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Influence of Drum Motion Parameters on Shearer Cutting Properties

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Abstract

In order to study the influence of motion parameters of shearer drum on shearer cutting properties, in this paper, theoretical analysis about the influence of drum rotating speed and shear pulling speed on drum cutting properties was carried on and an embedded system for cutting load test that can identify the cutting resistance indirectly were developed and put into test experiment underground. The analysis results indicated that in the case of pulling speed being constant, when pulling speed is small, the cutting resistance nonlinearly declined and cutting specific energy consumption (CSEC) increases nonlinearly with the increase of the drum rotating speed; when pulling speed is large, cutting resistance approximately linearly decreases and CSEC linearly increases with the increase of the drum rotating speed; in the case of drum rotating speed being constant, the cutting resistance presents linearly reducing form with pulling speed increasing its value in the range of higher speed and increases nonlinearly with pulling speed increasing its value in the range of lower speed, and CSEC decreases nonlinearly with the increase of the pulling speed. The consistency of the theoretical analysis and the test results confirmed the reliability of the proposed embedded system which provides an effective way for the detection and analysis of mine shaft cutting load and also provides the instruction for shearer speed-changing cutting coal.

Keywords: *shearer drum, drum rotating speed, drum pulling speed, embedded system, cutting resistance, CSEC*

1. Introduction

As the operating mode and the environmental condition of coal mining are severe, devices for detecting shearer load spectrum are required to have good properties, such as explosion-proof, waterproofing, anti-interference; also in consideration of the narrow space of mine shafts, the instruments are required to be of small volume [1, 2]. Therefore, it is necessary to develop a mine intrinsically safe device that can be put in the own explosion-proof box of a shearer and have the properties of multi-channel data acquisition and mass data storage in order to obtain more information for research and analysis. Due to bad environmental condition in mine shafts, there are few related reports on detection of shearer drum cutting load. Massive experimental studies on the cutting properties of cutting picks have been conducted by domestic and foreign scholars [3, 4]. Evans [5] from the United Kingdom and Nishimatsu [6] from Japan built their cutting force formulas respectively from the maximum tensile stress and the maximum shear stress. But this formulas were suitable for design of coal ploughs and unreasonable to some extent for describing the cutting force of shearer drum picks [7, 8]. The domestic scholars have conducted experimental studies on the cutting force of knife-type picks and conical picks, built their mechanical models and pointed out the effect parameters and its variation laws about cutting force of conical picks [9-14], but this researches were all carried out in the straight line cutting conditions which were of great differences with the actual conditions [15-18].

When a drum was cutting coal and rocks of different hardness, the rotating speed and the pulling speed should be adjusted correspondingly in order to obtain maximum lump coal rate. But it is not possible to get real-time and direct information of drum cutting resistance. In this paper, theoretical analysis about the influence of drum rotating speed and shear pulling speed on drum cutting properties was carried on and an embedded cutting load test system that can identify the cutting resistance indirectly were developed and put into test experiment underground. The work would provide the effective way for the examination and analysis of mine shaft cutting load and the instruction for the next speed change cutting realization.

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2. Theoretical Analysis

2.1. Influence of Motion Parameters on Cutting Resistance

The cutting resistance of a single pick, when a shearer drum was cutting coal, is expressed as [19]

$$F_j = A_z h \frac{(0.3+0.35b_p)S_j K_Y K_m K_\alpha K_f K_p}{K_\phi\left(b_p + h\tan\phi\right)\cos\beta}, \tag{1}$$

where K_m is the coefficient of coal bareness, represented by

$$K_m = \begin{cases} 0.32+0.2/(0.1h) & , \ h \le 10 \\ 0.25+0.66/(0.1h+1.3), & h > 10 \end{cases}; \tag{2}$$

and ϕ is the coal avalanche angle, in radian, represented by

$$\phi = \pi(0.00656h^2 - 0.934h + 71.769)/180; \tag{3}$$

S_j is the pick intercept, in mm; K_Y is the compression tension coefficient of coal; K_α is the influence coefficient of cutting angle; K_f is the influence coefficient of cutting face; K_p is the coefficient of picks layout, and when the picks are arranged in sequence, K_p is set to be 1 and when in checkerboard type, K_p is set to be 1.25; K_ϕ is the influence coefficient of coal avalanche angle, in radian; β is the nominal installation angle of picks, in radian; b_p is the calculated angle of picks, in radian.

