RESEARCH ON THE TECHNOLOGY OF MANUFACTURING A HEAT EXCHANGER ASSEMBLY USED AS A PART OF AN ELECTRICALLY DRIVEN CENTRIFUGAL AIR COMPRESSOR CCAE 15-300

Andrei Mitru[1], Mircea Mitru[2] and Augustin Semenescu[3,4]
[1] National Research and Development Institute for Gas Turbines COMOTI, blv. Iuliu Maniu, no.220 D, Bucharest, Romania
andrei.mitru@comoti.ro
[2] National Research and Development Institute for Gas Turbines COMOTI, blv. Iuliu Maniu, no.220 D, Bucharest, Romania
m.mitru@yahoo.com
[3] University Politehnica of Bucharest, 313 Splaiul Independentei, 060032, Bucharest, Romania,
augustin.semenescu@upb.ro, http://www.upb.ro
[4] Academy of Romanian Scientists, 3 Ilfov, 050044, Bucharest, Romania, http://www.aosr.ro

ABSTRACT: The paper presents the technical and operational characteristics of the heat exchanger assembly for a centrifugal air compressor CCAE 15-300. The structure and the component parts of the heat exchanger assembly are shown in the paper. The basic materials and the main characteristics of the components are described in the paper. The main objective of this article is represented by the description of the technology for manufacturing the components and the heat exchanger assembly by soft soldering with tin.
KEYWORDS: **soldering. heat exchanger assembly, manufacturing technology, centrifugal air compressor**

1. INTRODUCTION

CCAE is an electrically driven centrifugal air compressor and is intended for supplying the necessary industrial compressed air. For reasons of improving the performance of the installation, the aim is to optimize / modify the CCAE 15-300 compressor by redesigning the four stages of air compression and adding the fifth stage, according to an architecture already known to the CCAE 21-300 compressor. The optimization and modification will be made due to the need to increase the nominal flow of the installation, from 4,32 kg / s to 5 kg / s and to increase the discharge pressure from 15 bar to 25 bar.


Figure 1. View of electrically driven centrifugal air compressor CCAE [1]

The five stages of the air compression compressor are individually formed by a centrifugal rotor with backward curved blades, mounted on its own pinion and a palletized stator. The five sprockets, one for each compression stage, are part of the compressor multiplier.

The multiplier consists of a large diameter main gear, which is driven directly by the electric motor through a double tooth coupling and the five rotors driven by the main wheel, each at its optimum speed. The multiplier, together with the first four stages of compression are mounted in a poured housing, called a compressor housing.

After steps I, II, III and IV, an internal heat exchanger is placed, with the role of moving the temperature of the compressed air at the exit of the respective stage. After the fifth stage of the compressor, the heat exchanger will be mounted outside.

After each heat exchanger, a drop separator will be installed to remove condensation from the air flow, resulting from the cooling of the air when passing through the exchanger.

Heat exchangers and condensate separators are mounted in a second welded housing, called the rear housing and the fifth compression stage has a separate housing, attached to the compressor housing.

2. OVERVIEW AND STRUCTURE OF THE HEAT EXCHANGER ASSEMBLY

The air-water heat exchanger assembly of CCAE 15-300 has the following operating parameters:

- For the air circuit:
  - A nominal flow of 4,4 kg / s;
  - A maximum inlet temperature + 140°C;
  - A maximum outlet temperature + 40 ° C.
- For the water circuit:
  - A flow rate of 38,5 ÷ 48,3 m^3 / h;

- An inlet pressure of 2,5 ÷ 3,5 barg;
- A maximum inlet temperature of 30 ° C.

- The maximum dissipated thermal power is 445 kW.

