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題目(TITLE) MULTI-CAVITY BRIDGE COUPLER

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概要(ABSTRACT)

A multi-cavity bridge coupler was designed for power feed to coupled-cavity accelerating tanks of the Japanese Hadron Project linac. A high power model of the coupler, together with a pair of accelerating tanks, was fabricated and was successfully conditioned up to a rated power of 300 kW.

KEY WORDS: Ion Source, RFQ, DTL, CCL, Magnet, Monitor, Beam Dynamics, Transport, Vacuum, Cooling, Klystron, Low Level RF, High Power RF, Modulator, Control, Operation, Radiation, Others

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MULTI-CAVITY BRIDGE COUPLER

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Abstract

A multi-cavity bridge coupler was designed for power feed to coupled-cavity accelerating tanks of the Japanese Hadron Project linac. A high power model of the coupler, together with a pair of accelerating tanks, was fabricated and was successfully conditioned up to a rated power of 300 kW.

Bridging of Accelerating Structures

The final accelerating section of the Japanese Hadron Project (JHP) linac[1] is planned to consist of newly developed 1296 MHz annular coupled structure (ACS) cavity tanks[2] with focusing magnets in between. A bridge coupler is a useful device for power feed and transfer among such a train of accelerating tanks. It is composed of a pair of coupling cavities side-coupled to two adjacent accelerating tanks and a bridging cavity also side-coupled to the coupling cavities, looking as if it were a bridge over the magnets. Power is fed through a vacuum-tight WR-650 waveguide window into a bridge coupler and transferred to a train of accelerating tanks coupled with bridge couplers. The bridging method not only saves microwave circuit parts but also promises automatic phase matching and conserves the symmetry of the accelerating fields. A power source and a group of accelerating tanks are connected by a single branchless waveguide system. The couplers and the accelerating structures make a π/2-mode coupled-resonator chain and keep a consecutive phase relation. The accelerating cavity is free from field deformation due to a large input coupling geometry which is in charge of the bridge coupler.

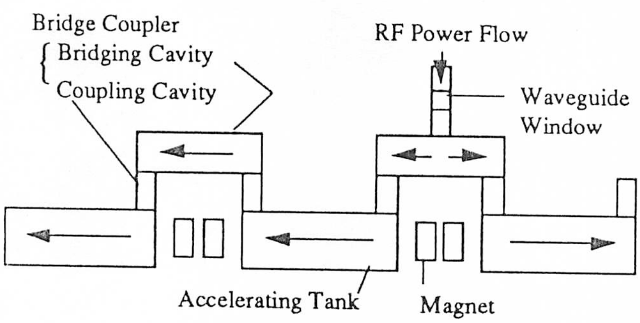

Fig. 1 Bridged accelerating tank chain

Design

The original example of the bridge coupler is found in the LAMPF coupled-cavity linac, where a long cylindrical single cavity was used as the bridging cavity and operated in the TM_{010} mode. Firstly the feasibility of a higher-order mode, for example the TM_{012} mode, operation for higher stability was investigated on this simplest structure. A simulation of the bridge coupler by the code MAFIA was attempted but led to the conclusion that a stable and controllable operation of this conventional bridging cavity cannot be expected in any mode because of a modal mixing with the neighboring modes[3]. The eigenmodes in such a long cavity are degenerately close in frequency (Fig.2) and the presence of the coupling to another cavity (like the coupling cavity) easily induces modal coupling resulting in complicated field patterns of mixed modes (Fig.3). The modal mixing is suppressed by bored disks partioning the bridging cavity into cells. A similar structure was already applied[4] for another purpose in order to ensure a stable operation by the TM010 π/2 mode with a large inter-cell coupling.

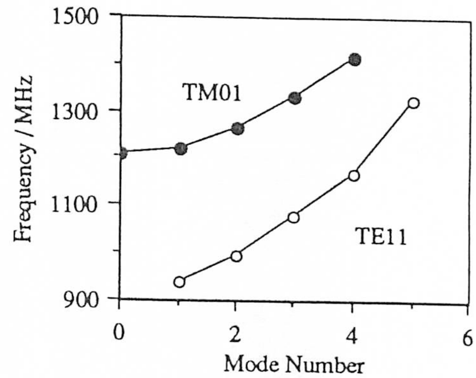

Fig. 2 Modes in a long cylindrical cavity with the diameter 19 cm and the axial length 80 cm.

