RESEARCH ARTICLE

MONITORING AND ANALYSIS OF THE TURBODETENTOR OPERATING SYSTEM FROM CRYOGENIC DISTILLATION PLANT USING LABVIEW SOFTWARE.

Carmen Maria Moraru[1], Iuliana Stefan[1], Ovidiu Balteanu[1], Ciprian Bucur[1], Nicolae Sofilca[1], Gabriel Ionescu[2],Maria Alexandra Retevoi[3],Florentina Enescu[4].

1. Department of Cryogenic Pilot Plant, National Institute of Research - Development for Cryogenic and Isotope Separation Technologies, ICSI-Rm.Valcea, Romania.
2. Department of Automation and Industrial Informatics, Automation and Computer Faculty, University Polytechnic of Bucharest, Romania.
3. Department of Computer Science, Jacobs University, Bremen, Germany.
4. Department of Electronics, Computer Science and Electrical Engineering, University from Pitesti, Romania.

Manuscript Info

Abstract

Paper aim was to set up contributions to the development and improvement the information system for monitoring the turbodetentor used in refrigerating cycle and ensuring safety in operation to an experimental pilot installation for the separation of tritium from tritiated heavy water, resulting in nuclear reactors used for electrical energy. The pilot plant features for the tritium separation, involve opportunities to obtain operating regimes very different and from their observation and study to derive conclusions on which is possible to maximize the efficiency of separation and to maintain the security of installations and the environment to acceptable levels. The tritium separation is based on the cooling to very low temperature, e.g. 21K at the peak of cryogenic distillation column. For this purpose it is used the nitrogen as a cooling liquid, obtained from a turbodetentor. The turbodetentor performs, through relaxation, a drop of gas temperature, accompanied by an enthalpy decrease as a consequence of the mechanical work. The optimization presented in this paper refers to determining the values of pressure and temperature on the nitrogen liquefaction cycle at the input and output of the turbodetentor, which maximize the cooling power and efficiency.

Introduction:-
The main objective of this work was to develop and improve an information system for monitoring and analyze the turbodetentor efficiency corresponding to an experimental pilot plant installation for tritium separation from heavy water.

The pilot plant for tritium separation is composed mainly of three major modules, namely: the installation of isotopic exchange, the installation of purification by catalytically burning and the installation of cryogenic distillation.

To satisfy the many requests that claim a pilot plant for research is needed a comprehensive information system consisting of numerous and varied hardware and software such as:

❖ hardware parts consisting of sensors and transducers, cable connections, modules for data acquisition, actuators, computers for data processing, display and remote control devices capable to implement various operating conditions;

❖ software programs for applications that include acquisition, data processing and presenting the information in a form suitable for easier understanding by the operators, programs for performing calculations for the identification, modelling, simulation and optimization, , programs for initiating controls, warnings, alarms and for ensuring the communications safety.

In order to bring the hydrogen up to process temperatures of 20K, first pre-cooling is performed at processing temperatures (about 20K) necessary for the correct operation of the distillation column. Pre-cooling is achieved using liquid nitrogen obtained in a nitrogen circuit which will be presented next in the paper.

Methodology:-

Figure 1 shows a simplified diagram nitrogen liquefaction cycle. Also, in the figure are presented the measurement points of temperature refrigeration necessary to assess the refrigerating cycle power.