The maximum cutting thickness of a single pick is represented by

$$h_{\max} = 1000v_q / nm, \tag{4}$$

where v_q is the pulling speed, m/min; n is the drum rotating speed, r/min; m is the pick number on per transversal, in 1/r.

Substitute h in Equations (1) to (3) by h_{max} in Equation (4), the relationship between the motion parameters, v_q and n, and the cutting resistance F_j can be represented as

$$\begin{cases} F_j = 1000v_q A_z \dfrac{(0.3+0.35b_p)S_j K_Y K_m K_\alpha K_f K_p}{K_\phi\left(nmb_p + 1000v_q\tan\phi\right)\cos\beta} \\ \phi = \pi(6560v_q^2/n^2m^2 - 934v_q/nm + 71.769)/180 \\ K_m = \begin{cases} 0.32+0.2/(100v_q/n) & , \ v_q/n \le 0.01m \\ 0.25+0.66/(100v_q/n+1.3), & v_q/n > 0.01m \end{cases} \end{cases}, \tag{5}$$

and their relational graph is shown in Figure 1. It can be seen from Figure 1 that in the case of v_q being constant, when v_q is small, F_j reduces in nonlinear form with the increase of n, and when v_q is large, the cutting resistance presents linearly reducing form with the increase of n; in the case of n being constant, when v_q changes its value in the range of higher speed, F_j presents linearly reducing form with the increase of v_q and when v_q increases its value in the lower speed range, F_j increases in a nonlinear form.

2.2. Research Method Influence of Motion Parameters on CSEC

CSEC reflects the size of energy consumption when drum cutting per unit volume of coal, the smaller the value, the higher the cutting efficiency. Because energy is basically consumed by picks cutting coal in the process of drum cutting coal, the relationship between the drum CSEC and the motion parameters can be reflected by the relationship between the pick CSEC and the motion parameters.

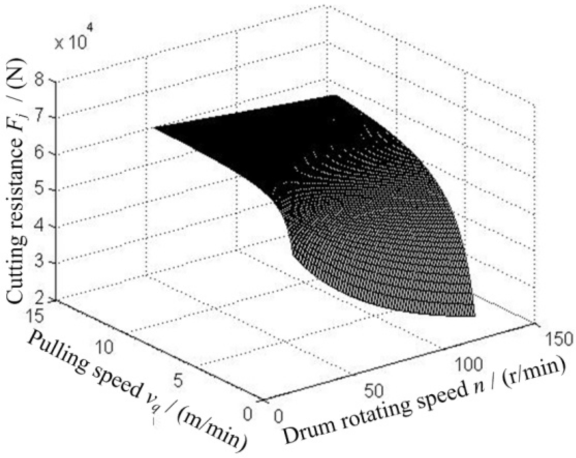


Figure 1. The Relationship between cutting resistance and drum motion parameters.

$$H_W = \frac{A_z K_Y K_m K_\alpha K_f K_p}{(b_p + htg\phi)/K_\phi} \times 10^{-3}, \tag{6}$$

where H_W is the pick CSEC, in KW·h/m^3.

Substitute h in Equations. (2), (3) and (6) by h_{max} in Equation (4), it can be obtained that

$$\begin{cases} H_W = \dfrac{A_Z K_Y K_m K_\alpha K_f K_p nm}{(nmb_p + 1000 v_q tg\phi)/K_\phi} \times 10^{-3} \\ \phi = \pi(6560 v_q^2/n^2 m^2 - 934 v_q/nm + 71.769)/180 \\ K_m = \begin{cases} 0.32 + 0.2/(100 v_q/n) & , \ v_q/n \le 0.01m \\ 0.25 + 0.66/(100 v_q/n + 1.3), & v_q/n > 0.01m \end{cases} \end{cases} . \tag{7}$$

Figure 2 illustrates the relationship between v_q and n, and H_W. In the case of v_q being constant, when v_q is taken in the range of larger values, H_W increases approximately linearly with the increase of n; and when v_q is taken in the range of smaller values, H_W increases nonlinearly with the increase of n. When n is constant, H_W decreases nonlinearly with the increase of v_q.

