Cold Model Test of A Four Vane RFQ
for Multi–Purpose Use Linac

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RF characteristics of a four vane RFQ linac have been studied using a 400MHz cold model cavity with unmodulated vanes. The equivalent inner diameter and length of the cavity are 154.5 and 1220.0mm, respectively and the dimensional errors of the gaps between the neighbouring vanes are within 0.03mm. The field distributions were measured using the Bead Perturbation Method and a field stabilization by magnetic coupling between the quadrants was examined. It is possible to obtain the good field distributions by using the field stabilization scheme, whose azimuthal symmetry and longitudinal uniformity are within ±1.3% respectively.

1. INTRODUCTION

A design study of a 10MeV proton linac for multi–purpose use has been carried on since April, 1990, in cooperation of the Institute for Chemical Research of Kyoto Univ., Mitsubishi Heavy Industries, Ltd and Mitsubishi Atomic Power Industries, Inc.. It is intended in this study to investigate an optimum combination of accelerators such as RFQ and DTL to accelerate proton beams from 50KeV to 10MeV. The average beam current is aimed to be 1 mA and the operating frequency is selected to be around 400MHz because of the requirement for the neutron yield and the transportability of the linac.

As a part of this study, RF characteristics of a four vane RFQ linac have been studied using a cold model cavity. The four vane cavity is operated in a TE210 mode and field distributions with azimuthal symmetry and longitudinal uniformity are required. If TE11n modes lie close to the TE210 mode, the mixing of these modes distorts the field distribution. Dimensional errors of the cavity also distort the field distribution. Furthermore, another objective of the cold model test is an experimental determination of the shape of the vane at the end, otherwise a three dimensional calculation is needed for the determination.

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2. STRUCTURE OF MODEL CAVITY

The equivalent inner diameter and length of the model cavity are 154.5 and 1220.0mm, respectively. The cavity–wall and vane are made of aluminum alloy (5052). The structure of the cavity is shown in Fig. 1. The vane tip is fabricated to have a curvature of 3.00±0.03mm. The cavity–wall and vanes had been so precisely assembled to make dimensional errors within 0.03mm in the gaps between the neighbouring vanes. The RF contactor used between the cavity–wall and vanes is the EMI shield spiral made of beryllium–copper alloy. The cavity–wall has 32 holes of 8mm in diameter and 4 holes of 20mm in diameter for the RF measurements.

Opposed to the each vane end, eight end tuners are mounted on the end plates. The tuner is a copper rod of 12mm diameter and the tuner–to–vane gap is adjustable from 10.0 to 0mm with a micrometer head. There is a cutback at the each end of the each vane. The cutback space is adjustable by adding a cutback–block whose material and thickness are the same as those of the vane. Addition of the cutback–block causes a reduction of the inductance in the end region and increases the resonant frequency of the cavity.

A basic problem in the four vane RFQ is the balancing of the four quadrants. In general, the flatness in the field distributions is related to the separation of the TE210 mode from other modes. There are three methods to increase the mode separation and relax the tuning sensitivity. The first method is the use of Vane Coupling Rings (VCR)[1], which directly connect opposing vanes with a low inductance. The second one makes magnetic coupling between the quadrants with Resonant Loop Rings (RLR)[2,3]. And the third one is the use of π mode Stabilizing Loops (PISL)[4]. Among these methods, the second scheme is preferable because the vanes are mechanically unstressed. The RLR mounted on the end plate of the model cavity is shown in Photo. 1. The RLRs mounted on both end plates are 90° turned each other corresponding to two dipole modes.

The Q value up to 3800 had been obtained by improvements of the contact between the cavity–wall and vanes. The Q value calculated with SUPERFISH is 9250 for the infinitely
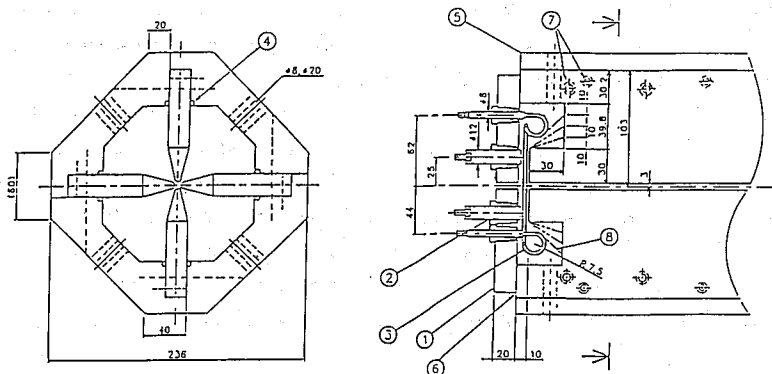

