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SCHEDULING HL-LHC MAGNET PRODUCTION: BUILDING A COMPLEX PLANNING TO IDENTIFY BOTTLENECKS

S. Fleury*, E. Todesco, M. Barberan Marin, M. Bernardini, CERN, Geneva, Switzerland

Abstract

The High-Luminosity LHC project aims to enhance the integrated luminosity of the LHC machine by a factor of 10, by upgrading various components located in the LHC tunnel just before the collision points, with cutting-edge technologies. Among these innovations are the new superconducting magnets equipped with a combination of $Nb-Ti$ and Nb_3Sn. conductors. Over 100 magnets are being produced, each undergoing multiple production and test stages across different facilities worldwide, including laboratories outside CERN. Various technology systems are integrated into the magnets, involving collaboration with different groups for assembly work.

Recognizing the complexity of this production process, a comprehensive production and test schedule at CERN was established.

This paper elucidates the schedule tools implemented to oversee the entire resource loaded process. The compiled data serves to identify strategic or technical bottlenecks in the production flow. By adopting such an approach and simulating various production scenarios, the aim is to proactively address potential conflicts, to ensure the optimal allocation of resources and the readiness for installation during the Long Shutdown 3.

HL-LHC MAGNET PRODUCTION

The HL-LHC project [1] is an important equipment upgrade using innovative technologies in both side of two collision points of LHC, for a total of 1.2 km accelerators components.

The new $Nb-Ti$ and Nb_3Sn superconducting magnets [1] will offer a more intense and concentrated beam to produce 140 collisions for each bunch collision compared to 50 to 60 collisions in the today's LHC [2]. A chain of several types of magnets, as shown on Fig. 1, were designed on each side of experiment points to achieve the target collision number. To develop the new magnets technology, validate them with the overall accelerator system through the Inner Triplet String test [3] and produce the series, more than 100 magnets are being fabricated. Each type of magnet has its own role in the beam optics which require that the inner assemblies presents different designs.

Figure 1 shows also the layout inside the cryostats, the outer layer of the component that separate the ambient temperature from the cold mass cooled at 1.9K. According to the type of component, the cryostats have different combination of main magnets and correctors [4]. The same type of magnet can present variations in its worksteps depending on its end purpose and location. This includes prototypes,

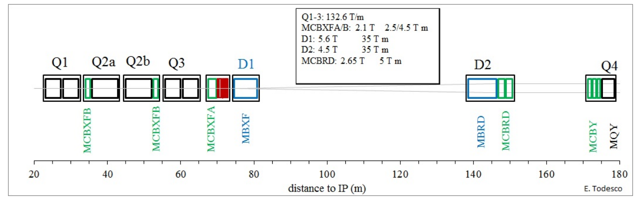

Figure 1: Chain of magnets on one side of a collision point with cryostats and specific content up to Q4.

magnets for the Inner Triplets String test [3], magnets to be installed in the LHC and spares. The duration on the facility's benches to produce the magnet can therefore vary from less than a day to a couple of weeks depending on the type of magnet to produce.

The fabrication of magnets does not take place only at CERN. Indeed, worldwide laboratories are involved in defined production steps for the magnets be then delivered and installed at CERN [5].

Once a magnet has been delivered to CERN or started to be produced at CERN, it passes through up to 3 different facilities depending on the stage of production. In the magnet assembly facility (LMF), the cold mass is being assembled and shaped for insertion in the cryostat. Then, the cold mass is inserted inside the cryostat in the cryostating facility (SMI2) where electrical connection or piping are welded to the assembly. Both the workers and the bench availability limits the flow of production. In the test facility (SM18), the main magnets and the corrector magnets are respectively horizontally and vertically cold tested. The specific interface between the magnet and the bench prevents the magnet to be tested on any bench. High power and cryogenic fluids are needed, these resources govern the number of tests that can be performed in parallel. The Radio-Frequency group, testing cavities and the Superconducting link work package [6] are using cryogenic capacity and their tests should also be considered and prioritized along the magnet tests.

Magnet fabrication requires the coordinated interventions of many groups to install specific systems at determined production steps. For instance, the survey group is installing on the triplet a tracking system to monitor the position of the cold mass. They are also responsible of fiducialization, where the position of the magnets and piping are stored with respect to the cryostat [7]. Vacuum group is installing the beam screen and the Beam Position Monitor (BPM) systems at the end of the production process, before closing the cryostat for storage and is also responsible for leak tests.

