

150 KW CW CIRCULATOR

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Abstract

We developed Y-junction waveguide circulators for the the 508.6 MHz RF system for superconducting cavities of the TRISTAN main ring. Thirty-six circulators were constructed and thirty-two of them have been installed. Before installation, they were tested at a power level of up to 150 kW CW with the output port shorted. The results showed sufficient power handling capability. In this paper, the high power performance of these circulators is presented.

Introduction

We developed 150 kW CW Y-junction waveguide circulators in order to install in an RF system for superconducting cavities of the TRISTAN main ring. A high power section of the RF system is shown in Fig. 1. Four cavities are driven by one klystron. The output power of the klystron is divided into four channels by three magic-tees. The circulator is installed in each channel between the second magic-tees and the cavities. The reflected power from the cavity is dissipated at a 160 kW water-cooled dummy load. As thirty-two superconducting cavities have been installed, the same number of circulators are needed. The reason for their installation is as follows.

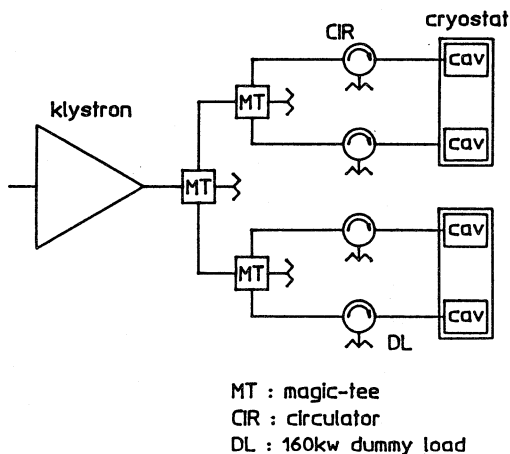


Fig. 1 High power section of the RF system

First, the circulators protect the klystron from the destruction of the output window or the unstable operation due to the power reflected from the cavities. Second, the cavities are desired to be isolated from each other by the circulators. Without them, a small amount of the reflected power from a cavity might go through the magic-tee and reach the other cavities. This will affect the stability of phase and amplitude of the superconducting cavity.

The circulators should have the power handling capability of 150 kW. They should continue the operation even when the superconducting cavities are detuned. The circulators should also fulfil the requirement that the phase shift in the circulator should not change so much either at the low power condition or the total reflecting condition of the full power, because this phase deviation makes the operation of the cavities unstable. Specifications of the circulator is listed in Table 1.

Table 1
Specifications of 150 kW Circulator

VSWR	< 1.15
Insertion Loss	< 0.2 dB
Isolation	> 25 dB
Input Power	150 kW
Frequency	508.581 ± 1.5 MHz
Cooling Water	
Flow Rate	40 l/min
Pressure (max.)	10 kg/cm ²
Waveguide	WR1500
Waveguide Flange	UDR6

There are two types of waveguide circulators, a differential phase-shift type and a junction type. The differential phase-shift type circulator has high power handling capability, but has a rather large insertion loss and a bulky body. On the other hand, the junction type circulator, in general, has a better performance, but less power handling capability. Therefore, the junction type is preferable if the circulator with the sufficient power handling capability can be constructed.

Although the junction type is inferior at high power handling, this type of circulator with the capability of 100 kW was already realized at 940 MHz.¹⁾ Junction type circulators of 500 MHz are operated at a

transmitted power level of 180 kW in the Photon Factory of KEK.²⁾

To investigate the high power limit, we carried out a preliminary test using a junction circulator of the same structure as those used in the Photon Factory, but tuned to 508.6 MHz. With a matched load, we could operate it at the power level as high as 240 kW. Then, we tested it with the output port shorted. In this case, at the power level of a slightly below 150 kW, sparking occurred. From the check of the interior structure, we concluded that we must make the metallic corners rounder and electric contacts better to achieve higher power ratings.

We measured the phase shift for various power levels with the output port terminated by a matched load. The phase shift characteristics are affected by temperature rise of the ferrite due to the insertion loss. The power lost in the ferrite in the total reflecting condition is equal to the power loss when the power of 300 kW is transmitted to the matched load. The phase deviation at 300 kW, if extrapolated, is estimated to be about 5°. Although there might be other unknown factors which affect the phase deviation, we concluded that a circulator with small phase deviation could be constructed by selection of a proper ferrite with a low insertion loss and good temperature properties.

