MULTIFUNCTIONAL STAND FOR TESTING SCREW COMPRESSORS IN CLOSED LOOP TEST CONFIGURATION

STAND MULTIFUNCȚIONAL PENTRU TESTAREA COMPRESOARELOR CU ȘURUB ÎN CONFIGURAȚIE DE TEST ÎN BUCLĂ ÎNCHISĂ

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Abstract: *The screw compressors is increasingly demanded on the market. Many companies have been producing this type of compressor. The development of new types of dimensions must and is accompanied by the need to develop and modernize the test stands. The design and construction of a multifunctional stand took into account the various assortment of screw compressors - suction / discharge pressure variation, flow, speed. The test allows for different test configurations. In the stand the compressors are subjected to the mechanical test, followed by the performance test for the new compressors.The paper presents the solutions chosen for the multifunctional stand.*

Keywords: screw compressor, test configurations, multifunctional stand.

Rezumat: *Compresoarele cu șurub sunt din ce în ce mai solicitate pe piață. Multe companii produc acest tip de* compressor. *Dezvoltarea de noi tipuri de dimensiuni trebuie și este însoțită de necesitatea dezvoltării și modernizării standurilor de testare. Proiectarea și construcția unui stand multifuncțional a luat în considerare diversele sortimente de compresoare cu șurub ținând cont astfel de variația presiunii de aspirație / refulare, debit, viteză. Testul permite diferite configurații de testare. În stand, compresoarele sunt supuse testului mecanic, urmat de testul de performanță pentru noile*

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compresoare. Lucrarea prezintă soluțiile alese pentru standul multi-funcțional.

Cuvinte cheie: compresor cu șurub, configurații testare, stand multifunctional.

1. Introduction

The presentation is not intended to promote a particular structure / component of a screw compressor test stand. This is because every company, depending on the range of compressors in production, on the development strategy and last but not least on the requirements of ISO 1217, ASME PTC 9, API 619, ISO10440-in which specifies the operating / testing conditions of a compressor, Acceptance Test for Performance Determination - builds and develops the appropriate stand. Thus, in API619 / ISO 10440 it is stated that the compressor mounted and tested on the stand must meet the conditions specified in:

- pt. 7.3...7.3.2 - Hydrostatic test,
- pt. 7.3.3 - Mechanical running test,
- pt. 7.3.4 - Performance test,
- pt. 7.3.5 - Test data,
- pt. 7.3.6 - Test report.

In addition, ISO 1217 - Displacement compressors - Acceptance test - establishes the conditions that must be met regarding the determination of the respective flow rate and the power consumed during the compression process. It also defines the parameters to be measured, precision of the instrumentation, with the maximum deviations from the specified values. Also there are specified the corrections that must be made regarding the measured flow / power, taking into account the reference conditions.

We mentioned the conditions to be respected because, implicitly, they determine both the mechanical conditions of the compressor and the minimum structure of the test stand needed to determine the performance.

2. Considerations regarding the design of the test stand

Regardless of the builder - the specialized company or research/ development/testing department of the screw compressor company, there are general conditions, unanimously accepted, regarding the stand construction solution:

- to be able to test a wide range of compressors (as functional parameters);

- to assemble under precision and stability the minimum parameters imposed by the above mentioned norms, necessary for the testing and evaluation of the compressor;
- to provide a power source, with variations in speed, in the operating range of the compressor family;
- to have a cooling system for both the working fluid used in compressor testing and for the oil used in the compressor circuit;
- to be able to achieve the closed-loop circuit configuration with the compressor suction/discharge pressure control, according to the test chart;
- PLC for commanding and controlling the startup, operation and stopping sequences. Protection and data acquisition;
- instrumentation meets the requirements of precision and stability.

It is also worth mentioning that one of the important decisions taken at the stand construction is related to the type of working fluid, which can be:

- air;
- refrigerant;
- natural gas.

Choosing the working fluid requires specific conditions to be observed when constructing the stand (material, suitable for the Ex. area aso.)

We can also assert that two types of tests which can be carried out on the test bench:

a) The performance test according to the test sheet for the compressors in the series production - see Table 1 - Checking the compliance with the parameters in the data sheet (within the limits of admissible deviations)

Table 1. **Compressor data sheet**

Performance test name	**ERPBEZ**	**CU90G vi=2.60**	**CU90G vi=3.50**	**CU90G vi=4.80**
Test medium (Luft = air)	MEDIUM	Air	Air	Air
Ambient pressure abs.	P0	1	1	1
Ambient temperature	T0	25	25	25
Ambient relative humidity	PHI0	50	50	50
Test point no.	MP	1	1	1
Male rotor speed (1st stage only)	NHL	4080,9	4080,9	4080,9
Speed must be in tolerance of +/-	NANTTOL	4	4	4
Suction pressure abs. 1st stage	P11	1	1	1
Pressure must be in tolerance of +/-	P11TOL	10	10	10

Table 1 (continued)

