HIGH-POWER TEST OF A 432-MHz, 3-MeV RFQ STABILIZED WITH PISLs

Akira Ueno, Yoshishige Yamazaki, Chikashi Kubota, Kazuo Yoshino,
Yuuichi Morozumi, Masato Kawamura, Kikuo Kudo, Masaaki Ono, Shozo Anami,
Zenei Igarashi, Eiichi Takasaki, Akira Takagi, Yoshiharu Mori and Motohiro Kihara
National Laboratory for High Energy Physics, KEK
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

For high-duty, four-vane-type, radio-frequency quadrupole (RFQ) linacs, a -mode stabilizing loop (PISL) was devised as a new field-stabilization method against dipole mode mixing. The first high-power test of the PISL was performed in a 432-MHz, 3-MeV RFQ developed as a pre-injector of the 1-GeV proton linac for the Japanese Hadron Project (JHP). After 170 hours of high-power operation, the RFQ was successfully conditioned up to the design rf power level of 500 kW with a 1.5% duty factor (315 µsx50 Hz, a half of the design value). During the course of the conditioning, the PISLs were effective in stabilizing the field.

Introduction

A four-vane-type, radio-frequency quadrupole (RFQ) linac has been developed as a pre-injector of the 1-GeV proton linac for the Japanese Hadron Project (JHP) [1]. Its resonant frequency, duty factor, injection and final energies were determined from a beam-optics consideration of the entire system to be 432 MHz, 3% (600 µsx50 Hz), 50 keV and 3 MeV, respectively. The duty factor of the RFQ is significantly higher than that of conventional RFQs, and the highest in the RFQs with resonant frequencies of over 400 MHz. The final energy of the RFQ is also one of the highest among proton RFQs.

The field instability due to dipole mode mixing is the most significant disadvantage of a four-vane type RFQ without any field stabilizer. In order to practically avoid any dipole mode mixing, several pairs of vane coupling rings (VCRs) have so far been frequently used [2]. However, the VCR has a complicated shape and is difficult to fabricate. In particular, the cooling of the VCR and the electrical contact between the VCR and the vanes (important for high-duty operation) are extremely difficult. We therefore devised a -mode stabilizing loop (PISL) as a new field-stabilization method for high-duty, four-vane-type RFQs [3,4]. Since the PISL has a simple shape, the fabrication, cooling and electrical contact of the PISL are much easier than that of the VCR. Furthermore, the longitudinal electric-field distortion due to the PISL (1.5%) is significantly less than that due to the VCR (5%).

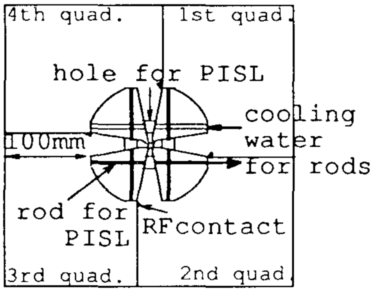


Fig. 1 A schematic drawing of PISLs installed to the RFQ.

The field-stabilizing effect of the PISL was empirically confirmed by installing several pairs of PISLs to the low-power model cavity for the JHP [5]. We therefore decided to construct an RFQ stabilized with PISLs (see Fig. 1) for the JHP [6,7].

In this paper we present the results of the first high-power test of the PISL in the RFQ developed for the JHP.

Experimental Set-up

The experimental set-up is schematically shown in Fig. 2. The rf power from a klystron (TH-2134 by Thomson) was divided into two WR-1800 waveguides by a magic-T (see Fig. 2a). In order to protect the klystron from reflected rf power, a circulator was located in between the klystron and the magic-T. As shown in Fig. 2b, these two waveguides were connected to the two input couplers of the RFQ. The rf power was fed into the RFQ through these two couplers. Since we adopted the dual structure shown in Fig. 2b (the RFQ cavity is contained in a large vacuum chamber), the couplers are fairly long. In order to increase the conductance for vacuum pumping around the ceramics window, eight slits of 6 mm width and 60 mm height were machined on the outer conductor of the WX-152D coaxial waveguide.

