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THE MANUFACTURING OF THE CSNS DTL TANK

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Abstract

The DTL tank is a crucial component of the China Spallation Neutron Source (CSNS) linear accelerator (LINAC), which mainly use the technology of oxygen-free copper (OFC) electroplating on the inner surface of the 20# carbon steel tube. It is the first time to perform OFC electroplating with high electrical conductivity in the high intensity beam accelerator in China. In the process of cavity manufacturing, problems such as machining deformation, plating surface nodule and plating peeling are encountered. In this project, based on pre-research and information from literature, the formula of acid solution was improved to construct a stable pickling process protocol. The manufacturing process of DTL tank and the measurement details are introduced in this paper.

INTRODUCTION

The CSNS DTL tank is approximately 36m long and contains 4 RF cavities. A total of 153 drift tubes are installed on the top of the cavities. Each RF cavity is equipped with 12 fixed tuners evenly distributed at the bottom of cavity, these tuners are used to compensate for the frequency shift caused by machining errors. 2 movable tuners are also used to modulate local frequency disturbances caused by high frequency heating. The high frequency power is fed by an iris waveguide coupler mounted in the middle of the cavity. There are 12 water cooling channels embedded into the tank out-wall. The tank will operate in a sufficiently high vacuum for RF environment by using 3 turbo molecular pumps and 9 ion pumps per RF cavity [1].

For ease of manufacturing, transportation and installation, each RF cavity is divided into 3 unit sections which can be bolted together [2]. The inner diameter of the unit section is about 566mm, and the length ranges from 2760mm to 3100mm. The manufacturing precision is high, and the key technical indicators are shown in Table 1.

The cavity manufacturing mainly include machining, electroplating, pickling and measuring. The machining factory that cooperated during the pre-research period is replaced by two new manufacturers. The electroplating process is also changed, which must be re-explored. The manufacturing and test details are presented in this paper.

Table 1: Key Technical Indicators of DTL Tank

Indicators	Tolerance
Length (before plating)	-0.30~-0.10 (mm)
Inner diameter (before plating)	± 0.10 mm
Side holes position (before plating)	± 0.10 mm
Plating thickness	0.15 ± 0.05 (mm)
Surface roughness	0.8 um
Plating adhesion	No peeling after baking
Vacuum	≤ 1.0 E-5 Pa

MACHINING

The cavity has a large size, a large number of side holes, and requires high precision. There are 15 key processes in machining, including turning, welding, benching, heat treatment, milling, boring, grinding, measuring, etc. The cylindricity of the cavity 1# machined by manufacturer A is out of tolerance (0.50mm>0.10mm). The precision of milling machine in the manufacturer B is low (the worktable moves 3000mm, its displacement deviation is -0.36mm; the reset deviation is -0.22mm, after the worktable moves 3000mm)，which results in difficulty in fine boring of the side holes on the cavity 2#.

It's analyzed that the reason for the deviation of the cavity 1# is because the process has been reversed between turning the inner surface of the cavity and milling cooling sink around the out-wall. In order to solve the problem, we strengthened communication with manufacturers, reconfirmed the process route, and required manufacturers to strictly implement the process. Offset value is offered by the laser tracker before the fine boring of the side holes on the cavity 2#. Our colleagues were stationed in factories to track the quality of machining at the critical stage of the processing. Finally, we successfully completed the machining of all cavities. The key indicators are shown in Fig.1.

The length precision is partially out of tolerance (Max ΔX=0.13mm), which can meet the design requirements (after plating) by controlling the plating thickness on the end plate. The inner diameter precision of all cavities meets the requirements. The position of all 153 drift tube holes is measured and only 3 out of tolerance (Max ΔX=0.02mm), which we considered to meet the installation requirements.

