

DEVELOPMENT OF LABGENE'S STEAM GENERATORS TUBE TO TUBESHEET WELDING QUALIFICATION PROCEDURE

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ABSTRACT

The welding qualification procedure of LABGENE's – Nuclear Electric Generation Laboratory – Steam Generators has special characteristics due to nuclear class 1 requirements, reduced dimensions of the LABGENE's equipments and combination of the materials involved with the tube to tubesheet welding.

The welding procedure was performed using an automatic orbital welding machine without material addition. The weld joint was simulated using a sample made of a tube (\varnothing ext. 12,7 BWG 18 x 90 mm) in SB-163 N08800 material and a plate (48 x 330 x 55mm) in 20MnMoNi55 material, covered with 8 mm AWS E NiCrFe-3 cladding.

For the development of the welding procedure, a lot of welding simulations were performed using machines and special devices designed for the dimensions of the pieces. Procedures related with operating, handling and cleaning conditions, essential to avoid the contamination of the pieces were issued. It was also developed a mixture of gases which contributed for the homogenising of the welding and also to avoid the appearance of cracks and defects on the weld joint.

The results obtained with the performed tests fulfilled the requirements of the applied specifications and standards.

The welding procedure was developed testing a lot of specimens removed from samples that were representatives of the equipment's tube to tubesheet welding.

1. INTRODUCTION

The LABGENE's – Nuclear Electric Generation Laboratory – Steam Generators are equipments which design was developed by CTMSP – The Brazilian Navy Centre in São Paulo and nowadays are under fabrication by Sulzer Brazil S.A. Company.

Due to its future naval purposes, those equipments have special and exclusive characteristics mainly related to its dimensions, geometry and involved materials.

The tube to tubesheet welding qualification procedure is one of the requirements of CTMSP's technical specification [1] and it is mandatory for the tube to tubesheet welding of the LABGENE's class 1 Steam Generators [2].

Considering the specialty of those equipments, for the correct tube to tubesheet welding the development of a special welding procedure for the first time made in the country was necessary. This work begun in 2003 by the manufacturer Sulzer S.A. and involved a lot of specialists on welding and metallurgical areas and consumed a lot of time, human resources and materials, aiming satisfactory results on the destructive and non-destructive testing required by the applied technical standard [3].

The target of this work is to show the involved activities, the testing results obtained and the learned lessons referred to the development of LABGENE's Steam Generators tube to tubesheet welding procedure.

2. THE LABGENE'S STEAM GENERATORS

On the LABGENE's project, the Steam Generators has the same heat exchange function as in a regular nuclear power plant; however, considering future naval application (ships and submarines) an equipment dimensions reduction was necessary, creating in the country a unique and pioneer design which technology is restricted to few countries in the world.

Comparing the LABGENE's Steam Generators to the same kind of equipment that exist in Brazil on the nuclear power plants Angra I and Angra II and also considering the peculiarities of each equipment, it is possible to see the significant differences between them, mainly related to the discrepancy of weigh and dimensions, quantity of tubes, sheet coating material and tube materials. The following Table 1 shows the comparative between the Steam Generators existing in Brazil considering general technical information:

Table 1. Comparative of Steam Generators existing in Brazil

Item	Angra I Westinghouse EUA	Angra II (Manufactured in Germany)	LABGENE Sulzer Brazil
Weigh x Length	> 300 ton > 20 m	> 400 ton > 20 m	> 10 ton > 4 m
Quantity of Tubes	> 5.000	> 4.000	> 1.000
Diameter of Tubes	Ext. 19,05 mm Int. 17,32 mm	Ext. 22 mm Int. 19,6 mm	Ext. 12,7 mm Int. 10,2 mm
Tube Material	"Inconel 690"	SB 163 N08800	SB 163 N08800
Coating Material	AWS E NiCrFe3	AWS E NiCrFe3	AWS E NiCrFe3
Welding Procedure	Automatic without addition material	Automatic with addition material	Automatic without addition material

Taking into account that the welding qualification procedure shall simulate, as similar as possible, the welding conditions during the manufacturing of the components, both the reduced equipment dimensions and the materials used on the LABGENE's Steam Generators

fabrication, contributed to increase the difficulty to perform the tube to tubesheet welding qualification procedure. In special, related to the reduced equipments dimensions, there is an additional difficulty for the fabrication of these components due to the short distance between the tube to tubesheet welding and the difficulty for the welders to reach the welding region. The dimensions of the water chamber on the primary circuit side of the equipments are so limited that the inspection of its interior or the tube to tubesheet welding inspection is a very stressful work [4].

