Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **68**, *2*, pp. 182–187, Bucarest, 2023

OPTIMIZING THE ELECTRONIC CONTROL OF SUCTION VALVES FOR GAS COMPRESSION UNITS

CRISTIAN NECHIFOR[1,2], VALENTIN NĂVRĂPESCU[1,2], SORIN TOMESCU[1,2], CLAUDIA SĂVESCU[1,2,*], MIHAELA ROMAN[1,2], RAREȘ CONȚIU[1,2], ADRIAN STOICESCU[1,2]

Keywords: Electronic control; Programmable logic controller; Proportional-integrative-derivative controller; Suction valve; Gas compressor; Monitoring sensors; Acquired parameters.

In certain compression stations where twin-screw compressors assemblies are installed, certain operational problems have been observed when starting the assembly again after it was shut down. The downtime can vary from several minutes to a few days, depending on the shutdown causes. The gases accumulated in the compressor suction pipe can cause the inlet gas pressure to be above the typical pressure values ranging from atmospheric pressure (1 bar) to 1.5 bar. The compressor is automatically shut down via the sequences implemented in the automation control system if the pressure at the inlet of the compression unit exceeds 1.5 bar, this value being the maximum suction pressure that the compressor unit is designed to withstand. The solution introduces a potentiometer for providing feedback on the suction valve opening angle and thus optimizing the valve control to prevent the occurrence of higher pressures which may lead to failed start-ups or emergency shutdowns.

1. INTRODUCTION

The optimization of butterfly suction valve control [1–4] in gas screw compressor units [5–10] holds significant importance in achieving efficient performance and maximizing operational advantages. Suction valves are pivotal components responsible for regulating the gas flow into the compressor, thus influencing its overall operational effectiveness. Gas compressors are widely used in industry [11,12], in applications such as gas transport through pipelines, gas storage applications, air separation plants, for pneumatic equipment, or tools requiring compressed air, etc. [13]. By meticulously optimizing control mechanisms governing these motor-operated valves (MOV), operators can attain enhanced reliability, reduced energy consumption, and improved system efficiency.

The optimization process entails using advanced technologies, sophisticated algorithms, and comprehensive data analysis methodologies. Different upstream and midstream applications lead to different compression system characteristics and control requirements, which, in turn, are the result of compressor requirements (such as high-pressure ratio and wide operating range) and process requirements [14]. These approaches facilitate fine-tuning suction valve operating parameters, encompassing opening and closing timings, valve lift, and valve profile, to achieve optimal gas flow characteristics. Typically, a compressor station receives a reference signal from the dispatch center, usually in the form of a total mass-flow setpoint for a parallel configuration or a pressure setpoint for a serial configuration [13]. Consequently, this optimization enables the gas compressor unit to adapt to changing operating conditions and variable demands, enhancing system performance and energy efficiency.

The gas compression system and the set of local controllers used in each piece of equipment can be considered a complex multivariable system due to the high number of controlled variables. A station can have several compressors and a large number of heat-exchangers and manifolds, the nonlinear dynamics of the different sub-processes, the high number of constrained variables in gas compressors (such as pressures and temperatures that have to be maintained within controllable ranges), and the coupling effects between the different manipulated and controlled variables [15]. One notable advantage of optimizing suction valve control lies in the reduction of energy consumption. By precisely controlling valve opening and closing timings, operators ensure that the compressor unit operates within its most efficient range, mitigating power losses, curbing energy wastage, and reducing operational costs. Furthermore, optimized control mechanisms for suction valves enhance the stability and reliability of gas compressor units, minimizing the likelihood of equipment failure and downtime. Multiple unit installations, installations with multiple compressors per train, and installations where the train must serve multiple gas streams, require specific process control considerations to match the compressors with the process system behavior and the objectives of the station or system operator [14].

Additionally, optimizing suction valve control contributes to improved system flexibility and responsiveness. The control system must be addressed concerning instrumentation and device requirements, the system dynamics, and the control methods of the drivers [14]. Leveraging advanced control algorithms, operators can adjust valve operations in real-time, swiftly responding to gas demand fluctuations, process condition variations, and changing system requirements.