Performance test name	**ERPBEZ**	**CU90G vi=2.60**	**CU90G vi=3.50**	**CU90G vi=4.80**
Suction temperature 1st stage	T11	25	25	25
Discharge pressure abs. 1st stage	P21	6,1	10	13,5
Discharge temperature 1st stage	T21	67,9	72,9	71,9
Temperature must be in tolerance of +/-	T21TOL	2	2	2
All over pressure ratio must be in tolerance of +/-	PIGESTOL	2	2	2
Volume flow related to suction conditions	V1	262,58	258,9	255,46
Flow must be in tolerance of +/-	V1TOL	5	5	5
Power consumption	PKU	23,07	31,674	36,83
Power must be in tolerance of +/-	PKUTOL	5	5	5
Specific power	PSP	5,2714	7,3404	8,6503
Oil viscosity (viscosity group)	VISKOS	ISO VG 46	ISO VG 46	ISO VG 46
Oil temperature at inlet 1st stage	TOEL11	50	50	50
Total oil flow 1st stage	VOELGES	36	40	50
Flow must be in tolerance of +/-	VOELGESTOL	10	10	10
Minimal oil pressure abs. 1st stage	POEL11MIN	2,5	2,5	2,5
Oil flow to injection port 1st stage	VOEL	13,7	13,4	20
Flow must be in tolerance of +/-	VOELTOL	40	40	40
Min. oil pressure abs. to suction bearings 1st stage	POELSS	2,5	2,5	2,5
Oil flow to suction bearings 1st stage	VOELSS	6,8	6,8	6,8
Flow must be in tolerance of +/-	VOELSSTOL	40	40	40
Min. oil pressure abs. to discharge bearings 1st stage	POELDS	3,6	7,5	11
Oil flow to discharge bearings 1st stage	VOELDS	5,5	9,8	13,2
Flow must be in tolerance of +/-	VOELDSTOL	40	40	40
Min. oil pressure abs. to mechanical seal 1st stage	POELGL	2	2	2
Oil flow to mechanical seal 1st stage	VOELGL	10	10	10
Flow must be in tolerance of +/-	VOELGLTOL	40	40	40

b) Performance test for new compressors developed by the company, which aims to determine the parameters in a wide range of speeds, with the variation of the suction / discharge pressure. During this test, according to the norms, the mechanical test, respectively the performance test is conducted. The recorded data allow the editing of flow/speed, power/speed diagrams at a predetermined suction pressure, a given volumetric ratio Vi and different discharge pressure values. Data acquisition, interpretation and re-routing are done according to the recommendations of the specific standards. It is possible to calculate the volumetric/adiabatic efficiency of the compressor by correlating the acquired data.

We could define and a third type of tests as part of a research activity concerning compression process - to verify the design data obtained by CFDs - but in this case it is necessary to have a stand with a specific endowment instrumentation, data acquisition speed etc. The functional diagram of the COMOTI multifunctional stand is presented in Figure 1.

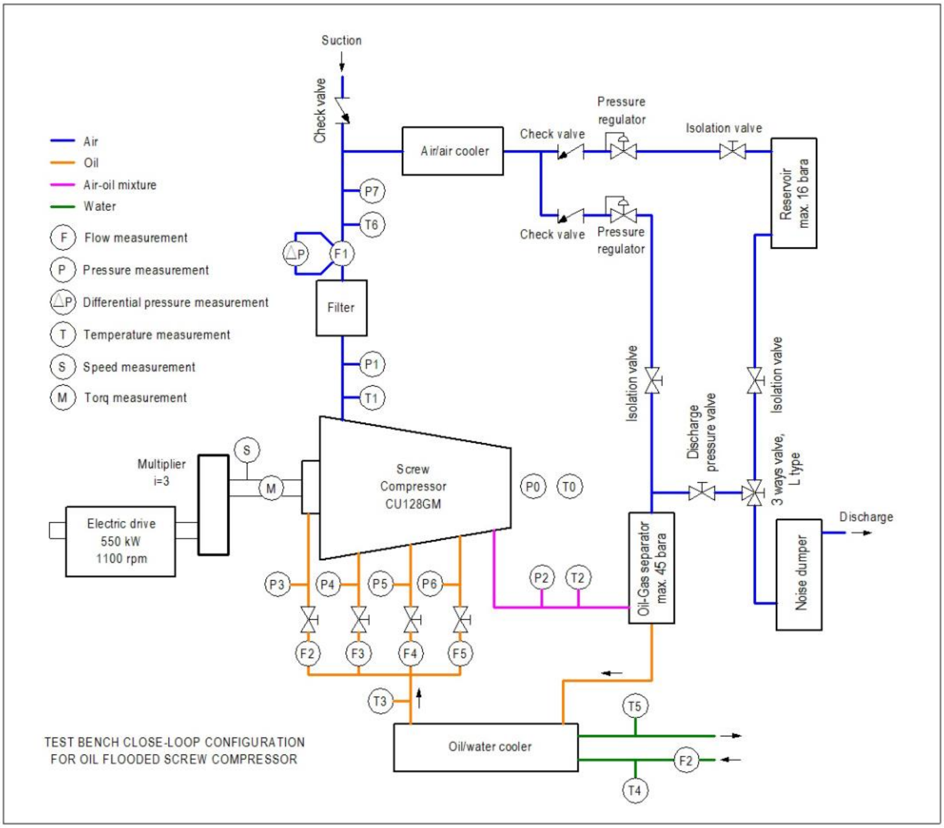


Figure 1. Multifunctional stand (closed loop configuration).

