CAVITY DESIGN TOOLS AND APPLICATIONS TO THE TRASCO PROJECT

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Abstract

In order to define the geometry of the beta scaled super-conducting cavities for the TRASCO Project an automated tool has been realized. By means of a useful parameterization of the cavity shape all the goal parameters, qualifying the design performances, can be obtained by an automatic iteration on the electromagnetic codes and design tools. The resulting cavity shapes and design parameters can be stored in a database for analysis and cross-checks. The results of this optimization procedure is presented for the case of the common cavity design for the TRASCO (Italy) and ASH (France) waste transmutation linac Projects. The tool has been interfaced with a finite element structural mechanics code in order to study the stiffening systems needed to increase mechanical stability and to decrease the Lorentz forces detuning in case of pulsed operation.

1 ELLIPTICAL CAVITY GEOMETRY

In order to determine a cavity geometry that has the necessary electromagnetic and mechanical performances for the TRASCO superconducting proton linac[1], we have used a geometry parametrization that allows easily to balance peak electric and magnetic fields and to control the cavity mechanical properties. The cavity geometry is elliptical both at the equator and at the iris, and is shown in Fig. 1.

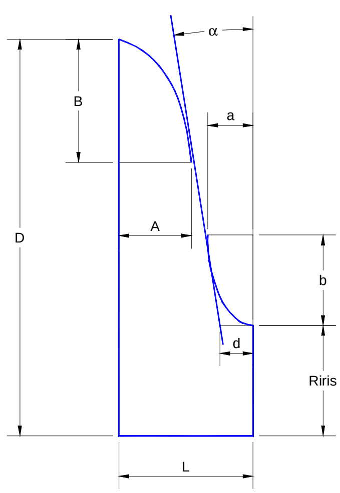

Figure 1: Elliptical half-cell geometry. For a list of the cavity geometrical parameters refer to the text. The ellipses ratio are defined as R=B/A and r=b/a.

The necessary parameters needed to design the cavity half-cell are 6:

1. **L**, the half-cell length (which determines the cavity beta value),
2. $\mathbf{R_{iris}}$, the iris aperture (which determines the cavity coupling factor),
3. α, the wall angle inclination (which influences the mechanical behavior of the cavity and controls its inductive volume),
4. **d**, the wall distance from the iris plane (which allows to reduce the capacitive volume in favor of the magnetic volume and viceversa, in order to balance the peak surface magnetic and electric fields on the cavity walls),
5. **R**, the equator ellipse aspect ratio (vertical axis divided by the horizontal axis, allows to find a local minimum for the peak surface magnetic field) and
6. **r**, the iris ellipse aspect ratio (which allows to find a local minimum for the peak surface electric field).

A last geometrical parameter, **H**, the distance between the equator and iris ellipse centers, is used as the free variable for tuning the cavity to the desired frequency, leaving all the other parameters unaltered.

With this parameterization, each geometrical parameter allows the control of a single cell electromagnetic (or mechanical) parameter, as described above.

It is important to note that the ellipse axes are not defined explicitly, only the ellipse aspect ratio is defined as a cell parameter. A change in the other cavity parameters (or of the tuning parameter H), will result in different ellipses, all having the same aspect ratio.

2 THE DESIGN TOOL

Although the cell parametrization described in the previous section is convenient for the analysis of the cavity behavior as a function of its shape, it is rather cumbersome to use in a standard RF code as SUPERFISH[2] for the cavity geometry definition, especially for tuning, where several iterations on the cavity parameters are needed in order to obtain the design frequency. For this reason, we have written a graphic interface to SUPERFISH, which converts the shape as specified by our parametrization into a geometry input for the code, executes the field solver iteratively for tuning purposes and gathers the solution data.

The code is interfaced to a cavity database that allows, with simple queries, a convenient analysis of the cavity behavior as a function of its shape.

2.1 Inner half-cell tuning

Tuning is accomplished by making use of the Slater coefficients reported on the SFO output, and iterating SUPERFISH runs until convergence to a specified approximation.

