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Development of a Methodology for Assessing the Quality of Drilling Machines

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Abstract: Optimization is one of the best techniques used in industries to assess the quality of the drilling machine at a lower cost. This work is based on the rotary drilling mode with different methods based on the physicomechanical properties of the rock, machine setting parameters, and tool geometry parameters. The aim of the research presented is to develop quality of methods for determining the parameters of the rational operating regime of the rotary drilling machine during its operation in geological and mining conditions.

Keywords: Setting parameter, axial force, drilling speed, rock, quality.

1. Introduction

The engineering community attempted to influence the use of energy to drill rock formations as early as the late 1940s when it developed some drilling machines [1], [2], [3], [4], [5]. So far, drilling a hole in rock with a machine tool is one of the most common operations, it is important in geotechnics, construction, in the mining and hydrocarbon industry (gas and oil) [6].

The most commonly used drilling methods for blasting are percussion drilling, roto-percussion drilling and rotary drilling [7]. Drilling technology plays a significant role in the Algerian mining industry. Optimizing drilling parameters is an integral part of the economic success or failure of any mining operation. The use of the appropriate drilling machine is always associated with the efficiency of excavation mining and overall project success. Operators and manufacturers are constantly exploring ways to reduce costs and increase productivity by improving the drilling penetration rate and decreasing drill bit wear [8], energy consumption, and the vibrations produced in the stem. Penetration speed is generally one of the most important factors in planning drilling in mineral deposits and estimating costs, therefore, it is necessary to predict the penetration speed to assess the total drilling costs using an accurate equation. This equation can be used to determine the type of drilling most suitable for certain conditions. In this work a method is presented for evaluating the drilling rig quality based on rock properties [9], [10] and operational variables such as rotational speed, thrust, blowing frequency, with the purpose to improve the quality [11], [12] of the drilling parameters of the machine, to increase the quality of the drilling rig and to enhance the production [13], [14], [15] at the lowest cost.

2. Nomenclature

P_{ax}: Axial force, P_{ax}=800-1500 [kgf];
d: Tool diameter, d=16 [cm];
Δ: Coefficient relating to the intermittence of the cutting edge of the bit; Δ=0,15;
m: Number of disconnected pair; m=1;
σ_d: Specific rock resistance;
f: The hardness of the rock, f=7;
C_{ft}: Coefficient of the geometric shape of the cutting edge;
nr: Rotation speed, nr=80 [1/min];
V_f: Drilling speed, [m/min];
β: Determines the position of the weathered rock surface, β=30°;
L: Maximum tooth wear, L=4 [mm];
r: Tool clearance, r = 7,5 [mm];
R: Tool radius, R=8 [cm];
C_f: Coefficient of friction, C_f=0,5;
σ_{com}: Compressive strength;
L: Footage of the drilled hole, [m];
T_p: Duration of a shift [min];
K_{exp}: Operating coefficient;
T_f: Productive working time of the drill [min];
T_{org}: Waste of time because of work organization, [min];
T_{aux}: Loss of time in carrying out auxiliary work downtime of the drill due to its imperfection, [min];
C: Cost of one meter of the drilled hole, [DA/m];
C_{ou}: Tool price, [DA];
H: The footage drilled of holes relating to a tool, [m];
C_p: Expenses relating to the operation of the drilling machine; [DA/post].

3. Theoretical determination of the indices characterizing the drilling process

The best choice of a drilling machine depends mainly on the operating conditions, rock properties and quality of the machine. The researchers carried out operating tests and laboratory tests in order to determine the operating indices and design characteristics of the machine. The researchers Rakov and Peretoltchin studied the performance of drilling machines [16].

According to the theoretical method of Rakov [16], the drilling speed can be determined using the following formula (1).

$$V_f = 0.01 \cdot n_r \cdot \frac{2.4 \cdot P_{ax} \cdot C_{ft}}{\sigma_d \cdot d \cdot (1-\Delta) \cdot m} \tag{1}$$

According to the theoretical method of Peretoltchin [16], the drilling speed can be determined using the following formula (2).

$$V_f = 0.01 \cdot n_r \cdot \left(\frac{P_{ax}}{m \cdot \delta_{comp}} - \frac{R-r}{2 \cdot R} \cdot L \right) \cdot \frac{\cos B \cdot (\sin \beta - C_f \cdot \cos \beta)}{C_f \cdot K \cdot (R-r)} \tag{2}$$

During the experiments we vary the axial force and calculate each time the drilling speed by the following formula:

$$V_f = \frac{L}{T_f} \tag{3}$$

4. Drilling rig productivity

Theoretical productivity is the number of meters of the hole drilled per unit of time.

$$Q_{theo} = 60 \cdot V_f \cdot T_p \tag{4}$$

The operating productivity depends on the degree to which the technical possibilities of a drilling rig are used in concrete operating conditions.

$$Q_{exp} = Q_{theo} \cdot k_{exp} \cdot T_p \tag{5}$$

$$k_{exp} = \frac{1}{1 + \left(\frac{T_{ax} + T_{org}}{L} \right) \cdot V_f} \tag{6}$$

5. Results and discussion

In Table 1 and Table 2 there are presented the results for a variable axial force, obtained by the application of formulae Rakov (1), Peretoltchin (2), and experimentally.