Fig. 1. Structure of model cavity

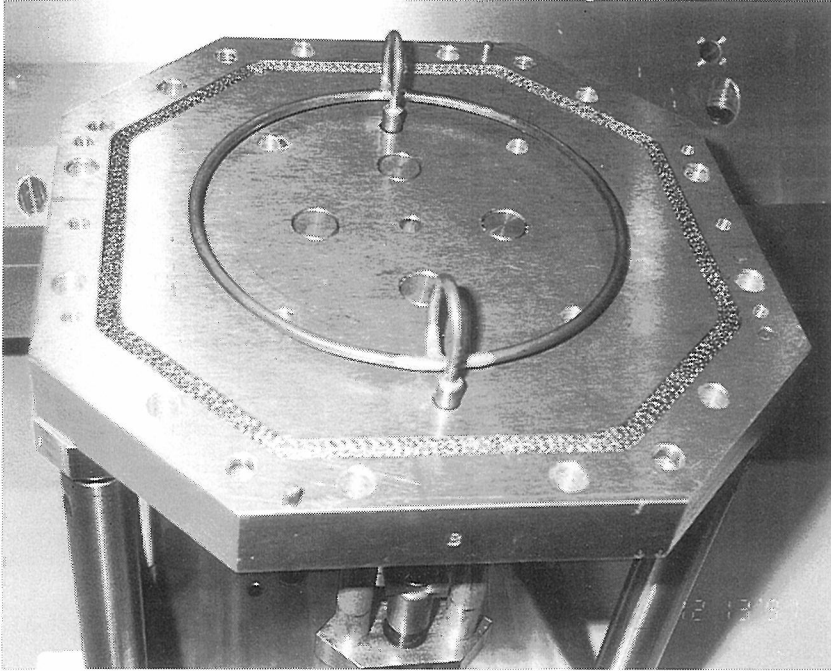| 1 End plate | 3 RLR | 5 Cavity–wall | 7 Cap bolt |
| 2 End tuner | 4 RF contactor | 6 Vane | 8 Cutback–block |

Photo. 1. RLR mounted on the end plate.

long cavity made of copper. Considering the difference of the electric conductivities between copper and aluminum–alloy, the calculated value is corrected to 5470. The main reasons of the difference between the corrected and measured values are considered to be the imperfect contact between the cavity–wall and vanes, end effect, surface oxidation and holes.

3. RESONANT FREQUENCIES

Resonant frequencies for various modes were measured on the model cavity without the RLRs and field tunings. The modes were identified by the polarity of the phase of the magnetic field detected with a pick–up loop. The dispersion curves of these modes are shown in Fig. 2. The measured resonant frequencies are 402.25MHz for the TE210 mode, and 396.86 and 397.78 MHz for the TE110 modes. The mode separation is pretty good in this short model cavity since the nearest TE110 mode lies about 4.5MHz apart from the TE210 mode. The values calculated with SUPERFISH are 409.84MHz for the TE210 and 398.66MHz for the TE110 mode, respectively. The measured frequencies for the dipole modes are higher than those for the quadrupole modes except for the lowest mode. This situation is considered to be caused by the different effects from the shape of the end region including the cutback.

