SHUNT IMPEDANCE OF A 6 MeV STANDING WAVE SIDE COUPLED STRUCTURE*

T. S. Dixit#, R. Krishnan, S.N.Pethe, C.S. Nainwad, A.P. Deshpande

Society for Applied Microwave Electronics Engineering & Research, (SAMEER), IIT Campus, Powai, Mumbai-400076, India.

Abstract

Shunt impedance of an accelerating structure is an important parameter. It gives an idea of the power coupled to the beam. The measurement of the shunt impedance of the cavity is done using bead pull method. The shunt impedance is calculated after plotting the electric field profile. The calculation is done using a C program which first calculates the area of the plot and then uses appropriate variables to give the final value of the shunt impedance. The automation of the bead pull setup is planned and then the integration of calculation and automated setup. This paper describes the method and calculation of shunt impedance.

INTRODUCTION

SAMEER has developed an S band 6 MeV side coupled standing wave electron linear accelerator for cancer therapy [1,2,3,4]. The oncology system is developed indigenously and is currently used for patient treatment in a hospital. The 6 MeV linac is a standing wave side coupled structure made of OFHC copper has a pierce type diode gun for injection of electrons and the compact side coupled structure is operated in π/2 mode at 2998 MHz frequency. The electrons produce hard X-rays of 6 MV after striking a high atomic number target. The dose rate achieved is 240 RMM flattened. The beam current measured is 130 mA peak.

Table 1: Machine Parameters

Parameter	Value
Energy	6 MeV
Frequency	2997.98 MHz
Dose Rate (Flattened)	240 RMM
Input Power	2.6MW(peak)

SHUNT IMPEDANCE

Shunt impedance of an accelerator section is an important parameter which gives an idea about the figure of merit of the accelerating structure. The stored energy and accelerating voltage can be compared by considering the amplitude independent ratio, *r/Q*. The quantity *r/Q* determines the energy required for acceleration of electrons.

The shunt impedance of a resonant type accelerating structure is calculated using perturbation techniques. This technique is based on slater perturbation theorem given by Eq.1. [5,6]. The change in the frequency of a microwave cavity depends on the volume, shape, material and position of the perturbing object. If the perturbing object is small,then the change in frequency ω is very near to the unperturbed frequency ω_0. Therefore we can write

$$\delta = k\frac{\int_{\Delta v}\left(\mu H^2 - \varepsilon E^2\right)d\tau}{2U} \tag{1}$$

where, $\delta = (\omega - \omega_0)/\omega_0$, U is stored energy, H and E are magnetic field and electric field, μ is permeability, ε is permittivity and k is a constant depending on the volume $\Delta\tau$ of the perturbing object. If H=0 then the above equation reduces to a simple form given by Eq.2.

$$\delta = \frac{-k\varepsilon\Delta\tau E^2}{4U} \tag{2}$$

The quantity E^2/U can be determined experimentally by placing a perturbing object of volume $\Delta\tau$ into the cavity and measuring the resultant frequency. If the electric filed is constant then

$$\frac{r}{Q} = \frac{L^2E^2}{2\omega U} \tag{3}$$

Therefore, we can write *r/Q* as

$$\frac{r}{Q} = \frac{-2L^2\Delta f}{k\varepsilon\Delta\tau\omega f} \tag{4}$$

Using a standard cavity with known fields e.g. a cylindrical cavity in TM_{010} mode, the constant $k\varepsilon\Delta\tau$ henceforth called as form factor can be determined for a perturbing bead. The ratio *r/Q* for a cylindrical cavity in TM_{010} mode is given by *371L/D* where *L* and *D* are length and diameter respectively. For a cavity with variable fields a correction factor is included to take care of the variable field.

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#tanuja@sameer.gov.in,dixit.tanuja@gmail.com

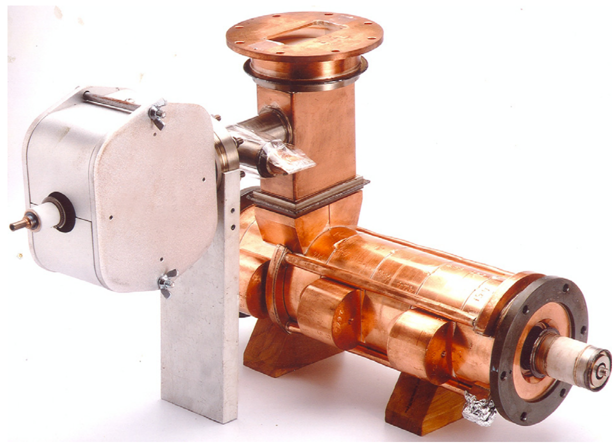

Figure 1: 6 MeV linac tube.

Measurements and Setup

Form factor of the beam is measured using a standard cavity. Standard cavity is a cylindrical cavity with length, L=49 mm and diameter, D=76 mm resonant at 3000.1 MHz. The field is almost constant along the axis when it is excited in TM_{010} mode. Since a constant field is established, the perturbation equation is simplified and the electric field is proportional to $\sqrt{\Delta f}$. This directly gives the form factor $k\varepsilon\Delta\tau$ of the dielectric bead in our case a cylindrical shape of length 11 mm and diameter 3 mm. To measure Δf , the bead is made to pass through the cylindrical cavity and the perturbed frequency is measured as a function of position. The maximum frequency perturbation measured was 0.92 MHz. The value of the form factor calculated for the dielectric bead was $3.3149*10^{-19}$. The form factor for a metallic bead of length 8 mm and diameter 3 mm was also calculated to be $2.3967*10^{-18}$.This factor was later used in the calculation of the *r/Q* of the linac cavity. The linac parameters are given in Table 2.

