NUMERICAL CALCULUS OF RESONANT FREQUENCY CHANGE BY 3D RECONSTRUCTION OF THERMAL DEFORMED ACCELERATOR TUBE

Z. Shu, L. G. Shen, M. J. Li, Y. Sun, X. C. Wang, W. Zhao, Y. J. Pei
University of Science and Technology of China, Hefei, Anhui, China

Abstract

Thermal deformation caused by Non-uniform temperature distribution in disk-loaded waveguide affects the resonant frequency of LINAC deeply. A new approach of multi-disciplinary integration is adopted to study the influence of the thermal deformation on the resonant frequency. The kernel technology is to simulate the thermal deformation of the accelerator tube loaded RF power via thermal-structure coupling analysis in FEM software I-DEAS first. Then a reconstruction of a new 3D geometric model is done from the nodes of deformed finite element model of accelerating cavities with self customized program. Finally the new model is coupled into the Microwave Studio to recalculate the resonant frequency. The method can simulate the real resonant frequency change cased by non-uniform deformation with high precision.

INTRODUCTION

A typical feature of a travelling wave electron linear accelerator is that the walls of the RF cavities dissipate microwave power when running. This causes non-uniformity of temperature distribution and thermal deformation which deeply affects the resonance frequency of the machine [1]. Typically the prediction of resonant frequency deviation due to the changes in the various cavity dimensions are obtained experimentally [2, 3]. Among various cavity dimensions, “2b” (the inner diameter of accelerating cavity) is the most effective one. It is -0.985Mc/mil [1] and 35.7MHz/mm [2] for working frequency 2856MHz. Several hundred kilohertz of frequency change will decrease accelerating efficiency. The total deformation is usually required to be controlled within 5μm. Researchers also analyze frequency change by theoretical analysis, e.g. perturbation theory [4, 5]. The change in frequency is always realized as a function of the volume change of infinitesimal volumes along the RF cavities surface. The biggest deformations of various parts are regarded uniformly as constant values. Then according to perturbation theory, the functions between frequency change and cavity dimensions are obtained. However, the real deformation of the accelerating cavity and tube are obviously non-uniform and non-linear due to the distributed microwave power dissipation and the complex structure of the tube, so it is difficult to acquire accurate result analytically. Here, a numerical approach is studied to obtain the frequency change of the cavities directly, on which microwave power dissipation acted.

The studies are carried out on an irradiation accelerator being served on food sterilization at pulsed power 4.8MW. The average power dissipated by the walls of cavities is 9.28kW when electron beam runs.

A 3D geometric model of the whole accelerating tube is created, on which a cooling system rounded. The temperature distribution and thermal deformation are calculated in mechanical FEA (Finite element Analysis) software I-DEAS (Integrated Design and Engineering Analysis System). As a result, the thermal deformed finite element model is gained, which is an integration of nodes’ information. However, it is not able to be used by microwave EDA (Electronic Design Automation) software Microwave Studio directly, but geometric model. Therefore, the deformed finite element model must be reconstructed to geometric model. A high precision reconstruction technology should be developed to avoid dig additional errors in dimensions of the cavities. With regards to this, a self customized program is developed to extract the coordinates of the displaced nodes and then to reconstruct a new 3D geometric model. In order to get high accuracy and high efficiency, NURBS curves and surfaces are utilized and software ANSYS is employed.

THERMAL DEFORMATION ANALYSIS

Presence of the resonant electro-magnetic fields creates electrical currents on the interior surface of the cavities and thus deposits thermal energy into the walls that causes thermal distortions which result in a resonant frequency shift. Thus the constant temperature system should be applied round the accelerator tube.

Symmetrical double helix jacket-style water cooling system is adopted to limit the temperature non-uniformity. Inlet water of 20℃ at a flow rate of 1.5kg/s is applied on each cooling channel, i.e. water velocity is 5.56m/s.

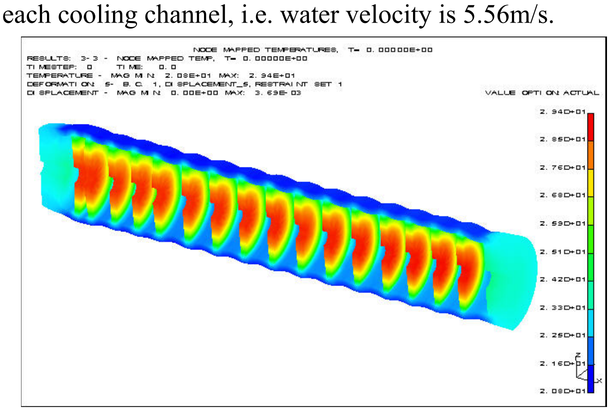


Figure 1: Temperature distribution on deformed tube.

