TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 66, Issue IV, November, 2023

COMPARATIVE ANALYSIS OF DYNAMIC COEFFICIENTS IN LIGNITE CUTTING AND OF THE EXCAVATION MACHINES IN THE OLTENIA'S OPEN PITS

Sorin Mihai RADU, Stela DINESCU, Florin VÎLCEANU

***Abstract**: Understanding the dynamic nature of the excavation process is crucial for studying the overall stability of the rotor excavator and any device displacing in homogeneous materials. This paper focuses on analyzing the influence of the dynamic coefficient, k_d, of the cutting process, determined for various lignite quarries in the Oltenia Coal Basin, on stress levels, frequencies generated during the excavation process, and the dynamic factor of the machinery. It is observed that under certain exceptional working conditions, the maximum value of the dynamic factor of the excavation process can be equal to the dynamic factor of the machinery. This analysis contributes to optimizing the cutting process, reducing tooth bucket change times, and enhancing the mechanical/structural reliability of the equipment. The investigation method employed is electric strain gauge measurement, a straightforward and efficient technique that eliminates the need for coal sample collection and transportation to the laboratory. Data are directly obtained from the excavation mode of the equipment in coal, overburden, or mixed coal overburden strata.*

***Keywords**: dynamic coefficient of the cutting process, dynamic factor of machinery during excavation, cutting depth, rotor excavator stability, specific deformations, strain gauge stamps.*

1. INTRODUCTION

In the excavation process of high-capacity equipment, such as the ERc 1400-30/7 bucket wheel excavator, most commonly used in the Oltenia Coal Basin, the excavation forces displacing coal through the bucket wheel mechanism impose demands on the equipment's metal structures. These excitatory forces, randomly generated during the excavation of heterogeneous material, induce varied stress states. To assess the dynamics of the rock-cutting process, the dynamic coefficient k_d is defined [1], a factor determined by sampling from quarries and subsequent laboratory analysis, expressed in relation to the characteristics of the respective samples.

The dynamic factor (ψ_{din}) is a parameter that can be determined for each piece of equipment, both in static and dynamic working conditions. It is obtained using resistive strain gauges and reflects the equipment's dynamics during the excavation process, considering the nature of the excavated material and how the metal structures bear excavation forces. The dynamic factor provides detailed information about the levels of stress, forces, and dynamic deformations acting on the metal structure under various operating conditions, offering a comprehensive perspective on the behavior and structural performance in dynamic exploitation contexts.

The aim of the study is to establish a methodology for determining the dynamic factor for such equipment, comparing it with industry standards and evaluating it against the laboratory-determined dynamic coefficient.

Knowledge of the average value of the cutting force F_{xm} as well the peak values F_{xmax} provides important information regarding the dynamic nature of the cutting phenomenon, which is useful for the study of the general structural stability of the excavators. Figure 1[1].

In order to characterize the dynamics of the cutting process the following parameters are introduced [1]:

- dynamic coefficient:

$$k_d = \frac{F_{x\max}}{F_{xm}} , \qquad (1)$$

which represents the probability of peak forces occurring during the cutting process

Received: 18.10.23; **Similarities**: 04.10.23: **Reviewed**: 26.10./01.11.23: **Accepted**:23.11.23.

- coefficient of the variation of the mean:

$$kv = \frac{F_{xmv}}{F_{xm}} \qquad (2)$$

which represents the dynamic intensity of the variation of the cutting forces with time.

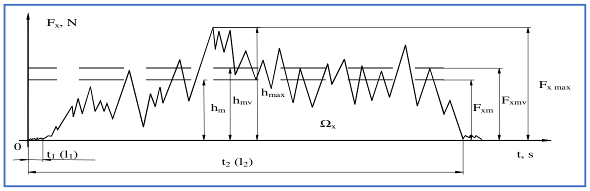

Fig. 1. The variation of force Fx

Thus, Figure 2 [1] presents the dynamic coefficient k_d as a function of the cutting depth h_o for different angular values of the orientation of the cutting tool.

It can be observed that this coefficient is not significantly influenced by the cutting thickness and has values between 2-8, Table 1.

