

# Nonlinear Vibration Characteristics Identification of Drum - Rocker System of Shearer Based on Artificial Intelligence

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**Abstract:** As the core component of coal interception and coal loading, the spiral drum of coal shearer directly affects the working efficiency of coal shearer and the quality of coal. In the past research on shearing force of shearer drum, there are many problems and deficiencies in research methods and theoretical analysis. Therefore, based on the actual production conditions and the original drum model parameters, a simulation model of shearer drum cutting coal wall is established to simulate the dynamic process of coal cutting, and the research on the nonlinear vibration performance of the shearer rocker system affects its stability. The key issue of the performance and service life is therefore important to study the nonlinear vibration characteristics of the rocker system. This paper mainly studies the nonlinear vibration characteristics of the rocker system. In this paper, based on ANSYS software, the model analysis of the rocker arm shell and the traction part shell is carried out. Harmonic response analysis was carried out on the housing of the traction part, and its response under sinusoidal excitation of different frequencies was obtained. The lateral vibration acceleration and swing angle acceleration of the shearer body are  $0.0098 \text{ mm/s}^2$  and  $0.0074 \text{ rad/s}^2$ , respectively. The larger the average cutting impedance of coal rock, the greater the lateral acceleration of each part of the shearer under the oblique cutting condition, the greater the fluctuation, and the direction changes with time. The average cutting impedance of coal rock has a great influence on the front drum and front rocker of the shearer. The experimental results show that the study of nonlinear vibration characteristics provides a reference for the optimization of the shearer's structural strength and the improvement of its resistance to shock and vibration.

**Keywords:** Shearer Drum; Rocker Arm System; Vibration Characteristics; Dynamics Research; Nonlinear Vibration

## 1. Introduction

Due to changes in coal seam thickness and complex geological structure, coupled with the adverse working environment of the shearer and complicated cutting conditions, the instantaneous impact load of the drum when cutting coal rock is multi-variable, strongly coupled, and non-linear. Due to time-varying and complex characteristics, the shearer is subjected to a large impact during the work process. Excessively strong vibrations easily cause the shearer's key components to bear greater dynamic stress, resulting in the shearer's mechanical system and hydraulic system. The failure of the electronic control system affects the normal operation of the shearer.

Excavation mechanization is a necessary technical means for the coal industry to increase production, increase productivity, improve working environment, and ensure safe production, and is also an effective measure to save manpower, energy and raw materials in the coal production process [1-2]. Shearer is a machine that breaks and loads coal, and is one of the main equipment's in fully mechanized coal mining face. At present, many types of shearers have appeared in various countries around the world, but the shearers widely used in coal mines are drum shearers. Due to the non-renewable coal resources, in recent years, the drum-type shearer has been developed in two directions of high-power and thin coal seam mining to improve the mining efficiency and utilization rate of coal resources [3-4]. Therefore, the research on the nonlinear vibration characteristics of the rocker system is of great significance to the development of mechanized mining technology.

In order to study the coal falling characteristics of the shearer drum under different working conditions, Mao J used the MG500 / 1180-WD shearer model as the research object and established a three-dimensional simulation model using EDEM discrete element simulation software. The influence of factors such as coal crushing and roof pressure on the cutting performance of the shearer was studied, and the dynamic process of the shearer cutting was studied. Using a single factor test, the particle trajectory during the cutting process was analyzed. The effects of coal load factor, drum load and average particle velocity within the drum envelope range at different cutting depths and speeds are analyzed [5]. However, this study only considers single factors, and there is no systematic combination of all factors for experimental analysis and discussion. Mao J, Wang X, Chen H, in order to improve the working performance and design efficiency of the shearer drum, and consider the size constraint relationship and performance index of the shearer drum, an optimized design model of the shearer drum is proposed, in which the load Efficiency, cutting energy consumption and load fluctuations are optimized variables based on blade thickness, blade spiral angle, number of teeth, number of teeth on the same line and tooth installation angle. He used NSGA-III algorithm to optimize the model of constrained multi-target shearer drum. The optimized design system of the shearer drum was developed with MATLAB. Taking the parameters and working conditions of coal in the cutting experiments of some companies as input, the optimized design scheme of the drum was obtained through the optimized design system of the shearer drum [6]. In order to achieve the best comprehensive performance of the shearer drum in the complex coal seam, Zhao L took the MG400 / 951-WD shearer model as the research object, based on the theory of coal cutting, obtained the force and torque of the drum through Mat lab. He combined the rigid-flexible coupling virtual prototype to build a virtual prototype model with a flexible drum, and discovered the weak links through simulation. After using it with EDEM, the loading performance was discovered. Combining the reliability sensitivity design theory, robust design theory and performance degradation theory, the influence of the drum design variables on the reliability sensitivity gradient is analyzed, and the multi-objective optimization evaluation function of the drum is established to obtain the best design variables. His results show that the optimized drum maximum stress is reduced, coal rate, comprehensive performance and reliability are improved. Combining reliability sensitivity design theory, robust design theory and performance degradation theory provides important support for mining machinery data theory and methods [7].