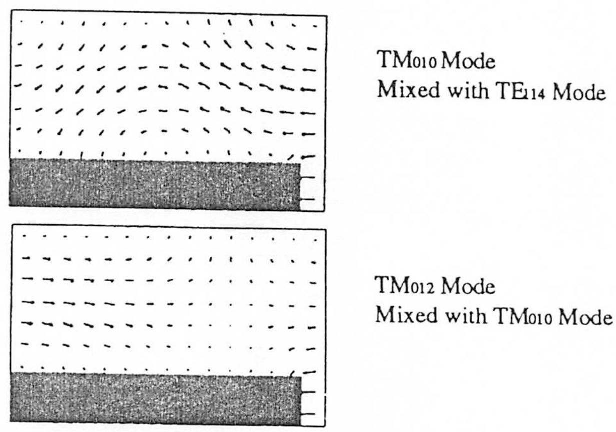

Fig. 3 Electric fields simulated with a half geometry of a single cavity bridge coupler under the electric short condition on the center symmetric plane. The actual system shows a more confusing pattern because of additional mixing with even modes such as TM_{011}, TM_{013}, TE_{115} which appear under the open condition.

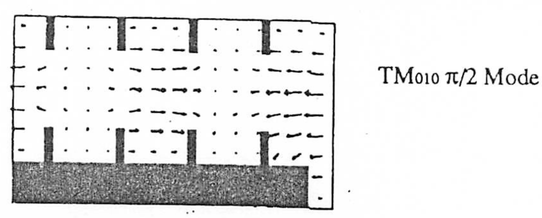

Fig. 4 Electric fields in a multi-cavity bridge coupler free f rom modal mixing. The bridging cavity is divided into short subcavities (cells).

The bridge coupler for the JHP was designed in this multi-cavity structure on the following principles.

1) The operation mode is separated far from the other modes in frequency, being free from mixing with any other mode.
2) The inter-cell coupling is strong enough to gain a large group velocity for stabilization.
3) The power loss in the bridge coupler is possibly small.
4) The frequency shift arising from dimensional error in design and fabrication and also from thermal deformation during operation is compensated by a tuning system.

The cavity radius is roughly determined (~ 9.3 cm) from the driving frequency although modified by the disk loading condition. A short disk spacing less than the radius gives a sufficient mode separation better than a frequency ratio of 1.5 (Fig. 5). The disk spacing was chosen to be 8 cm. A large disk bore makes a large inter-cell coupling but too large a bore allows a modal mixing again. The upper limit of the bore radius is about 55 % of the cavity radius, that is 5 cm, and the corresponding coupling coefficient amounts to 12 % (Fig. 6). The power loss in the bridging cavity is reduced with its large coupling coefficient to the coupling cavity compared with that of the accelerating

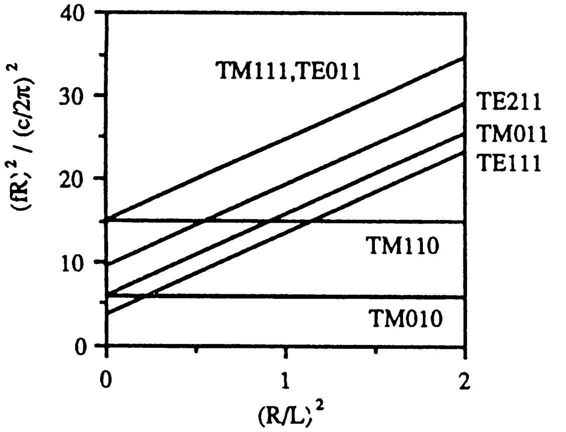

Fig. 5 Dependence of mode separation on cavity shape. Eigenmodes in a cylindrical cavity with the radius R and the length L are presented.

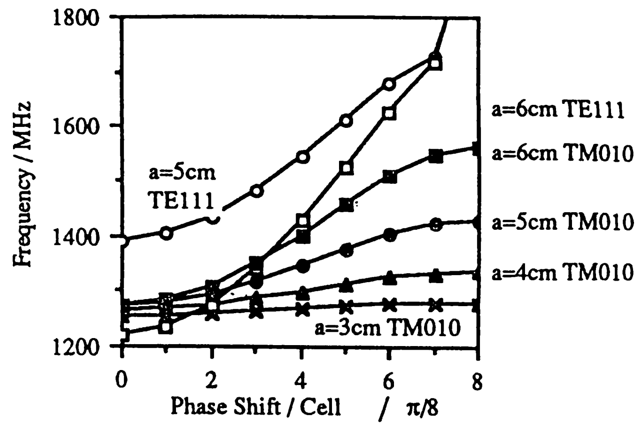

Fig. 6 Dependence of dispersion on disk bore radius a of an 8-cell cylindrical cavity with the radius 9.25 cm, the length 80 cm, and the disk thickness 1 cm.