Following test configurations can b performed on the stand:

- testing compressors in the licensed range with suction pressure atmospheric pressure;
- testing of new compressors, developed by COMOTI, in the configuration of closed circuit stand.

On the stand we can perform tests in the following versions:

a) suction pressure:1 ... 5 bar;
discharge pressure: max. 30 bar;
power: max. 250 kW.

b) suction pressure: 4.5 ... 10 bar;
discharge pressure: max. 45 bar;
power: max. 350 kW.

c) suction pressure: 8...20 bar;
discharge pressure: max. 45 bar;
power: max.350 kW.

d) suction pressure: 5...10 bar;
discharge pressure: max. 80 bar;
power: max.250 kW.

Configurations can be accomplished by proper valve sequences, for example changing the path where the pressure regulator appears (assigned to the closed loop configuration). By selecting different pressure regulators, the compressor suction pressures can be adjusted in the range:

- 0 ... 5 bar;
- 4.5 ... 10 bar;
- 8 ... 20 bar.

The discharge pressure is max. 45 bar. The discharge pressure adjustment is done manually via the discharge pressure regulating valve.

3. Measured parameters. Measuring equipment. Precisions

The equipment, precision and measurement methods are in accordance with the recommendations of ISO 1217, ASME PTC9, relating to the determination of the performance of a compressor during the test, delivered flow or required power (data required by the buyer).

We emphasize once again that for licensed compressors, the performance test - with air - is done for a point of operation indicated by the licensing company. Depending on the type of compressor, respectively volumetric ratio Vi, the licensor indicates the specific test parameters:

- suction pressure / suction temperature;

- discharge pressure;
- flow;
- speed.

During the test, you measure:

- the gas flow rate;
- the power;
- discharge temperature (controlled by oil flow).

The compressor will be declared accepted if the tests falls within the deviations mentioned in the test datasheet (Fig. 1)

For new compressors developed by COMOTI, the test conditions follow the recommendations in Annex E-ISO 1217- concerning the acceptance test for volumetric compressors driven by variable speed electric motors.

At the same time, ISO 1217 recommends that the measuring equipment that may affect test results be calibrated at the specified range to ensure the accuracy/reliability of the measured information.

Measurements of parameters used in performance calculations are made with instruments / devices that meet the following conditions (for the COMOTI stand):

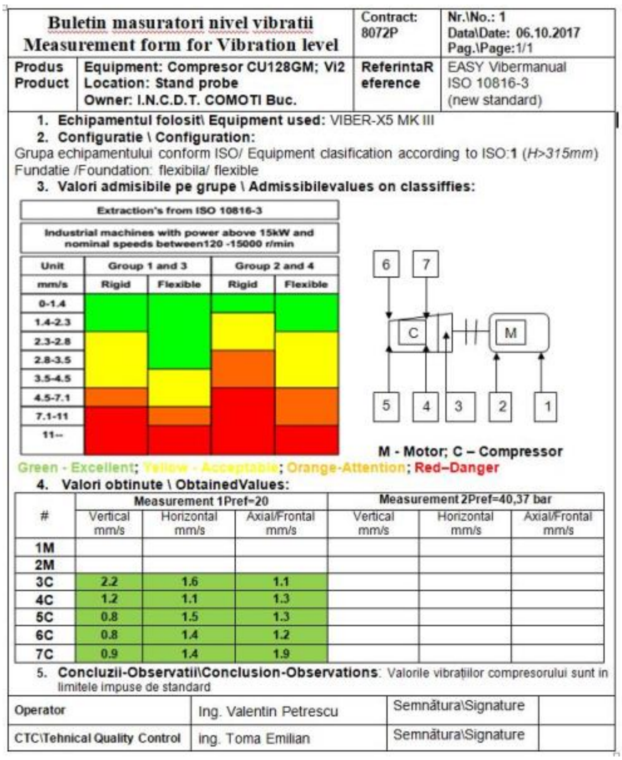
- pressure – pressure transducer, signal 4...20 mA, line precision ±0,2%;
- temperature – thermocouple, signal 4...20 mA, line precision ±0,5%;
- oil flow – flowmeter, signal 4...20mA, line precision ±0,2%;
- gas flow – differential pressure transducer, signal 4...20 mA, instrument precision ±0,1%, line precision ±1%.

The flow rate is measured at the suction of the compressor cf. ISO 5167-2, the flowmeter being mounted on the pipe according to the installation conditions. For calculating the corrections and displaying the flow in Nm3, the acquisition system picks up atmospheric pressure and ambient temperature signals (with transducers mounted in the vicinity of the suction port)

- power is measured with torque converter mounted on the drive shaft of the compressor, type HBM-T40 precision class 0,05%;
- speed - speed transducer, signal 4...20 mA, line precision ±0,2%c.