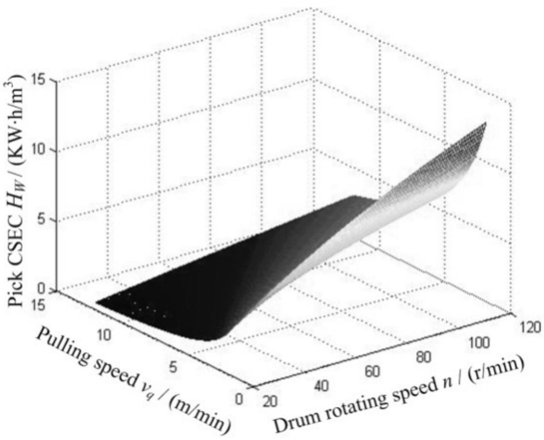


Figure 2. The Relationship between CSEC and kinematical parameters.

3. Research Method

The test system adopts the widely used strain gauges to detect the forces of the cutting unit on a coal mining machine. According to the structural characteristics and the cutting method of the double-drum shearer, the strain gauges should be glued to the reasonable position on surface of the rocker arm, which stands the larger force. When the force of the position is obtained, the three-axis coal-cutting load of the drum can be estimated according to the relevance between both. The system adopts the plane stress measurement methods with the principal stress direction unknown to measure the dynamic strain signals of shearer loading spectrum. Four strain gauges are arranged into the strain rosette and are all connected to the circuit in single-armed bridge form, as shown in Figure 3.

According to the test conditions and requirements, a S3C44B0X microprocessor of the ARM7 series was adopted as the test system core; a CF card was used as the storage medium to store the collected strain signals at high speed, which is later analyzed and processed on PC machines. The test system block diagram is shown in Figure 4.

Four printed circuit boards (PCB) for the embedded cutting load test device were developed. They are separately a PCB for S3C44B0X microprocessor and a CF card, presented in Figure 5, an ADC sample-hold amplifier circuit board, the operational mode control board and a WIGGLER&UART debug board.

In order to completely achieve the explosion-proof security, this test device uses hardwares which are conforming to the essential security standard and they are put in the electric control box of shearer. The device will be debugged in the laboratory before it is taken into a coal well and the PC machine will download the program to the flash memory of the system. When taking load spectrum analysis in off-line mode, only the CF card is taken out of the device and is read the data file from into the PC machine through the general card reader; and then the MATLAB software is used to carry on the loading spectrum analysis to the obtained data so as to obtain information about the characteristics of shearer cutting load which can further guide the design and use of shearer.

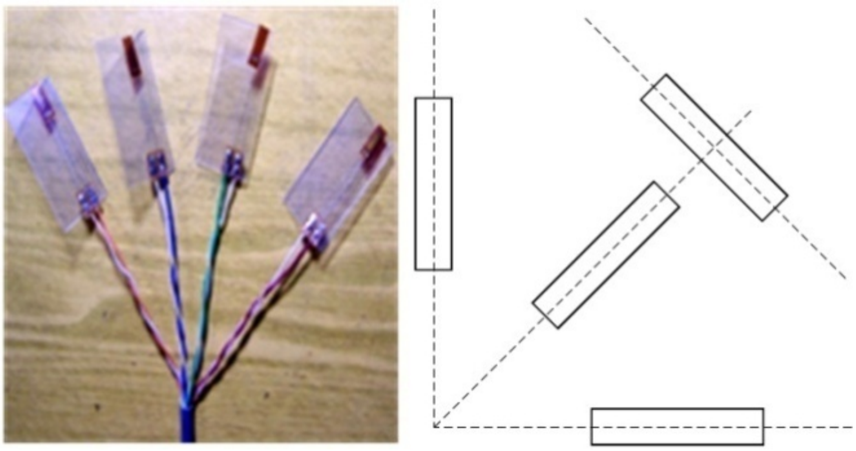


Figure 3. Wiring and arrangement pattern of strain gauges.

