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DESIGN AND FABRICATION CHALLENGES OF TRANSITION SECTION FOR THE CWA MODULE*

S. Lee†, W. Jansma, A. Siy[1], S. Sorsher, K. Suthar, E. Trakhtenberg, G. Waldschmidt, A. Zholents
Argonne National Laboratory, Lemont, IL 60439, USA
[1] also at University of Wisconsin, Madison, WI 53715, USA

Abstract

An effort to build Argonne's Sub-THz AcceleRator (A-STAR) for a future multiuser x-ray free-electron laser facility proposed in [1] is underway at Argonne National Laboratory. The A-STAR machine will utilize a compact collinear wakefield accelerator (CWA) assembled in modules. To extract the wakefield and monitor beam position downstream of each module, a 45-mm-long transition section (TS) has been proposed and designed. This paper will discuss the design and fabrication challenges for production of the TS.

INTRODUCTION

The CWA TS consists of multiple miniature components that must be brazed or TIG welded vacuum leak-tight using a multi-step brazing processes with filler material of successively lower temperature to maintain the integrity of previously brazed joints. The internal vacuum surface geometry of the TS will be fabricated by electroforming copper (Cu) on an aluminum (Al) mandrel and chemically dissolving the Al mandrel to create the structure. Micro-manufacturing processes such as high-precision milling and wire electric discharge machining (EDM) will be utilized to produce the TS Cu base. A cold drawing process will be considered to produce flexible waveguide tubes. The CWA vacuum chamber module is comprised of a corrugated tubing/strongback (CTS) unit, a bi-metal vacuum flange, and a TS unit with a bellows as shown in Fig. 1. The following sections will focus on the design and fabrication challenges of the TS unit for the CWA vacuum chamber module.

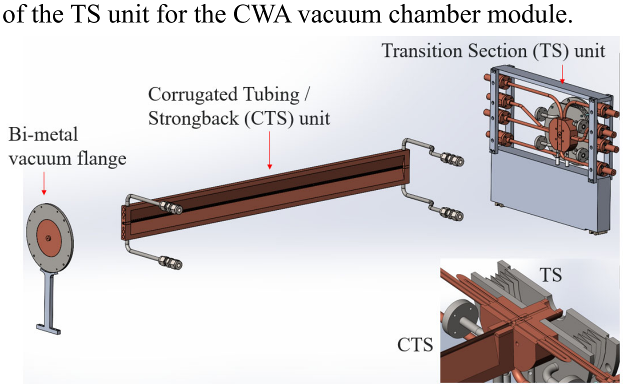

Figure 1: CWA vacuum chamber module and its components for the compact collinear wakefield accelerator.

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† shlee@anl.gov

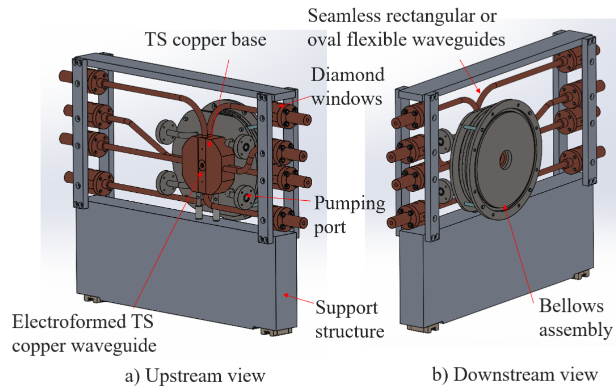

Figure 2: Transition section and its components for the compact collinear wakefield accelerator.

DESIGN OF TRANSITION SECTION

The TS unit is comprised of an electroformed Cu waveguide, a machined Cu base, eight seamless flexible rectangular or oval waveguides, diamond windows, and a stainless-steel bellows assembly with vacuum ports (see Fig. 2). The eight waveguides are utilized to extract unused TM01 accelerating mode from the output coupler of the corrugated waveguide while allowing the TE11 transverse mode to pass through to the integrated offset monitor (IOM) for beam offset measurements [2]. As shown in Fig. 3, its design consists of a four-way rectangular waveguide cross, which interfaces to the circular waveguide via tapers and a circular cavity. Immediately following the output coupler cross is a notch filter, designed to reflect the TM01 mode. Then, the IOM is located downstream to couple the transverse TE11 modes for beam offset measurements.

