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A New Computer Program for Cutting Head Design of Roadheaders and Drum Shearers

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ABSTRACT: This paper is concerned with a new computer program developed for the design, of the cutting heads employed on mechanical excavation machines. Computer aided design (CAD) technique was proven to improve the performance and life span of these machines, when used in designing cutting beads. A number of computer programs are utilized in practice, none of which considers the aspects of multi-tracking. A series of laboratory and İn-situ experiments were carried out through comparing a triple tracking arrangement that is widely employed on three-start shearer drums worldwide, to a single tracking arrangement in an effort to close this gap in this field. The data gained from these experiments were evaluated and embedded into the current computer program VAP (Vibration Analysis Program), and the new computer program was developed. The results of computer analysis for the both tracking arrangements were found to be in good agreement with those of laboratory and in-situ studies.

1 INTRODUCTION

Mechanical rock and coal excavation machines such as roadheaders, drum shearers and continuous miners excavate the rock material by a number of picks mounted on their cutting heads or drums with various shapes. The design of trie cutting head is of crucial importance since it comprises the machine-rock interface in mechanical excavation. Cutting power installed on the machine is transferred from the motors to rock by the interactive motion of picks relieving each other. Additionally, the machine vibrations during excavation significantly depend on the cutting head design. Vibration induces the damages on machine units, resulting in machine downtimes that increase the operating cost. These damages may require costly repairs, and in a further stage, the machine typically of high capital cost may be discarded, unless the proper cutting head design is employed. As the picks, pick holders and geometry of the cutting head are selected by considering the geomechanical properties of rock, proper disposition of the picks on a cutting head improves the overall performance of mechanical excavators (Roxborough & Rispin 1973, Hurt 1980, Hurt & McAndrew 1981b, 1985, Hurt et al. 1982, 1986,1988, Hurt & McStravick 1988, Hekimoglu & Powell 1990).

Therefore, selected cutting head for a particular operation must be evaluated in terms of cutting efficiency and vibrations prior to its mounting on machine. Some computer programs related to design and performance evaluation of cutting heads were developed by world's leading companies in mechanical excavation sector, research institutes, and universities. However, practical investigations and literature surveys revealed that, these computer programs did not consider the aspects of the tracking cutter arrangement or setting the number of picks required on each cutting line on a cutting head. Researches showed that, when the picks were arranged in multi-tracking, the machine performance could be affected conversely, and therefore single tracking arrangement was recommended for efficient cutting (Evans & Pomeroy 1973, Brooker 1979, Hurt 1980, Hurt & McAndrew 1981a, b, Hekimoglu 1984). However, it is known Üiat, in current computer programs, pick forces, i.e. cutting, normal and sideway forces, likely to be experienced by individual picks during cutting operation are estimated considering the single tracking arrangement, although the pick lacing follows the multi-tracking arrangement. This may be due to the lack of information obtained from the long-term comprehensive in-situ studies combined with laboratory simulation experiments.

This paper aims to present a new computer program for the cutting head design of roadheaders, drum shearers and continuous miners considering the effects of multi-tracking arrangements on pick forces, along with the other design parameters. Before the development of the new computer program, detailed laboratory rock cutting simulation experiments were earned out in an attempt to clarify the aspects of tracking cutter arrangement. Long-term comprehensive underground trials were conducted with drum shearers employed in Çayırhan Lignite Mine, during actual production operations The results from laboratory experiments and underground trials were utilized in developing the new computer program. The brief description of this program and the results of computer analysis applications on some cutting heads and shearer drums were presented.

2 COMPUTER AIDED CUTTING HEAD DESIGN

There are a number of scientific and commercial softwares that help scientists and engineers overcome the problems encountered throughout the cutting head design process in mechanical excavation. Many researchers reported that the performance of mechanical excavators could be improved significantly through utilising computer assistance İn cutting head design (Holt et al. 1984, Hurt & Morris 1985, Hurt et al. 1986, Kadiu 1995). Essentially, this improvement results from the softwares that are available to estimate the possibility of excessive cutting vibrations and inefficient cutting conditions due to the positions of picks on cutting heads. Where the possibility of the above-mentioned problems are estimated, it is likely to avoid die vibration induced damages on mechanical excavators and the machine downtimes due to these damages, and to utilize the installed power on these machines effectively in practice, by selecting appropriate pick lacing arrangements.

