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APPLICATION OF SPECTROSCOPIC (FOURIER'S) ANALYSIS FOR THE EVALUATION OF ROCK CUTTING PROCESSES

WYKORZYSTANIE ANALIZY WIDMOWEJ (FOURIERA) DO OCENY PREBIEGU PROCESÓW SKRAWANIA SKAŁ

The present is an attempt to apply the Fourier's single time series analysis for the evaluation of rock cutting processes with separated cutting wedges of specific geometry. It has been assumed that the time series here is the run of cutting force values (F_c) in time period (t) obtained in the rock cutting process with a cutting wedge. For the analysis it was suggested the use of FFT and especially spectroscopic density in the function of period. The time series was treated as a time series, with specific characteristic for the tool's geometry, cyclic rock loosening process. Experimental researches and results of time series for Rapid 83, NKP2w and AM-50/96° tools confirm cutting cycles appearance for each type of these tools. It was noticed that cycle quantity depends on both: cut rock, strenght parameters and geometry of the tool. Settlement of closer correlations requires further investigations.

Key words: time series, spectroscopic density, cutting force, Fast Fourier Transformation (FFT).

W artykule przedstawiono próbę wykorzystania analizy Fouriera pojedynczego szeregu czasowego do oceny przebiegu procesu skrawania skał, odosobnionym ostrzem skrawającym o określonej geometrii. Jako szereg czasowy przyjęto traktować przebieg wartości siły skrawania (F_c) w czasie (t), uzyskiwany w trakcie skrawania skały, danym ostrzem. Do analizy zaproponowano wykorzystanie Szybkiej Transformacji Fouriera, a zwłaszcza rozkładu gęstości widmowej w funkcji okresu. Wspominany przebieg czasowy, traktowano jako szereg czasowy, o pewnej charakterystycznej dla danej geometrii ostrza, cykliczności procesów odspajania.

Badania doświadczalne oraz wyniki analizy przebiegów czasowych, zarejestrowanych dla noży typu: Rapid 83, NKP2w oraz AM-50/96°, potwierdziły występowanie cykli skrawania, charakterystycznych dla każdego z noży. Stwierdzono, że wielkość cyklu zależy

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równocześnie od parametrów wytrzymałościowych skrawanej skały oraz geometrii ostrza. Ustalenie jednak bliższych związków korelacyjnych wymaga dalszych badań.

Słowa kluczowe: szereg czasowy, gęstość widmowa, siła skrawania, szybkie przekształcenie Fouriera (FFT).

1. Introduction

Numerous tool manufacturers offer a wide range of cutting tools with various geometry of cutting wedges. For example in Poland radial cutting tools type Rapid 83 (with „lenticular" cutting wedge geometry), Rapid 89 (with wedge-shaped rake and flank faces) are manufactured together with the cutting tools which were produced earlier such as: type NKP2w (with flat rake face and with an oval cutting edge [1]. Very often manufactures of the cutting tools follows specific orders from foreign contractors and are not concerned with any complex research on the influence of cutting tool's geometry on the course and the effects of the cutting process. It results from the fact that research in this field is expensive and often results are not univocal mainly because of the wide range of possible research directions that can be carried out both in laboratory and industrial conditions. Evaluation of the cutting wedge design is neither easy nor univocal. Experience shows that compromise must be reached. Even though, from the theoretical point of view, energy consumption in comminution is higher when a wedge-shaped punch is forced into samples than in the case of oval-tipped punches [4], when we consider the complete cutting cycle (impressions of suitable pressure marks by the tool in the rock, breaking off a chip and moving the tool to a new position), the result is that generally speaking energy — consumption is lower when the tools used a with relatively large tool rake angles and clearance angles (including side angles), a large width of rectilinear cutting edge and flat rake and flank faces. When tool durability is analysed, a series of tests showed that the most advantageous tool is of „lenticular" shape (for example Rapid 83) with small width near the corner that increases upwards, and convex shape of the rake and flank faces with sharp edge of the intermediate section and with negative rake angle near the corner which increases upwards. As it is generally suggested this kind of cutting tools are characterized by good durability and stable, gradual growth of the tool load with increasing edge bluntness. It is very important for the smooth operation of multi-point tool head and their drive sub assemblies. It can be said that the tool must attain cutting effect with minimum force applied and with a relatively long service time.

