High-Power Test of a Traveling-Wave-Type RF-Pulse Compressor

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A high-power model of an *S*-band rf-pulse compressor utilizing a coaxial traveling-wave resonator has been designed, manufactured and tested regarding the energy upgrade of the PF 2.5-GeV linac for the KEKB project. An output peak power of 201 MW was obtained at an input RF power of 45 MW with no serious rf breakdown. The average energy gain was estimated to be 1.75.

I. INTRODUCTION

An energy upgrade of the PF 2.5-GeV linac up to 8 GeV is underway for the KEK B-factory project with an extension of the linac and a reinforcement of the rf power [1]. For the rf power reinforcement, a new-type rf-pulse compressor utilizing a TE620-mode coaxial traveling-wave resonator has been developed in parallel with the SLED [2] application. The advantages of the new-type pulse compressor are simple structure and low cost.

A cold test using a low-power model was completed in 1994, and the expected pulse-compression ability has been demonstrated [3]. However, since the electric-field lines are perpendicular to the metal surface and the electric field gradient is extremely high (~100 MV/m for 45 MW input power), high-voltage breakdown may well occur. To test the breakdown and related problems, such as the radiation of X-rays and temperature rise, a high-power test has been carried out. The design and fabrication of a high-power model and the high-power test results are described in this paper.

II. DESIGN AND FABRICATION

The cavity comprises four parts: an inner cylinder, an outer cylinder, a bottom board and a ceiling board. These four parts and waveguide were assembled by silver and gold brazing. The material of the cavity is oxygen-free copper. The cavity dimensions were just the same as those of the cold model. Because the direction of the real current on the metal surface is normal to that of the lathe's blades, the surface flatness should be sufficiently smaller than the skin depth to obtain a high Q-value. The inner wall of the cavity was planed to less than 0.1 μm and finished by electrolytic polishing. A photograph of the high-power model of the pulse compressor is shown in Figure 1.

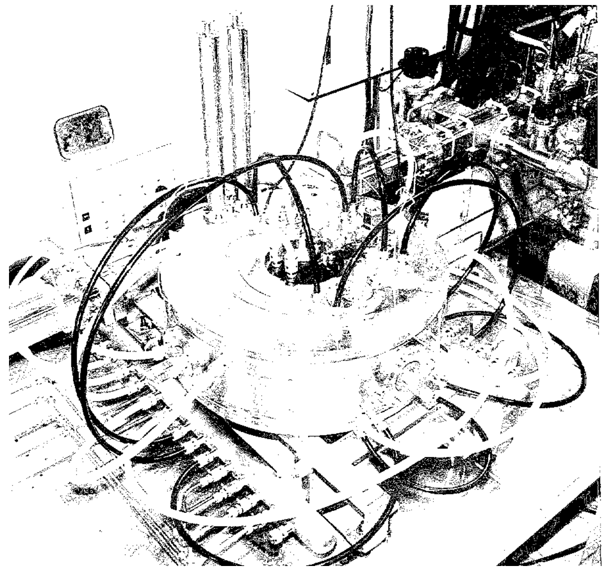


Figure 1: Photograph of the high-power model set at the test bench.

The measured rf characteristics of the cavity are summarized in Table 1 along with the design values. The decrease in Q_0 (unloaded Q-value) is attributed to insufficient electrical contact between the inner, outer cylinders and the bottom, ceiling boards. The total weight of the cavity, including support structure, is 179 kg.

Table 1

Electrical characteristics of the pulse compressor.

	designed	measured
f_0 [MHz]	2.856	2.858
Q_0	59000	48000
β	3.8	2.7
VSWR (tuned)	1.00	1.03
VSWR (detuned)	1.00	1.01
M	1.89	1.75

M : energy multiplication factor

Fine tuning of the resonant frequency was performed by adjusting the rf frequency during this work. The reflection from the cavity to the klystron was minimized by adjusting the stubs set at the ceiling board of the cavity.