During rf conditioning (described in the next section) the surface of the RFQ cavity or the ceramics windows of

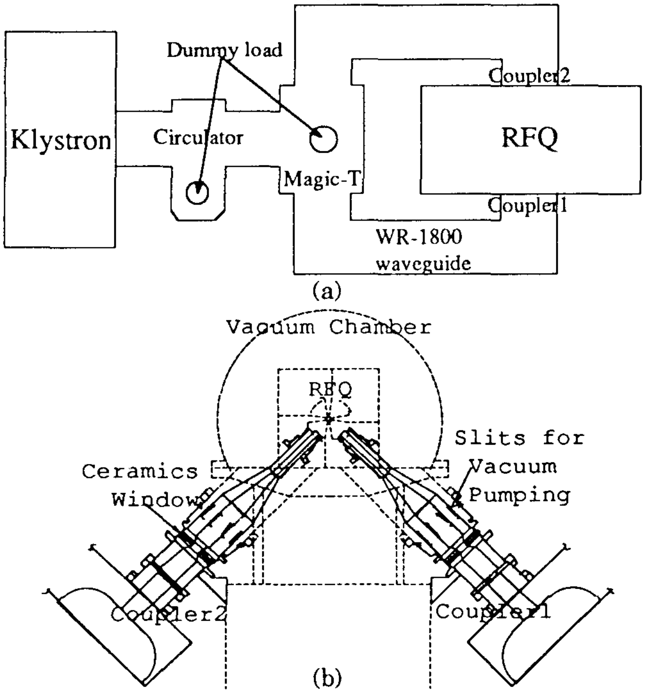


Fig. 2 Schematic drawings of the experimental set-up(a) and two input couplers installed to the RFQ (b).

the input couplers was protected from any large damage possibly arising from the discharge, as follows. The vacuum pressure in the vacuum chamber (outside the RFQ cavity) was measured continuously. The drive amplifier for the klystron was switched off for one second if the vacuum pressure became worse than 6x10^{-7} Torr, where the vacuum pressure without rf power was about 4x10^{-8} Torr. The pulse duration of the input rf power was reduced as soon as possible if the reflected rf power became larger than about 15% of the input rf power.

Results of High-power Test

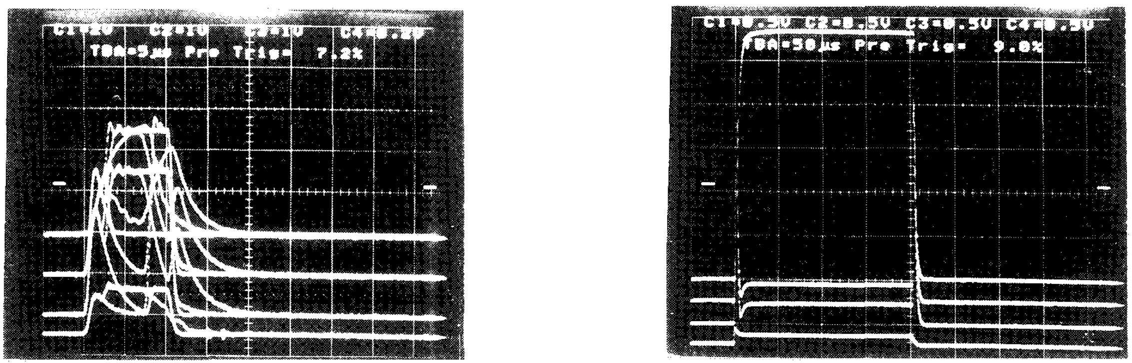
At first, we attempted to feed rf high-power into the RFQ with a low duty factor of 0.1% (20 μsx50 Hz). However, it seemed impossible to increase the rf power higher than 150 kW, at which level the maximum surface electric field on the vane tips was estimated to be nearly the Kilpatrick limit. When we fed rf power of 150 kW, flashes on the vane tips caused by discharges were observed at various longitudinal positions. We then attempted to feed rf power with a high duty factor of 2.75% (550 μsx50 Hz, almost the same as the design value of 3%). However, since it also seemed impossible to increase the rf power higher than 150 kW, we lowered the duty factor down to 0.01% (10 μsx10 Hz) in order to proceed the rf conditioning up to an rf power level of 700 kW (1.4-times as high as the design value). During this rf conditioning, flashes on the vane tips caused by the discharges were also observed at various longitudinal positions. The rf level in the RFQ and the reflected powers are shown in Fig. 3a. Here, the discharges on the vane tips frequently occurred at an rf power level of 560 kW. The top trace of the figure shows the rf level picked up with a loop monitor on the RFQ. The second and third traces show the reflected power from coupler1 and that from coupler2, respectively. The bottom trace shows the reflected power to a dummy load on the magic-T. Although the gain of each loop monitor was not calibrated, each signal height is proportional to the square root of the rf power. After the RFQ was thus conditioned up to an rf power level of 700 kW, we succeeded in feeding the design rf power level of 500 kW with a duty factor of 0.55% (550 μsx10 Hz). Finally, we conditioned the RFQ by increasing the pulse duration with a constant rf power level of 500 kW and a constant repetition rate of 50 Hz. The rf level in the RFQ and the reflected powers are shown in Fig. 3b, where the rf power is 500 kW with the duty factor of 1% (200 μsx50 Hz). After 170 hours of high-power operation the RFQ was successfully conditioned up to the design rf power level of 500 kW with a 1.5% duty factor (315 μsx50 Hz, a half of the design value). The history of the conditioning is summarized in Fig. 4. We decided to collect various data on the accelerated beam before increasing the duty factor to the design value of 3% (600 μsx50 Hz).