This adaptability enables the gas compressor unit to function optimally across various operating scenarios, ensuring reliable and efficient performance under various load conditions. The control system has to be addressed the instrumentation and equipment requirements, as well as the control methods of the electric drives [14].

The paper herein addresses a valid solution for the issues encountered at some gas compression stations owned by beneficiaries of INCD Turbomotoare COMOTI. These problems include building up pressure in the suction line, which can lead to failed startups. We developed a feedback system applicable to the current valves and a software solution for this problem, considering the information regarding the valve's positioning.

[1] Romanian Research and Development Institute for Gas Turbines COMOTI. [*]Corresponding author, E-mail: claudia.borzea@comoti.ro, cristian.nechifor@comoti.ro;sorin.tomescu@comoti.ro;mihaela.roman@comoti.ro;rares.contiu@comoti.ro;adrian.stoicescu@comoti.ro.
[2] University Politehnica of Bucharest, E-mail: valentin.navrapescu@upb.ro.

2. OVERVIEW ON VALVE TEST BENCH AND PROPOSED SOLUTION

Butterfly valves (Fig. 1) are quarter-turn rotary valves in which a closure disc is rotated to open, close, or regulate the flow passage, and can be used for flow in both directions. A pressure drop is induced in the flow, regardless of valve position, since the disc is always present within the flow [16].

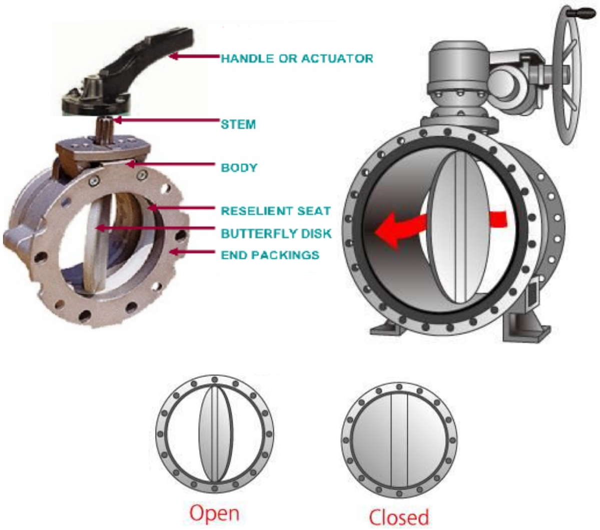

Fig. 1 – Butterfly valve construction and working principle [16].

At the moment, for facilitating the startup of a screw compressor, manual maneuvers are necessary for lowering the inlet pressure, such as: opening the discharge valve of the station and continuously purging an amount of gas, or half-opening the manual valve located on the station pipe to generate pressure drop, simultaneously with the initialization of the compressor start command. These maneuvers require the presence of two operators and do not always ensure that the compressor start condition is met.

The proposed solution involves installing a pressure sensor monitored by PLC (Programmable Logic Controller). This eliminates the need to send an operator outside to read the manometer display installed on the suction pipeline of the compressor.

A control cabinet [17,18] was designed for the valve, for the monitoring and control of the valve, both for testing its functionality on the bench with brake simulating mechanical load (Fig. 2), as well as testing its operation on the skid (Fig. 3). The PLC acquires and monitors data from the test bench, such as: the torque produced by the electric driving motor [19], current and power of the electric motor, valve opening/closing angle.

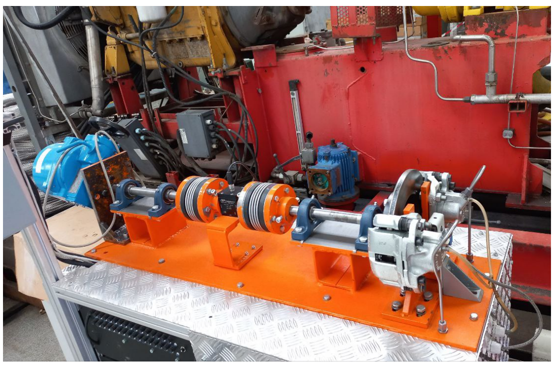

Fig. 2 – Valve test bench with brake.

