Control system for suction valves within gas compressors skids located in potentially explosive zones

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Abstract. The paper presents the implementation of a feedback loop controller for the suction valves used within the gas compressors skids manufactured by Romanian Research and Development Institute for Gas Turbines COMOTI. These compressors are installed at beneficiaries, in potentially explosive environments (e.g., gas extraction and transportation applications). The proposed solution addresses the problems observed due to the high suction pressures of screw compressors, which may occur at start-up or during operation, leading to failed start-ups or emergency shutdowns. An automatic sequence implemented in the control software and displayed on the operating panel, could assist the operator during high suction pressures (above 1.2 bar). These pressure conditions normally lead to alarm limits and to performing an automatic shutdown sequence for protecting the compressor. The paper herein discusses the implementation of a start-up sequence in the programmable logic controller's software, which can be applied without critical interventions on the compressor packages, only through minor control software modifications which can safely extend the inlet pressure range and the exploitation of the compressors. Thus, since no hardware modifications are required, we also ensure maintaining the ATEX certifications of equipment and assemblies.

1 Introduction

Compressors are used in all sectors of the national economy, and are valued for their reliability, high efficiency, and long service life. The scope of the equipment is very wide, without it the work of a feedback y large industrial enterprise is indispensable. Compressors are used in mechanical engineering, metallurgy, oil and gas industry, car services, construction and other industries [1].

Gas compressors are widely used in various industries, including oil and gas, petrochemical, and chemical plants, to increase the pressure of gases for transportation, storage, or processing purposes. These compressors often operate in potentially explosive environments where the presence of flammable gases or vapors poses a significant safety risk.

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A compressor is a power machine or device for increasing pressure and moving goods or their mixtures. The compressor together with the drive (electric motor, internal combustion engine) forms a compressor unit. A compressor unit with additional equipment is called a compressor unit [1].

Within gas compressor systems, suction valves play a crucial role in regulating the flow of gases into the compressor cylinders. The efficient operation of these valves is vital for maintaining optimal performance and preventing potential hazards. To ensure precise control and safe operation, feedback loop controllers are implemented for suction valves in potentially explosive environments.

The valves generally used by INCD Turbomotoare COMOTI have a degree of protection of at least IP 67, which means protection against dust particles and waterproof protection for immersion in liquid up to 1 meter deep, for a period of 30 minutes. Inside them we find electrical components that are classified in Group IIB, with temperature class T4 (max. 135°C). The marking of the electric valve actuation will be Ex II 2G d IIB T4.

In this foreseen evolution of the energy scenario, dispatchable generating units will play a crucial role both for distributed (small size) units and large centralized plants since they will be required to act in a flexible and efficient way in order to contribute at satisfying the system load and compensating renewable fluctuation and sudden contingency [2].

A feedback loop controller is a control system that continuously monitors the performance of a process or device and adjusts based on measured feedback signals. In the context of gas compressor suction valves, the feedback loop controller constantly measures relevant parameters such as pressure, flow rate, and valve position, and uses this information to adjust the valve's opening and closing actions.

The assessment of explosion and fire hazards is in this case of essential importance for the selection of equipment that is to be used in such facilities and for their configuration. For example, the usage of electrical equipment in areas with explosion hazard mandates an approach that differs from the case of normal areas, in several aspects [3].

The primary objective of the feedback loop controller for suction valves in potentially explosive environments is to maintain stable and reliable operation while adhering to stringent safety regulations. The controller aims to achieve the desired pressure and flow rate setpoints while ensuring that the valve operates within safe limits.

Gas generating units will play a significant role since in large power plants they are used in combined cycle configuration providing high efficiency and good dynamics responses to power variations [2].

In the case of the natural gas compressor station, the explosion risk factors were determined taking into account the tasks indicated in the job description files for the personnel operating within this facility, as well as the corresponding technological processes. The risk factors were then identified and grouped by the generating element within the facility (operator, work task, production means and work environment) [1-3].

Implementing feedback loop controllers in potentially explosive environments helps organizations comply with safety standards and regulations. These controllers are designed to meet industry-specific safety requirements, mitigating the risks associated with working in hazardous locations.