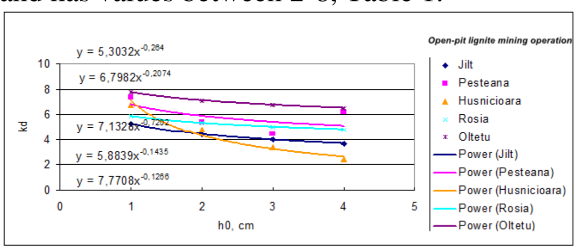

Fig. 2. The dependence of the dynamic coefficient k_d as a function of the cutting depth h_0 in quarries

Table 1

Range of coefficient k_d for different quarries

Range k_d	**Quarries**
2-6	Husnicioara
4-6	Jilț
4-6	Roșia
4-6	Peșteana

The variation of k_d with respect to h_o can be explained considering the angle of the tool and the cutting process, more specifically the formation of detachment of the cuttings.

It is well known that large cutting angles α generate larger cuttings with different granular structures which render the cutting process more dynamic.

The dynamic factor ψ_{din} of the machinery during the process of excavation is given in equation (4), [2], [3] applied to mining equipment:

$$\psi_{din} = \frac{\varepsilon_{dina}}{\varepsilon_{stat}} \qquad (4)$$

where:

$\varepsilon_{dina.}$ - maximum specific deformation at a point measured in dynamic regime;

$\varepsilon_{stat.}$ - maximum specific deformation measured at the same point as ε_{dina} in static regime.

Therefore one should consider that the physical parameters that could help determining the dynamic amplification coefficient can only be the deflections or specific deformations as these are physically measurable quantities in both static and dynamic regimes.

Accelerations are measured only in dynamic regimes thus cannot be considered for determining the coefficient of dynamic amplification.

2. STRAIN GAUGE PLACEMENT

The determination of static and dynamic deformations of the mining equipment ERc1400-30/7, Figure 3, was carried out using tensometric studies following a testing programme in static and dynamic regimes.

Fig. 3 Bucket wheel excavator type ERc1400-30/7

The strain gauges (SG) were placed in areas (Z1…Z4) with a high stress state determined from finite element analysis, using bar/plate elements for the discretization of the entire metal structure of the equipment, figure 4.

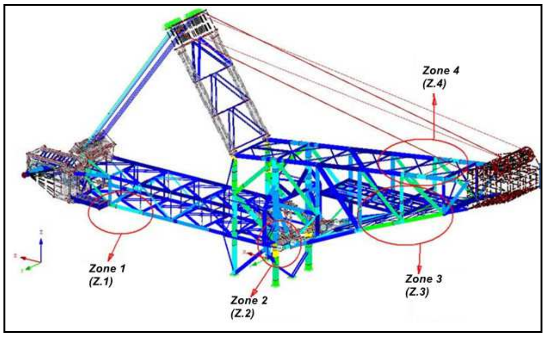

Fig.4. FEM of strain gauge locations

Loading was applied by considering a toque applied to the shaft of the rotor with a value of 1.5 times the maximum torque at which the rotor is decoupled. The analysis presented 4 zones for electro-resistive strain gauge placement (SG, identical to the symbol TER, are often referred to as strain gauge stamps due to their small size and T.1.. to channel for SG). The strain gauges formed a half bridge and one of the gauges was used for temperature compensation (TC), Figure 5.

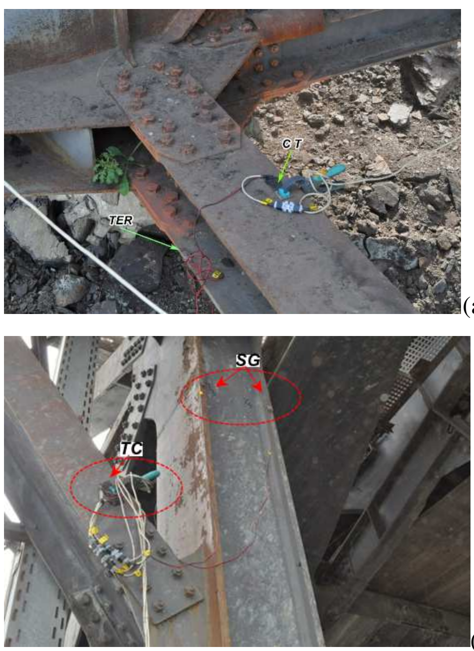

Fig. 5 Positioning of strain gauges (SG) in zones 1(a) and 2 (b) of the machinery in situ, temperature compensation (TC)

3. RECORDING OF DATA

After placing the strain gauges (SG1….SG8) on the strength elements in the areas determined through finite element analysis (FEA) and connecting them via cables to the strain bridge, the specific deformations of the equipment are determined in the field using the positioning scheme illustrated in Figure 6.

