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Manufacturing technology development for an 'angled' accelerator grid segment for DNB Beam Source

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ABSTRACT

The accelerator for the Diagnostics Neutral Beam (DNB) beam source is composed of a multi-aperture grid system with three water cooled grids made from Oxygen free Copper. To achieve the focusing requirements at the distance of > 20 m, the grid segments are designed with two stage angles (0.222° and 0.665°) from the centerline in the horizontal direction. The configuration of this kind of 'angled segment' includes the water cooling channels milled in the angular form, subsequently closed by copper electrodeposition, providing the angles on front and back surface and then drilling of apertures on the angular plane. The long beam path and low energy beam demands the tight tolerances on each of these mechanical features and therefore demands the high degree of manufacturing controls on each of the processes.

To unveil the challenges those could appear during the production of such grid, a 1:1 prototype of the most complex type of grid has been manufactured. This paper shall present the technical data generated out of manufacturing of this prototype, summarizing the recommendations for real grid production on: optimization of the sequence of manufacturing, effect of each of the operations, post-manufacturing handling and identifying the measurement techniques. The experience gathered here provides a recipe for the best manufacturing practices for the accelerators of NB system for ITER and upcoming devices.

1. Introduction

The acceleration system of the Beam Source (BS) of the Diagnostic Neutral Beam (DNB) [1,2] system is composed of water cooled Oxygen-Free Copper (Cu OF) multi-aperture grid systems (composed of Plasma Grid, Extractor Grid and Grounded Grid) which is designed for focusing of beamlets to a focal point located at distance > 20 m from the Grounded Grid [1–3]. The focusing is obtained using a combination of segment angling and aperture offsets. In vertical direction, segments (1&3) and (2&4) are angled by 0.549° and 1.647° respectively. Each segment is shaped in horizontal direction (over length of ~825 mm) to have two stage angles (i.e.0.222°, 0.665°) on each side of centerline (see Fig. 2) and to be fixed on a frame with flat plane, which therefore forms a 'six-planed' grid (see Fig. 1) [3]. Manufacturing of such 'Angled Grid Segment' with stringent functional demands of tolerances on positioning, flatness and angle has been undertaken for the first time to the best of authors' knowledge. Further, geometrically complex aperture shape Fig. 3 is needed to be machined perpendicular to its own plane with very thin material left (1 mm) after milling of water cooling channels and scooping of material (which are required for current distribution in Plasma Grid (PG)). Therefore, need arose to establish a manufacturing methodology along with the impact and interdependence of various operations (i.e. milling of water cooling channel, aperture drilling, copper electro-deposition, material scooping, angled machining to achieve desired angle, and intermediate stress relieving).

A full scale prototype of PG has been manufactured and significant data is available on achievable manufacturing tolerances and a prescription is now available on how to handle the 'angled grid segment' during and after manufacturing. Typical manufacturing sequence followed was: (1) Targets on dimensions (2) Material grade selection (3) Pre-milling (4) Milling of cooling channels and welding of cooling tubes (5) Electro-deposition (6) Machining from ED side and aperture drilling (7) Dimensional inspection for first stage (8) second side aperture machining (9) Dimensional measure-

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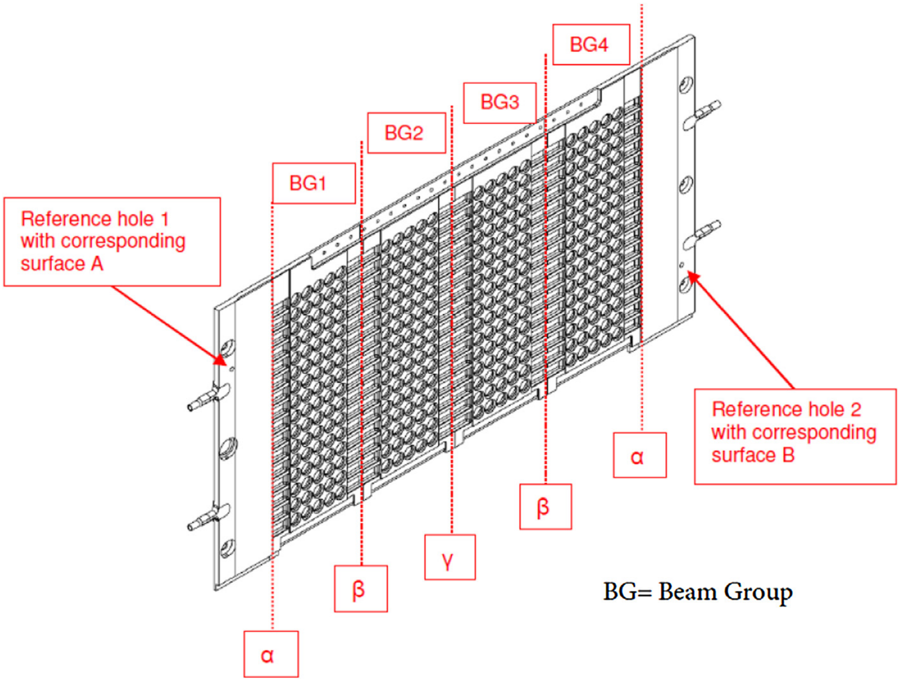