2.1 *Computer programs in use*

Intensive and consistent studies on cutting head and shearer drum design carried out at Mining Research and Development Establishment (MRDE) of National Coal Board (NCB) yielded the first and well-known CAD package for roadheaders and drum shearers (Morris 1980, NCB 1984, Holt et al. 1984, Hurt et al. 1986). This package is based on the idea of employing pick-lacing arrangements that make almost all picks to be subjected to the equal forces in order to prevent excessive vibrations and to have efficient cutting conditions (Hurt 1980a, Hurt & McAndrew 1981b). However, the studies at MRDE did not clarify all aspects of maintaining me picks on a cutting head with equal forces.

There have been several investigations leading to development of a CAD package, following that of MRDE, Kadiu et al. (1991) developed a package named PC DRUM for drum designs of continuous miners and drum shearers. Cordelier & Kadiu (1991) then improved PC DRUM and developed a new package named SIMHEAD for both cutting heads and shearer drums.

Price and Jeffrey (1992) reported to succeed in developing a CAD package for performance evaluation of drum shearers, which uses the results of the linear cutting tests carried out on actual rock materials by full-scale picks in order to estimate pick forces. This package is known to result similar performance predictions to those obtained from MRDE package for given drum design parameters.

A comprehensive computer program was developed during the investigations for utilizing roadheaders in excavating rooms of a nuclear waste repository in welded tuffs at Yucca Mountain (Rostami et al. 1993). This program was developed through full-scale rock cutting tests by using a linear cutting machine (LCM) and model cutting trials by using the boom of a roadheader in laboratory, at the Earth Mechanics Institute (EMI) of Colorado School of Mines (CSM), for the roadheaders with transverse type cutting heads. Program is also available for the roadheaders with the axial type cutting heads when a few modifications are carried out.

Kadiu (1995) proposed to employ a knowledge base for design and performance calculations of shearer drums. By using this knowledge base, he has developed software named ARCHD for shearer drums.

Tiryaki (1998) from Hacettepe University proposed a cutting head and drum simulation program named VAP, depending on the principles of CAD package of MRDE, and the results of the long-term extensive underground trials carried out at Çayırhan Lignite Mine, for performance evaluation of drum shearers, continuous miners and roadheaders with both axial and transverse cutting heads.

It is also known that, world's leading cutting head and drum manufacturers such as Krummenauer, IBS, Krampe, Dosco, Kennametal, Eickhoff etc. use computer assistance for cutting head design. These commercial programs were generally developed through projects undertaken by universities or research institutes, which are understood to have the deficiencies similar to those of scientific programs.

2.2 *Procedure followed in CAD of cutting heads*

In general, computer aided cutting head design procedure begins with the evaluation of cutting efficiency and relative duties of individual picks by drawing breakout pattern for the selected pick lacing arrangement (Fig. 1). This pattern enables design engineer to see the picks that are under-utilized or overloaded and to realize if the picks tend to deepen an existing groove instead of effectively breaking the rock (Brooker 1979, Hurt 1980, Holt et al. 1984, Hurt et al. 1986, Hurt 1988). Design engineer enters the type and geometry of the cutting head, picks and pick holders, and the details of the pick lacing arrangement to the computer program as input data. Then computer program automatically draws the breakout pattern for a certain advance per revolution of the cutting head.

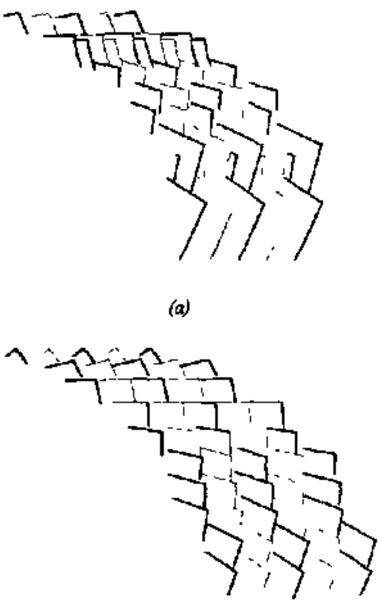
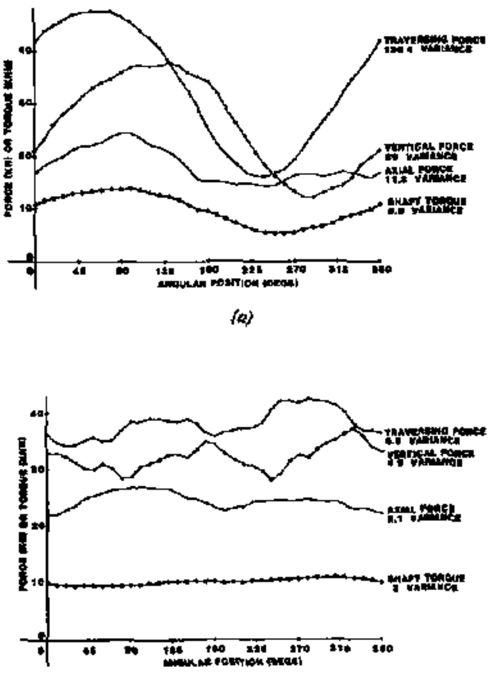


