# THE FABRICATION OF A PROTOTYPE 30 GHZ ACCELERATING SECTION FOR CERN LINEAR COLLIDER STUDIES

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**Abstract**

Design features and fabrication details of a precision machined and brazed 30-cell section of accelerating structure for CERN linear collider studies are described. Microwave matching techniques for the power couplers are discussed and preliminary results are given.

## Introduction

Each linac proposed for the CERN linear collider CLIC is composed of 50'000 25 cm long accelerator sections operating at 30 GHz with gradients of 80 MV/m to produce beam energies of 1 TeV. The basic design parameters for these accelerating sections are summarised in Table 1 and have been discussed elsewhere [1][2]. The most promising fabrication method (at least for the moment) is still the brazing of machined copper cups. This paper describes the fabrication of a short prototype piece of CLIC accelerating structure by this method.

**Table 1: Main structure and linac parameters**

| | |
|---|---|
| Shunt impedance | 109 MΩ/m |
| Quality factor | 4112 |
| R'/Q | 26.5 kΩ/m |
| Group velocity ($v_g/c$) | 7.4% |
| Field attenuation | 0.25 Nepers/section |
| Gradient | 80 MV/m |
| Section length | 25.8 cm |
| Fill time and pulse length | 11.3 ns |
| Cells per section | 72 |
| Sections per linac | 50'000 |
| Ratio output/input power | 0.61 |
| Total peak input power | 1.875 TW/linac<br>150 MW/m |
| Repetition rate | 1.69 kHz |
| Total average input power | 35.75 MW/linac<br>2.86 kW/m |
| Average dissipated power | 1.125 kW/m |

A cross-section of the accelerating structure is shown in Fig. 1. The outer diameter of the structure, machined to a precision and concentricity with the inner beam hole of ± 1 μm, serves as the reference for alignment purposes during fabrication and assembly. The structure is pumped through a series of radial holes (or damping slots if incorporated) by four vacuum manifolds. If necessary these manifolds could also act as sinks for the dissipation of higher mode energy. The four 5 mm diameter holes which provide the cooling have been positioned in such a way that two diametrically opposed 1.6 mm diameter recessed holes can be incorporated for dimple tuning.

The dimensions of a cell of the constant impedance disk loaded waveguide are shown in Fig. 2. A cell diameter of 8.704 mm gives a measured $2\pi/3$ mode frequency of 29.906 GHz at 23°C in air.

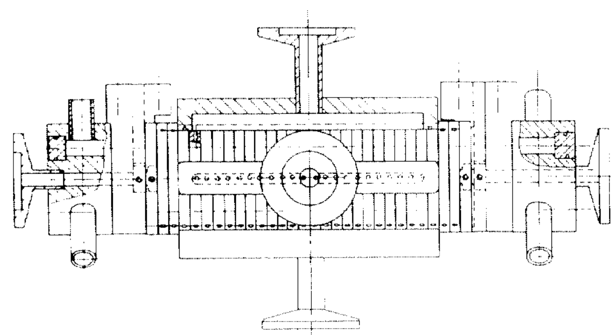

Fig. 1 Cross-section of the 30-cell accelerating structure

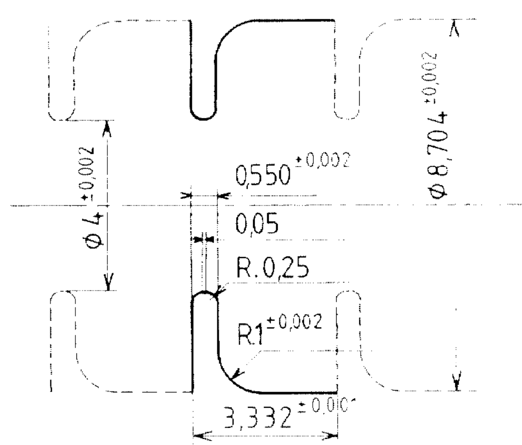


Fig. 2 Cell dimensions

## Tolerances

The tolerances required on cell dimensions in order not to exceed an accumulated random phase error of 5° over a section length of 75 cells are of the order of a few microns. It has been estimated that an N2 (Ra = 0.050 μm) surface finish is required to obtain 95% of the theoretical Q value. Such tolerances and surface finishes can only be obtained using sophisticated diamond turning techniques.

## Machining

The high-precision copper cups used in this prototype work (see Fig. 3) were made on Pneumo MSG 325 diamond tool lathes by Optische Werke G. Rodenstock (Munich) and British Aerospace Dynamics (Stevenage). These Pneumo machines have CNC control, closed-loop laser interferometric feedback with 25 nm resolution, vibration isolation and air bearing spindles and slides. The tools are single crystal natural diamonds lapped to a form precision of < ± 0.5 μm over 100°. Typical turning speeds of 1000 rpm were used with finishing cuts of about 2 μm resulting in cutting forces of < 1 g. Overall tolerances of ± 2 µm and surface finishes better than N1 have been consistently achieved by both manufacturers. Checks of overall tolerances were made at CERN using a Ferranti Merlin 750 CNC coordinate measuring table.

