DYNAMIC SIMULATION BASED DESIGN OF POWERED SUPPORT IN INTEGRATED MECHANIZED COAL MINING

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ABSTRACT
Powered support is one of the key equipments in the integrated mechanized coal mining. The kinematics equations of powered support are presented and the optimum model is built. The simulation and optimization improve the original design greatly. Force analysis is made and force balance equations of main parts are deduced. Computer program and software are developed to derive solutions to calculate the interact forces of the powered support. The dynamic simulations are made for powered support in different working conditions. The results show the variations of loads of the roof and the floor acting on canopy and base, and the variation forces of the front and the back linkages as the height of powered support increases. The simulation based design of powered supports have achieved great success in the application of integrated mechanized coal mining in Pingsu mines of Zhongmei Group in China.

Keywords: dynamic simulation, force analysis, powered support design, coal mining

1. INTRODUCTION

The coal represents a major source of energy among all natural resources, and 60-70% of the energy consumption in China depends on the coal. Underground coal mining is complex and challenging (Costa, J. F., Zingano, A. C., Koppe and J.C., 2000; Kelly, M. 1999; Singh, T. N., Singh, B. 1985). The design of supports is one of the most important for effective roof control in coal mining. Powered supports had come after a long development of wood and steel supports in longwall faces of coal mine. The earliest powered supports were manufactured by the Gullick Company of England. In the middle of the past century, the shield supports were developed to keep with easily caving faces in coal mine.

Technological progress over the past decade has allowed Chinese engineers to construct a considerable number of modernized underground coal mines, which deeply involves mechanization, automation, information technology equipments, and which has brought the risks, toughness and disadvantages of underground coal mining to an end. Examples of such constructions are the various coal mines in Shendong of China Shenhua Group. Annual production level of these coal mines are over tens of millions of tons, and they are also home to the largest coal mine longwall face, equipped with the biggest integrated mechanized mining machines (shearer, conveyor and powered supports) in the world, machines of which the shearing height amounts to 7m. These mining machines, equipped with advanced hydraulic, controlling, sensory, communication, electronic, and computer systems, realize considerable productivity, efficiency and safety. The Pingsu coal mine of China Zhongmei Group applies integrated mechanized top coal caving mining techniques to realize annual production level of tens of millions of tons under the condition of the hard top coal and rocks, breaking the world record of top coal caving mining. The design, manufacture, assembly and operation of the integrated mechanized mining machines applied by these large longwall faces of coal mines are very demanding and complex, making simulation technology one of the best ways to achieve the desired effect (Li, J., Chen, H. and Zhang, J. 2007).

This paper deals with the dynamic simulation based design of powered support in integrated mechanized coal mining, and the analysis of the kinematics and dynamic characteristics for the optimum of powered support.

2. STRUCTURE OF POWERED SUPPORT

2.1. Integrated Mechanized Mining Equipment

The integrated mechanized mining equipments mainly consist of the shearer, the conveyor, and the powered supports. The shearer cuts the coal seam between the top and bottom rocks by the two drums with helical blades, which is assembled with hard alloy teeth, and moves the coal on the conveyor, as shown in Fig.1. Then the conveyor transports the coal to the belt and to the ground. The powered supports support the top roof (rock or silt stone above the seam) of the longwall face, providing safety rooms and protects the top roof (rock or silt stone) from falling down and damaging the shearer and the conveyor (Dong, Z., Chang, H. and Wang, S. 2001), or wounding the workers. The shearer and the conveyor are serial, standard, products with different types, but geological conditions, such as the characteristics of rocks, silt stone and coal seams are formed by nature and therefore multifarious (Knessel, H.C.W. and Mischo, H. 1999). As the types of the shearer and the conveyor are selected according to the power, running speed and productivity of the longwall face, the design of powered supports must not only take into consideration the thickness and inclination angle of different seams and the variable pressure, hardness and strength of top roof rocks (Qan, M., He, F. and Miao, X. 1996), but also the uniformity and coordination of position and movement among the shearer and the conveyor. Therefore, the design of powered support is demanding and complex (Dong, Z., Li, H. and Sun, M. 2004), and the importance of kinematic and dynamic analysis is highlighted.