Outlining the HL-LHC magnet production amounts to saying that numerous magnets are produced by multiple actors with various parameters in different facilities during the production process. The novelty of the new material and

* sarah.agathe.fleury@cern.ch

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technology in the HL-LHC magnet, which present variation for each type of magnet makes it much more complex and difficult to estimate in terms of readiness for installation and resources. We are therefore facing a complex production that requires advanced processes and tools to plan and unfold the production as smoothly as possible.

MOTIVATION

One critical element to consider when launching a production process is to examine the resources available to accurately calculate the readiness date for installation. Delivery dates at CERN, stages duration, facilities maintenance and resources availability are driving the production flow and can create bottlenecks. To identify potential conflicts, a comprehensive view considering all detailed inputs is essential to control the production and avoid critical delays.

Acknowledging the multiplicity of locations of production, tests and actors involved in the production of the magnet, a common schedule is therefore crucial to allow coordination between the different stakeholders of the production and with the other teams of the HL-LHC project.

There was therefore a push to create a resource loaded planning for activities at CERN and that could shift dynamically in time to enable to calculate important milestones and identify potential bottlenecks. The HL-LHC project office requested the coordination and scheduling team to assist the magnet group to establish such tool.

TOOLS FOR PLANNING

The coordination and scheduling team, in collaboration with the magnet group, utilizes a Microsoft Project file as their primary tool. This enables automatic date recalculation based on the entered data. Considering the challenges for the HL-LHC magnet production, the duration for all activities at CERN per type of magnet, per facilities and per bench depending on the type of magnet and end location, were saved in the file. The collaboration delivery dates is the starting point for the activities at CERN to proceed with the next production steps of the magnet. The flow of activities with the resources, depicted as an example on Fig. 2 for a Q2, along the resources used for each step, is automatically recalculated in case of shift.

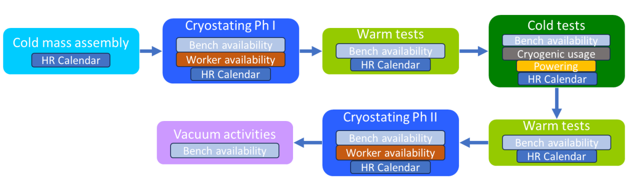

Figure 2: Flowchart for a Q2 magnet production and the corresponding resources used.

To control the resources, the coordination team studied together with the technical engineers the critical aspects of the production facilities. For HL-LHC magnet production, resources diversify in several types:

- Personnel resources, which impact the production speed depending on the year period and on the facility. A calendar describing the average availability of the personnel was built in accordance to previous year manpower availability and then inserted in the planning to account for the lower personnel resources to work on the magnet. The duration of the activity will therefore automatically be updated depending when it occurs in the years. For the cryostating activities, a limit of workers was added, which allows only 4 cryostating activities to take place simultaneously.

- Bench availability, is a support where magnet can be placed to undertake specific actions thanks to the tooling. It is crucial to define them, as there is a finite number available.

- The consumable usage, precisely the power and cryogenics for cold tests. Test benches are grouped by cluster of two, sharing the same power supply. Therefore, both benches cannot be used simultaneously for magnets testing. Cryogenics usage relies a lot on live management, because the capacity needed in terms of pumping and liquefaction for one test is not constant according to the test phase. It is therefore essential to simplify the problematic for an algorithm to solve. The rule was therefore adapted to perform a defined numbers of horizontal tests in parallel depending on the type of magnet. Cryogenics control helps to know what test we can run in parallel along other users in the facility.

These resources limitations were translated into virtual rules that the Microsoft Project file can treat. The optimisation of the resources usage might introduce idle period in the production process of one magnet. These slacks shall be tracked to arbitrate whether they are acceptable or if the strategy should be modified. For the algorithm to optimize which magnet has the priority on using a resource among others, the priorities are described by a score, in line with the production strategy of the management. With all these inputs, MS project can recalculate a schedule without over-allocation of resources, respecting the sequence of activities and providing new readiness dates. Resources usage profiles are used to understand the workload and potential shifts due to unavailability of one of them. It allows adjusting the quantity of resources for the next years of production. To have a robust approach, reference documentation containing the baseline duration, workflows and resources were established and stored. There is therefore a difference between the working planning where live information and small adjustment are entered and the more stable and long-term baseline information.

