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ADVANCED ENGINEERING SIMULATION METHODS DEVELOPED IN THE EN-MME ENGINEERING UNIT

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Abstract
The Engineering Unit within EN-MME is in charge of CERN-wide advanced computations and simulations. The team, currently composed of 15 engineers (staff, fellows, MPA, industrial support) from the EN-MME-EDS and EN-MME-EDM sections, has a strong connection and interaction with the other sections of the group (FS, FW, MA and MM). The Engineering Unit is responsible for complex analyses with a high impact on fabrication, operation, and safety of equipment, for a diverse user's community which includes, on top of the other sections of the EN-MME group, other CERN groups and departments, as well as projects and experiments. This contribution will highlight the competences developed within the Engineering Unit in the recent years, on analytical and numerical techniques, including implicit and explicit Finite Element Method (FEM) calculations, multiphysics studies, semiempirical methods, materials modelling, as well as safety standards concerning pressure vessels, handling, and structural elements. The contribution will also give examples on the application of such methods to specific projects managed by CERN and the experimental community.

Contents

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Abstract

The Engineering Unit within EN-MME is in charge of CERN-wide advanced computations and simulations. The team, currently composed of 15 engineers (staff, fellows, MPA, industrial support) from the EN-MME-EDS and EN-MME-EDM sections, has a strong connection and interaction with the other sections of the group (FS, FW, MA and MM). The Engineering Unit is responsible for complex analyses with a high impact on fabrication, operation and safety of equipment, for a diverse user's community which includes, on top of the other sections of the EN-MME group, other CERN groups and departments, as well as projects and experiments. This contribution will highlight the competences developed within the Engineering Unit in the recent years, on analytical and numerical techniques, including implicit and explicit Finite Element Method (FEM) calculations, multiphysics studies, semiempirical methods, materials modelling, as well as safety standards concerning pressure vessels, handling, and structural elements. The contribution will also give examples on the application of such methods to specific projects managed by CERN and the experimental community.

INTRODUCTION

The Engineering Unit is a team, within EN-MME, grouping high-level experts in technical fields such as mechanics, materials, heat transfer, electro-magnetism, cryogenics. In the past 10-15 years, thanks to the contribution of past and current members, the Engineering Unit has been able to develop a strong expertise in advanced materials and computations, including analytical, semi-empirical and numerical techniques. These techniques are widely adopted to develop engineering studies for several groups and departments at CERN, as well as for LHC and non-LHC experiments.

This paper focuses on the main fields of expertise of the Engineering Unit, providing examples of recent projects treated with each type of method.

IMPLICIT FINITE-ELEMENT METHODS

At the EN-MME Engineering Unit, implicit FEM are usually adopted to solve problems involving a complex geometry, quasi-static regimes and non-linearities excluding materials' changes of phase. For this type of problems, the tool of preference is ANSYS Workbench [1], which features a powerful geometry generator, as well as a stable solver and a highly detailed post-processor.

One example of recent project treated with this technique was the design and analysis of the Facility for Reception of Superconducting Cables (FRESCA2) [2]. This is a facility that will be installed at b. 163 and operated by TE-MSC, featuring a big-sized (about 4 m high, 2 m wide) double-nested cryostat for the measurement of superconducting samples. To validate the pressure equipment according to EN 13445-3 safety standard, a wide range of advanced simulations have been performed at the Engineering Unit, including nonlinear buckling and gross plastic deformation [3].

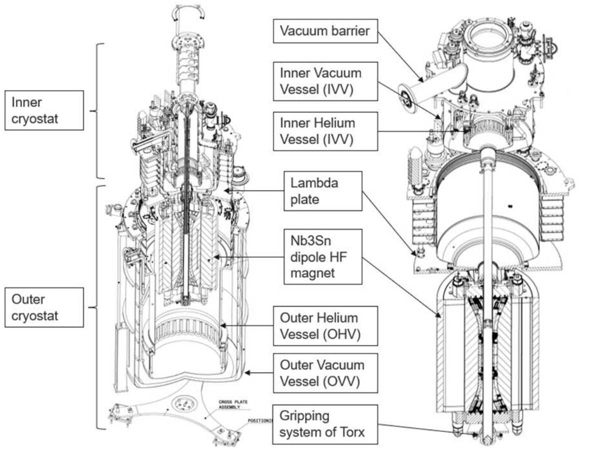

Figure 1. FRESCA2 3D view.