Fig. 1 Integrated Mechanized Face in Coal Mine

2.2 Structure of Powered Support

Powered support is mainly composed of a horizontal base plate that sits on the floor, linkages, shield, canopy, cylinders, and legs, as shown in Fig. 2. The canopy and the base are connected with the shield and the linkages by hinges. The special linkages between the base and shield maintain a constant distance between the face and canopy tip whether the hydraulic cylinders of legs move up or down. The top ends of the two legs are connected with the canopy by sphere pairs, and the bottom ends of the two legs are connected with the base also by sphere pairs. The top end of the balance cylinder is connected with the canopy by hinge, and the bottom end of it is connected with the shield by another hinge. The legs are double telescopic cylinders driven by hydraulic power, and push the canopy up to support the loads of top roof rocks, then unload and bring the canopy back down when the powered support moves. The broke rocks and blocks from the top roof are sheltered by the shield from the workers.

Theoretically, powered support is a multi-linkages mechanism. The positions, displacements and movement paths of the different structures and parts are changing when the hydraulic cylinders drive the powered support. These geometry parameters of the powered support determine the positional relationship between the powered support and the shearer, and the relationship between the powered support and the conveyor in the working space. Kinematics parameters of the powered support determine its coordinate actions with the shearer and the conveyor. The relative positions of the shearer, the conveyor and the powered supports change in accordance with the variation of geology conditions, such as the thickness and inclination angle of the seams, therefore the alternation of the relative positions must be controlled effectively.

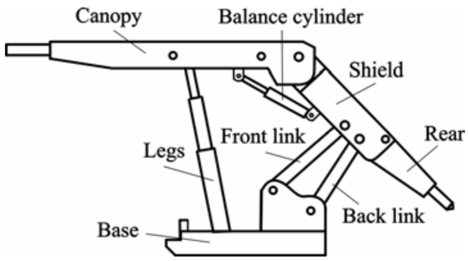


Fig. 2 Powered Support Structure

3. KINEMATIC SIMULATION

Kinematics equations are built to calculate and simulate the positions, displacements and movement paths of the different structures and parts when the hydraulic cylinders drive the powered support. The simulation provides fundamentals for the kinematics design of powered support, and protects the shearer, the conveyor and the powered supports from the interfering with each other or collision during operation.

3.1. Kinematics Equations

The coordinate system of powered support is built as shown in Fig. 3.

The point *M* on shield is expressed as follow:

$$U^2 + V^2 = W^2 \quad (1)$$

This is the equation of the canopy movement.
Where, there are:

$$\begin{cases} U = f[(x-d)\cos\gamma + y\sin\gamma](x^2+y^2+e^2-a^2) \\ \quad -ex[(x-d)^2+y^2+f^2-c^2] \\ V = f[(x-d)\sin\gamma - y\cos\gamma](x^2+y^2+e^2-a^2) \\ \quad +ey[(x-d)^2+y^2+f^2-c^2] \\ W = 2ef\sin\gamma[x(x-d)+y^2-dy\cot\gamma] \end{cases} \quad (2)$$

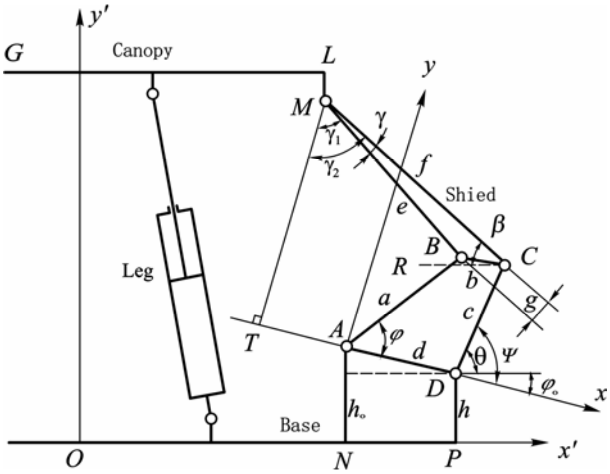


Fig. 3 Coordinate System of Powered Support

Translate the coordination from xAy into x'O'y', and $ON = s$

$$\begin{cases} x' = s + x\cos\varphi_0 - y\sin\varphi_0 \\ y' = h_0 + x\sin\varphi_0 + y\cos\varphi_0 \end{cases} \quad (3)$$

Equations (3) are expressed as following:

$$\begin{cases} x = ((x' - s)\cos\varphi_0 + (y' - h_0)\sin\varphi_0) \\ y = ((y' - h_0)\cos\varphi_0 + (s - x')\sin\varphi_0) \end{cases} \quad (4)$$

3.2. Kinematics Simulations

The distance variation between the face and canopy tip must be limited to a certain small value whether the hydraulic cylinders move up or down in working height.

