EXPERIENCES OF A SPANISH SUPPLIER OF STEAM GENERATORS

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INTRODUCTION

Equipos Nucleares, S. A., hereinafter called ENSA, was created in 1972 as a result of the Administration's invitation to increase the national level of participation in construction of the Spanish Nuclear Power Plants Program. As a result, ENSA was conceived to undertake the manufacture of the main primary circuit components: Reactor pressure vessels, steam generators, pressurizers, core structures and primary piping.

From the very beginning, we were conscious of the different technologies involved in the Spanish nuclear program and we established the required capacities to satisfy market demands. Such a technological diversification has allowed us to become an unique case in the world, as we have had the opportunity to work with technologies from Westinghouse, KWU, General Electric and other customers who have helped us "to understand" several techniques and to reach the highest technological level.

MAIN FACILITIES

To undertake the above mentioned manufacturing program, ENSA was designed with facilities not commonly found in the domestic market. A summary of such facilities is shown below:

- Three bays with a total surface area of 18,000 m^2 and handling capacity of 225 t, 325 t and 900 t, respectively.
- Schiess vertical boring machine with 7 m diameter (maximum of 12 m) and a maximum weight of 250 t.
- INNSE machining center with two milling machines with mobile heads & columns. Rotation table and internal tower with numerical control.
- Deep drilling machines (2) Deepmatic type, with n.c. and three spindles with capacity to drill one meter.
- Welding equipment: Safex, C3, C2, TIG, CT-300, plasma, AGA-GAS, SAF-MIG-355, TIG A MATIC, etc.
- Positioners of 250 t, Teledynes and Bode with adjustable turning speed.

The following auxiliary installations were also built: shut-blasting station, radiographic bunker with linear accelerator, heat treatment furnace for pieces up to 17 m long, 12 m hydraulic pit, mechanical shop with lathes and milling machines with n.c., etc.

ENSA's organization was designed with special care insofar as its capacities in the engineering and quality assurance areas. Knowledge of the ASME Code, TUV requirements and Customer specifications was given special attention.

A complete Welding laboratory with Metrology, Metallographic, Chemical and Non-Destructive equipment and capacities was included.

MAIN STEAM GENERATOR CHARACTERISTICS

We consider the Steam Generators to be the components requiring a maximum number of manufacturing techniques. Therefore, we will concentrate our article on the main steps involved in manufacturing S.G.'s.

We will start by describing the different steam generators that have partially or totally been manufactured at the ENSA shop:

- Three models "E-2" Westinghouse type for Sayago Site.
- Three models "F" Westinghouse type for Vandellos Site.
- One model "D" Westinghouse type for Lemoniz Site.
- Six models "54CT" KWU type (with preheaters) for Trillo Site.
- Four KWU type (without preheaters) for Konvoi project.

Table I shows the main characteristics of the steam generators, describing the different manufacturing processes used for each one.

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T I
Main steam generator data

Data/Site	Trillo-I/II	Konvoi (1)	CN Sayago (2)	CN Vandellos
Design	KWU	KWU	Westinghouse	Westinghouse
Type	Vert-Haz U-tube	Vert-Haz U-tube	Vert-Haz U-tube	Vert-Haz U-tube
Power	1009 Mw	1300 Mw	900 Mw	900 Mw
No. of TIES	3	4	3	3
Pressure/temp. design				
– Primary	178,5 kg/cm^2 350 °C	–	174 kg/cm^{2-} 343 °C	174 kg/cm^{2-} 343 °C
– Secundary	89 kg/cm^2 350 °C	–	90 kg/cm^{2-} 316 °C	83 kg/cm^{2-} 316 °C
Weight	440 t	–	413 t	313 t
Total length	21.500 mm	5.540 mm	22.000 mm	20.600 mm
Upper part diam.	4.610 mm	–	5.040 mm	4.476 mm
Lower part diam.	3.700 mm	3.667 mm	3.768 mm	3.454 mm
Max. wall thickness	135 mm	155-mm	114 mm	130 mm
Tube sheet thick.	700 mm	700 mm	–	534 mm
Number of U tubes	4.000		–	5.626
Tube dimensions	Ø 22 x 1,2	–	–	Ø 17,32 x 0,91
Preheater	Sí	No	Sí	No
Feedwater in.	Upper+Power level (Aux. & emerg.)	Upper level	Upper level	Upper level
Materials:				
Shells	20MnMoNi55 (Laminated)	20MnMoNi55	SA-533Gr.A Cl.2	SA-533 Gr. A Cl.2
Upper bottom	Laminated " (Conformed)	–	" Gr.B	"
Lower bottom	" (Conformed)	–	" Gr.B	SA-216 Gr. wcc (cast.)
Tube sheet	" (Wrought)	20MnMoNi55 (Wrought)	–	SA-508 Cl.2a (Wrought)
Nozzles	"	"	SA-508 Cl.2a	SA-508 Cl.2a (Wrought)
Tube bundle	Incoloy 800	–	–	SA-166
Baffles	1.4541 (DIN 17440)	–	–	SA-240 Tp-304
Processes:				
Rottom Cladding	SAW Banda+SMAW Austenitic Stainless	–	SAW-Banda aus.	SAW-Banda aus.
Tube sheet cladding	SAW Banda+SMAW	SAW Banda+SMAW with Inconel 600	–	MIG with wire
Tube-Tube sheet weld.	TIG aut. pressing (with wire)	–	TIG without wire	TIG without wire
Tube expansion	2 zones (primary & secondary) Mechanical step	–	Hydraulic	Hydraulic
Tests:				
Superficial NDE	Liquid penetrant Magnetic Particle	Liquid penetrant Magnetic Particle	Liquid Penetrant Magnetic Particle	Liquid Particle Magnetic Particle
Volumetric NDE	Ultrasound Radiography	Ultrasound Radiography	Ultrasound Radiography	Ultrasound Radiography
Hydrostest:				
– Primary	233 kg/cm^2	–	217 kg/cm^2	217 kg/cm^2
– Secundary	116,7 kg/cm^2	–	112 kg/cm^2	103 kg/cm^2
Helium test	Yes (max. allowable leak) 1 x 10^{-7} std. cc./sec.)	–	Yes	Yes
Extens. measures	No	–	No	No