The simulation is done by I-DEAS. The highest temperature of 29.3℃ is at the centre of the disk of the output end. The biggest temperature difference in accelerating tube is 8.5℃. Fig.1 shows the temperature distribution on the deformed tube. It indicates that the thermal deformation of the surfaces is wavelike. Fig. 2 shows the temperature distribution of single cavity.

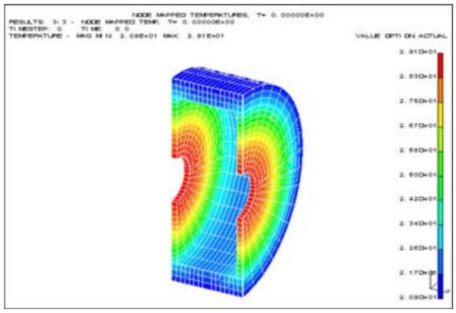


Figure 2: Temperature distribution of cavity.

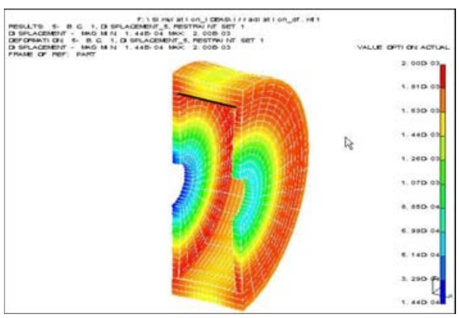


Figure 3: Displacements of cavity.

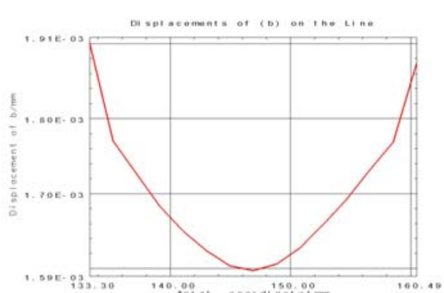


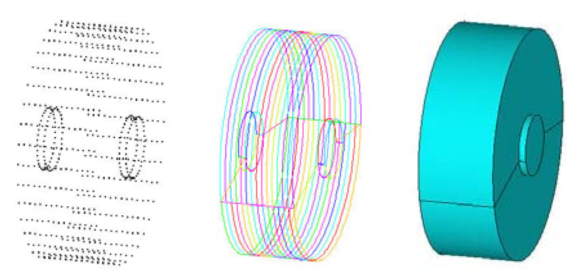
Figure 4: Alteration of b on the black line of Figure.3.

Deformation is caused by thermal load which is transformed from temperature distribution and temperature changes. It is non-uniform and the maximum occurs at a unilateral outside edge of the cavity. Fig. 3 shows the deformation of the fifth cavity of the accelerator tube. Fig.4 shows the deformation on the black line in Fig.3. It is obviously non-uniform. The deformation is presented by the displacements of all nodes on the line. The biggest deformation on the interior diameter of the cavity (2b) is approximately 3.9μm, and it is 0.4μm on the interior diameter of the disk-load (2a), -1.08μm on the periodic length. The uniform change of 2b contributes the resonance frequency change -50 kHz/μm [2]. Only thermal deformation makes frequency change about -195 kHz.

3D RECONSTRUCTION OF DEFORMED CAVITIES

In order to study the real frequency of deformed cavity, Microwave Studio, abbreviated as MWS, is utilized. In view of the software to accept only three-dimensional geometric model, the calculated result which just includes position information of the nodes, must be transformed to geometric model.

A self customization strategy is as following. Surface skinning modelling technology [6, 7], also known as lofting, is adopted to reconstruct interior surfaces. Non-uniform rational B-spline (NURBS) model is using for generating and representing curves and surfaces which offers great flexibility and precision for handling both analytic and freeform shapes. As a pretreatment, all the nodes on interior surfaces of the cavities are extracted from the finite element model. A data set, including the coordinates of the nodes and the corresponding displacements, are saved in an Excel document and are sorted by a customized Java program which output txt files. According to the data set, a new solid model is reconstructed with a self developed 3D reconstruction technology in ANSYS. First, the nodes which are with same axial coordinates before deformation are fitted to be NURBS curves. Then the curves are used to reconstruct NURBS surfaces by surface skinning technology. The reconstructed deformed solid model is exported in IGES format which can be imported into MWS to calculate the resonant frequency.



(a) (b) (c)

Figure 5: Process to reconstruct the deformed model .

