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AIR FLOW MODELLING AND SIMULATION IN A TWIN-SCREW COMPRESSOR BASED ON THE FLOWXPRESS ANALYSIS WIZARD MODULE OF SOLIDWORKS

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Abstract: *Twin-screw compressors can generate pressures of up to 7.4-10 bar and airflow rates of up to 750 m³/min. From this perspective, these are also of interest to the mining industry because they combine the advantages of both piston and turbo compressors. Generally, the efficiency is better and overall dimensions are smaller as compared to piston compressors having for similar technical performances. In this study, we aim to analyze the airflow process in a virtual model of a twin-screw compressor, using the FlowXpress Analysis Wizard module of the SolidWorks application, and visually present the flow velocity.*
Keywords: *twin-screw compressor, flow analysis, flow velocity, pressure, air volume, simulation.*

1. INTRODUCTION

The mining industry is a vital part of the global economy, providing essential resources that drive various industries and support modern infrastructure [1]. Within this industry there are several specific machines and equipment used in all phases of mining operation [2-4]. For all these machines, their reliability, efficiency and safety are of paramount importance [5, 6].

One of the critical equipment used in mining operations are compressors. They are used for a variety of applications, including pneumatic tools, ventilation systems, and the operation of heavy machinery [7]. It is a vast area of research, with several topics covered: energy efficiency prediction [8] or improvement [9], advances in general [10] or rotor profile [11] design, and studies regarding leakage [12] and/or flow, using CFD and computer simulation [13-15].

The present study aims to develop a computer simulation model to predict the air flow characteristics of a twin-screw compressors. The choice of software is based on the expertise of the authors who used it in past works of simulation in engineering [15-17].

In the future the study can be extended for analysis of temperature, pressure analysis, and possibly other types of compressors.

2. THEORETICAL CONSIDERATIONS

The twin-screw compressors are gas/air compressors, that operate using a rotary-style positive-displacement mechanism. Widely used in industrial applications including mining, these compressors often replace the traditional piston ones, when higher volumes of compressed gas are required. This compressor types deliver a continuous supply of compressed air, which is crucial for running tools, machinery, and ventilation systems in tough mining conditions.

Air compression is achieved using two screw shaped rotors with different profiles (Figure 1), which are housed in a bicylindrical casing with very small clearances. As seen, the protruding parts of one rotor fit into the recesses of the other, such that the shapes of the teeth and cavities are conjugated.

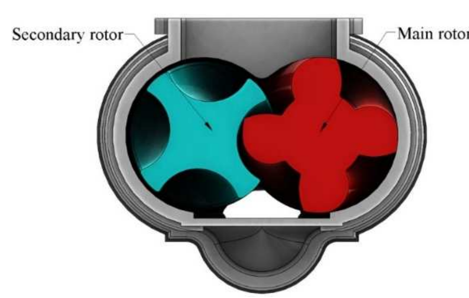

Fig.1. Cross-section of a twin-screw compressor

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It can be observed that contact between the two rotors occurs along a single plane, which moves from one end of the rotors to the other during rotation.

The primary rotor, with a convex profile, has four teeth and is driven by the actuation mechanism. The secondary rotor also has four teeth, featuring a concave profile.

The rotational movement between the rotors is transmitted via a pair of gears (Figure 2).

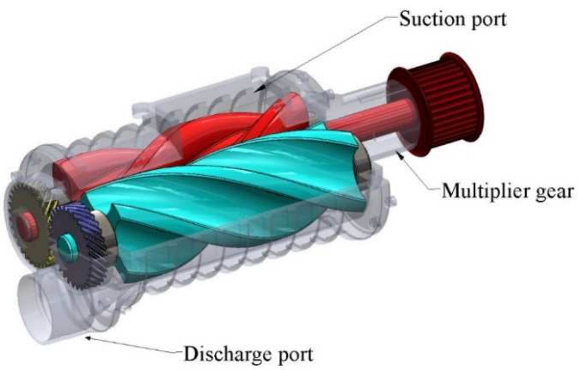

Figure 2 Longitudinal Section of a Helical Compressor

The rotors rotate without making contact with each other or the cylinders, eliminating the need for lubrication. This prevents the contamination of air with oil, a significant advantage for the safety of underground workplaces. Additionally, because the rotors do not contact each other, they experience no wear, thereby reducing maintenance requirements.

The primary drawback of these compressors is the high rotational speed required for the main rotors. This speed is on the order of 20,000 rpm and is achieved through speed-increasing gear mechanisms. Consequently, sliding bearings with pressure lubrication are preferred for the rotors instead of ball bearings. From a functional standpoint, the peripheral speed of the rotors is within the range of v = 30-120 m/s.

