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LOGISTICS OF LHC CRYODIPOLES: FROM SIMULATION TO STORAGE MANAGEMENT

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Abstract

The main families of LHC superconducting cryomagnets consist of approximately 1240 cryodipoles and 480 Short Straight Sections (SSS). The different contracts, which are constraining the production and installation of these cryomagnets, have been initially rated according to the baseline schedule, based on a "just in time" scheme. However the complexity of the construction and the time required to fully test the cryomagnets require that each contract is decoupled as much as possible from the others' evolutions and impose temporary storage between different assembly and test activities. Therefore, a tool simulating the logistics over the whole duration of the project was created in order to determine the number of cryomagnets to be stored at the various stages of their production. In this paper the organization of cryomagnet flow and the main challenges of logistics are analyzed on the basis of the planning of each main step before installation in the LHC. Finally, the solutions implemented for storage, handling and transportation are presented and discussed.

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1 INTRODUCTION

The LHC cryomagnets are delivered at CERN either as almost completed units or needing to be assembled before they are ready to be installed in the tunnel. The different contracts involved in the assembly and preparation process at CERN are in place, and the reality rates for each one differ from those foreseen. Therefore, between each activity, storage surfaces are necessary, and the cryomagnet surface logistics have to be considered as a full activity. This report deals with the logistics of the components from their arrival at CERN to their final installation in the tunnel.

2 CRYOMAGNETS WORKFLOW

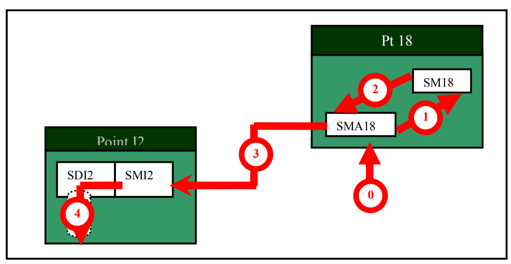
The assembly work for cryomagnets to be performed at CERN consists of 18 work packages executed in sequence by different contractors and at different locations.

The organization for both cryodipoles and SSS main components between the cold masses delivery and their final transportation down in the tunnel are summarized below.

2.1 Cryodipoles workflow

The cold mass and the cryostat for one cryodipole arrive at point 18. They are controlled, assembled and prepared for the cold tests in building SMA18.

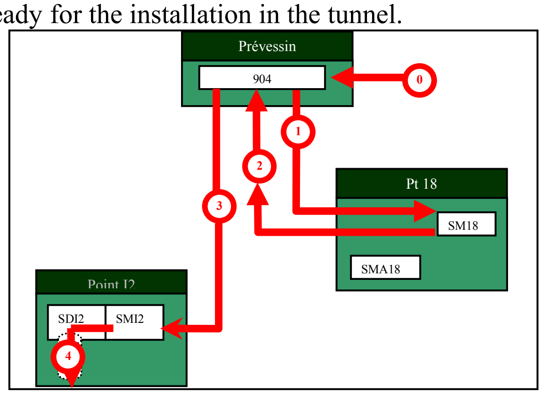
After its transportation from its assembly stands to its test bench in building SM18, the cryodipole is cold tested, and prepared in building SMA18 for the connection in the machine. Then it is transported to building SMI2 where it is finally equipped with ancillary equipment (beam screens, etc...) and made ready for installation in the tunnel.



2.2 SSS work flow

The cold mass and the cryostat for one cryodipole arrive in building 904 (Prévessin site). There, they will be controlled, assembled and prepared for the cold tests.

After its transportation from its assembly stands to its test bench in building SM18, the SSS will be cold tested, returns to building 904 to be prepared for the connection in the machine. Then it is transported to building SMI2 where it will be finally equipped with ancillary equipment (beam screens, etc...) and made ready for the installation in the tunnel.



3 STORAGE SIMULATION

The contracts for the main components and activities are now in place. Originally, the planning of this whole process was supposed to be based on a "just in time " scheme, but the delivery, assembly and test rates of these very highly advanced products as well as the availability of their final position in the tunnel are different than those foreseen in the different contracts. Therefore, buffer storages between each main activity needs to be implemented, and transport between sites need to be analyzed in term of resources (material and human). For this purpose, a simulating tool was created giving the number of cryomagnet to be stored between each activity, as well as all the relevant time information concerning one cryomagnet "trip" between its cold mass arrivals to its final installation in the tunnel.

3.1 Simulation tool

The inputs are:

- The rates for the different activities given by project engineers, i.e. the rate for cold mass delivery, assembly, test, preparation in SMI2 and transport,
- The cryomagnets list generated from the LHC reference database,
- The installation schedule: the cryomagnets transport in each sector is constrained by the cryogenic line installation (QRL), and the maximum rate for underground transport. The new updated schedule (April 2004) shows that all the cryomagnets (1232 cryodipoles and 474 SSS) will be transported between June 2004 and October 2006, with a given rate in each sector.

