RF FIELD MEASUREMENT OF AN RFQ COLD MODEL CAVITY FOR THE JHP

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Abstract

A radio-frequency quadrupole (RFQ) linac will be constructed as a preinjector linac for the Japanese Hadron Project (JHP). Its resonant frequency, injection and final energies are determined from beam-optics considerations of the entire system to be 432 MHz, 50 keV and 3 MeV, respectively. In order to achieve these requirements, keeping the maximum surface electric field to less than 1.8-times the Kilpatrick limit, the RFQ becomes about 2.7 m long. In order to examine the field stability of such a long RFQ cavity, a cold model cavity without vane modulation or a side-tuner was constructed with relative intervane-distance errors of less than ±30 μm. The measurements showed that a good longitudinal and azimuthal field uniformity within ±3.5 % could be achieved by adjusting only end tuners.

Introduction

A long RFQ linac with a resonant frequency of 432 MHz and a length of 2.7 m (about four times of the rf wavelength) will be constructed as a 3-MeV preinjector linac for the Japanese Hadron Project (JHP).[1,2] Its rf duty is to be 3 %, rather higher than that of common RFQs.

In general, it is difficult to fabricate a four-vane type RFQ linac that is long compared with the rf wavelength for the following reasons.[3] Since the frequency separation between two neighboring quadrupole or dipole modes (TE21n- and TE21(n+1)-modes or TE11n- and TE11(n+1)-modes) becomes smaller for a longer cavity and the lowest-order dipole mode (TE110-mode) has a slightly smaller frequency than does the accelerating mode (TE210-mode), the frequency difference between the accelerating mode and the nearest dipole mode, or the nearest higher-order quadruple mode, becomes smaller for a longer cavity. The frequency difference between two modes is closely related to the tolerance of the machining, since a small amount of the asymmetry can mix the two modes with a small frequency separation. Therefore, the specifications for the machining accuracy become more severe for a longer RFQ. On the other hand, accurate machining naturally becomes more difficult for longer vanes.

The mixing of the dipole mode arises from the azimuthal asymmetry, resulting in non-uniform distribution of the stored energy among the four quadrant cavities. On the other hand, the mixing of the higher-order quadrupole mode is caused by a longitudinal imperfection, resulting in a longitudinal field tilt. It is noted that the mixing of the dipole mode has a worse effect on the beam than does the field tilt, since the dipole mode has a bending effect on the beam, reducing the acceptance of the RFQ.

Neither of the four-vane type RFQ with vane coupling rings (VCRs)[4] nor a four-rod type RFQ[5] that may cure the above problem of the dipole-mode mixing can easily meet the present requirements of both high duty and high frequency. On the other hand, the above mentioned difficulty with the four-vane type RFQ was not sufficiently understood quantitatively to make a final decision to choose the RFQ parameters. Thus, a cold model was fabricated in order to develop a machining method that can meet the severe specifications and to study the rf characteristics of the long RFQ cavity.

Machining Method and Errors

A cold model of the RFQ cavity (Fig. 1) was fabricated by assembling four pieces, as was originally proposed at LANL (Los Alamos National Laboratory).[6] Each piece is made of vacuum-melted oxygen-free copper pillar, to which silver is added (0.2 %) in order to strengthen the material mechanically. Each pillar was machined with formed cutters into a cross-sectional shape designed with the computer code SUPERFISH,[7] as shown in Fig. 1. This cold model is an ideal RFQ cavity without vane modulation, a radial matching section or a side-tuner, except for the vane-ends and the end plates. The vane-end cuttings are rectangular (Fig. 2a)) and their vane-end conditions can be adjusted by inserting the tuning plates shown by the hatched areas in Fig. 2b-c). Each of the end plates is equipped with four capacitive tuners (C-tuner) and four inductive tuners (L-tuner) made of copper plungers (Fig. 3). The rf field is measured with the bead-perturbation method, introducing a bead into the inside of the cavity through one of the five holes bored in each of the end plates. The five holes are located in order to measure the field at the beam axis and the stored energies of the four quadrant cavities. Loop monitors can be installed in the end plates. A photograph of the cavity is shown in Fig. 4, where the end plates are removed in order to show the inside of the cavity.

The intervane-distances could be measured when three pieces of the pillars were assembled. Deviations of the measured distances from the designed value are shown along the longitudinal position in Fig. 5. It can be seen that the relative intervane-distance errors are less than ±30 μm.

The measured resonant frequency and Q-value of the accelerating mode is 431. 236 MHZ and 8000, respectively. The former is a little lower than the calculated value of 432.244 MHz. This discrepancy is understandable as a result of the dipole-mode mixing described in the next section. The latter is 80-percent of the calculated value.