This paper proposes a solution for implementing a feedback loop controller for the suction valves used within the gas compressors skids installed in potentially explosive environments in order to avoid the re-certification of the valve.

2 Exposure of the current problem

Over time, we have carried out various studies regarding the possibility of creating a command-and-control cabinet that has ATEX certification. Their usefulness appears when it is necessary to place the command-and-control unit near the compression units or the objectives of interest.

Gas-fired power plants (GFPP) are expected to play a crucial role in compensating the renewable generation variability because of its fast response. Accordingly, the role of gas network is changing to highlight its increasing value in providing flexibility to electricity sector [4].

These units must be built according to ATEX safety standards [3-6], to be safe during use in potentially explosive areas. The safety standards that must be respected include certain specifications for construction, protection methods and testing procedures plus certification. The command-and-control devices that are installed in dangerous areas must be designed and installed so that the possibility of sparks or overvoltage that can generate ignition is reduced to zero.

Part of the advantages of installing command and control cabinets in hazardous areas could be cost-effectiveness and reduced types of commissioning. Placing the control units as close as possible to the process reduces the distance between the monitoring equipment and the element of interest, and hence results in a lower cost of execution, design, or site preparation works.

The command-and-control cabinets of the compression units contain signal adapters with "Ex i" protection type [5], which represents intrinsic protection, and they can also be mounted in potentially explosive areas. As we have already stated, by installing them in a hazardous environment, time can be saved when commissioning takes place at the beneficiary, but also an economy of resources such as fewer cables and conductors.

3 Analysing critical factors

Butterfly valves are quarter-turn rotary valves that may be utilized for flow in both directions by rotating a closure disc to open, close, or control the flow path. Because the disc is constantly present in the flow, a pressure drop is created in the flow regardless of valve position [7-8].

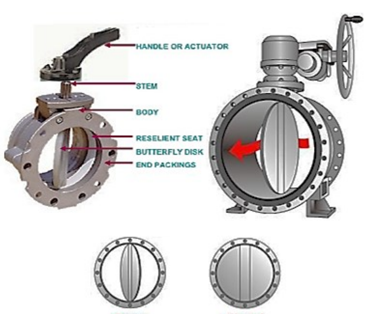

Fig. 1. Butterfly valve construction and working principle [7].

Due to the ATEX rules in force, any hardware intervention (adding or removing elements) inside an "Ex" certified equipment leads to the loss of its certification. This implies extra costs and procedures for the recertification. For this reason, we are proposing a second solution for starting the compression units when there is a high pressure in the suction line.

In the variable head device, the flow rate in the calibration line is controlled to be close to a stable value by controlling the opening degree of the butterfly valve. In order to obtain the ideal flow characteristics, domestic and foreign scholars have conducted extensive research on butterfly valves [8].

Another critical factor that has led us to the proposal of the paper was that, in the current state, manual maneuvers for decreasing the intake pressure are required to facilitate the startup of a screw compressor, such as opening the discharge valve of the station and continually purging an quantity of gas, or half-opening the manual valve placed on the station pipe to induce pressure drop, while the compressor start command is being initialized. These actions necessitate the presence of two operators and do not always guarantee that the compressor will start [9-12].

4 The proposed solution

We are proposing the introduction of a button that activates a start in high pressure conditions when the pressure exceeds the value of 1.2 bar at the compressor suction level. The solution is strictly software, without interfering with the execution elements used, and the only condition is that the shutdown valve (SDV) valve is of the butterfly type, but it can also be tested on ball valves.

A start-up is proposed in which the valve must reach the 45° opening position, which means that the initial opening will take 1/2 of the total opening session, which is tested in the commissioning (PIF) functional tests. This value can be easily changed through the software routine that we will present next, but it can also be implemented on the HMI screen, a control menu of the initial opening angle, with a limitation of 20°, so that the compression assembly is not endangered by the appearance of a prolonged vacuum at the suction level.

