TUNING PROCEDURE FOR THE LINAC4 PI MODE STRUCTURE (PIMS)

P. Ugena Tirado, F. Gerigk, R. Wegner, CERN, Geneva, Switzerland

Abstract

PI-Mode-Structure (PIMS) cavities will be used in the high energy section of LINAC4 (102-160 MeV). Each cavity is made of 7 coupled cells, operated in the π-mode at a resonant frequency of 352.2 MHz. The cell length remains constant for each of the 12 cavities but changes from cavity to cavity to synchronise with the increased beam energy. This paper reports on the tuning process required to get a constant voltage in each cell at the resonant frequency and consisting in re-machining to the required level the tuning rings located on each cell-wall. An algorithm based on single cell detuning, equivalent circuit simulations and precise 3D simulations for the 3 different cell types of each cavity has been developed and successfully applied to the tuning of the first PIMS cavity. In order to reduce the simulation effort for the remaining 11 cavities, an interpolation algorithm based on 3 cavities has been developed and validated. In a second tuning step, after the electron beam welding of all elements, the final adjustment of single-cell frequencies and field flatness is achieved by cutting the length of one plunger tuner per cell.

INTRODUCTION

Figure 1 shows a cut through a PIMS cavity that is assembled of 15 elements (8 discs and 7 rings) which are joined by electron beam welding after the first tuning step. The 7 cells can be classified into 2 end cells, 4 intermediate cells and 1 central cell [1] which connects the cavity to the wave-guide system. A tuning range of ±1.5 MHz is provided by the tuning islands (±1.0 MHz) located at the walls of discs [2] and the piston tuners (±0.5 MHz) in each cell.

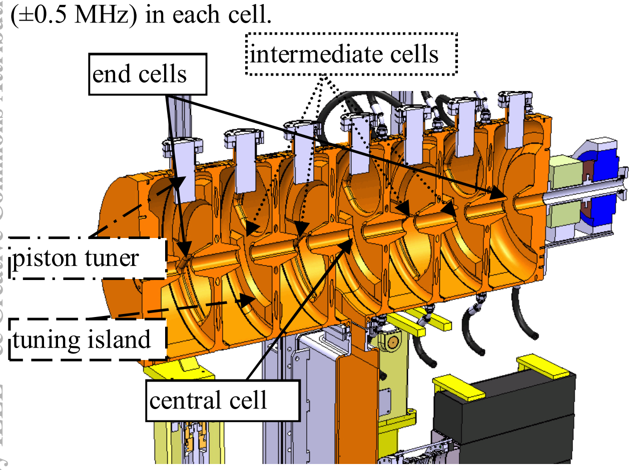

Figure 1: 3D model of a PIMS cavity which is made of 7 cells: 2 end cells, 4 intermediate cells and a central cell.

INITIAL FLAT FIELD TUNING

In a first step, the complete structure is assembled vertically before welding and an initial bead pull measurement is performed. The first module of the PIMS was tuned at CERN following this procedure (compare [3] and Figure 2).

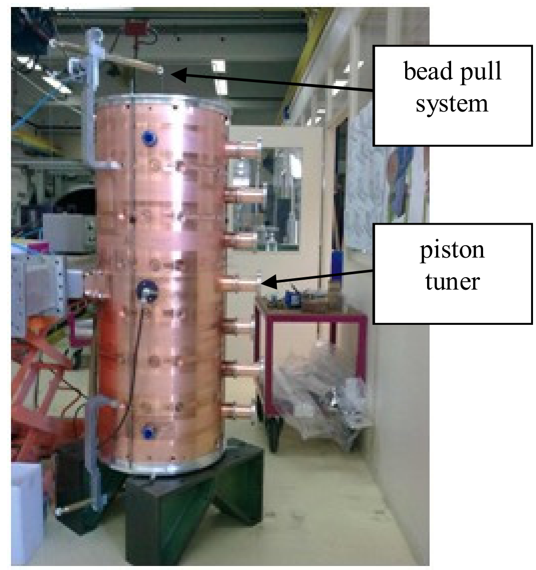

Figure 2: PIMS hot model. First measurements before electron beam welding.