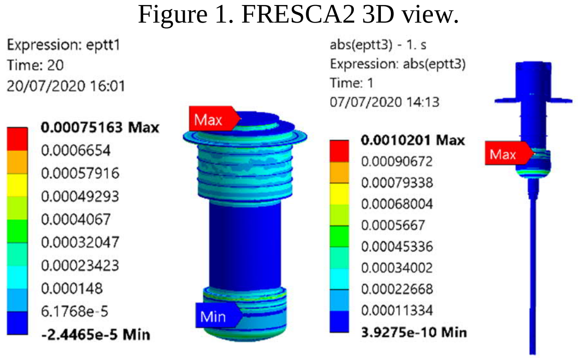

Figure 2. Left: Nonlinear buckling results. Right: gross plastic deformation FEM results.

The handling and lifting structures have been assessed according to EN 13155 and the Eurocode 3, in collaboration with the EN-HE and HSE-OHS. To assess the non-standard welds which are critical for the functioning and safety of the cryostats, tensile tests with Digital Image Correlation technique have been performed in collaboration with the EN-MME Mechanical Measurements Laboratory.

EXPLICIT FINITE-ELEMENT METHODS

Explicit FEM are used to simulate processes involving large deformations, with the possibility of including even changes of phase. The characteristic time of the simulation can involve quasi-instantaneous domains, such as those typical of particle beam impact on structures (discussed later in this paper, see Figure 8), as well as slower processes, for example those related to manufacturing technologies. In this second case, LS-Dyna is adopted at the Engineering Unit as the preference tool.

Methods developed based on LS-Dyna allow tackling many different types of manufacturing processes such as: deep drawing, stamping, hydroforming, spinning, trimming [4]. By simulations, it is possible to validate efficiency of the fabrication process, optimize the process parameters, and justify the manufacturing choices [5]. Such simulations are performed for a wide range of projects at CERN (HL-LHC, FCC, etc.), in particular when the process feasibility requires innovative fabrication techniques and is challenging in terms of tool design and cost. To achieve good results, it is of paramount importance a strong interaction between the Engineering Unit and the other CERN engineering services (Main Workshop, EN-MME-MM, …), as well as the international partners (*e.g.*, KEK for the hydroforming techniques).

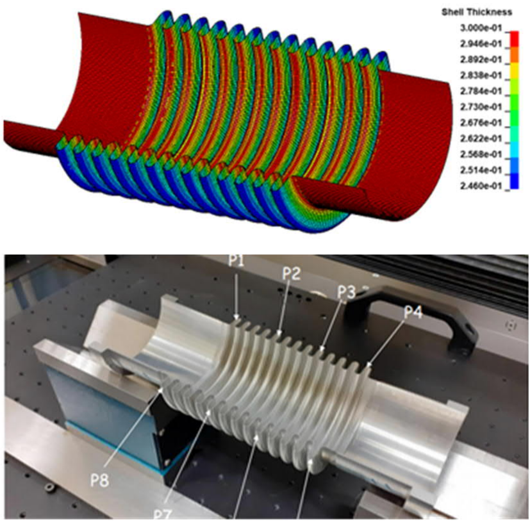

Figure 3. Top: simulation of the hot forming for the ATLAS bellows. Bottom: experimental test [6].