During the tests, the vibrations are measured with VIBER X5 – see Figure 2 – and thermal imprint with Fluke – see Figure 3

During the tests, the instrument reading is only performed after a sufficiently long operation to ensure a steady state of the parameters (accordingly to 6.2 Test Arrangements - ISO 1217).



Buletin masuratori nivel vibratii Measurement form for Vibration level		Contract: 8072P	Nr.\No.: 1 Data\Date: 06.10.2017 Pag.\Page:1/1
Produs Product	Equipment: Compresor CU128GM; Vi2 Location: Stand probe Owner: I.N.C.D.T. COMOTI Buc.	ReferintaR eference	EASY Vibermanual ISO 10816-3 (new standard)

1. **Echipamentul folosit\ Equipment used:** VIBER-X5 MK III
2. **Configuratie \ Configuration:**

Grupa echipamentului conform ISO/ Equipment clasification according to ISO:**1** (*H>315mm*)
Fundatie /Foundation: flexibila/ flexible

3. **Valori admisibile pe grupe \ Admissibilevalues on classiffies:**

Extraction's from ISO 10816-3

Industrial machines with power above 15kW and nominal speeds between120 -15000 r/min

Unit	Group 1 and 3		Group 2 and 4	
mm/s	Rigid	Flexible	Rigid	Flexible
0-1.4				
1.4-2.3				
2.3-2.8				
2.8-3.5				
3.5-4.5				
4.5-7.1				
7.1-11				
11--				

M - Motor; C – Compressor

Green - Excellent; Yellow - Acceptable; Orange-Attention; Red–Danger

4. **Valori obtinute \ ObtainedValues:**

#	Measurement 1Pref=20			Measurement 2Pref=40,37 bar		
	Vertical mm/s	Horizontal mm/s	Axial/Frontal mm/s	Vertical mm/s	Horizontal mm/s	Axial/Frontal mm/s
1M						
2M						
3C	2.2	1.6	1.1			
4C	1.2	1.1	1.3			
5C	0.8	1.5	1.3			
6C	0.8	1.4	1.2			
7C	0.9	1.4	1.9			

5. **Concluzii-Observatii\Conclusion-Observations**: Valorile vibrațiilor compresorului sunt in limitele impuse de standard

Operator	Ing. Valentin Petrescu	Semnătura\Signature	
CTC\Tehnical Quality Control	ing. Toma Emilian	Semnătura\Signature	

Figure 2. Vibration analysis.

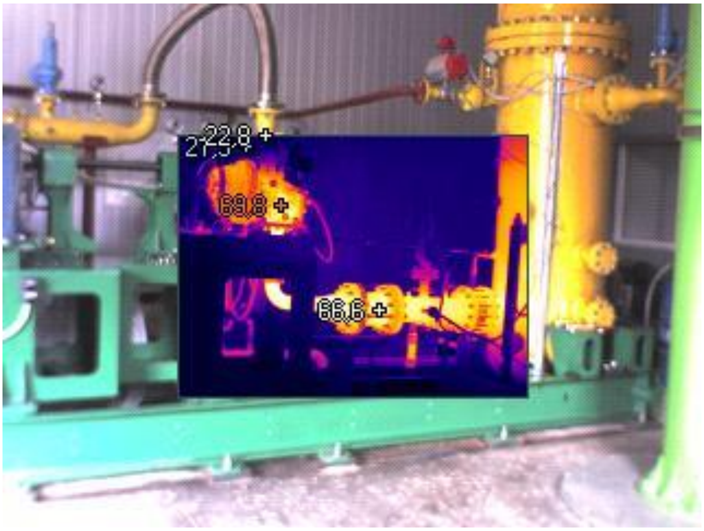


Figure 3. Thermal image compressor.

The acquisition of parameters is done continuously in an Excel file, analyzing their evolution, for parameter analysis, considering the sequence of operation that shows their stabilization. Before the final analysis, the recorded data is analyzed, the fluctuation of the readings must fall within the maximum deviations, relative to the established values (Table 1 – ISO 1217).

Also, on the screen of the monitor, in the synoptic diagram, the parameters can be viewed (also continuously). Upon operator's command the variables can be stored, in a separate file, the registered parameters page (in the stabilization phase, the data can then be processed for determination volumetric, adiabatic efficiencies)

We highlight an important aspect that simplifies the analysis of the test results, namely that, at preset, real-time display can be read on the monitor screen for:

- - the speed of the compressor;
- - the compressor flow rate in Kg/h respectively Nm^3/h.

The flowmeter is diaphragm type, the flow calculation formula is according ISO 5167-2. A subroutine makes corrections for corrected flow display, respectively flow display in Nm^3 / (at 20 ^oC and 101325 N/ m^2);

The power displayed is the power at the compressor axis in kW and Nm. From the user's point of view, it is the power information it needs - the necessary compression power, depending on which it can dimension the power of the electric motor (measured power includes power losses in gears, bearings- their measurement requires specific instrumentation, and is not useful information for the compressor user but is useful in the research process).

