HIGH POWER TEST OF C-BAND PULSE COMPRESSOR USING LOW THERMAL EXPANSION MATERIAL

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Abstract

The first high power model of C-band (5712 MHz) RF pulse compressor was developed for the e^+e^- linear collider. To obtain high efficiency and stable operation of the pulse compressor, we developed thermally stable high-Q cavity using Super Invar material, which has ultra-low thermal expansion coefficient which is lower than 1.0 x 10^{-6} /°C.

Since the RF pulse compressor uses the narrow resonant cavity of highest Q-factor in electron linear accelerator systems, it is extremely sensitive to temperature variation. To stabilize this cavity, one solution is to employ a low thermal expansion material to make the cavity. However, such material usually has poor electrical conductivity. To maintain high Q-factor, we made use of copper plated invar material. To improve plated copper property, we applied two different methods, special electroforming technique (PR process) and HIP process in addition.

This paper describes the detail fabrication technique of this type of RF cavity, and present status of high power test of the RF pulse compressor.

DESIGN

Electrical Design

The C-band RF pulse compressor was designed for the e^+e^- linear collider in Japan (JLC) based on C-band technology [1]. We adopted 3-cell coupled cavity system [2] to obtain maximum efficiency for the flat output pulse, which is required for multi-bunch beam operation. The design goal is to compress the pulse width of the 100 MW input power by a factor of 5, and generate 350 MW peak power. Figure 1 (left side) shows the pulse form of normalized input and output power of the RF pulse compressor.

The RF pulse compressor consists of three cavities as shown in Figure 2. The first and third cavities are designed for $TE_{01,15}$ mode and the second cavity is designed for $TE_{01,5}$ mode. The ideal Q value using Oxigen Free Copper (OFC) is 185,400 for $TE_{01,15}$ and 82,600 for $TE_{01,15}$, respectively.

Thermal and Mechanical Design

At an optimum condition, the microwave energy is mainly stored in the third cavity. Thus the performance of the third cavity dominates the compressor performance. The frequency sensitivity of the third cavity is $\Delta f/\Delta L$=10.8 kHz/μm for the cavity length (L) and $\Delta f/\Delta D$ = 6.6 kHz/μm for the cavity diameter (D).

Figure 1 shows the energy gain change due to the resonant frequency shift (Δf) of the third cavity. To reach 99% of the maximum efficiency, acceptable resonant frequency change is only ±25 kHz. This value corresponds to ΔL = 2.3 μm. To satisfy this permissible range using only OFC material, we must control the temperature within 0.3 °C. In order to relax this severe temperature requirement, we decided to make the energy storage cavity using Super Invar, which is ultra low thermal expansion material.

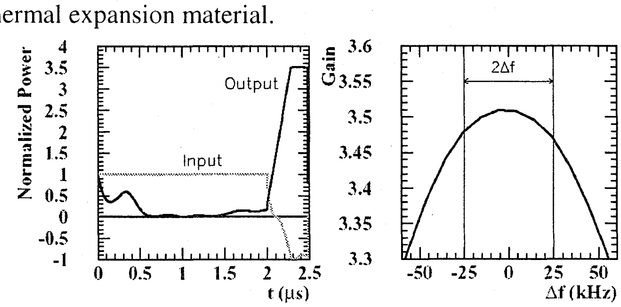

Figure 1: RF pulse compressor performance (simulation), normalized power of the pulse compressor (left side) and power gain dependence on resonant frequency of the third cavity (right side).

Table 1 shows characteristics of copper and Super Invar material (Fe:63%, Ni:32%, Co:5%). The thermal expansion coefficient of Super Invar is 1/40 of the one of copper . If we can replace all parts of cavities by Super Invar, 10°C temperature change is acceptable. Thus using Super Invar material for the base material of cavities, very big improvement in temperature stability is expected.

Table 1: Material properties of the super invar and copper

	Copper	**Super Invar**
Thermal Expansion Coefficient	16 x 10^{-6}/°C (Poor)	0.4 x 10^{-6}/°C (Excellent)
Electrical Conductivity	1.7 x 10^{-8} Ωm (Good)	Poor (improved by making copper wall on inner surface)
Thermal Conductivity	394 W/m·°C (Good)	13.5 W/m·°C (Poor)