RF Field Measurement

At first, the best tuning plate regarding the field distribution was chosen by varying the tuning plates, while locating the tuning plungers at the end plates on the inner surfaces of the end plates, where the effects of the tuners vanish. Among the four cases shown in Fig. 2, the best result was obtained with the tuning plates shown in Fig. 2c). Figure 6 shows the result of a field measurement for the lowest-order quadrupole mode (TE210-mode) in a form of the distribution of the squares of the magnetic fields among the four quadrant cavities. It can be seen that the distribution was already fairly uniform, even without any adjustment of the end tuners. Nevertheless, it is noted that the magnetic fields are a little drooped near the vane-ends, indicating that the local resonant frequencies near the vane-ends are slightly higher than the average. Also, the magnetic field strengths of the second and third cavities are slightly larger than those of the first and fourth cavities. This is understandable as a result of the mixing of the accelerating quadrupole mode with a dipole mode.

Keeping these indications in mind, we adjusted the positions of the end tuners, and obtained the results shown in Fig. 7. The squares of the magnetic fields are more uniformly distributed among the four quadrant cavities and along the longitudinal direction. The distributions are uniform within ±7 %. (The field uniformity is within ±3.5 %.) The measured dispersion curves of the dipole and quadrupole modes are shown in Fig. 8. The accelerating quadrupole mode (TE210-mode) is located near the middle of the two dipole modes (TE111-, TE112-modes) and fairly separated from the dipole modes, resulting in only slight mixing of the dipole modes. Also, good machining accuracy can be seen from the small breaking of the degeneracy of the dipole modes. It is noted that more mixing of the dipole modes is expected for the shorter RFQ, where the TE210-mode becomes closer to the TE111-mode. Paradoxically speaking, the field distribution of a longer RFQ will be easier to tune than that of a shorter one in this region of the length.

Although the magnetic field distribution of the TE210-

mode can be tuned fairly well, the dipole modes are still mixed, as can be seen in Fig. 7. In order to remove the mixing entirely, side tuners will be necessary in addition to the end tuners, resulting in a more difficult adjustment of the tuners. It was already fairly difficult to adjust the end tuners, probably because of the complicated relation of the TE210-mode to many other modes such as the TE110-, TE111-, TE112- and TE211-modes. Furthermore, the field distribution of the TE210-mode was slightly unstable: a few-percent change of the square of the magnetic field arose from a few-degree change of the ambient temperature. The change of the field reflected a redistribution of the stored energy among the four quadrant cavities, indicating that the amount of the mixing of the dipole modes was unstable. It should be noted that the mixing of the TE211-mode, revealed in the field tilt, was not as unstable as that of the dipole modes, although the frequency of the TE211-mode is as close to that of the TE210-mode as the dipole modes (see Fig. 8). This phenomenon can be understood as follows. If one of the vanes is bent for some reasons, by slight thermal stress for example, one intervane-distance will become narrower, while the other intervane-distance will become enlarged, resulting in a perturbation that can give rise to a mixing of the dipole modes. On the other hand, the effect of this perturbation on the local frequency of the quadrupole mode is cancelled out in a lowest-order approximation. Therefore, the amount of mixing of the dipole mode is more unstable against thermal stress, or something like that.

So far, we have been concentrating on the field distribution of the quadrupole mode. It is also interesting to see the field distribution of the lowest-order dipole mode (TE110-mode) in Fig. 9. The distribution was far from uniform. This can be understood as follows. The shape of the vane end shown in Fig. 2c) was adjusted in order to make uniform the field distribution of the quadrupole mode. The vane end, thus adjusted, simulates the open-boundary condition at the vicinity of the end plates for the quadrupole mode, but not necessarily for the other modes. The longitudinally uniform field distribution of the lowest-order dipole mode was obtained with the vane end shown in Fig. 2b). The difference between the real and ideal boundary conditions at the vane end of Fig. 2c) has another effect: the measured resonant frequency 420.114 MHz of the TE110-mode is slightly higher than the calculated value of 418.810 MHz with the SUPERFISH. This effect is larger for shorter RFQ cavities.

Conclusion

In order to examine the field stability of a 432-MHz RFQ cavity with a length of 2.7 m, a cold model without modulation or a side-tuner was constructed with relative intervane-distance errors of less than ±30 μm. A good longitudinal and azimuthal field uniformity (within ±3.5 %) was achieved by adjusting only the end tuners. It is expected that a more uniform field distribution can be obtained by installing side tuners. However, the tuning will be difficult owing to the complicated relation of the accelerating mode to many other modes. Also, the uniformity of the field distribution was slightly thermally unstable, since the mixing of the dipole modes seems to be easily modified by thermal stress in the vanes. This is not preferable under the high-duty operation necessary for the JHP. Therefore, a new field stabilizing structure, PISL,[8,9] will be adopted for the JHP.

