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Abstract

A prototype of a muffin-tin accelerating structure operating at 32 times the SLAC frequency (2.856 GHz) was built for research in high gradient acceleration. A traveling-wave design with single input and output feeds was chosen for the prototype which was fabricated by wire electrodischarge machining. Features of the mechanical design for the prototype are described. Design improvements are presented including considerations of cooling and vacuum.

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DESIGN AND FABRICATION OF A TRAVELING-WAVE MUFFIN-TIN ACCELERATING STRUCTURE AT 90 GHZ †

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ABSTRACT

A prototype of a muffin-tin accelerating structure operating at 32 times the SLAC frequency (2.856 GHz) was built for research in high gradient acceleration. A traveling-wave design with single input and output feeds was chosen for the prototype which was fabricated by wire electrodischarge machining. Features of the mechanical design for the prototype are described. Design improvements are presented including considerations of cooling and vacuum.

I. INTRODUCTION

The cavities of high gradient accelerating structures in the 90 GHz frequency range have millimeter dimensions. Micromachining is more suitable for the fabrication of mm-scale structures than conventional machining. Therefore, a rectangular geometry of the muffin-tin design[1] was chosen. Various fabrication techniques have been reviewed[2] with the conclusion that wire electrodischarge machining(EDM) and deep x-ray lithography(LIGA)[3] were the most promising candidates.

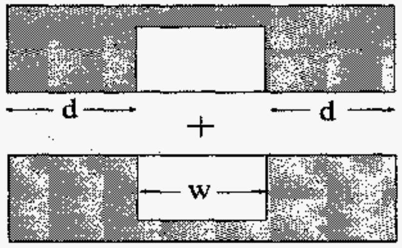
To test wire EDM as a fabrication technique and to gain experience in measuring RF properties of 90 GHz structures, a 7-cell traveling-wave prototype with a single-feed, vertical-coupling input/output scheme was built. This first prototype was used for low-power RF measurements only[4]. The absolute dimensional tolerance required for 90 GHz structures is under 3 μm. A test cut with key features of the design was performed prior to the fabrication of the finished prototype.

Cooling and vacuum were not included in the prototype design. To reduce the need for tight dimensional tolerances and improve the compatibility with cooling and vacuum, a second generation design is contemplated and described in this paper.

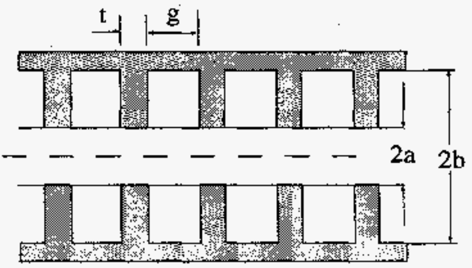
II. DESIGN AND FABRICATION OF THE FIRST PROTOTYPE

Figure 1 depicts the sketch of the accelerating cavities. The dimensional parameters in [mm] are: 2a=0.788, 2b=2.364, t=0.263, g=0.831, w=2.364, and d=1.049.

Figure 2 shows the mechanical design of the prototype prior to the assembly. A laminated design with power coupling in the vertical direction was used. The structure is divided accordingly into five layers from top to bottom: input waveguide taper(*a*), coupling iris for input(*b*), muffin-tin cavity structure(*c*), coupling iris for output(*d*), and output waveguide taper(*e*). The linear waveguide taper matches standard WR10 waveguide(2.54 mm × 1.27 mm) to the input coupler(2.54 mm × 0.831 mm); it has a transition length of 10 mm which causes only 1% conversion loss. Each layer is registered by precision alignment pins in two diagonal reference holes. The most critical alignment is between the coupling iris and the coupler cavity. A 5 μm misalignment there could increase the VSWR significantly. Since the coupling irises and coupler cavities are in different layers, this poses a great challenge on the alignment technique.



end view



side view

Fig. 1: Sketch of muffin-tin accelerating structure.

The pumping slot and beam pipe were cut through both sides of the middle piece, c in Fig. 2. The width of the beam pipe was chosen to be 1.4 mm in order to prevent leakage of the TM_{11} accelerating mode. Since this prototype will only be used for RF cold tests, the finished structure is just clamped with screws and belleville washers.

Figure 3 shows the cross section of the input coupler sliced along the xy plane. Because of the single-feed input/output scheme, a shallow well with dimensions equal to the coupling iris was used to symmetrize the electromagnetic fields. Without this well, the RF power could leak out through the beam pipe or pumping slot. The geometry of the input/output coupler was designed to obtain a VSWR less than 1.1 and a 1 GHz flat bandwidth centered around the operating frequency[4].