Fig. 1. Characteristics of a grid segment (angles, beam groups, reference planes and holes).

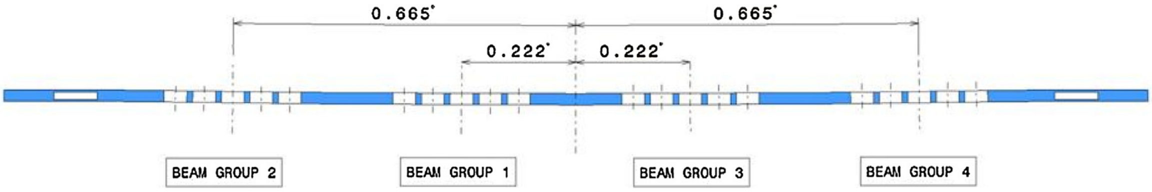

Fig. 2. Bending angles in horizontal direction of the beam groups for a given segment.

ment (10) Electro-polishing and baking at 180 °C (11) Dimensional measurement. The following sections describe some of the major aspects along with the outcome and experience of the manufacturing.

2. Targets on dimensions

The focusing of the beam at the desired distance of >20 m is sensitive to mainly aperture positioning, flatness of plane of individual beam group and angles [2,3]. These parameters have therefore been identified as mandatory dimensional inspection at various stages of manufacturing. As there is no past experience of manufacturing such grid segment available, minimum feasible achievable tolerance on these geometries have been defined together with the manufacturer and they were: aperture positioning tolerance of 50 μm, angle tolerances of +/−0.002^0 and flatness on the individual plane of 40 μm.

3. Material selection and initial milling

From the functionality point of view (mainly for the thermal conductivity), the material desired is CuOF. CuOF in annealed condition was considered as adequate for structural assessment during thermo-mechanical design stage. However, manufacturer had expressed a difficulty in achieving desired accuracies in the manufacturing during the machining of “soft” CuOF. This called for a work hardened material with grade R220 [4] which has superior mechanical properties (Min. tensile strength at room temperature is 220 N/mm^2 and yield strength 140 N/mm^2) compared to annealed material. Even with this higher grade material, the initial milling operation showed up that as soon as the base plate is removed from the vacuum clamping fixture (see Section 4), it bent from short and long direction in the range of 4 mm to 9 mm (see Fig. 4). This experience showed that internal stresses generated during the milling operation are still high and therefore two major improvements have been done as: (1) using the forged plate with higher grade of R240 [4] (2) reducing the milling speed to half. These improvements in process have resulted in better control of the stress and the resulted deformation was limited to 2.6 mm. The

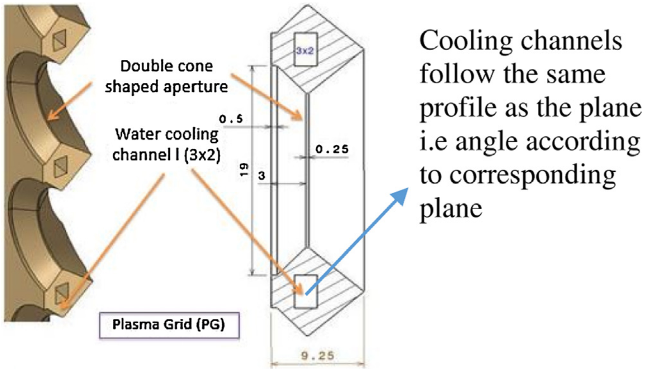

Fig. 3. Geometrical shape of aperture (cross-section through aperture and cooling channel).

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