Tool geometry exerts influence on the elements of total force acting on the cutting wedge. It is essential to know them to design parameters of the cutting tool shank and the chuck in which it is to be fixed. As it is suggested by Gehring [2], efficiency of the cutting process with a given cutting wedge can be estimated by analyzing cutting force run during mining time. The ideal run of the force in time would be a saw — shape run in which the force grows gradually and linearly to its maximum value and after the breaking off the chip element by the cutting tool decreases jumping down to zero. However, in the actual run this force does not decrease down to zero but to a certain minimum value which is characteristic of a given cutting wedge geometry (Fig. 1). Chip elements break off as a result the so called total useful cutting force action (rock loosening) ΔFc [2]. The bigger the peaks of the force, the bigger winning grids are broken off. Flattening of the run graph and lack of the distinct peaks confirms that crushing complex friction processes of the cutting wedge take place in the cutting zone during tool application. Gehring suggests considering the $\overline{\Delta F_c} / \overline{\Delta F_{cr}}$ values (Fig. 1) as a criterion of for the estimation of cutting tool performance. Efficiency of the cutting process with a given cutting wedge is very low when this ratio is lower than 1 and the best when it is more than 5.

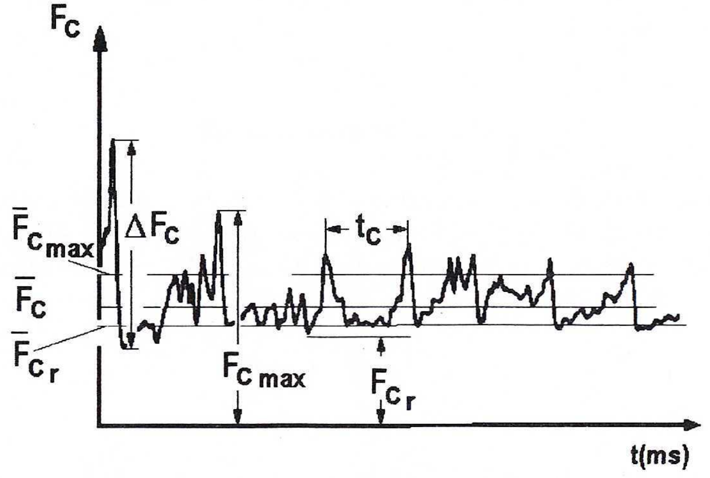

Fig. 1. Actual run of the cutting force F_c in time t $\{F_{cr}$ — residual cutting force, ΔF_c — usable cutting force (of chip loosening), $\bar{F}_c$ — average force, t_c — time of the elementary loosening cycle$\}$

Up till recently complex analyses of these processes were very difficult as they were carried out by means of traditional methods by "manual" counting of the parameters such as number of cycles in which bigger chip elements are formed (accompanied by the maximum local cutting forces), per 1 m of the chip length and/or average length of such a period ($s = l/i$). Both parameters are useful for some analysis of the mining heads working dynamics.

At present, any kind of research on the cutting processes both in the laboratory and industrial conditions are carried out using computer software. More and more sophisticated software enables carrying out more detailed analysis of the processes which are discussed here.

Since the run of the cutting force in time may be treated as a time series with certain characteristic geometry of the cutting wedge, cyclic loosening processes, application of mathematical procedures applied in the analysis of time series particularly (Fourier's) spectroscopic analysis for the analysis of cutting processes is possible. The above mentioned analysis based on the Fast Fourier Transformation (FFT), is used for the examinations of a harmonic structure of the time series. Its aim is decomposition of a complex time series with cyclic components into a few basic sine and cosine functions with specific wave lengths. As a result of this analysis a few periodical cycles with different wave lengths may be discovered within the time series of interest, even though in the beginning it seemed to be more random. A period-graph may be particularly useful as its values can be interpreted as a variance corresponding to specific frequency (or periods) of oscillations [3]. Usually the values of the period-graph are plotted against frequencies or periods. By smooting up the values in the period-graph by means of the moving weighted average we can find frequencies with the highest spectroscopic density, i.e. the frequency areas that consist of many adjacent frequencies with the greatest contribution into the general harmonic structure of the series.