The main components of the heat exchanger assembly are:

- Front tubular board, 1 pc, base material 1.4306 (X2CrNi19-11 according to EN 10088-1 or 304L according to AISI / SAE or S30403 according to UNS) which is a chrome-nickel austenitic stainless steel with low carbon.
- Rear tubular board, 1 pc, base material 1.4306 (X2CrNi19-11 according to EN 10088-1 or 304L according to AISI / SAE or S30403 according to UNS) which is a chrome-nickel austenitic stainless steel with a low carbon content.
- Exchanger element subassembly 288 pcs, composed of:
    - 28x1 mm pipe, 1 pc, basic material Cu 99,9;
    - 13x1 mm pipe, 1 pc, basic material Cu 99,9;
    - Fins, 3 pcs, basic material Cu 99,9, sheet with a thickness of 0,15 mm.
- Central tube subassembly, 1 pc, base material 1.4306 (X2CrNi19-11 according to EN 10088-1 or 304L according to AISI / SAE or S30403 according to UNS) which is a chrome-nickel austenitic stainless steel with a low carbon content.
- Spirometallic gasket, 2 pcs, GS mark Ø277 x Ø260 x 4,5, base material 321 + graphite.
- Screw N10x30, 12 pcs, according to ISO 40017.
- Grower washer N10, 12 pcs, according to SR 7666-2, basic material OLC 55A
- Cavil, 5 pcs, base material 1.4306.
- Stiffening rod, 6 pcs, base material S355JR.
- Spacer, 24 pcs, basic material S235JR.
- Sealing ring Ø16xØ24x1,5, 12 pcs, base material Cu 99,9.
- Lifting connection, 12 pcs, base material S355JR.
- Elastic bushings, 576 pcs, viton base material.
- Outer mantle subassembly, 1 pc.
- Screw M5x8 mm, 6 pcs, according to ISO 4017.
- Sealing element, 2 pcs, basic material nitrile rubber.

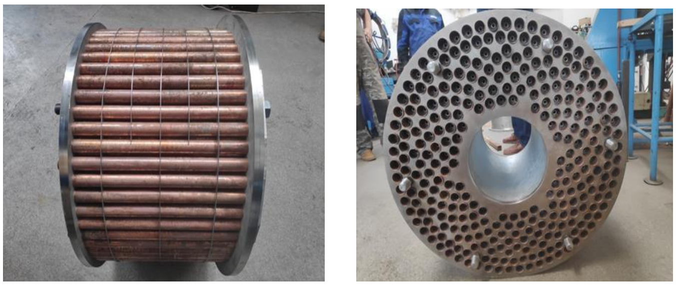

Figure 2. Side and frontal view of the heat exchanger assembly

3. MATERIALS USED IN THE MANUFACTURING OF THE HEAT EXCHANGER ASSEMBLY

3.1 Stainless steel 1.4306

1.4306 stainless steel (X2CrNi19-11 according to EN 10088-1 or 304L according to AISI / SAE or S30403 according to UNS) is a chrome-nickel austenitic stainless steel with a low carbon content. The type of 304L stainless steel is a variant of the basic type 304 which, due to its low carbon content (maximum 0,03% compared to maximum 0,08%) eliminates carbide precipitation due to the welding process. Consequently, this alloy can be used in a normal state even in severe corrosion conditions. Also, the need to anneal welded parts is eliminated, except for applications where their stress relief is explicitly requested.[2]

The chemical composition, mechanical properties and physical properties of this material are described in Table 1, Table 2 and Table 3, respectively.

% C	%Si	%Mn	%Cr	%Ni	%N	%P	%S
≤ 0,03	≤ 1,0	≤ 2,0	18,0 ÷ 20,0	10,0 ÷ 12,0	≤ 0,11	≤ 0,045	≤ 0,015

Table 1. Chemical composition of stainless steel 1.4306

Hardness HB30 HB	0,2 % Flow limit R_p N/mm^2	Traction resistance R_m N/mm^2	Elongation A_5 %	Elasticity kN / mm^2
≥ 215	≥ 180	460 ÷ 680	45 / 35	200

Table 2. Mechanical properties of stainless steel 1.4306 at 20°C

Density g / cm^3	Specific heat capacity J/kg K	Thermal conductivity W / m K	Electrical resistance $\Omega\ mm^2 / m$
7,9	500	15	0,73

Table 3. Physical properties of stainless steel 1.4306 at 20°C

The annealing and stress relief of the welded parts with the basic material 1.4306 / 304L is performed at a temperature of 399 ° C maintaining the level for 0,5 ÷ 2 hours.