In order to obtain relevant information about cutting forces, the developed test system was used to test stress of the linking part of a shearer ranging arm in the working face of a coal mine underground. The coal seam in that working face is of medium hardness, and its thickness is 2.6 m. A MG200/500QWD shearer, a SGZ730/2×200 scraper conveyor and a ZY3800/16/35 standing shield hydraulic support are equipped in the working face. Due to the limited condition underground (shown in Figure 6(a)), a special connection mode has been designed for strain gauges and attachments should have been welded in the laboratory and therefore it will be easy to paste strain gauges to the rock arm surface with adhesive. Based on the researches [20-22], it is concluded that the stress at the root of the linking part of the shearer ranging arm is higher, so strain gauges should be pasted there shown in Figure 6(b).

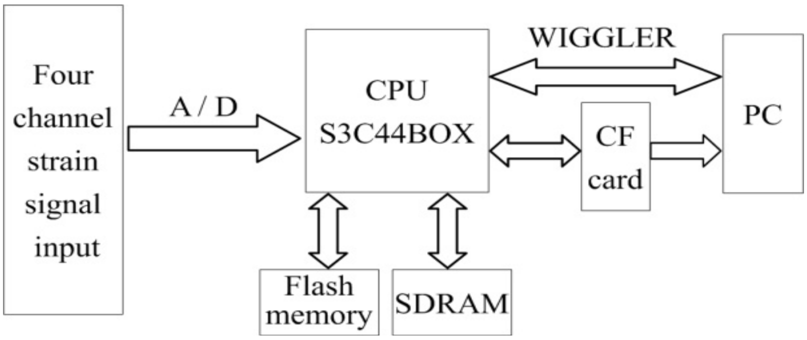


Figure 4. A block of the test system.

Figure 5. The PCB for the S3C44B0X microprocessor and the CF card.

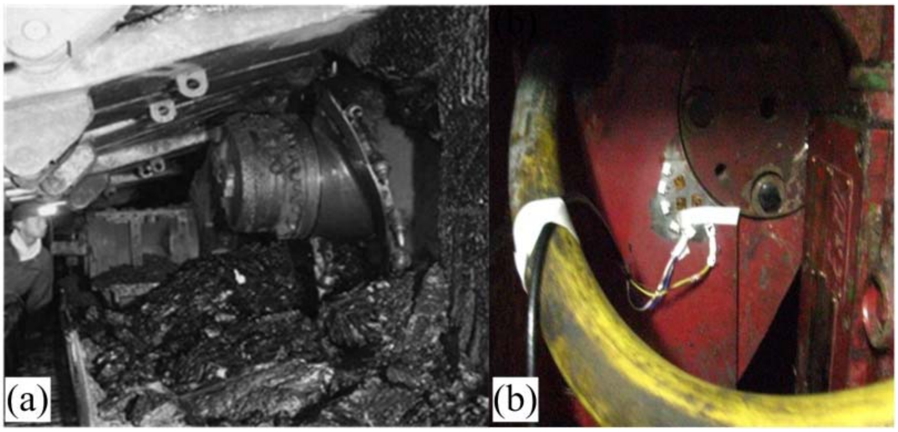
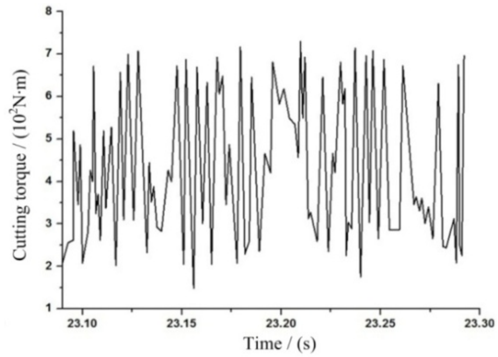


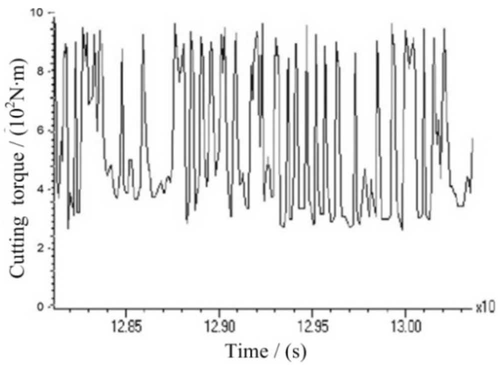
Figure 6. A working state of a shearer and the paste position of strain gauges on the drum.