In this paper, combined with coal and rock cutting mechanics, a vertical and lateral dynamic model of the shearer is established; the vertical and axial loads of the shearer drum under different conditions obtained as above are used as external excitations. Using the method of numerical analysis, the vibration characteristics of the shearer under different coal rock hardness and different traction speeds in vertical, lateral and diagonal cutting conditions were obtained. The analysis results show that: coal rock hardness and shearer traction speed have greater influence on the vertical and axial load of the drum. The larger the load fluctuation, the greater the vertical and lateral vibration of the coal mining machine, and the impact of the vibration will also increase. The lateral vibration characteristics of the body, the rear rocker arm and the rear roller change periodically. Since the drum and the coal rock come into contact during the operation of the shearer, the vibration of the drum is greatest under different conditions of the whole shearer.

## 2. Nonlinear Vibration of Rocker System

### 2.1 Coal and Rock Cutting Mechanics

#### (1) Coal rock strength

The strength of coal rock refers to the critical value of the external force when coal rock resists damage under certain conditions. The strength of coal rock depends on the internal friction and cohesion between coal rock particles. The cohesion of coal rock is expressed as the cohesive force between coal rock particles and cement. Internal friction is the main cause of resistance when coal rock mass breaks [8-9]. The relationship between compressive strength  $\sigma_y$ , shear strength  $\sigma_j$  and tensile strength  $\sigma_l$  of coal rock mass is as follows:

$$\sigma_y : \sigma_j : \sigma_l = 1 : 0.3 : 0.1 \quad (1)$$

#### (2) Coal and rock contact strength

In practice,  $P_k$  is usually used to represent the contact strength of coal and rock bodies. It represents

the pressure on the coal and rock bodies per unit area and represents the ability of the entire coal and rock bodies to resist external forces. The contact strength is usually obtained by the experimental method, which is expressed by the ratio of the load  $P_i$  on the indenter of the special testing machine and the surface area  $S$  under the indenter. Due to the error, it needs to be measured and averaged multiple times [10].

### (3) Elasticity, plasticity and brittleness of coal rock mass

The elasticity of coal rock mass refers to the property that the coal rock mass can recover its original shape after the external force acting on it disappears. The plasticity of the coal rock mass refers to the property that the external force acting on the coal rock mass cannot completely restore the original shape and volume after the disappearance. The brittleness of coal and rock mass refers to the nature of coal or rock mass without residual deformation or minimal deformation after external force disappears [11-12]. Normally, coal and rock materials are relatively brittle, and most of the damage during drum cutting of coal and rock is brittle failure. The more brittle the coal and rock bodies are, the easier it is to break, and the less energy consumption during cutting. On the contrary, the higher the elastoplasticity of the coal and rock mass, the less likely it is to break, and the more energy consumed during cutting [13-14].

### (4) Friction of coal and rock mass

In the process of coal cutting and coal loading, the helical roller blades and the installed cutting teeth inevitably squeeze and friction with the coal rock, which not only consumes cutting power, but also aggravates the wear of the cutting teeth and reduces their life. The friction coefficient  $\mu$  between the shearer picks and other parts and the coal rock body is not only related to the picks and other materials, but also related to the pressure and speed of the two relative movements [15-16].

## 2.2 Forces of Cutting Drum and Pick

Pick picks are used as cutting tools commonly used in modern mining machinery. Different from the previous "dense core" theory of knife-shaped picks, pick picks are used to gradually wedge into the coal and rock bodies using the effects of tensile stress and shear stress, causing the coal and rock bodies to deform and fracture to reach the coal rock. The tensile or shear strength is damaged and then peeled off.

In the process of coal cutting, the tooth tip receives the reaction force from the coal wall. The entire cutting force can be decomposed into cutting resistance, feed (traction) resistance and lateral resistance force. The scholars of the former Soviet Union obtained the mathematical relationship model between cutting force and pick, coal rock material parameters and in the process of coal cutting. For sharp picks, the calculation formula is shown as formula (2).

### (1) Cutting resistance $Z_0$

$$Z_0 = 10A \frac{0.175d + 0.3}{0.5d + B \cdot h^{0.5}} h \cdot t \cdot K_z \cdot K_\varphi \cdot K_y \cdot K_c \cdot K_{ot} \cdot \frac{1}{\cos\theta} \quad (2)$$

In the formula,  $A$  is the average cutting impedance of the non-compressed area of the coal seam on the working face, generally 240N / mm;  $d$  is the diameter of pick, mm;  $B$  is the brittleness of coal rock, and the values of coals with different properties are also different. Generally speaking, 2.1 to 3.5 for brittle coal, less than 2.1 for ductile coal, and more than 3.5 for extremely brittle coal;  $h$  is the average cutting thickness of pick, Obtained by calculation, mm;  $t$  is the average intercept line distance, ie the distance between the centers of two adjacent troughs, mm;  $K_z$  is the coefficient of influence of the exposed free surface;  $K_\varphi$  is the coefficient of influence in front of the pick,  $K = 0.9 \sim 0.95$ ;  $K_y$  is the intercept Coefficient of influence of tooth cut angle on cutting ratio energy consumption;  $K_c$  is the influence coefficient of pick arrangement, and 1 and 1.25 are taken for sequential arrangement and checkerboard respectively;  $K_{ot}$  is the influence coefficient of rock pressure, the closer to the exposed surface of the coal seam, the smaller, Generally 0.7;  $\theta$  is the installation angle of the pick.