Fig. 3 – Valve installed on screw compressor skid.

The front door of the control cabinet, presented in Fig. 4 is equipped with a touchscreen operating panel, emergency shutdown button, start/stop buttons, and switch for selecting the operating mode between test bench or operation on the electro-compressor (ECS) skid, voltage indicator.

Fig. 4 – Control cabinet front door.

The equipment installed inside is shown in Fig. 5. On the upper row, from left to right, we have circuit breakers, two 24 Vdc power supplies, the PLC with its I/O modules, and an Ethernet switch for connecting the operator panel and a laptop for data acquisition and any software modifications the. On the middle row, torque analyzer, 230 Vac socket, eleven 24 Vdc relays, four solid-state relays, a circuit breaker for dc, RTD adaptor that reads 0 ÷ 5 kΩ, and dc fuses. We have terminal blocks and a current analyzer on the bottom row on the right side.

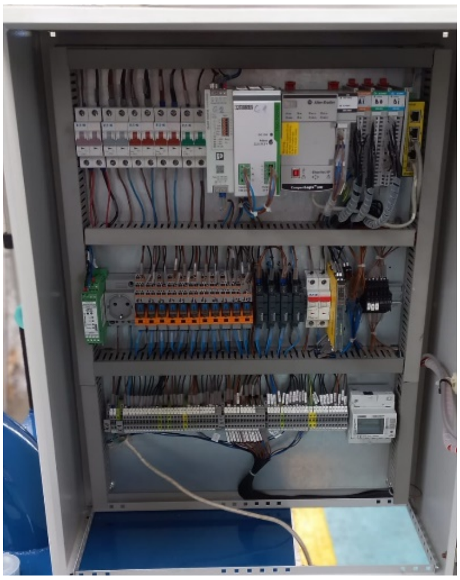

Fig. 5 – Control cabinet inside equipment.

3. BUTTERFLY VALVE WITH POTENTIOMETER

When starting up the screw compressors installed in various locations, problems have arisen as a result of the high inlet pressure of the compressor, namely, a pressure greater than 1.5 bar. In the PLC's software, designed for the automatic and safe operation of the compression units, we implemented a fault alarm that will stop the compression unit if the suction pressure indicates values higher than 1.5 bar. The only safe method successfully implemented for our compression units in secure conditions was delaying the error related to the inlet pressure by two or three seconds. This method allows the compression unit to undertake the higher inlet pressures at start-up. Other conceptual methods would be starting the automatic procedure of opening the inlet valve once the main engine driving the compressor unit starts up or gradually opening the valve on the inlet pipe.

Installing a second pressure transducer is a good practice, based on the experience with the compression process and butterfly valves (Fig. 6). This second transducer is useful during the start-up, its role being to monitor the pressure in the suction pipe while the compression unit is stationary. At the same time, it will also indicate the initial opening position of the suction valve if the pressure is higher than 1.2 bar.

Using a valve with a potentiometer for position adjustment, controlled by a PLC, it is possible to control the pressure level in the inlet line, especially when the compression unit is started-up. Suppose the pressure reaches the maximum threshold value allowed at the inlet. In that case, the sequences of PLC software will command the execution elements to gradually close the butterfly valve so that the pressure at the compressor inlet decreases. Pga2 is the parameter notation for the compressor inlet pressure, and Pga1 is the gas pressure value when entering the skid. In other words, the pressure is measured before the inlet valve (Pga1) and after the valve (Pga2).

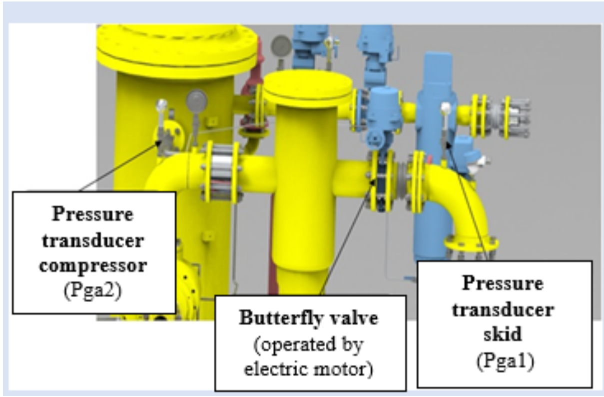

Fig. 6 – Valve installed on screw compressor skid.