2. The calculation example

To illustrate this problem a typical cutting force run in time (Fig. 2), i.e. mining of a weak limestone with the cutting tool Rapid 83, was examined. The cutting speed (v_c) was 0.45 m/s, depth $g = 12$ mm and cutting graduation $t = 90$ mm.

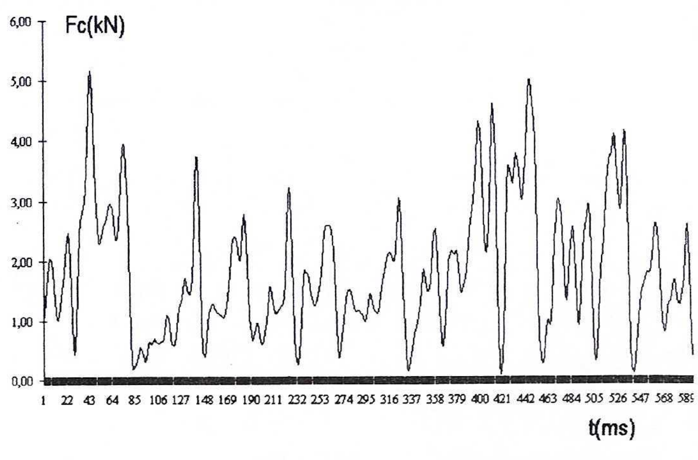

Fig. 2. Force run in time when cutting limestone with Rapid 83 cutting tool

As can be gathered from the Fig. 3, a strong 80-millisecond cycle is present in the cutting force run presented in Fig. 2 (the highest spectroscopic value of the series), which means that the maximum of the force (F_{cmax}) appears in this very period. Other less numerous cycles are 20, 40 and 150-millisecond cycles. At the assumed cutting speed in 80 milliseconds the wedge will make about 36 mm and in 20, 40 and 150 milliseconds 10, 20 and 67,5 mm, respectively. As each local maximum of the force corresponds to breaking off a bigger chip, we can expect that in the process of cutting weak limestone (R_c = 7,4 MPa) with Rapid 83 cutting tool and the cutting depth g = 12 mm and the cutting graduation t = 90 mm the most often formed chip will have the maximum size of about 36 mm (measured in the cutting direction). To a lesser extend, bigger chips (about 67 mm) and also smaller ones (10 or 20 mm) will be formed.

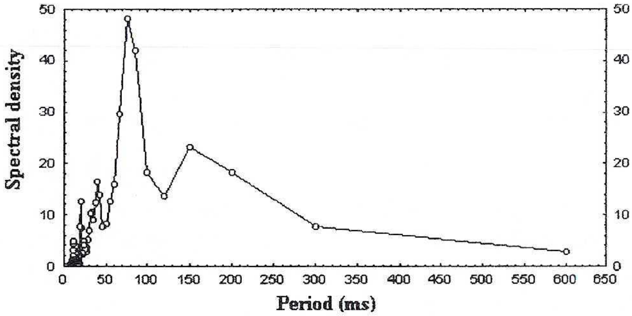

Fig. 3. Spectroscopic density graph for the force time run in time in Fig. 2

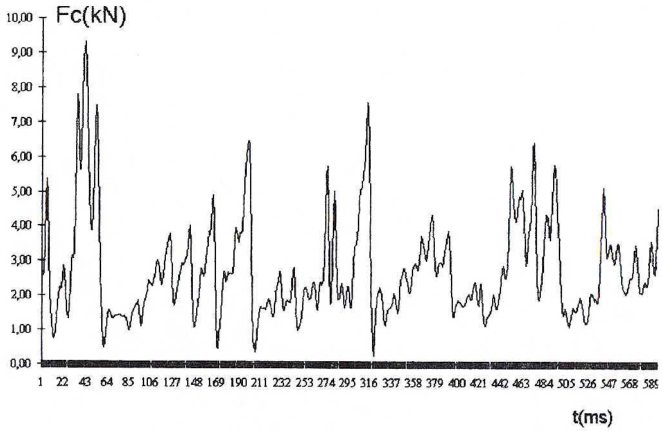

Fig. 4. Force run in time when cutting sandstone with Rapid 83 cutting tool

Since the question of the influence of the rock strength characteristics on the process may arise, Fig. 4 shows a typical cutting force run in time with the cutting tool discussed acting on grey sandstone (R_c = ~39 MPa).