Figure 3 shows the normalised electric field along the beam axis. The flat field deviation was only 4.2% and a symmetry in respect to the middle cell was observed, which underlines the high machining precision of all 15 elements. After the initial measurement, the PIMS is tuned with the help of the piston tuners placed in each cell to a flat field. By changing the penetration of the tuners, the field distribution can be modified while the resonant frequency of the whole structure changes. During this first step the resonant frequency can be freely chosen – it will be adjusted in the next step, using the circuit model.

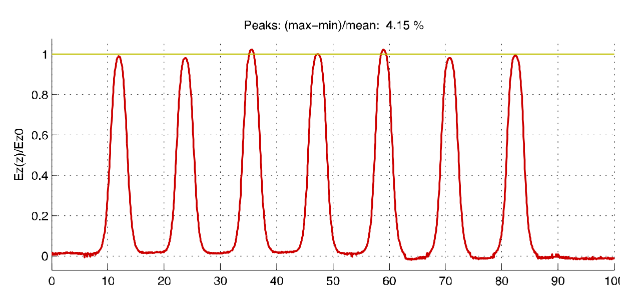

Figure 3: First PIMS bead pull measurement.

After a flat field distribution is achieved, the tuners are completely removed from the cavity one by one and the change in frequency of the π-mode is recorded. These values allow us to calculate the resonant frequency of individual cells.

CIRCUIT MODEL CALCULATIONS

The circuit model is used firstly for relating the global change of the π-mode frequency to the local frequency change of one single cell. Secondly, the circuit model is employed to determine the individual cell frequencies to achieve a flat field at a desired frequency of the π-mode. This frequency shift is afterwards translated to a change in tuning ring heights:

The equations applied are based on a coupled resonator model [4] [5], which considers complete cell terminations and next nearest neighbour coupling:

$$I_n = X_n\left(1-\frac{\omega_{0n}^2}{\omega^2}+1/jQ\left(\frac{\omega_{0n}}{\omega}\right)\right)+\frac{k_1}{2}(X_{n-1}+X_{n+1})+\frac{k_2}{2}(X_{n-2}+X_{n+2}) \qquad n=0\ldots6 \qquad (1)$$

where $I_n = E_n\sqrt{2}/j\omega\sqrt{L_n}$, $X_n=\sqrt{2L_n}i_n$, $\omega_{0n}^{-2}=2L_nC$ and $QR=2\omega_0 L_n$. X values vanish for negative sub indexes and higher than 6. L_n is the circuit inductance, R_n is the circuit resistance (which is equivalent to the shunt impedance in circuit definition) and C_n is the capacitance. E_n is the voltage driven in the nth circuit and i_n is the circulating current. In this case, $\omega_{0,n}$ will differ from one cell to the other. The nearest neighbour coupling is k_1 and the second nearest neighbour coupling is k_2. For the PIMS hot model k_1 = 5.7%, k_2 = -0.1%. Due to the bigger volume of the end cells, the coupling to the adjacent cells (2 and 6, respectively) is with k_{end} = 5.4% slightly lower than k_1.

The eigenvalues $(\omega_{e,m})^2$ and eigenvectors X_m of the equation system above are calculated and the π-mode (lowest frequency) is identified. The 7 unknown, individual cell frequencies are varied until a flat field at the initially measured π-mode frequency is reproduced. Then, the recorded changes of the π-mode frequency when removing the piston tuners are reproduced so that the resonant frequencies of the 7 individual cells without piston tuners are found. Thereafter, the individual cell frequencies are varied again to obtain a flat field at the desired π-mode frequency. By comparing these two calculated frequencies for each cell and including the frequency increase for the desired position of the piston tuner (for example 350 kHz), the necessary frequency shifts for the first tuning step are determined. They can subsequently be related to the corresponding reduction of the tuning island heights.