4. Interpretation of the measured results. The volumetric / isentropic efficiency

We have previously shown that at the operator command it is possible to store, in a separate file, the page with the registered parameters – Figure 4 – in the stabilization phase, the data can then be processed to determine the volumetric, isentropic (adiabatic) efficiency. Stored in the Excel file – with operating parameters – charts are being developed for data validation (related to parameter stabilization for a given operating mode).

Since the test parameters do not always coincide with the specified parameters established by the test sheet, corrections of the flow rate or the absorbed power are applied. Thus, respecting the max. deviation limits (ISO1217-Table 1):

- flow rate is corrected considering deviation of speed, isentropic exponent, suction temperature, suction pressure aso;
- - used power – measured - is corrected considering deviation of speed, suction pressure, isentropic exponent, compression ratio aso.

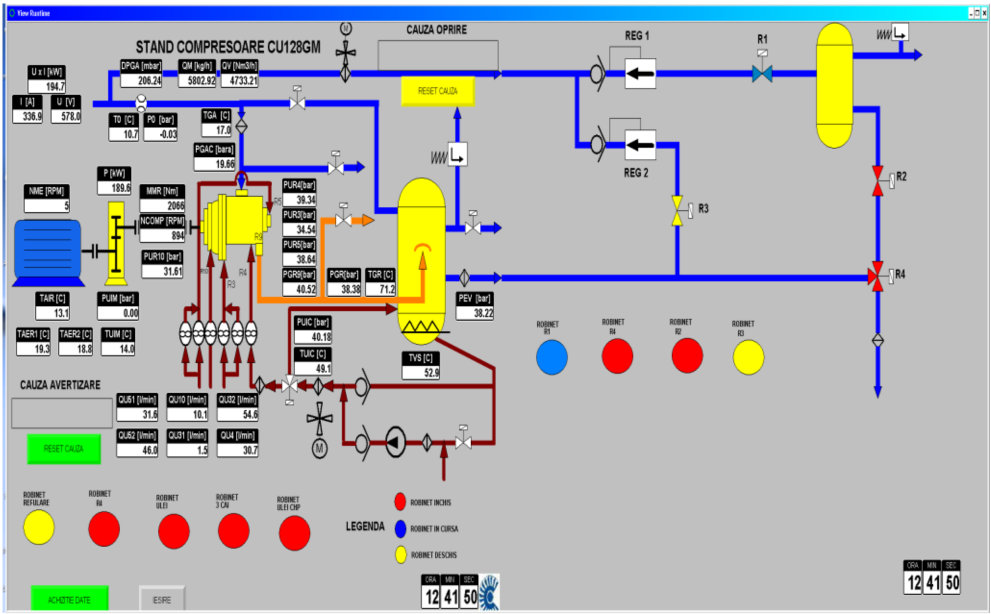


Figure 4. Measured parameters (print –screen).

The values corrected are compared to the specified values when testing a regular manufacturing compressor, following for acceptance, compliance with specified deviations.

When testing a new compressor developed by the company, the tests in the stand are thorough, aiming at the acquisition of data allowing the development of the operating diagrams (previously mentioned: flow/speed and power/speed chart for a given suction pressure, a given volume ratio Vi and different discharge pressures, in operating range).

a) Calculation of volumetric efficiency.

Volumetric efficiency is defined as:

$$\eta_v = \frac{measured\ flow\ rate}{theoretical\ flow\ rate}, \tag{1}$$

For a certain speed, compression ratio / suction pressure, measured in kg/h.

The theoretical flow is a constant dimension, a characteristic of a type of compressor (in m^3/h) at a given speed. The measured, corrected flow rate is determined at the reference speed (at which the theoretical flow is calculated).

b) Calculation of isentropic efficiency.

Isentropic efficiency is defined as:

$$\eta_{\mathrm{iz}} = \frac{P_{iz}}{P_{mas}}, \tag{2}$$

P_{iz}=isentropic power [kW]

P_{mas}= measured power [kW]

both at the same specific parameters (pressure, suction temperature, discharge pressure, flow rate, speed etc.)

Isentropic power is calculated with the relation:

$$P_{iz} = \frac{m*k}{k-1} * Z_m * R * T_a * \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right] [kw] \tag{3}$$

m = mass flow [kg/s];

k = isentropic exponent, calculated using a program subroutine;

Z_m = Z_1 + Z_2 / 2 average compressibility factors, calculated from suction/discharge, calculated using a program subroutine;

R = gas constant [kJ/kg°K], calculated using a program subroutine;

T_a = suction temperature [°K];

P_1 = suction pressure [bar abs.];

P_2 = discharge pressure [bar abs].

The measured and then corrected power is the one indicated on the print-screen acquired or extracted from the evolution charts of the parameters recorded in Excel.

5. Conclusions

Even through its construction, the multifunctional stand allows tests to be carried out for the regular manufacturing compressors and the performance tests for the new compressors developed by the company.