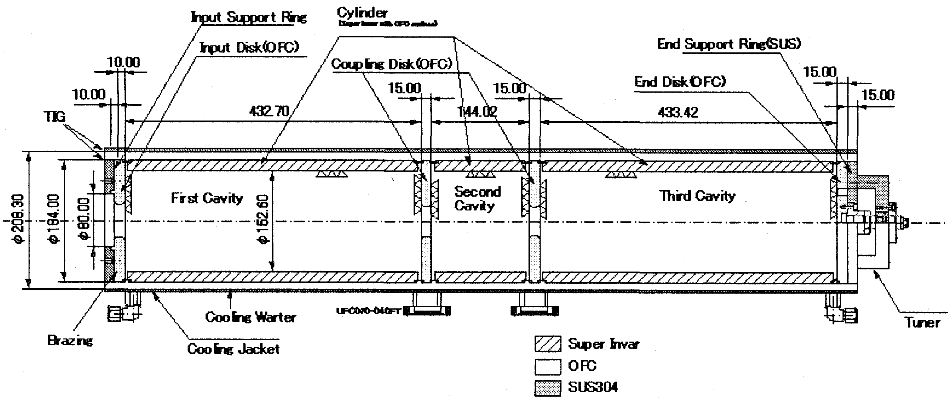

Figure 2 : RF pulse compressor.

Since Super Invar has poor electrical conductivity, it is necessary to make pure copper plating on inner surface of Super Invar for high Q cavity. We applied two methods to form the copper layer; the PR electroforming [3] and HIP method.

Since the thermal conductivity of Super Invar is fairly smaller than the one of the copper, we have to be careful about the heat load density. The thermal loading of the third cavity is 25 J per one RF pulse, of which 38 % is dissipated in the surface of the cylinder and 31 % each is dissipated in the both end plates. Under 50 pps operation, thermal loading of the cylinder surface becomes 2.2 kW/m^2. At this condition, the temperature rise at the inner surface of Super Invar becomes 3 °C (outer wall is water-cooled). If we assume that the average temperature rise inside of the body is 1.5 °C, the frequency shift becomes only 5 kHz.

MANUFACTURING

Invar Material with Cylindrical Shape

Because of the hardness of Super Invar material, it is hard to forge and machine on turning lathe. To solve this problem, we applied the casting method to make directly the cylinder from Super Invar. The ordinary cast products have, however, impurities and defects, which cause troubles in electroforming process and under ultra high vacuum. Therefore we selected the high quality cast Super Invar which has low carbon, high purity and few defect developed by Nihon Chuzou Company.

Copper Surface (PR electroforming process)

The PR (Periodic polarity Reverse) copper electroforming process was recently developed by Mitsubishi Heavy Industry Company. The copper surface formed by this process becomes very pure copper. It is suitable to make high-Q cavities operated at ultra high vacuum condition. The process time is fairly long, since we have to grow the copper layer very slowly to avoid impurity contamination, and results higher cost.

Copper Surface (HIP)

Another candidate to form copper layer on the invar is HIP (Hot Isostatic Pressing) technique. HIP process has many advantages;

- Suitable for mass production,
- Lower fabrication cost (especially in mass production),
- Diffusion bonding is very strong, thus it becomes possible to braze all components after HIP,
- OFC-class 1 material can be used. This leads to high reliability and no defects.

HIP process for this bonding was done under 800 °C, 1000 atm for 2 hours.

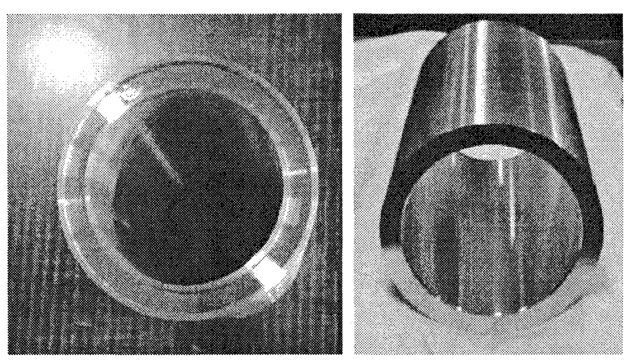

Figure 3: Triple layer pipe (OFC-Super Invar-OFC) using HIP method.

Assembling

The machining process for final adjustment and the assembling process using TIG welding were done at TOYAMA Company. This company has skill in treating precise components under ultra high vacuum. We can quickly perform the repetitive process to tune the resonant frequency of cavities, since the company has almost all basic machine tools near from the assembling place and the working environment is enough clean to assemble the RF pulse compressor.

