

Analysis of the Dynamics of the Lower Drill String Assembly in a Deep Well Coring Operation

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ABSTRACT

In order to carry out the geological characteristics, evolution law and other scientific research of the deep strata in the extra-deep well, it is necessary to carry out the coring operation in the extra-deep depth. However, with the increase of drilling depth, the force of drill string in the underground becomes more and more complicated, and there is contact collision between the core and the core after the core tool is bent, which makes the core broken. Clarifying the dynamic behavior of the BHA during the extra-deep well coring process is helpful to obtain a more complete core. Therefore, this paper adopts the simulation analysis method to simulate the coring process of the extra-deep well with a 163.5mm diamond bit and a 140mm corer under the real drilling hole trajectory. The stress, eddy motion and the contact between the inner barrel of the core tool and the core of the lower 1000m drill assembly are analyzed. The results show that the hole expansion rate of coring bit is 2.5% in the process of low bit weight and low rotational speed. When the core is 8m, the core barrel is under compression, bending and torsion, and under the restriction of the centralizer and the core hole, the middle and upper part of the core tool bend greatly, and the contact degree with the core is high, and the larger contact force is easy to cause the lower core to fracture.

KEYWORDS

Extra-Deep Well; Coring Process; BHA; Dynamic Behavior.

1. INTRODUCTION:

As oil and gas exploration and development enter deep and ultra-deep depths, the dynamics of drilling string in borehole becomes more complicated and has complex nonlinear characteristics. For the core operation in extremely deep Wells, the contact collision between the lower drill string and the shaft wall, the axial vibration of the drill string and the vortex reduce the dynamic stability of the lower drill assembly, and the contact collision between the inner barrel of the core tool and the core may lead to core fracture, and it is difficult to obtain the core with high integrity. It is difficult to obtain the complex dynamic parameters of the drill string in the lower part of ultra-deep Wells by direct measurement. At present, the mechanical parameters of the drill string in the lower part of ultra-deep Wells are usually obtained by simulation methods [1][2][3].

Many scholars have carried out the simulation and analysis of drill string dynamics characteristics in ultra-deep and ultra-deep Wells. Zhu Xiaohua et al. [4], aiming at the problem that the drilling tool life of large-size hole in the upper part of ultra-deep well is lower than expected, based on the whole-well drillstring system dynamics model and the numerical simulation method, and compared the SDCK-1 well with the adjacent 8000m ultra-deep well, targeted the drilling string dynamics characteristics of large-size hole. Wang Wenchang et al. [5], based on the actual borehole trajectory and considering the collision characteristics between the drill string and the borehole wall, obtained

the dynamic characteristics of the whole well (8013.35m) through finite element simulation analysis, and studied the fatigue strength of the whole well drill string under the asymmetric cyclic amplitude varying stress state in the ultra-deep well according to the fatigue damage accumulation theory. In order to explore the motion characteristics of drill string in ultra-deep Wells, Di Qinfeng et al. [6] used Newmark method to discrete the time of the governing equation of drill string motion, and then used SOR node iteration method to solve the overall configuration of drill string at each time step to simulate the dynamic characteristics of drill string with a total length of over 9000m. Ji Guodong et al. [7] developed a bottom-hole drill string vibration reduction and energy increase device to evaluate the effect of bottom-hole drill string vibration reduction and energy increase through simulation, aiming at the problems such as severe drill string vibration, difficulty in energy transfer, low rock breaking efficiency and short bit service life during the drilling process of ultra-deep and ultra-long Wells in 10,000 meters deep.

Referring to the previous research methods, this paper uses simulation methods to simulate the coring process of a five-hole Shaylik group in an extra-deep well, mainly analyzes the dynamics characteristics of the BHA, in order to provide theoretical support for the coring operation.

2. ESTABLISHMENT OF DYNAMIC MODEL OF CORING DRILL STRING

2.1. Control equation for drill string motion

In the process of core drilling, the motion of drill string in 3D hole is affected by gravity, hook load, wellhead torque and reverse torque, formation pressure, damping force of drilling fluid, collision reaction force and friction force. As a super slenderness ratio structure, according to Hamilton principle [8][9], considering the energy dissipation caused by the non-conservative force of the drill string system, the kinetic energy, potential energy and external work of the system meet the following requirements:

$$\delta \int_{t_1}^{t_2} (T - V) dt + \delta \int_{t_1}^{t_2} W dt = 0 \quad (1)$$

Where δ represents the variational symbol; T, V, and W represent the work done by kinetic energy, potential energy, and external forces, respectively; J; t1 and t2 represent the start and end time of movement respectively, s.

The continuous displacement within the drill string element is calculated by interpolation of node displacement at both ends of the element, and node displacement is expressed as:

$$U_e = [u_x \ u_y \ u_z \ \theta_x \ \theta_y \ \theta_z] \quad (2)$$

Where U_e represents node displacement; u_x 、 u_y 、 u_z represent the translational displacement of the unit in x, y and z3 directions respectively, m; θ_x 、 θ_y 、 θ_z represent the rotational displacement of the unit around the x, y, and z3 axes, respectively, rad.