Another feature of 1.4306 / 304L stainless steel is the high degree of cold plastic deformation. Sheet metal parts can be easily formed or expanded into various shapes and sizes, immediately followed by annealing or stress relief.[3]

The weldability of the parts from this basic material is very good, in most cases no special conditions are imposed for the achievement of the welded joints. A special problem is represented by the tendency of hot cracking due to the formation of ferrite in the weld joint.

The 1.4306 stainless steel type has a wide use in the automotive, chemical, textile, pharmaceutical, aeronautical industries and is delivered in the form of sheets, pipes, bars, wires, forged products.

3.2 Copper-based alloy having Cu 99,9

Copper-based alloy Cu 99,9 is characterized by a very good electrical and thermal conductivity. The alloy is malleable, having a good ductility and a high degree of cold plastic deformation. Sheet metal, parts and pipes can be easily formed into a variety of shapes and sizes.[4]

The chemical composition, mechanical properties and physical properties of the copper-based alloy Cu 99,9 are described in Table 4, Table 5 and Table 6, respectively.

% Cu	% Bi	% Pb	% O	% Other elements
99,9	max. 0,0005	max. 0,005	max. 0,040	0,03

Table 4. Chemical composition of copper-based alloy Cu 99,9

Traction resistance Rm MPa	Flow limit $Rp_{0,2}$ MPa	Elongation $A_{100\ mm}$ %	A %
250	min. 200	min. 8	min. 12

Table 5. Mechanical properties of copper-based alloy Cu 99,9 at 20°C

Density g / cm^3	Solidification °C	Electric conductivity %IACS	Thermal conductivity W / m K	Thermal expansion µm / m K
9,0	1070	100	390	17

Table 6. Physical properties of copper-based alloy Cu 99,9 at 20°C

Copper-based alloy Cu 99,9 has a wide use in the automotive, IT, construction, electrical, mechanical, aeronautical industries and is delivered in the form of sheets, pipes, bars, wires, semi-finished products.[4]

3.3 Soldering alloy LP60 / Sn60Pb40 (tin)

The LP60 / Sn60Pb40 alloy for soldering copper pipes with tubular plates front and back in stainless steel, is a material widely used for soldering copper parts with nickel and steel alloys.

This alloy is used for general soldering, but is not used for soldering in drinking water systems and it is not recommended to use soldering alloy for joints subject to high stresses or vibrations, due to the lack of sufficient elongation properties.

The melting point of the soldering alloy is between 183° C ÷ 190° C, and its density is 8,95 g / cm^3.

The soldering alloy LP60 / Sn60Pb40 (tin) has a wide use in the aeronautical, automotive, electrical, IT, construction, mechanical industries and is delivered in the form of wires, bars and rods.

4. MANUFACTURING TECHNOLOGY OF THE HEAT EXCHANGER ASSEMBLY

To manufacture the heat exchanger, the rear tubular board is placed on the assembly device. The central tube with the spirometallic gasket is placed on the rear tubular board. The six stiffening rods are inserted in the six holes of Ø18,5 mm. The five cavils and the 24 spacers are inserted on the six stiffening rods. The outer mantle is positioned on the rear tubular board.

The second spirometallic gasket is placed above the central tube and the front tubular board is positioned over it.

The six stiffening rods are fixed inside on the rear tubular board with six screws and six washers. At the other end, the six stiffening rods are fixed inside on the front tubular board with six screws and six washers.

On the outside of the front tubular board, each of the six stiffening rods is fixed with a sealing ring and a lifting connection. The assembly thus obtained is extracted from the device by positioning the rear tubular board upwards. The other six lifting connections with sealing rings are tightened on the six stiffening rods, achieving the final height of 402 mm.

The structure is repositioned on the assembly device with the front board facing up. Each end of the 288 exchanger element subassemblies is mechanically cleaned on the outside with abrasive paper and chemically pickled with a zinc chloride solution. The cleaned parts are inserted in the assembly fixed on the device in the holes of Ø28,5 mm until the end of the pipe is at the same level with the outer surface of the front board.

The 288 exchange element subassemblies are soldered in turn with LP60 / Sn60Pb40 tin rods with a diameter of Ø2 mm. The operation is performed based on the capillarity phenomenon with a brener having a diameter of Ø1,2 mm using an oxygen gas tank and a butane gas tank.

