[A17a10]

RF-CHOPPER FOR THE JHF 200-MEV PROTON LINAC

S. Fu*, Z. Igarashi, T. Kato, E. Takasaki, F. Naito and K. Yoshino

High Energy Accelerator Research Organization, KEK
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305-0801, Japan

Abstract

A fast chopper has been designed for the JHF 200-MeV proton linac. A 324-MHz RF deflecting cavity is applied as the chopper, due to its various merits, such as high field and compactness. Since the beam current of the linac is high, control of the beam losses becomes a very essential design target. Therefore, any unstable beam generated by partial deflection during the RF transient time should be limited to a very low level. To this end, the RF cavity should have a low loaded Q value of about 10 so as to obtain a transient time of about 10ns. A high transversal shunt impedance is also a cavity-optimization aim to allow the cavity to be powered by the commercially available solid RF source. The HFSS code was applied for the cavity design. It has been shown that a loaded Q of 10 can be reached by using a pair of large coupling loops. An aluminum model cavity was made for an RF test. In this paper, the design and test results are presented in detail.

1 INTRODUCTION

The JHF 200-MeV linac provides a H$^-$ beam of 30mA–60mA peak current for injection into the following 3-GeV rapid-cycling ring[1]. A beam chopper must be used in the linac in order to produce a pulsed beam with a pulse length of 278ns and a pulse separation of 222ns. This chopper is located in the 3MeV medium-energy beam-transport line (MEBT) between the 324MHz RFQ and DTL[2]. As a high-current linac, beam-quality preservation and beam-loss control are of superior importance in the design. The MEBT should be short so as to avoid emittance growth, since the beam energy is low. An RF deflector (RFD)[3] was chosen as the chopper cavity owing to its compactness and high deflecting field. A fast rise/fall time is a fundamental requirement for the RFD to minimize the beam losses due to partial deflection to the beam during the transient time. This can be achieved in an RF cavity with a very low loaded Q value. On the other hand, a high transverse shunt impedance is pursued in the design in order to keep the RF power demand from a solid RF source within a reasonable range.

In this paper, a design study of the RF deflector cavity is presented. We first give the cavity simulations by MAFIA[4] and HFSS[5] codes in order to show the detailed design investigation in the geometry needed to meet the requirements mentioned above. Then the measurements of a cold model cavity are presented and shown to have a good agreement with the code simulation and a satisfactory result for our purpose.

2 CAVITY DESIGN STUDY

The RF deflector cavity is operated in a TE_{11}-like mode with two electrodes, as shown in Fig.1. A transverse electric field oscillating at 324MHz between the two electrodes deflects the beam bunches away from the beam axis to a beam dump downstream during the beam-cutoff time of 222ns.

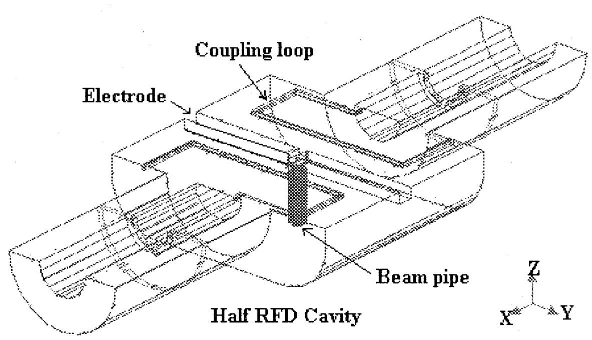

Fig.1 RF deflector cavity with large coupling loops

One of the design target of the cavity is a high value of Z/Q_0, while keeping in mind the beam dynamics limitation. Here, Z is the transverse shunt impedance and Q_0 the unloaded Q value. In order to achieve a very short rise/fall time, the cavity will be heavily loaded by two coupling ports. In this case, the power demand from a solid RF source for operating the cavity becomes very high. To minimize the power demand P, a large value of Z/Q_0 should be pursued according to the approximate relation

$$P \cong \frac{V^2}{\omega_0 \tau (Z/Q_0)} \qquad (1)$$

where V is the deflecting voltage, ω_0 the oscillation frequency and τ the rise time.

2.1 Geometry of the electrode region

The ratio Z/Q_0 is determined by the equivalent capacitance C according to the relation

$$Z/Q_0 = \frac{1}{\omega_0 C} \qquad (2)$$

* On leave from China Institute of Atomic Energy

The C for the mode is mainly dependent on the geometry of the electrode gap region. Therefore, the parameter choice around this region must be paid a close attention.

