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HIGHER ORDER MODE DAMPER WITH SELF-COOLED COUPLER

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Abstract A higher order mode damper was developed for the suppression of beam instability in the TRISTAN accelerator. Installed in a 9-cell structure cavity of the main ring, the damper, as designed, lowered the Q factor of TM111 mode to less than a third of its intrinsic value and those of TM011 and TM021 modes roughly to half. In the case of an 11-cell structure cavity of the accumulation ring equipped with one damper in each cell, the Q factor of the TM111 mode was reduced by more than an order of magnitude while the other modes were so drastically damped that they could hardly be measured. Experiments indicated that the damper appreciably suppressed beam instabilities caused by these modes and improved beam performance. The internal coupling antenna made of heat pipe cooled itself efficiently against induction heating in the cavity.

INTRODUCTION

The beam acceleration is performed by 508 MHz accelerating cavity tanks of an alternating periodic structure, both in the accumulation ring (AR) and in the main ring (MR) of the TRISTAN at KEK, National Laboratory for High Energy Physics. It was known that higher order modes such as TM110 (794 MHz), TM011 (866 MHz), TM111 (1045 MHz) and TM021 (1387 MHz) have significant coupling impedances (Table) and are therefore responsible for undesirable large interactions with beam. In particular the early study on instabilities concluded that the transverse impedance of the TM111 mode must be reduced at least to half for storing a beam current of more than 20 mA in the MR.[1] Furthermore there were experimental proposals requesting a more stable higher current operation of the AR. With this background a higher order mode damper was designed in order to reduce the impedances of these higher order modes except the

TABLE Higher order modes in an 11-cell structure accelerating cavity of the TRISTAN AR. Longitudinal and transverse modes are listed up to 1500 MHz in the upper rows and in the lower rows, respectively. Impedances were calculated with the code URMEL.

Mode	Frequency	Impedance	Q factor measured		
	in MHz	in MΩ/cavity	No damper	2 dampers	12 dampers
TM011	866	9.4	27000	<16000	-
TM020	1164	1.7			
TM021	1387	8.3	35000	<18000	-
TM012	1463	1.3			
	in MHz	in MΩ/ m·cavity	No damper	2 dampers	12 dampers
TE111	762	15			
TM110	794	77	30000	←	←
TM111	1045	140	17000	3200	1500
TE121	1268	5.4			
TE112	1318	26			
TM120	1419	12			

TM110 mode. The TM110 mode was to be left undamped because of a difficulty in its selective coupling separately from the TM010 accelerating mode.

STRUCTURE

The damper is composed of a coupler with an internal antenna, an external load resistor and a power transmission line between them. The feature is to be self-cooled. The whole system works without any driving power or any maintenance in its cooling.

Coupler

It consists of a rod-shaped coupling antenna, a coaxial transmission system with a kind of accelerating mode rejector, a power extraction terminal and a cooling device for the antenna head (Figure 1). The coupler was to be mounted in a cavity with its antenna pointing at the beam axis. The length of the antenna was chosen to obtain a loaded Q factor of the TM111 mode below a third of its intrinsic value with little influence on the accelerating mode. A certain damping of the TM011 and TM021 modes was also intended. The antenna was followed by a WX-20D equivalent coaxial line with a short-circuited branch. The extraction terminal was built in a T shape perpendicularly to the branch line. The position and the length of the branch line were so fixed as to pass the higher order modes but to impede the accelerating mode. The terminal was equipped with a BFX-20D connector and a specially developed vacuum-tight feedthrough. A brazed alumina disc window supported the coaxial structure and sealed it up hermetically. The matching at the feedthrough was better than 1.05 in VSWR over a wide frequency range from 0 to 2.3 GHz. The antenna and the inner conductor of the coaxial structure were a single straight heat pipe leading to the external cooling fins. When the antenna head is heated, the heat pipe automatically begins to transfer heat efficiently to the fins with an effective thermal conductivity hundreds times as large as that of metal. The more heated, the more efficiently. This