III. PERFORMANCE TEST

A. SETUP

A test bench was constructed in order to perform a high- power test of the pulse compressor. The layout of the test bench is shown in Figure 2. The output power from the pulsed high- power klystron (45 MW, 2856 MHz, 3.8 μs,

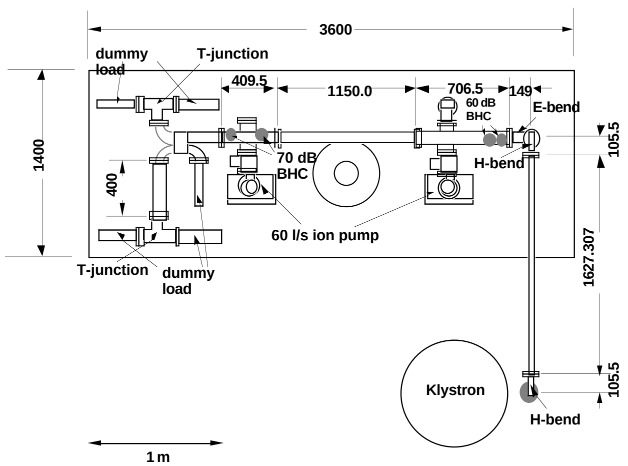


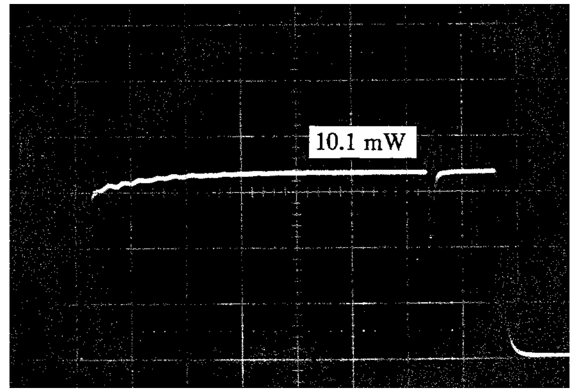
Figure 2: Layout of the test bench.

50 pps) was fed into the cavity, and the output power from the cavity was divided between a 3-dB hybrid and two T-junctions, and absorbed by four high-power water loads (1 μs, 50 pps, 100 MW) developed by Nihon Koshuha Co. The rf power was monitored for forward and backward waves before and after the cavity. The vacuum was evacuated by two ion pumps (60 l/min) and the pressure was monitored by cold cathode gauges. The cavity temperature was monitored using a thermistor thermometer. For the interlock to stop the klystron, vacuum pressures were used as well as the cooling water for the klystron and modulator. The flow rate of the cavity cooling water was 80 l/min (30 ± 0.2 °C).

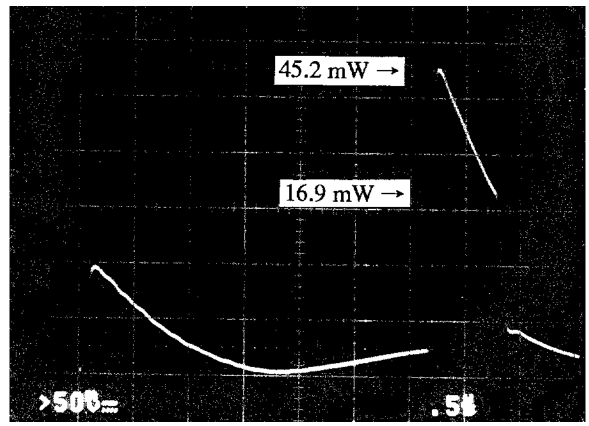
B. RESULTS

The rf conditioning was carried out while monitoring the vacuum pressure and rf power. The base pressure was ~ 10^{-6} Pa after a bakeout at 100 °C for 4 hours; the pressure was kept below 2 x 10^{-4} Pa during rf operation.

After 250 hours rf conditioning, an output peak power of 201 MW was obtained for an input RF power of 45 MW with a pulse width of 3.8 μs. An example of the output wave form from the pulse compressor is shown in Figure 3. The



(a)



(b)

Figure 3 : Output wave form, (a) detuned, (b) tuned.

average energy multiplication factor (M) was estimated to be 1.75 from the pulse shapes for the tuned and detuned conditions, assuming that the output power decreases linearly with time :

$$M = \sqrt{\frac{(45.2 + 16.9)/2}{10.1}} = 1.75.$$

The temperature rise of the cavity was 1.0 °C for an input power of 45 MW, 25 pps.