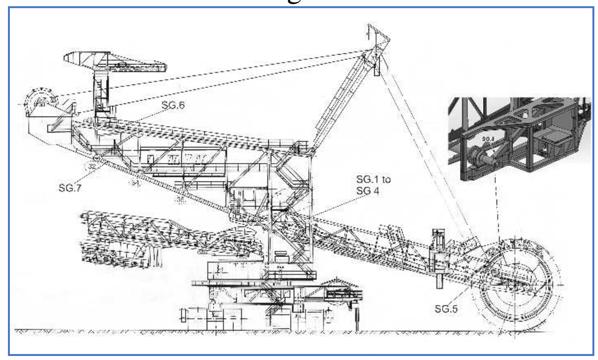

Fig.6 Numbering of strain gauges (SG1..SG8) on the machinery

It must be stressed that the two loading modes, static and dynamic, are defined as follows:

a. *static* – strain gauge measurements will be taken by rotating the upper platform + raising/lowering of the rotor arm;

b. *dynamic* – in this case strain gauge measurements are recorded in normal operating mode of the excavator.

In order to ensure the relevance of the results, measurements were carried out under both static and dynamic operating conditions on four ERc 1400-30/7 type machines, large-capacity excavators with wheel and bucket systems from the lignite exploitation quarry in Jilț, Oltenia lignite surface mining area [3]. The machines were numbered as ERc 1400-30/7.01, ERc 1400-30/7.02, ERc 1400-03/7.03 and ERc 1400-30/7.04, originating from the German variant SRs 1400-30/7. For each machine, a measurement table was prepared, numbered from tabels 2...5 [4], where the specific deformations measured by electric strain gauges and mechanical tensions determined by Hooke's law were recorded. Figures 7...10 present the evolution of specific deformations under static/dynamic operating conditions for the machines subjected to measurements. For specific deformations, a series of statistical parameters were calculated: mean value, standard deviation, variation, maximum /minimum value. Similarly, for mechanical tensions, the following were calculated: average tension, maximum tension, and tension amplitude. All these measures were taken to ensure that the results are as conclusive and clear as possible.

4. CONCLUSION

It can be observed that in certain exceptional working conditions, the maximum value of the dynamic factor in the excavation process may be equal to the dynamic factor of the equipment.

The method of determining the dynamic coefficient through electrical strain gauges proves to be simpler, eliminating the need for sampling, transport, and laboratory analysis of coal samples. The data are directly obtained from the equipment's excavation process in the coal, sterile material, or mixed coal-sterile environment.

The study results indicate that the variation of k_d in relation to h_0 takes into account the tooth clearance angle, the equipment's operating mode, advance, and excavation speed. This conclusion is supported by the compact shape of specific deformations, as shown in Figure 7, compared to the dynamic regime graphs in Figures 8…9.

Regarding mechanical stresses, it is noteworthy that despite the high value of ψ_{din} (4.9), the maximum mechanical stress $\sigma_{.max}$ is lower than the value for which ψ_{din} is lower (1.2…2.0) [5]. This phenomenon is explained by the dynamic nature of the excavation process, which occurs continuously and with constant cutting parameters, avoiding significant variations in stress (shocks) within the metal structure.

The method also allows for periodic evaluation of the equipment's load-bearing metal structure and certain mechanisms, such as the upper platform's rotation bearing, under various excavation conditions.