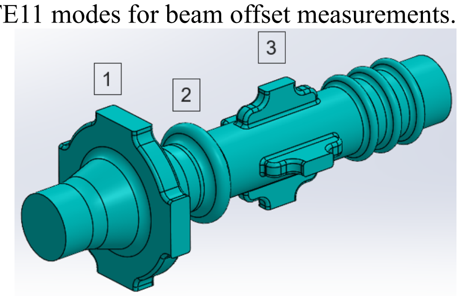

Figure 3: Geometry of the mandrel: (1) TM01 output coupler, (2) notch filter, and (3) integrated offset monitor.

Electroforming is utilized to fabricate complex features of the output coupler, notch filter and IOM in the TS. A negative form of the internal TS features is machined on an Al mandrel, and reference holes are added for alignment during future brazing and micro-machining steps. The mandrel is electroplated with Cu, and Al is then chemically dissolved, leaving behind the TS Cu structure. Finally,

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external micro-machining of the TS Cu waveguide for future brazing joints to the TS Cu base can be performed as shown in Fig. 4.

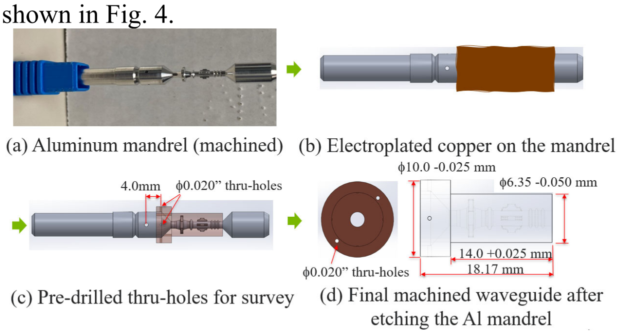

Figure 4: Schematic of the electroforming and micro-machining process of the electroformed TS Cu waveguide.

TS Waveguide-Base Unit

The electroformed TS Cu waveguide will be embedded into a pre-machined TS Cu base by a high-temperature brazing process as shown in Figs. 5(a-b). This TS waveguide-base unit will be vacuum leak-tested with two connectors as shown in Fig. 5(c). After the unit is leak-tested, holes (ϕ 0.30~0.50 mm) will be drilled for threading of thin wire rods into the unit for profiling of the rectangular waveguide, shown in Fig. 5(d). Finally, the unit will be machined to create the brazing joints for eight flexible waveguides and the CTS unit as shown in Figs. 5(e–f).

Flexible Waveguides and Diamond Windows

Custom-sized waveguide tubing will be used to extract unused RF power and for beam offset measurements. The waveguide is a non-standard size with an internal cross-section of 1.78 mm x 0.723 mm and can be produced by either extrusion or cold drawing. In the extrusion process, the temperature change can cause deformation with shrinkage of the inner walls. Cold drawing pulls the tubing through hardened steel die at room temperature, holding the shape and the tolerance of the waveguide and producing a fine grain structure. Cold drawing is our preferred method to make our custom-made waveguide tubing. As shown in Fig. 6, we plan to use double diamond windows to isolate the CWA system vacuum. After brazing a diamond and a Cu flange, the diamond window unit will be brazed to a flexible waveguide. The 2nd diamond window will be bolted to the 1st diamond window with two O-rings.

Bellows Assembly

A bellows assembly will be utilized to pump out the CWA vacuum chamber module and for proper installation and handling during installation and maintenance. The concept selected utilizes off-the-shelf thin-wall edge-welded bellows allowing a ±2.4-mm translational stroke with four pumping ports, made of stainless-steel 304L or 316L as shown in Fig. 7. We also consider formed metal bellows to compensate for manufacturing and installation misalignment errors.