cavity. Assuming the equivalence of a bridging cavity cell and an accelerating cavity the ratio of their stored energy is the inverse square ratio of their coupling coefficients to the coupling cavity. The ratio of coupling coefficients was set 2 : 1 and thus the ratio of power 1 : 4. Since the number of excited cavities is 3 for the bridge coupler and 10 for the ACS tanks, input power is shared between them in the ratio 3 : 43. For the present purpose of an off-beam experiment the waveguide should be in the critical coupling with the bridge coupler and ACS tank system, namely, the coupling factor is unity. The coupling factor to the bridge coupler alone should be 43/3 on the above assumption. The required iris radius was calculated at 6.5 cm on the basis of the preparatory experiment. The largest available tuning plungers 5 cm in diameter were prepared in order to acquire the widest possible tunable range. The tuner covers a frequency range of at least 20 MHz for the bridging cavity alone and 1.4 MHz for the total system. The coupling cavities were also equipped with tuners for adjustment.

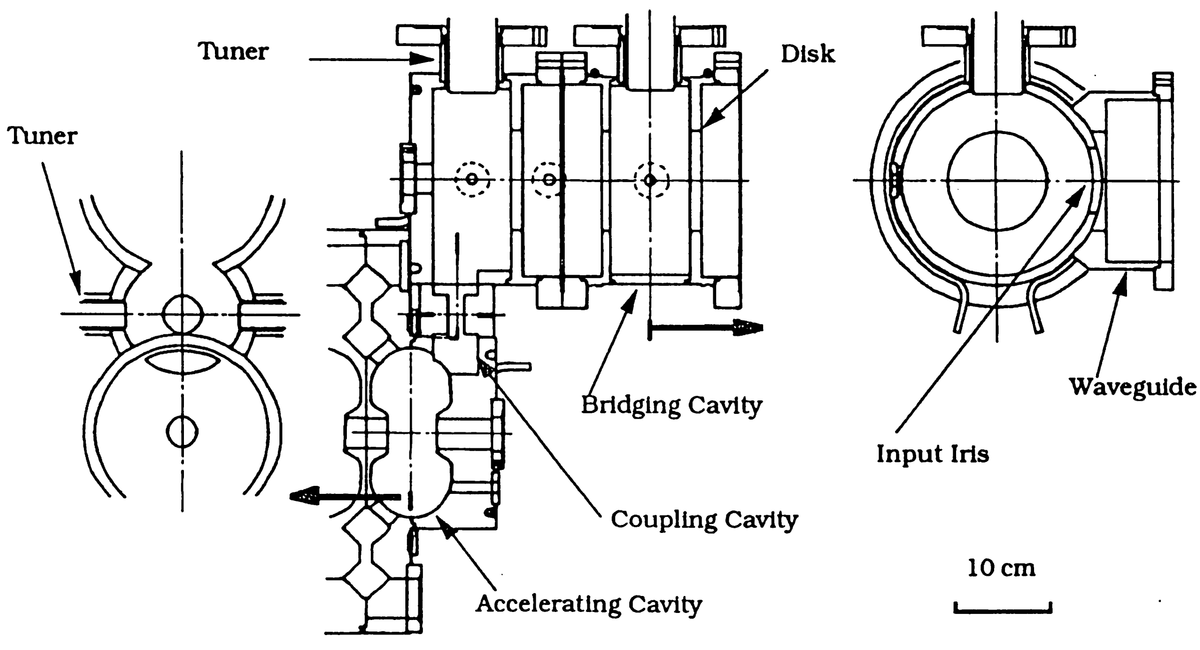

Fig.7 RF Structure of bridge coupler with 5-cell structure bridging cavity.

The designed values characterizing the RF structure are as follows.

Component Cavity Frequency	1296 MHz ± 5 MHz
Intra-Bridging Cavity Coupling Coefficient	12 %
Bridging-Coupling Cavity Coupling Coefficient	11 %
Coupling-Accelerating Cavity Coupling Coefficient	5.5 %
Input Coupling Factor	1.0 ± 0.1

The slightly loose allowance covers the difficulty in defining the frequencies of the mutually side-coupled cavities. Such a strongly coupled non-periodic asymmetric cavity structure lacks well-defined electromagnetic boundaries, which gives rise to the ambiguity in frequency. On the other hand the large coupling also allows a considerable tolerance. The cavity dimensions were determined from the computation with the codes SUPERFISH and MAFIA. The essential part of RF structure of the test 5-cell coupler is presented in Fig. 7.

The bridge coupler was divided into 3 sections by center planes of the 2 unexcited cells. Both end sections are joined to ACS tanks. They were connected with double-bite vacuum-sealing and RF-contacting flanges. The heat generation in the bridge coupler is quite small, which is less than that in an accelerating cavity of the ACS tank. It is enough to cool the periphery of each disk by a single turn of cooling tube. The parts were cut out of specially processed high-grade oxygen-free copper and precisely finished. They were brazed in a vacuum furnace with gold and silver filling alloys. Details are described elsewhere[5]. Photo shows the assembled whole system of bridge coupler and accelerating tanks.