Taking into consideration figures 2 and 4, it can be noticed that the length of the loosening cycle increases slightly. However, any more detailed visual analysis is very difficult (can give false results). More precise conclusions can be drawn on the basis of the spectroscopic density graph (Fig. 5). In this case the basic cycle is 90-milliseconds in which the maximum of the cutting force is present. But the importance

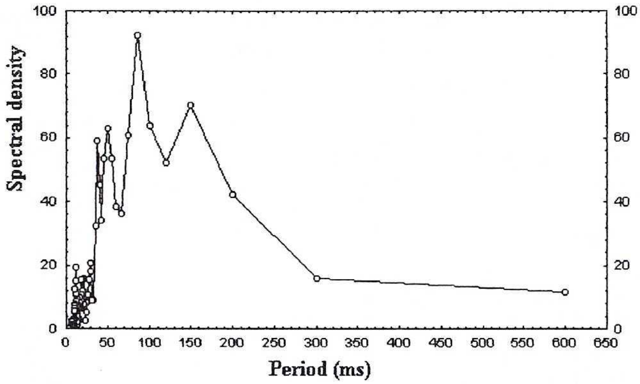

Fig. 5. Spectroscopic density graph for the force time run in Fig. 4

of other cycles increases considerably, i.e. the cycles of 30, 50 and particularly 150-milliseconds. In the actual practice it may mean that during the cutting process of more compact but at the same time more bedded grey sandstone bigger chips will be generated. Chip formation processes will be submitted to longer cycles than when weak and brittle limestone is cut.

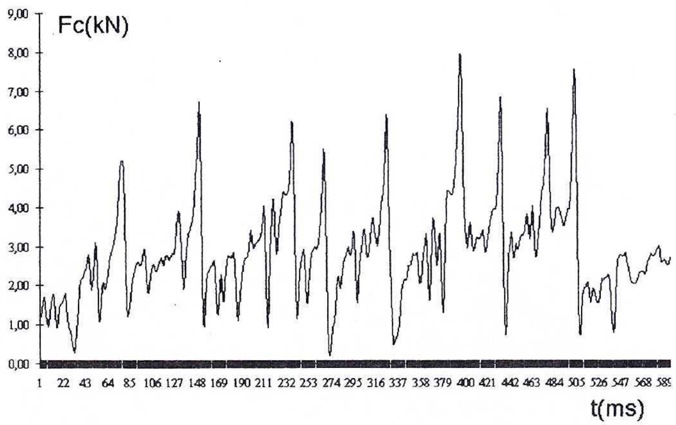

Fig. 6. Force run in time when cutting sandstone with NKP2w cutting tool

The next problem worth consideration is a potential influence of the cutting wedge geometry on the chip formation run or cycles of cutting force. To signal this problem, a cutting force run in the time recorded when cutting sandstone with a typical radial cutting tool NKP2w (with flat rake face and oval cutting edge) was shown on Fig. 6. Whereas, Fig. 7 presents its spectroscopic density graph. As can be seen from the graph, in this case two essential cycle dominate, i.e. 90 and 300 – millisecond ones (with corresponding probable chip size of 40 and 135 mm). Thus the importance of longer cycles increases considerably. The rest of the cutting cycles are concentrated within the range from 0 up to 40-milliseconds.

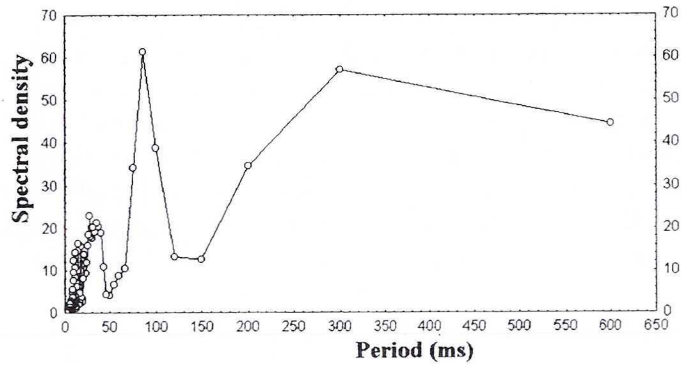

Fig. 7. Spectroscopic density graph fro the force time run in Fig. 6.