After soldering all the 288 exchange element subassemblies on the front board, the assembly is removed from the device by positioning the rear tubular board upwards. At the other end of the rear tubular board, the soldering of the 288 exchange element subassemblies is repeated.

After finishing the soldering of all the 288 exchange element subassemblies at both ends on the front tubular board, respectively on the rear tubular board, the visual inspection of all the soldered areas is performed with the help of a magnifying glass having 10x magnification. The visual inspection is performed in an area that has a brightness of 1000 lx.

If non-conformities areas are found (cracks, lack of filler material, pores, etc.), they will be marked and remedied by a new soldering operation.

According to the execution drawing, "WATER OUTPUT" and "AIR INPUT" are marked on the front tubular board. According to the execution drawing, "WATER INPUT" and "AIR OUTPUT" are marked on the rear tubular board. The marking will be made by engraving, the height of the letter being 6 mm and the depth 0,25 mm.

The marked assembly is tested for sealing in the "S" space with water at ambient temperature and a pressure of 12,5 barg for 15 minutes on the pressure test bench. No pressure drops or leaks are accepted.

At the end of the test of the assembly on the pressure bench, the visual inspection of all the soldered areas is performed again with the help of a magnifying glass having 10x magnification. The visual inspection is performed in an area that has a brightness of 1000 lx.

If non-conformities areas are found (cracks, lack of filler material, pores, etc.), they will be marked and remedied by a new soldering operation.

The heat exchanger assembly is performed outwards with a lathe at the execution drawing dimensions. At the end of the lathe operation, the two sealing elements are fixed on the outer mantle by bonding with Prenadez 400 solution.

At the end of the technological cycle, the heat exchanger assembly is subjected to the final inspection in which the external part is visually checked. Dimensional control of all quota in the execution drawing is performed. Then the appearance of the assembly and the marking is checked.

4.1 Frontal tubular board

The front tubular board is made of a board having the basic material chrome-nickel austenitic stainless steel with a low carbon content with a thickness of 24 mm and dimensions of 750x750 mm. The board is performed according to the execution drawing on the DOOSAN DB130CX carousel lathe with numerical control, after which it is milled and drilled on a Bolwer SC14M CNC machining centre.

During the drilling operation, six equidistant holes having Ø18,5 mm are made for the insertion of the six stiffening rods. For the insertion of the exchanger element subassemblies, 288 holes are performed having Ø28,5 mm, equidistant on the diameters.

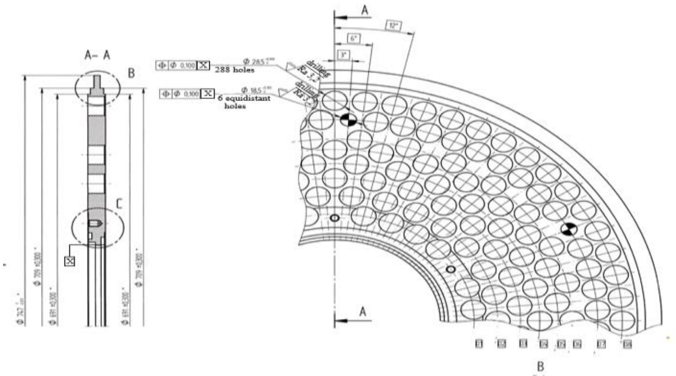

Figure 3. Front tubular board drawing

4.2 Rear tubular board

The rear tubular board is made of a board having the basic material austenitic chromium-nickel stainless steel with a low carbon content with a thickness of 24 mm and dimensions of 720x720 mm. The board is performed according to the execution drawing on the DOOSAN DB130CX carousel lathe with numerical control, after which it is milled and drilled on a Bolwer SC14M CNC machining centre.

During the drilling operation, six equidistant holes having Ø18,5 mm are made for the insertion of the six stiffening rods. For the insertion of the exchanger element subassemblies, 288 holes are performed having Ø28,5 mm, equidistant on the diameters.

