Sheet Metal Forming of Niobium Crab Cavities at CERN

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1 Introduction

The installation of superconducting Radio Frequency (RF) Crab Cavities is one of the key upgrades in the framework of the High-Luminosity Large Hadron Collider (HL-LHC) at CERN. These devices – built out of niobium sheets – are shaped and joined into a complex geometry entailing very tight tolerances, in order to comply with strict RF requirements.

For production purposes, the so-called Double Quarter Wave (DQW) Crab Cavity was sub-divided in three major sub-elements: *elliptical cap*, *main body* and *bowl* (Fig. 1). These sub-elements were formed in multi-step shaping processes, ranging from deep-drawing to extrusion and bending.

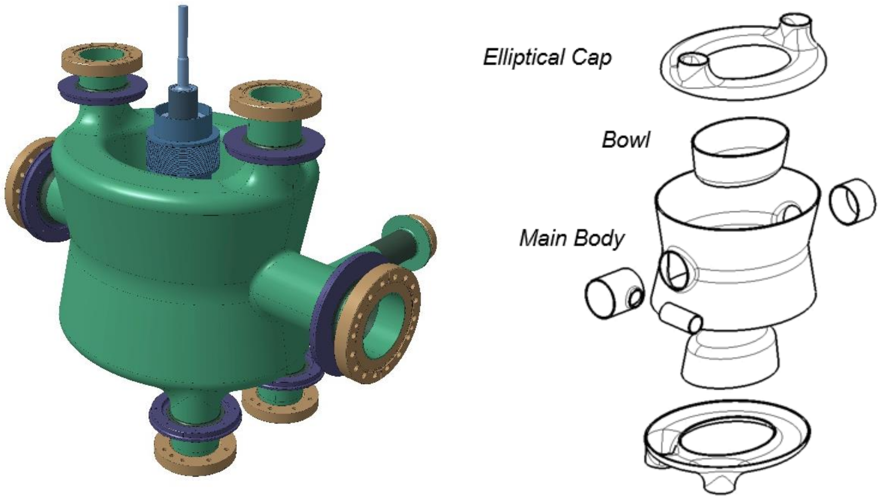

***Fig. 1**: DQW and its main subelements: Elliptical Cap, Bowl and main Body. Overall envelope of the cavity is 660x411x510(mm).*

The forming of 4mm thick niobium sheets into the final cavity shape is a demanding process given the high aspect ratio of the different pieces and their tolerances, which are in the order of 0.1mm. This made clear the necessity of better understanding the behavior of the material itself and also of the shaping processes themselves.

In response to this need, LS-DYNA simulations were performed throughout the R&D and production phases. The objective of this study is to present the numerical model set up, to show the results obtained and to analyze their capacity of prediction and of steering production choices.

2 Numerical approach

An initial modelling of niobium elasto-plastic properties has been performed via **`*MAT_PIECEWISE_LINEAR_PLASTICITY`** [1] and the adoption of data from past structural tests performed at CERN; despite the sheet typical dimensional ratios and production processes, isotropic properties have been assumed. Few literature may be found regarding the mechanical aspects and numerical modeling of niobium; the authors thus felt the necessity to improve the initial material model employed, via an extended test campaign which is currently ongoing.

For all studied processes, the behavior of the 4mm-thick niobium sheets, has been modelled via fully integrated shell formulation ELFORM 16 (with 7 through thickness integration points).

For all the rigid parts: punches, pads and molds, the standard rigid body model was employed.

Contacts between the different tool parts and the sheets were defined with **`*CONTACT_FORMING_ONE_WAY_SURFACE_TO_SURFACE`** [2]. The boundary conditions were imposed

with `*BOUNDARY_PRESCRIBED_MOTION_RIGID` and `*LOAD_RIGID_BODY` for displacement-based simulations and load-based simulations respectively.
Figure 2 shows a cross section view of the tool used for shaping of the Bowl (Left) and the corresponding numerical model (right). A pseudo-elliptical punch deep-draws the niobium sheet into the dual mold. Press-pads are used to guide the sheet during the process.

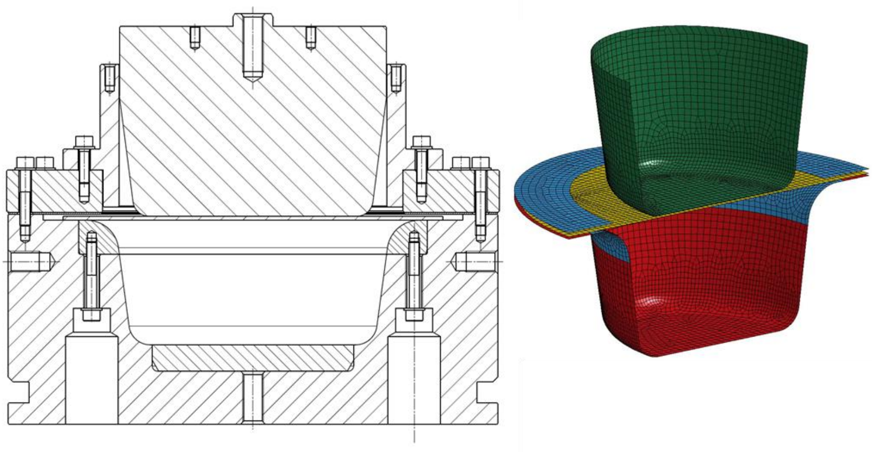

Fig. 2*:* *Tool for deep-drawing of the Bowl sub-element (Left) and its corresponding numerical model (Right).*

3 Benchmarking

Punch load and displacement data was collected during the different forming processes, in order to provide an evaluation means of the model accuracy. Such data has been obtained via an ad-hoc system of optical and pressure sensors embedded in the hydraulic press.
Each formed piece has also undergone thorough metrology of its surfaces. Shape results have been compared between reality and model.
A script has also been developed, which allows to extract data from metrology results and determine thicknesses at given sections. Such thicknesses have also served as comparison between the numerical and the real process.
The synergy of the above-mentioned methods has allowed insightful benchmark of the numerical model versus the real process, to an accuracy deemed satisfactory for the project's needs. The finite element model has thus served as a powerful tool in understanding the physics of the shaping processes and in steering tool design choices.

Fig. 3: *Metrology of the Bowl.*

4 Literature

[1] LS-DYNA Keyword user's manual Volume II, LSTC, February 2013
[2] LS-DYNA Keyword user's manual Volume I, LSTC, February 2013