DEVELOPMENT OF C-BAND RF PULSE COMPRESSION SYSTEM FOR e^+e^- LINEAR COLLIDER

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Abstract

A new type of RF compression scheme was proposed by the authors for the C-band RF system in the e^+e^- linear collider in 1996[1]. This scheme generates a flat pulse output using 3-cell coupled-cavity for the high-Q energy-storage. A cold model cavity was fabricated and tested to test the flat pulse generation. The input RF amplitude is modulated with a scheduled waveform in order to compensate the output power ripple associated with the coupled cavity resonances. The cold model generated a flat pulse compressed with gain G_p of 3.25.

1 INTRODUCTION

A new scheme to compress an RF pulse into a short square high peak-power pulse was proposed by the authors in the course of R&D study for e^+e- linear collider[2]. Figure 1 shows the schematic diagram. This scheme uses a 3-cell coupled cavity as an RF energy storage. After the filling time, when the input RF phase is flipped by 180 degree, the compressed RF pulse is emitted into the output port and no reflection power backs to the input port because of the 3-dB hybrid coupler same as in the case of SLED. The coupling irises limit the group velocity of the propagating wave inside the 3-cell cavity, and make it like a delay line. Therefore, this scheme is an extension of the SLED-II pulse compressor, which uses a long circular waveguide as a delay line and generates an ideal square output pulse[3]. The irises make the delay line length short, however it causes the frequency dispersion effect in the propagating wave, resulting in a large distortion in the output waveform. To compensate this, we apply the amplitude modulation (AM) on the input RF power into the compressor. Basically, we can do this with one klystron. However, the klystron is non-linear device, that is, the input to output power response is not a linear function, we need a careful compensation to this effect. The klystron will be operated below saturation condition, then the power efficiency will be lowered. In the two klystron configuration shown in Fig 1, the klystrons operate at saturation condition with enough power efficiency. The input RF phase is modulated (PM), and the two output powers are combined in the 3-dB hybrid. The in-phase component (vector sum) goes to the pulse compressor, and the quadrature component (vector difference) is damped in the dummy load. Since the two vectors rotate in the opposite directions, the vector sum always runs on the real axis, and no phase change is came out in the output sum vector. The amplitude of the two vectors is adjusted to the same value with the input RF power knob. The phase modulation pattern will be generated automatically in the self-learning pulse-to-pulse feedback system.

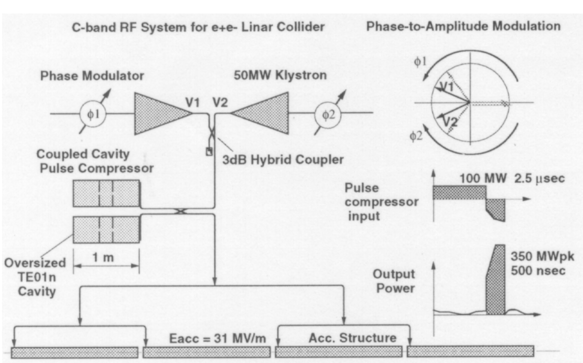

Fig.1 System diagram

2 DESIGNED COMPRESSION PARAMETERS

In the coupled cavity system, only the $\pi/2$-mode does not generate dynamic phase variation during the transient pulse response. Because the $\pi/2$-mode stays just in the middle of the Brillouin diagram, all vectors of the sideband components associated with the AM modulation rotate symmetrically, and generate a real vector sum same mechanism as the PM-to-AM modulation scheme in Fig. 1.

We studied the pulse response of the delay line by a computer simulation based on the equivalent circuit model. We chose the 3-cell design as the optimum. The simulation predicted the power gain of 3.5 at the pulse-length compression factor of 5, thus the effective power efficiency was 70% (= 3.5/5).

3 COLD MODEL DESIGN

Figure 2 shows the cold model of the RF compressor. One delay line is enough to study the RF pulse compression by detecting the reflection wave using a directional coupler. The input power is fed through a rectangular waveguide, and converted into the circular TE01 mode in the newly developed mode converter, then injected into the 3-cell energy storage cavity. The total cavity length is about 1 m.

Table 1 Cavity parameters. The symbol *k* stands for the coupling constant between two cavities.