Acknowledgement

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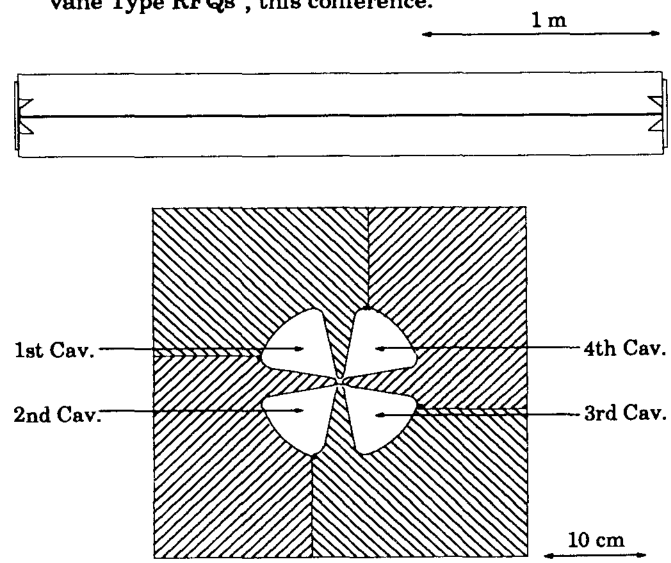

Fig. 1. Schematic of the cold mode RFQ cavity.

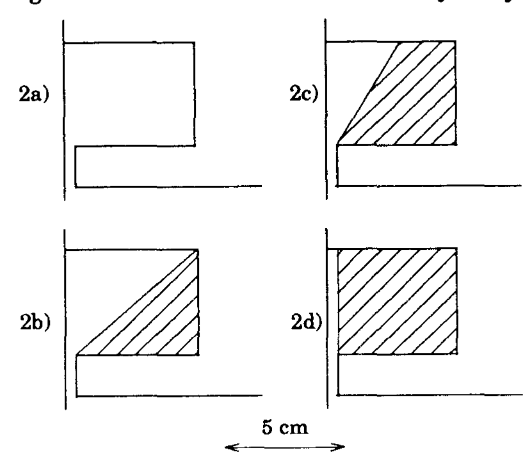

Fig. 2. Vane end cutting and tunimg plates.

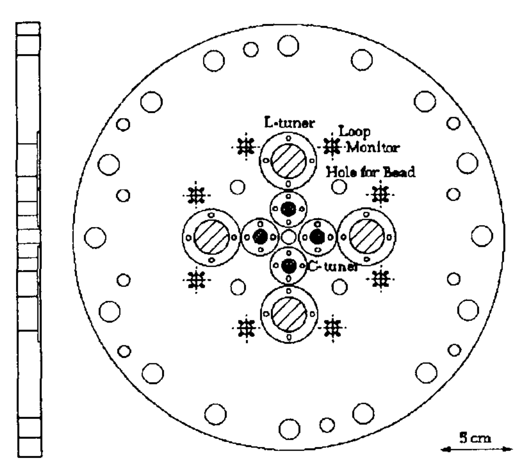

Fig. 3. Scheme of the end plate.

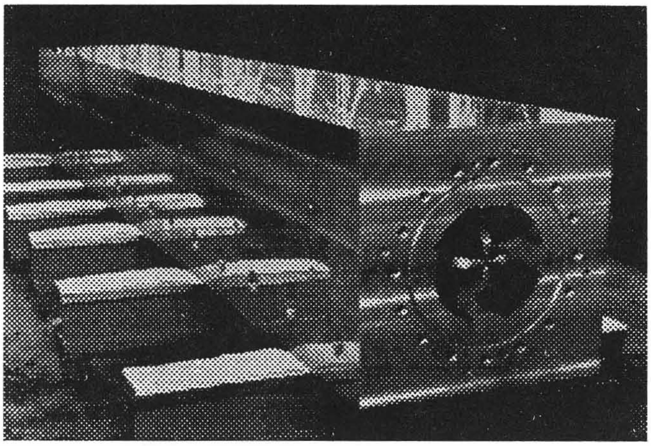

Fig. 4. Photograph of the cold model RFQ cavity.