The effective suction flow rate is calculated using the equation:

$$Q = n_1 \cdot z_1 \cdot \lambda_0 \cdot l\left(f_1 + f_2\right) \quad [\text{m}^3/\text{min}] \quad (1)$$

where:

- n_1 is the rotational speed of the main rotor, expressed in rpm;
- z_1 is the number of teeth on the main rotor;
- l is the length of the rotors, expressed in meters;
- f_1, f_2 are the effective cross-sectional areas of the voids in the screw pitch of the two rotors, expressed in square meters;
- λ_0 is the volumetric efficiency (0.73…0.82 for compression ratio of 4, and 0.75…0.88 for compression ratio of 2.5).

The driving power under conditions of imperfect cooling is determined based on the mechanical work of adiabatic compression:

$$L_{c(ad)} = \frac{k}{k-1} p_1 \left(\frac{p_2^{\frac{k-1}{k}}}{p_1} - 1 \right) \quad \left[\text{J/m}^3\right] \quad (2)$$

$$P = \frac{L_{c(ad)} \cdot Q}{60 \cdot 1000 \cdot \eta_{i(ad)} \cdot \eta_m \cdot \eta_{tr}} \quad [\text{kW}] \quad (3)$$

where:

- $\eta_{i(ad)}$ is the adiabatic indicated efficiency;
- η_m is the mechanical efficiency;
- η_n is the transmission efficiency.

3. PRESENTATION OF THE MODEL OF THE TWIN-SCREW COMPRESSOR SUBJECTED TO SIMULATION

The virtual model was created using the SOLIDWORKS application and represents an assembly consisting of four parts.

The first two parts are the main rotor with five teeth (Figure 3) and the secondary rotor with six teeth (Figure 4)

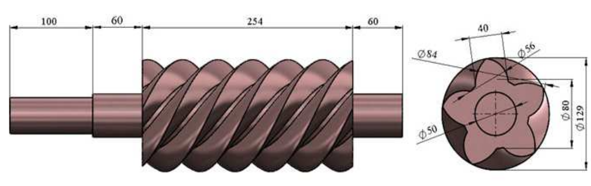

Fig.3. The main rotor

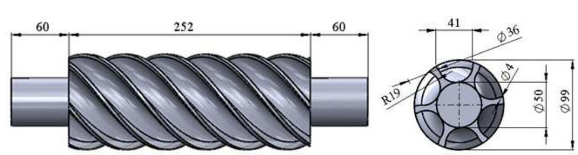

Fig.4. The secondary rotor

The two rotors are encompassed in a case consisting of the compressor base (Figure 5), and its cover (Figure 6).

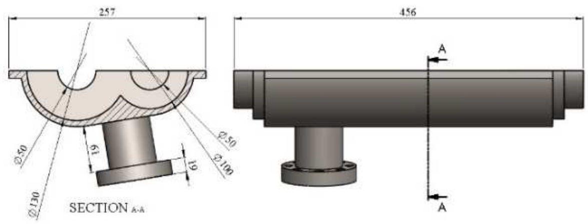

Fig.5. The base of the casing

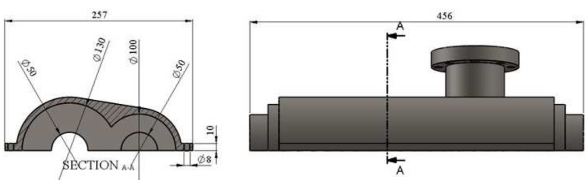

Fig.6. The cover of the casing

Figure 7 shows the model of the helical compressor described earlier, created at 1:2 scale using 3D printing.

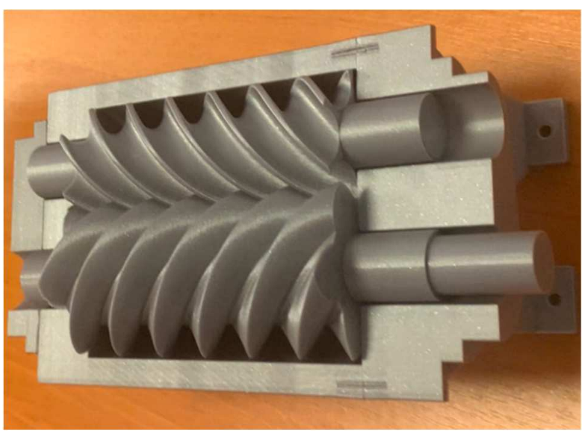

Fig.7. 3D printed physical model

4. SIMULATION OF THE AIR FLOW THROUGH THE VIRTUAL MODEL OF THE TWIN-SCREW COMPRESSOR

Before performing the actual simulation using the FlowXpress Analysis Wizard of SolidWorks, the relative position of the two rotors was determined using a Motion Analysis study. In order to achieve that, a contact-type mate was imposed between the main and secondary rotor. Thus, the airflow analysis through the compressor will be conducted for actual functional positions of the two rotors.