### (2) The traction resistance $Y_0$ calculation formula (3) on the pick is:

$$Y_0 = K_q Z_0 = (0.5 - 0.8) Z_0 \quad (3)$$

In the formula,  $K_q$  is the ratio of traction resistance and cutting resistance on the pick pick, which is related to the brittleness of coal and rock and decreases with the increase of brittleness of coal and rock mass. The general value is 0.5 to 0.8.

(3) When the lateral force  $X_0$  pick picks coal, due to the impact of the structure of the pick itself, the arrangement of the pick and the uneven brittle material of the coal rock, it will cause an asymmetric cutting slot, which causes unbalanced forces produce lateral forces. It is related to cutting resistance, cutting thickness and cutting width, and the calculation formulas are (4) and (5).

For sequentially arranged picks:

$$X_0 = Z_0 \left( \frac{1 \times 10^{-3}}{0.1h + 0.3 \times 10^{-3}} + 0.15 \right) \frac{h}{t} \quad (4)$$

For checkerboard picks:

$$X_0 = Z_0 \left( \frac{1 \times 10^{-3}}{0.1h + 2.2 \times 10^{-3}} + 0.1 \right) \frac{h}{t} \quad (5)$$

(4) Mechanical model of blunt picks

The pick on the drum of the shearer becomes no longer sharp after cutting for a period of time. Most of the time the pick is cut in a blunt state. The calculation formula of the force on it is (6) and (7) shown: Cutting resistance Z:

$$Z = Z_0 + 100 f' \cdot k'_y \cdot \sigma_y \cdot S_d \quad (6)$$

Drag resistance Y:

$$Y = Y_0 + 100 K'_y \sigma_y S_d \times 10^6 \quad (7)$$

In the formula,  $f'$  is the cutting resistance coefficient related to the cutting thickness, generally 0.38 ~ 0.42;  $K'_y$  is the ratio of the average contact stress of the pick related to the brittleness of coal and the single compressive strength of the pick;  $\sigma_y$  is the unidirectional compressive strength of the pick, MPa;  $S_d$  is the wear area of the pick. Based on the projection area of the wear surface of the pick on the cutting plane, the pick pick is  $15\text{mm}^2 \sim 20\text{mm}^2$ .

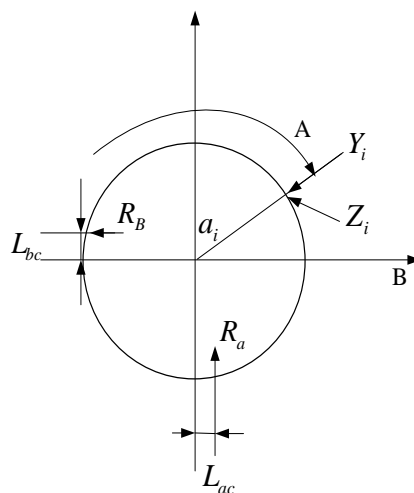


Figure 1: Exploded view of drum force

During the process of coal interception, the drum is subject to cutting resistance, propulsion resistance, lateral resistance and other resistances. The force received by the drum is the vector sum of the cutting force and moment involved in cutting. The special physical and mechanical properties of

coal rock cause the uneven distribution of the cutting teeth of the drum end disk, and the number of cutting teeth participating in cutting at different times is also different. Therefore, the size of the load on the drum at each moment and its point of action are constantly changing. At a specific moment, the cutting force of the  $i$ -th pick on the drum is decomposed in the vertical direction A, feed direction B, and axial direction C as shown in Figure 1.

The three-way force calculation formula can be obtained from the force decomposition method, as shown in equation (8).

$$\begin{cases} A_i = Y_i \sin \alpha_i + Z_i \cos \alpha_i \\ B_i = -Y_i \cos \alpha_i + Z_i \sin \alpha_i \\ C_i = X_i \end{cases} \quad (8)$$

In the formula, it represents the cutting resistance, traction resistance and lateral force of the pick at the  $i$ -th position on the drum at a certain moment; it is the position angle of the pick on the drum.