Notes:
(1) ENSA only manufactured the tube-sheet subassembly and upper shell, including tube-sheet drilling.
(2) ENSA did not manufacture upper port of S.G.

SPECIAL PROCESSES

ENSA has developed and qualified several processes to manufacture the referenced S.G.'s. The main processes are described hereinbelow:

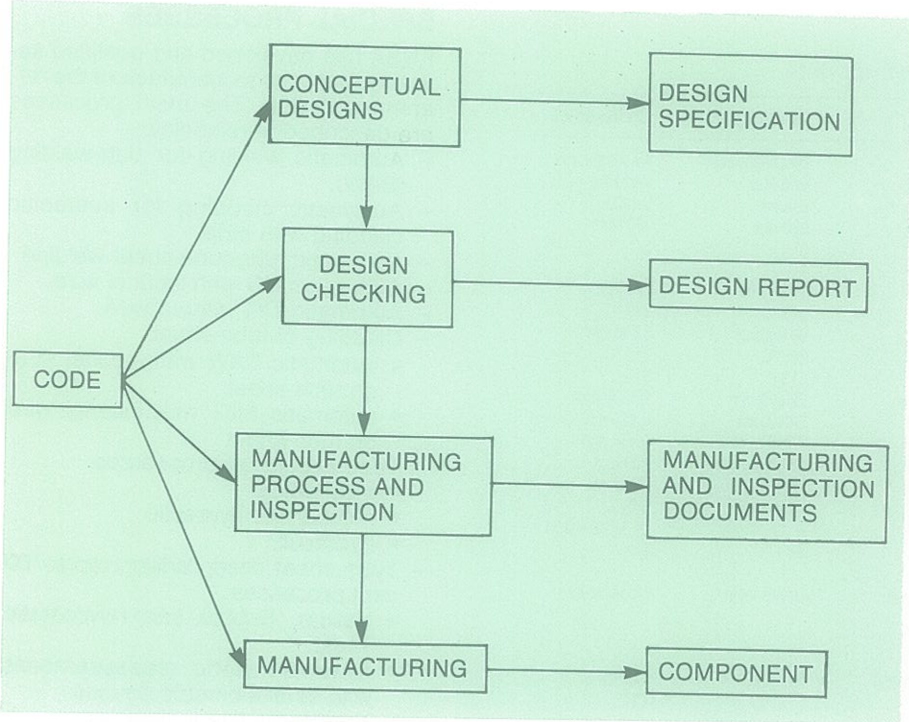
- Automatic welding for butt-welding (SAW).
- Automatic cladding for austenitic cladding with strip.
- Automatic tube-tube sheet welding.
- Automatic TIG with inconel wire.
- Automatic TIG without wire.
- Cladding of tube-sheet:
  - automatic SAW with inconel strip on tube-sheet
  - automatic MIG with inconel wire on tube-sheet
- Tube expansion procedures:
  - mechanical
  - mechanical-hydraulic
  - hydraulic
- Tube sheet deep drilling (up to 700 mm) processes.
  - Helium, Bubble and Hydrostatic Tests.
  - Extensiometric measurements with extensiometric gauges.
  - Nondestructive techniques.

MAIN MANUFACTURING STEPS

Processes used during manufacture of the intermediate section of the S.G. are the most critical ones. We describe some of them that are performed inside a special area identified as the "clean area", where special cleanliness and control requirements are in force.