Fig.5 is the process to form the deformed 3D model. Among it, (a) shows the nodes on the interior surface of the cavity. (b) shows the B-Splines created by the extracted and sorted nodes. And (c) shows the final reconstructed solid model. It is essentially the vacuum space in the cavity which can be modelled in the software MWS to calculate resonance frequency.

FREQUENCY CHANGE STUDIES

In the process of reconstruction, necessary interpolation will bring error. Furthermore, the model used in MWS is based on the ACIS kernel whose format is in SAT format. So the imported model in IGES format should be converted to ACIS data. The complex reconstructed solid model would be slightly changed in the conversion process. In order to evaluate the frequency shift caused by the errors of the reconstruction, a set of simulation are implemented. Fig.6 shows the results. Line (a) shows the frequency corresponds to mesh number of the reconstructed deformed cavity, line (b) shows the frequency corresponds to mesh number of undeformed model created in MWS directly, and line (c) shows frequency corresponds to mesh number of undeformed model in IGES format imported into MWS from ANSYS or I-DEAS.

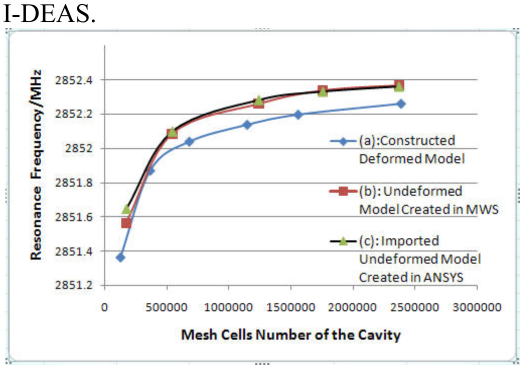
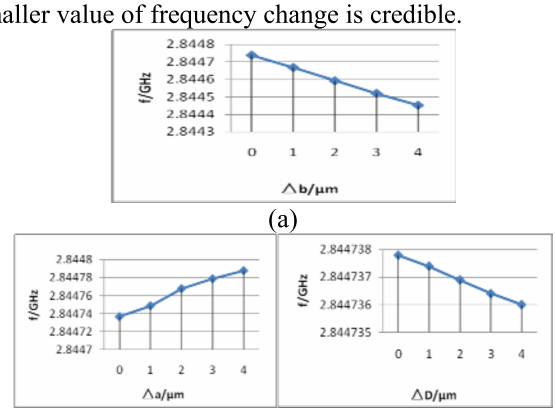


Figure 6: Frequency studies on undeformed and deformed models in different simulating accuracy.

From (b) and (c), the errors generated in the operation of importing IGES files will gradually minish as the simulating accuracy increases. When the mesh cells number is up to 2370816, the value is 2852.365 MHz in (b) and is 2852.363MHz in (c).

The frequency of the reconstructed deformed model is 2852.137MHz when mesh cells number is 114296, while for undeformed model created in MWS is 2852.260 MHz. The error in the process of reconstruction for the import model in IGES is nearly –25 kHz when mesh cells number is on million level. And frequency change caused by thermal deformation is approximately –123 kHz which is smaller than the evaluated value above. The evaluated value above is according to the biggest deformation, so smaller value of frequency change is credible.



(a)

(b) (c)

Figure 7: Relationship between resonant frequency and dimensions change of cavity.

The above research evaluates the impact of the integrated deformation on resonant frequency shift by reconstruction method. However, the change of single parameter as 2b, 2a and D affect the frequency totally differently. We change the parameters factitiously by micron in our programs when reconstructing. The affect of single parameter as b, a and D on the frequency in the process of reconstruction is shown in Fig.7. Note that the relationships are almost linear. And it is shown that $\Delta f/\Delta b$ equals -71 kHz; $\Delta f/\Delta a$ is nearly 13kHz and $\Delta f/\Delta D$ is -0.5kHz.

CONCLUSIONS

A method of multi-disciplinary integration is discussed, which is for numerical simulating in thermal, structural and frequency simulations for the irradiation accelerator.

This approach allows the simulation goes well. The reconstruction method of 3D model utilizes surface skinning modelling technology and stores the model in IGES format which can be imported by various kinds of CAD/CAE software. Errors will occur when reconstruction and can be controlled while the simulation accuracy is high enough. A sufficiently accurate approach is provided to evaluate the influence on frequency change cased by non-uniform deformation. Such multidisciplinary and comprehensive study can make optimal solution possible. Frequency shift studies help us to optimize the cooling system and determine the tunable range, not only in linear accelerator tube, but also another types of RF cavities.

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