PRELIMINARY EXPERIMENTS OF THE NEW FACILITY AND TECHNOLOGY FOR VACUUM DRYING AND THERMAL POLIMERIZATION OF THE TURBOGENERATORS STATOR BARS INSULATION (INTEPOL)

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Abstract: *This paper presents the* ***Preliminary Experiments of the New Facility and Technology for Vacuum Drying and Thermal Polymerization of the Turbogenerators Stator Bars Insulation*** *(INTEPOL), achieved in 2008 year by the authors at* ***SC Alstom General Turbo SA,*** *in the frame of the PNCDI 2 (Innovation Program). The vacuum drying and thermal polymerization of the turbogenerators stator bars insulations is used for eliminating of the volatiles from the turbogenerator coil insulation in order to increase their breakdown voltage. The vacuum and the temperature are the most important parameters of the technological process with a great influence on the breakdown voltage of the stator bars insulation.*

Key words: *vacuum drying, thermal polimerization, turbogenerator stator bars insulation.*

1. Introduction

The processes of the vacuum drying and the thermal polymerization by izostatic pressuring with warm and fluid bitumen in the INTEPOL Facility is performing alternatively in two Autoclaves, with the following technical data:
V_1 = 115.3 m^3, **D_1 = 3.5 m**; **L_1 = 11.5 m** - for Autoclave-1 and **V_2 = 140 m^3**, **D_1 = 3.5 m**; **L_1 = 13.5 m,** for Autoclave-2, but could be performed also only in the Autoclave 1.

In order to allow the vacuum drying and thermal polymerization of the turbogenerator coil insulation the INTEPOL Facility, contains the following systems/ equipments [4]:

1. Two Technological Chambers (*Autoclave-1 and Autoclave-2*);
2. Four Bitumen Reservoirs (*2 pcs for Autoclave-1 and 2 pcs. for Autoclave-2*);
3. Two Vacuum Pumping Systems (*one for Autoclave-1 and one for Autoclave-2*);
4. Two Heating Systems with Warm Oil for the Autoclaves and Bitumen in the Reservoirs;
5. An Oil Reservoir for the Heating Oil;
6. Two Vent Systems for the Nitrogen in

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the Autoclave;

7. The Utilities Systems (*Electricity, Cooling Water and Compressed Air Systems*);

8. A Nitrogen Compressing System for:

- Bitumen Transfer between Bitumen Reservoirs and Autoclaves;
- Pressuring with N_2 at 7 bar of the bitumen in the autoclaves during the polymerization process;
- Recuperation of the nitrogen from Autoclaves in the Nitrogen-Gas Reservoirs;
- Three Storage Reservoirs for the Nitrogen Gas;

9. One Storage Reservoir for the Liquid Nitrogen.

2. Experimental Detail

After ending the construction and the montage of the new facility we have performed the first experiments to know the real parameters of the new Vacuum Pumping System of the INTEPOL plant.

2.1. The Final Pressure (p_f) and the Compression Ratio (K) of the Pumping System

The Pumping System of the new facility and technology (INTEPOL) contains the following most important components, from Pfeiffer Vacuum [3]:

1. Four Rotary Vane Pump type BA 501, with total pumping speed of 4 x 500 m^3/h and ultimate pressure of $6 \cdot 10^{-2}$ mbar.
2. One Roots Pump type Okta 6000, with pumping speed of 6000 m^3/h and a compression ratio $5 < K_0 < 70$ (*depending on the type of the gases flow range, laminar or molecular*).
3. Four Angle valve with DN 100 ISO-K, for isolation of the Rotary vane pump.
4. One Water Vapor Condenser type Cds-2-DN 160/DN 160.
5. One controller type TPG 256 with 6 measuring channels equipped with 6 Pirani gauges for monitoring of the pressure: of every preliminary pump, inside of the water vapor condenser and inside of the autoclave.
6. The Vacuum Pumping System is isolated from the New Autoclave by a special electropneumatical valve (6-163) for vacuum and pressure (10^{-3} mbar until 7 bar) with DN 250 from Klinger.