The increases in the resonant frequencies for the TE210 and TE110 modes were measured reducing the cutback spaces on both sides by using the cutback–blocks. The measured increases in the resonant frequency for the TE210 mode are 0.90, 2.06 and 3.34MHz when the cutback spaces are reduced by 12.6, 25.1 and 37.7%, respectively. The measured increases in

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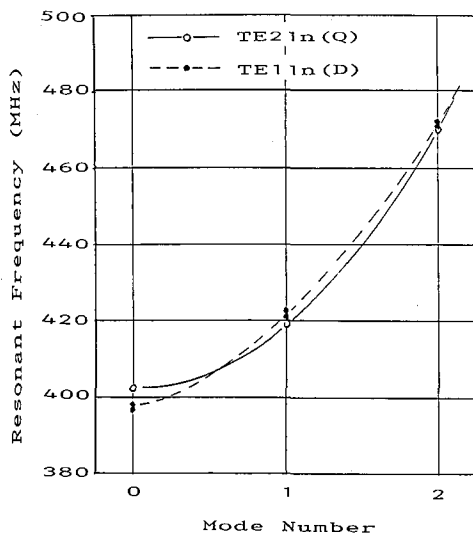H. Okamoto, A. Noda and M. Inoue

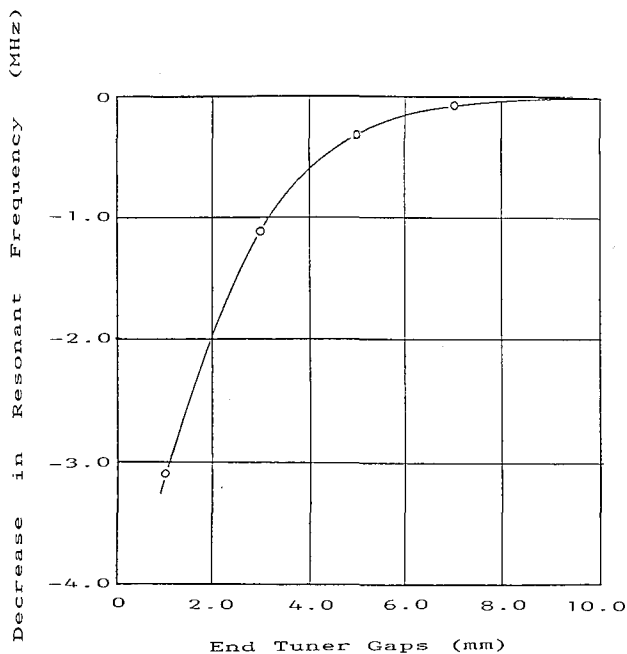Fig. 2. Dispersion curves without RLRs and field tunings.

Fig. 3. Effect of end tuners on the resonant frequency for the TE210 mode.

the resonant frequencies for the TE110 modes are about 10% less than these values, respectively. It can be said that the measured frequency for the TE210 mode agrees rather well with the calculated value if the effect of the cutback on the resonant frequency is taken into account which can not be treated by SUPERFISH. In Fig. 3, measured decreases in the

resonant frequency for the TE210 mode are shown when all the end tuner gaps on both sides are decreased stepwise to 1.0 from 10.0mm.

An evaluation of the effects of the RLR scheme on the mode separation and the field stabilization is one of the main objectives of this cold model test. The shifts of the resonant frequencies for the TE110 and TE111 modes were measured on the cavity with the cutback spaces reduced by 25.1%, changing the distance between the RLR ring and end plate. The results are shown in Fig. 4. As expected, the resonant frequencies for the quadrupole modes are not affected by RLRs. Prior to these measurements, the resonant frequency of the RLR mounted on the end plate which was removed from the cavity–wall was related to the distance between the ring and end plate. The results are shown in Fig. 5.

The separation between the TE210 mode and TE110 modes increases to the value more than 10MHz when the distance between the ring and end plate is nearly 2.5mm as seen in Fig. 4, although the identification of the TE110 modes is rather difficult in the transition stage. The separation between the TE211 mode and TE111 modes also increases when the distance is nearly 3.5mm. Therefore, it can be concluded that the RLR scheme is effective on the mode separation even in case of our cavity whose ratio of the length to the free space wavelength of the operating frequency is about 1.6.
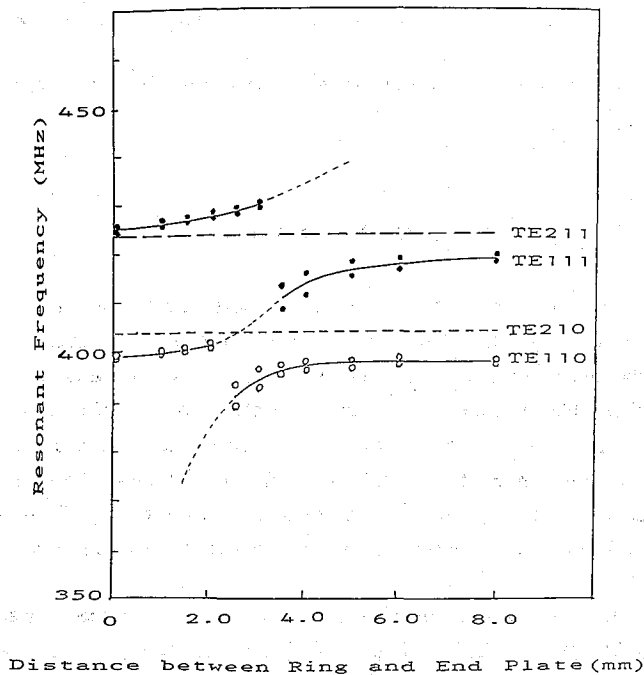