Table 2: Linac Parameters for Calculation

Parameter	Value
π/2 frequency	2996.7MHz
Q (unloaded)	15000
Length of linac, L_{Linac}	31.25cm

The linac measurement set up is shown in Fig.2. The dielectric bead was attached to a nylon thread and it was moved along the centre of the linac axis using alignment jigs. One side of the nylon thread was attached to the movable vernier scale and other side was attached to the load to provide tension and to prevent sag. The linac was connected to the vector network analyzer VNA using coaxial to waveguide adaptor for tracking the perturbation in frequency due to the bead. The vernier scale was moved with an accuracy of 1 mm and the change in frequency was recorded. The measured field profile is shown in Fig.3. $\sqrt{\Delta f}$ is plotted because it is proportional to the electric field. This plot gives the strength of the electric filed along the axis in different cavities using a metallic bead. The legends B1 and B2 represents buncher cavity and M represents acceleration cavities in the linac.

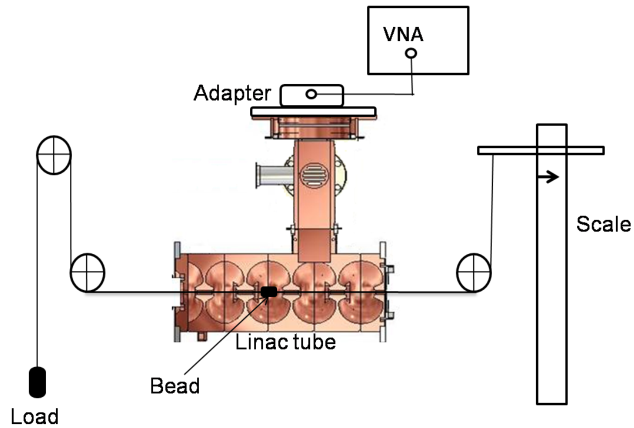

Figure 2: Setup for shunt impedance measurement.

Calculation

After determining the form factor the same bead is used to measure the perturbed frequency of the linac tube. The $\sqrt{\Delta f}$ vs position is plotted to get the field distribution of the linac tube. The frequency deviation for shunt impedance calculation is obtained after calculating the area under each field distribution and then estimating the effective $\sqrt{\Delta f}$ if the field of the cavity is to be made constant. So, for each cavity in the linac chain the factor r/Q is calculated and then using the value of Q unloaded $\sqrt{rT}$ is calculated where T is the transit time factor. Transit time factor for various cavities is tabulated in Table 3. The effective shunt impedance is then calculated of the entire linac structure. The effective shunt impedance, Z_{eff}

$$Z_{eff} = \left(\sum_n \sqrt{rT} \right)^2 \qquad (5)$$

is calculated for the linac tube with n number of cavities. The final shunt impedance, R is calculated using $R = 2Z_{eff} / L_{Linac}$ where L_{Linac} is the length of the accelerating section.

Table 3: Transit Time Factors

Item	Transit time
Buncher 1,B1	0.9
Buncher 2,B2	0.8503
Acceleration M	0.8287

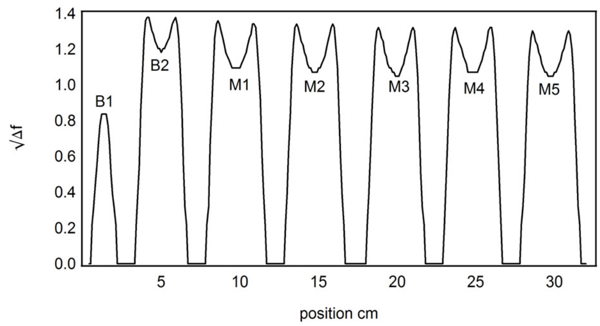

Figure 3: Measured electric field profile of the linac tube.

The frequency deviation for each cavity is calculated using a computer program. This program takes the input data of position and perturbed frequency of the bead pull experiment and then calculates area under the curve. The normalized area assuming constant field is calculated and it gives the frequency deviation for each cavity. The calculated value of shunt impedance using a dielectric bead is 104 MΩ/m and using a metallic bead is 87.45 MΩ/m.

DISCUSSION

The calculated value of the shunt impedance is higher than the actual shunt impedance achieved during high power testing. The final energy of electrons measured for linac structure is 6 MeV. The magnetron used to power the linac tube is capable of delivering 2.6 MW peak. The amplitude of field generated in a cavity is given by following relationship $V = \sqrt{P_{in} R}$. If input power of 2 MW is assumed then the energy gained by electrons should be 7 MeV.

The shunt impedance measured using this technique is collective impedance due to all the excited modes in the cavity. But, the mode which is used for acceleration is TM_{010}, therefore during high power measurements the energy gained by electrons in a certain length is less than the calculated in low power condition.

The impedance measurement of all possible excited modes in the cavity is needed to determine the contribution of only TM_{010} mode. A more detailed study of the higher order modes in the cavity is required. Also, a sophisticated measurement setup for measuring shunt impedance is underway. The setup will be automated for convenience using stepper motor for precise bead movement and a data acquisition system integrated with VNA for storing perturbed frequency values is required. PC with LabView application will control the entire measurement system. This modification will reduce the manual hard work and ensure error free readings.

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