The components of the liquefaction cycle nitrogen respectively heat exchangers SN-301 and SN-302, turbodetentor TD-301, expansion valve RL-301 and liquid nitrogen bath-C301 are mounted in cold-boxing CB-302.
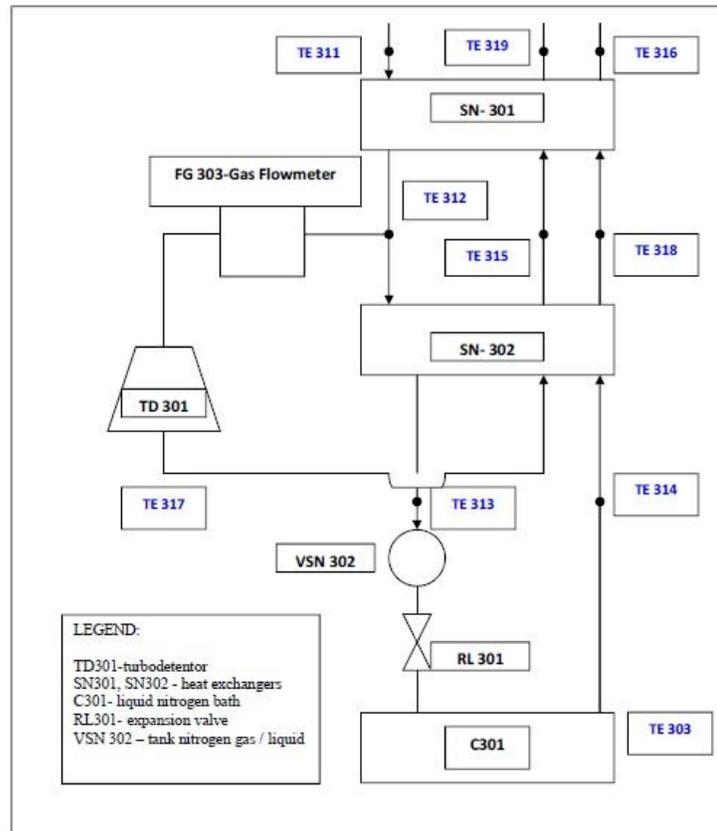

Figure 1:- Block diagram of nitrogen liquefaction cycle

Description of mathematical model for simulating the behavior of nitrogen liquefaction installation and determining the turbodetentor efficiency

Thermal balance equations of the nitrogen liquefaction cycle are:
-on heat exchanger SN-301

$$m_i\left(h_{311} - h_{312}\right) = q_1\left[m_L\left(h_{316} - h_{318}\right) + m_T\left(h_{319} - h_{315}\right)\right]$$ (1) -on heat exchanger SN-302:

$$m_L\left(h_{312} - h_{313}\right) = q_2\left[m_L\left(h_{318} - h_{314}\right) + m_T\left(h_{315} - h_{317}\right)\right] \tag{2}$$

-on expansion valve

$$h_{313} = h_{303} \tag{3}$$

The gas temperature at the exit of the TD-301 Turbodetentor is:

$$T_{317} = T_{312}\left(1 - \alpha\right) \tag{4}$$

$$\alpha = \frac{T_{312} - T_{317}}{T_{312}} \tag{5}$$

Where:

$$\alpha = \eta\frac{\left(\dfrac{p_{312}}{p_{317}}\right)^{(\gamma-1)/\gamma} - 1}{\left(\dfrac{p_{312}}{p_{317}}\right)^{(\gamma-1)/\gamma}} \tag{6}$$

$$\eta = \frac{\alpha \cdot \left(\dfrac{p_{312}}{p_{317}}\right)^{\frac{(\gamma-1)}{\gamma}}}{\left(\dfrac{p_{312}}{p_{317}}\right)^{\frac{(\gamma-1)}{\gamma}} - 1} \tag{7}$$

Where:

η is the turbodetentor efficiency

The transfer coefficients of the heat exchangers, their transfer surfaces and the average temperature variationΔtm of the heat exchangers temperature was correlated with the enthalpy variation on the warm agent and circulated flow. Thus, for SN-301 we have:

$$\Delta t_m^{301} = \frac{\left(t_{311} - t_{316-319}\right) - \left(t_{312} - t_{315-318}\right)}{\ln\dfrac{t_{311} - t_{316-319}}{t_{312} - t_{315-318}}} \tag{8}$$

$$m_i\left(h_{311} - h_{312}\right) = K_{301}S_{301}\Delta t_m^{301}$$

where:

m_i-input flow

m_T-turbine flow

m_L-laminar flow

h-enthalpy

t-temperature

S-entropy

q_1, q_2-specific heats

γ-factor for perfect diatomic gas

P-pressure

In an identical manner we have for second heat exchanger SN302:

$$\Delta t_m^{302} = \frac{\left(t_{312} - t_{315-318}\right) - \left(t_{313} - t_{317-314}\right)}{\ln \dfrac{t_{312} - t_{315-318}}{t_{313} - t_{317-314}}}$$

(9)

$$m_L \left(h_{312} - h_{313}\right) = K_{302} S_{302} \Delta t_m^{302}$$

For this heat exchanger the average temperatures of the cold agent to the input and the output are:

$$t_{315-318} = \frac{m_L t_{318} + m_T t_{315}}{m_i}$$

$$t_{317-314} = \frac{m_L t_{314} + m_T t_{317}}{m_i}$$

(10)

Cold installation availability is expressed through:

$$P = m_L \left(h_{314} - h_{313}\right)$$

(11)

The system of equations (1) - (11) characterizes the behavior of the thermodynamic cycle in this configuration. Entropy, enthalpy of the gas and the specific heatsare calculated using the state equation Beattie-Bridgeman.