Design and Construction

The circulator consists of a central junction section with the shape of deformed hexagon, and three 540 mm long waveguides attached to it, as shown in Fig. 2. The interior of the junction section is divided into three gaps by two metal plate, and there are six ferrite disks, as shown in the cross-sectional view given in Fig. 3. The ferrite disks are 4 mm thick and about 25 cm in diameter. Each disk is fixed on a copper plate, as shown in Fig. 3. Part of each waveguide is also divided by the metallic plates. Each port is matched by posts inserted in every gap of the plates in the waveguide section.

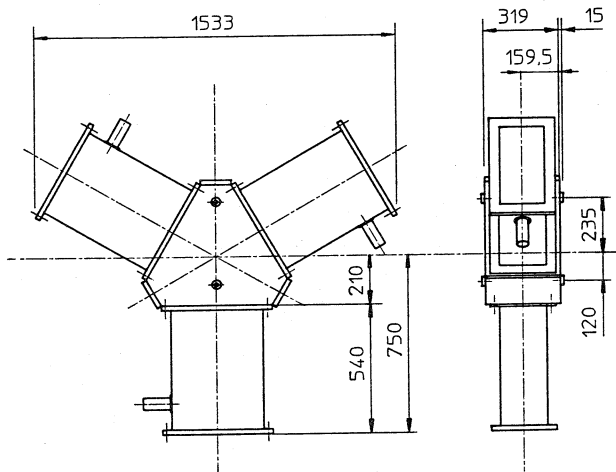


Fig. 2 150 kW cw circulator

As pointed out in the previous section, the performance of the circulator is affected by the temperature rise of the ferrite due to the power loss in it. Therefore, to satisfy the above requirements, it is important to select the ferrite material with low loss and good temperature properties. For this purpose, small stripline circulators were made with three kinds of ferrite material, "Y-5" and "6E-3" supplied by TDK and "G-DF" supplied by Mitsubishi Electric. Measurements of the VSWR, insertion loss, isolation and phase deviation were carried out at room temperature and at 60°C. The ferrite material which showed the least temperature dependence was not selected, because it has large insertion loss. The other two kinds of ferrite had a loss half of the first sample. Therefore, we have chosen the one which showed the better temperature dependence. The selected one is "G-DF". It is a gadolinium and aluminum doped yttrium-iron garnet $(Y,Gd)_3(Fe,Al)_5O_{12}$, which has the saturation magnetization $4\pi M = 650$ Gauss, Curie temperature $T_C = 200^\circ C$, dielectric loss $\tan \delta < 3 \times 10^{-4}$ and thermal conductivity 6.7 W/m°C.

Each ferrite disk consists of 16 small ferrite plates which are fixed on the copper base by an epoxy resin and teflon screws. Cooling water channels are embedded in the copper bases to remove the heat generated in the ferrite. The magnetic field of about 1000 Gauss is generated by permanent magnets. The magnets are set on the top and bottom sides of the junction section as well as in the two partition plates.³⁾ This has the good advantages of obtaining a uniform magnetic field and making the circulator body compact.

High Power Performance

Two different tests were carried out to investigate the high power behavior of the circulators; a forward power test and a power test with total reflection. All circulators were tested in the total reflecting condition. On the other hand, the forward power test was carried out for five circulators only.

Forward power test

The performance at the power level of 150 kW was measured with both the port-2 and port-3 terminated by matched loads. The results show that the

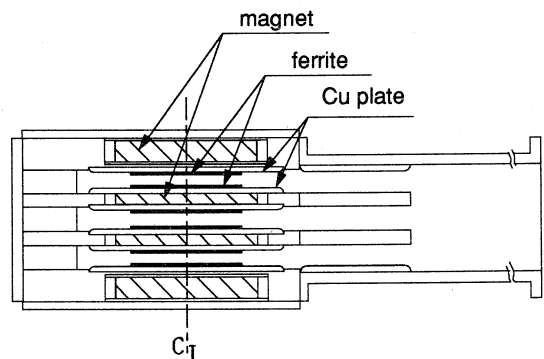


Fig. 3 Cross-sectional view of the circulator

input VSWR is less than 1.12 and the isolation greater than 22 dB. Typical values of the insertion loss and the phase deviation are 0.13 dB and 2.3°, respectively.