The function of goal is:

$$\min f_M = (x'_{Mmax} - x'_{Mmin}) \quad (5)$$

Where, x'_{Mmax}—the maximum value of M in the x' axis during the hydraulic cylinders move up or down in working height.

x'_{Mmin}—the minimum value of M in the x' axis during the hydraulic cylinders move up or down in working height.

Pingsu coal mine of China Zhongmei Group applies integrated mechanized top coal caving mining techniques in the coal mine. Where, the ZF12000/23/40D type of powered supports are used and manufactured by Beijing Mining Machinery Company. In the original design of the powered supports, the maximum distance variation between the face and canopy tip was 129 mm during the powered support move up or down from height of 2300 mm to 4000 mm. Therefore, the maximum distance variation between the face and canopy tip was reduced to 20 mm in the same conditions by simulation and optimum design, which improves greatly. The kinematics simulation of the F12000/23/40D type powered support is shown in Fig. 4, in which the different positions stepped by height of 2300 mm, 2600 mm, 2900 mm, 3200 mm, 3500 mm, 3800 mm and 4000 mm, and the simultaneous centers of the linkages at these positions are displayed. The results of kinematics simulation are the foundations for the force analysis and design of the powered supports.

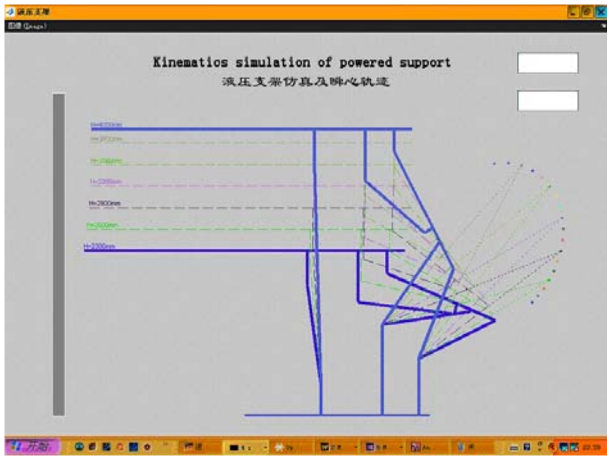


Fig. 4 Kinematics Simulation Diagram

4. DYNAMIC SIMULATION

4.1 Load Analysis

In order to ensure safety and reliability, dynamics, loads analysis and simulation are essential to the design of the powered support. Since the coal seams are hundreds or even thousands of meters down from the earth surface, the working face under ground is acted by great pressure during coal mining. All these pressure, forces and loads are supported by the powered supports. In practice, the magnitude and position of loads acted on canopy by top roof rocks change with the mining process, and the interact forces of base, linkages, shield, and canopy of the powered support also change.

4.2 Equations and Solution

The loads, forces and the dimensions of the main parts of powered supports are shown in Fig. 5.

In order to solve and calculate the complicated problem, the loads and forces are simplified, and the equations are shown as following.

The force balance equations of canopy are:

$$\begin{cases} fQ_1 + R_y\sin(\alpha) - R_x\cos(\alpha) - P\sin(\beta) - P_E\cos(\alpha_2) = 0 \\ R_x\sin(\alpha) + R_y\cos(\alpha) + P\cos(\beta) + P_E\sin(\alpha_2) - Q_1 = 0 \\ Q_1x_1 - fQ_1L_7 - P\cos(\beta)L_2 - P\sin(\beta)(L_5 - L_7) \\ \quad -P_E\sin(\alpha_2)L_4 - P_E\cos(\alpha_2)(L_6 - L_7) = 0 \end{cases} \quad (6)$$