Depending on the Pga1 value at start-up, the valve opens between 20° and 90° in the first stage. As soon as the valve opens and Pga2 increases, the valve position is adjusted according to its recorded value. The compressor takes in the pressure from the suction pipe, and after the first stage, the valve will continue to open completely.

A potentiometer with 0 ÷ 5 kΩ electrical resistance was mounted at the bottom of the electrically actuated valve. The rod drives the potentiometer mechanically, indicating the angular position of the valve. A gear mechanically drives the stem and moves with the butterfly, which closes or opens the valve.

Since the total stroke of the actuated valve is only 90°, to increase the precision, we introduced a toothed gear to amplify the angular displacement (Fig. 7).

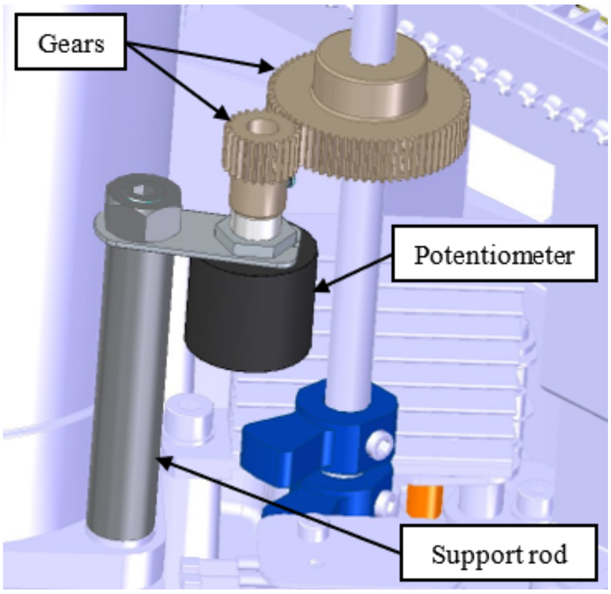

Fig. 7 – 3D model showing the potentiometer mounted for providing valve position feedback.

The driving gear was mechanically mounted on the stem indicating the working position of the valve. The driven gear was mounted on the potentiometer shaft (Fig. 8).

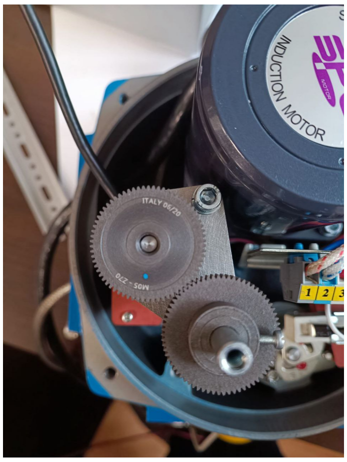

Fig. 8 – Physical implementation of the solution.

An adapter converts the information provided by the potentiometer, from the resistance into unified current 0÷20 mA. There are commercial PLCs that are able to read the resistance information on their own, but this implies very high costs. Moreover, there is a risk of data altering and reading errors due to requiring a communication cable longer than 50 meters to transmit the information between the potentiometer and the PLC. The difference in resistance is due to its increase with the length of the cable and the cross-section of the conductors.

4. EXPERIMENTAL TESTS AND OPTIMIZATION SOFTWARE

Valve tests have been carried out employing the PID function provided by the PLC development software, and the results are shown in the graph in Fig. 9. We observed that the valve could not maintain the prescribed value of 0.3 bar, this leading to an oscillating opening-closing movement. The mechanical wear of the valve actuation can be foreseen, leading us to consider other approaches.