The figures in which the software is presented have explanations for each individual line, but for a clearer understanding, we will list them and explain them in detail. It is understandable that each software line is numbered on the left side with a red number. Each line can contain logical elements, such as "AND" conditions or "OR" conditions. A string on a single line of bits that must have a value of 0 or 1 to be active represents an "AND" condition. A parallel arrangement of some "IF" bits or elements represents an "OR" condition. For a line in the software to be executed, it is necessary that the Bits and "IF" elements on that line are true, these are usually found on the left side of the lines, but they can also be found on the right side in the positions where parallel lines appear.

For a better understanding of our proposal and the operational mode, we will now further explain the software's diagram presented in Fig. 2-5:

- line 1: In the test state (TESTE) of the valve, the "TESTE" bit will have the value 1, the button "Start sequence SDV - Suction Valve" (OP_SDV1_ON) is activated, which executes a pulse to reset the time units "Tmr_SDV_Open" (the time in which valve opens) and "Tmr_SDV_Close" (the time the valve closes)
- line 2: In the test state (TESTE) after the two pulses occur and the "Rst_tmr1_SDV" and "Rst_tmr2_SDV" bits become 1 (line 1), the value 0 is moved to the register responsible for estimating the valve position "valve_position", after which bits "bit_write_time_1" and "bit_write_time_2" becomes 0, to make sure they didn't retain the value 1 by accident.
- line 3: In the test state (TESTE), with the button "Start sequence SDV - Suction Valve" (OP_SDV1_ON) pressed, provided that the valve is not open ("ONsdv1_2I5") and provided that the valve is not closed (" OFFsdv1_2I6" negated), valve open time timing ("Tmr_SDV_Open") starts. At the same time, the "ONsdv1_Q7" - SET and "OFFsdv1_Q8" - RESET commands are executed.

- line 4: In the test state (TESTE), when the digital input %I 21 is activated and the valve is in the open position, "bit_write_time" bit is set to 1.
- line 5: In the test state (TESTE), when the "bit_write_time" bit is activated, and when the digital inputs "ONsdv1" and "OFFsdv1" are inactive, i.e. the valve is in travel, the recording of the closing time "Tmr_SDV_Close" begins. At the same time, the valve closing command "OFFsdv1_Q8" is set to 1.

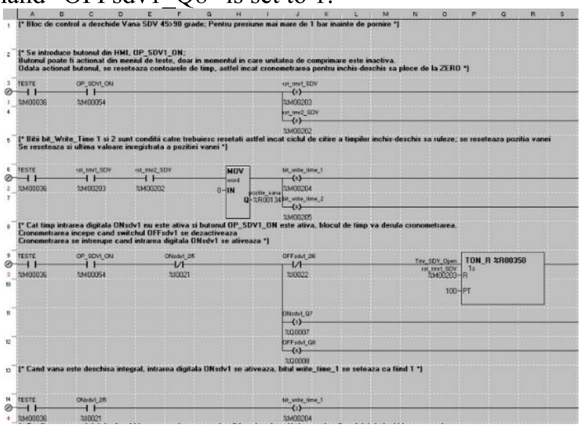

Fig. 2. First software page for starting the compressor under high pressure conditions

- line 6: In the test state (TESTE), when the bit that confirms the closing of the valve (OFFsdv1_2I6) is active, and the condition bit "bit_write_time_1" has the value 1, the closing digital output (OFFsvd1_Q8) is reset, the button "OP_SDV1_ON" is also reset , and the condition bit "bit_write_time_2" is set to the value 1.
- line 7: In the test state (TESTE), when the condition bits "bit_write_time_1" and "bit_write_time_2" have the value 1, and the valve sequence operation button is inactive (zero), the time records are written to the registers for the opening and closing the valve. After writing the registers, a pulse command is actuated for the "calc_bit" bit.
- line 8: In the test state (TESTE), when the condition bit "calc_bit" has the value 1, the operation of adding the registers containing the duration of time for closing and opening is performed. Afterwards, the arithmetic mean is performed for the division by 2 of the value obtained after the addition.
- line 9: In the test state (TESTE), when the condition bit "calc_bit" has the value 1, the operation of dividing the total opening angle, which is 90o by the time average between the closing cycle and the opening cycle, is executed. We will get the angle that the valve opens in one second.
- line 10: In the operating state of the compressor (FUNC) when the electric motor is started, if the "high_pressure_button" button is operated, the valve is not in the open position, and the "pas1_done" bit is not activated, the division of the value of 45 will be executed in the previous calculation, where we see how many degrees per second the valve opens. We will thus find the number of seconds needed for the valve to open approximately 45°. Afterwards, there is the condition that the digital input of the valve is not in the closed position, which will lead to the timing of the time interval required for the valve to open the necessary 45°. Before the condition for starting the timing, the digital command to start opening the valve is also executed, simultaneously with the reset of a possible closing command.
- line 11: In the operating state of the compressor (FUNC), if the button "High_Pressure_Button" is pressed, and the time unit on line 10 has completed the scrolling of the number of seconds required for the 45° opening (tmr_SC_Done), at