Figure 1. Breakout patterns drawn by MRDE 's program for cutting heads with (a) poor design and (b) good design (NCB 1984).

The next step in design procedure is the prediction of the levels and fluctuations in horizontal, vertical and axial reaction forces acting on the cutting head and die shaft torque generated, which may be experienced during actual cutting operations (Fig. 2). In this step, the individual pick forces are estimated before the calculations for reaction forces and shaft torque have been performed. The current scientific and commercial computer programs mentioned above relate the pick forces to only the cross-sectional rock area removed or the depth of penetration achieved by individual picks after one entire revolution of the cutting head is completed, regardless of tracking cutter arrangement İn which the pick is laced. Therefore, these programs do not take into account of any differences between single tracking or multi-tracking arrangements in terms of individual pick forces.



(b)
Figure 2 Vibration graphs drawn by MRDE's program for cutting heads with (a) poor design and (b) good design (NCB, 1984).

However, it was reported that the forces acting on a pick in a multi-tracking arrangement differ from the forces acting on a pick in a single-tracking arrangement, even if both picks removed the same rock area or achieved the same depth of penetration (Evans & Pomeroy 1973, Hurt 1980, Hurt & McAndrew 1981a, Hekimoğlu 1984). Consequently, current computer programs estimate similar values for reaction forces and torque acting on the cutting head, for both single and multi tracking arrangements, causing the accuracy of the performance evaluation of a particular cutting head design to decrease.

The reaction forces and shaft torque are calculated, considering the active picks in cut sector at each defined angular interval of rotation of a specified reference pick on the cutting head in degrees, until one entire revolution of the cutting head is completed. Data gained from computer simulation are then subjected to statistical analysis and the fluctuations in these data are expressed İn terms of variance, individually. Cutting heads with lower variance values for the calculated parameters are considered to be balanced in terms of cutting vibrations and the machines employing these cutting heads are expected to perform efficiently İn practice (Hurt 1980, Hurt et al. 1988, Hekimoğlu 1991, Tiryaki & Hekimoğlu 1998).

3 DESCRIPTION OF THE NEW COMPUTER PROGRAM

The new computer program was developed through modifying the existing computer program VAP, considering the results of laboratory investigations to formulate the effects of tracking cutters for pick force estimation, together with in-situ trials to investigate the effects of tracking cutter arrangement on machine performance under similar conditions.

3.1 *Details of VAP*

VAP is a scientific program consisting of two subprograms, one of which is for drawing the breakout pattern and the other is for generation of simulation values of reaction forces and shaft torque (Tiryaki '1998, 2000b). Prior to the program development, the motion of the picks on axial and transverse cutting heads and shearer drums during cutting was analysed both dynamically and kineraatically in detail, so that the computer simulation could be achieved. Breakout pattern subprogram was developed by using AutoLISP programming language in order to utilize me drawing facilities of AutoCAD software. The data files including the design specifications of the cutting head and advance per revolution value desired for performance evaluation,, must be prepared and stored in hard disk before the program execution, since this program was developed in batch-programming mode. When the program is run, the breakout pattern of the cutting head is automatically drawn and displayed on computer's screen, and then, the individual breakout areas for picks are determined by using the area function of AutoCAD. These values are stored in a data file for further processing by the vibration evaluation subprogram that was developed by using Quick BASIC programming language. The vibration evaluation subprogram calculates the respective values of horizontal, vertical, and axial reaction forces and shaft torque, asking user for the additional information on type, sumping depth, cutting mode, and extraction height of the cutting head. Calculations are performed at one-degree angular interval until one entire revolution of the cutting head is completed. Program estimates the pick cutting forces, only depending on the cross sectional rock area removed by the pick as stated İn a previous research by Hekimoğlu (1984), whereas pick normal forces are assumed to be 1.5 times the pick cutting forces. Reaction forces and torque are estimated considering the formulas proposed by Hurt et al. (1988).