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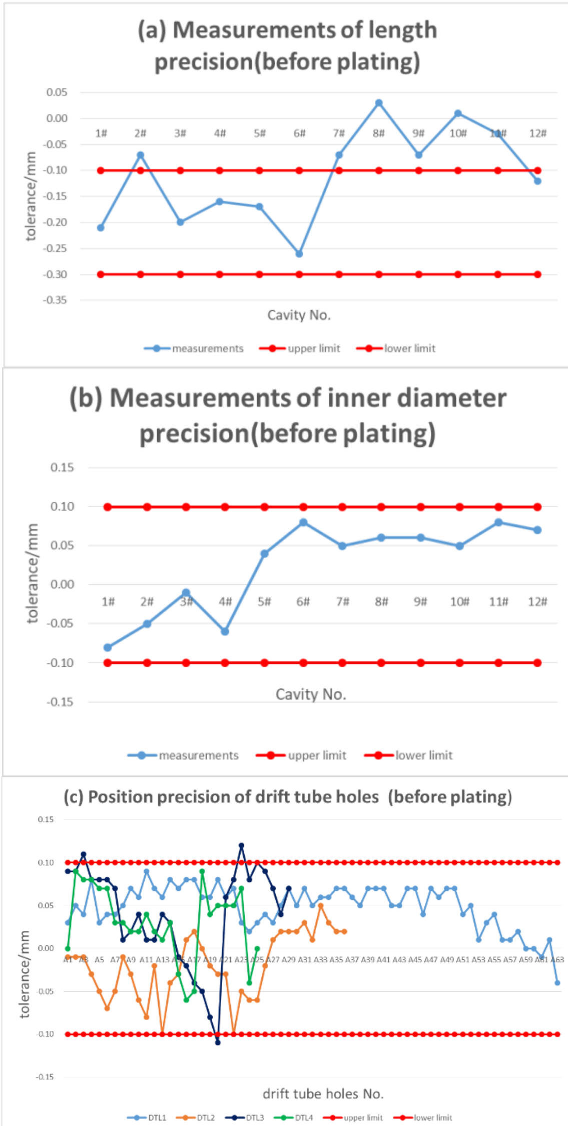

Figure 1: Measurements of the machining: (a) length precision, (b) inner diameter precision, (c) position precision.

ELECTROPLATING

Electroplating is the most critical technic in manufacturing of the cavity. The electroplating process has been changed compared to the pre-research process, which must be re-explored. The new process has led to two difficulties, plating surface nodule and peeling.

Plating Surface and Nodule

All side holes of the cavity 1# are nodulated (Fig. 2) after electroplating. The nodules are in the same direction of each side hole (downward by gravity), and the closer to the bottom of the plating bath, the more severe the nodule.

The main reason for the nodule are as follows: 1) the surface isn't completely degreased before plating; 2) the dirty things flow out of the screw holes to contaminate the plating solution; 3) the anode current density of the side holes is high.

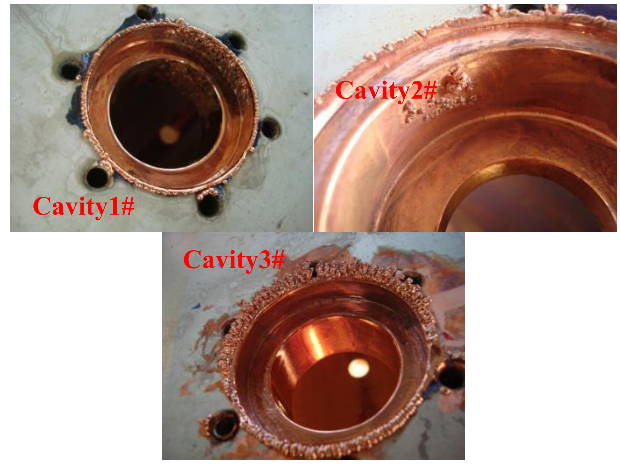

Figure 2: Electroplating of the first three cavities.

We improved the process when plating the cavity 2#, including: 1) the plating solution is equipped with circulating filtration equipment; 2) all the screw holes are blocked with clean rubber; 3) all side holes are installed with flushing pipes; 4) filter bags are installed on all side anodes; 5) reduce anode current. The nodules of the cavity 2# are significantly reduced (Fig. 2).

The process was further improved when plating the cavity 3#: 1) we use a cleaning agent to scrub the oil instead of the electrolytic degreasing; 2) cleaning the anode mud and the filter bag; 3) reduce the copper plating time of the side holes by half. There is no nodule on the inner wall of all side holes after the improvement (Fig. 2).

Plating Peeling

After electroplating, the cavity 2# was cleaned and baked at a high temperature (100℃ for 72 hours), followed by a large amount of peeling phenomenon (Fig. 3), that is ,the plating layer and the substrate were detached.

Figure 3: Plating peeling.