The instantaneous load of the drum is the vector sum of all the cutting force of the cutting teeth participating in the cutting at a certain moment. The force in the three directions of the drum at  $j$  is as follows:

$$R_{Aj} = \sum_{i=1}^{n_p} A_i \quad R_{Bj} = \sum_{i=1}^{n_p} B_i \quad R_{Cj} = \sum_{i=1}^{n_p} C_i \quad (9)$$

The torque in the three directions is shown in equation (9).

$$\begin{cases} M_a = -R_B L_{ba} + R_C L_{ca} \\ M_b = -R_A L_{ab} + R_C L_{cb} \\ M_c = -R_B L_{bc} + R_C L_{ac} \end{cases} \quad (10)$$

### 2.3 Vibration Characteristics

The shearer is a complex system, and the forced vibration equation can be expressed as:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{p(t)\} \quad (11)$$

Where:  $M$  is the modal mass matrix;  $K$  is the modal stiffness matrix;  $P(t)$  is the external excitation;

$C = \alpha[M] + \beta[K]$  is the damping matrix, where  $\alpha$  and  $\beta$  are proportional coefficients. Then its characteristic equation is:

$$Det(-w^2[M] - [K]) = 0 \quad (12)$$

Find its  $N$  eigenvalues:  $w_1^2, w_2^2, \dots, w_N^2$  and the corresponding eigenvectors are:  $\{\phi_1\}, \{\phi_2\}, \dots, \{\phi_N\}$ , these features.

The eigenvectors form an  $n$ -order square matrix which is the modal matrix.

After coordinate transformation:

$$\{x\} = \{\phi\}\{\eta(t)\} = \sum_{r=1}^N \phi_r \eta_r(t) \quad (13)$$

Where:  $\{x\}$  is physical coordinates;  $\{\eta(t)\}$  is modal coordinates;  $\{\eta\} = \{\phi_1, \phi_2, \dots, \phi_N\}$  is modal matrix.

### 2.4 Parameter Modelling of Gear Transmission System

(1) Structural parameters of reduction gear

The planetary deceleration mechanism of the shearer MG500-1180 cutting section is located at the linking drum of the cutting section, between the drum and the motor. Its role is to transmit torque and power. Its main parts and functions are: The sun wheel accepts the motor power as the transmission speed of the driving wheel, the planetary gear provides support and transmits power and speed, the external ring gear is fixed to provide support for the planetary gear, the planetary carrier output shaft is connected to the roller output coal breakage and auxiliary parts include: bearings, shaft pins Splines, etc. The planetary reduction mechanism uses a spur gear rotation structure. The transmission mode is simple and relatively stable. The force is only subjected to the analysis of the radial force. It has low impact and noise, and high transmission efficiency. The power source motor in the cutting section first transmits the power to the high-speed zone deceleration mechanism. The power passes through the high-speed deceleration zone to reduce the speed transmission. Among them, the power is transmitted through multiple idlers (the idler has no practical significance, mainly for the long rocker required length), and finally the planetary reducer transfers the belt drum, which is mainly used for coal breaking [17-18]. The safe, stable and efficient operation of the planetary gear system is a prerequisite for ensuring the high efficiency of coal mining in the shearer. The material of the reducer system must fully guarantee the safety of the gear under different working conditions during the operation process, which means the material processing technology has put forward new requirements [19].

### (2) Bearing parameters

Since only one bearing of the spherical roller bearing is subjected to complex loads, namely axial load and radial load, the bearing roller and the shaft ring are seriously worn. With the extension of working time, the vibration effect will be strengthened and the bearing will float. The oil seal static ring is becoming more and more inclined, and the bearing wears sharply. At present, only small-power coal shearers use this bearing. Single-row tapered rolling bearings bear radial and axial loads, resulting in relatively low wear and vibration of the bearings, long working life, less space occupation, and less impact on the floating oil seal, making it one of the best choices for coal shearers. As the assembly process needs to be improved, the single-row tapered roller bearing, the axial working oil gap is artificially controlled, which is easy to cause inaccurate control assembly process, resulting in oil leakage [20-21]. Double-row tapered rolling bearings will compensate for the occurrence of oil leakage and effectively make up for the shortcomings of the above two bearings. At present, high-power coal shearers are also widely used, but the cost is higher. This paper considers the power of shearer (1180W) and the difficulty of finite element model analysis. It considers the selection of single-row tapered roller bearings. The research object is 32216 tapered roller bearings.

### (3) Parameter modeling of gear transmission system

In this paper, the main steps to build a spur gear model are: first complete the process of establishing a wheel gear for spur gears, and then establish the gear teeth based on the parameter size of the hub, where the wheel gear is established by stretching the gear shaft hole and the root circle, The tooth profile curve is the standard involute of the base circle; in the design process of the gear transmission system, the involute curve is drawn in the sketch using the involute curve equation, and the gear teeth can be regarded as an involute line at this time, Tooth root circle, addendum circle and all over-curved curves of the tooth root are geometric entities formed by stretching along the entire hub axis direction, and finally use the array characteristics in Pro / E to perform 360-degree array along the hub axis Out of Z gear teeth.