Complying with the conditions regarding the structure of the stand, the precision of the equipment used ensures the measurement of the parameters and the possibility of processing the data in order to prepare the test (performance) sheets, under the conditions stipulated in the acceptance norms.

R E F E R E N C E S

[1] *ISO10440* „Rotary-type Positive Displacement Compressors for Petroleum, Petrochemical and Natural Gas Industries” (API 619).
[2] *ISO 1217* „Displacement compressors-Acceptance tests” (PTC 9).
[3] *ISO 5167-2* „Measurement of fluid flow by means of pressure differential devices in circular cross-section conduits running full-Part 2 Orifice plates”.

RISK FACTORS FOR THE UNDERMINED COAL BENCH MINING

FACTORI DE RISC PENTRU EXPLOATAREA MINIERĂ PE BANC DE CĂRBUNE SUBMINAT

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Abstract: *Coal seam exploitation in Jiu Valley coal basin is achieved in a percentage of 75% by employing the undermined coal bench mining method. The coal output obtained by this method is of about 3 million tons/year. The productivity obtained with this method is higher than 8 tons / shift. The values of these indicators, strongly recommends this mining method, for general use in the specific conditions met in Jiu Valley coal basin. However, over a time series of technical accidents such as explosions and ignitions of methane gas, roof blowing phenomena or self-ignition of coal and spontaneous combustions have occurred. In this respect, the paper tried to analyze the risk factors related to this mining method application.*

Keywords: Risk factors, geomechanical characteristics of rocks and coal, geodynamic phenomenon, spontaneous combustion phenomenon, gas accumulation.

Rezumat: *Exploatarea stratului de cărbune în bazinul de cărbune din Valea Jiului se realizează în procent de 75% prin folosirea metodei de exploatare a cărbunelui subminat. Producția de cărbune obținută prin această metodă este de aproximativ 3 milioane de tone/an. Productivitatea obtinuta cu aceasta metoda este mai mare de 8 tone/tur. Valorile acestor indicatori, recomandă cu tărie această metodă de exploatare, pentru utilizare generală în condițiile specifice întâlnite în bazinul carbonifer Văii Jiului. Cu toate acestea, de-a lungul unei serii cronologice de accidente tehnice, cum ar fi explozii și aprinderi de gaz metan, fenomene de suflare a acoperișului sau autoaprinderea cărbunelui și arderi spontane au avut loc. În acest sens, lucrarea a încercat să analizeze factorii de risc aferenti aplicării acestei metode miniere.*

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Cuvinte cheie: Factori de risc, caracteristici geotehnice ale rocilor și cărbunelui, fenomene geodinamice, fenomen de ardere spontană, acumulare de gaze

1. Risk factors

The main risk factors generating technical accidents are the geomechanical characteristics of coal and surrounding rocks, the dynamic phenomena occurring in the rocks within the coal seam's roof, accumulation of toxic and explosive gases in the gaps resulting from the exploitation, the mining method-s geometrical elements, the coal's proneness to spontaneous combustion.

1.1. Geomechanical characteristics of rocks and coal

The main geomechanical characteristics having implications in producing geodinamical phenomena were determined.

The measured parameters were: the cleave coefficient of structural weakening, specific density and volume, porosity, permeability, compressive strength and traction, the coefficient of strength, cohesion and internal friction angle, elastic and rheological characteristics of coal and surrounding rocks.

In view of assessing the main characteristics of the coal and rocks from the 3-rd seam coal samples have been collected from the several mine working faces of Petrila and from the direct roof and main roof. After the laboratory tests, the following results, listed in table 1, have been obtained.

2. Geodynamic phenomenon

The geodynamic phenomenon from face 431 had occurred due to the instantaneous decline of rocks within the main roof. Because of the piston effect, explosive gases within the gap developed in the third round, were pushed to the working face and on their route they met with the endogenous fire from slice IV, generating an explosion which resulted in 13 deaths and 18 injured workers (see figure 2).

2.1. The spontaneous combustion phenomenon

As a consequence of coal oxidation and self heating of coal mass left in the goaf spontaneous combustions can occur. . The oxidation mechanism is based on the theory of chain reactions, by which absorbed oxygen generates metastable compounds that dissociate easily, giving birth to phenolic groups, carboxylic or carbonyl and releasing the small quantities of heat.

The phenomenon of self-ignition includes 6 stages:

– Incubation phase

– Two stages of evaporation

– Two transition phases

– The combustion phase.

The main factors which are inducing coal self-ignition and combustion are:

– Physico-chemical composition;

– Moisture content, volatile material content, porosity, and specific surface;

– Petrographic composition

– Geological characterization: tilt and layer thickness, deposit's tectonics, gas content of coal layers

– Losses in the coal mined out;

– Inadequate ventilation system operation.

At the level of the 431 working face, the following spontaneous combustion occurrences took place:

– III subfloor, level - 222.3 13 February 2005

– II subfloor, level - 231.7 1 September 2006

– II subfloor, level - 200 1 October 2007

– III subfloor, level - 200 16 November 2007

Spontaneous combustions have occurred were basically generated by coal mass left in the goaf, low face advancing rates and also due to significant air losses within the retreating goaf.