The production of HL-LHC unites numerous and various actors going from the pure technical side, in charge of building the magnet to the management of the HL-LHC project and equipment groups, here the magnet group, passing also by all the interfaces with other groups that are installing

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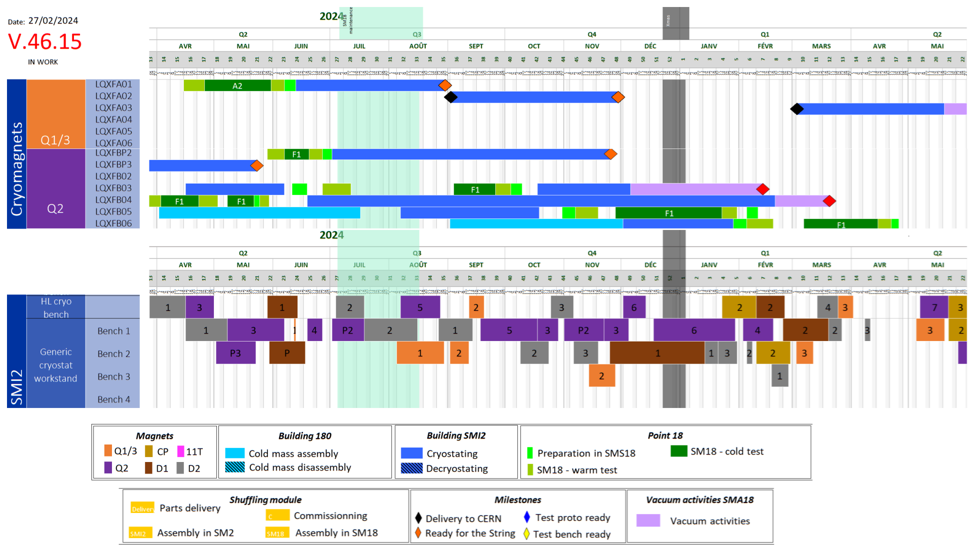

Figure 3: Extract of the overall planning with magnet and cryostating facility view.

equipment in the magnet or that are testing in the same facilities and might use the same resources. These groups are also seeking to control their resources. The optimised planning gives a common view on these activities to be done and helps everyone to be aligned.

An updated schedule is key for a smooth production, the frequency of updates depends on the targeted audience: for the management office, a quarterly update is needed whereas, for the facility manager or the test engineers, a bi-weekly update is necessary. The reality of the production generates shifts in the planning that are communicated and shared by the stakeholders during dedicated meetings organised at a defined frequency.

Side tools and methodologies were also implemented to allow for quick information retrieval and data storing. Versioning the planning using logbook showed to be a very useful tool to assess the causes of a schedule changes. Deliverable definition and tracking with respect to a planning version was implemented to analyse the shifts of specific readiness in the production flow.

COORDINATION & CHALLENGES

The coordination task could be considered as a bridge between the reality of the production driven by the constraints and the management strategy to implement. It is the role of coordination in collaboration with management to search for possible planning optimisation identifying slacks and playing with controllable parameters such as resources capacity or tasks priority. Simulations are launched to study a strategy and identify the best possible scenarios and above all to avoid conflicting production steps.

The planning for the HL-LHC production of magnet is therefore a complex but yet very powerful tool. In an organization like CERN, many other activities are happening at the same time in the same facilities and can have an impact on the production. For these effects, an assessment is made of whether it is possible and useful to have such information in the planning. The end purpose is to avoid over-constraining the planning. Furthermore, in a fast evolving planning environment where prototypes are tested and first series produced, the planning can evolve frequently. The multiplicity of actors and the task dependencies for other groups to work on the magnet make challenging to deliver a planning for everyone with the latest information.

RESULTS

After compilation of the new dates, the coordination team is generating a linear planning to show the overall production planning in one graph, depicted in Fig. 3. The automated date calculation using the dependencies, resources usage and priority creates a resources loaded comprehensive planning. In the magnet production process follow-up, it is critical to provide different views on the production to understand the slack in the production process and therefore the bottlenecks. Analyzing the planning per bench and per magnet in a parallel manner helps to decrypt the situation and assess the strategy applied in the planning.

Using such schedule in the production process allows to finally get an overview on a complex production of magnets for HL-LHC and improve decision making, efficiency and anticipate for future conflicts and thus delays. The communication is also enhanced between all parties involved from the engineers up to the manager and external groups, which provides a strong added value to the project.

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