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R&D OF CHOKE MODE CAVITY

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Abstract

Multi-bunch beam operation is essential to obtain high luminosity for future linear colliders. The Shintake type choke mode structure was proposed to eliminate the multi-bunch instability problem by damping the higher-order-modes (HOMs) in the cavity. In 1994 the first model of this structure was made at S-band frequency and tested with beam at 50 MV/m driven by 100 MW of input rf power. It was demonstrated that this structure has sufficiently high power performance for practical applications.

A re-design of the structure for C-band (5712 MHz) frequencies was begun in 1996 as a candidate for the main linac for the linear collider [1]. R&D studies are ongoing which aim to braze a SiC-ceramic onto the structure with small deformation, using a low temperature brazing technique. Recently both button shaped (D: ø2.4-cm, t: 1-cm) and ring shaped (ID: ø9.6-cm, OD: ø11.6-cm, t: 1-cm) SiC-ceramic HOM absorbers were successfully joined to the copper base plate for a C-band structure.

1. INTRODUCTION

The Linear Collider-1 (LC1) project, which is proposed for the next generation of high energy physics research, requires collision energies in the 0.5 to 1 TeV region. Multi-bunch beam operation will be essential to obtain the high luminosity needed for physics experiments. It is also very important to accelerate a low emittance beam in the main linac to achieve a nano-meter size beam at collision point. However, this is not easy because of the wake field power that accumulates in the structure.

Thus, R&D on HOM-free structures is one of the most important issues for realization of the linear collider. From the beginning there have been some ideas for HOM-free structures. However, they were not realistic; having very complicated structures and not being suitable for mass production at a reasonable cost.

In 1992 T. Shintake proposed a simple HOM-free accelerating structure which combines a choke mode cavity with rf absorbers. A high power model 0.5 m long was made at S-band (2856 MHz), and beam tested at KEK (July 1994) to confirm the performance [2]. The test was very successful, and the beam was accelerated with an energy gain of 26 MeV at an accelerating gradient of 52 MV/m. The main purpose of the first experiment was to confirm the high power performance of the novel structure, and it was very successful at that. At that time the structure was not implemented with HOM absorbers.

The next step of the R&D program was started in 1995. Both an original and a modified C-band (5712 MHz) high power choke mode type HOM-free structure are now under development. The modified structure is to avoid the need for providing a separate vacuum chamber, and to introduce an in-line type rf dummy load which will be installed on a few of the end cells.

SiC-ceramic is one of the best materials for a microwave absorber and has been adopted for the high power dummy load at the KEK-PF linac and the ATF injector [3]. SiC-ceramic will be used as the HOM absorber, and also for the in-line dummy load, which will be put in the last few cells to terminate the rf power.

This paper will describe the details of the choke structure and its fabrication problems.

2. CHOKE MODE CAVITY CONCEPT

One of the best solutions to damp the wake field excited by an intense beam in an rf-structure is to allow the wake field to exit out of the cavity [4]. In the choke mode cavity this is done by making a cut in the cavity wall, which connects to a parallel plate radial line with a good rf absorber at the end of line. The structure does not have a cutoff frequency from DC to high frequency. Thus the wake field power at all frequencies propagates very smoothly out to the rf absorbers.

However, if only this is done the accelerating mode also propagates out and is dumped into the rf loads. Thus, it is necessary to cut off the accelerating mode; this can be done by inserting a simple choke cavity between the accelerating cavity and the rf absorber. The choke cavity has a very simple groove shape and surrounds the accelerating cavity as shown in Figure 1. From the manufacturing point of view, the choke mode type HOM-free cavity has a great advantage over any slot type of the HOM-free (or damped) structures. Also, there should be no problem in setting up mass production within a reasonable cost and time frame.

