SIMULATION, MEASUREMENT AND TUNING OF A PROTOTYPE DISK LOADED RF CAVITY

Sasan Ahmadiannamin†, Mohammad Lamehi Rachti, Mahyar Shirshekan, Institute for Research in Fundamental Sciences (IPM), Tehran, 19395-5746, Iran
Fereydoon Abbasi Davani ,Shahid Beheshti University,Tehran, 1983969411 , Iran
Farshad Ghasemi, Nuclear Science and Technology Research Institute (NSTRI),Tehran, 14155-1339, Iran

Abstract

Constant impedance accelerator RF cavities are constructed from similar resonator cells that stacked to each other. Best operation condition is achieved when all of cells resonate in one resonance frequency with similar quality factors. So, measurement and tuning of RF cavities is the critical step for final best operation of linear accelerators. In this paper, the electromagnetic computer simulations, RF measurement and final tuning of a nine cell periodic accelerator structure was represented. All of cavities tuned in one resonant frequency and according to theoretical concepts we obtain nine resonant modes from RF measurements by vector network analyzer.

INTRODUCTION

Linear electron accelerators are designed in various types and have wide applications in medicine, industry, agriculture and physics researches [1-2]. Main components of RF electron Linacs are RF power generators, power transmission waveguides, vacuum pumps and components, electron gun and acceleration cavities [3-4]. The IPM e-Linac project is first try of Iranian scientific societies for fabrication of RF electron Linacs based on domestic capabilities. The main goal of this project is to construct a 10 MeV, 10 mA electron beam in a 1.5 m Linac section with 2.5 MW input RF power. Two different procedures were tested for manufacturing of the accelerator cavities. In the first method, the disks and rings are stacked in the periodic arrangement by pressure of long screws. In the second method, the shrinking is used for placing the disks inside hallow circular waveguide. This methods are according to procedures that have been used in MARK I and MARK II, III respectively Stanford University [5-6]. In the following sections, the simulation, measurement and tuning of prototype accelerator cavities are presented. At the moment, this project passes the final assembling steps for commissioning start up.

DESIGN AND SIMULATION

By selection of 7 MV/m accelerating gradient and operational parameters of linac, shunt impedance and quality factor should be calculated analytically and then optimized by computer simulations. In constant impedance TW Linacs, the structure has periodic outline with 4 geometrical parameters, as shown in Fig. 1.

† Email Address: Ahmadiannamin@ipm.ir
Sasan.ahmadiannamini@gmail.com

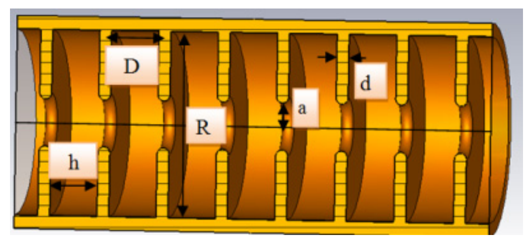


Figure 1: Geometrical parameters for design of constant impedance TW accelerator cavities.

The design parameters are 1- outer diameter of cells (R), 2- length of cells (D), 3- web thickness between adjacent cells (d), and 4- central beam hole radius of disks (a) that is required for passing of electron beam and generation of electromagnetic coupling between adjacent cells [7-8]. Since it has smallest frequency sensitivity against dimensional errors among all of Operation modes, π/2 phase advance was selected for cavity design. After analytical estimation of geometrical parameters, the precise dimensions were optimized by CST Microwave Studio [9] and SUPERFISH [10] electromagnetic simulation software. Analytical calculations and design procedure can be found in scientific papers [11-12]. The profile of Electric field of π/2 operation mode is represented in Fig. 2 and 3 for simulations with CST STUDIO SUIT and SUPREFISH correspondingly.

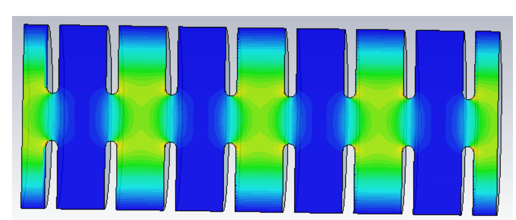


Figure 2: Electric field profile of π/2 (CST Studio Suit).