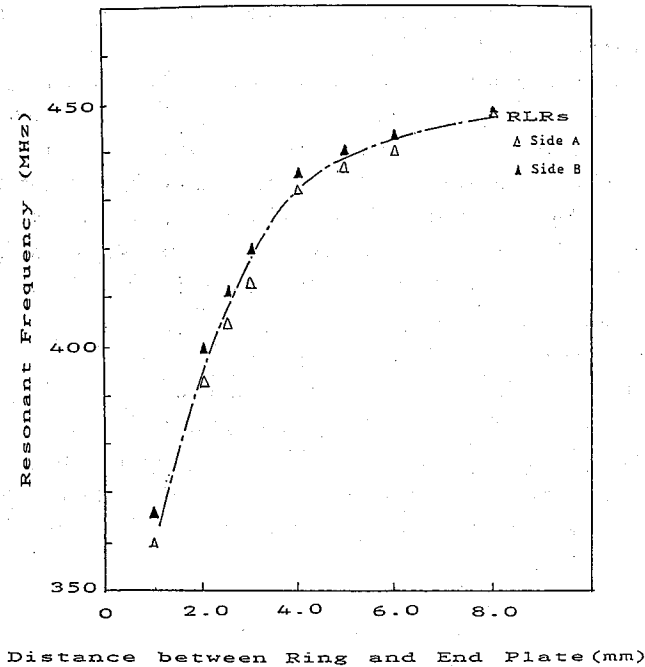Fig. 4. Shift of resonant frequencies for the TE110 and TE111 modes by RLRs.

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Fig. 5. Resonant frequency of the RLR vs the distance between the ring and end plate.

4. FIELD DISTRIBUTIONS

Magnetic and electric field distributions were measured using the Bead Perturbation Method. An aluminum cylindrical bead of 4.5mm diameter and 9.0mm length is inserted through holes of the end plates into a quadrant at 50mm off axis to measure the magnetic field distribution. And an aluminum bead of 3.0mm diameter and 3.0mm length is inserted along the axis to measure the electric field distribution. The drive mechanism of the beads mounted on the end plate is shown in Photo. 2. A nylon string of 0.235mm diameter tensioned by a spring is used to carry the bead. The magnetic field distributions in the four quadrants can be measured sequentially without opening up the end plates because the string is set in each quadrant.