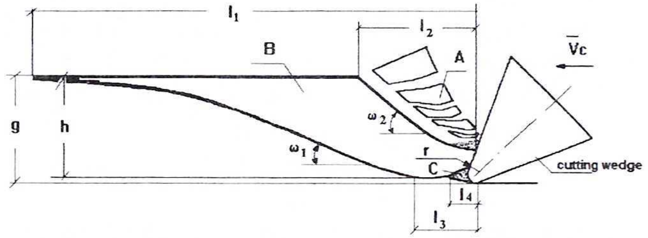

Fig. 8. Characteristic parameters of the chip elements loosened at the specific depth of cutting, where: A — the main chip element (of the biggest sizes) B — the forming zone of the finer chip elements, rounded cutting edge radius, C — the crushing zone of the material (a separated part of pressing zone), l_1 — the length of the main chip element, l_2 — the maximum dimension of finer fractions of the chip, l_3 — the cutting path with the depth comparable to the radius of the corner, l_4 — the range of crushing zone, h — the maximum thickness of the chip, g — the depth of cutting, r — rounded cutting edge radius, ω_1 — average angle of loosening of the main chip element, ω_2 — average angle of loosening in the zone of chips with reduced size

As can be gathered from research and observations by the present author [5], the average estimated values of some chip parameters (Fig. 8) gathered while cutting grey sandstone with a cone cutting tool type AM — 50/96° (production made) with position angle of 50° and side displacement of 0°, and the cutting depth $g = 16\,\text{mm}$ are as follows: $l_1 = 75\,\text{mm}$, $l_2 = \sim 28\,\text{mm}$, $h = \sim 13\,\text{mm}$, $l_4 = \sim 3 \div 5\,\text{mm}$, $\omega_1 = \sim 10°$ and $\omega_2 = \sim 22°$. The transverse dimension of the main chip element was $\sim 95\,\text{mm}$ on the average and, what is relevant, the average angle of side crushing was $\psi = \sim 75°$. When the cutting depth was $g = 20\,\text{mm}$, the most often observed dimensions were, $l_1 = \sim 125\,\text{mm}$, $l_2 = \sim 40\,\text{mm}$ respectively, the transverse dimension of chip was up to 175 mm, $\omega_1 = \sim 8°$. The angle of the side cutting calculated according to the parameters of the main chip element was even up to 75°. Due to the limited number of observations, the above data can only be treated as approximate. To receive more detailed data it is necessary to carry out complex research followed by thorough statistic analysis.

However, there are indications that the cutting wedge geometry, and the shape of rake face in particular together with the value of the tool rake angle and the width and the shape of the cutting edge, are of great importance for the process of chip formation. At this stage of the research, since only a limited number of measurements is available, it is difficult to establish detailed relations between these parameters and the cyclic characterictics of the cutting process. More complex research on the influence of cutting wedge geometry, cutting parameters, granulometric composition of the winning, as well as cutting force runs in time are necessary. The research should be supplemented by the analyses of parameters suggested by Gehring, especially the values of $\overline{\Delta F_c}$ and $\overline{\Delta F_{cr}}$ forces (Fig. 1).

3. The summary

The present author is of the opinion that the application o Fourier's Spectroscopic Analysis for the examination of time runs of the total force components acting on the cutting tool wedge will considerably simplify evaluation of the influence of specific wedge geometry on the granulation of winning, efficiency or dynamics of the winning process. However, it requires further complementary research which have already been mentioned above.

The above statements seem to be confirmed by the examples presented here and the fact that similar type of research is parallelly carried out in machine industry on the application of te methods mentioned above for the monitoring of cutting process by means of chip formation process control [6]. First of all, it concentrates on shape recognition ad decisions on chip qualification to one of the groups: admissible and inadmissible. The current evaluation of the cutting wedge wear and its influence on the chip breaking is also possible.

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