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the position information of the value of 45 is added to the valve. On the right side, the digital output that commands the opening of the valve and the bit "pas1_done is set to 1" are reset.

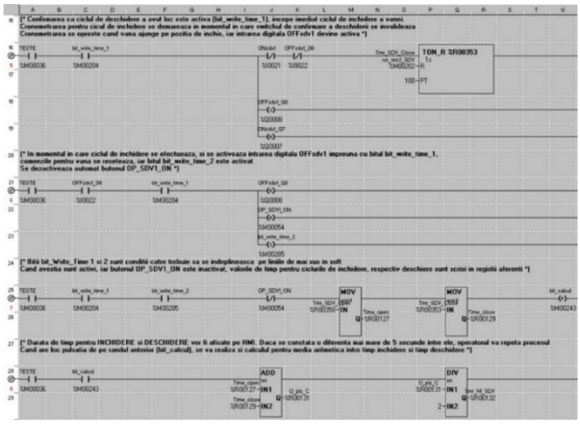

Fig. 3. Second software page for starting the compressor in high pressure conditions

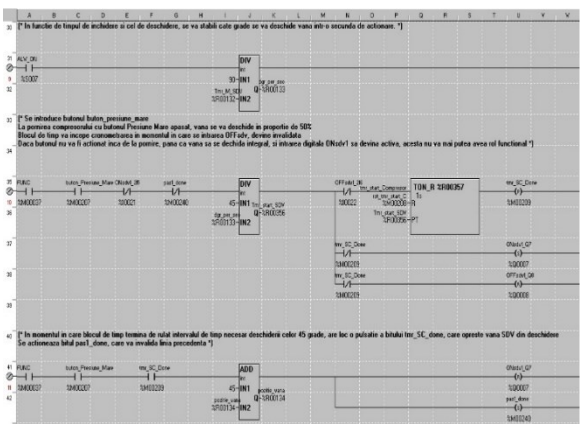

Fig. 4. Third software page for starting the compressor in high pressure conditions

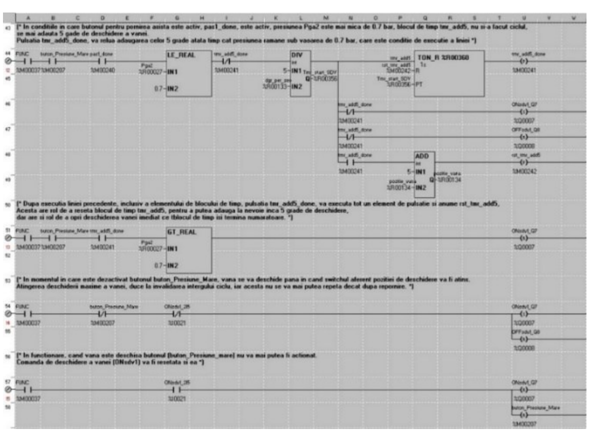

Fig. 5. Forth software page for starting the compressor in high pressure conditions