	1st cell	2nd cell	3rd cell
Diameter [mm]	152.60	152.60	152.60
Length [mm]	432.70	144.02	433.42
Mode	TE0,1,15	TE0,1,5	TE0,1,15
Q (analytical)	190 k	85 k	190 k
Q (measured)	181 k	82 k	187 k

	1-2 cell	2-3 cell
Iris Diameter [mm]	43.6	42.4
k (designed)	1.00	0.65
k (measured)	0.95	0.66

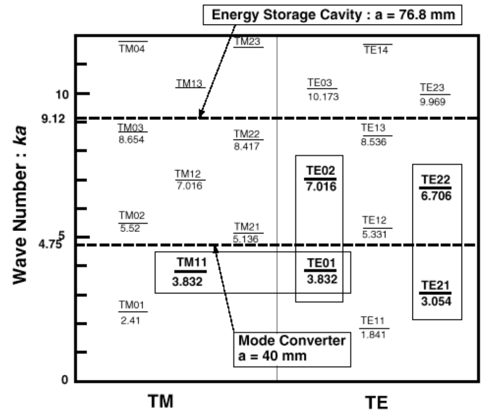

Fig. 3 Mode diagram.

3.1 *Energy Storage Cavity*

The design and achieved parameters are listed in Table 1. In order to get a higher Q-value and low loss mode, we need to use a copper pipe with a large diameter. We chose the pipe diameter at 152.60 mm, which corresponds to $ka = 9.12$. Since the operating frequency is much higher than the lowest cutoff frequency (1.1 GHz for TE11), there are many unwanted low-Q modes as shown in Fig. 3. We use TE01n mode for the energy storage. To avoid mode mixing, all of the structure in the energy storage cavity was made cylindrically symmetric, which makes no mode coupling to the modes other than TE0n. Additionally, to avoid direct excitation of those mode from the external circuit, we use a mode converter.

From a pulse simulation with the measured coupling constants, the highest attainable power gain is 3.45.

3.2 *Cavity Tuning*

The $\pi/2$-mode pattern and its resonance frequency is exactly identical to those in the individual cell-mode. We can establish the cell-mode by replacing the neighboring cells with detuned cavities. Since the dimension of the detuned cavity is chosen not to resonate at the target frequency in any mode, no power can leak into the detuned cavity and all field is trapped within the test cell.

We measured the cell-mode using detuned cavities, and machined the cavity length on a turning lathe. Each of the three cavities was tuned to the target frequency. The maximum error was 100 kHz in the 2nd coupling cavity.

3.3 *Mode Converter*

In order to limit the number of propagation mode inside the circular waveguide, its diameter was chosen as small as 80 mm (see Fig. 3). The four coupling irises generate rotational electric field symmetrically to excite only the TE01 mode. Residual imbalance can generate a small amount of TE21 mode. Computer simulation using HFSS predicted the excitation power of unwanted mode is less than 1%.

RF performance was measured from rectangular waveguide port, attaching a matched load in the circular waveguide port. The measured VSWR was 1.05 for 5 MHz bandwidth.

4 PULSE MEASUREMENT TEST

For this cold model measurement, the input pulse to the cavity was generated by AM modulation with a double balanced mixer. The modulation signal was provided by HP8175A Digital Signal Generator. The input signal was fed into the cavity, then the reflected signal was detected. After fine trimming of the modulation pattern in order to

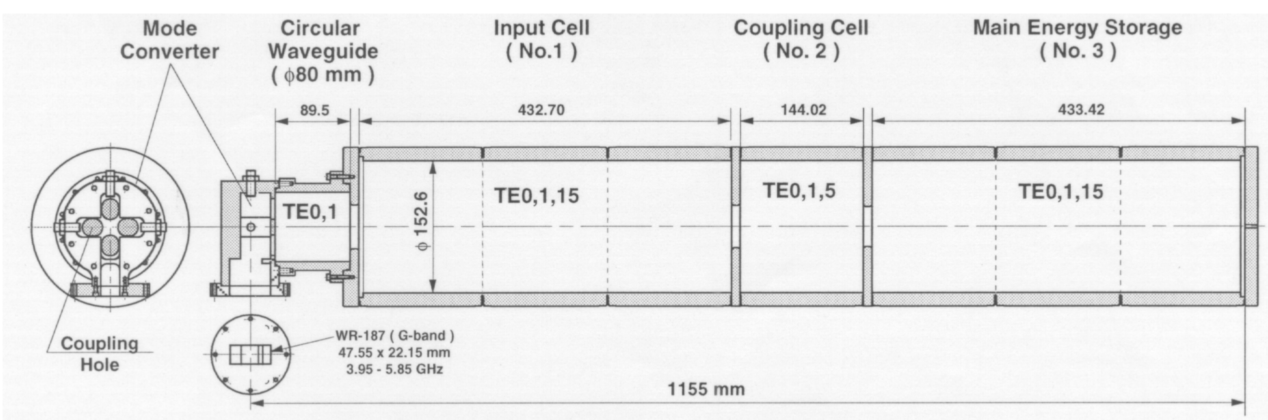

Fig. 2 Energy storage cavity and mode converter.