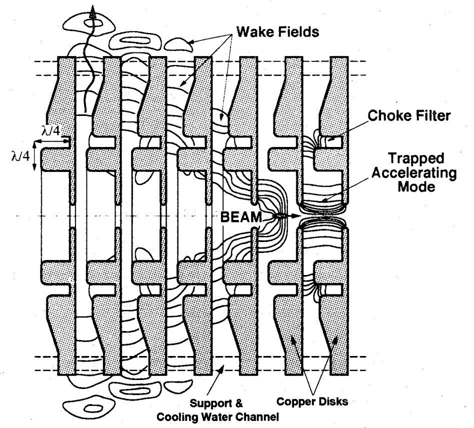

Figure 1: Choke mode type HOM free accelerating structure.

3. PARAMETERS OF THE ACCELERATING STRUCTURE

The structural parameters for the LC1 (500 GeV at C.M.) are listed in Table 1. The sensitivity to alignment errors in a constant gradient structure is approximately proportional to $a^{-3.5}$, where a is an iris aperture radius [5]. Thus, the iris diameter (2a) is the most important parameter which is determined to obtain a realistic alignment tolerance of 30 μm per cavity.

Table: 1 Main parameters of the accelerating structure

Frequency	5712	MHz
Phase shift per cell	$3^{1}/4$	
Field distribution	C. G.	
Number of cells	91	cell
Active length	180	cm
Iris aperture (2a) : up-stream : down-stream	1.82 1.31	cm cm
Cavity diameter : up-stream : down-stream	4.47 4.25	cm cm
Disk thickness: t	0.4	cm
Quality factor: Q	9950	
Group velocity : up-stream : down-stream	0.035 0.012	c c
Average shunt impedance: rs	53.1	M½/m
Attenuation parameter	0.53	
Filling time: Tf	286	nsec

The structure was designed so as to obtain an unloaded electrical field gradient of 40 MV at 83 MW of rf input power. The klystron peak power required would be 50 MW, at a 2.5 μsec pulse width and 100 pps repetition rate; all obtainable without any special technology. The loaded electrical field gradient will be 31.3 MV/m with 1×10^{10} electrons per bunch and 77 multi-bunches. For the case under consideration, the active length is 14.7 km for the two linacs. The system is comprised of 4080 klystrons and their modulators, and 8160 accelerating structures. The wall-plug power requirement is 150 MW for the two linacs [1].

4. BASIC CHARACTERISTICS OF AN SiC CERAMIC HOM ABSORBER

SiC powder is produced by a chemical reaction between silicon-dioxide (SiO_2) and carbon-black (3C) powder at a temperature in the range of 1500 to 1800 °C in an inert atmosphere:

$$SiO_2 + 3C = SiC + 2CO.$$

SiC-ceramic may be made from SiC power by sintered in a vacuum furnace at 2100 °C. The basic characteristics of the SiC-ceramic are listed in Table 2. SiC-ceramic has some very attractive characteristics for application to an HOM absorber or a high power vacuum rf-load. In particular: (1) Large heat conductivity, (2) Exceptionally large hardness and abrasion-proof properties, (3) Light weight, (4) Excellent heat and oxidation resisting properties, and (5) High chemical stability against most reactive chemicals, gases, etc. Further it is important to note that SiC-ceramic has a large microwave loss with a broad-band frequency response as measured by microwave network-analyzer in this study.

Table 2: Basic characteristics of SiC ceramic

Density (g/cm^2)	3.14	
Hardness (Knoop, kgf/mm^2)	2900	at room temp.
Thermal conductivity (cal/cm•s•°C)	0.19 0.14	at room temp. at 600 °C
Thermal expansion coefficient (1/°C)	4.6×10^{-6}	room temp. to 1200 °C
Oxidation weight gain (mg/cm^2)	0.015	at 1200 °C for the 24 hours
Resistivity (½•cm) at DC	5×10^{5} 7×10^{-1}	at room temp. at 800 °C
Dielectric constant	31	at 2856 MHz
Loss tangent	5 to 6×10^{-1}	0.5 to 20 GHz

5. FABRICATION OF THE CHOKE MODE HOM-FREE STRUCTURE

An original choke mode type HOM-free structure is shown in Figure 2. Each cell is comprised of an accelerating cavity with a choke, button shaped HOM absorbers and cooling water holes. From the manufacturing point of view, clearly there is no requirement of any special machining technique for fabrication. Typical high precision machines can deliver machine parts with less than ±10 μm errors, that is enough for C-band work.