Transition Section Unit

As shown in Fig. 8, all the components listed above will be brazed together to produce the TS unit for the CWA vacuum chamber module.

FABRICATION CHALLENGES

Successful fabrication of the CWA vacuum chamber module relies on proper brazing and machining techniques [3]. We anticipate several technical challenges in developing the TS unit during brazing of dissimilar or similar metals, micro-machining of the electroformed TS Cu waveguide, and wire-EDM of the TS Cu base, etc.

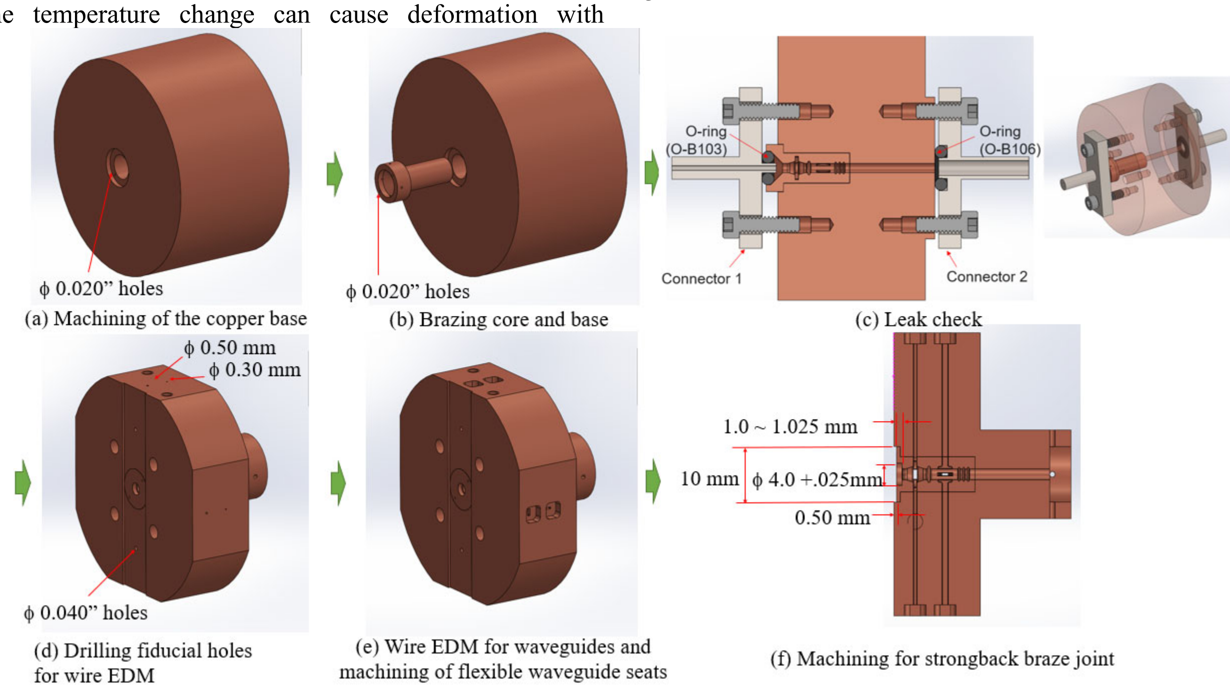

Figure 5: Figures show manufacturing process of the transition section core-base braze assembly.

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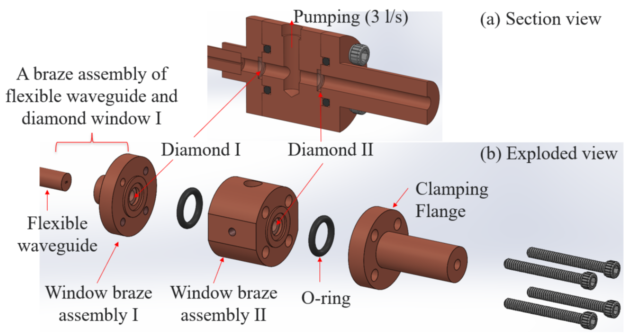

Figure 6: Flexible waveguides and double diamond window assembly.