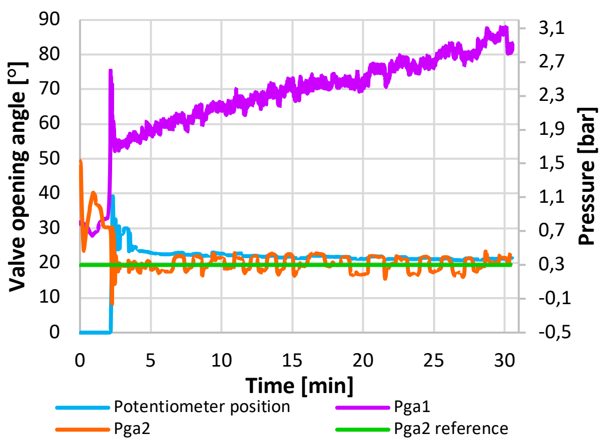

Fig. 9 – Valve experimental data acquired with PID control.

The PID controller [20] is a form of controller widely used in industry. A PID controller is simple to use and can address a wide range of control problems. The essence of the regulation task is to bring certain quantities from the technological process (temperatures, pressures, speeds, etc.) to prescribed values and to maintain them at these values, by eliminating or mitigating the effect of disturbances.

The signal variation with time can be described by the function below. The constants k_P, k_I, and k_D must be adjusted for a particular process and desired control mode. The PID controller coefficients k_P, k_I, and k_D are frequently tuned and set for a particular control problem, in which case the PID controller is strictly a time-invariant linear system [21].

$$y(t) = k_P \cdot x(t) + k_I \int x(t)dt + k_D \frac{dx(t)}{dt}, \qquad (1)$$

where: k_P – proportional constant; k_I – integrative constant; k_D - derivative constant.

The previously mentioned approach consists of a software, which has the role of verifying, through the Pga1 pressure switch, the value of the pressure at the entry into the compression skid. Depending on this value, a predefined opening command is given. After the initial opening, the opening angle of the valve can be calculated relying on the information provided by the second transducer, Pga2.

The parameters for valve control, presented in Table 1, are set according to the mechanical design limitations of the compressor.

Table 1

Operating ranges

Parameter	Symbol	Value
Valve minimum opening angle	θ_{SDV_min}	20°
Valve maximum opening angle	θ_{SDV_max}	90°
Minimum pressure in the compressor	$Pga2_{min}$	0.5 bar
Maximum pressure in the compressor	$Pga2_{max}$	1.2 bar

The control loop (2) is done so that its adjustment conforms to the linear fit defined by the points of interest. If the value recorded by the pressure transducer will be less than 0.5 bar, the valve control value will go to a maximum opening of 90°. If the value indicated by the Pga2 transducer will be greater than 1.2 bar, then the command for the valve will be to close/open only 20°.

$$y = (x - x1)\left(\frac{y2-y1}{x2-x1}\right) + y1\,. \qquad (2)$$

In the case of our linear adjustment loop (Fig. 10), for which we have information from the pressure transducer, Pga2, considering the points of interest for the linear parameters specified in Table 1, the eq. (2) can be written with our parameters as (3):

$$\theta_{SDV} = (Pga2 - Pga2_{min})\left(\frac{\theta_{min}-\theta_{max}}{Pga2_{max}-Pga2_{min}}\right) + \theta_{max} \qquad (3)$$

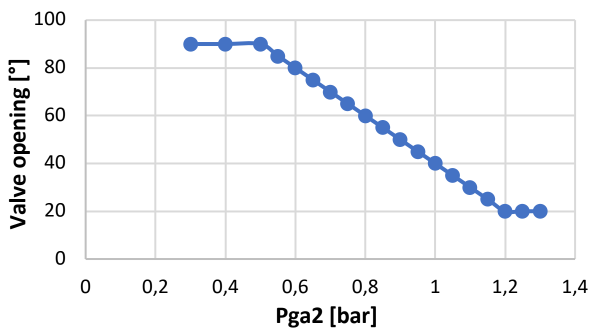

Fig. 10 – SDV opening with respect to the pressure in the compressor.

We have thus implemented a register in the ladder diagram software (Fig. 11), which can be addressed as control_SDV, and a parameter recorded by a transducer, in this case Pga2.