Where, Q_1 — vertical load of roof on canopy

Q_2 — vertical load of on base

f — friction coefficient

P — pushing force of legs

P_e — force of balance cylinder

W — load on rear plate
F_1 — force of front linkage
F_2 — force of back linkage

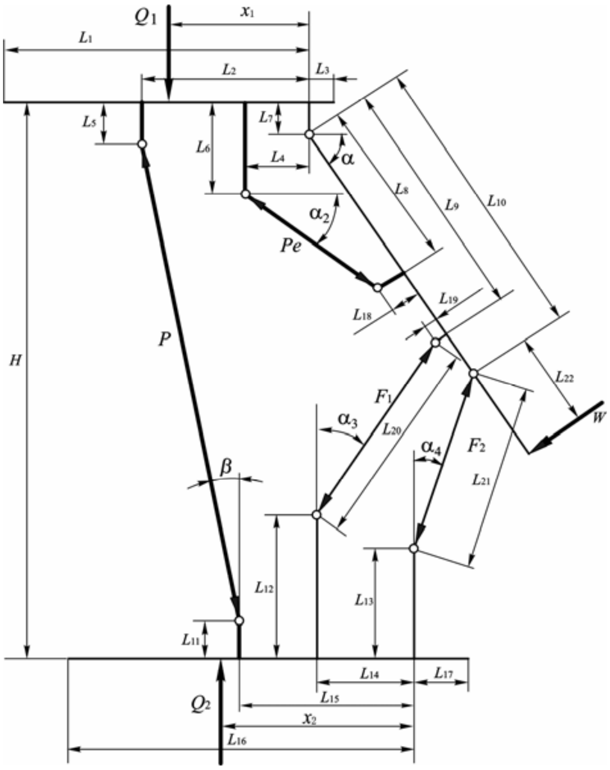


Fig.5 Loads and Forces on Powered Support

The force balance equations of shield are:

$$\begin{cases} P_E\cos(\alpha-\alpha_2)+R_x-F_1\sin(\alpha-\alpha_3)-F_2\sin(\alpha-\alpha_4)=0 \\ P_E\sin(\alpha-\alpha_2)+F_1\cos(\alpha-\alpha_3)+F_2\cos(\alpha-\alpha_4)-R_y-W=0 \\ P_E\cos(\alpha-\alpha_2)L_{18}+P_E\sin(\alpha-\alpha_2)L_8+F_1\cos(\alpha-\alpha_2)L_9 \\ -F_1\sin(\alpha-\alpha_3)L_{19}+F_2\cos(\alpha-\alpha_4)L_{10}-W(L_{10}+L_{22})=0 \end{cases} \tag{7}$$

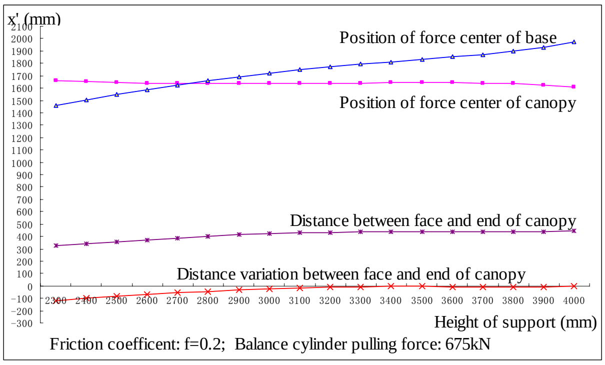
The force balance equations of base are:

$$\begin{cases} P\sin(\beta)-F_1\sin(\alpha_3)-F_2\sin(\alpha_4)-fQ_2=0 \\ Q_2-P\cos(\beta)-F_1\cos(\alpha_3)-F_2\cos(\alpha_4)=0 \\ P\cos(\beta)L_{15}-P\sin(\beta)(L_{11}-L_{13})+F_1\cos(\alpha_3)L_{14} \\ +F_1\sin(\alpha_3)(L_{12}-L_{13})-Q_2x_2-fQ_2L_{13}=0 \end{cases} \tag{8}$$

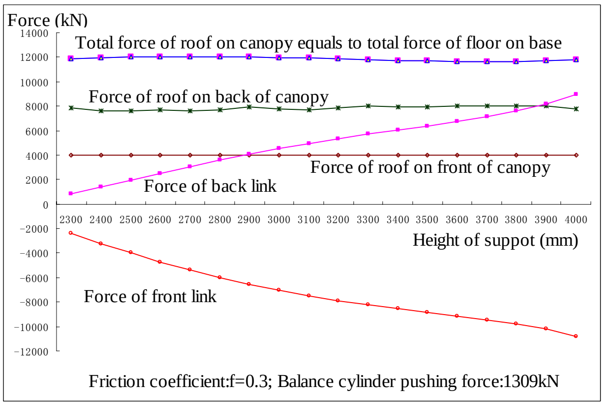
The computer program and software are developed to derive solutions to simulation problems. The simulations, done by computer software, are able to calculate the interact forces of the base, the linkages, the shield and the canopy of the powered support at different heights and positions.

