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THE CMS ECAL ENFOURNEUR: A GIGANTIC MACHINE WITH A SOFT TOUCH

V. Pettinacci, INFN Roma, Rome, Italy

Abstract

The electromagnetic calorimeter (ECAL) of the CMS experiment at the LHC is composed of 75848 scintillating lead tungstate crystals arranged in a barrel section and two endcaps. The barrel part is made of 36 supermodules (SM), 2.7 tons each, and is installed inside the CMS magnet. There are 18 SMs on each side of CMS, with each SM containing 1700 crystals. During Long Shutdown 3, all ECAL SMs must be extracted to refurbish the electronics in preparation for HL-LHC. A dedicated machine called the "Enfourneur" is used to extract and re-insert the SMs inside CMS, with a required accuracy of about 1 mm. In order to speed up the extraction and insertion process, two Enfourneurs will be employed, operating in parallel on both sides. In view of the purchase of the second Enfourneur, the design has been improved, starting from the feedback of past operations. The improvements to the new Enfourneur design include: increased space for the operators, optimization of the operations and the controls with the use of electric motors, and an updated alignment system. Handling plans inside the CMS cavern have been defined in order to be compliant with the rest of CMS structures and procedures.

THE FIRST ENFOURNEUR AND ECAL SUPERMODULES

The CMS [1, 2] electromagnetic calorimeter (ECAL) barrel is made of 61200 lead tungstate scintillating crystals, equipped with readout electronics. The crystals are arranged in supermodules (SMs), containing each 1700 crystals. The crystals and the associated electronics are fragile, but very heavy. Therefore a dedicated machine, called "Enfourneur" (French name, meaning the "loader") [3] is needed to carefully and precisely position the SMs in CMS. Figure 1 shows the machine during the first installation (in 2007) inside the CMS cavern at P5 (Cessy, France).

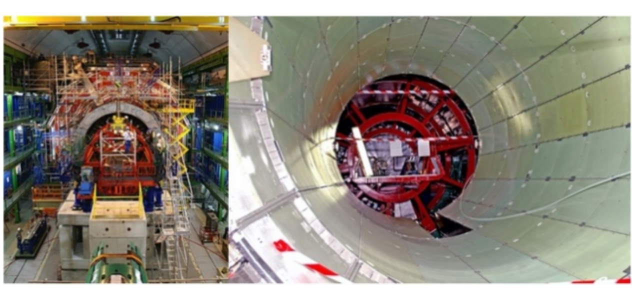

Figure 1: Enfourneur first operations and last supermodule installation (2007).

The calorimeter geometry and SMs pattern (18 SMs per side, denoted plus and minus sides) is represented on the right of Fig. 1.

The previous pictures also show the axis height from the cavern floor (about 9 m), to be aligned with the LHC beam pipe. Each SM is about 3 m long and weighs about 2.7 tons. Considering dimensions, mass, and position in-height the handling of these supermodules, which are extremely fragile, plays a critical role.

Figure 2: Original Enfourneur at P5 site (Cessy, France).

The loading of the supermodule is performed from above, using a crane and a dedicated lifting interface, called Yellow Beam, which precisely matches the free slot of the rotating cylindrical structure [3]. The Enfourneur is a large and heavy machine (about 7x6x5 m overall dimensions and a weight of 20 tons), hydraulically actuated. It is able to perform three motions: main body axial sliding, rotation of the central cage, and axial translation (with pushing or pulling force depending on whether it is insertion or removal) of the supermodule. The original machine, that successfully performed these operations during the first installation, is represented in Fig. 2.

During the third Long Shutdown (LS3), currently foreseen to start in 2025, all ECAL barrel supermodules must be extracted from CMS to upgrade the electronics to cope with operations with high intensity beams [2]. In order to accomplish this critical task, the existing machine must be upgraded, following feedback from previous operations. The design and construction of a new Enfourneur was also decided, with electrical, instead of hydraulic, actuation and a series of optimized controls to make operations simpler and faster.