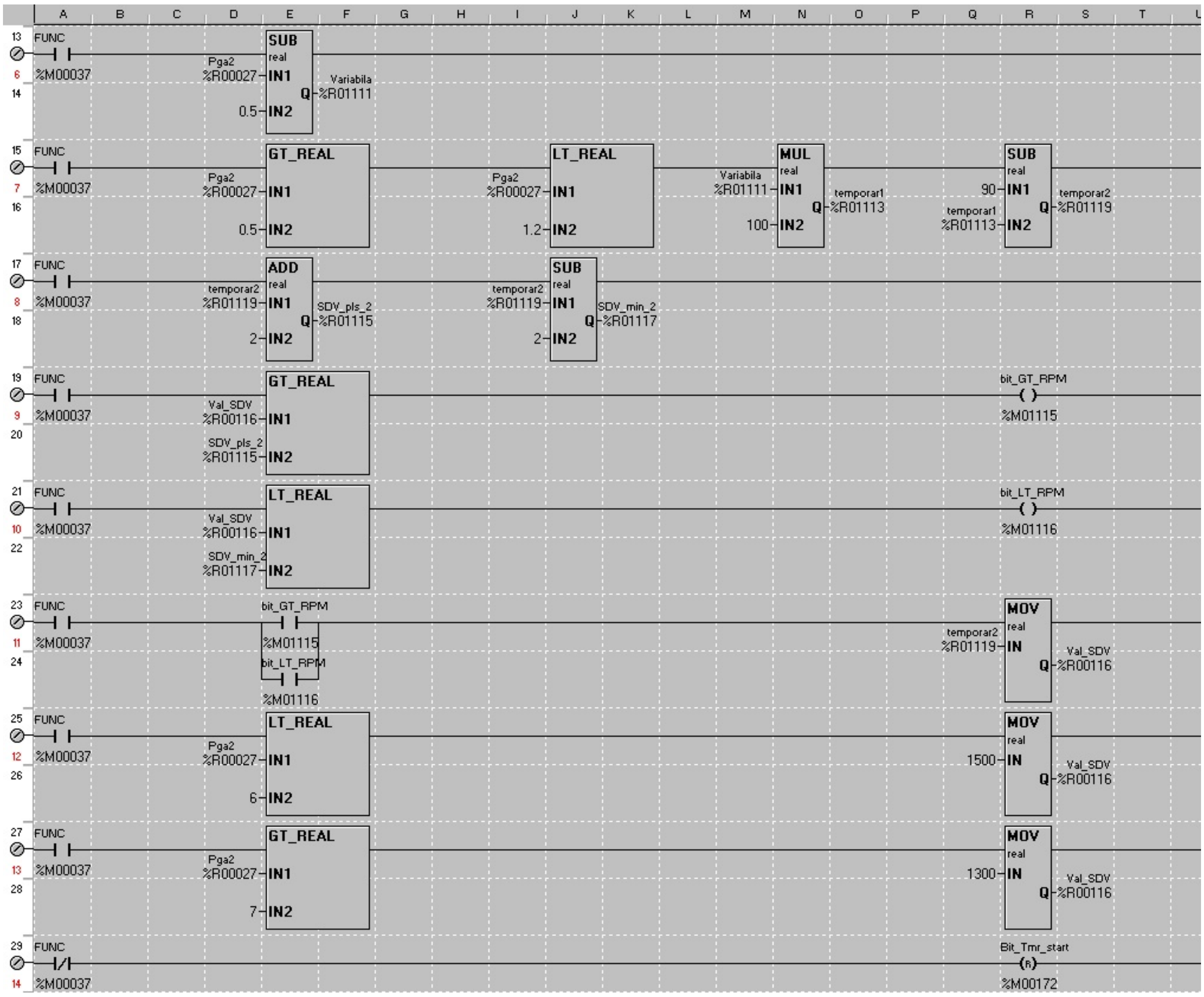

Fig. 11 – Ladder diagram software .

The software lines display the condition written for the software, where the FUNC bit needs to be active and the Start bit, inactive; after 5 seconds, the Start bit becomes inactive, as specified in previous software lines.