4.3 Dynamic Simulation

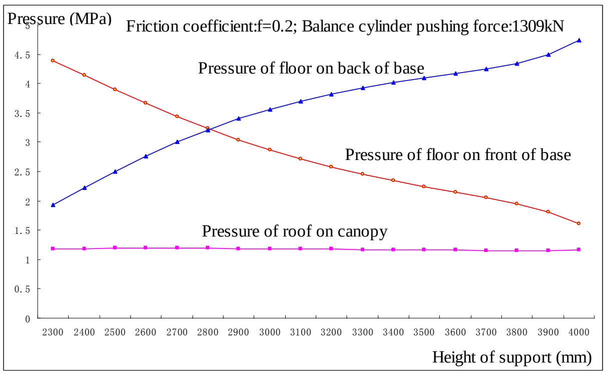
For ZF12000/23/40D type powered supports, the interact forces of base, linkages, shield and canopy of



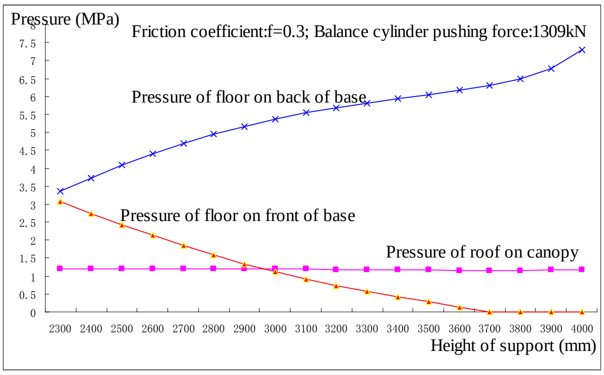
(a) Force Centers and Canopy Position



(b) Force Variation of Different Parts of Support



(c) Pressure Variations on Canopy and Base



(d) Pressure Variations on Canopy and Base

Fig. 6 Dynamic Simulation

the powered support at different heights and positions are calculated and simulated. Some of the results are shown in Fig. 6.

Figure 6 (a) shows the center positions of total normal force of roof acted on canopy and that of floor acted on base, distance between the front end of canopy and face of the coal wall, and the distance variations between the front end of canopy and face of the coal wall. In this simulation example, the calculation friction coefficient of roof and floor acted on the powered support is set as 0.2, and the force of balance cylinder of powered support is 675 kN, which is polling force acted on canopy and shield. The simulation results indicate that the center positions of total normal force of roof acted on canopy and that of floor did on base change with different trends as the height of powered support increasing, which the center point of total normal force of roof acted on canopy moves backward slightly, and that of floor acted on base moves forward gradually.

Figure 6 (b) shows the forces variation of main parts of powered support. In this simulation example, the calculation friction coefficient of roof and floor acted on the powered support is set as 0.3, and the force of balance cylinder of powered support is 1309 kN, which is pushing force acted on canopy and shield. The simulation results indicate that the total normal force of roof acted on canopy equals that of floor acted on base, which is about 12000 kN, same as working resistant force. In order to investigate the affectivity of canopy of powered support to the roof, the calculation is done respectively for both ends of canopy. The results indicate that the normal force of roof on the back end of canopy varies approximately from 3950 kN to 4000 kN as the height of powered support increasing from 2300 mm to 4000 mm, and of roof on the front end of canopy varies approximately from 7900 kN to 8000 kN as the height of powered support increasing from 2300 mm to 4000 mm. The forces of linkages change obviously as the height variation of powered support. The pushing force of front link increases sharply from 2400 kN to 10800 kN as the height of powered support increasing from 2300 mm to 4000 mm. The polling force of back link increases sharply from 800 kN to 9000 kN as the height of powered support increasing from 2300 mm to 4000 mm.