A fundamental requirement in SolidWorks–for performing the flow simulation inside any devices or machines like pumps or compressors–is sealing the volume to be analyzed. To achieve this, two lids were placed at the inlet and outlet orifices of the virtual compressor model, as shown in Figure 8.

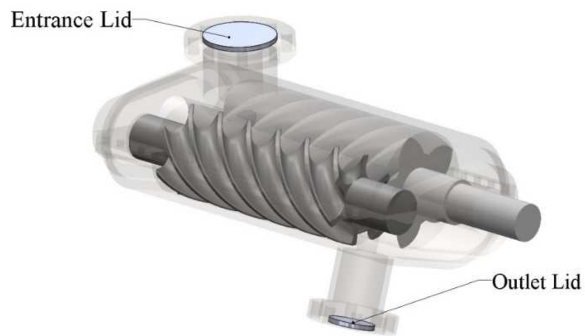

Fig.8. Placement of the sealing lids

The sealing with the two lids, allows for determining and visualizing the fluid inside the compressor, as shown in Figure 9.

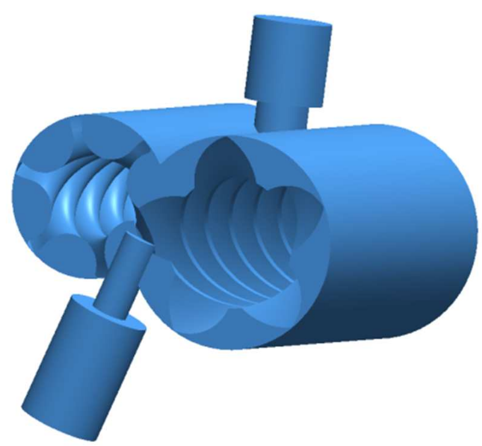

Fig.9. The air volume inside the compressor

On the inner surface of the inlet lid, an air flow rate of 0.005 m^3/s and an air temperature of 293.2 K was imposed, while a pressure of 303,975 Pa was set on the inner surface of the outlet lid.

After running the simulation with the aforementioned initial conditions, the variation of air velocity in the compressor and the corresponding flow lines were obtained. Figures 10, 11, and 12 present the results in side, front, and isometric views, respectively.

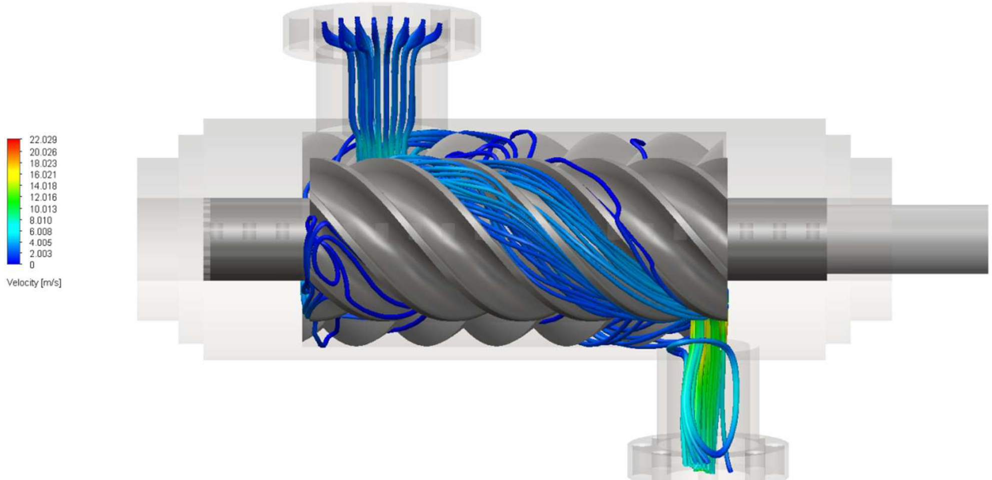

Fig. 10. Variation of air velocity inside the compressor and flow lines – side view