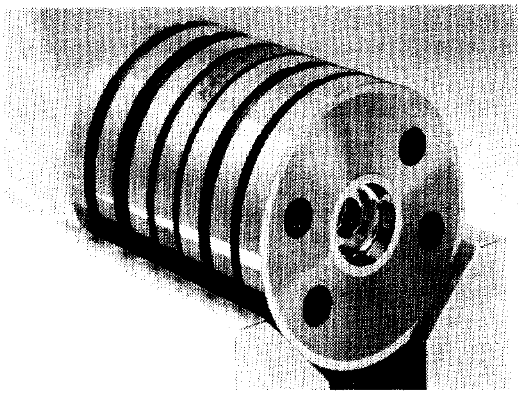

Fig. 3 Precision machined copper cups

### Frequency tuning

Results from measurements of cell-to-cell phase shift errors on unbrazed clamped stacks are shown in Fig. 4. The standard devaition for 15 discs is approx. 0.1°/cell; this is equivalent to a change in the cell diameter of about 0.5 µm and confirms the outstanding precision of these Pneumo lathes. Although these results demonstrate that copper cups can be machined to an accuracy that would eliminate the need to dimple tune, non-reproducible frequency changes produced by the subsequent brazing operations indicate that dimple tuning to the target frequency will probably be required. The 30-cell structure has been designed to require a 3° phase shift change per cell after final brazing. To ensure more than adequate tuning capability however for this prototype stage, the structure has four dimples per cell which permit more than 10° of adjustment.

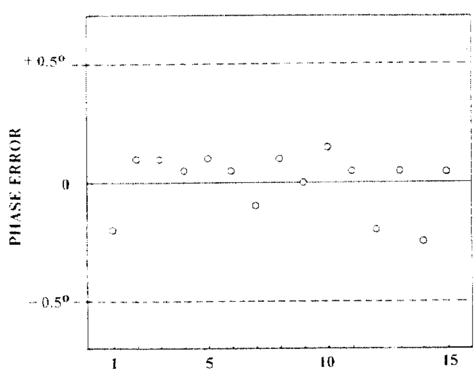


Fig. 4 Phase advance errors for 15 cells

### Microwave matching of couplers

The 30 GHz microwave power flows into and out of CLIC accelerating sections via SLAC-type side iris couplers. Due to the geometric asymmetry of the CLIC disc-loaded waveguide, matched input and output couplers have different iris widths and cell diameters. Before brazing the 30-cell prototype section, the input and output couplers were pre-matched to a clamped reference stack to VSWRs of about 1.02. The coupler match was measured using the moveable load technique. A terminated output coupler was used as the load and the electrical distance between couplers was varied discretely by adding and removing discs from the clamped stack. Because the standard Kyhl method [3][4] was found not to work for CLIC structures which have a large cell-to-cell coupling ($a/\lambda = 0.2$), tuning of couplers after brazing is problematic but will hopefully be resolved by adapting the Kyhl technique or by designing a suitable internal matched load.

### Brazing

The ability to produce high quality brazed joints in a consistent way for such small structures has been a major concern. Excess flow of braze from the joint into the cell leads to a local degradation of the surface finish and produces unpredictable frequency changes. These difficulties have been overcome by using the braze joint geometry shown in Fig. 5. A 1 mm wide diffusion-bonded annular surface at the inside edge of the discs provides electrical contact and blocks flow of excess braze material into the cavity. The copper/copper diffusion bond between the clean mirror-finish contacting surfaces is made during the normal brazing cycle under slight pressure. A similar ring machined to the same height at the outer edge prevents braze leakage to the outside. The alloy for brazing is housed in the four partially drilled cooling water channels. The six-cell test cavity shown in Fig. 6 was successfully brazed using this technique.

The prototype stack was brazed together in two stages with an intermediate machining step to drill out the cooling water channels and to mill the recesses for the vacuum manifolds. The first braze, made at 817°C using a 27% Cu/68% Ag/5% Pd alloy, was used to assemble the 30 main cells, the two power couplers and the two end manifolds. The assembly for this first braze is shown in Fig. 6. The stack is aligned in a V-block and held together by a Nimonic 90 high temperature spring which applies an axial force of about 7 kg. The piece is shown in Fig. 8 after the first braze. The second braze, made at 780°C using a 72% Ag/28% Cu alloy, was used to attach the stainless steel manifolds, cooling water pipes and vacuum tubes.