Based on the above gear modeling strategy, the planetary reduction system is then geometrically parametrically modeled. The planetary reduction mechanism of the cutting part mainly includes the planetary gear part and the tapered rolling bearing. The planetary gear transmission mechanism mainly includes: four planet gears, sun gears, planet carrier (output shaft), four shaft pins, splines and external ring gear; single row tapered rolling bearing part, according to the matching parameters of the tapered rolling bearing and the combined model Assembly characteristics, the establishment of the parameterized model is divided into three steps, first, the inner sleeve part of the bearing is established; secondly, the tapered roller is modeled based on the size of the sleeve and the roller parameter size, and the tapered roller needs to be drawn The reference point and the reference line, this process is more complicated, and it is also a difficult point in the modeling process; Finally, the outer ring part of the tapered bearing is established based on the tapered angle of the tapered roller, and the modeling of the planetary reducer system parts is completed. After the part is created, click on the Pro / E toolbar option to complete the assembly of the whole part.

### 3. Non-Linear Vibration Characteristics Test

#### 3.1 Addition of Vibration Test

Using the ADAMS / Vibration analysis module, the forced vibration analysis of the shearer rigid-flexible coupling can be performed. The obtained simulation results can be viewed through post-processing. Analysis of the results can obtain the external excitation effect of the shearer rigid-flexible coupling model Dynamic response under.

Based on the established rigid-coupling model of thin coal seam shearers, external excitation is added at the input channel, frequency response function is calculated at the output channel, and the vibration characteristics of the system are determined by analyzing the dynamic response of different test points.

In this study, the input excitation is the frequency domain curve of the instantaneous load at the centroid of the drum calculated using MATLAB software, that is, the input channel is the X, Y, Z component force and moment excitation of the front and rear drums simulated, as shown in Table 1. The application position is at the center of mass of the front and rear rollers; the output channel can be established at several measurement points as needed to obtain the vibration response in each direction at the corresponding position. After the input and output channels are added, the establishment of the vibration model of the thin coal seam shearer is completed.

Table 1: List of input channels

| NO | Input Channel Name         | Input Marker     | Direction | Parameters | Spline   |
|----|----------------------------|------------------|-----------|------------|----------|
| 1  | Input_Channel_qiantong_lx  | EYC010301-01G-CG | Local_x   | PSD        | SPLINE_1 |
| 2  | Input_Channel_qiantong_ly  | EYC010301-01G-CG | Local_y   | PSD        | SPLINE_2 |
| 3  | Input_Channel_qiantong_lz  | EYC010301-01G-CG | Local_z   | PSD        | SPLINE_3 |
| 4  | Input_Channel_qiantong_ljx | EYC010301-01G-CG | Local_x   | PSD        | SPLINE_4 |
| 5  | Input_Channel_qiantong_ljy | EYC010301-01G-CG | Local_y   | PSD        | SPLINE_5 |
| 6  | Input_Channel_qiantong_ljz | EYC010301-01G-CG | Local_z   | PSD        | SPLINE_6 |

#### 3.2 Setting of Simulation Parameters

Through the selection and setting of the ADAMS solver ADAMS / Solver, the simulation solution calculation of the system model can be completed, thereby solving the problems encountered in various complex projects.

##### (1) Solver selection

The model in this study is a rigid-flexible coupling model. Since the high frequency of flexible bodies such as rocker arm shells and traction part shells in the model is generally not excited, it can still be regarded as a rigid system. ADAMS solvers for numerical calculation of rigid systems mainly include Gstiff, Wstiff, Dstiff, etc. Among them, Gstiff solver has the advantages of fast calculation speed and high displacement accuracy, which can effectively reduce the simulation time and the failure rate of the simulation. Therefore, in this study, Gstiff was used to solve the calculation.

In addition, due to the large model of the shearer, it has a variety of flexible bodies and contains large flexible parts such as rocker shells and traction part shells. It requires a large amount of memory during simulation to ensure smooth simulation. To proceed, set the ASolver / Preferences of ADAMS and the memSize of Aview / Preferences.

When calculating and solving the system, ADAMS provides three integral formats: Index3, SI2, and SI1. By comparing the three-way integration format, it is found that the SI2 integration format is suitable for solving the model calculation, which can effectively control the calculation error, and can accurately find the speed and acceleration. In addition, SI2 integration is not prone to failure during the correction phase of the solution process, and is also suitable for the treatment of high-frequency problems.

This article mainly focuses on the vibration analysis of the shearer. The SI2 format can solve displacement, velocity and acceleration, and the solution has high accuracy and good stability. Therefore, the SI2 format is selected. The comparison of three different integration methods is shown in Table 2.