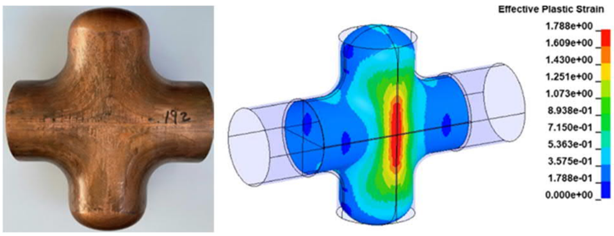

Figure 4. Simulation of the crab cavity HOM antenna's hook cold forging.

STRONGLY COUPLED MULTIPHYSICS TECHNIQUES

Particle accelerator components are subjected to operational scenarios that often involve the simultaneous acting of multiple loads of different nature (mechanical, thermal, electrical, magnetic, etc.). In many cases, such loads are interdependent. A simple example of this are structures subjected to Joule heating: the dissipated power is a function of the electrical resistance of the element, which depends on the temperature. However, the temperature is a function of the amount of dissipated power.

It is clear that such problems must be studied with strongly coupled methods, adopting finite elements that can accept multiple load fields at the same time. For such cases, a powerful tool adopted at the EN-MME Engineering Unit is COMSOL [7]. This software feature multiple types of solvers that can be combined to simulate complex load fields in a single analysis. COMSOL has been, for example, adopted at the Engineering Unit to study the effect of external loads on the Crab Cavity fundamental frequency, which controls the deflecting kick to the particle beam (see Figure 5).

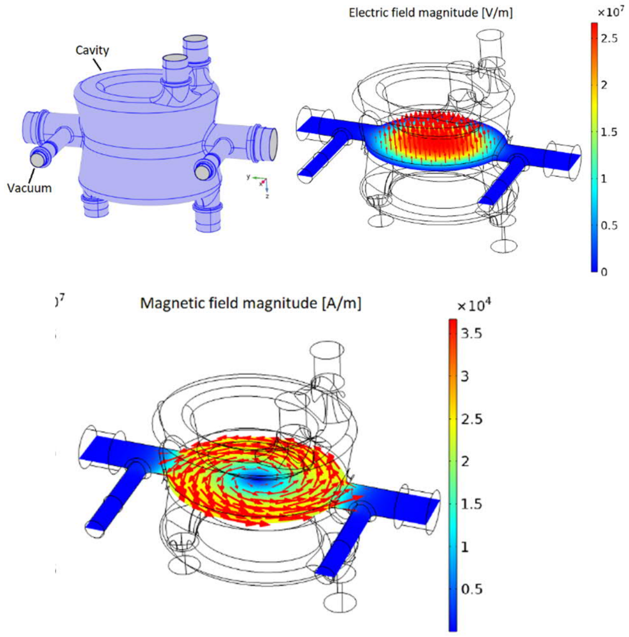

Figure 5. Top left: COMSOL calculations for the DQW Cavity, defined volumes. Top right: electric field magnitude. Bottom: magnetic field magnitude.

R&D ON NOVEL MATERIALS

In the past years, an important work of research, development and industrialization has been performed at EN-MME, with important contribution from the Engineering Unit. The scope is conceiving new, advanced materials, with excellent thermophysical and shock resistance properties, for use in HL-LHC beam intercepting devices such as the collimators, as well as for societal applications like nuclear energy, aerospace, thermal management and medicine. The effort led to the development, patenting and industrial production of a ceramic carbide – reinforced graphite composite, named Molybdenum-Graphite (MoGr) [8] which has been successfully installed, in coated and uncoated state, in the 15 primary and secondary collimators installed during the LS2 [9]. In parallel, also a Copper-Diamond composite (CuCD) [10] was optimized for potential use in the new, robust tertiary collimators to be installed during the LS3.

Such advanced materials require dedicated, unconventional testing techniques on top of the extensive in-lab characterization performed at the EN-MME Mechanical Laboratory. For this reason, in 2021, a dedicated test under proton beam impact, named “Multimat-2”, was performed at the CERN HiRadMat facility [11].

