DEVELOPMENT OF AN RF PULSE COMPRESSOR USING A TRAVELING-WAVE RESONATOR

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Abstract

The development of an S-band RF pulse compressor using a traveling-wave resonator is underway to increase the energy of the PF-2.5 GeV linac up to 8.0 GeV for the KEK B-factory (KEKB) project. This pulse compressor consists of a traveling-wave resonant cavity connected to a waveguide by a two-hole directional coupler. The TE_{620} mode with a coaxial cylinder was selected as the resonant mode. The cavity dimensions were determined to have an sufficient separation of the competing modes. Experiments using a low-power model are described in which a peak power-multiplication factor of 5.24 was obtained.

Introduction

An energy upgrade of the PF 2.5-GeV linac (S-band, 400 m long) up to 8.0 GeV is required for the KEKB[1]. To realize this upgrade, an extension of the accelerating structure and a reinforcement of the rf power source are needed. For this purpose, some rf pulse compression as well as upgrading of the existing klystron are necessary .

We have started to develop a new-type rf pulse compressor utilizing a coaxial traveling-wave resonator. This method is similar to that used in the SLED-type pulse compressor[2] at the point at which it releases a high peak power upon switching the rf phase during a pulse after storing the rf power in a cavity. The resonant mode of the new rf pulse compressor, however, is not a standing wave, as used in the SLED cavities, but is of the traveling-wave type. The structure is simple (only one storage cavity and a waveguide are used), as contrasted with SLED which uses two cavities coupled with a 3-dB coupler. A schematic drawing of this new type rf pulse compressor is shown in Fig. 1. The design of the system and the results of a low-power test are reported in this paper.

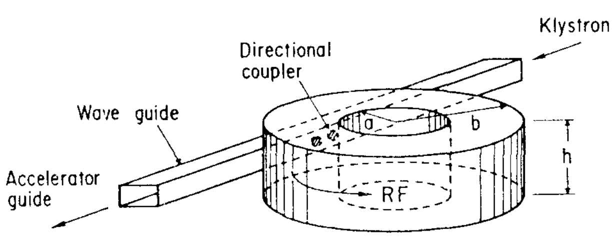


Fig.1 Schematic drawing of a new-type rf pulse compressor using a traveling-wave resonator.

Design

Principles of pulse compression

The system comprises of a waveguide to which a traveling wave resonant cavity is coupled through a directional coupler, as shown schematically in Fig. 2.

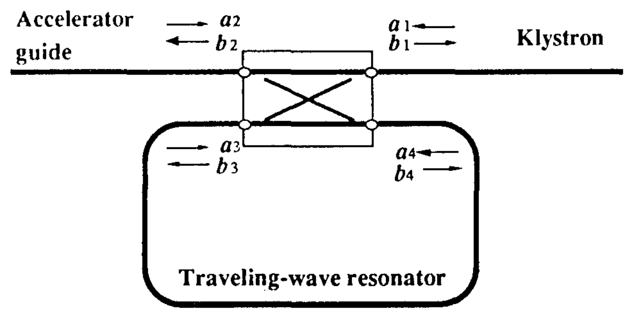


Fig.2 Four-terminal network representation of the pulse-compression system.

Let the amplitude of the incident and emitted waves to the coupler be a_i and b_i (i=1, 2, 3, 4), and the scattering matrix be (S_{ij}). If the directivity of the coupler is infinite, we obtain the following equations:

$$(b_i) = (S_{ij})(a_i), \tag{1}$$

$$(S_{ij}) = \begin{pmatrix} 0 & \sqrt{1-C^2} & jC & 0 \\ \sqrt{1-C^2} & 0 & 0 & jC \\ jC & 0 & 0 & \sqrt{1-C^2} \\ 0 & jC & \sqrt{1-C^2} & 0 \end{pmatrix}, \tag{2}$$

where C is the coupling of the directional coupler. Let the phase-switching time and pulse width be t_1 and t_2, respectively, the amplitude of the output (b_2) is given as follows[3]:

$$b_2 = \begin{cases} -A + B(1 - e^{-\alpha t}) & 0 \le t \le t_1 \\ A - B[1 - 2e^{-\alpha(t-t_1)} + e^{-\alpha t}] & t_1 \le t \le t_2 \\ -B[e^{-\alpha(t-t_2)} - 2e^{-\alpha(t-t_1)} + e^{-\alpha t}] & t_2 \le t \end{cases} \tag{3}$$

where, $A = \sqrt{1-C^2}$, $B = \dfrac{C^2 T}{1 - T\sqrt{1-C^2}}$, $\alpha = \dfrac{1 - T\sqrt{1-C^2}}{L / v_g}$.

Here, T is the transmission rate in the ring, L the length of the ring and V_g the group velocity of rf in the ring. We thus have a compressed pulse shape of the output power, $(b_2)^2$ as shown in Fig. 3.