*Table 2: Comparison of three integration methods*

| Index                        | 3                                   | SI2   | SI1   |
|------------------------------|-------------------------------------|---|---|
| Improve accuracy             | High displacement accuracy          | High precision in displacement, velocity and acceleration | Displacement, velocity, acceleration, Lagrangian multiplier with high precision |
| Break through stability      | General                             | Good  | Good  |
| Breakthrough speed           | Fast                                | General   | General   |
| Handle high frequency issues | Suitable for low frequency problems | High frequency fit  | High frequency fit  |

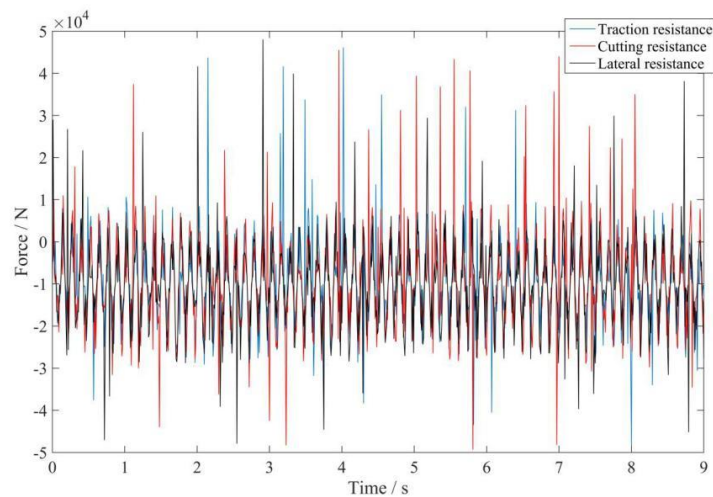
(2) Simulation parameter setting

Perform forced vibration analysis on the shearer, add external excitation to the input channel, the output channel is the acceleration response from each measurement point, the frequency is set to 0.001 ~ 500Hz, and the number of steps is set to 1000 steps.

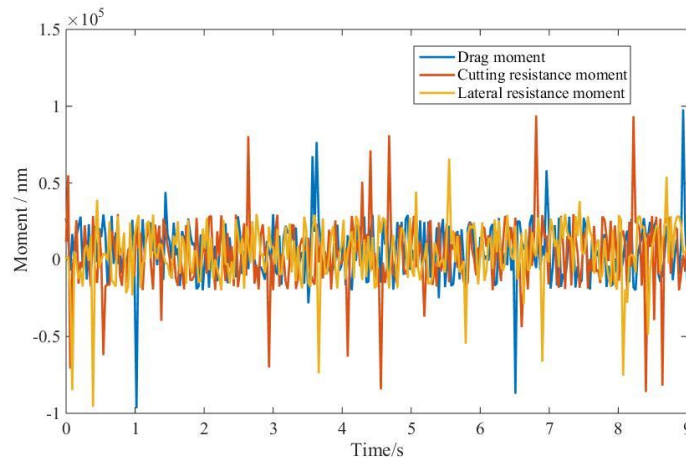
#### 4. Discussion and Analysis of Nonlinear Vibration Characteristics

##### 4.1 Three-Dimensional Force Analysis of the Shearer Drum

The three-way force on the drum is mainly based on the cutting resistance and traction resistance, and the cutting resistance and traction resistance show a certain periodicity, and the lateral resistance fluctuates around zero. As shown in Figures 2 and 3, the phase torque is mainly the cutting torque and the lateral torque, and the traction torque is small.



*Figure 2: Three-dimensional force curve of the shearer drum*



*Figure 3: Three-way torque curve of the drum*



The rocker shell is an important structural part of the shearer. The cutting part transmission system is arranged in its internal cavity. The extension end is connected to the drum through the square head. In the actual work of the shearer, it is subject to the complicated and variable load from the cutting head and the impact of the traction unit when it is walking, and structural damage is prone to occur; the load received by the drum is transmitted to the traction unit shell through the cutting unit. At the same time, the traction part bears the impact transmitted by the walking part during the walking of the shearer, and the ears connected to the cutting part and the walking part are also prone to fatigue damage. The excessively strong vibration not only affects the internal transmission system. It has an adverse effect, and it also affects the electric control box distributed in its internal cavity, which is easy to cause damage to electrical components. Therefore, the rocker arm shell and the traction part shell must have sufficient strength and rigidity.

#### 4.2 Force Analysis of Drum Cutting Coal Wall

Table 3: Statistical Table of Mean and Standard Deviation

| Cut-off distance/mm | 60    | 65    | 70    | 75    | 80    |
|---------------------|-------|-------|-------|-------|-------|
| Average / N         | 15527 | 15422 | 15598 | 15482 | 15489 |
| Standard deviation  | 19369 | 19372 | 19511 | 18913 | 19435 |

As shown in Table 3, the average value of the force on the pick is not much different under different intercept lines. The average value of the force on the pick when the intercept is 70mm is slightly larger than that of other intercept lines; The force fluctuation of the pick with a cutting distance of 70mm is greater, and the force fluctuation of a pick with a cutting distance of 75mm is smaller; there is not much difference between the force of the other cutting distance of 60/65/80.

The support force of the drum (speed application point) is the force of the drum against the coal wall, which is the cutting force. From the cutting force curve, it can be seen that the change trend of the cutting force (branch reaction force) of drums with different blade elevation angles is basically the same. At 0.468s, the cutting teeth start to contact the coal wall, and the contact force is generated and increases rapidly from 0. Large, the cutting curve peak appears near 0.542s, and then the curve drops rapidly, at this time, the drum and the coal wall are separated. This is because the coal wall is intact before the drum contacts the coal wall, there is cohesion, and no cracks appear inside. After the contact, the pick gradually wedge into the coal wall to generate contact force, and cracks begin to appear and expand. During the cohesion, the coal wall breaks down and the coal lumps are dropped (cells in the finite element software will disappear). At this time, the drum is detached from the coal wall, and the contact force is rapidly reduced.