Table 2 – Strain ERc 1400-30/7-01										
Analyse: Statics - ERc 1400-30/7-01										
Strain [mm/m]							***Stress [N/mm²]***			
Channel [CH]	**No. records**	**Mean value**	**Standard deviation**	**Variance [s²]**	**Maximum value**	**Minimum value**	**Stress average, $s_{.med}$**	**Stress maximum, $\sigma_{.max}$**	**Stress minimum, $\sigma_{.min}$**	**Amplitude Stress, $\sigma.v$**
T.1	[1:7530]	8.97	6.88	47.31	20.38	-19.40	1.88	4.28	-4.07	6.32
T.2	[1:7530]	1.30	6.31	39.82	15.15	-20.10	0.27	3.18	-4.22	5.29
T.3	[1:7530]	-25.93	24.14	582.63	3.59	-115.63	-5.44	0.75	-24.28	12.89
T.4	[1:7530]	-18.97	32.32	1044.83	8.34	-137.56	-3.98	1.75	-28.89	16.19
T.5	**[1:7530]**	**16.52**	**21.85**	**477.31**	**43.17**	**-24.67**	3.47	9.07	-5.18	11.66
T.6	[1:7530]	4.63	32.04	1026.48	33.72	-83.68	0.97	7.08	-17.57	15.87
T.7	[1:7530]	-5.44	4.40	19.32	3.17	-24.60	-1.14	0.67	-5.17	3.25
T.5	**Maximum static value**				**43**			**9.1**	**-28.9**	**16.2**
Static average value					**18**			**4**		**10**
Analysis: Dynamics - ERc 1400-30/7-01										
T.1	[1:9630]	-6.35	39.11	1529.95	**107.21**	-211.53	-1.33	22.51	-44.42	44.72
T.2	[1:9630]	-25.12	40.49	1639.71	109.01	-239.31	-5.28	22.89	-50.25	48.02
T.3	[1:9630]	2.09	43.32	1876.91	191.03	-118.98	0.44	40.12	-24.99	52.61
T.4	[1:9630]	18.28	41.66	1735.59	**212.07**	-92.97	3.84	44.54	-19.52	54.30
T.5	[1:9630]	-3.72	18.93	358.42	41.41	**-92.84**	-0.78	8.70	-19.50	18.45
T.6	[1:9630]	57.45	15.64	244.54	149.43	12.67	12.06	31.38	2.66	30.05
T.7	[1:9630]	-1.40	9.36	87.70	43.49	-43.58	-0.30	9.13	-9.15	13.71
T.4	**Maximum dynamic value**				**212**			**45**	**-50.3**	**54.3**
Dynamic average value					**122**			26		**37**
$\psi_{.d.mas.}$	**The dynamic factor: $\psi_{d.mas} = \varepsilon_{.dina} / \varepsilon_{.static}$**				**4.9**					