The release of coal bed methane gas is an extremely complex phenomenon, that depends on many geomechanical and technical factors and parameters. The amount of methane released from working faces and preparation of working front is due to uncovering new areas, operations and cutting cleaves layers of coal mining under the pressure. A certain proportion of the free methane was evacuated in the return polluted air stream, and another part has been accumulated in the gaps of the exploited seam. Concentrations of methane in the transport and ventilation galleries ranged between 1.68% and 3.46% in the weeks before the explosion.

Ventilation activation, employed in order to reduce the concentration, led to increased losses of air through the use of fire and endogenous fire reactivation. In the gaps resulting from the mining operation, having a volume of 175,000 m3, methane has accumulated in explosive concentrations.

When rocks from the main roof were suddenly undermined, gas has been pushed to the endogenous fire zone.

3. The pressure and the height of the undermined coal bench geomechanically considered

For the exploitation with undermined bench method, we suggest a calculation hypothesis for the pressure according to which the pressure that actuate upon the working front is considered to be given by the weight of the smashed rocks which are to be found above the undermined bench, to that is added the bed's own weight, bed that gets broke on the (x) breadth which is the equivalent of the undermined pitch.(see figure no.3).

4. Equations

The force that oppose to the stress, is given by the cohesion and possibly by the friction force that actuates according to the shearing plan on the height (h).

Therefore, it can be written:

$$p = p'_1 + p''_1 \tag{1}$$

where:

p – the pressure that actuates upon the working front

p'_1 – the pressure created by the smashed rocks above the undermined bank and wich according to the hypothesis of the powder medium has the value:

$$p'_1 = p_1 \cdot i \cdot e^{-\Pi tg\varphi} \qquad [\text{MPa}] \tag{2}$$

in which:

$$p_1 = 1{,}784 \cdot \gamma_a \cdot H \cdot x \qquad [\text{MPa}] \tag{3}$$

φ – the friction angle of the smashed rocks;

x – undermined pitch

p''_1 – the pressure created by the undermined bank which is given by the undermined bed weight, less the shearing force that actuates upon the undermined bed height or:

$$p''_1 = Q - \tau_f \tag{4}$$

where: Q – the weight of the coal in the undermined bank:

$$Q = x.h.\,\gamma'_a \quad [\text{MPa m}] \tag{5}$$

γ'_a – the apparent specific weight of the coal;

$$\tau_f = C + \sigma_x\, tg\varphi \quad [\text{MPa.m}] \tag{6}$$

If neglecting the lateral pressure then:

$$\tau_f = C \quad [\text{MPa.m}] \tag{7}$$

On the height (h):

$$\tau_{fh} = C.h \quad [\text{MPa.m}] \tag{8}$$

Considering a coefficient of structural weakening (C_s):

$$\tau fh = C.Cs.h \tag{9}$$

We obtain:

$$P = x.1{,}784\,\gamma a.H\,I.e{-}\pi tg\varphi + h\,(x.\gamma' a - C.Cs) \tag{10}$$

The limit height of the undermined bench is obtained from the following condition:

$$p' + Q = \tau fh \tag{11}$$

Substituting:

$$h = x.1{,}784.\gamma a\;H\;.i.\cdot e{-}\pi tg\varphi \qquad [\text{ m }]. \tag{12}$$

$$C.Cs - x.\gamma' a \tag{13}$$

If the result is divided by (x), we obtain the value of pressure in [MPa]. In this case, we have:

$$p''_1 = x.h.\,\gamma'_a - h.C.C_s = h\,(x.\,\gamma'_a - C.C_s) \quad [\text{MPa}\cdot\text{m}]$$

Wherefrom, it results: (14)

$$P = x.\,1{,}784\;\gamma_{a.H\,I.\,e}{}^{-\pi tg\varphi} + h\,(x.\,\gamma'_a - C.C_s) \quad [\text{MPa}\cdot\text{m}] \tag{15}$$

From the pressure relation structure and implicitly to the height of the undermined bank, we observe that among the parameters that influence these values the depth of the working front towards the (H) surface; the coal cohesion (C); the inner friction angle of the smashed rocks, φ ; the structural weakening coefficient, C_s, stand out.

5. Tables

Table 1. **Average values of the physical, mechanical, and elastic characteristics of 3-rd coal seam and rocks within the roof**

Name	**Coal**	**Direct roof rocks**	**Main roof rocks**
Specific weight, *g*, 10^4 N/m^3	1,45	2,65	2,67
Apparent specific weight, γ_a , 104 N/m3	1,31	2,58	2,6
Porosity, *n* %	9,7	3,5	2,6
Pares number, *e*	0,107	0,02	0,025
The breaking strength to compression σ_{rc} MPa	9,5	44,1	128
The breaking strength to dries σ_{rt} MPa	0,8-1,3	5,6	13,2
Cohesion *C*, Mpa	1,1-2,5	6	20,5
Inner abrasion angle φ ^{o}	49-58	50	54
Elasticity modulus, *E*, MPa	5300	8500	10500
The coefficient of Poisson, μ	0,17	0,2	0,12
Energetic, coefficient, I_e	-	1,32	2,2-3,7
The structural weakening coefficient, C_s	0,1	-	-

6. Figures

Based on the data synthesized in table1 the pressure and the height of the undermined bench have been calculated for the depths of Petrila working faces. They are plotted in the diagram represented in figure1.