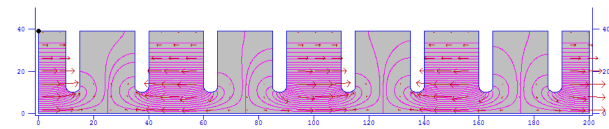


Figure 3: Electric field profile of π/2 (Superfish).

FABRICATION

In the Fig. 4 and 5, the first separate disk and washer prototype with screw pressure and measurement setup was shown respectively. The highest quality factor achieved based on this method of fabrication was 6300. Fabrication of new prototypes for increasing the quality factor up to 10000 was considered based on shrinking procedure. The prototype and its cross section after cutting are shown in Fig. 6(a) and 6(b) respectively. Another shrinked prototype with 8 periodic length and quality factor of 9700 was shown in the Fig. 7. This prototype was used for bead pull measurements and tuning practice.

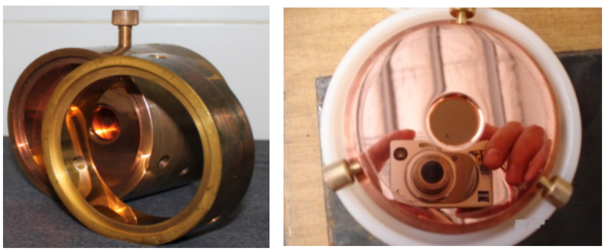
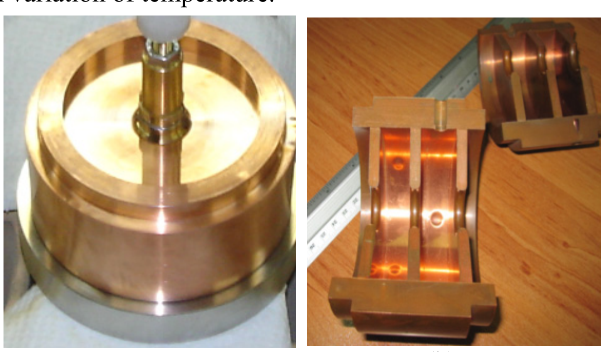


Figure 4: The first prototype with separate disk and copper cylinders.

Figure 5: Experimental setup for measurement of frequency and quality factor and evaluation of them based on variation of temperature.



(a) (b)

Figure 6: (a) Shrinked prototype (b) Wire cut view.

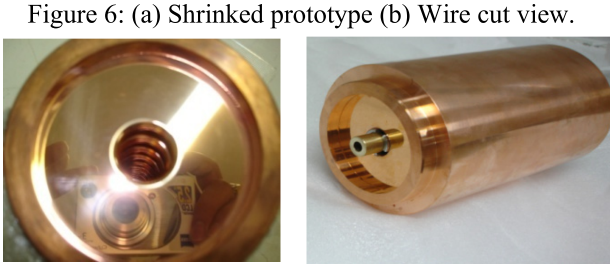


Figure 7: Longer prototype with 8 periodic lengths.

MEASUREMENTS AND TUNING

Cavity tuning has been done cell by cell with deformation of outer wall. The frequency shift due to temperature change is calculated to be 50.7 KHz/^{0}C for our prototype structure. Also, the frequency difference because of different dielectric constant for operation in vacuum and tuning in environment condition should be considered.

The measurement of electric field profiles for different modes is the first step for tuning. This step was done by application of an automated bead pull measurement system. This bead pull measurement system can displace perturbing objects by different speeds along the central axis of accelerator cavities. The smallest step of displacement is 0.1 mm. The beadpull measurement system during measurement of prototype shrinked cavity was shown in the Fig 8.

Figure 8: Attached bead pull system on prototype 9 cells cavity.