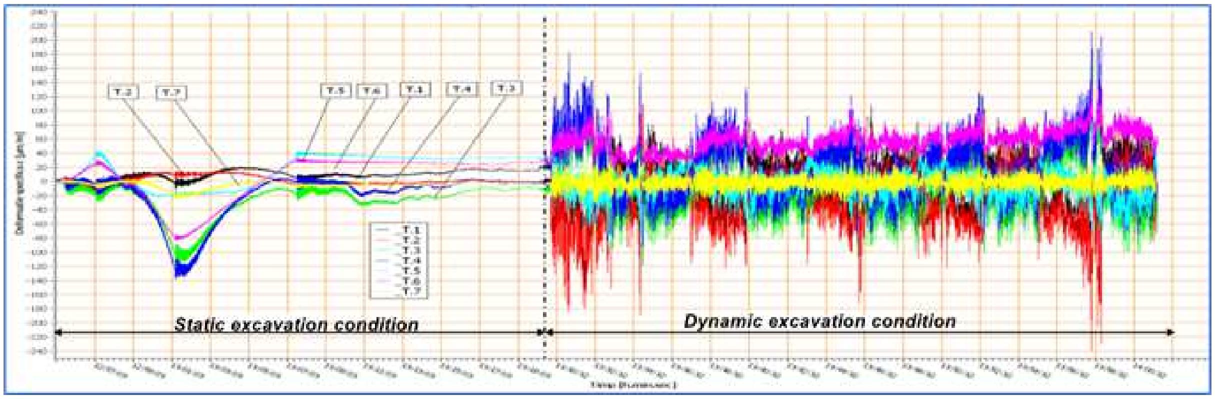

Fig. 7. Static and dynamic strain, ERc 1400-30/7-01

Table 3 – Strain ERc 1400-30/7-02										
Analyse: Statics - ERc 1400-30/7-02										
Strain [mm/m]							***Stress [N/mm²]***			
Channel [CH]	**No. records**	**Mean value**	**Standard deviation**	**Variance [s²]**	**Maximum value**	**Minimum value**	**Stress average, s.med**	**Stress maximum, σ.max**	**Stress minimum, σ.min**	**Amplitude Stress, σ.v**
T.1	[1:4645]	-5.39	19.27	371.51	83.54	-60.41	-1.13	17.54	-12.69	23.89
T.2	**[1:4645]**	**-0.32**	**19.70**	**388.20**	**97.90**	-56.46	-0.07	20.56	-11.86	26.49
T.3	[1:4645]	-173.63	51.36	2638.23	-22.60	-306.39	-36.46	-4.75	-64.34	27.43
T.4	[1:4645]	-48.97	33.90	1149.38	43.13	-117.65	-10.28	9.06	-24.71	21.41
T.5	**[1:4645]**	**-14.21**	**33.52**	**1123.54**	**92.61**	**-87.83**	-2.98	19.45	-18.44	28.67
T.6	[1:4645]	-46.10	21.92	480.65	5.84	-84.91	-9.68	1.23	-17.83	10.14
T.7	[1:4645]	-9.73	11.02	121.38	47.20	-58.81	-2.04	9.91	-12.35	16.09
T.2	**Maximum static value**				**98**			**20.6**	**-64.3**	**28.7**
Static average value					**50**			**10**		**22**
Analysis: Dynamics ERc 1400-30/7-02										
T.1	[1:9607]	56.67	43.22	1868.11	**226.98**	-72.42	11.90	47.67	-15.21	55.27
T.2	[1:9607]	26.48	40.79	1664.04	204.18	-97.59	5.56	42.88	-20.49	53.12
T.3	**[1:9607]**	**-382.41**	**256.96**	**66027.68**	**265.00**	-877.41	-80.31	55.65	-184.26	147.78
T.4	[1:9607]	19.01	29.76	885.74	87.31	-110.56	3.99	18.33	-23.22	29.94
T.5	**[1:9607]**	**-114.79**	**48.36**	**2338.62**	**-25.86**	**-351.66**	-24.10	-5.43	-73.85	31.49
T.6	[1:9607]	-20.00	17.41	303.06	41.71	-73.30	-4.20	8.76	-15.39	16.46
T.7	[1:9607]	1.35	11.89	141.41	69.57	-50.54	0.28	14.61	-10.61	19.92
T.3	**Maximum dynamic value**				**265**		-12.4	**56**	**-184.3**	**147.8**
Dynamic average value					**124**			26		**51**
$\psi_{.d.mas.}$	**The dynamic factor $\psi_{.d.mas} = \varepsilon_{.dina} / \varepsilon_{.static}$**				**2.7**					

