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Assessing and Predicting the Vibration Signals in Rock Machining Process

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Abstract

Besides stone perishing, generated vibrations during stone cutting process can lead to bending, deflection and finally breakage of cutter disks. Therefore, study and predicting vibrations, is unavoidable in stone cutting process. In this research, by means of laboratory and statistically analysis, a study is carried out to predicting vibration of stone cutting process. For this purpose, a stone cutting machine in laboratory scale which equipped with vibration measurement tools, was provided. On a carbonate rock specimen, the study is carried out under different circumstance such as different practical cut depth (15, 22, 30, 35 mm), different cut advance rate (100, 200, 300, 350, 400 cm/min), different cutter disk rotation speed (1540, 1770, 2550 rpm). Results indicate that increasing in cut depth and cut advance rate, lead to increase in vibration intensity. Vibration intensity quantity even increased 6 times, when cut advance rate varies from 100 to 400 cm/min. Using SPSS software, after laboratory result investigation and statistically data analysis, vibration signal predicting statistical models are presented. Results of statistical tests indicates that the best fitting models enable predicting vibration quantity accurately and precisely with correlation coefficient range of 0.92 - 0.87, confidence level of 90% and error less than 10%.

Key words: *Rock sawing, Vibration signal, Operational parameters, Statistical model.*

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Extended Abstract:

1. Introduction

The dimension stone cutting process is an abrasive process. So that cutting a stone with the help of diamond segments can be considered as abrasion of the particles forming the stone by passing diamond grains on the rock surface. In general, the process of cutting stone using diamond equipment can be summarized in two steps. The first stage of the stone cutting process can be considered as the result of the movement of diamond segments on the cutting surface and the subsequent formation of rock chips as a result of the penetration of diamond grains inside the stone. During this process, the diamond grain scratches and splits the cutting surface to form a chip and create a new surface for the next diamond grain. When a stone is cut by a diamond tool, the mechanical interaction between the tool and the stone creates process forces that are mainly due to factors such as the elastic and plastic deformation in the stone, the friction between the diamond grain and the matrix with the stone and the chip. Are the result of cutting. These force changes, along with the post and heights on the workpiece surface, chip thickness irregularities, chip breakage and layering, and friction between surfaces, cause vibration signals. Therefore, the most important source of vibration in machining is the change in chip thickness and as a result, changes in process forces. Excessive vibration, in addition to increasing the throw of the stone, causes buckling, deflection and ultimately failure of the tool. Therefore, it is necessary to study and predict the amount of vibration during the cutting process. Examining vibrations and reducing them during the cutting process, in addition to reducing production costs, increases the life and performance of cutting tools and also increases the quality of products produced. The use of vibrations in machining began in 1946, when Arnold described the umbrella phenomenon and its cause as a negative dumping effect (Arnold, 1946). This theory was immediately rejected by Tlusty and Tobias (Tobias & Fishwick, 1958; Tlusty & Polacek, 1963). In 1958, Tobias & Fishwick developed a model for determining the umbrella and examining the instability of the machine tool (Tobias & Fishwick, 1958). Telesti & Polacek (1963) found that the effect of re-vibration was the main cause of the instability that caused the umbrella to form (Tlusty & Polacek, 1963). In the field of stone machining, we can refer to the studies of Polini and Turchetta in 2007. They conducted their studies to monitor tool wear using vibration signals and to evaluate forces in the cutting process of a type of granite. The results of their studies showed that by monitoring signals such as acceleration along the z-axis and force, machining operations, especially tool wear, can be evaluated (Polini & Turchetta, 2007). In 2001, Ozçelik et al. examined the relationship between shear depth and vibration. They concluded that in hard rocks, increasing the cutting depth reduces the amount of vibration of the rock cutting machine (Ozcelik et al. 2001). In 2011, Ozçelik and Yilmazkaya investigated the anisotropic effect of rocks due to the presence of lamination plates on the vibration of a diamond cutting wire. For this purpose, the placement of the cutting machine relative to the lamination plates in different conditions was investigated. The results showed that the highest vibration is obtained at a cutting angle of 55 degrees and the lowest vibration at a cutting angle of 25 degrees (Ozcelik & Yilmazkaya, 2011). In 2011, Mikaeil et al. Examined and classified building stones from the perspective of vibration generated in a disk cutting machine using fuzzy theory (Mikaeil et al. 2011). In 2014, Mikaeil et al. Investigated the relationship between the vibration of the disc cutting machine in the process of cutting building stones with the brittleness of stone (Mikaeil et al. 2014). In 2018, Aryafar et al. Investigated the vibration of disc cutting machines using metaheuristic algorithms (Aryafar et al. 2018). According to the studies, it can be seen that the number of articles related to the subject of vibration in the process of cutting building stones compared to topics such as energy consumption of cutting machines, wear of diamond tools and also the production rate is very small. This in itself requires further studies and research in this area. For this purpose, the present study will try to investigate the relationship between the operating parameters of the cut in the disc cutting process and the amount of vibrations obtained in the cutting machine during the cutting process of a soft building stone using statistical studies.