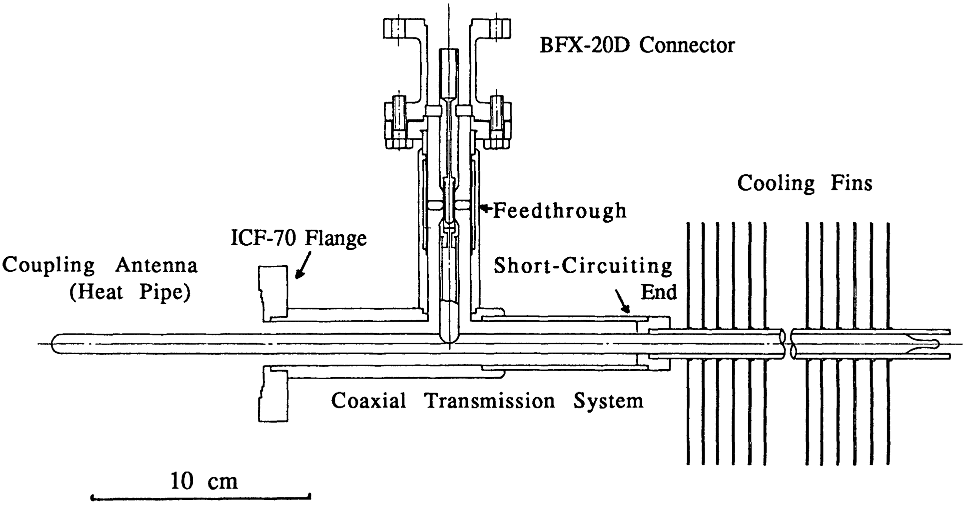


FIGURE 1 Self-cooled coupler

auto-cooling system was supposed to keep the temperature rise of the antenna below 60 K against a heat generation of 100 W. Metallic parts of the coupler, except copper-plated Kovar coaxial pipes of the feedthrough, were made of oxygen-free copper because of its high electric conductivity and low outgas in vacuum. They were brazed in a vacuum furnace.

Load Resistor

The load resistor requires broad-band impedance matching for the widely distributed higher order modes and high cooling performance against the worst possible heat generation of hundreds of W in the MR or of a few kW in the AR. The resistive absorber was a metal film evaporated on a backing plate of beryllia, a highly thermo-conductive ceramic comparable to metal. The beryllia plate was mounted closely in a thick copper (an AR 2 kW model) or aluminium (an MR 500 W model) casing working as a matched terminator and also as a heat sink, where finned copper heat pipes were planted to remove heat to the atmosphere (Figure 2). The slope of the heat pipes, the size and the number of the fins were optimized in order to keep the temperature rise within 90 K at the rated input power. Commonly available resistors with an equal performance are more than two times heavier. The use of heat pipes enabled an efficient maintenance-free natural cooling and a substantial weight reduction. The resistor was well-matched with a VSWR better than 1.1 over a broad frequency range up to 2 GHz.

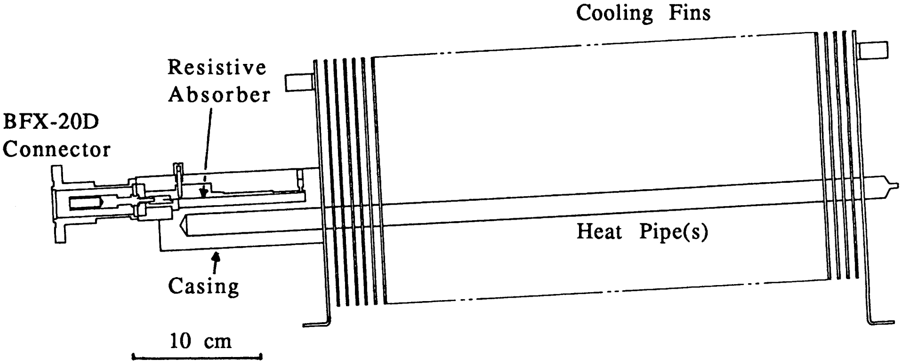


FIGURE 2 Load resistor

Transmission Cable

A bendable coaxial cable equivalent to the WX-20D was used with rotatable BFX-20D connectors. Normal insulators of Teflon and silicon rubber were replaced by radiation-resistant materials such as polyethylene and urethane rubber at a little cost of heat resistance.

CHARACTERISTICS AND PERFORMANCE

As is known from the power distribution among cavity cells, the damper was the most effective for the TM111 mode damping when it was in the center cell. At first only 2