Therefore, the Lagrange equation for controlling drill string motion can be obtained:

$$F_i = \frac{d}{dt} \left[\frac{\partial(T - V)}{\dot{U}} \right] - \frac{\partial(T - V)}{\partial U} \quad (3)$$

Where F_i represents external forces of drill string unit nodes, including gravity, centrifugal force, contact and collision force between drill string and well wall, etc. U stands for displacement, m; \dot{U} stands for speed, m/s.

The drill string unit kinetic energy is expressed as:

$$T = \frac{1}{2} \dot{e}^T (M_t + M_r + M_\varphi - 2M_e) \dot{e} + \frac{1}{2} J \dot{\Omega}^2 - \dot{\Omega} \dot{e}^T G_t e \quad (4)$$

Where M_t represents translational mass matrix of drill string element; M_r Represents the rotational inertia mass matrix of drill string element. M_φ represents the torsional mass matrix of drill string element. M_e represents the mass matrix of torsion and lateral inertia coupling of drill string element. J represents the moment of inertia of the drill string unit rotating around the axis, kg·m²; $\dot{\Omega}$ represents the constant angular velocity of the wellhead drill string, rad/s; G_t stands for gyro matrix; e represents the unit node displacement vector; \dot{e} represents the cell node velocity vector; The superscript T represents the transpose of a vector or matrix.

Potential energy of drill string element is expressed as:

$$V = \frac{1}{2} e^T (K_L + K_N) e \quad (5)$$

Where K_L represents linear stiffness matrix; K_N represents the nonlinear stiffness matrix.

Equations (4) and (5) are substituted into equation (3) to obtain the dynamic equation of drill string element, and then the overall control equation of drill string motion is obtained by using the direct stiffness method:

$$M\ddot{U} + C\dot{U} + KU = F \quad (6)$$

In the formula, M , K and C represent the overall mass matrix, stiffness matrix and damping matrix of the drill string respectively. \ddot{U} 、 \dot{U} 、 U and F represent the generalized acceleration, velocity, displacement and external force vectors of the system, respectively.

2.2. Dynamic model parameters of coring drill string

In this paper, taking a special deep well as an example, with a diameter of 168.3mm PDC drill bit drilling to the design coring position after coring, coring drill assembly is: With a diameter of 163.5mm core drill bit 0.32m+ Φ 140mm core tool 10.5m+ Φ 166mm centralizer 1.89m+ Φ 127mm float valve 0.5m+ Φ 127mm spiral drill collar 212m+ Φ 101.6mm heavy drill pipe 144m+ Φ 101.6mmS135I slope drill pipe 3000m+ Φ 101.6mmV150 incline drilling pipe 2000m+ Φ 149.2mmV150I incline drilling pipe 3059.28m+ Φ 149.2mmV150 incline drilling pipe 2700m+ top drive. Coring is divided into three processes: tree core, core entry and core cutting. The core cutting is the process of cutting the core through the upper body drill string. Therefore, this paper mainly analyzes the process of tree core and core entry. Tree core generally adopts low weight on bit and

low speed, but the weight on bit and speed can be appropriately increased when the core is entered. The drilling parameters of this well are shown in Table 1.

Table 1 Drilling parameters at different stages of coring

Type	WOB/kN	Rotational speed/rpm
Tree core	20	45
Centre	40	60

2.3. Boundary conditions for dynamic model of coring drill string

In this paper, the wellbore model of drilling string is established by using the measured borehole trajectory data. The coring process involves multiple physical processes. The finite element model diagram of the coring drill string dynamics is shown in Fig. 1. In the simulation process, the collision friction between the drill string and the well wall, the interaction between the drill bit and the formation rock, and the contact collision between the inner wall of the coring tool and the core should be considered. Under the action of a certain speed, the top of the drill column transmits torque to the bit through the drill string. In the process of the bit rotation, the core as a whole moves slowly upward along the central axis of the coring tool to realize the coring process. In this process, due to the transverse vibration and structural bending of the coring tool, the core collides with the inner wall of the coring tool.

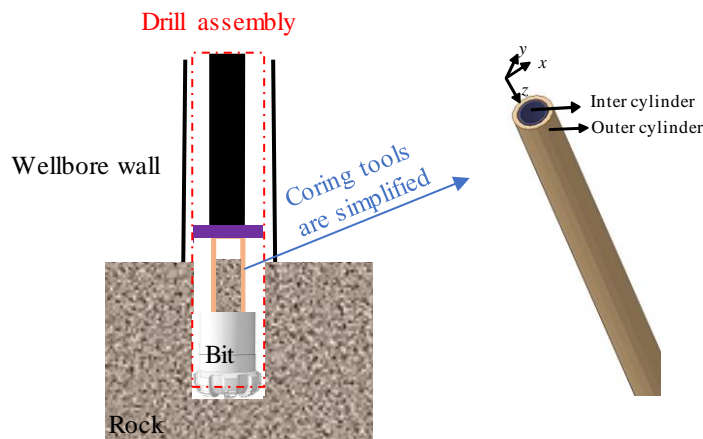


Fig. 1 Coring finite element model diagram

The coring tool is a structure consisting of an outer barrel and an inner barrel, and the inner and outer barrels have relative rotational motion in the axis. In the model, coupling constraints are applied according to the actual thickness and clearance of the inner and outer barrels, so that the inner and outer barrels of the coring tool have the same movement behavior of 5 degrees of freedom except rotation. The upper part of the outer barrel of the coring tool is connected with the drill string, and the lower part is connected with the drill bit to transmit the rock breaking torque and speed.