Table 1: The variation of the drilling speed as a function of the axial force by the two formulas (Rakov, Peretoltchin)

P_{ax} [kgf]	$V_{f\ rakov}$ [m/min]	$V_{f\ pert}$ [m/min]
0	0	0
800	0.195	0.114
850	0.207	0.122
900	0.219	0.13
950	0.231	0.139
1000	0.243	0.147
1050	0.256	0.155
1100	0.268	0.163
1150	0.28	0.171
1200	0.292	0.18
1250	0.304	0.188
1300	0.316	0.196
1350	0.329	0.204
1400	0.341	0.212
1450	0.441	0.276
1500	0.457	0.286

Table 2: Result of the experimental study

Test nr	Pax (kgf)	Vf (m/min)
1	800	0.114
2	850	0.12
3	900	0.1122
4	950	0.124
5	1000	0.134
6	1050	0.137
7	1100	0.149
8	1150	0.152
9	1200	0.161
10	1250	0.173
11	1300	0.17
12	1350	0.192
13	1400	0.1876
14	1450	0.196
15	1500	0.2

For the treatment of the results the regression analysis by the method of least squares is used, assuming that the relationship between the drilling speed and the axial forces is represented by a straight line.

Table 3: Results of the experimental study obtained by linear regression

P_{ax} [kgf]	V_f [m/min]
800	0.1073
850	0.1141
900	0.1209
950	0.1277
1000	0.1344
1050	0.1412
1100	0.148
1150	0.1547
1200	0.1615
1250	0.1683
1300	0.1751
1350	0.1818
1400	0.1886
1450	0.1954
1500	0.2022

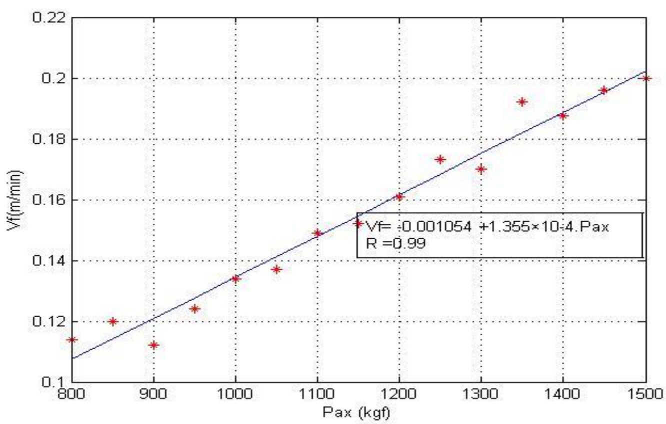

Figure 1: The variation of the experimental drilling speed as a function of the axial force

Table 4: Productivity calculated by the two methods (Rakov; Peretoltchin)

P_{ax} [kgf]	Q_{exp_Rakov} [m/post]	Q_{exp_Pert} [m/post]
0	0	0
800	78.74	49.42
850	80.881	51.76
900	84.395	54.731
950	86.17	56.819
1000	87.182	58.613
1050	88.115	60.241
1100	89.091	61.768
1150	78.873	57.59
1200	64.325	50.07
1250	54.059	43.926
1300	49.556	41.359
1350	46.769	39.665
1400	43.624	37.606
1450	42.087	36.604
1500	39.326	34.78

Table 5: Experimental results obtained

P_{ax} [kgf]	V_f [m/min]	$Q_{thé}$ [m/post]	K_{exp}	Q_{exp} [m/post]
800	0.1073	51.504	0.906	46.656
850	0.1141	54.768	0.887	48.536
900	0.1209	58.032	0.879	51.008
950	0.1277	61.296	0.862	52.832
1000	0.1344	64.512	0.841	54.248
1050	0.1412	67.776	0.821	55.644
1100	0.148	71.04	0.802	56.97
1150	0.1547	74.256	0.719	53.384
1200	0.1615	77.52	0.6056	46.95
1250	0.1683	80.784	0.514	41.52
1300	0.1751	84.048	0.467	39.25
1350	0.1818	87.264	0.432	37.698
1400	0.1886	90.528	0.396	35.849
1450	0.1954	93.79	0.374	35.078
1500	0.2022	97.056	0.343	33.35

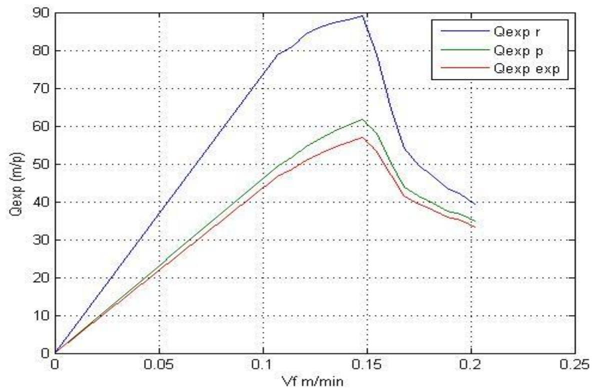

Figure 2: Comparison of operating productivity results

6. Criteria for choosing the rational operating regime of drilling machines

When carrying out mining works, as a general criterion of the effectiveness of any method of drilling, one can take the cost price of one meter of the hole drilled. This is used for determination of the parameters of a rational regime of rotary drilling having the best results and determines the optimum settings for the rotary drilling machine.