The Upgrade of the First Enfourneur

The current machine was the starting point of the development of the new one, that will keep the main dimensions and operation features. It has undergone a major overhaul aimed at making it more compliant with current safety standards, and more suitable in terms of space available for the operators required to operate it (up to 5 people at the same time). This machine will have to be installed at a height of 8.79 m from the ground, complete with hydraulic

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pistons, hoses, and control unit, as shown in Fig. 1. Therefore, the possibility for operators to move from one point to another of the machine, and to access simply and quickly the various elements is fundamental. The rework started in 2018; a finite element modelling and analysis - of the whole machine and of the single parts - has been performed to verify the compliance of new structures designed to applicable norms (Eurocode), calculating forces applied on all the screws (all frictional joints with preload applied) and stress on the constituent beams and deformation (requested within 1 mm at cage level to not affect alignment procedures). An example of the single platform checks performed and the structural analysis of the overall machine is represented in Fig. 3, with the analysis of the rear lower balcony, one of the most critical areas of the machine because supporting the hydraulic control unit – point load by about 250 kg – plus 250 kg per square meter distributed load (applied on all walkways of the Enfourneur as requested by norms and CERN HSE division). Per each design change, the maximum deformation, the stress in the preloaded bolts, and the structure Von Mises stress were calculated and verified to be compliant with acceptance limits defined by Eurocode 3 (Fig. 3).

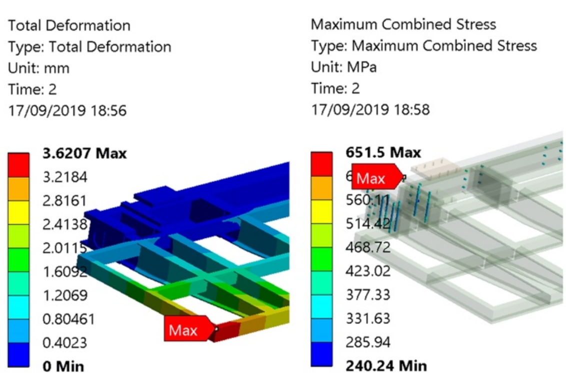

Figure 3: Maximum combined stress calculated on the screws with preload applied on the new rear low balcony.

The objective was rather challenging as these modifications entailed a significant increase in the surface area of the gangways and platforms for the operators, while at the same time having to comply with certain constraints including the total mass of the object (maximum 20 tons per load limit of the cranes involved in the movements) and maintaining the same modularity as the original structure while still guaranteeing the full functionality of the machine. After some iterations and optimizations, the design was frozen and the changes implemented on the existing machine, introducing new platforms, new lighter aluminium stairs and new rigid tubing for the hydraulic controls, replacing the previous one made of flexible pipes that caused routing difficulties during the various movements. The machine at the end of upgrade (early 2021) is shown in Fig. 4.

Installation Inside the CMS Cavern (UXC)

A dedicated study was needed for the installation in the CMS cavern, on the two opposite sides of the detector (plus

Figure 4: The first Enfourneur upgraded.

side and minus sides). The minus side is relatively easy to access thanks to a large shaft equipped with a large-capacity overhead crane (40 tons), that can lower the Enfourneur directly into the operation area. The challenge - from an engineering point of view – is the possibility of installation on the plus side. Unlike the first installation, the plus side now can only be reached through a smaller shaft with a reduced capacity crane followed by a tunnel. With these constraints, considering the size and mass of the Enfourneur, it was necessary to carry out a technical and logistic feasibility study aimed at verifying the possibility of disassembling the machine into its main sub-assemblies, moving them individually and transporting them through the mentioned passages. Further structural calculations were necessary due to the introduction of additional lifting points for the handling configurations, that imply different orientations with respect to gravity and therefore a different load on the carpentry structure beams and related joints. The main technical outcomes of the study were implemented in the design of the second Enfourneur. The final configuration of the systems operative on both sides of the detector is represented in Fig. 5.

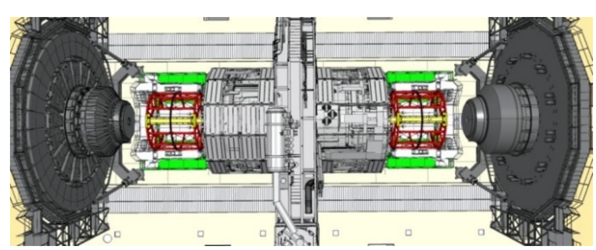

Figure 5: Enfourneurs installed on both sides of CMS (integrated 3D CAD model).