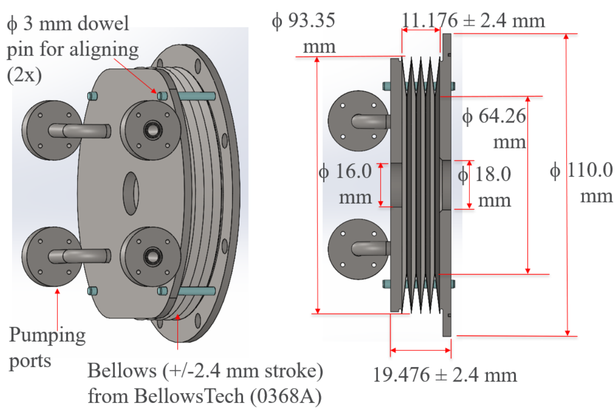

Figure 7: TIG welded stainless steel bellows assembly.

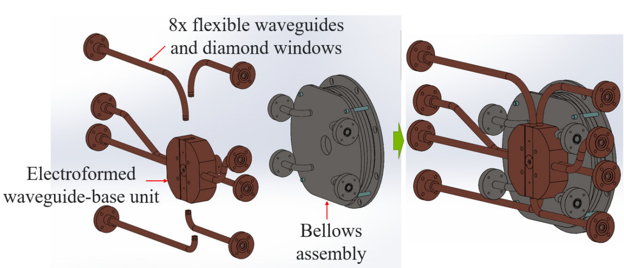

Figure 8: Transition section unit.

Currently, the 35/65 Au/Cu (BVAu-9) brazing filler metal is chosen to braze the TS waveguide-base unit and diamond window flange or assembly. For brazing of the flexible waveguide and the diamond window flange, BVAu-4 is considered as a filler metal to maintain the integrity of previously brazed joints. Then, BVAg-8, having a relatively low melting temperature, is considered as a filler metal to braze the TS waveguide-base unit with eight flexible waveguides. Finally, BAg-7 is considered in brazing of the TS unit, the CTS module, and the bi-metal vacuum flange for the CWA vacuum chamber module.

For successful braze joints, the part must be cleaned appropriately to remove oxides before and after brazing and the joints to be brazed must be designed to have a proper gap clearance for capillary attraction. When we braze, a clearance of 0.038-0.050 mm between the joining surfaces will be maintained. All brazing will be performed in a vacuum furnace that can decompose oxide layers to enhance the base metal wetting properties and reduce metal distortions due to precisely controlled heating and cooling rates [4]. Micro-EDM technology will be utilized to produce micro-features of the internal rectangular waveguide profiles including internal round corners. For achieving high-aspect-ratio micro-features, wire with a diameter as small as 0.020 mm can be utilized, but manipulating and handling wire rods with small diameters is difficult because frequent wire breaks require manual intervention, even tungsten or tungsten carbide rods with diameters in the range of 0.10 - 0.40 mm [5]. Furthermore, the small holes for threading such thin wire rods must be placed in the TS Cu base by drilling or EDM drilling process, as they are in the range of 0.30-0.50 mm diameter with a very high-aspect-ratio as shown in Fig. 5(d). It also requires accurate positioning from fiducial holes in a mandrel and in an electroformed TS Cu waveguide. Common sources of errors include machine positioning, temperature instability, spark gaps, and electrode wear. Thus, care should be taken to keep the permissible tolerances of the wire-EDM process by avoiding any activities that can accumulate machining errors.

CONCLUSION

In this paper, the design and fabrication strategies of the transition section unit and technical challenges anticipated in the fabrication process are discussed. The transition section unit requires multi-step brazing of subsequent lower temperature, micro-drilling, and wire-EDM processes. Future work includes further optimization of the joint geometries, machining tolerances, and machining process through a step-by-step process evaluation in fabricating a transition section prototype.

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