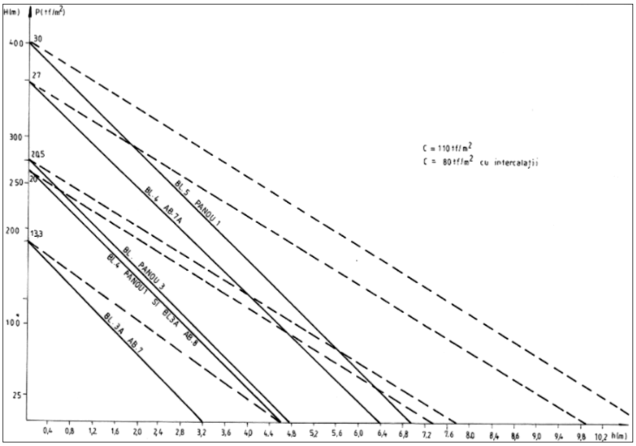

Fig. 1. The correlation between the depth (*H*), pressure size and height of the undermined bench, (*P*).

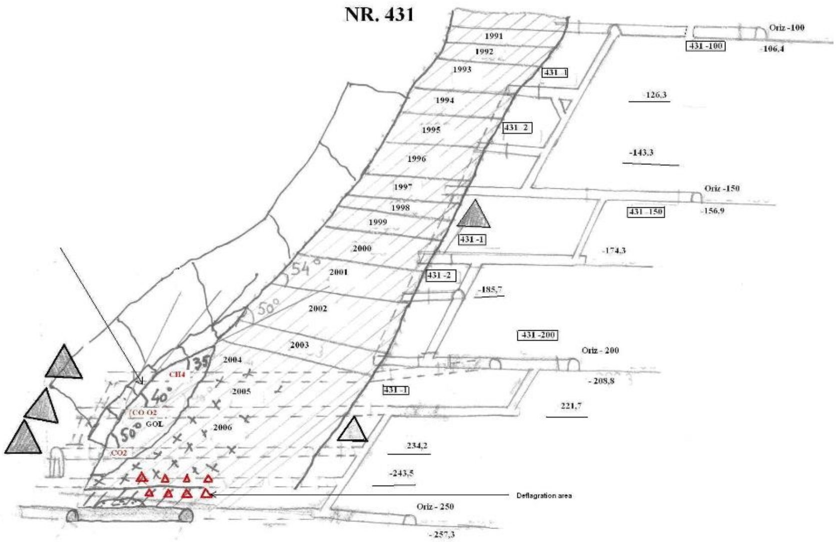

Fig. 2. The geodynamic phenomenon.

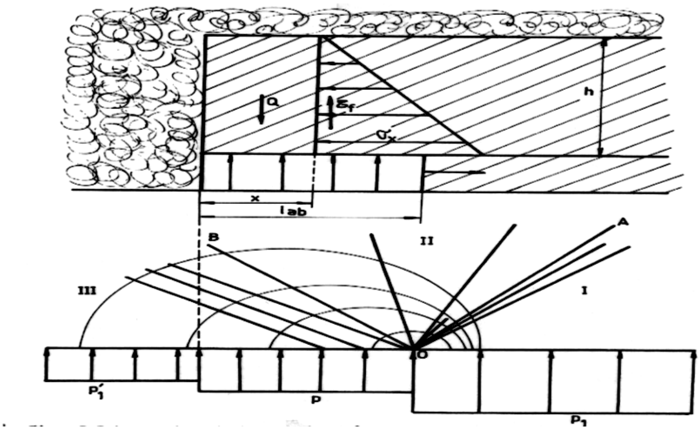

Fig. 3. The pressure calculation scheme for the undermined bank exploitation methods.

7. Conclusions

For the specific conditions encountered in Petrila colliery, the undermined banks height should be comprised between 5 and 7 m, depending on the geomechanical characteristics of coal and surrounding rocks.

The rocks within the main roof are having high values of the mechanical strength and energetical index, being characterized by a significant degree of proneness to dynamic phenomena. These kind of rocks are difficult to cave in, that is a major reason in resorting to controlled under-caving techniques.

The hard coal from seam no. 3 in Petrila colliery are having a pronounced tendency for self-ignition and spontaneous combustion, fact which is confirmed by several self-heating and endogenous mine fire episodes occurred already in this seam's area.

The hard coal mined at Petrila mine also has a high methane content, so values exceeding 15 m^3/ ton were usually met and measured.

Conclusively, we can state that the conditions from the working face AB 431, Petrila colliery all the risk factors were gathered, developing consequently a dynamic phenomenon and an explosion in the goaf.

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