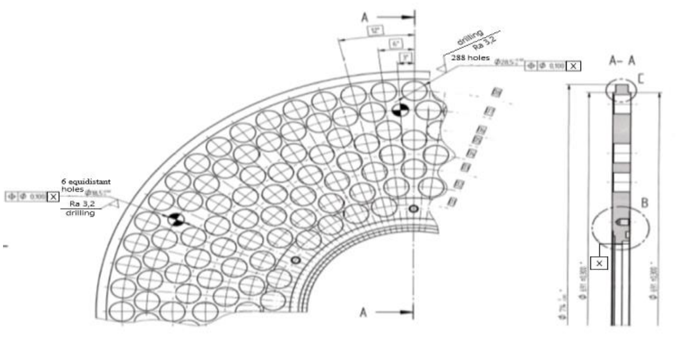

Figure 4. Rear tubular board drawing

4.3 Execution technology of the exchanger element subassembly

To obtain the exchanger element assembly, three fins are rolled so as to be fixed at the inside on the 13x1 pipe and at the outside, on the 28x1 pipe having a distance between them of 26,5 mm. A longitudinal overlap is allowed when rolling the fins at the ends of 0,5 ÷ 2 mm. The distance between the first fin and the end of the 28x1 mm pipe must be 28 mm.

The assembly thus made is introduced into the centrifugal soldering device which performs a continuous soldering on the entire generator of each rib of each fin inside and outside according to the execution drawing.

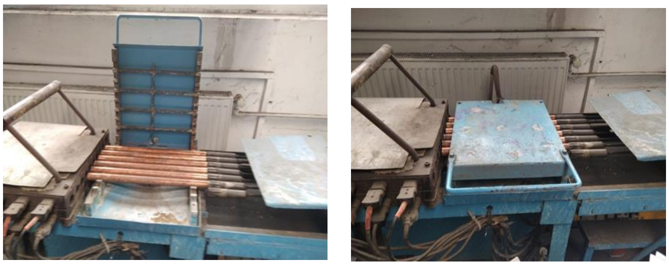

Figure 5. Fixing and soldering of the exchanger element subassembly

The soldering of the three components is done by melting followed by the solidification of the LP60 / Sn60Pb40 tin film deposited during the execution of the fins.

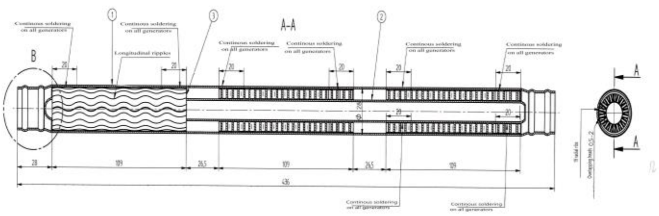

Figure 6. Exchanger element subassembly drawing

4.3.1 28x1 mm pipe

It is used as base material Cu 99,9 in the form of Ø28x1 pipe. To obtain straight fronts at both ends, the pipe is cut and turned to a length of 436 mm.

4.3.2 13x1 mm pipe

For the manufacturing of the pipe is used as base material Cu 99,9 in the form of Ø28x1 pipe. To obtain straight fronts at both ends, the pipe is cut and turned to a length of 398 mm.

4.3.3 The fin

Sheet with a thickness of 0,15 mm having the base material Cu 99,9 is used for the execution of a fin, which is cut to the dimensions of 109x250 mm.

The 19 radial ribs and the longitudinal ripples of the fin are formed by pressing with forming die. The fin thus formed is rolled so as to achieve a diametrical tightening of at least 0,4 mm from the 13x1 pipe (inner diameter of 13 mm) and 28x1 pipe (inner diameter of 26 mm).

The formed and rolled fin is tinned at both ends on a length of 20 mm, with a minimum thickness of 0,03 mm by immersion in a liquid tin bath (LP60 / Sn60Pb40 cf EN 29453). The surfaces of the outer and inner extremities of the formed and rolled fin are tinned with the same minimum layer thickness.

5. CONCLUSIONS

The soldering alloy used for the heat exchanger assembly is LP60 / Sn60Pb40. Depending on the soldering temperature, the soldering process of the heat exchanger is a soft soldering.

The soldering is performed manually and semi-automatically to the heat exchanger subassembly. The technology for the soldering process is performed with gas burners and with a centrifugal soldering device.

Depending on the shape and technology, capillarity soldering is used for the joints and immersion soldering is applied in the case of the fins.

Depending on the heating mode of the basic metal parts, the soldering is done with local heating.

6. ACKNOWLEDGEMENTS

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