HIGH POWER ISOLATOR FOR THE KEK PROTON LINAC

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Summary

A high power 200-MHz isolator was developed at the KEK proton linac in order to reduce coupling interaction between the linac tank and the amplifier and to ease the operational tuning of the linac. The isolator consists of a ferrite-loaded circulator with three coaxial ports and a high power rf dummy load. The operational rf peak power is more than 2 MW and the VSWR, the isolation and the insertion loss are 1.2:1, 20 dB and 0.5 dB, respectively. The operational performance of the linac using the isolator is also described.

Introduction

As pulsed rf power is fed into a high-Q accelerator cavity, some rf power is always reflected back towards the generator during the transient phase while the rf field is building up in the tank. Also, when accelerating a high intensity beam, a considerable reflection occurs due to the resistive and reactive loading effect of the beam on the cavity matching and tuning. In order to compensate for beam loading effects, the cavity is usually detuned and over-coupled, which then results in further reflection after the buildup time until the beam is injected.

Such reflected power is returned to the generator where it is dissipated, but because the generator voltage-current relation is disturbed, the output power is reduced, as may be seen in the Rieke diagram. Not only is the output power reduced, but the wave shape is also distorted.

At the KEK proton linac, the single accelerator tank is excited by two rf amplifiers (TH516-I,II) which affect each other, since they are closely coupled through the tank. For example, if the output power from the first amplifier is changed, the reflected power to the second amplifier is also changed, and just as though its own load impedance had changed, the second amplifier accordingly also changes its output power. Therefore, operating adjustments become complicated since this kind of phenomenon frequently occurs and straightforward non-interactive adjustment is impossible.

For a long time, a means was sought that would isolate the amplifiers from the load. Figure 1 shows the amplifier (TH516-II) and tank rf field before the introduction of such an isolator. Due to the influence of the reflected power, the rising edge of the output power is rounded, lengthening the buildup time for the tank field.

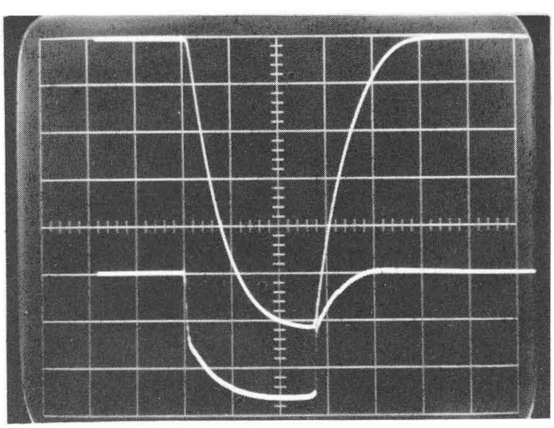


Fig. 1 Upper: rf level in the tank
Lower: TH516-II rf output power
Horizontal: 100 μsec/div

Isolator Structure and Characteristics

The design parameters for the isolator are shown in Table I. Basically, it is a Y-junction type circulator (see Fig. 2,3); the inner conductor is sandwiched top and bottom by five ferrite disks and a permanent magnet for the external magnetic field. The coaxial ports are of 203 mm diameter. A tube for cooling water is soldered around the circumference of the inner conductor and both ends of the tube are brought out at the $\lambda/4$ position, where they are electrically shorted.

In order to raise the breakdown voltage, the entire assembly is immersed in oil. In the original design, the inside was filled with SF_6 for better high voltage performance. However, after about one month of operation, discharges occurred at the circumference of the ferrite disks breaking them. After that the design was changed to oil immersion. This necessitated the insertion of compensating rings on each of the inner conductors of the three coaxial ports to allow matching. It was feared that the insertion loss would become larger because the oil used was not a special type for high frequency use, but tests at low power levels could detect no increase in loss.

Table I

Summary of isolator specifications

Frequency		201 MHz
Power rating	(peak)	2 MW
	(average)	10 kW
Isolation		20 dB
Insertion loss		0.5 dB
VSWR		1.2:1
Insulation		oil immersion
Cooling		water
Connector		WX-203D