3.2 *Laboratory and in-situ investigations*

Laboratory experiments were conducted on blocky rock samples, simulating the actual motion of the picks on a three-start shearer drum during cutting operation, when laced in both single and triple tracking arrangements, by using a linear shaping machine (Ayhan 1998). These experiments showed that the picks in a multi-tracking arrangement will be subjected to higher forces than those in a single tracking arrangement. Plotting the mean cutting force values that were measured during experiments, against the depth of cut for both tracking cutter arrangement individually, showed the superiority of single tracking on triple tracking (Fig. 3).

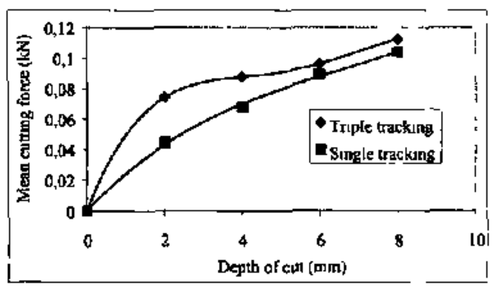


Figure 3 Variation of mean cutting force with depth of cut.

Specific energy values also reflected the same result. Statistical analysis of the results of laboratory experiments revealed the necessity of using a cutting force coefficient given in the equations below in. order to have more accurate values of pick forces, considering the angular position of the pick in cut sector for single and multi-tracking arrangements respectively.

For single tracking arrangement;

$$F = \left[(\mathrm{Sin}\theta)^{0.642}\right] - 0.00724 \quad (1)$$

For triple tracking arrangement;

$$F = 1.185\left[(\mathrm{Sin}\theta)^{0.321}\right] - 0.05364 \quad (2)$$

where; *F:* Cutting force coefficient and 9: Angular position of the pick in cut sector (in degrees).

The cutting force acting on a pick for a given angular position İs proposed to be calculated by multiplying the pick cutting force at maximum depth of cut by cutting force coefficient instead of SinG, as used in current version of VAP regardless of tracking cutter arrangement.

In-situ experiments were carried out by using Eickhoff EDW 230-L type double-ended ranging drum shearers employed at Çayırhan Lignite Mine, during the actual coal production operations in lower seam that has thickness of around 1.70 m and average gradient of 15°. Shearer has a couple of three-start drums with 1.30 diameter and 0.85 m web depth. Pick lacing of me current shearer drums considering the triple tracking concept was changed and a new pick lacing was adopted considering the single tracking concept, while keeping the all remaining drum design parameters intact. The new pick lacing was applied on the drums at Central Workshop of Çayırhan Mine and the modified drums were produced. These drums were then compared to current drums under identical cutting conditions.

Throughout the underground trials, performance of the machine, when fitted with the current and modified drums at different periods of time, was observed and recorded in terms of pick consumption, life span of drums, power consumption, machine downtimes, and vibrations, until the drums reached the end of their service lives. The results of the in-situ trials showed that the overall performance of the shearer substantially increased with die modified drums, e.g. pick consumption, specific energy, machine downtimes, and machine vibration acceleration decreased by 45%, 35%, 30%, and 50% respectively and the life span of drums increased by 70%. Results of machine power consumption measurements implied that the picks on a drum with single tracking arrangement were likely to experience lower forces than Ihose on a drum with triple tracking arrangement even at the same cutting rate, confirming the results of the laboratory experiments (Fig. 4).

Design specifications of the drums that were put into underground trials and the detailed information on the results of these trials can be found elsewhere (Tiryaki 1998, Tiryaki & Hekimoğlu 1998, Tiryaki 2000a). Taking into account of the findings from in-situ experiments, VAP was modified through embedding the cutting force coefficient equations for both single and triple tracking arrangements into the program code.

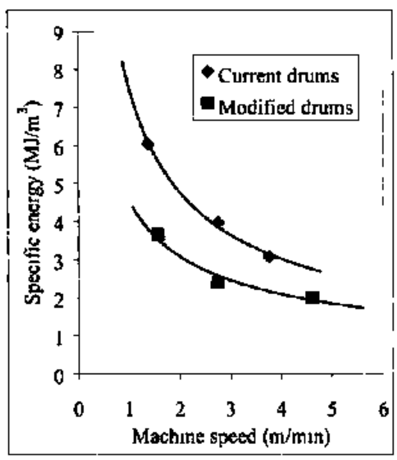


Figure 4. Variation of specific energy consumption with machine speed in upward direction

4 EXAMPLES ON THE APPLICATIONS OF THE NEW COMPUTER PROGRAM

Current and modified drums that were compared throughout the underground experiments were subjected to a performance analysis for 9 cm advance per revolution by using VAP. Breakout patterns showed the inefficiency of the triple tracking arrangement (Fig. 5).