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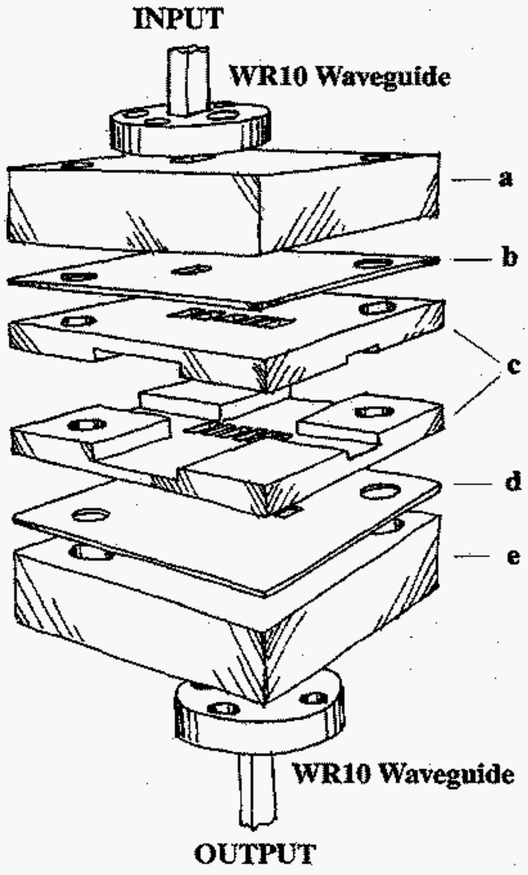

Fig. 2: The mechanical design of the first prototype prior to the assembly.

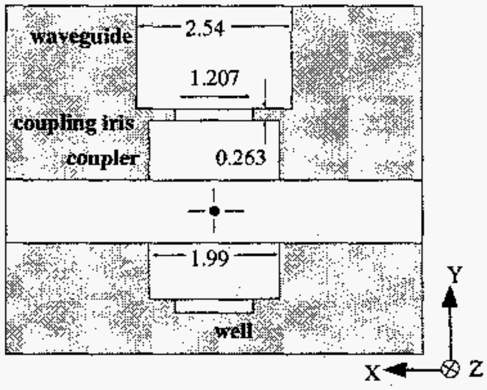

Fig. 3: The cross section of the input coupler sliced along the xy plane. Note that the width of the end cells is w= 1.99 mm as compared with w= 2.364 mm for the other cells.

To assess the machining accuracy provided by wire EDM, a test piece which contains key features such as reference holes, pumping holes, and cavity cells, was fabricated and evaluated by a Leitz coordinate measuring machine which has a measurement accuracy of ±0.5 µm. This test piece was cut on a AGIECUT 150 HSS wire EDM using a 4 mil brass wire at Ron Witherspoon, Inc.. The design of this test piece is depicted in Fig. 4.

The deviation of nominal centers of cavities was within 1 µm, and the variation of sizes of cavities was less than 2.7 µm. The center of pin hole at the upper right corner was off by 3.5 µm in z and 0.3 µm in x direction. The distance between two pin holes are 38 mm in z and 39 mm in x respectively. The results from the test cut seem encouraging. The above results suggest that the fabrication error might be dominated by the accuracy of alignment and assembly of all constituent layers.

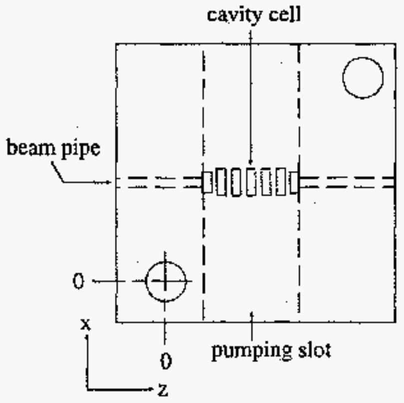

Fig. 4: The schematic sketch of test piece. The reference zero is the center of the pin hole at the bottom left corner.

The RF evaluation of the complete first prototype is presented in P.J. Chou et al. submitted to this conference[4].

III. THE SECOND GENERATION DESIGN

The desire to improve compatibility with cooling and vacuum and relax the tight requirement on layer to layer alignment leads us to the design depicted in Fig. 5. The structure will be divided into four layers. The key parts are layers a and b. The RF power will be coupled into the structure from the horizontal direction. The matching devices used to reduce the reflection of incident power will be integrated into the same layer with the cavity cells. From the results of previous test cuts, we are more confident in the machining accuracy provided by EDM than in the alignment technique. The sketches for layer a and b are shown in Figs. 6 and 7 respectively. The matching devices have the same height as the cavity cells. This one height level design will make technique LIGA[3] a possible candidate for fabrication. Besides wire EDM technique, sinker EDM could also be used to fabricate the structure.