2. Materials and methods

In general, the study stages of this research include study design, sampling, measurements and data analysis. The study plan is the first step and one of the most important parts of a research that is generally obtained after conducting library studies and reviewing previous studies. The study design of the present study can be used to investigate the relationship between operating parameters of the cut, including cutting rate and advancement speed with vibrations generated in the cutting machine. Samples or in other words research materials, stone plates prepared from Azarshahr travertine building stone sample (one of the most widely used examples of building stones in the country). Data analysis using statistical methods in SPSS software environment.

3. Tests results

Studies show that at a constant rotational speed of the disk (1540 rpm) the amount of vibration increases with increasing amount of cutting depth and feed rate. The rate of change increases with increasing rate of feed rate and depth of cut, so that the ratio of these changes in rate of feed rate is 400 to 100 cm / min and depth of cut is 15 to 35mm is about 6 times. The reason for this is the increase in stresses on the disk due to process forces, including two components of tangential and vertical forces. Vertical forces cause the penetration of diamond grains into the rock and the formation of the chip, and tangential forces cause the chip to be removed, which in total, the action of the two forces causes the rock to cut. The stresses in the body of the disk due to these forces appear in the form of compressive stresses and flexural moment, which if these forces increase beyond the allowable limit, will intensify the vibration, followed by buckling and deflection of the disk. The thickness of the chip is directly related to the feed rate and the cutting depth. In other words, with increasing the feed rate, the penetration depth of the diamond grain and the chip thickness also increase. Increasing the penetration depth of diamond grain increases the forces and stresses in the rock, which in turn leads to the formation and growth of lateral and radial cracks.

4. Conclusion

So far, no comprehensive studies have been performed on the evaluation of vibrations, especially its relationship with operational characteristics. The present study can be considered as a continuation of previous studies with a special focus on operational characteristics with the help of statistical studies for soft rock samples. The results of the initial studies in this study showed that, with increasing the amount of operational parameters such as cutting depth and feed rate, the amount of vibration intensity increases. At the opposite point, however, the intensity of specific vibrations follows a decreasing trend. The reason for this can be seen in the cutting mechanism and the ease of chip formation in the cutting depth and high advancement rate. The slope of the changes in the vibration intensity diagram relative to the cutting depth has increased significantly with increasing the feed rate, so that the ratio of these changes at the feed rates of 400 to 100 cm / min is more than 6 times. However, there are no significant changes in the intensity of vibration relative to the change in the feed rate at different cutting depths. This can be considered as a reason for more correlation of vibration than high values of feed rate. Then, in order to predict the vibration rate and specific vibration, multivariate nonlinear regression models were presented. Thus, the amount of vibrations and special vibrations were evaluated and predicted according to variables such as cutting depth, feed rate and disk rotation speed. The results of statistical tests (t and F tests) showed the accuracy of the coefficients of the variables in the models. The scattering of the predicted points and the actual points relative to the 1: 1 half-line showed the good accuracy of the models with an error of less than 10% in predicting the vibration values. In addition, each model had a good explanation coefficient (0.87 and 0.92) with an acceptable level of significance. The coefficients assigned to each of the variables in the models correspond to the logic governing the cutting process. Using the presented models, in addition to predicting the amount of system vibrations, the optimal cutting conditions can be approached according to other influential parameters such as energy consumption rate and tool costs. In other words, it is necessary to pay attention to this issue that in order to achieve an ideal cutting condition, all effective factors are examined together to determine the best cutting conditions.

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