(a)

(b)

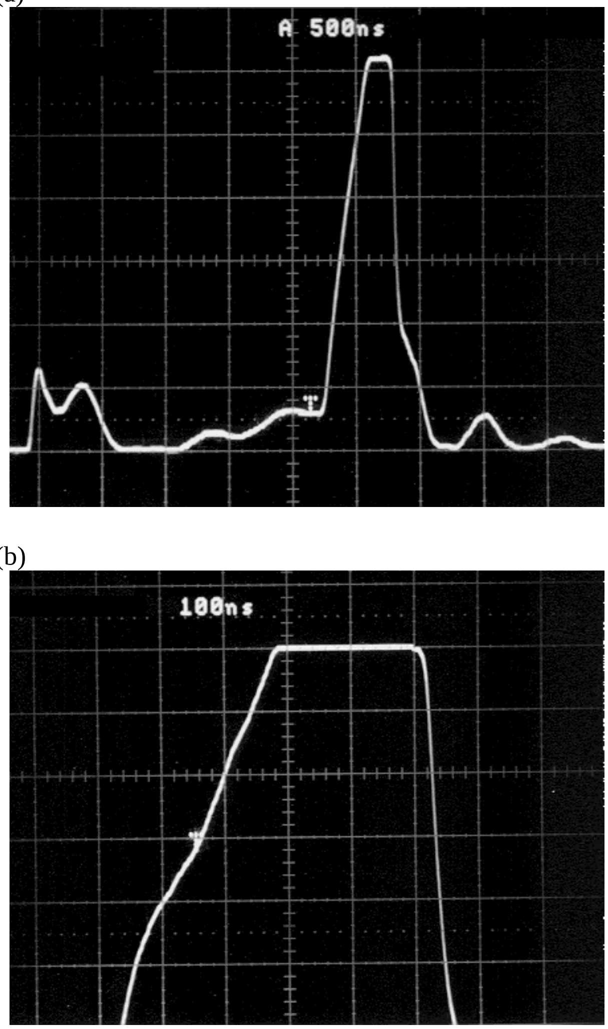

Fig 4. (a) Output pulse. (b) Zoom at the flat top.

obtain the maximum power gain and to make the pulse top flat, the resulting output signal is shown in Fig. 4. At the flat top, the output power is constant within 1%. The measured power gain G_p is 3.25, which is 94% of the expected value of 3.45. Further analysis on the power gain measurement is under way.

5 DISCUSSION

The required tuning accuracy was estimated by the coupled cavity analysis[4]. Thanks to the high stability in π/2-mode, errors in the cell resonance frequency do not cause large phase or voltage error in the stored field. Therefore, tuning accuracy of the cell-to-cell frequency is not tight. For example, 300 kHz frequency error (the relative frequency error of 10^{-4}, which corresponds to dimension error of 50 μm of cavity length or 15 μm of cavity diameter) on the 3rd cavity cause only 1% amplitude error and 0.06 degree phase error in the 3rd cavity voltage. The leakage power into the 2nd coupling cell is sensitive to the 3rd cavity error. However, the deterioration in the total Q-factor due to this leakage is only 0.67%. Dimension accuracy in a practical machining of a cylindrical cavity on a turning lathe is much better than the error assumed above.

We need to study the error effect due to the brazing process. According to some experience in fabrication of the disk-loaded structure, the resonance frequency shift due to brazing is below 200 kHz at S-band (2856 MHz). Therefore, the brazing will not cause a difficulty.

After the brazing, we will measure the π/2-resonance using the detuned cavity attaching to the input port, and adjust the screw mounted on the end plate of 3rd cavity to meet the frequency to the right operation frequency of 5712 MHz. The π/2-mode resonance frequency is simply given by

$$\omega_{\pi/2} = \frac{U_1\omega_1 + U_3\omega_3}{U_1 + U_3},$$

where U_n is the stored energy in the *n*th cavity. Since the large energy stored in the 3rd cavity, we can adjust the π/2-mode resonance by tuning the 3-rd cavity frequency. To get phase stability of 3 degrees in the compressed RF pulse, the required frequency accuracy is 8 kHz, and temperature must be kept constant within 0.1 °C. This is the same accuracy level required to the conventional SLED cavity.

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