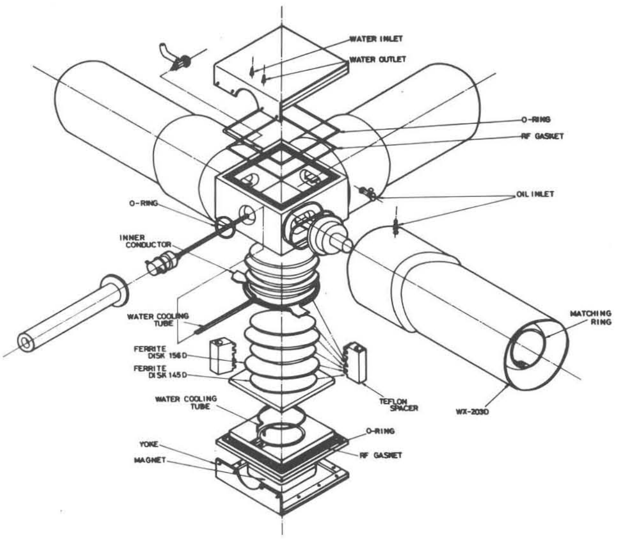


Fig.2 Circulator assembly drawing

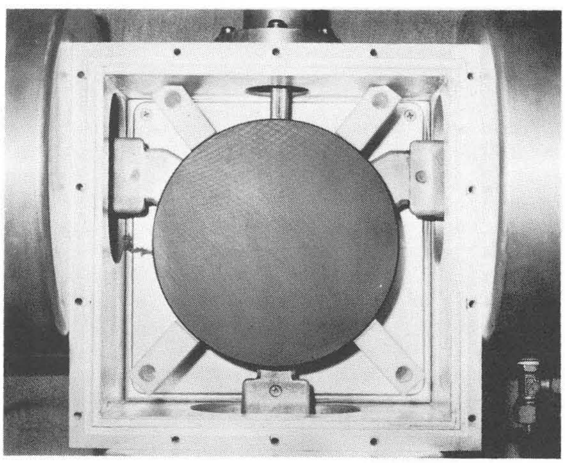


Fig.3 Circulator inside view

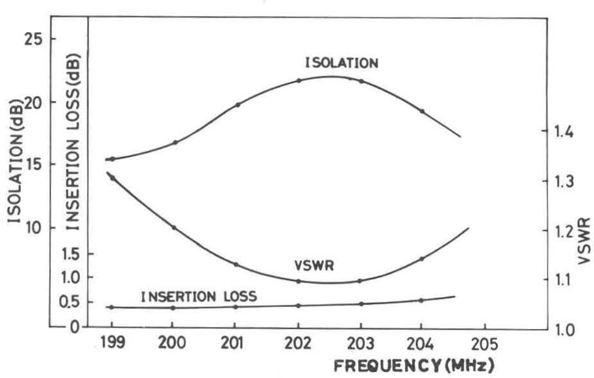


Fig.4 Isolator characteristics

The results of measurements are shown in Fig. 4. At 201 MHz, a VSWR of 1.2:1, insertion loss of 0.5 dB and isolation of 20 dB were obtained. These values measured, with oil immersion, were degraded from the 1.1:1 VSWR, < 0.5 dB insertion loss and > 25 dB isolation obtained with SF_6.

High Power Test

High power measurements were performed with the setup shown in Fig. 5. Since a testbench was still under construction, the measurements were made on the actual proton linac. Since this had to be done during the brief periods when the accelerator was shut down, there was no time to make corrections or to calibrate the rf monitor system.

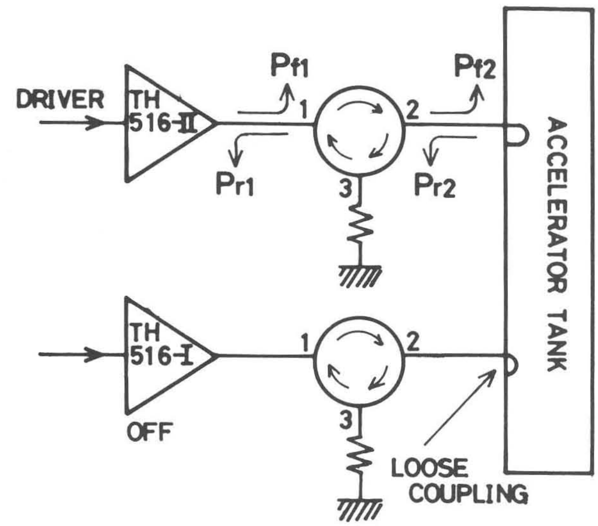


Fig. 5 High power test setup

In Fig. 5, Pf1/Pr1 and Pf2/Pr2 stand for the forward and reflected power of the respective circulator ports. The reflections at each port and from the dummy load also enter into it, but Pf2/Pf1 is related to the insertion loss and Pr1/Pr2 is related to the isolation. During the measurements, Pf1 was approximately 1 MW; the other amplifier (TH516-I) had only the heater on and its tank coupling was made as loose as possible.

