STUDIES ON HIGH-PRECISION MACHINING AND ASSEMBLY OF CLIC RF STRUCTURES

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Abstract

The Compact Linear Collider (CLIC) is currently under development at CERN as a potential multi-TeV e^+e^- collider. The manufacturing and assembly tolerances for the required RF components are essential for the final efficiency and for the operation of CLIC. The proper function of an accelerating structure is sensitive to mechanical errors in the shape and the alignment of the accelerating cavity. The current tolerances are in the micron range. This raises challenges in the field of mechanical design and demands special manufacturing technologies and processes. Currently the mechanical design of the accelerating structures is based on a disk design. Alternatively, it is possible to create the accelerating assembly from quadrants, which has the potential to be favoured for the mass production due to simplicity and cost. In this case, the functional shape inside of the accelerating structure remains the same and a single assembly uses less parts. This paper focuses on the development work done in design and simulation for prototype accelerating structures and describes its application to series production.

INTRODUCTION

The number of accelerating structures for CLIC at 3 TeV will be over 141,000. Each accelerating structure contains about 30 disks, which form the accelerating cavity [1]. Disks have been traditionally manufactured by turning with diamond tools, which guarantees high surface finish and shape accuracy. This is especially true for the axisymmetrical accelerating cavity design. Figure 1 shows an accelerating structure assembled from disks.

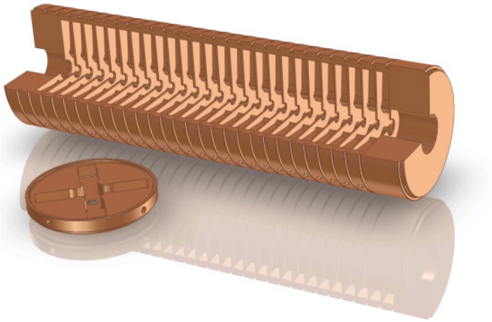

Figure 1: Example of an accelerating structure made of disks (one quarter removed) together with a single disk.

Operational CLIC accelerating structure designs will also include damping waveguides, which cause a break in this symmetry and require milling in addition to turning. Alternatively the disks can be completely manufactured by milling. After the disks have been manufactured, the final accelerating structure is assembled and diffusion bonded together at high temperature. Alternatively to the disks, it is possible to create the accelerating cavity also from quadrants [2]. A quadrant structure is shown in Figure 2. When quadrants are used, milling becomes the major manufacturing technology [3, 4].

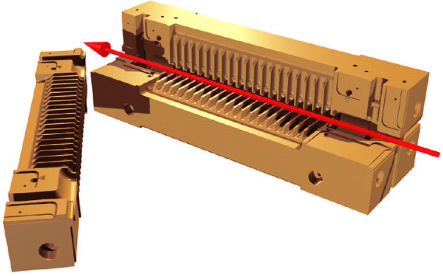

Figure 2: Example of an accelerating structure made of quadrants.

Both disks and quadrants have high requirements as individual components, but the requirements also apply for the assembled structures. Components must be aligned with micron precision along the beam axis and with each other. In the case of the disk structures, the assembly is done in a high-precision V-groove. The turned outside surface is used to align the centre of the disks. In the case of the quadrants two different methods have been used, cylindrical pins in grooves and spheres in pyramid-shaped holes, to align the parts with respect to each other.

This paper concentrates on the ongoing efforts to develop and improve the prototype accelerating structures in terms of design, manufacturing technologies and assembly to achieve an efficient series production of these RF components.

STUDY METHODS AND RESULTS

As the manufacturing of a complete structure is a complicated process including many production steps, small changes in the first steps might cause unexpected effects on the final assembled structure and on its performance. To minimize these risk factors, all the processing options for each step and their effects on the final result need to be assessed already in the design phase.

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The design strategy is to validate conceptual designs with careful simulation and testing before implementing the corresponding changes into the general design. This starts from the initial RF design and continues up to the actual testing of the complete accelerating structure. The following three studies show the implementation of this strategy, concerning mechanical design, from the level of basic research to testing.