After tuning, all the cell geometrical parameters and electromagnetic output (peak surface electric and magnetic fields, resonant frequency, R/Q, Q factor and cell to cell coupling) are stored in the database. Cells can then be extracted from the database according to any criteria and the results can be graphically analyzed. The half-cell geometry can be also converted to a structural model for mechanical considerations, as discussed in the following.

Figure 2 shows an example of a typical output for a tuned half-cell shape.

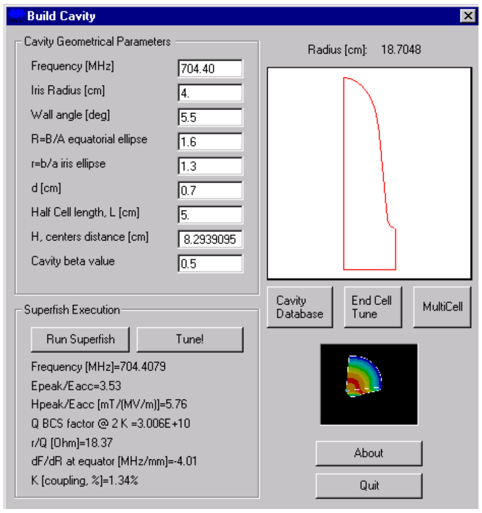

Figure 2: Typical output for an inner half-cell, tuned by means of the Slater coefficient dF/dR at the equator.

2.2 End half-cell tuning

A separate tuning procedure is needed for the end cells of a multi cell cavity. In this case we want to keep the equator diameter equal to that of the inner cell, so H can no longer be used for tuning. Choosing an inner half-cell stored in the cell database, we define possible changes to the end half-cell geometry and we then add the beam tube, obtaining an asymmetrical end cell to be used for the multi cell cavity. We decided to keep the external half-cell length equal to the inner half-cell and tune the cell by varying the wall angle α, i.e. by acting on the cavity magnetic volume. The motivation for changing only the external half-cell geometry is that we want to reduce the number of tooling needed for the half cells spinning.

The beam tube at the main coupler side can be larger than the iris of the inner cell, in order to provide better power coupling in the cavity.

Figure 3 shows the output for an end cell at the main coupler side.

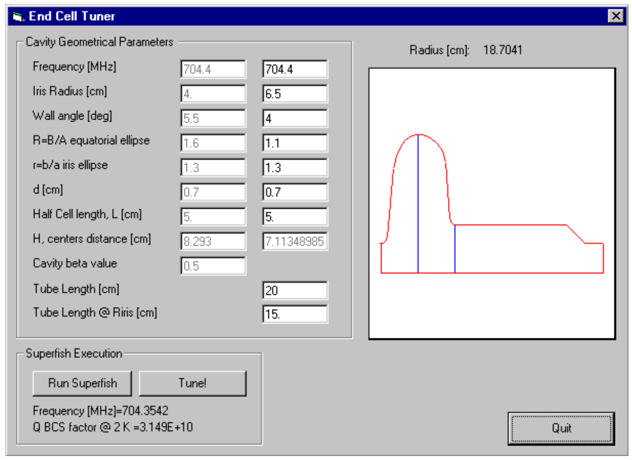

Figure 3: Output of the end cell tuning procedure.

2.3 Multicell cavity analysis

Finally, when both inner half-cells and corresponding end half-cells are stored in the database, a multicell cavity can be assembled and analyzed for performances. Graphically picking the desired entries of the database and specifying the number of cells is the only necessary action in order to run SUPERFISH on the final multicell cavity.

For the whole multicell cavity the electromagnetic parameters are reported, the field flatness is analyzed, the transit time factor over a specified beta range is computed and the equivalent "sin-like" cavity beta is derived. An example of full cavity output is given in Fig. 4.

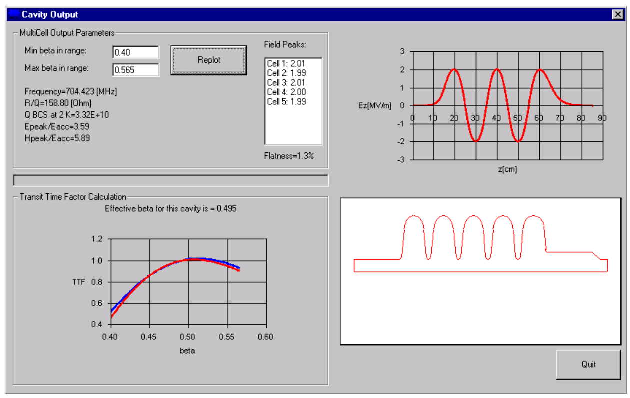

Figure 4: Summary output for a multicell cavity, displaying the geometry, the on-axis electric field, the field flatness data and the transit time curve in the specified β range.