The dependence of the thermal detuning of the RFQ cavity upon the averaged input rf power is shown in Fig. 5. The dashed line shows a prediction of a two-dimensional thermal-analysis using the computer code ISAS2 [8]. The measured slope (-1.64 kHz/kW) is about half the predicted value (-3.45 kHz/kW). A three-dimensional thermal analysis is probably necessary for a further study of the thermal detuning. By using the measured slope, the frequency shift at the design duty factor of 3% was estimated to be -25 kHz. This value is within the tunable range (from 432 MHz-56 kHz to 432 MHz+167 kHz without any rf power) of the eight movable tuners installed in the RFQ.

In order to estimate the power loss on a rod for the PISL (see Fig. 1), we carefully measured the temperature rise and flow rate of the cooling water for the rod. At a peak rf power of 500 kW, the peak power loss on the rod, thus measured, was 1.1 kW. This value is about twice the value (0.6 kW) predicted by an analysis using the MAFIA code package [9,10]. This discrepancy can be reasoned as follows. Since the mesh size was limited by the performance of the computer used (the cross section of the rod was divided into only four meshes in the analysis), the concentration of the electric current on the rod could not be correctly estimated. Under the design operating condition (a 3% duty factor), the averaged power loss on the rod and the temperature rise of the cooling water for the rod were respectively estimated to be 33 W and +1.1 °C.

From the empirical results of the thermal detuning due to the input rf power and the power loss on the rod for the PISL, operation with a 20% duty factor is probably feasible. When we feed the design rf power of 500 kW with a 20% duty factor, the thermal detuning and the temperature rise of the cooling water for the rod are respectively estimated to be -167 kHz (within the tunable range as described in the previous section) and +7.3 °C.

Since the field distribution measured with the loop monitors was not varied by the rf power input, the PISLs have been effective for stabilizing the field.



(a) (b)

Fig. 3 Photographs of rf level in the RFQ (the top trace), reflected powers from the coupler1&2 (the 2nd&3rd traces) and reflected power to the dummy load of the magic-T (the bottom trace). Where the input rf power and the duty factor are (a) 560 kW and 0.01 % (10 μsx10 Hz), (b) 500 kW and 1 % (200 μsx50 Hz), respectively.

After 170 hours of high-power operation we measured the Q-value and the coupling factor of the input couplers. The unloaded Q-value was improved from 7170 to 7400 (from 75% to 78% of the calculated value with the MAFIA code package). Therefore, the necessary rf power to generate the design vane voltage was reduced from 490 kW to 474 kW. The coupling factor was increased from 1.098 to 1.152. This value is close to the ideal coupling factor of 1.12 for no rf power reflection from the cavity with the design beam loading. Here, the ideal coupling factor was calculated from a wall loss of 474 kW and a beam power of 59 kW (a 20 mA beam is accelerated from 50 keV to 3 MeV). An improvement in the Q-value and an increase in the coupling factor are commonly observed in a number of accelerating cavities during high-power conditioning [11]. These phenomena are understandable as results of reducing the oxidized cavity surface due to discharges on the cavity surface and the resulting hydrogen desorption.

