same information in many files.)
- Widely available (SM18 floor level, control room, in the CERN domain and on the CERN official web pages)
- Easily customised to our needs (Special tests, repeated magnets, manual tests)
- Data presentation separation (No more excel files with built in Macros)
- Information open to everybody and even the outside world (e.g., via the LHC project page)
- Possible automation of the tasks (automatic updates from TTS or from the labview based tests applications)

Infrastructure

The web server is a dedicated central server running standard web services. This machine is maintained by the CERN IT Dept. The CERN Web Services provide hosting for several thousands of sites and users. The offered functionality covers a wide variety of needs: Static and dynamic pages (CGI, ASP), Secure connections (HTTPS), Access protection, Database connectivity (supports DBs local to your side as well as connections to external DBs), Electronic forms and Site Access log information

At the beginning of this project, only the particular magnet test sequences were put on the web. Thanks to widely available literature on internet, some freeware (generic DB) and help from CERN colleagues, it was possible to run the first prototype version in ~2 months of part-time work. The first version had only a few pages but soon, people became very interested in the tool. The security became a major problem and we decided that only computers in the control room should have the right to write data. This was achieved by discrimination of the IP addresses.

Web based database server

When the system was more widely used, there were constant requests to provide different view of the same data (by bench, by magnet, by date, by number of quench, by shift, etc.), which could easily be provided. Earlier, these processes were very time-consuming because people had to look at many Excel files in different directories. Hence, SMTMS provided the pages giving overview of the tests facility with only one click. This was done as well for instantaneous view and for weekly review. The web server was also able to generate a global overview of the facility concerning the status of each of the utilities (water, electricity, rotary switches, Helium g/s, etc) in SM18.

In the control room, we also have a screen showing the advancement and the time in each phase that each magnet is undergoing on the bench (Fig 3)

The system was also able to generate on-the-fly, old style quench tables for backward compatibility and as well as a M(agnet) A(ppraisal) & P(erformance) S(heet) (MAPS) to help us to determine at first glance if a magnet has passed the necessary qualification tests. From the same page it is also possible to generate a tests sequence undergone by each magnet.

Basic Statistics

The system has evolved with many other tools for statistics, some reserved for specialists, others open to everybody. The 2 more widely used are:

- The Test overview shows the current situation on the test bench and the time taken by each phase allowing operation team to react and take action when a task takes too long.
- The weekly results shows week-by-week the number of magnets tested, the number of quenches per magnet, whether the magnet is undergoing a repeat set of tests, whether it has fulfilled the performance criteria and so forth. There is also a bar graph representation of this.

Later Extensions

The web site is also used to be able to send priority levels [4] for cooling and warming, allowing us to cope as best as possible with the cryogenic limitations in the cooling and warming processes.

The site is used to ease the entering of data in the main LHC database (MTF), by computing direct links to the requested pages instead of manual searching through many pages.

The web site also provides names of the magnet and test description by LED driven displays in front of each bench.

Automating the SMTMS update

In the beginning, all the tests and results were manually entered in SMTMS by the operator from a predefined list of tests. This was also true for the steps that the operation team was not doing (e.g., Cooling down of a magnet is done by the cryogenic team). As the database became more effective, it was desirable that more accurate time stamps were provided. It was a difficult task to fulfil the requirement of concurrency and

consistency on 2 different servers. The idea was that each team should sign only once for an achieved task in either TTS or SMTMS. We have developed a system to automatically look in the TTS web site and update SMTMS database with selected information provided from tasks performed by other teams.

The effort to automate the update of the tests we do was more difficult as the data was not centralised on one web server but distributed over many files on different file systems. Thanks to the power of Perl programming language and with interaction of the existing web site, it was finally possible to scan files on different volumes and generate corresponding test sequences. After this, the operator has to update the record with the result of the quench analysis he has carried out. The operator has of course the possibility to delete or rename the automatically generated report.

Other end-products

The database also generates tables by manufacturer showing the number of quenches for each magnet.

The web site also serves to generate the correct name for the magnet in case the magnet returns for retesting a second or third time. This permits having different directories for magnets when they are retested.

CONCLUSION

More than half of the 1706 cryo-magnets needed for the LHC are presently accepted after cold tests at CERN. The development of Web based tools to help the 3 teams in their round the clock task was an essential ingredient to reach the required test rate. Common databases and organisational tools dramatically improved their efficiency. Now, all people involved in running the facility (operation teams, and management) have far less to worry about logistics problems by relying on our web-based systems and can concentrate longer on their productive tasks. In addition, clear communication is ensured between the teams understanding different languages. So, a better efficiency has been achieved through relatively simple ideas and implementing light-weight software and hardware tools.

The magnets tests programme is now capable of meeting the LHC schedule.

This project has been challenging and very interesting. Despite the novelties in web programming, it was quite easy to find help and support from experienced people at CERN and from the web community. This project has proved its utility as the number of people connected to the site is regularly rising. Information is now widely spread and corrective actions can be rapidly taken if bottlenecks are encountered.

These web based facilities can be also useful in many projects where several teams have to work together. This is particularly true in complex hardware systems' multi-tasking & commissioning where a wide distribution of different information and communication between teams is essential.

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