The field distributions shown in Fig. 6a are those measured in the four quadrants of the cavity without the RLRs and field tunings. The fields are strong in the Quadrant-1 and 4, and weak in the Quadrant-2 and 3 revealing dimensional errors of the gaps between the neighbouring vanes. The longitudinal field distributions are bowed indicating improper dimensions of the cutback spaces. The field distributions compensated by using the cutback-blocks and end tuners are shown in Fig. 6b. The azimuthal field symmetry is within ±2.3% and the longitudinal field distributions are uniform within ±3.1%. It is impossible to improve the azimuthal field symmetry by using only the cutback-blocks.
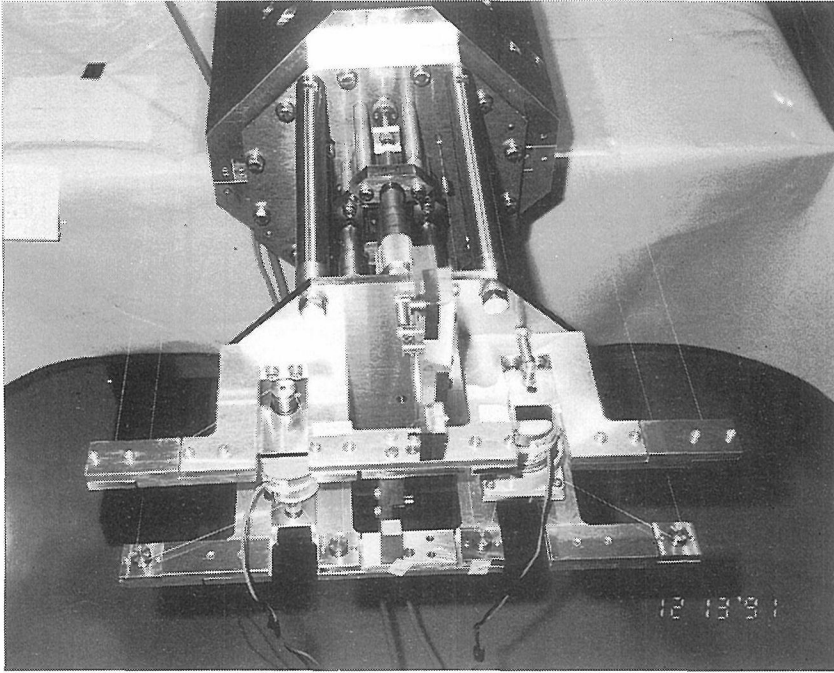
Photo. 2. Drive mechanism of beads for field measurements.

In order to examine the effect of the RLRs on the field stabilization, the field distributions were measured on the cavity with the cutback spaces reduced by 25.1%, changing the distance between the RLR ring and end plate. It was observed that the field distributions were largely disturbed when the distance was about 2.5mm. The RLR should be tuned to some frequency which is lower than the resonant frequency for the TE210 mode and higher than the resonant frequencies for the TE110 modes.

The field distributions shown in Fig. 7a are those generated when the distance between the ring and end plate is 2.2mm on the side A and 1.9mm on the side B of the cavity. The balancing of the four quadrants is almost similar to that in Fig. 6a. However, these field distributions can be improved very easily by using the end tuners. The field distributions shown in Fig. 7b are those obtained after the field tunings. The distance between the ring and end plate is 2.2mm on the side A and 2.0mm on the side B. The azimuthal symmetry and longitudinal uniformity of the field distributions are within ±1.3% respectively. It should be noted that the field distributions are much improved comparing with those in Fig. 6b. The uniformity of the electric field distribution along the axis is also comfirmed. Therefore, it can be concluded that the RLR scheme is effective to improve the field distributions in case of our cavity.

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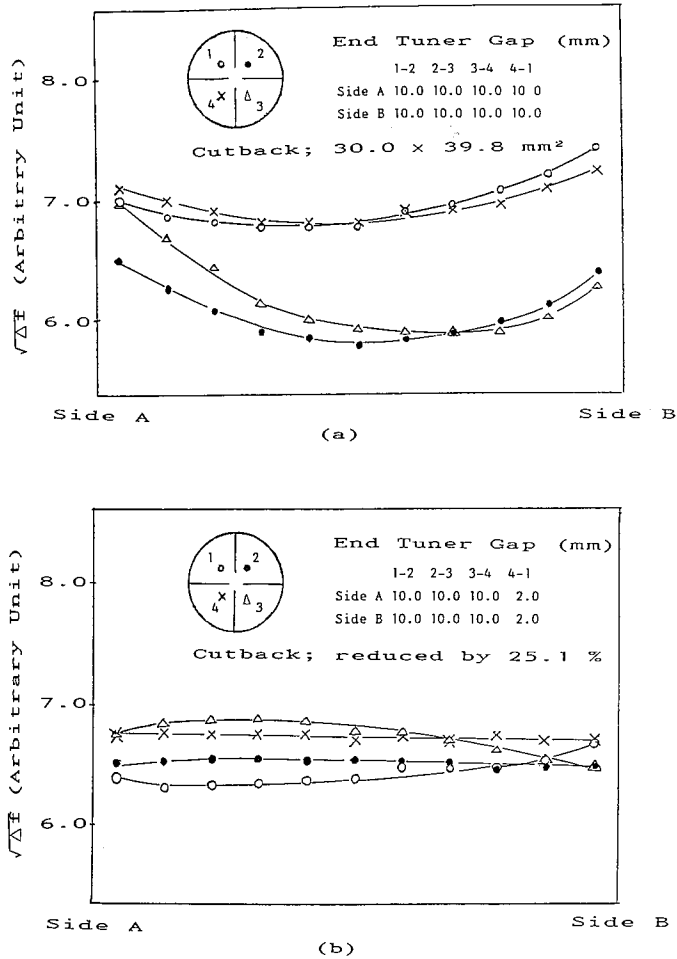H. OKAMOTO, A. NODA and M. INOUE