- line 12: In the operating state of the compressor (FUNC), if the button "High_Pressure_Button" is pressed, the "pas1_done" bit has the value 1, a conditioning takes place that contains a comparison where the pressure recorded by the transducer "Pga2" should be lower than the value of 0.7 bar. If the condition is true, the negated "tmr_add5_done" bit follows, which has the role of reinitializing the line when the "tmr_add5" time block finishes numbering, and the Pga2 < 0.7 bar comparison remains valid. Next is the operation of dividing the value 5 by the number of degrees per second, previously calculated. Along with the timing, there is also the digital command to execute the opening of the valve, a reset of the closing command, and on the last secondary line, 5 is added to the value of the valve position. This cycle occurs as long as the condition Pga2 < 0.7 is true; if the pressure will increase or is greater than 0.7 bar after opening the 45°, then line 12 will be disabled, and the PLC will wait for the pressure to drop below the value of 0.7 bar, after which it will open another 5°.
- line 13: In the operating state of the compressor (FUNC), if the button "High_Pressure_Button" is pressed, the end bit of the time unit for adding the 5° activated and the condition that the pressure Pga2 is greater than 0.7 bar, the command to open the valve will be temporarily stopped.
- line 14: In the FUNC operating state), if the button "High_Pressure_Button" is not pressed, the valve will receive the command to open up to the maximum position.
- line 15: In the compressor operation state (FUNC), when the valve reaches the open position, the opening command stops, and the high-pressure button is deactivated.

In Fig. 6 below is the "TESTING" test screen of the SDV intake valve. This screen coincides with an individual state of the machine, from where the valve will be commanded to record the closing time and the opening time, which will be written in the related registers.

There is also another test screen, from where various tests and sequences of operation can be executed, but also the execution of controllable elements on the skid, such as electric motors, solenoid valves, heating resistance and others.

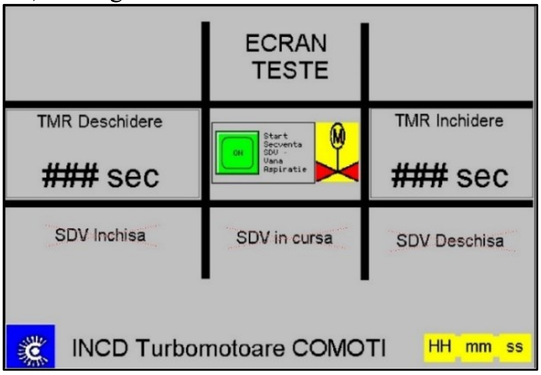

Fig. 6. HMI Tests screen; Display times for the closed - open cycle

Further down we present Fig. 7-9, which displays the following elements: All elements on a yellow background (1) represent analog inputs. Exceptions are the Boot Unlock button and the Alerts Border. The power-unlock button and power button (2). The release button has the role of heating the oil in the separator vessel up to 20°. The elements with a red background (3) represent the digital inputs, when these inputs are functional or do not transmit a problem, their color is green.

The valves shown can change their color in 4 ways:

- Black – Faulty valve
- Red – Valve Closed
- Blue – Vana in the race
- Green – Valve open

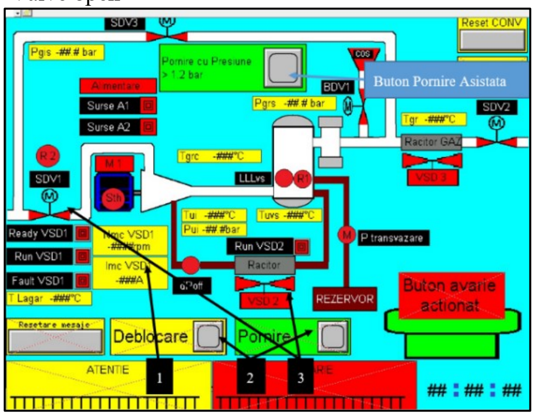

Fig. 7. Main screen "INIT" status of a screw compression unit; With the assisted start button

The "Switch Properties" window in Fig. 8 represents the configurable menu of the "Start with Pressure > 1.2 bar" button. Here the address of the button (%M207) was entered, as it is found in the software lines, and after entering the address the name "button_Presiune_Mare" is written automatically. Also, from this menu you can configure the background color, the display type of the button, the text that will appear to the left of it and other elements. An important element to point out is the type of action the button has, which is of the "Toggle" type. This type of button action maintains its state until it is pressed again, or until a command appears in the software to close it. If the action was of the "Momentary" type, the state of the memory unit "%M207" became active, i.e. 1, only as long as the button was pressed. For the logic created in the software shown below, the button action type had to be set as "Toggle".