3D SIMULATIONS AND INTERPOLATION

In order to considerably reduce the time needed for tuning, the tuning is foreseen to be done in a single operation. Therefore, precise correlation curves between the change of the tuning island height and the resonant frequency are required. 3D electromagnetic simulations have been performed with HFSS for this purpose. Simulations for the 3 cell types (end, intermediate and central cell) for all 11 remaining PIMS modules are needed. To reduce the computational effort, interpolations have been employed based on simulations for three modules (2, 6 and 12) and six different heights of the tuning islands between 0 and 15 mm. Figure 4 shows the resulting curves of module 2 and in Figure 5 the interpolated curves for the intermediate cells of modules 2, 6 and 12 are plotted. Moreover, modules 4 and 9 have been simulated to validate the interpolation principle. The maximum deviation, seen from the two-dimensional interpolation, is below 100 kHz, compare Figure 6. This uncertainty in addition to the one of the ±0.1 mm re-machining tolerance (corresponding to ±25 kHz) will be compensated by cutting the piston tuners in the second tuning step after welding.

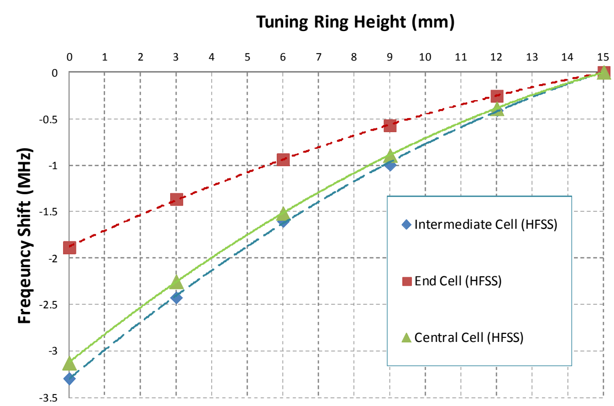

Figure 4: Frequency shift as a function of the tuning island height for module 2. The effect of the end cell is smaller because here only one side is equipped with tuning islands.

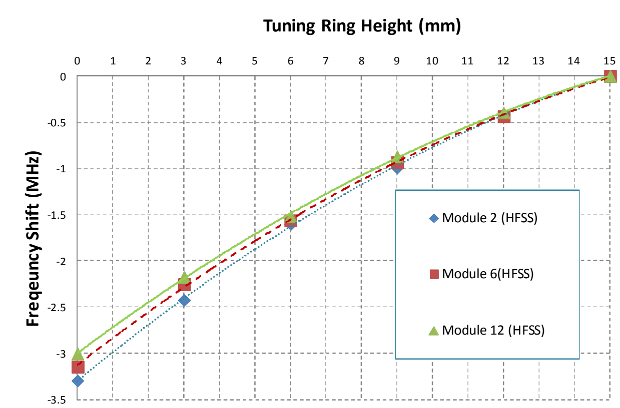

Figure 5: Frequency shift as a function of the tuning island height for the intermediate cells of modules 2, 6 and 12.