The fringe field of the electrode along the beam axis should be taken into account in the beam dynamics to calculate the effective deflection. To avoid an inverse deflecting effect of the high fringe field, the length of the electrode along the beam axis should not be equal to, but less than, $\beta\lambda/2$, with β being the relative speed of a particle (c/v) and λ the free-space RF wavelength. To determine the length, MAFIA runs were conducted and the electromagnetic field distribution from MAFIA was used in a modified TRACE3-D[6] for beam-deflection tracking. The result showed that the length of the electrode should be slightly less than $\beta\lambda/2$. In this way, Z/Q_0 is larger (due to smaller C) and the high fringe field beside the electrodes can work in phase with the field in the central part of the electrodes, while keeping the effective deflecting length long. It was concluded that the electrode length along the beam axis should be 29mm. Furthermore, the fringe field between the electrodes and the cavity wall needs to be sheltered so as to minimize its inverse effect. A beam-deflection simulation of a cavity without beam pipes showed that the net deflection is less than half that in a cavity with a pipe. Therefore, two beam pipes are added beside the electrodes with 5.5mm gaps between the pipes and the electrodes.

Of course, the two electrodes should be as close as possible to generate high deflecting field between them. This gap is, however, limited by the full beam size. The beam envelope from TRACE3-D suggests that the gap should be larger than 10mm in order to guarantee no particle losses on the electrodes.

Also, the size of the electrode in non-deflection direction should be small in order to obtain a large Z/Q_0 value. Again, the beam envelope sets the minimum limit. The necessary size is 20mm according to TRACE3-D simulation on beam size and the MAFIA result concerning the field distribution.

2.2 Cavity shape optimization

After the electrode size has been decided, the other dimensions of the cavity is then further optimized for the value of Z/Q_0 to be as high as possible. Since two RFD cavities will be cascaded in the beam line, the cavity should not be too long along the beam axis, due to a lack of focusing to the beam in this space, which may result in a beam emittance increase. Taking all of these factors into account, MAFIA runs suggested a cavity of 324MHz with Z/Q_0= 437Ω. It can be estimated from Eq.(1) that the demanded power from a RF source is reasonably about 21kW (more accurately, HFSS gives the power of 17kW in the next subsection) to generate a necessary deflecting field of 1.4MV/m if a rise time of 10ns is required. Such a fast rise time indicates that the loaded Q of the cavity should be decreased down to about 10.

2.3 Cavity design with a very low loaded Q

The use of two large input/output loops is an easy option to realize a low loaded Q. A loop-coupled cavity was redesigned using the HFSS code on the basis of the previous design by MAFIA in terms that the electrode region maintains the same geometry. A modification to the cavity shape is necessary because of the introduction of large loops into the cavity, which shift the cavity oscillation frequency due to the additional inductive reactance.

Two large loops with the same size are inserted into the cavity. The loops are connected to a coaxial transmission lines of 50Ω. To reach such a low loaded Q value, the size of the loop is 75mm$\times$218mm in the surface with the maximum flux. An HFSS simulation gives the S parameter, S_{21} and S_{11}, versus the frequency, as shown in Fig.2. From the figure, it can be found that the resulting Q_L is about 10, assuming it is given by the whole frequency width, Δf (31MHz), at 70% maximum value.

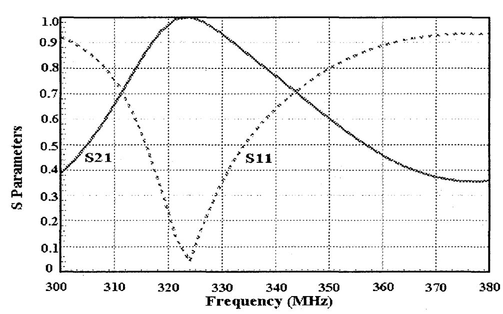

Fig.2 S-parameters from the HFSS for the cavity with Q_l=10

The two loops of the same size are placed asymmetrically with respect to the middle plane. This induces a spectrum asymmetric with respect to the central frequency: the high-frequency side is wider than the other side, as depicted in Fig.2. It thus helps to reach a larger Δf. On the other hand, it also makes the fundamental mode to be close to and mix with the higher mode. To avoid such a problem, the loop should not be too deeply inserted into the cavity. It must keep a sufficient distance between the loop and the electrode in order to insure that the electric field between them remains extremely low. We thus increase the other dimension of the loop to a very large value (i.e. 218mm) so as to guarantee a sufficient coupling as well as a wide mode separation.

HFSS simulations also showed the dependence of the large coupling on the diameter of the coaxial transmission line. A large coaxial line of WX-152D was adopted for the input/output of the cavity, resulting in a loaded Q of 10. However, the loaded Q became 17 if a coaxial line of WX-77D was used.

The variation of the deflecting field Ey in three directions is plotted in Fig.3 according to HFSS. The original point corresponds to the center of the cavity. The beam radii in x and y directions are both less than 5mm according to the TRACE3-D result. It can be observed from the figure that the field has no obvious variation within the beam-size region, and hence that the beam can be deflected by a field having the same magnitude. HFSS gives Ey=1.4MV/m in the deflecting gap when the input power is 17kW.