Vibration evaluation graphs drawn for current and modified drums at 180° and 90° cut sectors were given in Figures 6 and 7, respectively. When individual variance values of reaction forces and shaft torques are considered, modified drums are understood to be better balanced than current drums. Mean values of calculated parameters indicate that the shearer is likely to experience lower reaction forces and torque with the modified drums than with the current drums, under the identical operational and cutting conditions, utilizing the available power installed on the machine efficiently.

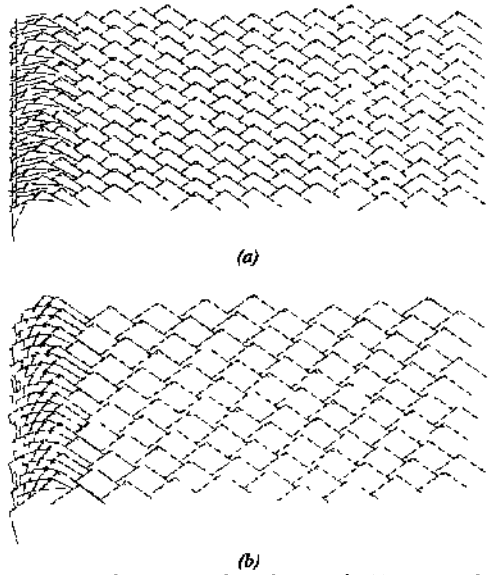


Figure 5. Breakout patterns drawn by VAP for (a) current and (b) modified drums.

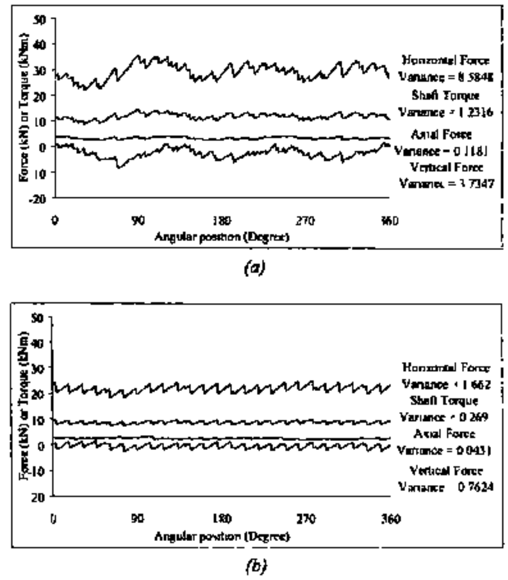


Figure 7 Vibration graphs drawn by VAP at 90° cut sector for (a) current and (b) modified drums.

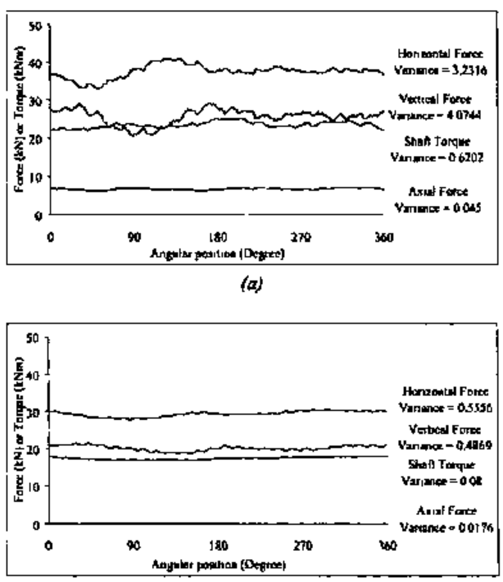
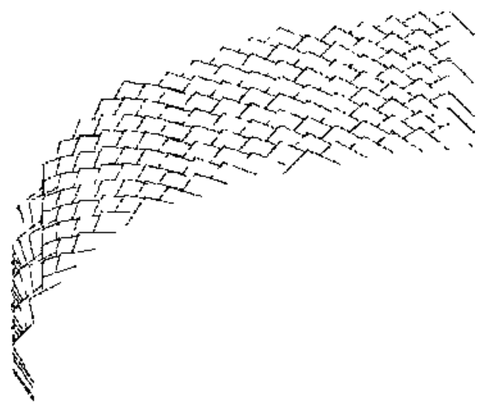


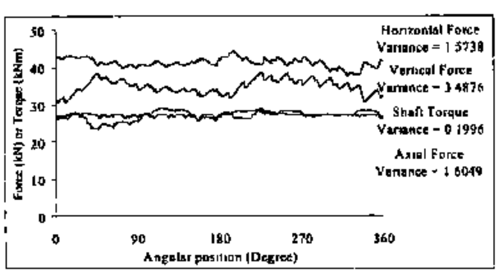
Figure 6. Vibration graphs drawn by VAP at 180° cut sector for (a) current and (b) modified drums.