Implementation:-
Simulation in LabView of the behavior liquefaction installation and determiningthe turbodetentor efficiency using mathematical model

Based on the mathematical model was developed the software in LabViewfor determining the turbodetentor efficiencywhere were used the structures: "While," "Sequence"(Figure 2 and Figure 3) and "Formula Node" for calculating the mathematical equations (1) - (11).
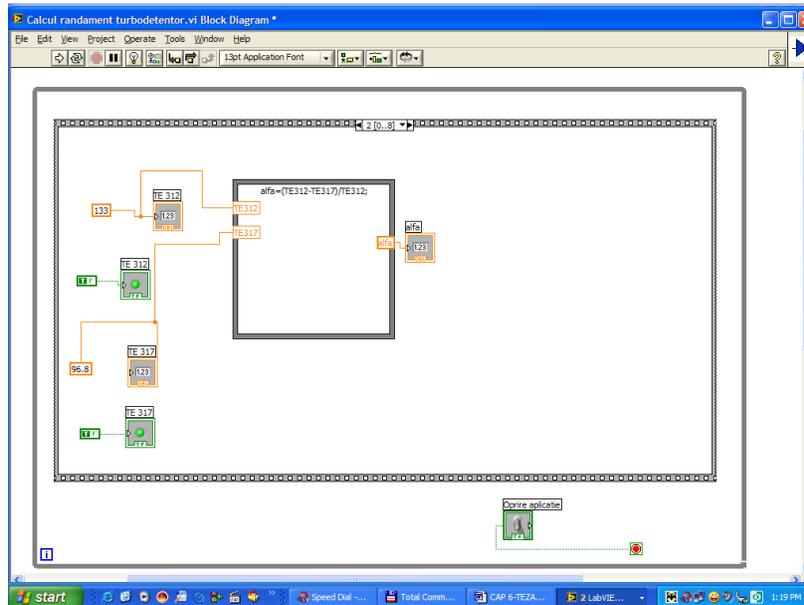

Figure 2:- Structure "Sequence" in LabView software to calculate the parameter alpha depending on the temperatures $T_{312}$and T_{317}
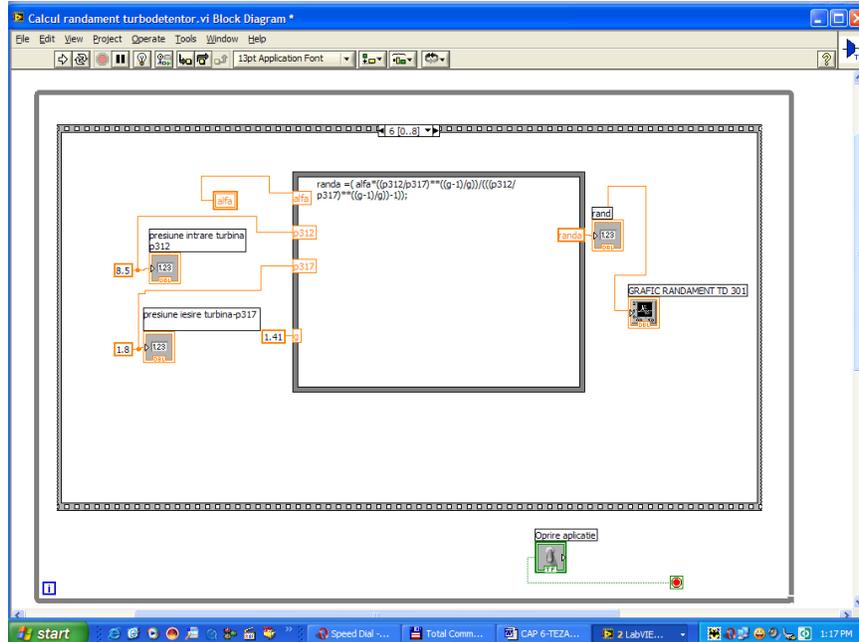
Figure 3:- Structure "Sequence "in which the turbodetentor efficiency is calculated