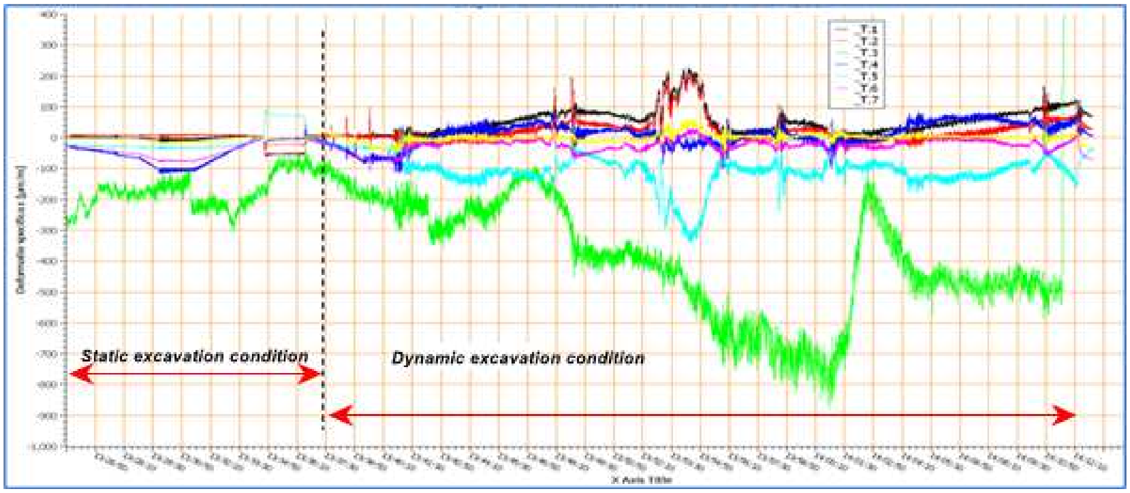

Fig. 8. Static and dynamic strain, ERc 1400-30/7-02

Table 4 – Strain ERc 1400-30/7-03										
Analyse: Statics - ERc 1400-30/7-03										
Strain [mm/m]							***Stress [N/mm2]***			
Channel [CH]	**No. records**	**Mean value**	**Standard deviation**	**Variance [s²]**	**Maximum value**	**Minimum value**	**Stress average, s.med**	**Stress maximum, σ.max**	**Stress minimum, σ.min**	**Amplitude Stress, σ.v**
T.1	[1:6276]	12.53	21.66	469.03	178.87	-75.30	2.63	37.56	-15.81	45.47
T.3	[1:6276]	14.17	54.59	2980.57	193.86	-113.82	2.98	40.71	-23.90	52.66
T.4	**[1:6276]**	**44.66**	**149.72**	**22416.08**	**300.00**	**-300.05**	**9.38**	**63.00**	**-63.01**	**94.50**
T.5	[1:6276]	-10.78	16.03	256.93	35.26	-56.99	-2.26	7.40	-11.97	13.39
T.6	[1:6276]	-17.24	29.43	866.25	33.54	-91.20	-3.62	7.04	-19.15	16.62
T.7	[1:6276]	-33.40	23.94	573.03	21.80	-124.46	-7.01	4.58	-26.14	17.65
T.4	**Maximum static value**				**300**			**63.0**	**-63.0**	**94.5**
Static average value					**127**			**27**		**40**
Analiza: Dinamica ERc 1400-30/7-03										
T.1	[1:9532]	65.36	36.87	1359.29	**226.23**	-71.20	13.72	47.51	-14.95	54.98
T.3	[1:9532]	142.18	35.93	1290.82	273.27	17.89	29.86	57.39	3.76	55.51
T.4	**[1:9532]**	**104.56**	**132.74**	**17618.97**	**369.25**	**-170.69**	**21.96**	**77.54**	**-35.84**	**95.46**
T.5	[1:9532]	-74.27	42.36	1794.14	25.71	-251.50	-15.60	5.40	-52.82	31.81
T.6	[1:9532]	30.57	26.17	684.68	134.70	-34.40	6.42	28.29	-7.22	31.90
T.7	[1:9532]	-84.59	21.40	458.01	-6.35	-172.92	-17.76	-1.33	-36.31	16.82
							0.00	0.00	0.00	0.00
T.4	**Maximum dynamic value**				**369**			**78**	**-52.8**	**95.5**
Dynamic average value					**170**			36	-	**41**
$\psi_{.d.mas.}$	**The dynamic factor:** $\psi_{.d.mas} = \varepsilon_{.dina} / \varepsilon_{.static}$				**1.2**					