In the first line, the SUB function subtracts the minimum value of interest (0.5 bar in our case) from the Pga2 recorded value and writes it in the “Variable” register.

The following line describes the adjustment loop, which works between the 0.5 and 1.2 bar pressure values according to the second line. If the pressure range condition is met, the “Variable” is multiplied by 100 and is written in the register called “temporary1”, subtracted from the maximum value at which the valve will be opened (90° in our case) and the result will be written in the “temporary2” register.

The stabilization is realised in the next two lines, where the “SDV_plus_2” and “SDV_minus_2” registers are added to the third line and represent the tolerance of ±2° considered herein. According to Fig. 9 above, this range can be adjusted after the first testing program, depending on the data obtained. The next lines we have the comparison conditions regarding the last value imposed on the valve: if “Val_SDV” is 2° higher than “SDV_plus_2”, then the “bit_GT_dgr” bit will be activated, else if “Val_SDV” is 2° In lower than “SDV_minus_2”, then the “bit_LT_dgr” will be activated.

For activation of one of these bits, the required control value has an offset of at least 2° to the last imposed value for valve position, which will lead to a smaller variation of the valve position command. Bits "bit_GT_dgr" and "bit_LT_dgr" will act only when the adjustment imposes a value with 2° offset from the previously calculated position.

The next lines show the activation conditions for “bit_GT_dgr” and “bit_LT_dgr”, for the subsequent computed value to be written in the register that controls the process element, namely the shutdown valve (SDV). We have the MOV (motor operated valve) block, which moves the calculated value from the "control_SDV" register to the "Val_SDV" register.

The Pga2 values are compared to our target values. If Pga2 is lower than 0.5 bar, the 90° opening will be written in the valve control register, if the Pga2’s value is greater than 1.2 bar, the valve will close at the maximum allowed position (20° in our case).

The last line implements the fault or shutdown sequence. “Bit_Tmr_start” that was previously activated in line 1.2 is reset after the FUNC bit becomes inactive.

5. CONCLUSIONS

The paper presents a conceptual solution to be tested and validated for optimizing the inlet valve control. The proposed solution is simple, effective, and does not require a PID for valve position feedback from the potentiometer.

Future research will consider the implementation and experimental testing. The parameter values and ranges are easily adjustable, as well as the angle tolerance. Depending on the results, the tolerance can be increased from the 2° given by the designer up to higher values for avoiding valve oscillations, the aim being to reduce the mechanical straining of the valve and thus avoiding premature mechanical wear. Future research will also involve controlling the valve only via the PLC software, without any mechanical modification (without potentiometer). The aim is to avoid the ATEX recertification of the anti-explosion valve involving third-party entities, procedures, and documentation.

ACKNOWLEDGEMENT

The paper was realized with the support of the OPTIM Research project, code MySMIS 153735, co-funded by the European Social Fund (FSE) through the Operational Programme Human Capital (POCU) 2014-2020, implemented in 2022-2023.

The research work presented herein was funded by Competitiveness Operational Program 2014-2020, Priority Axis 1 – Research, Technological Development and Innovation in Support of Economic Competitiveness and Business Development, project acronym EPAVREDI, contract no.: 132 / 23.09.2016, carried out with the support of Romanian Ministry of European Funds.