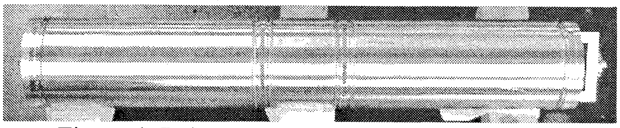

Figure 4: Pulse compressor after TIG welding

Figure 4 shows the RF pulse compressor which is assembled using TIG welding. In this assembly, the most serious problem is how to tune the resonant frequency of the first and the second cavities which have no tuner, because the cavity length is shrunk irregularly after TIG welding. To tune these cavities, we prepare another welding guide to adjust the cavity length using low controlled current of the TIG welding.

Performance of cold test

Table 2 shows the comparison of electrical characteristics between design value and measured values of two pulse compressors. From these measured values, we can expect to obtain over 95% of the designed power gain.

Table 2: Electrical characteristics

	Design value	First one	Second one
f_1(MHz)	5712.00	5712.21	5712.05
f_2(MHz)	5712.00	5711.88	5711.93
f_3(MHz)	5712.00	Adjustable	Adjustable
k_{12}	0.0012	0.00112	0.00114
k_{23}	0.00069	0.00059	0.00075
Q_L	32	27	29

Concerning about the thermal stability, the resonant frequency drift by the temperature change becomes 13kHz/°C. This value is lower than 1/6 of ordinary copper cavity system, and is low enough to operate easily such a high-Q cavity.

HIGH POWER TEST

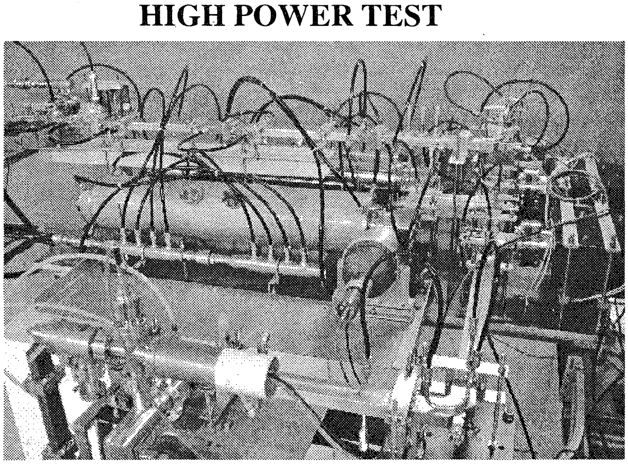

Figure 5: High power test.

Components

Figure 5 shows the high power test stand of the RF pulse compressor. For this high power test, we newly developed two RF pulse compressors, two mode converters for rectangular TE_{10} to cylindrical TE_{01} mode, a 3 dB hybrid, two -3 dB attenuators using slow wave structure. And 4 ion pumps were arranged for fast aging process.

Before the high power test of the RF pulse compressor, we tested the high power test stand without the pulse compressor with the input RF power of 40 MW.

Current Status

We are now operating the RF pulse compressor at the input RF power of 35 MW of 2.5 μs and the compressed RF power of 105 MW of 0.5 μs. Figure 6 shows the pulse waveform of the input and output power of the RF pulse compressor.

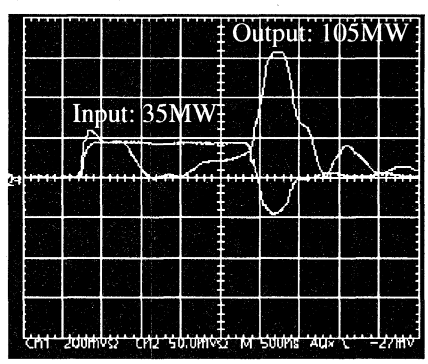

Figure 6: Pulse waveform of input and output power of the RF pulse compressor.

Under the present circumstances, the compressed power gain becomes only 3. This value is a little bit lower than the target gain of 3.5. This low gain caused by the detuning of the resonant frequency of the first cavity is due to the deformation by the force of the vacuum flange. And the actual operating time is almost 2 months because the inverter power supply has frequent troubles in the other days.

SUMMARY

We developed the RF pulse compressor using Super Invar material, which has ultra low thermal expansion coefficient. We successfully achieved the resonant frequency change by temperature less than 13 kHz/°C for the whole pulse compression system. We are currently working on the high power test to reach the target output power of 175 MW, 220 ns, 50 pps.

REFERENCES

[1] http://c-band.kek.jp/

[2] T.Shintake et al., "A New Pulse-Compressor Using Multi-Cell Coupled-Cavity System", EPAC96, Sitges, June10-14, 1996, KEK Preprint 96-71.

[3] K.Tajiri et al., "PR copper electroforming method for JHF", Proceedings of 25th Linear Accelerator Meeting in Japan, 2000.