2.4 Transfer to the FEM code

In order to address the mechanical issues of the reduced beta cavities, the cavity geometrical model and the fields on the cavity boundaries can be transferred to a standard commercial finite element structural analysis code (ANSYS™[3]).

The SUPERFISH electric and magnetic fields on the metallic boundaries are used both for computing the radiation pressure acting on the cavity walls, which induce time-dependent cavity deformations in case of pulsed operations, and for evaluating the frequency detuning caused by geometry modifications, by means of the Slater theorem[4-5].

The structural code can then be used to evaluate the influence of the cavity geometrical parameters on the mechanical properties of the cavity, to investigate the necessity of structural stiffening for the vacuum load and pressurized He operation, for mechanical tuning considerations, for the evaluations of a proper stiffening structure for the Lorentz forces and for the evaluation of the cavity structural eigenmodes, in order to investigate the possibility of exciting microphonics vibrations.

Figure 5 shows the output of a 2D ANSYS™ axisymmetric structural model of a half-cell, where the radiation pressure load computed from the electric and magnetic fields from SUPERFISH is responsible for the cavity deformation, causing a 1 KHz frequency detuning.

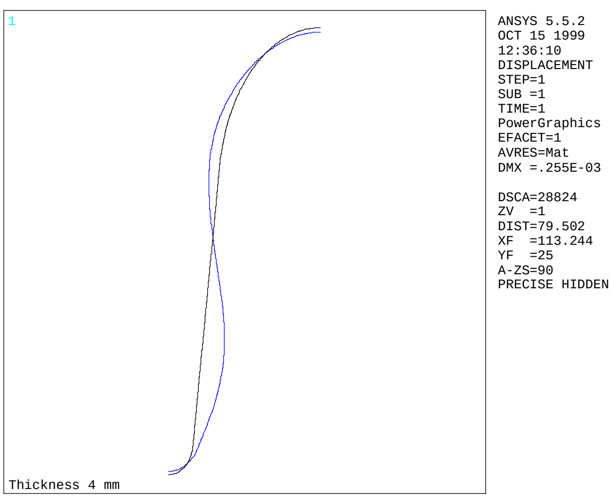

Figure 5: Beta 0.5 cavity displacement under the effect of the radiation pressure.

3 THE TRASCO/ASH CAVITIES

Both Italy[1] and France[6] are supporting national projects (TRASCO and ASH, respectively) for the study of a superconducting linac driver option for a nuclear waste transmutation system. In the framework of a close collaboration between these two projects and the sponsoring institutions (INFN in Italy, CEA and IN2P3 in France), we have agreed to join our efforts and work on a common reference design for such a linac.

One of the first necessary steps for the definition of the common design was to set the geometries of the superconducting cavities, in order to maximize the benefits of the prototype production foreseen by the two projects.

The reference cavity design work has been recently completed by the collaboration[7] and the main geometric and electromagnetic parameters for the chosen cavities are reported in Table 1.

Table 1. Main cavity parameters.

Geometrical Parameters			
Cavity synchronous beta	0.50	0.68	0.86
Number of cells	5	5	6
Cell geom. length [mm]	100	140	180
Geometrical beta	0.470	0.658	0.846
Full Cavity Length [mm]	900	1100	1480
Iris diameter [mm]	80	90	100
Tube $\emptyset$ at coupler [mm]		130	
Internal wall angle, α [°]	5.5	8.5	8.5
Equator ellipse ratio, R	1.6	1	1
Iris ellipse ratio, r	1.3	1.3	1.4
Full cavity electromagnetic Parameters			
Max. E_{peak}/E_{acc}	3.59	2.61	2.36
Max. B_{peak}/E_{acc}	5.87	4.88	4.08
Cell to cell coupling [%]	1.34	1.10	1.28
R/Q [Ohm]	159	315	598

Note that the full cavity electromagnetic parameters are computed defining E_{acc} at the geometrical beta value of the cavity, and this values should be scaled to the synchronous beta value for beam dynamics calculations if the sin-like cavity model of Ref. [8] is used.