From the standpoint of RF design, the horizontal coupling scheme is better than the vertical coupling scheme used in the prototype in Fig. 2. The vertical coupling scheme could induce a TE_{10} mode which can leak out through the beam pipe or pumping slot if the electromagnetic field is not properly symmetrized for a single-feed design. This is why we have a narrow beam pipe(1.4 mm) in the prototype. From the standpoint of wake fields, we would like to have a wider beam pipe. The horizontal coupling scheme will allow us to use a wider beam pipe without worrying about power leakage. The basic principles are the same as those of a magic T[5].

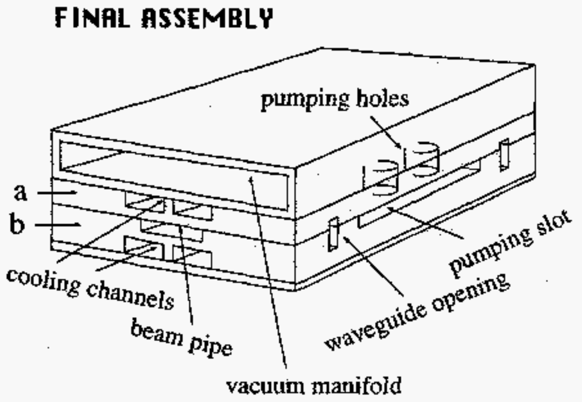

Fig. 5: Sketch of the 2nd generation design. Vacuum and cooling channels are included.

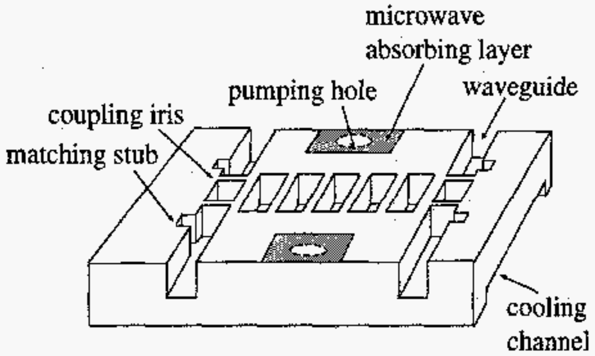

Fig. 6: Sketch of layer a — the top half of the structure.

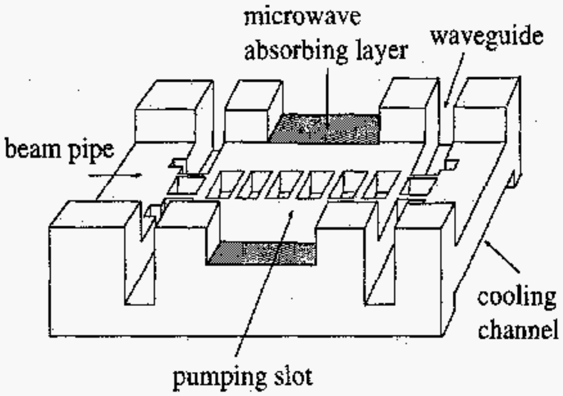

Fig. 7: Sketch of layer b — the bottom half of the structure.

IV. ENGINEERING ISSUES OF THE SECOND GENERATION DESIGN

Simplified models were used to estimate some basic characteristics of the cooling and vacuum. A flat duct carrying water at high velocity is used. The duct is assumed to have an infinite width. The higher the water flow velocity, the higher the heat transfer up to the point where water flow erodes the metal and the water cavitates(boils) where it is forced around corners or over edges. As a practical limit, a flow velocity of 600 cm/sec is used. For a 10 °C temperature gradient between the metal wall and 600 cm/sec fluid velocity, the heat transfer was calculated to be 50.5 watts/cm^2 in a 2 mm high duct. An estimate of the average heating due to the RF power dissipation on the wall was made with the following parameters: E= 300 MV/m, r_s= 250 MΩ/m, RF pulse length= 40 ns, repetition rate= 150 Hz, structure width= 4 mm. The average heating per unit area was estimated to be 25 watts/cm^2.

Vacuum has been estimated to be around 10^{-10} Torr for a 1mm × 10 mm rectangular duct that is more or less continuously connected to the structures. The estimate assumes only outgasing from temperature rise due to average RF power. The flux of outgasing from the accelerator structure itself due to pulse heating of peak RF power would have to be added in. The pulse heating problem is currently under experimental investigation[6].

V. SUMMARY

We have presented the design concepts, results of mechanical test cuts, and discussions on various engineering issues for 90 GHz accelerating structures. Cooling and vacuum do not seem to be major problems. Fabrication issues do not seem to be an obstacle.

VI. ACKNOWLEDGMENT

The authors would like to thank Ron Witherspoon, Inc. in Campbell, California for many helpful discussions.

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