Flatness of electric field along the central axis of cavities is the best measure of efficiency of tuning beside the resonant frequency adjustment. The electric field profile measurements can be done by two different perturbation methods of Slater and Steele. In the Slater method the variation of frequency or phase in fixed frequency is measured and related to electric field strength at different bead positions. In the Steele method, the variation in S11 parameter relative to unperturbed condition is measured and is related to electric and magnetic field strength on different bead positions [13, 14 and 15]. For periodic structures in standing wave condition, the Slater method can be used for measurement. So, we developed two MATLAB codes for analysis and plotting of electric field profile based on recorded results from Slater resonant and phase measurement methods [16].

The other way of measurement and tuning of accelerator cavities is application of two detuning plungers. In this method, two plungers detune the adjacent cells of the cavity under measurement. In one of them, an antenna is placed on the plunger head and excites the cell. This method was used for measurement and cell by cell tuning of 9 cells prototype. The setup of measurement and designed plungers are represented in the Fig. 9.

The electric field profile of π and $\pi/2$ modes before tuning is shown in the Fig. 10(a) and 10(b), respectively. Also the measurement after tuning and simulation results were shown in the Fig. 11(a) and 11(b) for π and $\pi/2$ modes respectively.

ISBN 978-3-95450-182-3

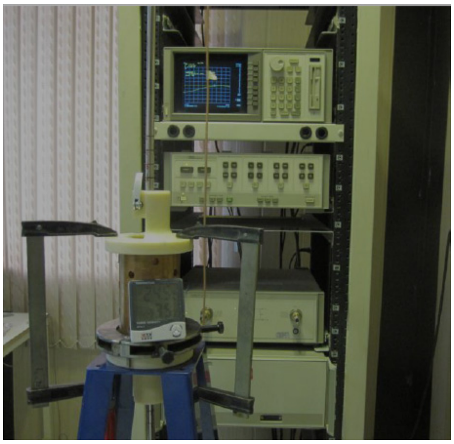
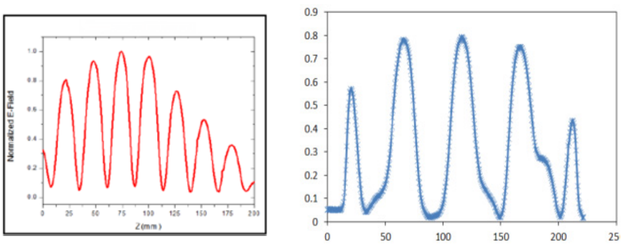
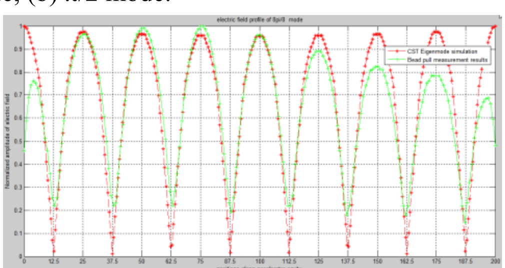


Figure 9: cell by cell Measurement and tuning of prototype.

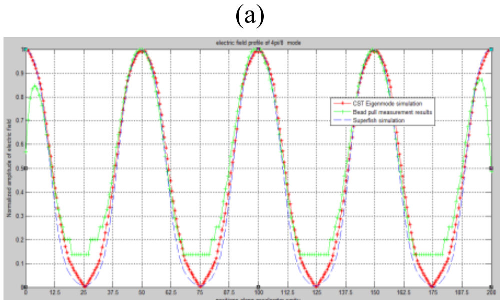


(a) (b)

Figure 10: The electric field profile before tuning for (a) π mode, (b) π/2 mode.



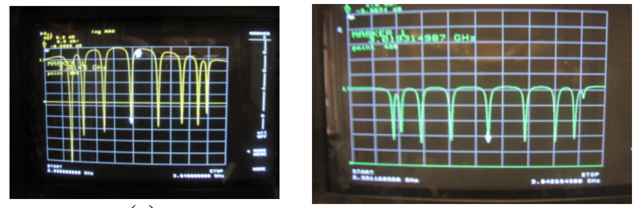
(a)



(b)

Figure 11: CST and SUPERFISH simulation and bead pull measurement results in Red, Blue and Green colours (a) π mode, (b) π/2 mode.