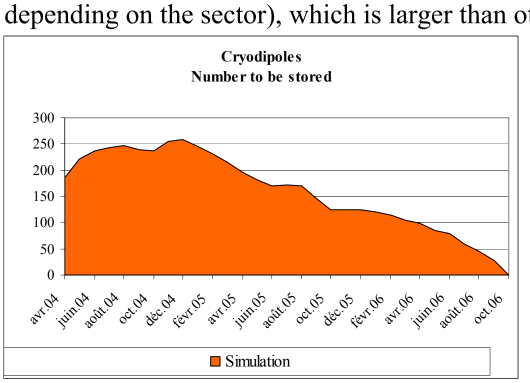
The tool simulates how much storage is needed between each activity by calculating for each week the difference between the number of cryomagnet treated by activity n-1 and the number treated by the activity n. The results are presented graphically as shown below, and are available on request in table sheets.

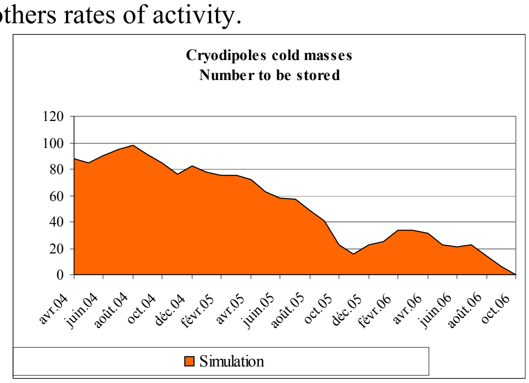
Then, from the installation scheme defined by the planning team, it calculates when one cryomagnet should be prepared, tested and assembled according to the different rates given by project engineers.

3.2 First results

According to the simulation performed in March 2004:

- Maximum cryodipoles to be stored: the simulation shows that the maximum amount of cryodipoles to be stored will be approximately 250 cryodipoles and 100 cold masses.
- Curve shape: this maximum will be reached in December 2004, whilst the installation in the tunnel has started but still does not exceed the quantity of cold masses delivered. The curve will start to decrease when the transport rate will raise its "cruising speed" (between 15 and 20 / week, depending on the sector), which is larger than others rates of activity.





A new simulation performed, according to an eventual delay in the cryomagnet installation in the tunnel, shows that for a 2 months delay, the maximum number of cryodipoles and cold masses to be stored will be approximately 420.

4 STORAGE STRATEGIES

4.1 The transportation and handling means

Transporting cryodipoles requires some precautions, as described in specification (EDMS n° 360893). A dedicated trailer, with a 100 tons (up to two cryodipoles) capacity, is used for this purpose.

The main mobile crane has a 160 tons capacity, and is able to move the load of 40 tons (cryodipole with handling tool) at a distance up to 12 m, or 32 tons (cold mass with handling tool) up to 14 m. A new trailer was recently made operational (see with the crane on the picture 1).

Figure 1

4.2 The various zones and related capacities

The initial plan was made on the basis of 150 cryomagnets. At that time (end of 2002), the plan was to group the cryomagnets by batches of 25, without individual sorting. The policy was based on a LIFO (Last In First Out) logics, with 6 stacks. It was therefore possible to deal with only one storage area. The choice was made to use the LEP dismantling zone called 1027, on Prévessin site, which offered the necessary space. The additional constraint to be able to reach any magnet at any time (individual sorting) arose during summer 2003 from the MEB (Magnet Evaluation Board). The capacity of the 1027 zone was then reduced to approximately 120 cryomagnets, in order to cope with the necessary additional dead space for the evolution of the mobile crane. The proposal was to have a unique long stack of magnets, and an additional storage space along the border of the zone.

Given the results of an initial simulation performed for the first time after the Schedule Change Order (EDMS n°424751), it appeared clearly that the capacity of the zone would not cope with the huge amount of additional cryomagnets to be stored.

Furthermore, at the beginning of January 2004, the decision was finally taken to store the cold masses at Prévessin in order to avoid saturation of SM18 external storage areas. The additional storage zone along the border of the 1027 zone was dedicated to the storage of 30 cold masses. In February, an additional 30 cold masses were stored in the cryodipoles zones, leading to quick saturation of the 1027 zone.

A second zone was then created, along Gentner road, still at Prévessin. On the right of the zone, 23 cryodipoles were positioned in March on large heavy concrete blocks. On the left of the road, a technical gallery prevented the full use of the same solution: with a load of 20 tons per linear meter, cold masses could be stored every 1.6 m, and in April, more than 35 cold masses were stored there. For the first time, they were stored on 2 points only, with a span of 9m, and on dedicated wood cradles in order to avoid any induced torque.

In the meantime, pressure was put on the electrical group in order for them to release the zone called 1026, contiguous to the 1027 zone. The SAX zone was therefore tidied up in March, and many turrets and cable drums were moved there and in other areas prepared around. The first magnet could be installed safely early April on the first half of this zone (capacity: 40 cryomagnets). The 2nd half is still under discussion, and could lead to an additional storage of 50 magnets.

At that point, the overall storage capacity of 1027, Gentner and 1026 zones was estimated at about 200 cryomagnets, all in all. Saturation was anticipated to happen in May, and it was decided end of January to proceed with the preparation of a new zone near point 18, called point 19.