In figure 4 is shown thefront panels of the LabView application for calculation the turbodetentor efficiency, where the parameters are defined or acquiredfrom the nitrogen liquefaction installation which is part from tritium removal plant.
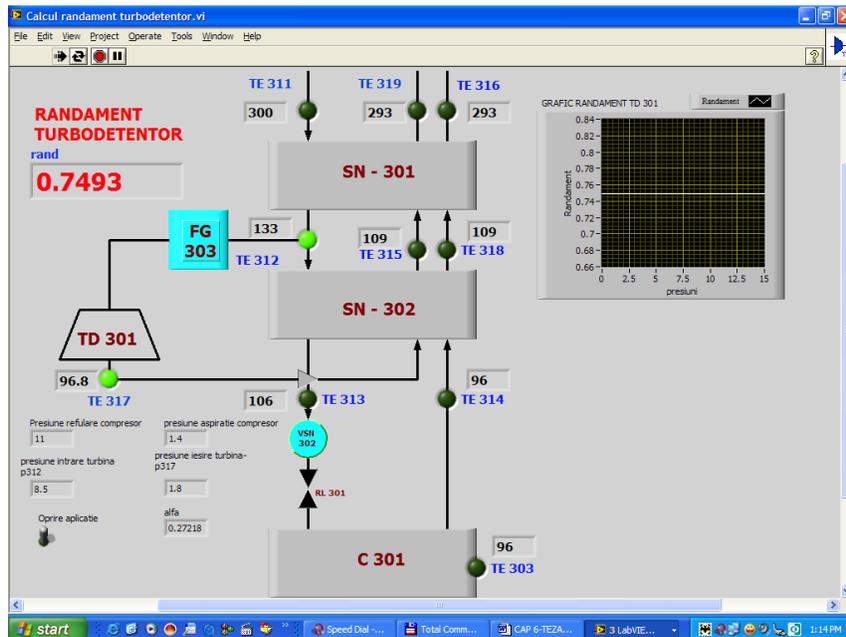

Figure 4:- The front panel from LabView software of the application for calculation the turbodetentor efficiency for P_{312} = 8.5 bar, P_{317}= 1.8 bar and
T_{312} = 133 K, T_{317} = 96.8 K

It was observedthat thelow pressuresat the entrance and exit of the turbodetentorwithT_{312} and T_{317} temperatures constants,generates the efficiency decreasing. At the low temperaturesT_{312} and T_{317} and constants pressures P_{317} and P_{312}, the efficiency of the turbodetentor increases, but not too much.

Conclusions:-

The software developed in LabView demonstrated that the most influence in maximizing the efficiency had pressures from input (P_{312}) and the exit (P_{317})from turbodetentor.

Changing the turbodetentor efficiency is influenced more by pressures and not by temperatures.

Arguments in favor of this optionare based on the fact that, more significantly than other programming languages, LabView has extensive libraries of functions and subroutines which can be directly used in many applications, such as acquisition, processing, analysis, presentation and storage of data, measurement and display of various physical quantities, procedures of modeling, simulation and process calculations.

A special attention was given to the software LabView graphical programming that has proven to be particularly advantageous, having adequate facilities for applications as monitoring and control of processes, also including capabilities for modelling, simulation and optimization. The authors consider that by implementing solutions, partially illustrated in this paper, there are satisfied at an appropriate level the requirements of a pilot installation to ensure the flexibility of operating modes and to increase the quantity and quality of information necessary to perform complex research programs in the field of tritium separation.

Acknowledgement:-

References:-

1. National Instruments Corporation. Academic solutions: Remote experiment control with LabVIEW. Available:http://www.ni.com/ academic/remote.htm.
2. L. Wells and J. Travis, LabVIEW for Everyone: Graphical Programming Made Even Easier. Englewood Cliffs, NJ: Prentice-Hall, 2000.Available: http://www.ni.com /reference/books/ lv4every.htm.
3. Stuart A. Boyer, SCADA: Supervisory Control and Data Acquisition, 4th Edition, Publisher ISA, 2010
4. L. Sokoloff, "Applications in LabView", Prentice Hall, 2003
5. C.M. Retevoi Retevoi (Moraru), "System for Optimization and Control the processes from Isotopic Exchange Column", PHYSICA-StudiaUniversitas Babes Bolyai, Special Issue 2,PIM 2003, ISSN-0370-8578