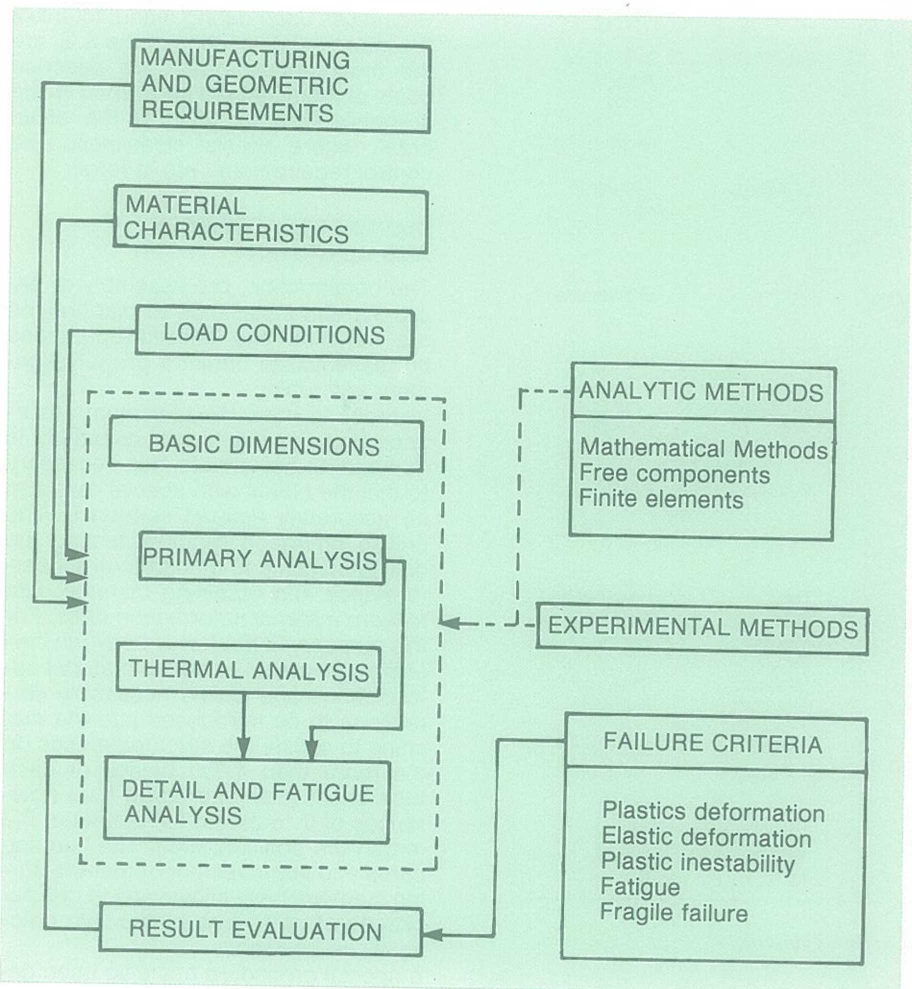
DIAPHRAGM ASSEMBLY AND ALIGNMENT

The construction, pre-assembly of packages and installation of diaphragms are complex and difficult operations but essential to obtain a proper alignment and tubing.
In order to have the maximum assurance that the diaphragm assembly is going to be acceptable, it is necessary to drill the plates with special care and an accurately defined sequence. The drilling operation requires testing the drilling machine to monitor correct performance and obtaining material data to learn material deformation rates. For this purpose, ENSA has already run several experiments to obtain material deformations and define necessary corrections to be introduced into the machine to satisfy the strict tolerances on the more than 4.000 holecs of each tube sheet (diameter 3.000 mm) (tolerances of 0.15 mm to the diameter, 0,2 mm in the position, etc.). The learning curve and improvement of manufacturing methods have allowed us to drill packages of up to nine plates with practically no deviation.
A special procedure has also been de-



F I *Design and manufacture of a steam generator*

F II *Analysis justification*



veloped to process the data from control equipment (optical alignment telescopes) through a computer program and provide the necessary modifications to optimize the alignment.
The above performance and a detailed and conscious dimensional control of the structuring of grids, tie-rods, separator tubes, etc. will assure an adequate tubing operation.

TUBE-TUBE SHEET WELDING

Experience shows that the tube-tube sheet weld is the most critical point of the steam generator. Any of the thousands of identical welds have to assure the integrity of the generator. The individual welds are required to show "no indication" under liquid penetrant test, and leakages between $1\times 10^{-6}/1 \times 10^{-7}$ std.cc/sec. when subjected to the helium leak test.
To obtain such a quality, ENSA has qualified several tube-welding and tube-expansion procedures which are shown in Table I. It has also been necessary to homologate equipment and operators, and any modifications of parameters and/or equipment have also been homologated.
Further to the requirements described above, it is necessary to perform a thorough and detailed follow-up of the operations, shift by shift and operator by operator. At the beginning of each shift, coupons with identical requirements as for the steam generator have to be manufactured and tested daily to monitor that quality established during qualifications is maintained during manufacturing performance.

DESIGN JUSTIFICATION

ENSA has run stress calculations on all components of the primary circuit of steam generators. However for purposes of this article, we believe it is advisable to describe the calculation process we have followed.
The mechanical design of the S.G. is based on the stress analysis justification concept. This concept is defined in design standards such as ASME Code and KTA rules. Following this philosophy, the design study of the S.G. is performed in the following steps:

- Design and operational condition definition.
- Material selection.
- Stress design justification.
- Document preparation for manufacturing, testing and opeation of S.G.'s.

The complete sequence is shown in Table I.
On customer requirement, ENSA is responsible for monitoring the mechanical design, according to the standards, codes and requirements applicable on

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