ISBN 978-3-95450-115-1

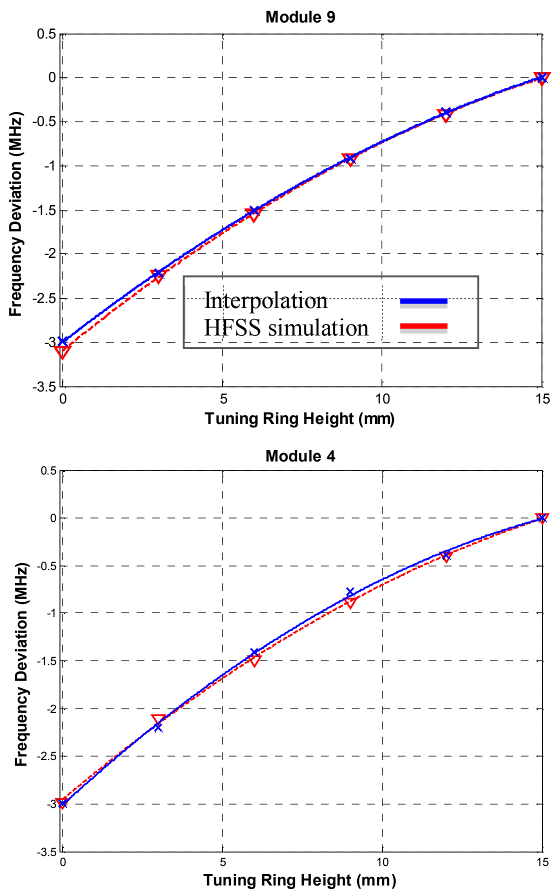

Figure 6: For Modules 4 and 9, the HFSS simulation results and the interpolated curves of frequency shift versus tuning island height are plotted.

FINAL TUNING AND MEASUREMENTS

Once the complete cavity is welded, the final tuning of the PIMS is carried out: The plunger tuners are used to achieve the final flat field configuration. During the welding process the cell length shrinks typically between 0.18 and 0.24 mm per weld. This effect has been taken into account during the design stage but implies a final tuning effort. This process defines the final length of each tuner. In a last measurement, the field distribution is verified. A field flatness of better than ±2% can easily be achieved, for the prototype measurement shown in Figure 7, the flatness is better than ±1%.

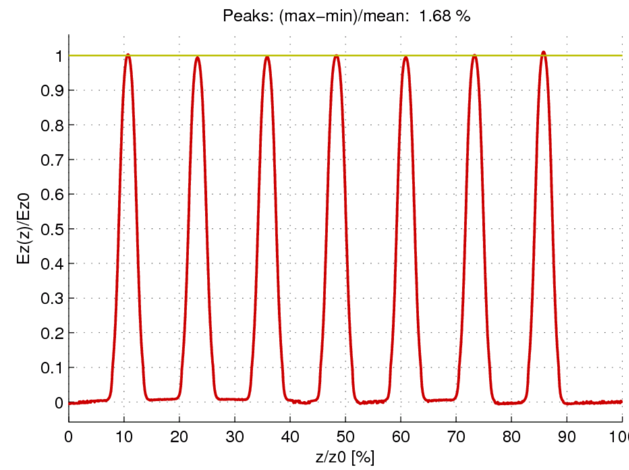

Figure 7: Final PIMS (hot model) bead-pull measurement at 352.14 MHz (π-mode).

SUMMARY

The procedure for tuning the 11 remaining PIMS cavities for Linac4 has been described in detail: After an initial flat field tuning at an arbitrary frequency, equivalent circuit simulations are made to calculate the necessary frequency shift of each cell to obtain a flat field at the desired resonant frequency of the π-mode. 3D RF simulations and a two-dimensional interpolation are used to correlate this frequency shift to the necessary re-machining of the tuning islands. After the electron beam welding of the cavity, the piston tuners in each cell are cut in a last step to obtain a field flatness of better than ±1%.

REFERENCES

[1] Gerigk F. et al. (2010). Layout and machine optimisation for the SPL at CERN. Tsukuba: Proceedings of LINAC 2010 Conf.

[2] Wegner R. and Gerigk F. (2009). PIMS -- A simple and robust accelerating structure for high intensity proton Linacs. Nucl. Instrum. Methods Phys. Res. A , 606, 257-270.

[3] Gerigk F. et al. (2010). The Hot Prototype of the PI-Mode Structure for Linac4. Tsukuba: Proceedings of LINAC 2010 Conf.

[4] D.E. Nagle, E. A. (1967). "Coupled Resonator Model for Standing Wave Accelerator Tanks" (Vol. 38). Rev. Sci. Intrum.

[5] Wangler, T. (1998). "RF Linear Accelerators". John Wiley & Sons.