Power test with total reflection

This high power test was carried out with the output port shorted. Each circulator was tested with two different short conditions : L = 1374 mm and L = 1604 mm, where L was the distance from the circulator center to the short plate position. We were afraid that sparkings might occur around the contact part between the central junction section and the waveguide. Hence, one short condition (L = 1374 mm) was chosen so that the electric field takes its maximum at this contact plane. In the other condition (L = 1604 mm), the electric field takes its minimum there.

All circulators stand the total reflection of 150 kW input power for more than 30 minutes in both short conditions.

Figures 4 and 5 show the input VSWR and the insertion loss in two different short conditions, where the horizontal axis represent temporal serial numbers of the circulators. The results on the phase deviation are given in Fig. 6. Although the results are rather large at L = 1374 mm, they are less than 4° at L = 1604 mm. The average temperature rises of the cooling water were 2.2°C at L = 1374 mm and 1.1°C at L = 1604 mm. Calculated power losses using these values are 0.18 dB and 0.09 dB, respectively. The temperature difference along the 4 mm ferrite thickness is estimated to be 6.1°C and 3.0°C, respectively. The different behaviors of the phase deviation between the two short conditions are considered partly because of this temperature difference.

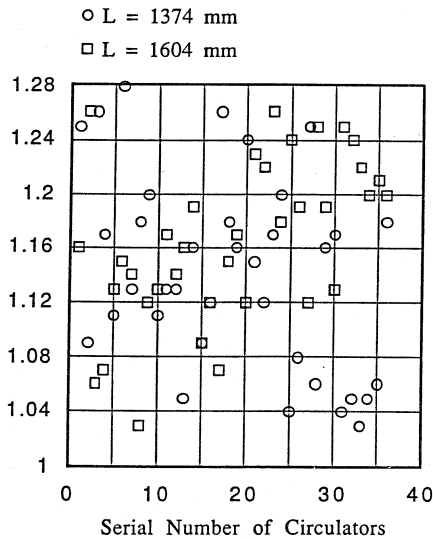


Fig. 4 VSWR at 150 kW

Conclusion

Thirty-six circulators were constructed for the RF system of the superconducting cavities. They showed the power handling capability of up to 150 kW and the sufficiently small phase deviation, even when the output port is shorted. Sixteen of them were installed in summer of 1988, and other sixteen in this summer. Since then, they have been in operation without any trouble.

References

- 1) F. Okada and K. Ohwi, IEEE Trans. Microwave Theory Tech., vol. MTT-26, pp. 364-369, May 1978
- 2) S. Tokumoto, private communication
- 3) A patent of Nihon Koshuha Co., Ltd., PAT. 57-43363

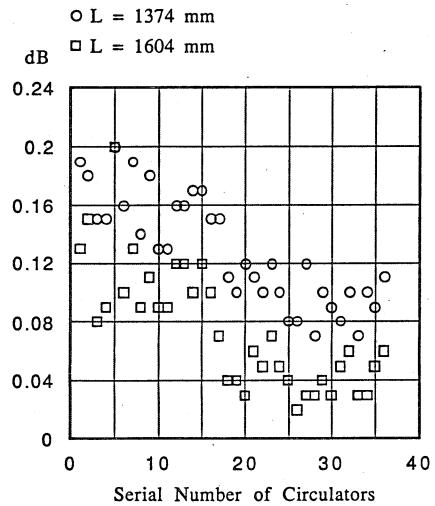


Fig. 5 Insertion loss at 150 kW

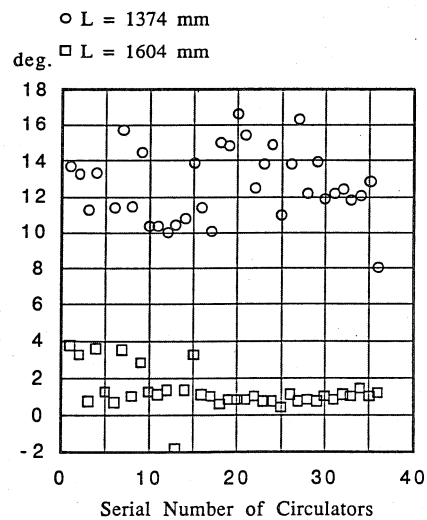


Fig. 6 Phase deviation at 150 kW