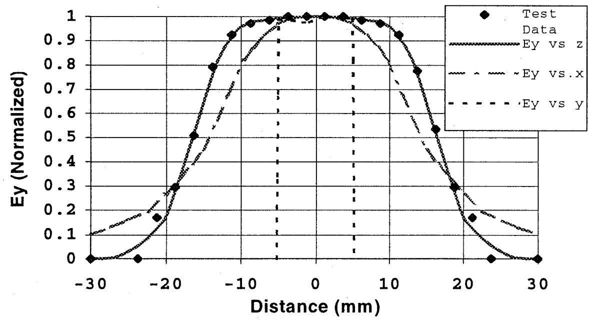

Fig. 3 Ey field distribution in three directions (test data is in z direction).

3 COLD MODEL TEST

An aluminum cold-model cavity was manufactured according to the design by HFSS. A series of measurements were conducted to check the applicability of the design.

A direct measurement of the rise time was performed by means of a digitizing oscilloscope with the result shown in Fig.4. It indicates that the rise time (Delta T) is 18.3ns, which includes about a 9ns contribution from the pulsed RF signal source. The effect of the transient time on the beam dynamics is discussed in Ref. [2], in which an improved method is proposed for the cavity, and the unstable particles are estimated.

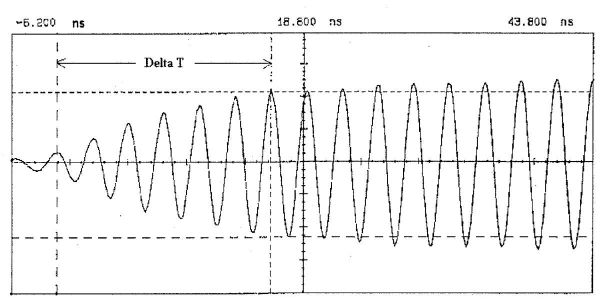

Fig.4 Measured rise time (Delta T) of the RFD cavity.

Network Analyzer depicted the scattering parameter S_{21} versus frequency in Fig.5. It gave a loaded Q of 9.7 and a resonance frequency of 324MHz. The results are well concordant with the HFSS simulation. Some small coupling loops were prepared for a test of the dependence of the loaded Q on the size of the loops. For example, when the loops size became 65×218, the loaded Q increased to 23. With two very small coupling loops, the loaded Q equaled 1463 and S_{21} was –2.18dB. The unloaded Q was deduced to be 6580.

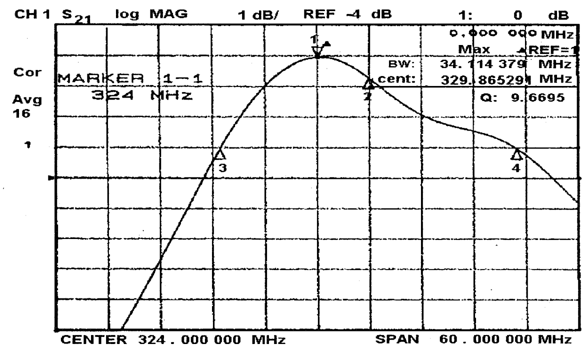

Fig.5 Spectrum of S_{21} showing the Q_L=9.7

The field pattern in the deflecting gap was measured with a pulling bead of ϕ5. In Fig.3 the measured deflecting field (Ey) along the beam axis (z direction) is dotted. It shows a good agreement with the calculation result from HFSS.

Since the cavity is heavily loaded with a very wide spectrum, it is possible to operate it without a tuning device. To verify the temperature dependence of the resonance frequency, the cavity was heated. It was found that the cavity has a frequency shift of 60KHz when the temperature rises up to 10°C.

CONCLUSIONS

A 324MHz RF deflection cavity used for JHF linac was design and a cold model was tested with satisfactory results. The measurement gives a loaded Q of about 10, which is necessary for a fast rise/fall time. The test results are in good agreement with the design calculations with MAFIA and HFSS. To meet the deflection requirement, the cavity requires an input power of 17kW according to HFSS.

ACKNOWLEDGMENTS

The authors are very grateful to Prof. Y. Yamazaki and Mr. Wang for their great support and many helps.

REFERENCES

[1] JHF Project Office, JHF Accelerator Design Study Report, KEK Report 97-16, March,1998
[2] T. Kato, S. Fu, MEBT Design for the JHF 200-MeV Proton Linac, Proc. of LINAC98, Chicago, Aug. 23-28,1998
[3] T. Kato, New Design of an RF Beam Chopper, Proc. of 7th Symp. On Acc. Sci.& Tech. (1989) 288
[4] T.Weiland, Part. Accl. , Vol.17 (1995)227
[5] HFSS Ver. A.04.01, Ansoft Corp, HP Co.
[6] K.R.Crandall, D.P.Rusthoi, TRACE3-D Documentation, LA-UR-97-886, May,1997