4.3 Situation at point 18

All magnets to be stored were coming, in this initial phase, from point 18. The logistics in this area is heavily constrained. The purpose of this paper is not to detail this; however some references may be are of direct impact on our subject.

Cold test benches are the bottleneck of the project, and demand to be fed in real time. The only logistical means for this are the Rocla robots. In addition, there is only one external crane, whose hook coverage area is very small (capacity of only 25 cryomagnets). In April, some actions were launched in order to increase the storage capacity of this zone to be dealt by Rocla, and not requesting the use of the mobile crane.

Close to point 18, 3 small storage zones were created. One is dedicated to non-conform long term storage of cryodipoles, with a capacity of 15 cryodipoles. The 2 others are dedicated to storage of cold masses. One zone is situated at the bottom of point 18 near bldg BA7, on a new platform. The 1st cold mass was stored there mid-April and another 25 can be stored, together with 10 cryostats and bottom trays (one week autonomy). The other one is on the other side of BA7 building, and can accommodate about 25 magnets. The purpose of these 2 zones is to offer a buffer zone to cope with the cold masses slightly exceeding the just-in-time capacity of SM18 cold tests benches.

The time between the agreement for storage of a given magnet, and its actual storage, need to be kept under 3 days, if the number of buffered magnets is not to exceed the capacity below the crane. The transport activities are hence permanently on the critical path, and can be seriously perturbed in the case of unavailability for more than a few days of one or the other means. Unfortunately, this does occur...

4.4 The 2081 accident

On the 16th of April, an accident happened on this new 1026 zone. The 5th cryomagnet to be stored, number 2081, experienced an accelerated landing. The floor below the crane slowly collapsed, and in about 10 seconds, the most loaded foot of the crane was 0.5m underneath the surface. The crane driver luckily had the good sense to put the magnet on the floor as quickly as possible, avoiding any injury. However, the magnet landed on the trailer. In half a minute, the 3 handling means (trailer, tractor and crane itself) were damaged and put out of service.

As a consequence, all cryodipoles transport were stopped, and all storage activities and handling of magnets with cranes were put on hold on by the Safety Commission. It took several days before the floor limits were analyzed and better understood. The 1026 floor was analyzed to be of bad quality. Other activities in other areas could resume, with compulsory use of large steel plate below the feet of the crane.

During the same period of time, the first magnets after insertion of beam screens at SMI2 were announced to be ready for storage. But the remaining storage capacity was dramatically less than 20 units (2-3 weeks capacity). By chance, the preparation of point 19 zone came to a good end, and the crisis was avoided, but by a margin of only a few days.

4.5 Situation and prospective early May

The following table gives the state of the zones, as updated the 10th of May 2004.

Table 1 : Storage status – 10th of May 2004

					Maximum load t. / m^2	
Cold masses	**Capacity**	**Actual storage**	**Rate**	**Remain**	**Road**	**Ground**
890 Gentner	40	34	85%	6	30	special
1027 transit	30	30	100%	0	20	
BA718	24	14	58%	10	20	10
BA7	0	0		0	20	
Total	94	78	83%	16		
Cryodipoles	**Capacity**	**Actual storage**	**Rate**	**Remain**	**Road**	**Ground**
1027 transit	100	96	96%	4	20	
1026 drums	4	5	125%	-1	10	
893 Gentner	23	23	100%	0	30	10
BA7	15	15	100%	0	20	
point 19	150	3	2%	147	20	
Total	292	142	48%	151		
Hors point 19	142	139	98%	4		

The 1026 zone exceeds its capacity, because the cryodipole 2081 was provisionally stored there after the accident, waiting for the availability of the decryostating bench. After repair of the holes in the floor, the capacity will then be increased to circa 40 cryodipoles.

After start of use of point 19 areas, the crisis was overshadowed, and capacity more than doubled. Some additional discussions led to an extension of this zone, for a capacity of more than 350 cryodipoles. The total capacity will then be above 450 cryodipoles, and no new crisis should happen by October 2004.

On the right, the limits given by Civil Engineering group are summarized. They are quite conservative, and should evolve with better knowledge of the behavior of the floor.

This table, as well as the detailed information on stored magnet, is updated daily, and available on line through the following link: http://lhc-dipcoor.web.cern.ch/LHC-dipcoor/Ground-logistics.xls

5 CONCLUSION

Due to the evolution of the different contracts, it is important to simulate and follow the cryomagnets surface flow, in order to have a clear overview of the storage space and its location.

We would like to highlight the difficulty involved in dealing with many transports in various areas within a limited time-frame. The need for individual sorting leads to access constraints, and requires frequent moving from one area to another. The danger of these manipulations has to be underlined, as recalled by the 2081 accident: cryodipoles are heavy, fragile and dangerous objects.

Transport of cryodipoles are the life-blood of the project . This daily activity seems to be rather straightforward; however, its criticality was shown, and it will demand a very good coordination throughout all the installation.

6 ACKNOWLEDGEMENTS

The people involved in this simulation and storage undertaking are too numerous to be mentioned. The authors would thus like to sincerely thank all members of the Installation group, all those involved in

the transport and handling operations, and all those who provided the information input to perform the simulation.

7 REFERENCES

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