It is well known that [1], [2]:

- **the pumping speed,**

$$S = \frac{dV}{dt} = \frac{\Delta V}{\Delta t},$$

is the mean volume flow through the cross section of the inlet port of a vacuum pump and it is indicated in **m^3/h**; **m^3/s** or **L/s**;

- **the pumping capacity (throughput),**

$$q_{pV} = S \cdot p = \frac{dV}{dt} p = \frac{m}{t} = V \frac{p}{t},$$

denotes the gas throughput in a vacuum pump as a function of the inlet pressure and it is indicated in $P_a \frac{l}{s}$ or $mabr\frac{l}{s}$. In a Pumping System the throughput of any pump is the same;

- **the final/ultimate pressure (p_f)** is the lowest pressure that is asymptotically approached by the pressure of a blank-flanged pumping system, without gas inlet;
- **the compression ratio,** $K_0 = \frac{p_2}{p_1}$, is the pressure ratio between **the discharge pressure p_2** and **the intake pressure p_1**, of a pump or of a pumping system:

In the case of blank-flanged inlet ports, the compression ratio is measured through gas inlet on the discharge side, because any vacuum pump has a **backflow loses** through gaps ($L_P(p_1 - p_2)$, *where L_P is the conductivity of the pump*). The backflow loses through gaps limit the compression ratio of a pump or of a pumping system.

If we consider our Vacuum Pumping System with a Roots pump (*OKTA 6000, having a pumping speed* S_0, *and a compression ratio* K_0*)*, connected to a Technological Chamber and an additional Rotary Vane Pump (*4xBA 501, with a pumping speed* S_0, *that ensure a variable pressure =* p_v *at the exhaust of the Roots pump)*, connected to the discharge of the Roots pump, and by taking into consideration the law of throughput continuity of a vacuum system we can obtain the real compression ratio of the Roots pump from the equation of the continuity of the throughput in any moment:

$$q_p \cdot V = p_a \cdot S = \\ = p_a \cdot S_0 - L_R(p_v - p_a) - S_R \cdot p_V \,, \qquad (1)$$

where: p_a - the intake pressure (*a variable pressure from atmospheric pressure to the ultimate pressure of the pumping system*); p_v - the backing vacuum pressure (*a variable pressure at the Roots discharge port*); S_0 - the pumping speed of the Roots pump; S_R - the return pumping speed of the Roots pump; $S_R \cdot p_v$ - the return gas flow from the discharge side of the Roots pump; S - the real pumping speed of the Roots pump; L_R - the conductivity of the Roots pump.

At final pressure of the Pumping System we can consider that S = 0 and we can calculate the real compression ratio of the Roots pump (K):

$$p_a \cdot S_0 = L_R(p_V - p_a) + S_R \cdot p_V \,, \qquad (2a)$$

$$p_a \cdot S_0 = (L_R + S_R) \cdot p_V - L_R \cdot p_a \,, \qquad (2b)$$

$$K = \frac{p_v}{p_a} = \frac{S_0 + L_R}{S_R + L_R} \,. \qquad (3)$$

By closing of the Klinger valve (6-163) **the ultimate pressure of the pumping system**, measured with the Pirani gauge of the TPG 256 controller, **was** $3 \cdot 10^{-3}$ **mbar (*p_1*)**. Also the ultimate pressure at the exhaust port of the Roots pump (***p_2***) was $9 \cdot 10^{-2}$ mbar.

The real compression ratio of the Roots pumps which was obtained is:

$$K = \frac{9 \cdot 10^{-2}}{3 \cdot 10^{-3}} = 30 \,,$$

and this value is in correspondence with the compression ratio of the Pfeiffer Vacuum Roots pumps.