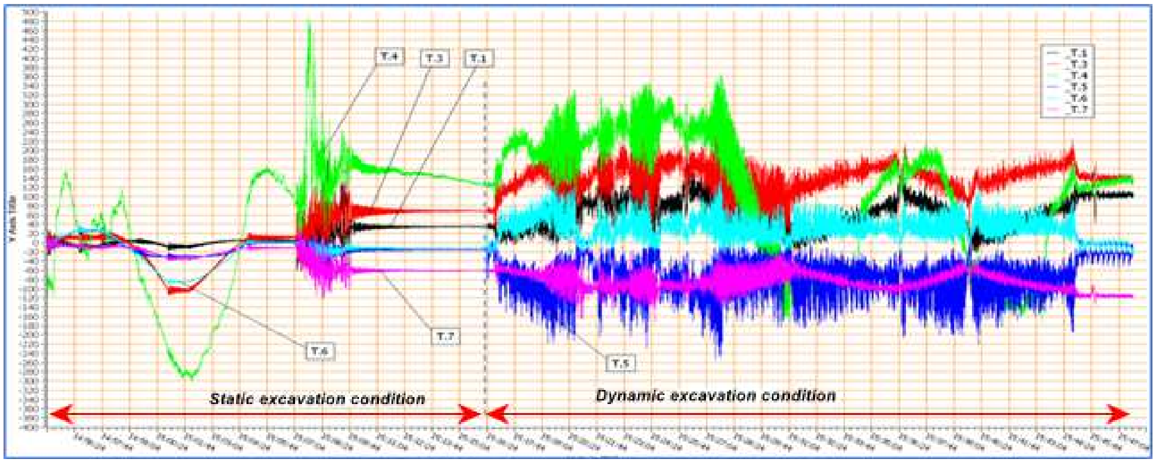

Fig. 9. Static and dynamic strain, ERc 1400-30/7-03

										Table 5 – Strain ERc 1400-30/7-04
Analyse: Statics - ERc 1400-30/7-01										
Strain [mm/m]							***Stress [N/mm2]***			
Channel [CH]	**No. records**	**Mean value**	**Standard deviation**	**Variance [s²]**	**Maximum value**	**Minimum value**	**Stress average, $s_{\cdot med}$**	**Stress maximum, $\sigma_{\cdot max}$**	**Stress minimum, $\sigma_{\cdot min}$**	**Amplitude Stress, $\sigma_{\cdot v}$**
T.1	[1:11063]	-11.59	13.35	178.27	43.02	-126.53	-2.43	9.03	-26.57	22.32
T.2	[1:11063]	-38.88	29.69	881.38	18.52	-203.97	-8.16	3.89	-42.83	25.31
T.3	**[1:11063]**	**-8.48**	**44.50**	**1980.50**	**102.83**	**-129.42**	**-1.78**	**21.59**	**-27.18**	**35.18**
T.4	[1:11063]	-0.85	75.82	5748.28	141.01	-197.86	-0.18	29.61	-41.55	50.39
T.5	[1:11063]	20.92	34.87	1215.61	79.46	-106.71	4.39	16.69	-22.41	27.89
T.6	[1:11063]	10.96	37.74	1423.98	92.46	-79.86	2.30	19.42	-16.77	27.80
T.7	[1:11063]	-3.03	9.75	95.07	91.59	-55.73				
T.4	**Maximum static value**				**141**			**29.6**	**-42.8**	**50.4**
Static average value					**81**			**17**		**31**
Analiza: Dinamica ERc 1400-30/7-04										
T.1	[1:11576]	17.51	44.63	1991.86	**242.50**	-117.60	3.68	50.93	-24.70	63.27
T.2	[1:11576]	-85.96	44.74	2001.68	200.59	-343.25	-18.05	42.12	-72.08	78.16
T.3	**[1:11576]**	**34.26**	**32.16**	**1034.31**	**240.42**	**-121.55**	**7.20**	**50.49**	**-25.53**	**63.25**
T.4	**[1:11576]**	**61.72**	**37.31**	**1391.88**	**275.86**	-121.61	12.96	57.93	-25.54	70.70
T.5	[1:11576]	10.12	38.57	1487.68	104.47	-207.20	2.12	21.94	-43.51	43.70
T.6	[1:11576]	31.47	29.41	864.78	120.30	-28.80	6.61	25.26	-6.05	28.29
T.7	[1:11576]	-0.89	14.57	212.25	98.21	-89.00	-0.19	20.62	-18.69	29.97
T.4	**Maximum dynamic value**				**276**			**58**	**-72.1**	**78.2**
Dynamic average value					**183**			38	-	**54**
$\psi_{\cdot d.mas\cdot}$	**The dynamic factor:** $\psi_{.d.mas} = \varepsilon_{\cdot dina} / \varepsilon_{\cdot static}$				**2.0**					