#### 4.3 Dynamic Response Analysis of the Drum Shearer

In the actual coal cutting process, the force received by the shearer drum is not a fixed value. During the cutting of coal and rock, the drum will produce longitudinal, transverse, torsional vibrations and coupled vibrations between them, and these vibrations will affect. On the rocker arm connected to the drum, complex vibrations will occur throughout the cutting section. This paper will analyze the vibration response of the shearer rocker arm under the excitation of variable load. The applied variable load is the measured three-way force and moment.

Take a time of 0 ~ 25s for dynamic response analysis, and set the angle of  $\varphi_1$  between the front rocker arm and the horizontal plane to 20°, and the angle between the rear rocker arm and the horizontal plane to  $\varphi_3$  is -8°, as shown in Figure 4 and Figure 5. As shown, the vibration displacement curves of the front drum and the front rocker arm, the three curves are the vibration curves of the three parts of the shearer body along the z-axis direction with time. It can be seen that the vibration curves of the three sections of the fuselage are basically the same, and the vibration displacement of the middle section is relatively larger, with a maximum of about 1.2 mm. The main reason for the similar vibration of each part of the fuselage is that they are closely connected by high-strength hydraulic tie rods, and the contact stiffness of the connected parts is very high.

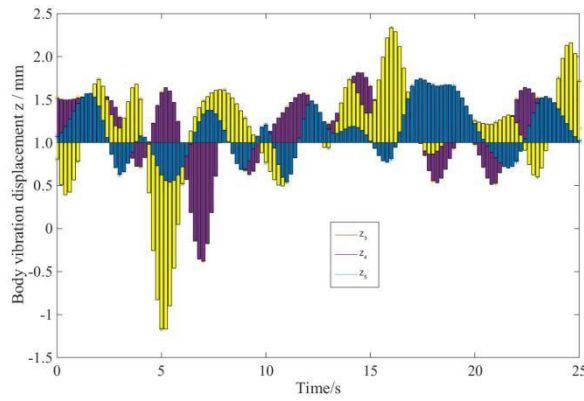


Figure 4: Vibration displacement curve of the fuselage

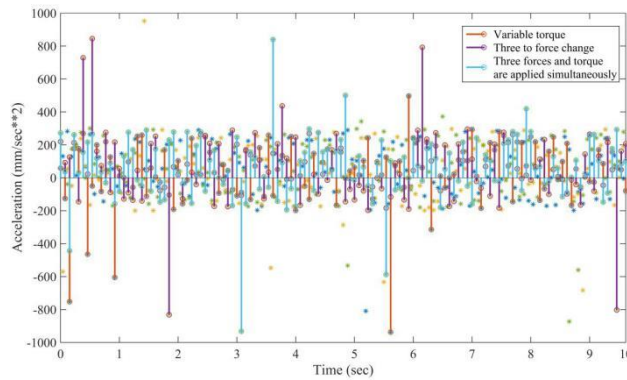


Figure 5: Response data graph under variable load

#### 4.4 Effect of Coal Rock Hardness on Vibration Characteristics

The hardness of coal rock is also divided according to the average value  $A$  of its cutting impedance. The method of numerical analysis is still used in MATLAB. The simulation solution time is set to 100 seconds, the step length is 0.001 seconds, the shearing speed of the shearer is  $v_q = 3m/min$ , the lift angle of the front rocker of the shearer is  $\alpha = 27^\circ$ , and the cutting resistance to coal rock. The average value  $A$  is taken as  $A = 200kN/m$ ,  $A = 300kN/m$ , and  $A = 400kN/m$ . Because the axial load of the shearer drum changes periodically, in order to better study and analyze the effect of coal rock hardness on the axial load of the shearer drum, the shearer drum is between 40 seconds and 42 seconds. The axial load variation curve is analyzed and studied. The average cutting impedance of coal rock has a greater influence on the axial load of the shearer drum under the condition of oblique cutting. The larger the average cutting impedance of coal rock, the greater the axial load of the shearer drum and the more intense the fluctuation. And the axial load of the shearer drum shows periodic fluctuations, with a period of 1 second.