Received on 20 May 2023

REFERENCES

1. C. Nechifor, C. Borzea, I. Vlăducă, I. Mălăel, F. Niculescu, *Electrically Actuated Valves for Gas Compression Installations Located in Potentially Explosive Atmospheres*, MATEC Web of Conferences, **305**, p. 00027 (2020).
2. F. Lu, J. M. Zhang, Y.M. Shen, *Simulation and Research on Flow-field of Butterfly Valve in Standard Variable Head Flow Device*, in 18th International Flow Measurement Conference, FLOMEKO, Lisbon, Portugal (2019).
3. O. Kivanc, O. Ustun, G. Tosun, E. Oguz, Y. Mutlu, *Design and Implementation of an Electric Actuated Valve for Precise Fluid Control*, Gazi University Journal of Science, **32**, *2*, pp. 483-492 (2019).
4. Q. Zhou, L. Liu, L. Jiang, Z. Xu, *CMAC-PID Composite Control for the Position Control of a Fully Variable Valve System*, International Journal of Automotive Technology, **24**, pp. 681–691 (2023).
5. A. Safaat, A. Noviyanto, *Failure analysis of rotary screw compressor and its modifications*, International Journal of Innovation in Mechanical Engineering and Advanced Materials, **3**, *3* (2022).
6. A. Bahadori, *Chapter 5 - Gas Compressors*, in the book: Natural Gas Processing, pp. 223–273 (2014).
7. Y. Zhao, X.Xu, M. Qadrdan, J. Wu, *Optimal operation of compressor units in gas networks to provide flexibility to power systems*, Applied Energy, **290**, p. 116740 (2021).
8. S. Tomescu, V. Petrescu, A. Serban, S. Voicu, *Energy Efficiency of an Oil Injected Screw Compressor Operating at Various Discharge Pressures*, 10th International Conference on Energy and Environment, CIEM (2021).
9. H.H. Patel, V.J. Lakhera, *A critical review of the experimental studies related to twin screw compressors*, Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, **234**, *1*, pp. 157–170 (2019).
10. N. Seshaiah, R.K. Sahoo, S.K. Sarangi, *Theoretical and experimental studies on oil injected twin-screw air compressor when compressing different light and heavy gases*, Applied Thermal Engineering, **30**, *4*, pp. 327–339, (2010).
11. I.C. Mustață, L. Bacali, M. Bucur, R.M. Ciuceanu, A. Ioanid, A. Ștefan, *The Evolution of Industry 4.0 and Its Potential Impact on Industrial Engineering and Management Education*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **67**, *1*, pp. 73–78 (2022).
12. S. Paker, I. Ekmekci, *Electrical Hazards in Industrial Facilities and Evaluation of the Measures*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **67**, *2*, pp. 133–138 (2022).
13. P. Milosavljevic, A.G. Marchetti, A. Cortinovis, T. Faulwasser, M. Mercangöz, D. Bonvin, *Real-time optimization of load sharing for gas compressors in the presence of uncertainty*, Applied Energy, **272**, p. 11488 (2020).
14. R. Kurz, K. Brun, *Process Control for Compression Systems*, Journal of Engineering for Gas Turbines and Power-transactions of the ASME (2017).
15. R.S. Gesser, R. Sartori, T.P. Damo, C.M. Vettorazzo, L.B. Becker, D.M. Lima, M.L. de Lima, L.D. Ribeiro, M.C.M. M. Campos, J.E. Normey-Rico, *Advanced control applied to a gas compression system of an offshore platform: From modeling to related system infrastructure*, Journal of Petroleum Science and Engineering, **208**, p. 109428 (2022).
16. ****Introduction to Butterfly Valves*, The Process Piping (2020).
17. C. Nechifor, C. Borzea, A. Stoicescu, D. Lale, M. Vasile, *Modular automation cabinet for proactive monitoring in ATEX Zone 2*, MATEC Web of Conferences, **354**, p. 00044 (2022).
18. S.A. Babichev, P.A. Zakharov, O.V. Kryukov, *Automated monitoring system for drive motors of gas-compressor units*, Automation and Remote Control, **72**, *1*, pp. 175–180 (2011).
19. A. Benachour, E.M. Berkouk, M.O. Mahmoudi, *A new direct torque control of induction machine fed by indirect matrix converter*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **62**, *1*, pp. 25–30 (2017).
20. R. Arun, R. Muniraj, M.S.W. Iruthayarajan, *Performance analysis of proportional integral derivative controller with delayed external reset and proportional integral derivative controller for time delay process*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **66**, *4*, pp. 267–273 (2021).
21. Q.K. Nguyen, K.H. Jung, G.N. Lee, S.B. Park, J.M. Kim, S.B. Suh, J.Y. Lee, *Experimental study on pressure characteristics and flow coefficient of butterfly valve*, International Journal of Naval Architecture and Ocean Engineering, **15**, p. 100495 (2023).