THE NEW ENFOURNEUR

The results of the design optimization and installation studies in the CMS cavern have been set as design constraints. The second Enfourneur was designed with the aim of making it more modern, more reliable, simpler and safer, from the point of view of actuation. While maintaining all

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the requirements for possible operation with traditional hydraulic drive (double-acting pistons), it was decided to implement an electric solution. In particular synchronous motors coupled with planetary ball screws for translations, and asynchronous motors couples with a rack and pinion system for rotation. The advantages are many: reduction of handling times by moving from a series of manual operations to a single and continuous movement (due to their limited stroke, the pistons must be continuously disassembled and reassembled), greater safety for personnel and experimental components avoiding leakage of oil from the pipes (with risks related to damage of experimental equipment), and greater accuracy in primary movements. In Fig. 6 the new design is represented with the new electric and mechanical elements. The main body translation synchronous motors are visible on the two side beams on the rear view (darkest parts). The top view shows the main body translation screws on the two sides: the two redundant asynchronous motors (for safety reason in the event of failure of one of the two) connected to the rack and pinion system devoted to central cage rotation (rack aligned with the centre of gravity of the whole machine to avoid secondary momentums). In the same top view the two synchronous motors devoted to SM pushing (or pulling) inside (or outside) the CMS calorimeter main structure are visible on the sides of the Yellow Beam.

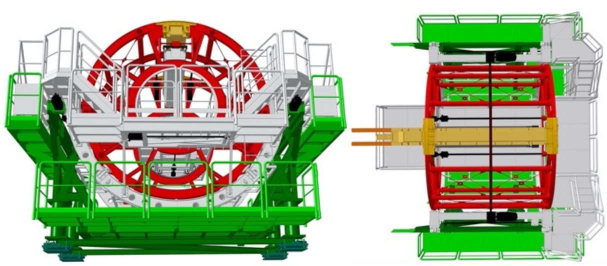

Figure 6: Rear and top views of the new Enfourneur 3D CAD model with electrical motors, translation screws and rack integrated (darkest parts).

The rack presents a removable segment to allow the insertion of the Yellow Beam carrying the SM from the top without clashing, at the beginning of each insertion operation. This segment will be equipped with dedicated sensors to confirm its proper installation and to prevent the rotation of the motor in case of missing part or wrong installation of the segment itself.

All motion control will be possible through a dedicated touch screen panel. Software will include predefined positions to be reached by the machine in order to ease and speed up operations. The motions will be compatible with acceleration limits based on the fragile SM components and imposed at the software level.

The alignment of the machine will be mechanical and identical to the previous version, with some pushing screws and sliding parts available on the four support pedestals and on the sliding guides, for a proper alignment of the whole machine with the main detector structure. The supermodule will exploit a dedicated tuning system (more fine and accurate) installed on its handling interface - the Yellow Beam - based on leverages and toothed wheels. This will allow a perfect alignment with the calorimeter guides and a smooth and continuous motion. All guides for mobile parts of the Enfourneur will have a surface coating to reduce the contact friction factor.

This design was extremely challenging because the main constraints related to the overall mass and the modularity, required by the installation plan, implied an important optimization of the overall structure. Compliance of stress levels with Eurocode limits and with deformation limit defined by the correct functionality of the machine (+/- 1 mm at level of the rotating cage) were checked during the design phase, in order to check the compliance with alignment requirements. Considering some relevant structural changes (in particular on the cage for the addition of the rack), a dedicated finite element analysis has been performed to check all these parameters. The design converged to its final version after some iterations and an optimization phase.

CONCLUSIONS

The Enfourneur project aims to provide two machines working in parallel and has achieved its goals with the improvement of the existing machine (to be completed by 2021) and the definition of the project for the second one (the construction work will start by the first half of 2021). The two machines will be able to operate at both ends of the CMS detector, in accordance within the available space, using the handling infrastructure, and in compliance with current safety regulations. The second Enfourneur will operate on the side with less space, exploiting the modularity imposed as a constraint of the project and in a faster and more flexible way thanks to the implementation of the electrical control of the three movements. The first Enfourneur has been fully refurbished and improved, making it safer and smoother in operation.

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REFERENCES

[1] CMS Collaboration, “The CMS experiment at the CERN LHC,” *Journal of Instrumentation*, vol. 3, no. 08, pp. S08004-S08004, Aug. 2008. doi:10.1088/1748-0221/3/08/S08004

[2] LHC experiments Committee “The Phase-2 Upgrade of the CMS Barrel Calorimeters”, Rep. CERN-LHCC-2017-011; CMS-TDR-015, Sep. 2017.

[3] “The CMS electromagnetic calorimeter supermodule insertion tooling,” *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 572, no. 1, pp. 141–144, Mar. 2007. doi:10.1016/j.nima.2006.10.170