Table 4: Average value of lateral vibration of shearer under different coal rock hardness in oblique cutting condition

| Coal and rock cutting impedance mean | Front roller/ mm | Front rocker arm /mm | Front rocker arm / mm | Body swing angle / rad | Rear rocker arm / mm | Roll back Jan / mm |
|--------------------------------------|------------------|----------------------|-----------------------|------------------------|----------------------|--------------------|
| $A=200kN/m$                          | 9.7812           | 3.9323               | 0.3412                | 0.7385                 | 0.3404               | 0.3392             |
| $A=300kN/m$                          | 15.5447          | 6.2487               | 0.5417                | 1.1742                 | 0.5408               | 0.5386             |
| $A=400kN/m$                          | 21.3055          | 8.5641               | 0.7423                | 1.6087                 | 0.7413               | 0.7385             |

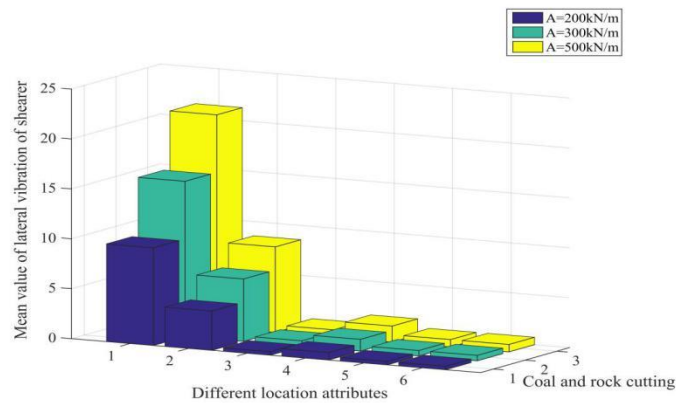


Figure 6: Average value of lateral vibration of shearer under different coal rock hardness in oblique cutting

As shown in Table 4 and Figure 6, the lateral vibration acceleration of all parts of the shearer under the oblique cutting condition fluctuates around 0, and the maximum and minimum peak values are basically the same. When  $A = 200\text{kN/m}$ , the lateral vibration acceleration of the shearer front and rear drums are  $0.0128\text{ mm/s}^2$  and  $0.0052\text{ mm/s}^2$  respectively; the lateral vibration acceleration of the front and rear rocker arms of the shearer are  $0.0121\text{ mm/s}^2$  and  $0.0023\text{ mm/s}^2$  respectively; The vibration acceleration and the swing angular acceleration are  $0.0021\text{ mm/s}^2$  and  $0.0025\text{ rad/s}^2$ , respectively. When  $A = 300\text{kN/m}$ , the lateral vibration acceleration of the shearer front and rear drums are  $0.0698\text{ mm/s}^2$  and  $0.0219\text{ mm/s}^2$ ; the lateral vibration acceleration of the shearer front and rear rocker arms are  $0.0211\text{ mm/s}^2$  and  $0.0123\text{ mm/s}^2$ ; the shearer body is laterally The vibration acceleration and the swing angular acceleration are  $0.0021\text{ mm/s}^2$  and  $0.0005\text{ rad/s}^2$ , respectively. When  $A = 400\text{kN/m}$ , the lateral vibration acceleration of the front and rear drums of the shearer are  $0.0548\text{ mm/s}^2$  and  $0.0181\text{ mm/s}^2$ ; the lateral vibration acceleration of the front and rear rocker arms of the shearer are  $0.0085\text{ mm/s}^2$  and  $0.00096\text{ mm/s}^2$ ; The lateral vibration acceleration and the swing angular acceleration are  $0.0098\text{ mm/s}^2$  and  $0.0074\text{ rad/s}^2$ , respectively. The larger the average cutting impedance of coal rock, the greater the lateral acceleration of each part of the shearer under the oblique cutting condition, the greater the fluctuation, and the direction changes with time. The average cutting impedance of coal rock has a great influence on the front drum and front rocker of the shearer.

## 5. Conclusion

When the shearer performs coal mining under the mine, the external load on the broken coal of the drum has the characteristics of complexity, non-circulation, and variability. The planetary reducer is subjected to strong external load vibration and heavy load when transmitting the motor power and speed. There are many internal excitations in the reduction transmission system to ensure the stable and efficient operation of the planetary reducer in the cutting section is the normal work of the coal shearer. Therefore, this paper analyzes and studies the planetary reducer of the shearer cutting part, which has certain practical significance for improving the working efficiency of the coal shearer and optimizing the shearer planetary reducer.

In this paper, simulation and response analysis of the dynamic model under variable load excitation are carried out. The vibration acceleration in the X direction, Y direction, Z direction and torsional direction is measured by applying variable torque only, three-way force only, and three-way force and torque at the same time. The acceleration time and frequency domains are measured. The analysis shows that the vibration in the X, Y, Z, and torsional directions when the variable three-way force and variable torque load are applied at the same time is greater than the vibration when only the variable three-way force and variable torque are applied, and X The frequency domain components of vibration in the direction, Y direction and torsion direction are basically the same, which proves that the vibration

of the rocker arm is a coupled vibration.

In this paper, the drum models with different intercept lines are established, the influence of the intercept line on the cutting performance of the drum is studied, and the cutting force curve of the drum is drawn. The energy consumption and the drum load spectrum curve are used to analyze the force and specific energy consumption data. In combination with the expansion diagram of the pick arrangement, the drum force is theoretically analyzed to obtain a more suitable drum intercept.

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