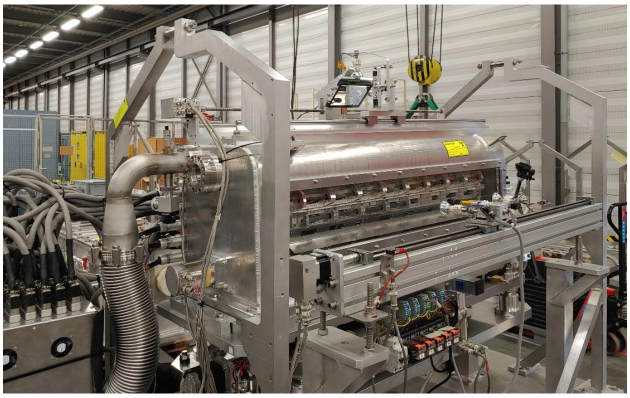

Figure 6. Multimat-2 experimental test bench.

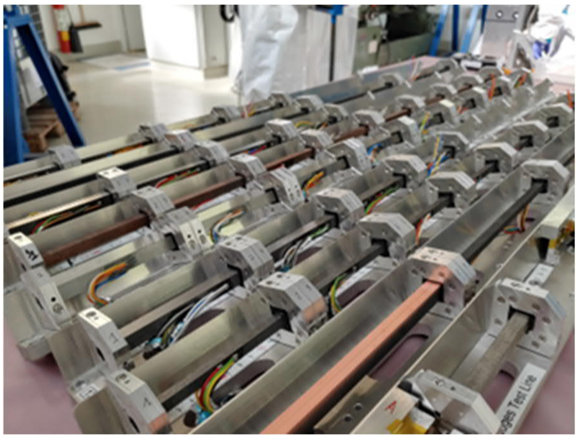

Figure 7. Sample target stations of Multimat-2 experiment.

The novel materials were subjected to beam impacts with the same equivalent energy levels expected in HL-LHC design cases and benchmarked against implicit FEM simulations. In 2022, the test bench has been opened, and the samples are currently undergoing a detailed Post-Irradiation Examination at EN-MME and TE-VSC premises.

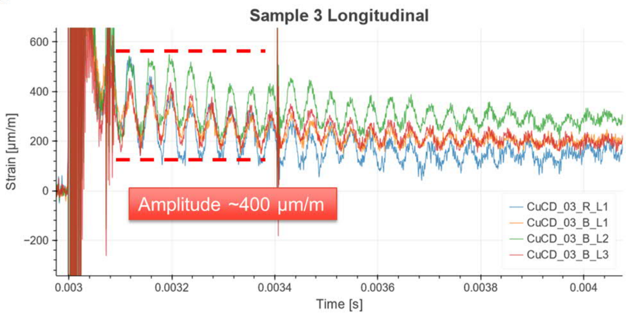

Figure 8. Example of acquired strains on CuCD.

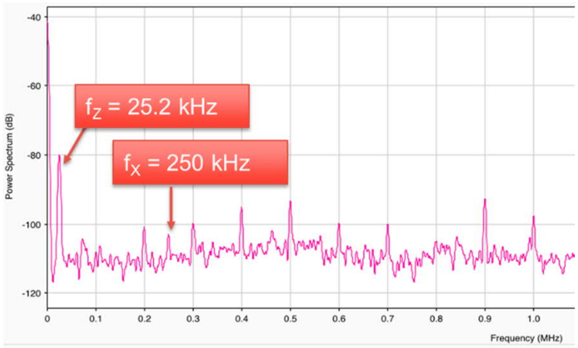

Figure 9. Example of simulated FFT on CuCD.

CONCLUSIONS

The Engineering Unit of the EN-MME group developed a core of competences including implicit and explicit FEM calculations, multiphysics studies, semiempirical methods, materials R&D and modelling, as well as safety standards concerning pressure vessels, handling and structural elements. Such expertise is effectively put at the service of CERN and the experimental collaborations, but it is also exploited within activities related to Knowledge Transfer and European projects. Notable, recent examples of novel techniques developed by the Engineering Unit have been highlighted in this paper.

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