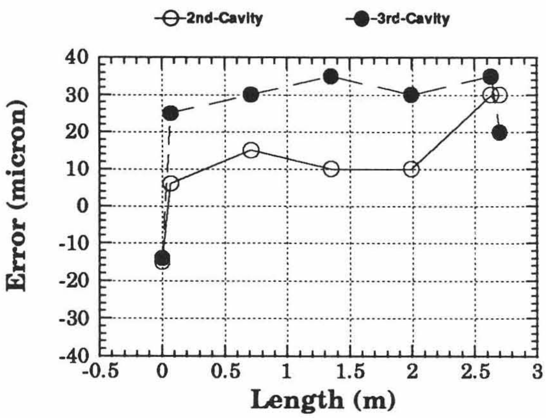

Fig. 5. Intervane-distance errors shown as functions of the longitudinal position.

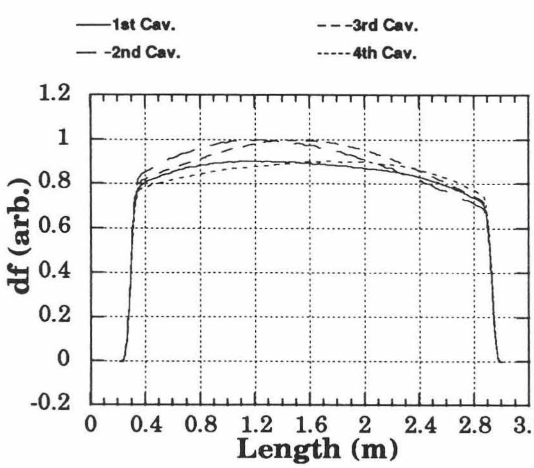

Fig. 6. Distribution of the square of the magnetic fields of the TE210-mode in the four cavities, measured by the bead perturbation method when every tuning plungers at the end plates is located on the inner surface of the end plate.

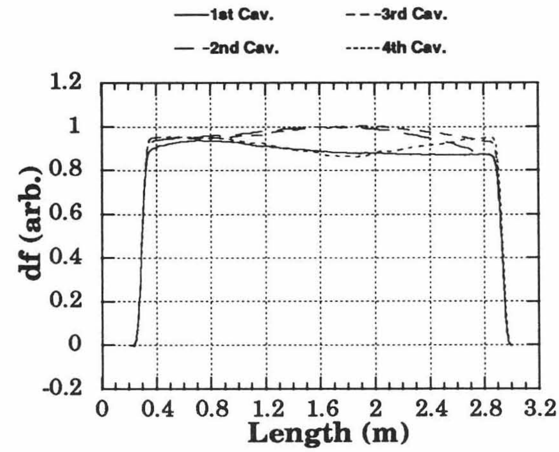

Fig. 7. Distribution of the square of the magnetic fields of the TE210-mode in the four cavities, measured by the bead perturbation method after the tuning of the end tuners.

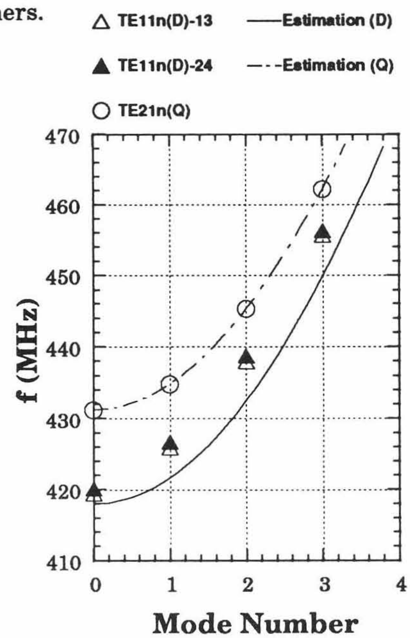

Fig. 8. Measured dispersion curves of the quadrupole and dipole modes.

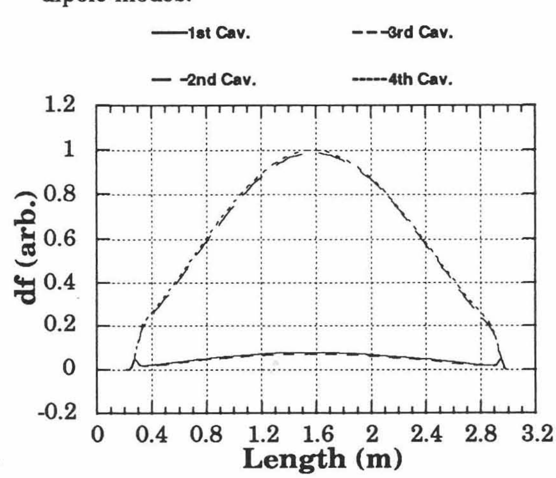

Fig. 9. Distribution of the square of the magnetic fields of the TE110-mode in the four cavities, measured by the bead perturbation method under the same condition of the measurement of Fig. 7.