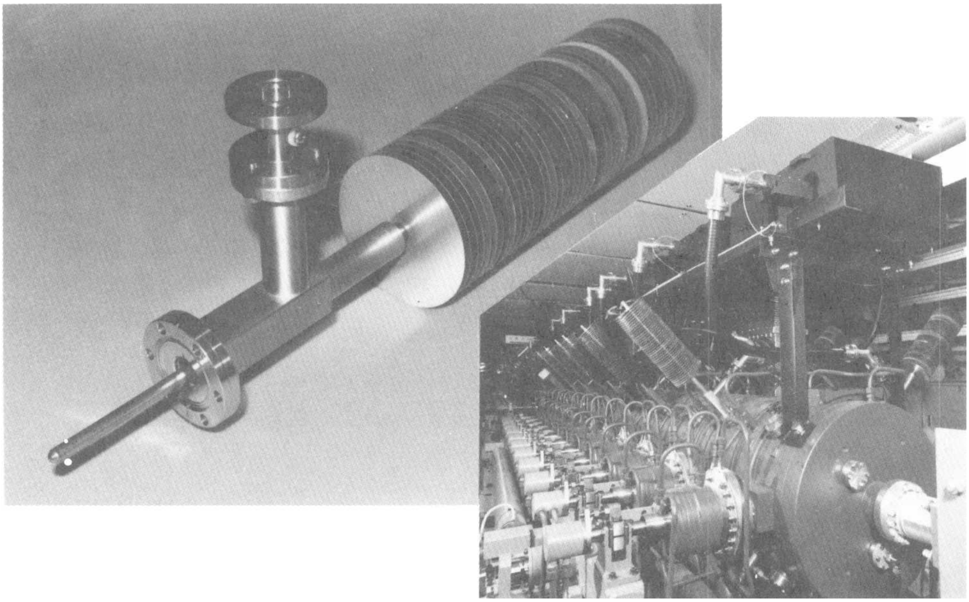


PHOTO Higher order mode dampers on AR accelerating tanks (right). Round-finned couplers (left) are mounted aslant on accelerating cavity tanks and are connected to square-finned load resistors arranged above.

dampers were mounted on each accelerating tank in the AR as well as in the MR. Then the AR dampers were reinforced both in capacity (of load resistors) and in quantity at the request of a high current operation. At present there are 12 dampers installed in every 11-cell structure tank of the AR, 2 for the center cell and 1 for each of the other 10 cells (Photo). Each 9-cell structure tank of the MR has 2 dampers in its center cell.

Fundamental High-Frequency Characteristics

The pass band of the coupler was centered at 1 GHz as designed, around which the higher order modes concerned are situated. The coupler, installed in a cavity tank,drew out a minute leakage of -55 dB of the input 508 MHz driving power. The insertion of the coupler raised the resonant frequency of the cavity in the accelerating mode only by 2 kHz, which is easily compensated by the tuners.

Cooling Performance

An input power of 150 kW to an 11-cell structure tank brought about a temperature rise of 13 K at the fin base of the coupler. On the basis of a thermal calibration by simulation heating (Figure 3 left) the temperature rise and the heat generation at the antenna head is estimated to be respectively 20 K and 25 W. The antenna would be heated up by 250 K if it were a solid copper rod instead of a heat pipe. Since the heat at the antenna head is proportional to the cavity input power, the coupler is expected to work even in a 600 kW cavity operation.

An average heat generated in the load resistor supposed to increase in proportion to a square of beam current. Actually the temperature rise of the resistor casing was 10 K at a current of 45 mA and 20 K at 60 mA in the AR. According to the calibration data of temperature rise versus input power a beam current of 45 mA induced 100 W in the

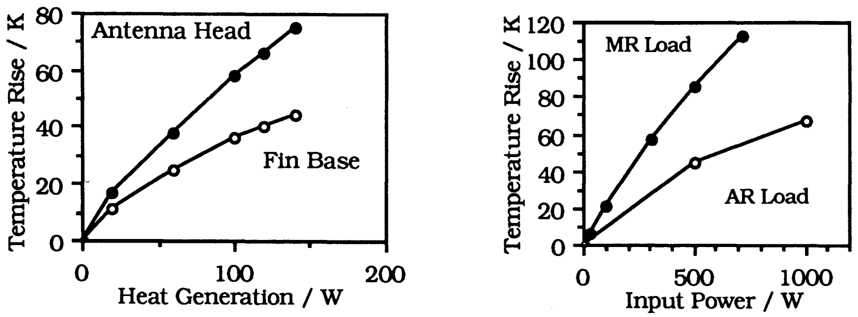


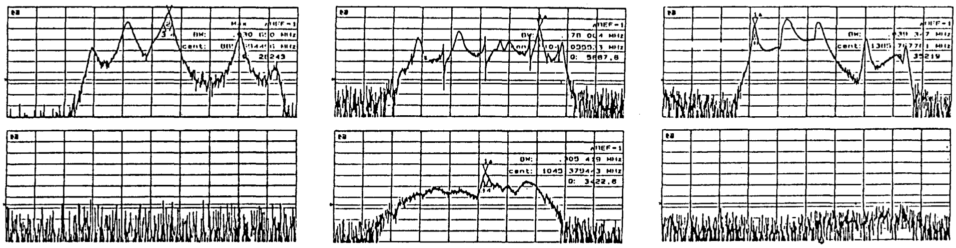
FIGURE 3 Thermal characteristics of coupler (left) and load resistors (right).

resistor and that of 60 mA 200 W (Figure 3 right). The AR load resistor will work even in a 200 mA operation. In the usual MR operation of 8 mA only 5 K rise was observed against an induced heat of 30 W. The allowable beam current for the MR load resistor attains 30 mA, which is beyond the design value of 20 mA.