3. Results

3.1. Leak test result for the New Autoclave

The leak test of the new and cleaned autoclave was made at normal room temperature and after 24 hours of pumping of the autoclave by isolating it from the pumping system and by measuring the increasing of the pressure in time in the autoclave (due to degassing processes and due to the leakages). The results of the leak tests are presented in the Table 1 and in Figure 1. In order to eliminate the influence of the degassing process to the leakage of the autoclave the test will continue by heating of the autoclave in future.

Leak test Table 1

No.	Hours	Pressure in the technological chamber p_i [mbar]
1	10.02	5.20 x 10^{-2}
2	10.05	1.26 x 10^{-1}
3	10.06	1.50 x 10^{-1}
4	10.12	2.50 x 10^{-1}
5	10.17	3.44 x 10^{-1}
6	10.22	4.44 x 10^{-1}

Δp = 0.444 – 0.052 = 0.392 [mbar],

Δt = 10.22 – 10.02 = 20 [min] = 1200 [sec],

q = the leaks of the new autoclave:

$$q = \frac{\Delta p \cdot V}{\Delta t} = \frac{0.392 \cdot 1.4 \cdot 10^5}{12 \cdot 10^2} =$$

= 45.73 [mabr · L/s].

The leak rate of the autoclave is higher than the theoretical estimated value. Taking into account that the pumping speed of the OKTA 6000 pump is:

$$6000\ [\mathrm{m}^3/\mathrm{h}] = \frac{6 \cdot 10^3 \cdot 10^3}{3.6 \cdot 10^2}\ [\mathrm{L/s}] =$$

$$= 21.8 \cdot 10^4\ [\mathrm{L/s}].$$

The final pressure that could be obtained in the new autoclave will be higher than:

$$\frac{45.73\ [\mathrm{mbar \cdot L/s}]}{21.8 \cdot 10^2\ [\mathrm{L/s}]} =$$

$$= 2.098 \cdot 10^{-2}\ [\mathrm{mbar}] = 0.02098\ [\mathrm{mbar}].$$

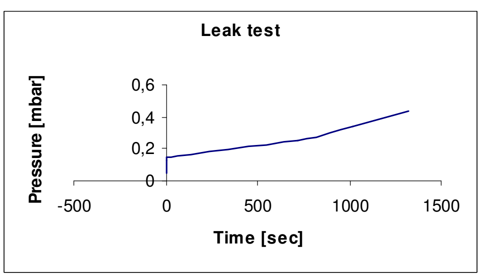


Fig. 1. *Leak test*

3.2. Ultimate pressure test in the technological chamber

The results of the experiments for the **pumping down pressure evolution in time**, **in the clean and empty autoclave at normal temperature** are presented in Table 2 and in Figure 2.

Table 2

Pumping down pressure evolution in the clean autoclave

No.	Pumping time [min]	Pressure in the autoclave [mbar]
1	0.00	1.000
2	12.00	500
3	20.00	0.9
4	30.00	0.09
5	40.00	0.08
6	60.00	0.05
7	1440.00	0.04