The measurement results of normal modes in pass band were measured by network analyzer before and after tuning are also represented in Fig. 12(a) and 12(b) respectively.



(a) (b)

Figure 12: Frequency spectrum of nine cell disk loaded cavity (a) before tuning (b) after tuning.

CONCLUSION

Test result of initial Disk-Ring prototypes showed that this method suffers from low quality factor and difficulty to reach to required vacuum level. Fabrication of tubes with 3 and 9 cavities using shrinking method showed that this method can be still suitable and efficient for constructing travelling-wave tube cavities. In Disk-Ring and Shrinked prototypes, quality factors improved up to 6300 and 9700 respectively. The maximum deviation between nominal and measured frequencies of all cells is better than 0.15 MHz after tuning. The results explained in this paper were used for fabrication and tuning of the main accelerating and bunching cavities of the IPM electron linear accelerator project. Also these investigations show the efficiency of shrinking method for improvement of quality factor of first prototypes and their better characterisation such as case of storage ring prototype cavities.

ACKNOWLEDGMENT

The authors are thankful to the e-Linac Mechanics group and specially Mehdi Bahrami for providing many helpful comments for construction of required components.

REFERENCES

[1] R. Mehnert, "Review of industrial applications of electron accelerators", Nuclear Instruments and Methods in Physics Research section B, Volume 113, Issues 1–4, 1 June (1996), Pages 81–87.

[2] W. Mondelaers, "Low-energy electron accelerators in industry and applied research", Nuclear Instruments and Methods in Physics Research section B, Volume 139, Issues 1–4, April (1998), Pages 43–50.

[3] Miller, R. B. (2005). Microwave Accelerator Subsystems and Components. Electronic Irradiation of Foods: An Introduction to the Technology, 173-193.

[4] P. Shrivastava, Y. D. Wanmode, et al, "Research, design and development activities on high power pulsed RF/Microwave systems and test facilities for particle accelerator", In Vacuum Electronics Conference (IVEC), 2011 IEEE International (pp. 53-54).

[5] R. F. Post, N. S. Shiren, "The Stanford mark II linear accelerator. Review of Scientific Instruments", 26(2), 205-209. (1955).

[6] M. Chodorow, E. L. Ginzton, , W. W. Hansen, et al, "Stanford High Energy Linear Electron Accelerator (Mark III)". Review of Scientific Instruments, 26(2), 134-204. (1955).

[7] J. Gao, “Analytical approach and scaling laws in the design of disk-loaded travelling wave accelerating structures”. Paris-11 Univ., 91-Orsay (France). Lab. de l'Accelerateur Lineaire. (1993).

[8] T. P. Wangler, ” RF Linear accelerators”. John Wiley & Sons. (2008).

[9] www.cst.com

[10] http://laacg.lanl.gov/laacg/services/download_sf.phtl

[11] W. Fang, D. Tong, Q. Gu, “Design and experimental study of a C-band traveling-wave accelerating structure”. Chinese Science Bulletin, 56(1), 18-23. (2011).

[12] W. Fang, Q. Gu, D. Tong, Z. Zhao, “Design optimization of a C-band traveling-wave accelerating structure for a compact X-ray Free Electron Laser facility”. Chinese Science Bulletin, 56(32), 3420-3425. (2011).

[13] Jr. Maier, J. C. Slater, “Determination of field strength in a linear accelerator cavity”. Journal of Applied Physics, 23(1), 78-83. (1952).

[14] C. W. Steele, “*A non-resonant perturbation theory*”. Microwave Theory and Techniques. IEEE Transactions, 14(2), 70-74. (1966).

[15] S. Ghosh, S. Seth, et al, “Bead-pull measurement using phase-shift technique in multi-cell elliptical cavity”. (Vol. 110904, No. IPAC-2011-MOPC088, pp. 280-282). (2011).

[16] http://www.mathworks.com/

ISBN 978-3-95450-182-3