4. Results and Analysis

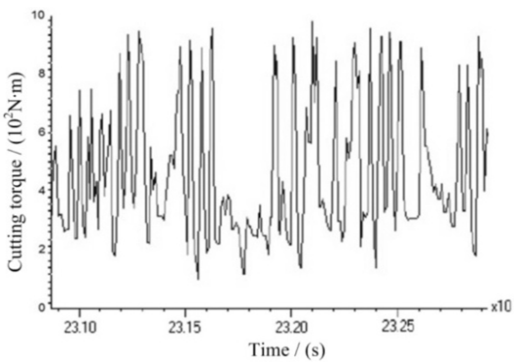
Gears in the shearer ranging arm can be replaced on the ground to get more than 2 kinds of drum rotational speeds in order to adapt to different coal properties, but once the gears have been replaced on the ground, it is impossible to change the speed when the shearer is working underground. Besides, pulling speed can adjust itself automatically according to different coal conditions in the work process. As it can be summarized from Equation (4) that though the drum rotational speed n is constant, but the maximum cutting thickness h_{max} changes linearly with the change of the pulling speed v_q, so cutting performance of the drum will changes eventually. The relationship between the pulling speed and cutting performance indexes has been studied in Section 2. For this reason, this paper carried on the experimental research of the impact of h_{max} on drum cutting performances by altering v_q to make h_{max} change. Real-time dynamic stress tests were taken under conditions of three haulage speeds, 1 m/s, 1.5 m/s and 2 m/s. Dynamic stress signals in time-domain are shown in Figure 7. Maximum cutting thickness h_{max} under three groups of different test conditions are obtained according to Equation (4), as shown in Table1.



(a) pulling speed v_q = 1 m/min



(b) pulling speed v_q = 1.5 m/min



(c) pulling speed v_q = 2 m/min

Figure 7. Dynamic Stress in time-domain under different pulling speed.

Table 1. The vaules of h_{max} under three groups of test conditions

Test serial number	n / (r/min)	h_{max} / (mm)	v_q / (m/min)
1	42.86	7.7773	1
2	42.86	11.6659	1.5
3	42.86	15.5545	2

In order to further study the relationship between the cutting torque and cutting thickness, test values were statistically analyzed, and the results are shown in Table 2 and in Figure 8. It can be seen from Figure 8 that the drum cutting torque which is proportional to cutting resistance increases approximately exponentially with the increase of h_{max}. In addition, due to h_{max} being proportional to pulling speed v_q which is small in the experiments, it can be concluded that when *n is constant and* v_q changes in the range of lower speed, cutting resistance F_j increases approximately exponentially with the increase of v_q, which is in accordance with the theoretical analysis in Section 2.1.

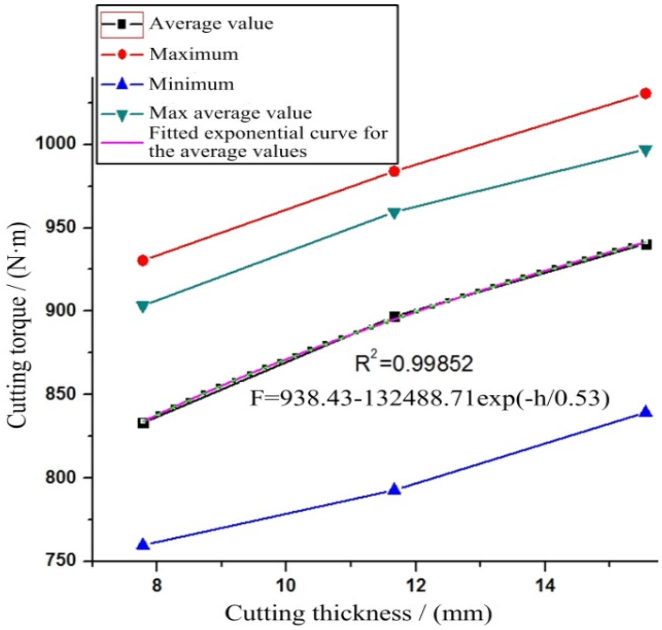


Figure 8. Relationship between cutting torque and the maximum cutting thickness.