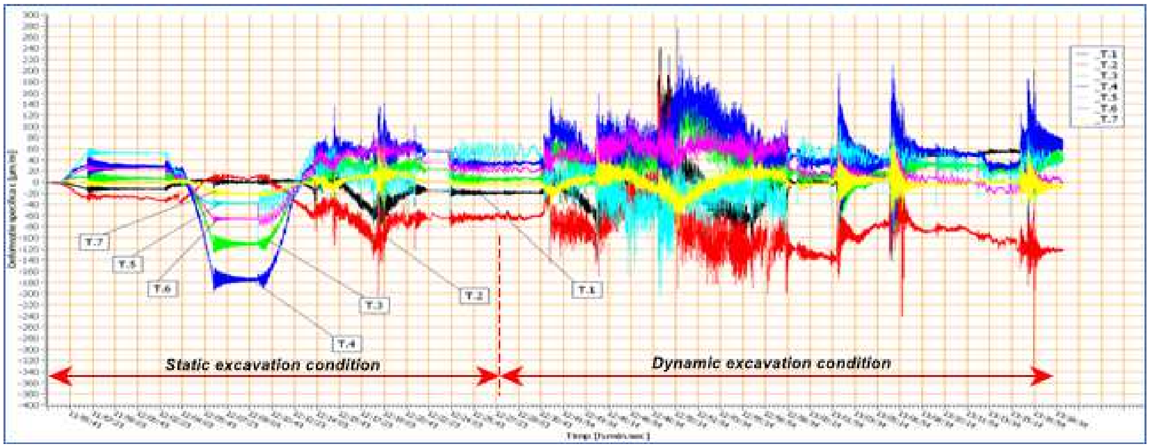

Fig. 10. Static and dynamic deformation, ERc 1400-30/7-04

5. REFERENCES

[1] Contract nr. 1/2006, Cercetări teoretice şi experimentale privind creşterea gradului de utilizare a utilajelor de excavare în carierele de lignit aparţinând S.C. Complexul Energetic Turceni S.A., Universitatea din Petroşani, Facultatea de Inginerie Mecanică şi Electrică;

[2] Ghindea, C., Crețu, D., Cruciat, R., Giumanca, A., A review on the dynamic testing of the bridges, DOI:10.13140/2.1.3589.8888, The 20th National Conference with international participation "in situ" behaviour of construction 8-10 October 2014, Brașov, ROMANIA

[3] STAS 12504-86 Poduri de cale ferată, de şosea şi pasarele. Încercarea suprastructurilor cu acţiuni de probă, IRS, Bucureşti, 1986.

[4] Universitatea din Petroşani,SC. UZIMET SRL, ICSITPML-S.A Craiova- "Servicii de expertizare stare tehnică utilaje de carieră privind prelungirea duratei normale de funcționare, conform HG 2139/2004"-Contract nr.165/CEOSM/2019;

[5] DIN 22261-2 Excavators, spreaders and auxiliary equipment in opencast lignite mines - Part 2: Calculation principles.

Analiza comparativă a coeficienților dinamici la tăierea lignitului și ai utilajelor de excavare în carierele din Oltenia

Rezumat: Cunoașterea caracterului dinamic al procesului de dislocare este esențială pentru studiul stabilității globale a excavatorului cu rotor și a oricărui dispozitiv de dislocare a materialelor neomogene. Această lucrare se concentrează pe analiza influenței coeficientului dinamic, k_d, al procesului de tăiere, determinat pentru diferite cariere din Bazinul Carbonifer Oltenia, asupra stării de tensiune, a frecvențelor generate de procesul de excavare și a factorului dinamic al utilajului. Observăm că în anumite condiții de lucru excepționale, valoarea maximă a factorului dinamic al procesului de excavare poate fi egală cu factorul dinamic al utilajului. Această analiză poate contribui la optimizarea procesului de tăiere, reducerea timpului de schimbare a dinților cupelor și îmbunătățirea fiabilității mecanice/structurale a utilajului. Metoda de investigare utilizată este tensometria electrică, o tehnică simplă și eficientă, eliminând necesitatea prelevării de probe de cărbune și transportului acestora în laborator. Datele sunt direct obținute din modul de excavare al utilajului în stratul de cărbune, steril sau mixt.

Sorin Mihai RADU, PhD Eng., Professor, University of Petroșani, Department of Mechanical, Industrial and Transport Engineering, sorin_mihai_radu@yahoo.com, 0722642340, 20 Universității street, 332006, Petroșani, HD

Stela DINESCU, PhD Eng., Lecturer, University of Petroșani, Department of Mechanical, Industrial and Transport Engineering, dinescustela@yahoo.com, 0722538740, 20 Universității street, 332006, Petroșani, HD

Florin VÎLCEANU, PhD Eng., Lecturer, University of Petroșani, Department of Mechanical, Industrial and Transport Engineering, florinv64@gmail.com, 0727848889, 20 Universității street, 332006, Petroșani, HD