Fig. 6. Field distributions in the cavity without RLRs.
(a) Before field tunings ($f_0 = 402.18$ MHz)
(b) After field tunings ($f_0 = 403.99$ MHz)

5. CONCLUSIONS

The RFQ cold model cavity with unmodulated vanes of 1200mm length had been so precisely fabricated and assembled as to make dimensional errors within 0.03mm in the gaps between the neighbouring vanes. Using this model cavity, RF characteristics of the four vane RFQ linac have been studied : The resonant frequency measured for the TE210 mode agrees rather well with the value calculated by SUPERFISH. The azimuthal symmetry and longitudinal uniformity of the field distributions obtained after field tunings were within ± 2.3% and ±3.1%, respectively. The RLR scheme is effective to separate the nearest TE110 mode from the TE210 mode and improve the field distributions even in case of our cavity
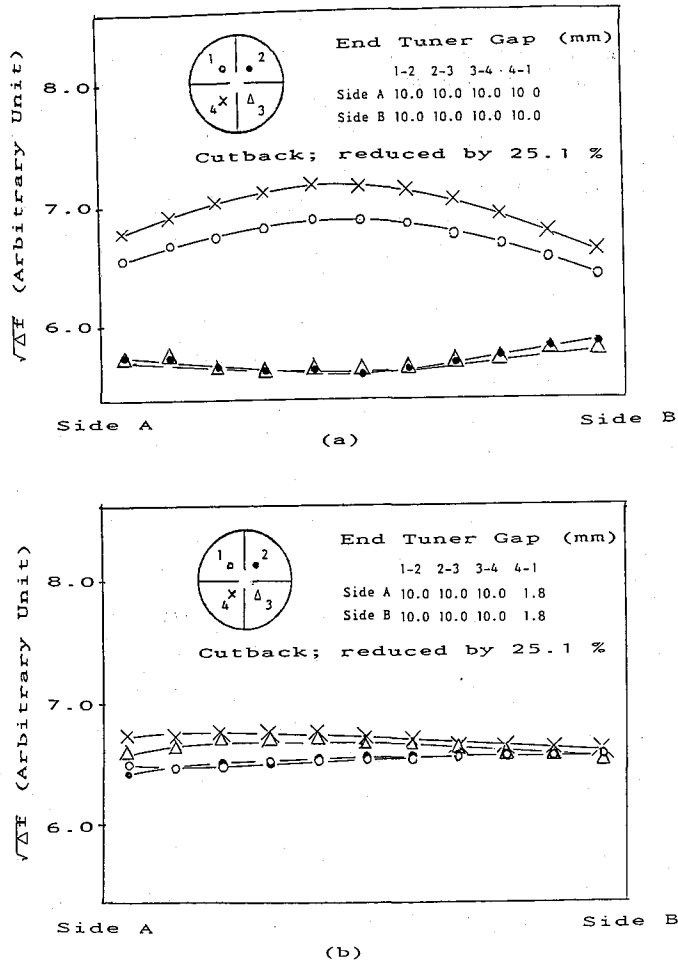
(106)

Fig. 7. Field distributions in the cavity with RLRs
    (a)   Before field tunings (f_0=404.39 MHz)
    (b)   After field tunings (f_0=404.05 MHz)

whose ratio of the length to the free space wavelength of the operating frequency is about 1.6. If the RLRs are used, it is possible to achieve the good field distributions whose azimuthal symmetry and longitudinal uniformity are within ±1.3% respectively.

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