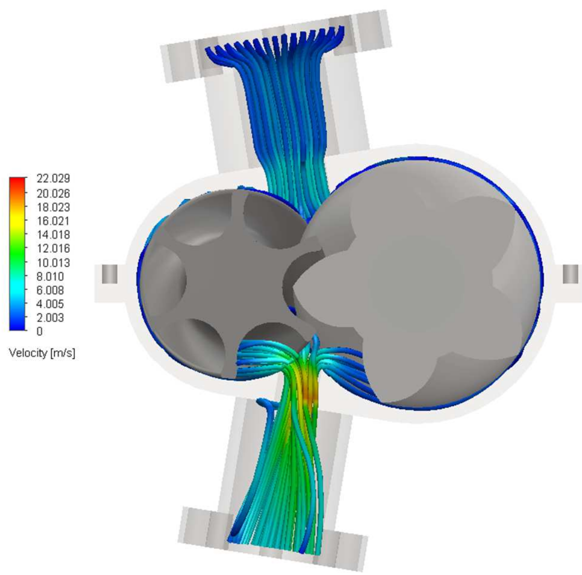

Fig. 11. Variation of air velocity inside the compressor and flow lines – front view

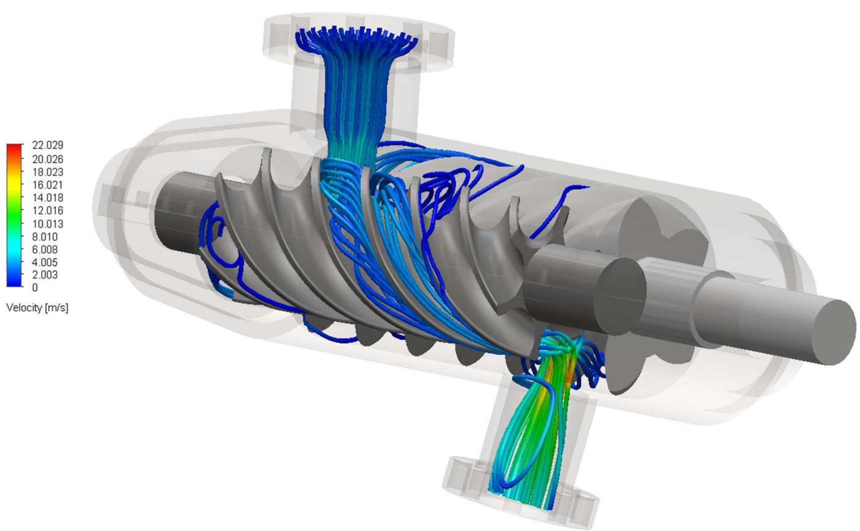

Fig. 12. Variation of air velocity inside the compressor and flow lines – isometric view

5. CONCLUSIONS

Twin-screw compressors belong to the category of rotary volumetric compressors. By eliminating the crankshaft mechanism found in piston compressors, these machines operate more smoothly and at higher speeds. The twin-screw compressor exhibits higher isothermal efficiency and better flow coefficients compared to other types of compressors.

The quantitative results obtained point to a maximum velocity of the fluid of 22.029 m/s. This is achieved after the end of the two rotors, at the outlet orifice situate at the base of the compressor casing. The flow lines also show that the higher velocity is concentrated towards the outside of the flow, at the intersection with the compressor outlet orifice wall.

The study emphasizes the significance of utilizing advanced modeling and simulation tools in engineering, particularly for analyzing the operation of screw compressors. The virtual model employed facilitated the assessment of air pressure and velocity variations within the compressor. The insights gained and the results achieved through this approach can be effectively applied to other screw compressor configurations.

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Modelarea și simularea curgerii aerului într-un compresor elicoidal utilizând modulul FlowXpress Analysis Wizard al SolidWorks

Rezumat: Compresoarele elicoidale pot genera presiuni până la 7,4-10 bari și debite de aer până la 750 m^3/min. Din acest punct de vedere acestea prezintă interes și pentru industria minieră, datorită faptului că înglobează atât avantajele compresoarelor cu piston cât și ale turbocompresoarelor. În general, eficiența este mai bună, iar dimensiunile generale sunt mai mici în comparație cu compresoarele cu piston care au caracteristici tehnice similare. În lucrare ne propunem să analizăm procesul de curgere al aerului într-un model virtual de compresor elicoidal utilizând modulul FlowXpress Analysis Wizard al aplicației SolidWorks.
Cuvinte cheie: *compresor cu două șuruburi, analiza debitului, viteza de curgere, presiune, volum de aer, simulare.*

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