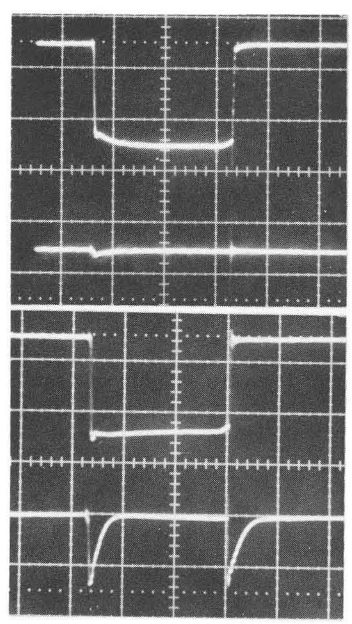


Fig.6 Forward and reflected power wave forms

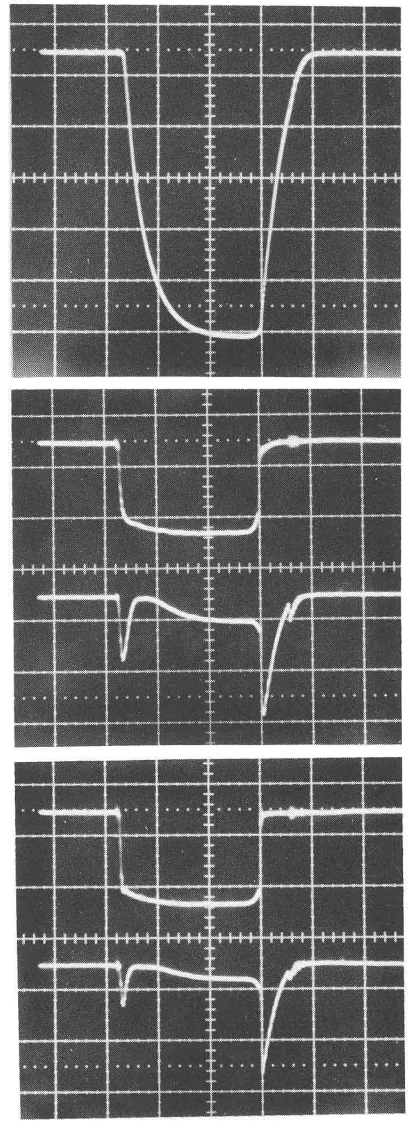
Figure 6 shows the Pf1/Pr1 and Pf2/Pr2 wave shapes. Without correction, their respective scalings may be in error by as much as 10%. Since only relative measurements were made, insertion loss could not be calculated. However, from the circulator surface temperature rise of about 1°C, with an average power of 6 kW, it is clear that insertion loss will not be a problem in normal operation. Also, it is thought that the isolation should be the same as in the low level tests.

Operational Performance

The most important result of installing the isolators between the amplifiers and the tank (see Fig. 7), is that it is easy to tune and adjust each component. Even when using dual feed, each amplifier can be tuned to optimum performance by simply tuning to increase the output power to its maximum value. Likewise for the tuning of the load side. Because the output power of each amplifier is stable and the wave shape is square, no matter what the load condition is, the various tuning adjustments are no longer interactive and each one has a clear and independent effect. For example, before using the isolators, the rf frequency of minimum reflected power did not coincide with the frequency of maximum rf level in the tank. With the isolator, the frequency of minimum reflected power and the frequency of maximum tank rf level are the same.

The only case in which interaction is still observed is when adjusting the tank coupling. Because of the dual-feed, it is necessary to bring the output power of each amplifier to an appropriate level, otherwise the reflected power into each amplifier will be different and this will affect the coupling.

The result of this improvement is seen in Fig. 8, which shows the detected waveforms after tuning. Since the forward power from each amplifier is almost square, the tank rf level buildup time is shortened considerably compared with Fig. 1. Furthermore, improved amplifier tuning increased the maximum power out of each amplifier by about 20%.



Tank rf level

TH516-I

← forward power

← reflected power

TH516-II

← forward power

← reflected power

Fig. 8 Waveforms using isolators

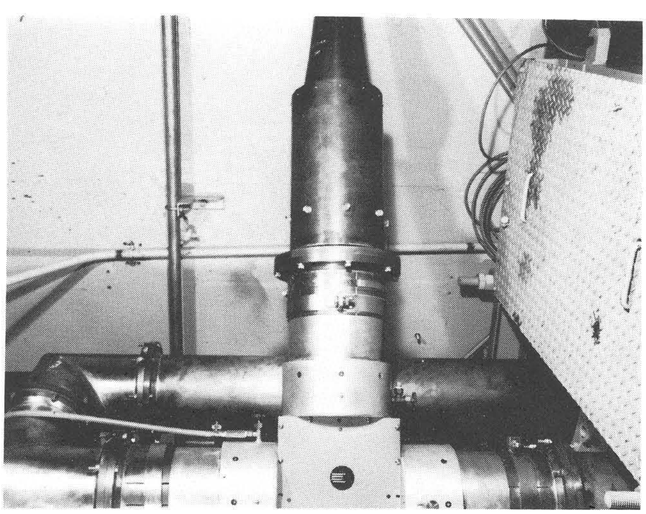


Fig.7 Isolator installation