We performed ultrasonic testing on the material to eliminate the possibility of defects in the substrate. It's judged that the factors causing peeling mainly include: 1) machining defects on the surface, such as gear mark, scratches, etc. 2) there are still uncleaned areas on the surface. The following improvements are made: 1) strengthened the surface quality acceptance of machining; 2) strengthened the intensity of degreasing and eliminated the blind spot (Fig.4). The standard of degreasing is that the water film does not crack 30s while washing.

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Figure 4: Surface acceptance and degreasing.

Each cavity was baked and pumped to ensure that the plating and the substrate are tightly bonded. Polishing, brush plating and re-baking are needed in case of some peeling occurred on the inner surface of the cavity after baking and vacuum test. Finally, we solved the problem of plating peeling after improving the process.

Measuring

The plating thickness is controlled from 0.05mm to 0.21mm, and the surface roughness is about 0.5 um<0.8um (Fig. 5).

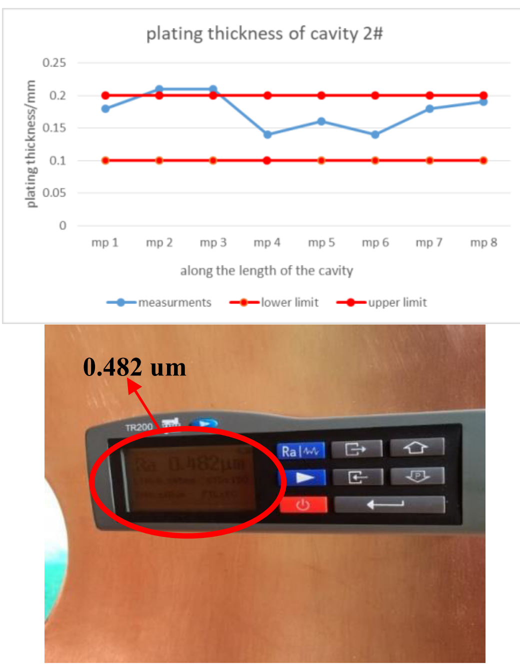

Figure 5: Plating thickness measurements and surface roughness measuring.

The RF properties of cavity 1# and 3# are measured by using network analyser. All holes are covered with copper-plated plugs and RF springs are added for measurement. The results are shown in Table 2, which meet the requirements.

Table 2: RF Parameter Measurements

No.	Measurements (Q_0)	Q	Q_0/Q	Freq. (MHz)
1#	70.099	78.023	90%	405.030
3#	73.126	77.983	94%	404.983

PICKLING

The purpose of pickling is to remove the oxide film on the plating and reduce the possibility of vacuum venting. We improve the acid ratio based on pre-research and form the final formula by carrying out small sample pickling test. The pickling process is also improved. The actual operation proves that the acid ratio is simple, no toxic gas is generated, the operation is simple, the cost is low, the oxide film can be effectively removed and the surface can be passivated.

The main process (Fig, 6) of pickling is as follows: degreasing, water washing (cold, hot) and drying, pickling, wash (tap-water, pure water) and dry, vacuum baking and seal.

Figure 6: Pickling.

We performed vacuum leak detection on all the cavities after pickling, and the leak rate satisfy the requirements. The ultimate vacuum test and residual gas analysis (RGA) were performed on the cavity 2#. The result was that the lowest pressure reached 3.3E-6 Pa, and the RGA spectrum (Fig. 7) showed no macromolecules such as oil. The vacuum test results meet the requirements.

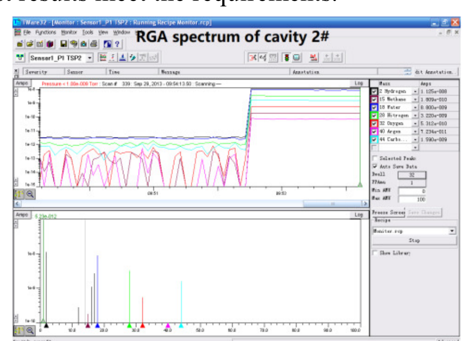

Figure 7: RGA spectrum of cavity 2#.

CONCLUSION

The DTL tank has a large size, a complicated structure, and high precision. Electroplating requires high-precision surface roughness, high uniformity, high electrical conductivity, strong adhesion, complicated process and great difficulty. The manufacturing of the DTL tank lasted 2 years, and the measurement results showed that the final product meet the physical design. In January 2015, the manufacturing of 12 cavities was completed and they were delivered to the CSNS site.

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