Results of computer evaluation for two tracking cutter arrangements are all in close agreement with those of in-situ and laboratory experiments. Therefore, further computer analyses were carried out for the axial and transverse type cutting heads that have been employed on roadheaders. For these analyses, an axial type cutting head with 41 picks (Head-A) and a transverse type cutting head with 72 picks (Head-B) were selected, both were designed and manufactured by one of the world's leading cutting head and drum manufacturers. Head-A was analysed considering the 180° cut sector, while Head-B was analysed for 120° cut sector that was typical for transverse type cutting heads. Breakout pattern and vibration graph of Head-A for 9 cm advance per revolution are shown in Figure 8, while those of Head-B for 8 cm advance per revolution are shown in Figures 9 and 10, respectively.

Although cutting force coefficient equations enable the simulation of reaction forces and shaft torque for the drums fitted on shearers and continuous miners, to be achieved with a great accuracy, further practical investigations may be necessary to be conducted for their use in axial and transverse type roadheader cutting heads with different geometries. The mode of roadheader operation, geometry of the cutting head, and the boom carrying it make the motion of a pick on a roadheader cutting head to be more complex in nature than that of a pick on a shearer drum.



(a)



(b)

FigureS. Results of performance analysis of Head-A produced by VAP (a) breakout pattern and (b) vibration graph.

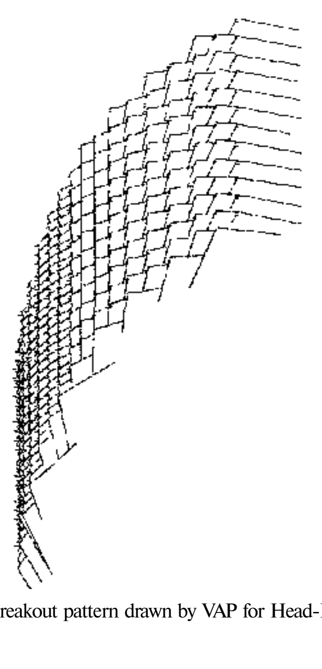


Figure 9. Breakout pattern drawn by VAP for Head-B.

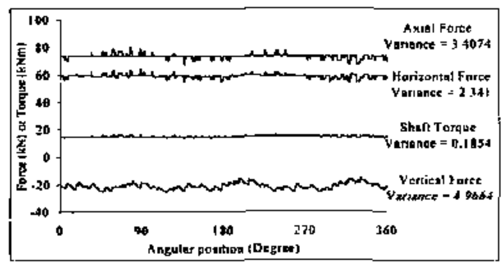


Figure 10. Vibration graph drawn by VAP for Head-B.

5 CONCLUSIONS

Theoretical and practical investigations on mechanical excavation machines indicated that these machines suffered from poor cutting head designs, which may prevent mine operators from obtaining the benefits offered by mechanical excavation. This may be due to the lack of conclusive information on some parameters that must be considered during the cutting head design process. The tracking cutter arrangement İs one of these parameters. The effect of this parameter on individual pick forces is not included İn current computer aided cutting head design programs used in practice. This situation can be regarded as a deficiency for these programs.

Extensive laboratory and underground investigations resulted in a reliable computer program for the cutting head design of roadheaders and drum shearers. This computer program is believed to enable the scientists and practising engineers to select the optimum design for the cutting heads with certain geometrical properties. The new computer program including the cutting force coefficient equations for pick force estimation succeeded to reflect the difference in pick forces between single and triple tracking, as seen throughout the laboratory and in-situ experiments. These experiments have also indicated the inefficiency of multi-tracking arrangements that have been persistently employed by the major cutting head and drum manufacturers worldwide, and single tracking arrangements were recommended to be employed on cutting heads.

Some additional features including specific energy prediction and the cutting head design selection in relation to geomechanical rock properties will also improve the functional properties of the new computer program. These improvements can only be achieved if the universities or research institutes undertake long-term research projects İn cooperation with tunnel and mine operators.

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