Conclusions

The first high-power test of the PISL was performed in an RFQ developed for the JHP. After 170 hours of high-power operation, the RFQ was successfully conditioned up to the design rf power level of 500 kW with a 1.5% duty factor (315 µsx50 Hz, a half of the design value). During the course of high-power operation, the unloaded Q-value of the cavity was improved from 7170 to 7400 (from 75% to 78% of the calculated value with the MAFIA code package). Therefore, the necessary rf power to generate the design vane voltage was reduced from 490 kW to 474 kW. Since the field distribution measured with the loop monitors was not varied by the rf power input, the PISLs have been effective for stabilizing the field.

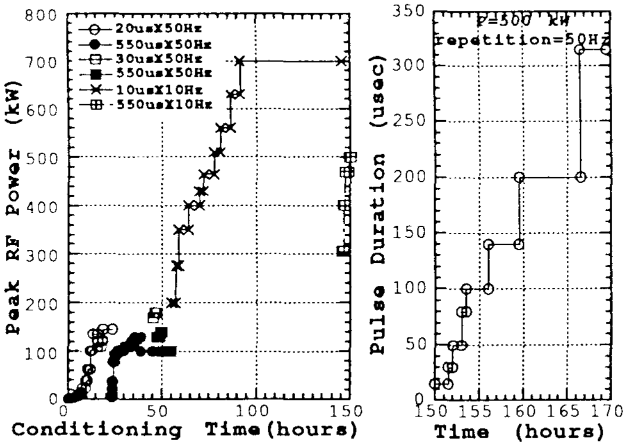


Fig. 4 The history of the first rf conditioning of the RFQ.

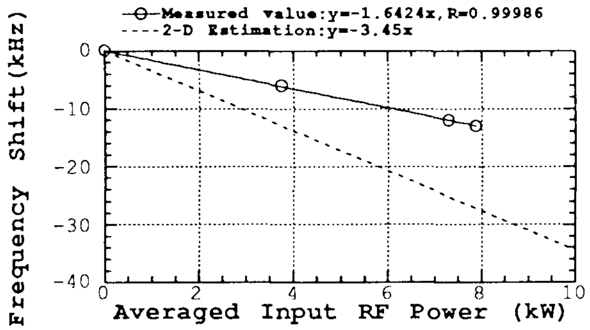


Fig. 5 The dependence of the thermal detuning of the RFQ cavity upon the averaged input rf power

By measuring the temperature rise and flow rate of the cooling water for the rod of the PISL, the peak power loss on the rod was found to be 1.1 kW at a peak rf power of 500 kW. Therefore, under the design operating condition (a 3% duty factor), the averaged power loss on the rod and the temperature rise of the cooling water for the rod were, respectively, estimated to be 33 W and +1.1 °C.

After collecting various data concerning an accelerated beam we intend to increase the duty factor to the design value of 3% (600 µsx50 Hz).

Acknowledgement

The authors wish to express their sincere thanks to Kazuyuki Suzuki and the other members of the Nuclear Equipment Design Section and the Tools Section at Hitachi Works, Hitachi, Ltd. for their technical support.

References

[1] Y. Yamazaki and M. Kihara, Proc. 1990 Linear Accelerator Conf., LANL report, **LA-12004-C**, 543, (1991).
[2] H. R. Schneider and H. Lancaster, IEEE Trans. Nucl. Sci., **NS-30**, (4), 3007, (1983).
[3] A. Ueno and Y. Yamazaki, Nucl. Instr. and Meth. **A300**, 15, (1991).
[4] A. Ueno, T. Kato and Y. Yamazaki, Proc. 1990 Linear Accelerator Conf., LANL report, **LA-12004-C**, 57, (1991).
[5] A. Ueno et al., Proc. 1992 Linear Accelerator Conf., AECL report, **AECL-10**, 728, (1992).
[6] A. Ueno and Y. Yamazaki, "Low-power RF Characteristics of a 432-MHz, 3-MeV RFQ Stabilized with PISLs", in this conference.
[7] A. Ueno et al., "The First Operation of a 432-MHz, 3-MeV RFQ Stabilized with PISLs", in this conference.
[8] K. Yoshino, A. Ueno and Y. Yamazaki, Proc. 8th Symp. on Accel. Sci. and Tech., RIKEN, 119, (1991).
[9] T. Weiland, Part. Accel. **17**, 227, (1985).
[10] R. Klatt et al., Proc. 1986 Linear Accelerator Conf., SLAC-report, **SLAC-303**, 276, (1986).
[11] T. Kageyama, private communication.