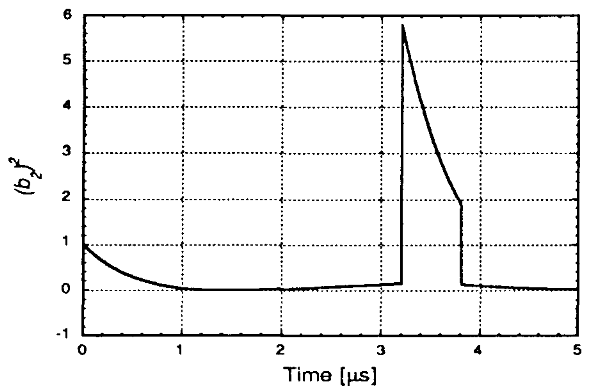


Fig.3 Output wave form from the pulse compressor.

Determination of the resonant mode and cavity dimensions

The resonant frequency (f_0) of a coaxial resonator in which the rf is traveling circularly is given by the following equations [3]:

$$f_0 = \frac{c}{2\pi}\sqrt{K_{nl}^2 + \left(\frac{p\pi}{h}\right)^2} \quad \text{(TE-mode)}, \qquad (4)$$

and

$$f_0 = \frac{c}{2\pi}\sqrt{K'^{\,2}_{nl} + \left(\frac{p\pi}{h}\right)^2} \quad \text{(TM-mode)}, \qquad (5)$$

where, K_{nl} and K'_{nl} are solutions of the following transcendental equations:

$$J_{nl}(K_{nl}a)N_{nl}(K_{nl}b) - J_{nl}(K_{nl}b)N_{nl}(K_{nl}a) = 0, \qquad (6)$$

and

$$J'_{nl}(K'_{nl}a)N'_{nl}(K'_{nl}b) - J'_{nl}(K'_{nl}b)N'_{nl}(K'_{nl}a) = 0. \qquad (7)$$

Here, J_n and N_n are the n-th order Bessel and Neumann functions.

A mode search was restricted to the TE_{620} because of practical size limitations. In the design of the cavity, it is necessary to find a dimensions for which the resonant mode is sufficiently far away from the others. The selected cavity dimensions are :

inner radius (a) = 88.75 mm,
outer radius (b) = 232.0 mm, and
height (h) = 130.0 mm.

A mode chart for the dimensions that were finally determined is shown in Fig. 4. The separations from the parasitic modes are +31 and -53 MHz for the nearest two modes (TE_{521} and TE_{412}); these values are sufficiently large. The Q-value (unloaded) and coupling coefficient(β), which gives the maximum energy gain are 59000 and 3.8, respectively. The voltage multiplication factor in the cavity and the maximum electric field strength (for klystron output of 46 MW) are 20.6 and 132 MV/m, respectively. The energy gain integrated along an accelerator guide is smaller than that of the SLED by 5%.

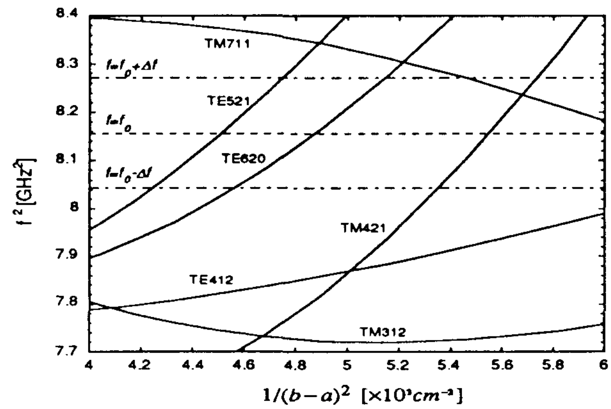


Fig.4 Mode chart (f_0=2856MHz, Δf=20 MHz).

Directional Coupler and Tapered Waveguide

As a directional coupler between the cavity and the waveguide, a two-hole coupler is used. The coupling is adjusted so as to give the maximum energy gain. A narrow-width waveguide is used to provide the same guided-wavelength at the irises for the waveguide and the cavity resonator (at most outside). Tapered waveguides are used between the narrow-width waveguide and ordinary ones (See Fig.5).

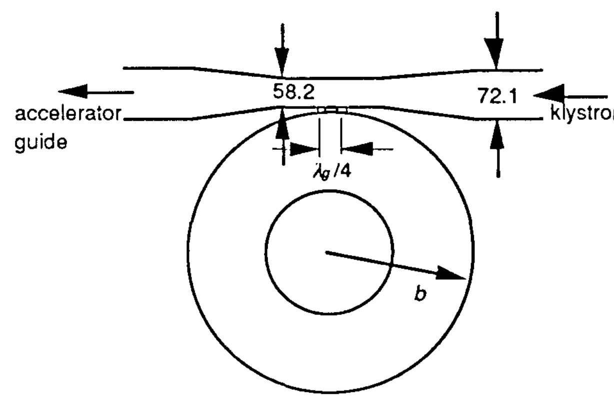


Fig.5 Directional coupler and tapered waveguide.

The length of the tapered waveguide and that of the narrow-width waveguide have been determined so as to give the minimum VSWR.

Tuner and detuner

The precise tuning of the resonant frequency will be achieved by pushing a part of the outer side wall. According to a MAFIA calculation, pushing/pulling of 1.0 mm is necessary for a frequency change of ±75kHz. Detuning of the cavity for non-pulse compression mode operation can be performed by inserting two rods just in front of the irises.