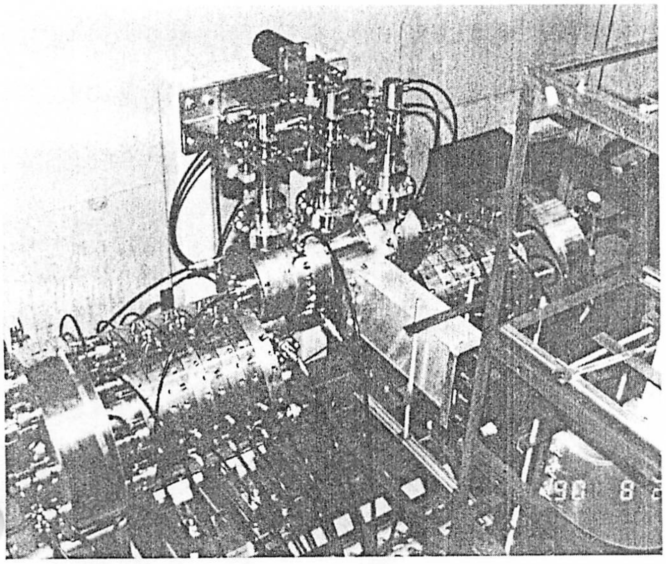

PHOTO Assembled bridge coupler and accelerating tank system

Measurement and Tuning

During and after fabrication the frequency of each component cavity was measured to tune to its design values. The detuning plunger method was applied to the frequency measurement. The frequency of the component cavity was measured detuning the neighboring cavities by conductive plungers with some correction based on computer simulation. The acquired frequencies agreed within the allowance and the coupling coefficients differed by no more than a few percent. The tuner effect on frequency shift was reduced to 7.1% when the ACS tanks were coupled. Accordingly the bridge coupler and ACS tanks share power in the ratio 7 : 93 almost equal to the ratio 3 : 43 estimated previously, which justifies the assumption that a cell of the bridging cavity is almost equivalent to an accelerating cavity. The dispersion relation of the bridging cavity is shown in Fig. 8. The theoretical dispersion equation was fitted to the data, yielding a coupling coefficient of 11.8 % in agreement with the designed and the separately measured values. The coupling factor of wave guide to the whole cavity system was measured to be 0.99 and the quality factor of the system was 9.9×10^3 when the system was tuned to the driving frequency by the tuners under the operation condition. The unloaded quality factor is, therefore, 2.0×10^4, which is consistent with the quality factor 1.5×10^3 of the bridge coupler itself loaded with the waveguide accounting the above power sharing ratio.

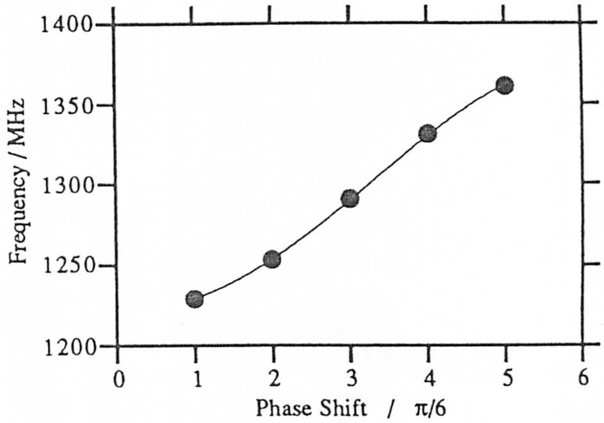

Fig. 8 Dispersion of the 5-cell bridging cavity with a fitted curve.

Power Test

The bridge coupler and ACS tank system was mounted in a test bench surrounded by a radiation-shield. It was equipped with evacuation pumps and a cooling system, and was linked to the waveguide from a klystron. Turbomolecular pumps evacuated the cavity system to an ultimate pressure of 1×10^{-7} Torr. The temperature was set 25.4 °C and controlled within ± 0.1 °C by a refrigerator-aided water circulation cooling system. The cavity system was driven by pulsed 1296 MHz RF power with a 200 μs width and a 10 Hz repetition and was conditioned up to 300 kW in about 10 hours. Frequent breakdown took place at 10 kW and 170 kW. Both cases were accompanied with rapid rise in pressure. They are assumed to be due to local discharge. Particularly in the latter case lightning was observed in the waveguide between the RF window and the input iris from the viewing window. There was nothing wrong elsewhere. The result is encouraging.

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