Table 2. Statistics of cutting torque with different maximum cutting thickness

h_{max} / (mm)	Average value / (N.m)	Maximum value / (N.m)	Minimum value / (N.m)	Max average value / (N.m)	Standard deviation
7.7773	833.1543	930.44137	759.8392	903.3852	38.5732
11.6659	896.9332	983.8938	792.8350	959.5016	43.26413
15.5545	940.5429	1030.606	839.4267	997.0677	45.84942

According to the definition of CSES, energy consuming when cutting per unit volume, the expression of CSES can be expressed as

$$H_W = \frac{\rho_m t n T_m}{9550 \times 3600 M_m}, \tag{8}$$

where t is the cutting time, in s; ρ_m is the coal density,in kg/m^3; M_m is the mass of the cut coal, in kg; T_m is the cutting torque, N·m.

Further, CSES for cutting coal of different compressive strength can be obtained according to the average values of measured cutting torque in Table 2, as shown in Table 3 with other related parameters.

Table 3. Drum CSEC with different maximum cutting thicknesses

h_{max} / (mm)	Average value for T_m / (N·m)	t / (s)	ρ_m / (kg/m^3)	M_m / (kg)	H_W / (KW·h/m^3)
7.7773	833.1543	10.625	1418.12	39.5711	0.39549
11.6659	896.9332	10.266	1418.12	45.7176	0.356071
15.5545	940.5429	10.465	1418.12	50.6754	0.343384

The relationship between CSEC and maximum cutting thickness based on the data in Table 3 is shown in Figure 9. It can be seen from Figure 9 that in the condition of the same drum structure parameters and the same structural parameters of the cutting pick, CSEC decreases nonlinearly with the increase of the maximum cutting thickness, which verifies the theoretical analysis on the relationship between CSEC and pulling speed in Section 2.2.

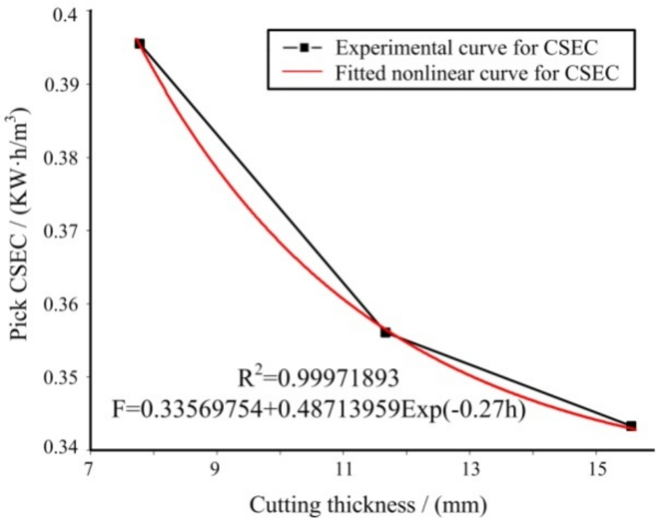


Figure 9. Relationship between CSEC with maximum cutting thickness.

5. Conclusion

The embedded shearer cutting load measuring system was developed based on the S3C44B0X microprocessor and the basic principle of control for the variable cutting speed and was put into test for cutting load on the MG200/500-QWD shearer in the underground working face. Through the real-time collection and analysis of dynamic stress signals of the shearer ranging arm, the feasibility of the embedded cutting load test system was verified. This not only provides means for underground shearer cutting load test, but also lays a solid foundation for further researches.

The relationship between cutting torque and drum kinematical parameters was derived based on the analysis of the data obtained in the experiments underground and the experimental conclusions were in accordance with the theoretical analysis on Equations (5) and (7). The analysis results indicate that:

(1) in the case of v_q being constant, when v_q is small, F_j reduces in nonlinear form with the increase of n, and when v_q is large, F_j presents linearly reducing form with the increase of n; in the case of n being constant, when v_q changes its value in the range of higher speed, F_j presents linearly reducing form with the increase of v_q and when v_q changes its value in the lower speed range, F_j varies in nonlinear form;

(2) in the case of v_q being constant, when v_q is taken in the range of larger values, H_W increases approximately linearly with the increase of n and when v_q is taken in the range of smaller values, H_W increases nonlinearly with the increase of n; When n is constant, H_W decreases nonlinearly with the increase of v_q.

Acknowledgements

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