The technological development of a nuclear Steam Generators tube to tubesheet welding is a complex process with requires a high volume of testing and evaluating, considering that the adjusts and optimization of the welding process are made thought several cycles of welding-testing-evaluating-modification-welding [4].

3. DEVELOPMENT OF THE WELDING PROCEDURE QUALIFICATION

The activities for development the LABGENE's Steam Generators tube to tubesheet welding qualification begun in September, 2003 by the manufacturer Sulzer Brazil S.A., however, only in December, 2006 it was possible obtain the final qualification.

The great difficult to obtain the approved results of testing were justified by the appearance of weld defects as such: porosity, undercut, cracks, lack of fusion, irregular geometry and visual aspect of weld joint.

Although the fabrication of Steam Generators for nuclear power plants and other nuclear applications have been made for more than 40 years, the technology involved in the welding process is complex and is under permanent evolution.

For this welding qualification procedure, it could be stated that the following parameters are the most important to reach the best results:

- welding process;
- weld joint;
- pre- expansion of tubes;
- welding parameters and weld machine;
- gas mixture; and
- surface cleaning

For the development of LABGENE's Steam Generators tube to tubesheet welding qualification procedure, a lot of testing samples were manufactured, representatives of the tube to tubesheet welding conditions according to the Figures 1 and 2.



Figure 1 – Testing sample



Figure 2 – Testing sample – Tubes detail

Following the tube to tubesheet welding qualification procedure, after de welding had been executed; the coupons were cut and delivered to the Laboratory for Macrographic testing. The required acceptance criteria were no indication of defects, as shown on the following Figures 3 and 4 [1, 2].



Figure 3 – Weld Joint Macrographic without indication of defects

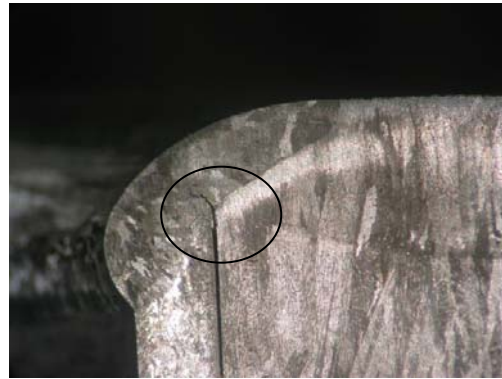


Figure 4 – Weld Joint Macrographic with indication of defect (crack)

3.1 Welding Process

Considering the history for Steam Generators fabrication in the entire world, the **Gas Tungsten Arc Welding (GTAW)** [5] welding process, was chosen for welding the LABGENE's Steam Generators.

Due to its reduced dimensions and difficulties of access and visualization inside the water chamber, it was necessary to choose for the LABGENE's application the automatic welding process without material addition.

Beyond the definition of the welding process, other important variables and parameters had to be frequently changed until the approved results of testing were achieved.

In performing an extensive investigation work, research and analysis of results and with the consequently modification of some important variables of the process, the first approved results began to appear.

Next, a new step of the work was started, aiming the development of the reliability and repeatability of the welding process.

The approval of the automatic welding process without the addition of material, associated with the materials involved in the welding joint of the LABGENE's Steam Generators, resulted in the creation of a pioneer welding process, which was never been performed before in the country.

3.2 Weld Joint

According to CTMSP's technical specification [1], at the execution of the welding qualification procedure, the components welding conditions, which will be used on the equipment, shall be simulated as faithfully as possible.