Figure 6 (c) shows the pressures variation of canopy and base. In this simulation example, the calculation friction coefficient of roof and floor acted on the powered support is set as 0.2, and the force of balance cylinder of powered support is 1309 kN, which is pushing force acted on canopy and shield. From the simulation results, it can be found that the average pressure value of canopy is almost constant from 1.15 to 1.19 MPa in the whole working height of the powered support. However, the pressure values of different ends of base change evidently. The pressure of front end of base decreases from 4.39 to 1.61 MPa, and the pressure of back end of base increases from 1.93 to 4.73 MPa.

Comparing with Fig. 6 (c), Figure 6 (d) shows the pressure variations of canopy and base. In this simulation example, the calculation friction coefficient of roof and floor acting on the powered support is set as 0.3, and the force of balance cylinder of powered support is 1309 kN, which is pushing force acted on canopy and shield. From the simulation results, it can be found that the average pressure value of canopy is almost constant from 1.19 to 1.21 MPa in the whole working height of the powered support. However, the pressure values of different ends of base change evidently. The pressure of front end of base decreases from 3.06 to 0.00 MPa, and the pressure of back end of base increases from 3.37 to 7.29 MPa, which must be paid attention in the design of powered support working under wet floor conditions.

The simulation makes foundations for the structure parameter optimizing design of the powered support.

5. MODELING AND DESIGN

The integrated mechanized coal mining technique significantly reduces the risks in underground working, increases productivity, and improves efficiency. At the same time, the integrated mechanized coal mining technique also brings about more requirements concerning the design, manufacture and application of the mining equipments. In order to meet engineering demand, 3D solid model of powered support are built based on the integrated mechanized coal mining in Pingsu, and virtual assembly prototype are created as shown in Fig. 7.

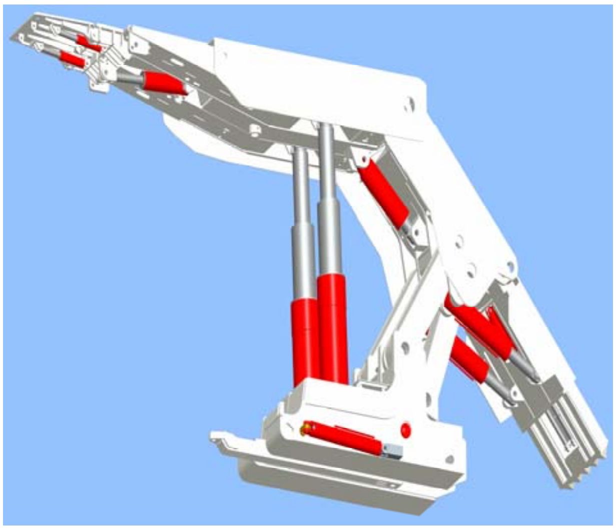


Fig. 7 3D Modeling and Design of Powered Support

The 3D graphics clearly and precisely display the parts, structures and the relationships of the powered support during movement, and simulate the powered support operation. Power supports designed on the basis of the dynamic, graphic simulation are performing with great excellence in Pingsu mines of Zhongmei Group in China.

6. CONCLUSIONS

(1) The kinematics equations of powered support are presented and the optimum model is built. Through simulation and optimization, the maximum distance variation between the face and canopy tip is minimized to 20mm, improving the original design greatly.
(2) Force analysis is made for powered support, and force balance equations of main parts are deduced. Computer program and software are developed to derive solutions to calculate the interact forces of the base, the linkages, the shield and the canopy of the powered support.
(3) The dynamic simulations are made for powered support under different working conditions. The results show the variation of loads of the roof and the floor acting on the canopy and the base, and the variation forces of the front and the back linkages as the height of powered support increases.
(4) The dynamic simulations indicate the effect of various friction coefficient between the roof and the canopy, and the floor and the base on loads. The pressure distribution on base and floor varies greatly, in which the maximum pressure is 7.29 MPa while the friction coefficient is 0.3, and the maximum pressure is 4.73 MPa while the friction coefficient is 0.2.
(5) The simulation makes foundations for the powered support of the structure parameter optimizing design. The simulation based design of powered supports have achieved great success in the application of integrated mechanized coal mining in Pingsu mines of Zhongmei Group in China.

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