At this time, a limiting technology is the brazing process between the SiC-ceramic absorbers and the OFHC copper plates [6]. In general, it is very difficult to join SiC-ceramic to OFHC copper, because the thermal expansion coefficients of the two materials are quite different; SiC-ceramic is ~4.6×10^{-6} and OFHC copper is ~2×10^{-5}. The other problem is deformation arising during brazing at high temperatures.

Thus, developing a low temperature brazing method such as is possible with Sn (Tin) alloys, which have a temperature range of 139 to 724 °C, was a priority issue. However, now SiC-ceramic has been successfully joined to OFHC copper by using a Sn+Au alloy low temperature brazing material [4].

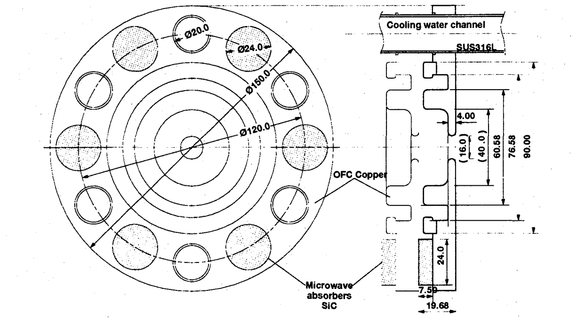

Figure 2: An original choke mode type HOM-free structure.

6. MODIFIED CHOKE MODE CAVITY

The original choke mode HOM free accelerating structure has open slots between the cells. Thus, it must necessarily be inside a vacuum chamber. And an external rf-load will need to be attached for high power operation.

Therefore for cost reduction, a modified choke mode cavity was proposed to avoid an extra external vacuum chamber and to introduce an in-line rf dummy load as shown in Figure 3. The structure is vacuum tight itself since it is closed by the ring shaped OFHC copper spacers; this is quite the same as conventional structures. There are two cell types. The first one is just a typical copper cell; the second type has two SiC-ceramic absorbers one on each side of the cell. The two kinds of cells are stacked alternately with spacers which are mounted between them. The SiC-ceramic absorber size will be ID=ø9.6 cm, OD=ø11.6 cm and t=1 cm.

An external rf-load is not necessary, because the SiC-ceramic in the last few end cells can be used as an rf dummy load. The leak rf power from the accelerating cavity to the SiC-ceramic is controlled by de-tuning the choke cavity to equalize the loss along the axis. Recently, the ring shaped SiC-ceramic of the size give above was successfully joined to the C-band cavity by vacuum brazing with a special alloy at 710 °C.

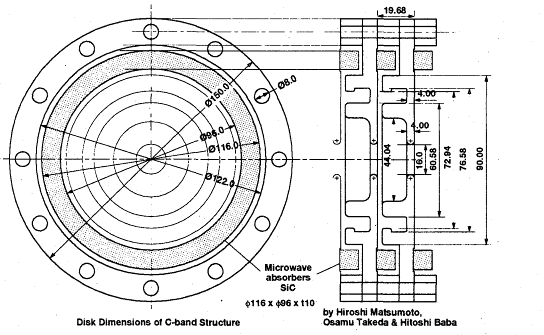

Figure 3: Modified choke mode HOM free accelerating structure.

7. CONCLUSION

The choke mode type HOM-free structure has a realistic alignment tolerance of 30 µm with a reasonable input rf power of 83 MW per structure at C-band frequency. Therefore the klystron rf power required, 50 MW, will be no problem given recent technology. There are no special machining requirements for either the original or the modified accelerating structure. The modified structure will be eliminate an extra vacuum chamber and external rf dummy load. Both button shaped and ring shaped SiC-ceramic absorbers were successfully joined to the C-band cell structure.Finally, it was confirmed that the Shintake choke mode type HOM-free structure will be one of the strong candidates in the quest to realize the future linear collider.

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