Low-power test

Identification of the resonant mode

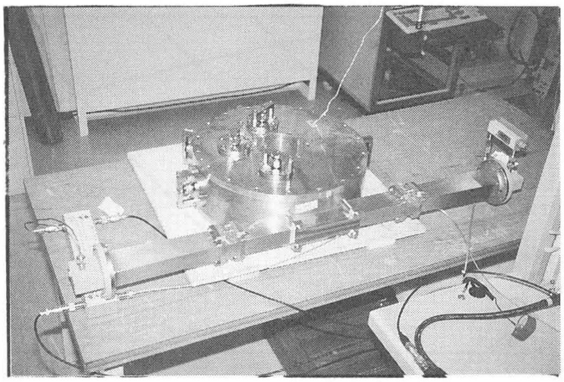
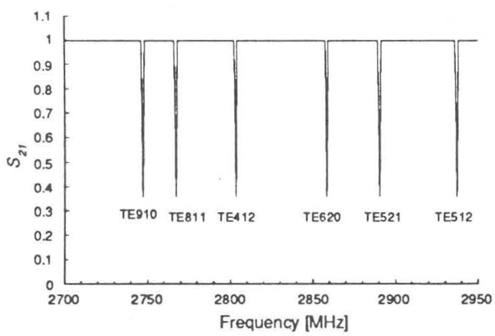
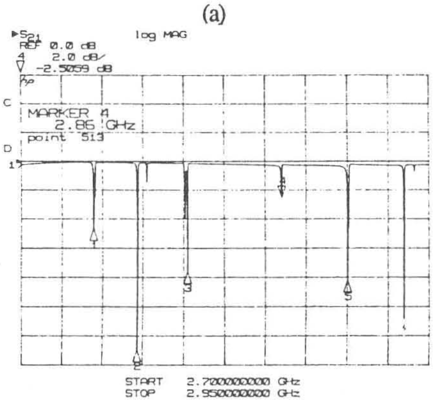


Fig.6 Photograph of the low-power model.

A photograph of the low-power model (made of copper) is shown in Fig.6. The calculated and measured frequency spectra of the resonator are shown in Fig. 7 (the TM modes are not excited, since the cavity is magnetically coupled with the waveguide). From this figure, the mode with a resonant frequency of 2854.60 MHz is considered to be the TE_{620} mode. Furthermore, the measured distribution of the electric field in the radial direction showed good agreement with the calculated one. From these information, it might be believed that this mode is the TE_{620} mode.



(a)



(b)

Fig.7 Frequency spectra of the resonator: (a) calculated and (b) measured.

Rf characteristics

The rf characteristics measured with this model were as follows:

Q_L = 12,019,
β =2.59, and
Q_0 = 43,156(73% of theoretical value).

The drop in Q_0 is attributed to an unsatisfactory electrical contact. The stub tuners were adjusted so as to make the VSWR as small as possible; the minimum VSWR was 1.09. The measured tuner's effect was 100 kHz per 1.0 mm. The VSWR with a detuned cavity was 1.01.

Pulse response

The measured pulse response of this pulse compressor is shown in Fig. 8. The pulse width and phase-switching time are, 3.8 μs and 3.2 μs, respectively. The peak power-multiplication factor is 5.55. This value is slightly smaller than the calculated value of 5.96. The reason is considered to be that the Q-value is smaller than the theoretical value by 27%.

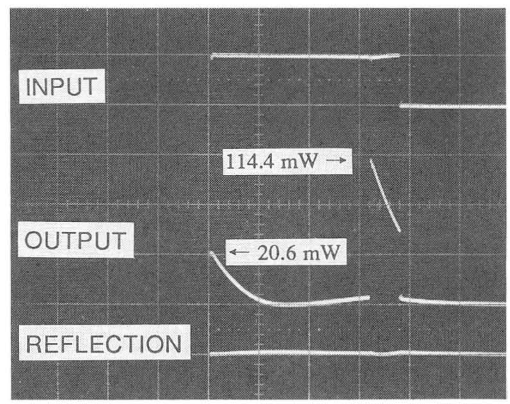


Fig.8 Wave form, input(upper trace), output(center) and reflected.

Conclusions

For the energy upgrade of the PF 2.5-GeV linac for the KEKB, an rf pulse compression system using a traveling-wave resonant cavity has been designed and a low-power test has been carried out. The expected pulse compression ability has been demonstrated. Fabrication of a high-power model is under way. High-power tests and beam acceleration tests are scheduled for this autumn.

References

[1] A. Enomoto, *et al.*, " REFORMATION OF THE PF 2.5 GEV LINAC TO 8 GEV", this Conference.

[2] Z. D. Farkas, *et al.*,"SLED:A Method of Doubling SLAC's Energy", Proc. 9th Int'l Conf. on High Energy Accelerators, SLAC 576 (1974).

[3] S. Yamaguchi, in "Design report for energy upgrade plan of the PF linac", to be published (in Japanese).