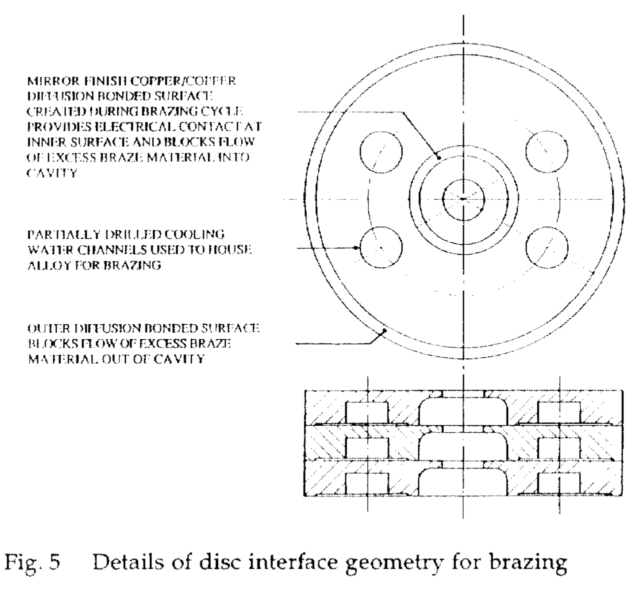


Fig. 5 Details of disc interface geometry for brazing

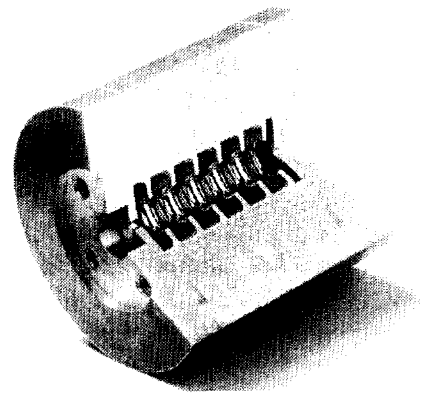

Fig. 6 Sectioned six-cell test cavity

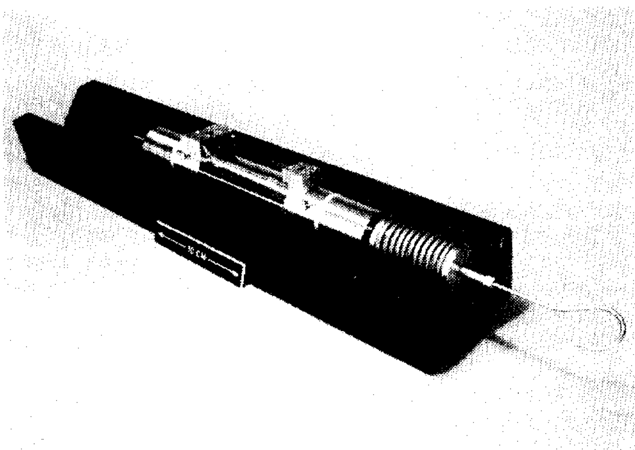

Fig.7 Assembly in V-block prior to first braze

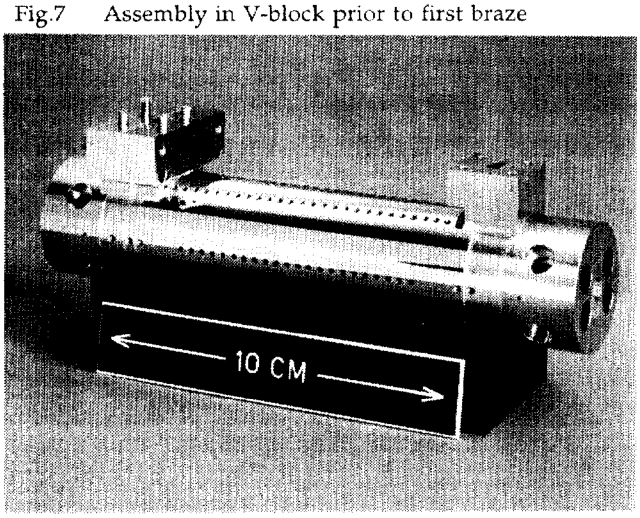


Fig. 8 30-cell section after first braze

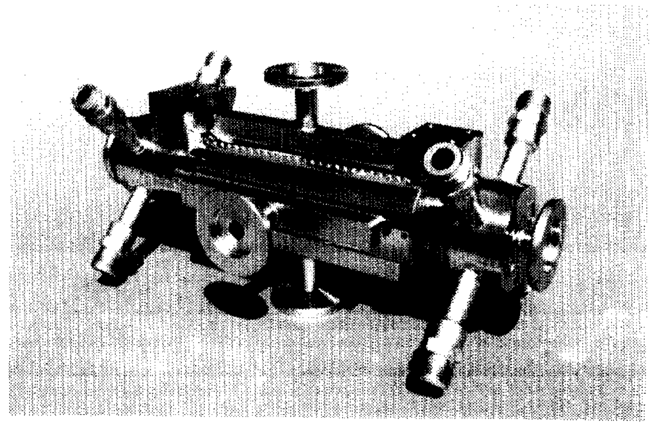

Fig.9 Finished 30-cell prototype section

**Present Status and Future Plans**

The finished 30-cell prototype section is shown in Fig. 9 and is ready for final adjustment by dimple tuning.

The construction of this prototype stack having been successfully completed, it is now planned to fabricate two full-length accelerating sections for high gradient testing on the CLIC test Facility (CTF). The cells for these sections have been ordered and fabrication is expected to start soon.

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**References**

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