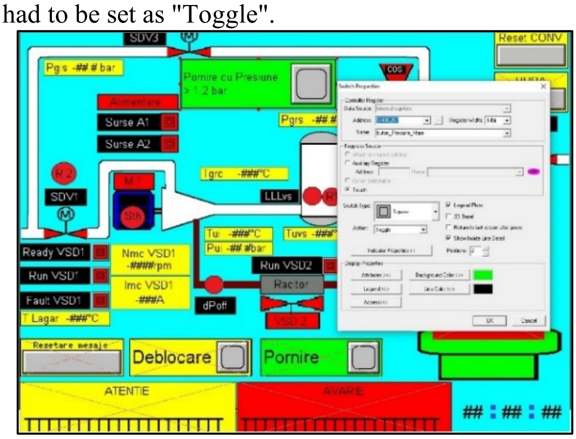

Fig. 8. Edit HMI display via the programming software

The high pressure start button only appears on the "INIT" initial status screen. After pressing the start button, the screen in Fig. 9 will appear on the HMI, where this time we notice that the stop button will appear with the pressurized stop button. This screen belongs to the operating state (FUNC) of the compressor.

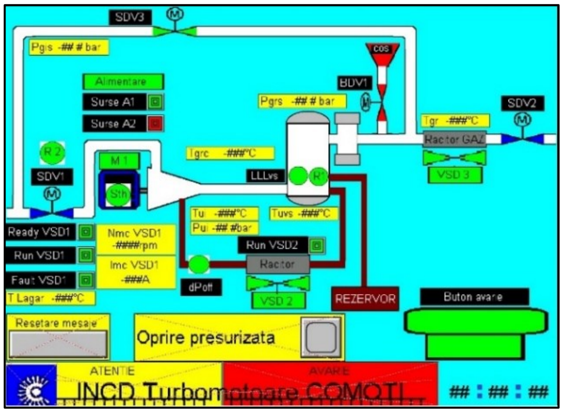

Fig. 9. HMI screen in operation mode (FUNC) of the compression unit

All the used terms in Fig. 7-9, which represent the terms used in the software proposal of the feedback loop controller in this paper, are explained in the following table (Table 1):

Table 1. The explanations of the tags used on the HMI screen of the compressor

TAG	Explanation
Imc	Current of the main motor
Nmc	Speed of the main motor
T Lagar	Temperature of the bearing opposite the coupling
Tui	Oil temperature at the exit from the cooler
Tuvs	The temperature of the oil in the separator vessel
Tgrc	Compressor discharge gas temperature
Sr1	Oil heater
Sr2	Anti-condensation resistance
VSD 1	Compressor main motor
VSD 2	Engine oil cooler
Pui	Dispensed oil pressure
Pgis	Separator inlet gas pressure
Pgrs	Separator discharge gas pressure
SDV 1	Gas suction valve
SDV 2	Gas discharge valve
SDV 3	Bypass valve
BDV 1	Blow valve
dPoff	Warping filter
Copt	Withdrawal pump (Separator pump)
LLLvsc	Low oil level in the separator vessel

5 Conclusions

With the help of the software presented above, it is possible to start safely any compression unit produced by INCD Turbomotoare COMOTI, without the need for any modification in the configuration of the automation cabinets already existing at the beneficiaries.

Of course, there can be many ideas adjacent to those presented by me in this chapter. We have reduced ourselves to the realization of a software configuration that will fit certain existing needs at the moment and that the beneficiaries of electro compressors in the OIL & GAS industry can use in the future, without generating very high intervention costs on the machines in work.

Future research endeavors will encompass the essential phase of experimental validation through experimental implementation. This imperative process is poised to substantiate the efficacy and viability of the proposed solution, thereby offering a methodical assessment of its functional attributes and potential real-world applicability. The integration of empirical validation, achieved through experimentation, is anticipated to serve as a pivotal bridge, engendering a comprehensive understanding of the solution's performance under controlled conditions and demonstrating its broader validation within relevant contexts.

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