For this welding qualification procedure a testing sample was performed with the following characteristics:

- Materials: 20MnMoNi55 (testing plate) + AWS E NiCrFe3 (coating) SB163 N08800 (tube); and
- Dimensions: 90 x 60 x 260 mm

In the specific application of LABGENE's Steam Generators, the weld joint is made by a plate in SA-508 cl.3 material, manually coated by 8 mm electrode AWS E CrNiFe3, which will be welded to a "U" tube Φ ext. 12,7 mm BWG 18 in SB-163 N08800 material.

The following Figure 5 presents a draft of weld joint of the testing sample related to the welding qualification procedure of the LABGENE's Steam Generators.

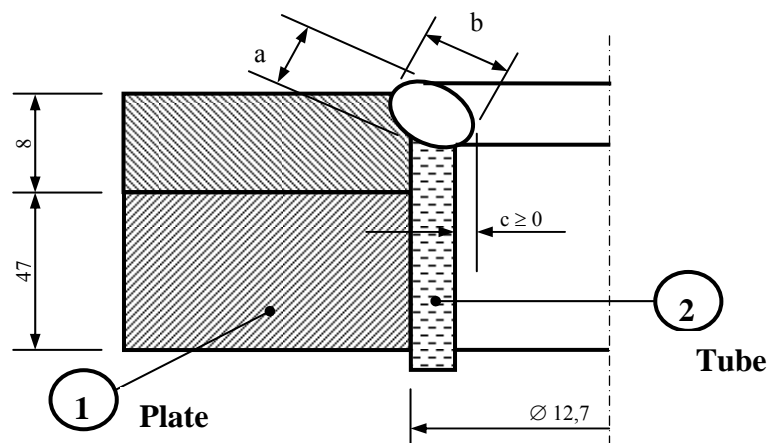


Figure 5 – Weld Joint of the testing sample

During the development of the welding qualification procedure, it was verified that beyond the cleaning and drying aspects of the pieces, probably responsible for the occurrence of porosity, the tube positioning parameters related to the sheet face and the electrode positioning related to the tube, had a great contribution for the first approved testing results.

3.3 Pre-expansion of Tubes

The pre-expansion is a mechanical process used to expand the tubes, with the function to provide a preliminary fixing of the tubes and guarantee the perfect contact of the external

surface of tubes with the internal wall of the holes in the tubesheet, before starting the welding process.

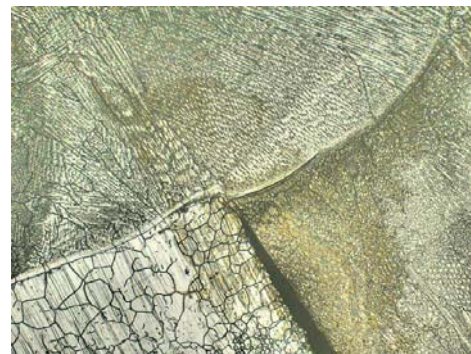
During the development of LABGENE's Steam Generators tube to tubesheet welding qualification, it was verified that the perfect execution of the tubes pre-expansion was an important variable to avoid defects in the welding, mainly related to gap termination (Figure 6), cracks and excessive gap between the external diameter of tubes and internal wall of the holes in the sheet.

According to the performed tests, the essential variables for better results on the pre-expansion process (Figure 7) were as follow:

- Machining of tubes and tubesheet holes with high precision;
- The expansion tool shall be perfectly positioned in the internal surface of tube;
- The expansion tool consumable pieces shall be changed when wearing signs are showed; and
- Preferably, an expansion machine with electronic torque control shall be used, which gives results with more homogeneity and superior quality than the conventional machines existing in the market. The use of this machine also contributes to the reduction of time involved in the pre-expansion of tubes process, minimizes the defects occurrence and, finally, increases the productivity and uniformity of the tube to tubesheet welding.