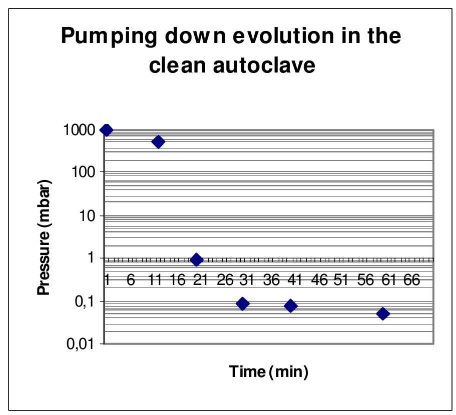


Fig. 2. *Pumping down evolution in the clean autoclave*

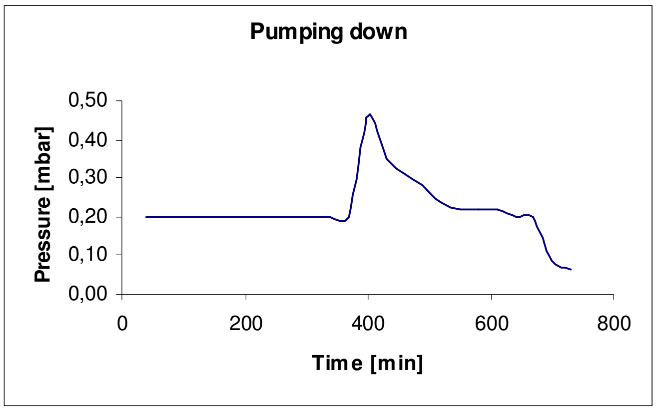
Due to the leaks and to the big degassing of the technological equipment from the autoclave, the final pressure in the autoclave was 0.04 mbar (after 24 hours) and not 0.020 mbar, as the result from the leak test of the new autoclave.

In the next period we will try to find the leaks of the autoclave with the technological equipments mounted in order to decrease the ultimate pressure in the autoclave under 0.02 mbar.

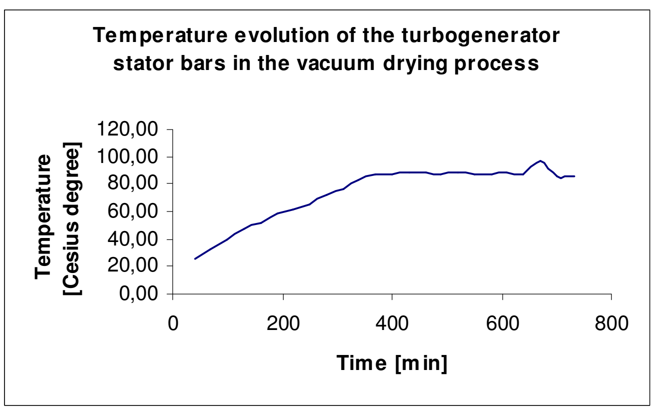
3.3. The preliminary results of the vacuum drying of the turbogenerators stator bar insulation

The preliminary experiments were made for a few times for the vacuum drying of the turbogenerator stator bar insulation (with 20 turbogenerator stator bars insulation in the autoclave) on a period of 22 hours/charge, with the measurement of the pressure and. temperature of the drying process.

The results of these preliminary experiments are presented in Figure 3.



a)



b)

Fig. 3. *a*) *Pumping down evolution*; *b*) *Evolution of the stator bars turbogenerator temperature in the vacuum drying process*

4. Conclusions

The facility and the technology of the vacuum drying and thermal polymerization of the turbogenerator stator bars insulation represents a very complex machine and technology and it will be necessary many experiments to improve the technological equipments of the plant and to optimize the technology in order to increase the quality of the turbogenerator stator coils.

The pressure and the temperature are the parameters of the technological processes of vacuum drying and thermal polymerization of the insulation for turbogenerator coils.

The breakdown voltage of the insulation of the turbogenerator stator bars is the final test that certifies the quality of the turbogenerator coils and the optimal parameters (pressure and temperature) for vacuum drying and thermal polymerization processes.

In order to find the optimal parameters of the technological process (pressure and temperature) that will ensure the higher breakdown voltage of the turbogenerator stator bars insulation, it is necessary to improve the ultimate pressure of the pumping system and to continue the experiments.

To cover the leakage of autoclave with all the technological equipments mounted on it and to reduce the ultimate pressure of the pumping system in the autoclave under 10^{-2} mbar it will be necessary to increase the pumping speed of the Roots pump by mounting in parallel of the second Roots pump type OKTA 6000.

The preliminary experiments achieved in the period of putting in operation of the plant have proved that the breakdown voltage of the turbogenerator stator bars insulation is higher than the standard imposed value.

Based on these first tests with good results, the plant is now used by the end user for production of the turbogenerator stator bars.

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