Basic ~~research~~ Research of Chip Formation

When aiming at the micron level precision, a comprehensive knowledge is required about the different phenomena, which needs to be taken into account at such scales. These include mechanical and thermal properties of the materials, in this case Oxygen Free Electronic copper, dynamic effects during milling such as vibrations and machine inaccuracies, chip formation and tool properties.

High speed machining is one of the example areas where the cutting parameters influence the quality and the cost of the manufacturing process. The determination of the machining parameters is not always very clear. In many cases the parameters are determined by trial and error compensation. The optimisation of the parameters is beneficial as it can limit the wear of the critical components such as machining tools and keep the cost-quality relation reasonable. Therefore, a more complete understanding of the chip formation mechanism is required. Figure 3 shows preliminary results on simulations made to understand the residual stresses formed during machining, in this case during ball end milling. The tool has a diameter of 1 mm and machining depth is 20 μm. Figure 3 shows the tool entering the bulk material and the created von Mises stress in the bulk.

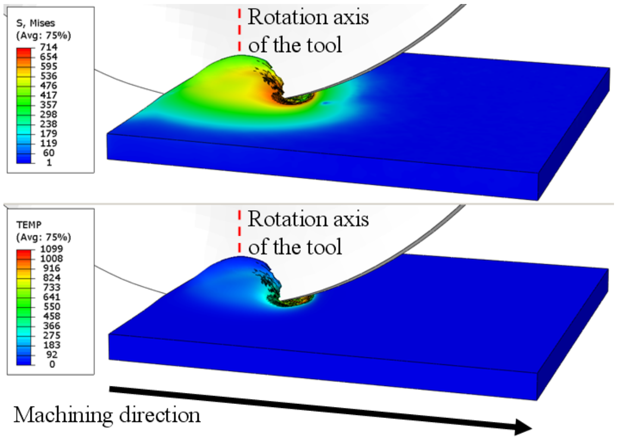

Figure 3: Chip removal simulation with 1 mm diameter ball end tool (shown in white) showing von Mises stresses in MPa (up) and temperature distribution in the material in °C (down).

The simulated stress levels can reach 700 MPa and temperatures of 1000 °C. In this phase they induce plastic deformation and damage to the material. The tool is in this case considered to be as a rigid body. This idealisation is done to limit the number of variables and to reduce the calculation time.

The final outcome of this study should be the understanding of the relations between the machining parameters and the resulting stresses in the material. This can then be used to optimise the machining processes to improve final accuracy of the components.

Finite Element Simulations of Deformations

The symmetrical disk design, with damping waveguides, has milled waveguides on both sides of a single disk. This leaves the material thickness small (~1.7 mm) in the areas of the damping waveguides. It has been noted that the disks tend to bend to a saddle-shape after machining or thermal treatment. Deformations of the order 10 μm are rather common. Figure 4 shows a deformation profile of a disk surface after milling measured with Veeco Wyko NT-3300 white light interferometer.

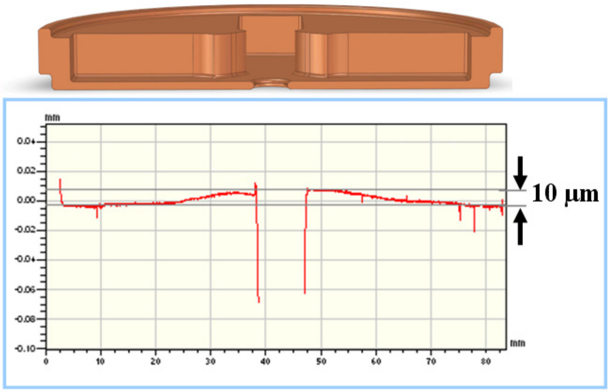

Figure 4: Measurement of the disk profile for a disk with milled waveguides.