**Figure 6 – Tube to tubesheet welding
Macrographic “gap termination”**



**Figure 7 – Tube to tubesheet welding
Micrographic without defect**

After performing a lot of simulations, considering the LABGENE's Steam Generators weld joint characteristics, the following pre-expansion parameters were adopted:

$$\left\{ \begin{array}{l} \text{Pre-expansion} = 8 - 10 \% \\ \text{Torque} = 2 - 3 \text{ Nm} \\ \text{Depth} = 8 - 12 \text{ mm from the face of tube} \end{array} \right.$$

3.4 Welding Parameters and Weld Machine

The orbital welding machine used for the tube to tubesheet welding qualification procedure was a 227 – OW model, manufactured by ARC MACHINE Company.

The equipment used consisted basically by the following components:

- a) Programmable continuous current welding source;
- b) Orbital welding head; and
- c) Orbital head cooler.

The welding process GTAW was totally automatic, without addition of material and used a specific orbital head with its reference center positioned on the tube that had to be welded.

The characteristics of this welding machine allowed the use of the previously defined parameters and the implementation of the programmed welding sequence, which are important variables to obtain approved results of testing. The following Table 2 shows the significant welding parameters.

Table 2. Welding Qualification Procedure Parameters

Weld		Technical	Position	Welding Parameters																
S e q	Level	Automatic Orbital Welding Process	Welding Position	Pre-Purge (sec.)	Pos-Purge (sec.)	Down-Slop (sec.)	Rotation	Delay (sec.)	Start Currency level (STLV)(A)	RPM	Time (sec.)	High Current (A)	Lower Current (A)	Tension (V)	Time High Current	Time Lower Current	Current and polarity	Shield Gas [l/min]	Pre-heat mín. [°C]	

The determination of the welding parameters is concerned to the weld joint geometry, the involved materials and the welding sequence that was defined as ideal to avoid defects on the weld such as: undercut porosity, cracks and lack of fusion.

3.5 Gas Mixture

The gas mixture used on welding process has a fundamental importance because beyond the atmosphere protection against particles, it contributes with the homogenization of material fusion involved with the welding. During the development of the tube to tubesheet welding qualification procedure many different gas mixtures were used. The following Table 3 resumes the results obtained:

Table 3. Welding Process Gas Mixtures

Gas Mixtures	Composition (%)	Results
Air	99,99	Reproved
Air + H ₂	95 + 5	Reproved
Air + H ₂	90 + 10	Reproved
Air + He	75 + 25	Approved

3.6. Surface Cleaning

The surface cleaning of weld joint pieces is considered an essential variable to obtain approved results of testing on tube to tubesheet welding of the LABGENE's Steam Generators. Previously performing of the welding qualification as well as for the welding of the equipments, a perfect cleanness of components according to the applied procedure [6] shall be done inside a Clean Room area.

According to the issued cleaning procedure, the internal surface of the tubesheet holes shall be previously washed and cleaned with demineralized water. The tubes shall be assembled immediately after opened its plastic packages. Before the insertion of tubes, the tubesheet surfaces shall be softly cleaned with isopropilic alcohol to remove any existing signs of grease and oil.

Finally, the tube to tubesheet contact surfaces shall be carefully polished using a dry cloth which must not leave small particles on the contact surfaces. The handling of pieces shall be done carefully to avoid any damage to the contact surface or leave any residual particles which could affect the quality of the tube to tubesheet weld.

The perfect cleaning of the contact surfaces deeply contributed with the positive results of the welding process, due to the removal of eventual contaminants, improving an adequate contact between the components surfaces and reducing the appearance of porosity and surface defects on the tube to tubesheet weld.

4. CONCLUSIONS

The development of LABGENE's Steam Generators tube to tubesheet welding procedure expended during many years until its conclusion a lot of working hours, material and human resources involving a lot of professional specialist in the welding, metallurgic and inspection areas. All these efforts resulted on the development of unique and pioneer welding process know-how in the country, considering the equipments application, dimensions, material and applied welding process.

Taking into account an expressive work of research, simulation and repetition of many welding parameters and sequences, it was possible to obtain approved results of testing with undeniable quality on the welding qualification procedure and tube to tubesheet welding of the LABGENE's Steam Generators.

The performed work shows the capacity of the Brazilian professionals and industry to overcome challenges and develop technologies on nuclear area.

ACKNOWLEDGMENTS

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