Damping of Higher Order Modes

When one damper was installed in the center cell of an MR cavity tank, the Q factor of the TM111 mode was decreased below a third of the intrinsic value and those of the TM011 and TM021 modes were also reduced to half . In the case of two dampers the TM111 mode Q factor dropped further to less than a fifth (Table).

Figure 4 shows the comparison between the damping effects of 2 dampers in the center cell and of 12 dampers distributed among all the cells of an AR 11-cell structure cavity tank. The TM011 and TM021 modes were so thoroughly damped in an AR cavity tank furnished with additional 10 dampers that their resonances were hardly detected. The TM111 mode Q factor was also lowered by more than an order of magnitude.



TM011 center: 865.5 MHz span: 1 MHz

TM111 center: 1045 MHz span: 15 MHz

TM021 center: 1386.5 MHz span: 4 MHz

FIGURE 4 Reduction in Q factor of an AR 11-cell structure tank with 2 dampers (upper) and with 12 dampers (lower). Horizontal axes denote frequency and vertical ones relative amplitude.

Suppression of Instabilities

The effect of the damper was investigated in the AR on the instabilities by the TM111 mode in comparison with those by the TM110 mode which was not damped. Initially the former had nearly twice the impedance of the latter (Table). The growth rate is proportional both to the impedance and to the stored current. The threshold current, which balances the growth rate with the damping rate, was observed at cavity resonant frequencies in these modes (Figure 5). The cavity was tuned in to those frequencies by means of the tuners. The current was over 20 mA at resonances of the TM111 mode whereas a few mA at those of the TM110 mode. The instability due to the TM111 mode was considerably suppressed. The measurement of the current dependence of damping rate indicates that its impedance is roughly a tenth of that of the TM110 mode, and therefore, at most a twentieth of the intrinsic value of the TM111 mode. This is in agreement with the result of the Q factor measurement. Spectrum analysis of beam-induced resonant modes in cavity tanks also showed that instabilities caused by the TM011 and TM021 modes were no longer present.

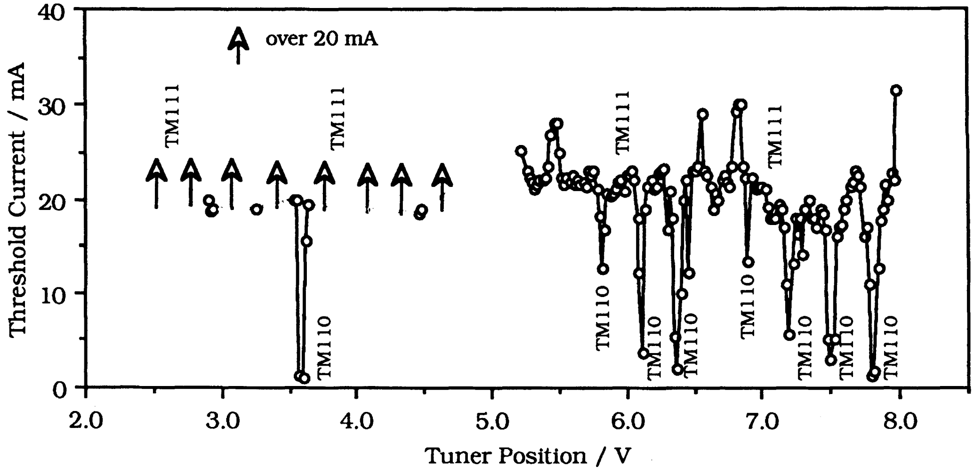


FIGURE 5 Threshold current of instability. Resonant frequencies were varied by cavity tuners. Instabilities due to TM110 mode are still present but not those due to TM111 mode.

CONCLUSION

A maintenance-free self-cooled damper was developed and installed in the TRISTAN accelerating cavity tanks. The TM111, TM011 and TM021 modes were damped and the induced instabilities were suppressed. A simple built-in auto-cooling system proved to work effectively.

ACKNOWLEDGEMENT

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1 T. Higo et al., KEK internal report (1985)