The geometry for the three cavities is seen in Fig. 6, and a few comments are in order. The beam tube at the coupler end of the cavity has a bigger aperture than the cell irises, in order to improve the main power coupling.

The lowest beta cavity has the worst mechanical stiffness (both with respect to Lorentz forces and vacuum load), and here the use of an elliptical shaped equator, which better distributes stresses along the cavity walls, simplifies the stiffening structure. The other cavities have a round shape in order to ease the cell fabrication process.

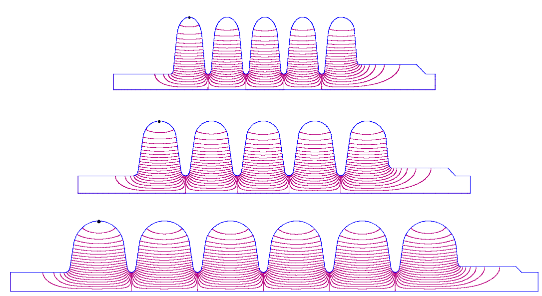

Figure 6: The geometry for the three cavities of the TRASCO/ASH cavities.

A stiffening structure for the beta 0.5 cavity (not shown in Fig. 6) by means of a TESLA-like welded ring, allows to reduce the Lorentz force detuning at the operating accelerating field from about 1 KHz to 620 Hz. The Lorentz force detuning of the higher beta cavities is well below 300 Hz, and hence the cavities do not require a stiffening structure. The accelerating fields used in forces calculations correspond to the maximum nominal peak magnetic field of 50 mT on the cavity walls.

An alternative stiffening scheme by means of copper deposition using plasma spay techniques seems promising and is being currently investigated by the collaboration[9].

A niobium thickness of 4 mm for the two lowest beta cavities is enough to guarantee (with proper stiffening of the beta=0.5) the mechanical stability of all the cavities and to maintain the stresses in all conditions below 50 MPa. For the highest beta cavity, a 3 mm thickness is being considered.

The lowest order vibration eigenmodes of the three cavities have been computed, and a complete characterization of the higher order transverse and longitudinal modes will be performed in order to avoid the occurrence of possible mechanical resonances. Figure 7 shows the lowest order transverse eigenmode of the stiffened beta 0.5 cavity, occurring at 53 Hz.

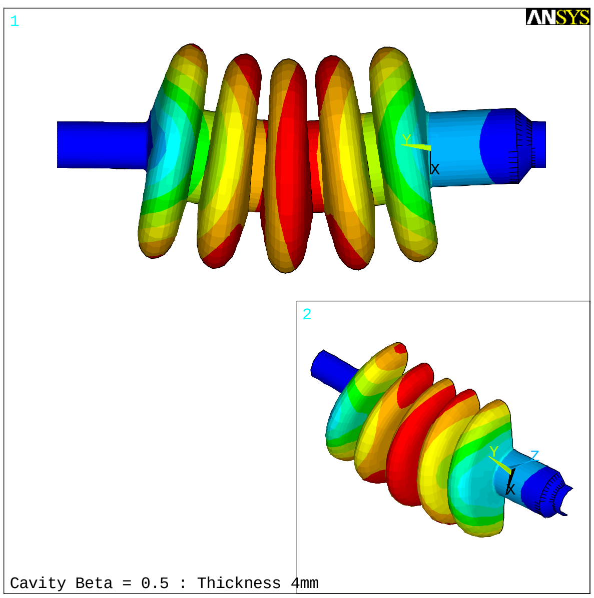

Figure 7: The lowest order vibration eigenmode of the beta=0.5 cavity at 53 Hz.

5 ACKNOWLEDGEMENTS

We wish to acknowledge the contribution of Henry Safa and Jean-Luc Biarrotte, from CEA/DAPNIA/SEA Saclay, in the definition of the common TRASCO/ASH cavity design.

6 REFERENCES

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