To increase the minimum thickness in the disk, the consecutive damping waveguides in the structure are rotated around the beam axis by 45 degrees. Finite Element Methods (FEM) can be used as a tool to check design changes. In Figure 5 pressure simulation results are shown considering different damping waveguide configurations in the disk design. The static simulations were conducted ANSYS Workbench 12.0. The simulated geometry consists of three disks, which are subjected to a pressure of 0.4 MPa. The pressure is applied to the top surface of the disk and represents the weight applied onto the accelerating structure, while the structure undergoes a diffusion bonding process.

The simulations indicate that the previous change in waveguide machining does not have a considerable effect on the disk deformation after the bonding process and that the maximum pressure does not change considerably from the standard design. The maximum stress is 4.2 MPa with the standard configuration and 3.2 MPa with the 45 degree rotation. From these results it can be concluded that the changes in the rotation do contribute to the pressure distribution, but do not cause permanent deformations to the components.

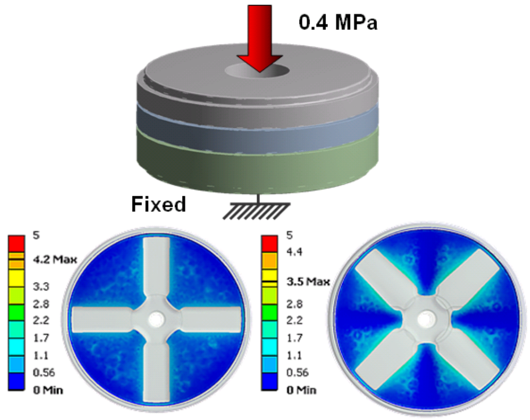

Figure 5: Simulation boundary conditions (top), pressure distributions in MPa on contact surfaces between disks with damping waveguides (lower left) and with damping waveguides with 45 degree offset (lower right)

Manufacturing and Assembly Tests

Ongoing manufacturing research and development work includes dedicated manufacturing tests, which can be done quite swiftly and have high informative value. A manufacturing test is usually done to benchmark different tooling options or assembly methods, and in some cases to minimise the amount of parameters.

A simplified assembly was manufactured with the objective to test an elastic averaging method of the quadrant structure. The results show that, with a two-piece assembly the repetition accuracy is of about 6 µm [5]. Figure 6 shows the two-piece test assembly.

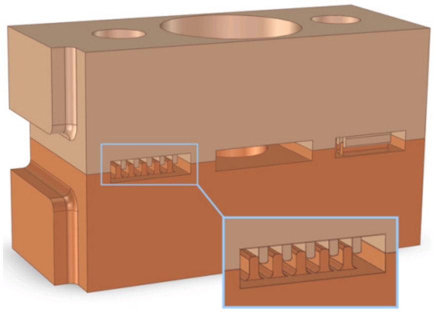

Figure 6: A two-piece test assembly to verify accuracy and repeatability of the elastic averaging method.

Although the final repetition accuracy was promising, the final assembly accuracy is still highly dependent on the manufacturing precision of the components, especially for systematic errors, which are not compensated by the averaging effect.

SUMMARY AND DISCUSSSION

The development work done to understand and improve the high precision machining in CLIC produces valuable information relating for the whole manufacturing chain. The work includes aspects from the very basics understanding of machining to the final assembled structures.

FEM-simulations can provide good grounds for design changes and they can be done in parallel to the mechanical design of test structures to help understanding the consequences of geometrical changes. Also, basic understanding concerning the machining parameters and their influence on the machined component has greatly improved. Optimization has started for the performance and productivity of the machining process.

Manufacturing tests continue to provide input for different aspects regarding assembly techniques and final accuracy of the components. CLIC has an ongoing manufacturing test program, where new methods are being developed, tested and put in use.

FUTURE WORK

As the manufacturing of the high-precision RF structures is being developed, more studies are foreseen to understand the effects of process and design changes to the series production of the components. Studies are already underway to provide information related to the cost of mass production and process development.

Better understanding and more research is still required for the selection of proper machinery and tools to optimise productivity and process steps, including the required thermal treatments and quality control. Tests are foreseen to obtain the optimal machining parameters. Studies will also continue on the presented subjects to finely tune the already validated procedures and design choices.

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