$$C = \frac{C_p}{Q_{exp}} + \frac{C_{ou}}{H} \quad (7)$$

Table 6: Cost price results

P_{ax} [kgf]	V_f [m/min]	H [m]	Q_{exp} [m/post]	C [DA/m]
800	0.1073	284	46.656	234.6
850	0.1141	248	48.576	226.48
900	0.1209	242	51.008	215.95
950	0.1277	219	52.832	209.36
1000	0.1344	196	54.248	204.88
1050	0.1421	178	54.152	200.706
1100	**0.148**	**165**	**54.412**	**196.895**
1150	0.1547	109	53.384	214.158
1200	0.1615	68	50.072	249.943
1250	0.1683	49	40.744	288.3
1300	0.1751	42	34.224	308.305
1350	0.1818	38	30.624	32328
1400	0.1886	34	26.072	342.569
1450	0.1954	32	22.56	351.886
1500	0.2022	29	20.568	372.539

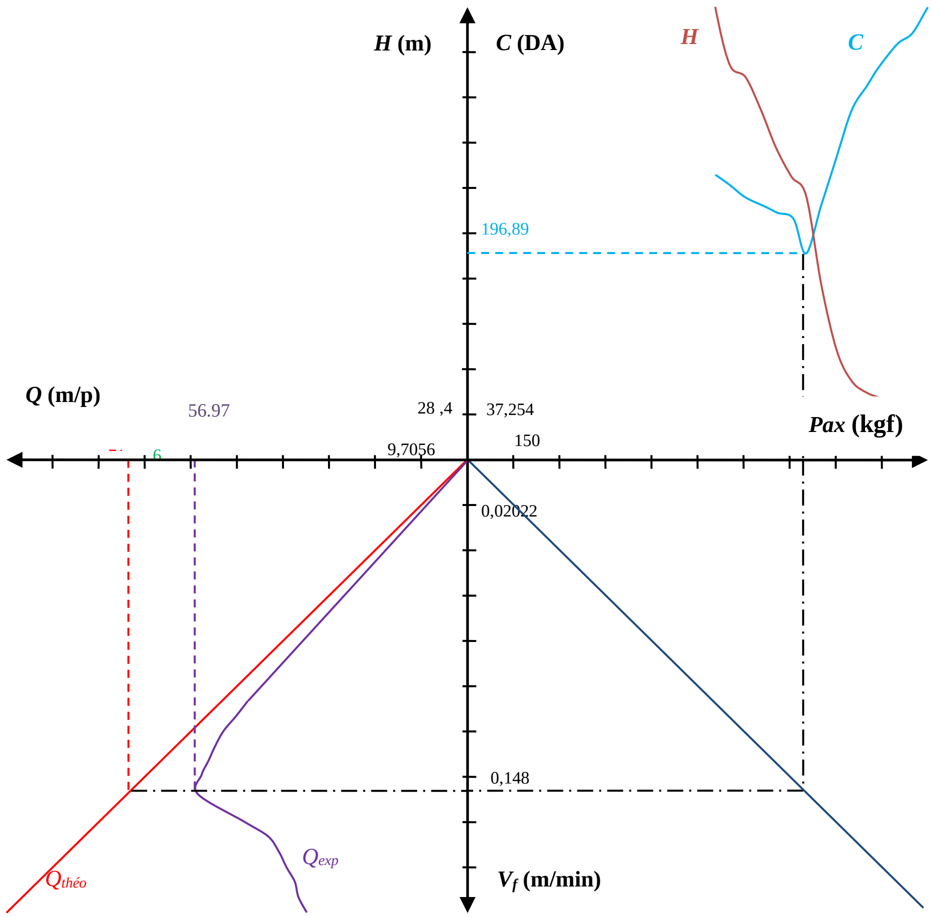

Figure3: Nomogram of experimental results

7. Conclusion

The selection methodology recommended through the technical-economic model allows the best alternative, hence the assertion that the method of; Peretoltchin is better than that of Rakov for the same conditions of the iron quarry of Ouenza (Algeria).

The optimization of this drilling method leads us to an optimal drilling cost. The rational parameters of the operating regime of drilling machines are:

Table 7: Optimal settings

P_{ax} [kgf]	V_f [m/min]	Productivity		C [DA/m]
		$Q_{thé}$ [m/p]	Q_{exp} [m/p]	
1100	0.148	71.04	54.412	196.895

From the results obtained using the proposed regression model, it can be concluded that there is a strong linear correlation between velocity and axial force ($R \approx 0.99$), and there is a very good relationship between theory and experiment.

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