Figure 4 shows the dose-equivalent rate of bremsstrahlung X-rays as a function of the input rf power measured by ionization chamber at a point 2 m away from the cavity center without shielding. The extrapolated value of the dose rate for an input power of 45 MW, 50 pps is about 100 μSv/h. The measured maximum energy of the X-ray was 1.8 MeV for a 40 MW input.

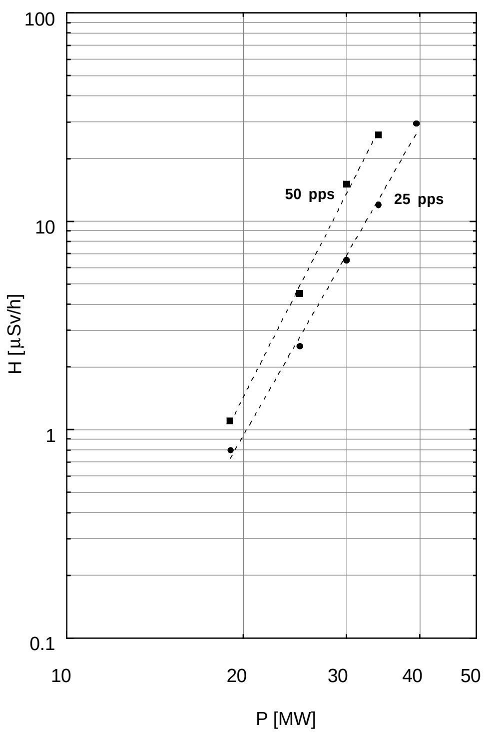


Figure 4: Dose-equivalent rate *vs*. input rf power. The pulse repetition rates are 25 and 50 pps.

IV. DISCUSSIONS

The high-power capability of the new-type rf pulse compressor was demonstrated experimentally in this work. To apply this pulse compressor to the PF-linac, however, there are two problems. One is that the energy multiplication factor (M) is slightly smaller than that required for the KEKB injector linac. The other is that the radiation-dose rate is too high to use this device in the klystron gallery from a radiation protection point of view (the maximum permissible dose rate is 20 μSv/h). Figure 5 shows the simulated trajectories of field-emitted electrons in a simple model using a tracking code for electrons in a traveling-wave field [4]. It is shown that some electrons are incident on the metal surface with very high kinetic energy, and that multipactoring-like motion is not observed. If we use a quite "clean" and flat surface metal, the amount of the radiation, which is caused by the bombardment of field-emitted electrons, will be reduced. It is not so easy, however, to obtain such a high-quality surface, especially at the mass production base.

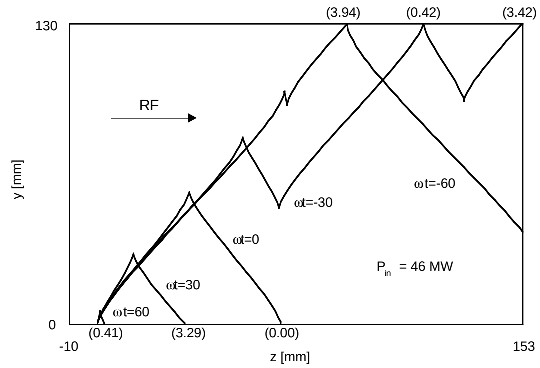


Figure 5: Typical trajectories of field-emitted electrons in a waveguide; field gradient is 130 MV/m and the phase velocity is 1.46*c*. The numbers in parenthesis are the kinetic energy of the incident electrons.

To overcome these problems, such an electromagnetic mode with a much higher *Q*-value (unloaded) than this cavity and with no component of electric field perpendicular to the metal surface should be selected. Design work for the cavity that satisfies these criteria is now in progress.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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