3. CORING PROCESS SIMULATION ANALYSIS

According to the coring assembly and drilling parameters shown in Table 1, dynamic parameters of drill bit, coring tool and lower 1000m drill tool were obtained through simulation calculation for analysis.

3.1. Tree core process analysis

Fig. 2 and Fig. 3 show the bit position bit weight fluctuation and eddy trajectory during the tree-center process. It can be seen from Fig. 2 that the bit position bit weight fluctuates between 13 and 26kN

when the bit weight is 20kN and the tree-center is 20kN. As can be seen from Fig. 3, the core bit just touched the broken rock at the bottom of the hole in the initial core stage, and its lateral swing displacement was about 2mm, that is, the hole expanded by 2.5% in the initial core stage.

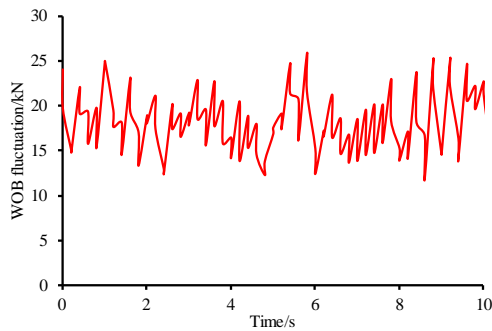


Fig. 2 Weight fluctuation in tree core process

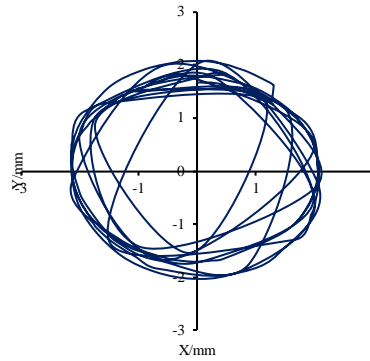
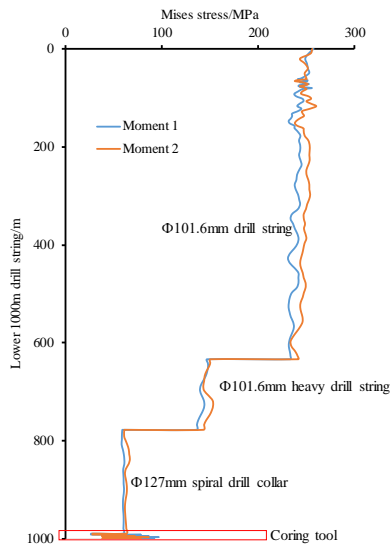
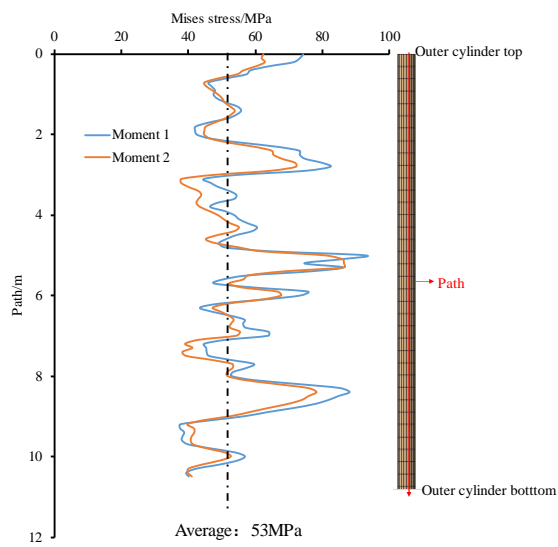


Fig. 3 bit movement trajectory in tree core process

Mises stress on the bottom 1000m drilling tool was extracted, as shown in Fig. 4. It can be seen from the figure that the Mises stress on the bottom 1000m drilling tool was the maximum with a diameter of 101.6mm S135I inclined-pipe (about 250MPa), and the diameter of the drill pipe with a diameter of 101.6mm from top to bottom was increased, while the wall thickness of the spiral drill collar with a diameter of 127mm was increased successively. Thus, the Mises stress is less than the diameter of 101.6mm S135I slope drill pipe during the tree-core process. Mises stress was taken along the top down path of the outer barrel of the coring tool, as shown in Fig. 4 (b). The Mises stress on the outer barrel of the coring tool was 53MPa on average, the maximum stress was about in the middle, and the fluctuation range was about 53MPa.



(a) Stress distribution in the lower 1000m drill string



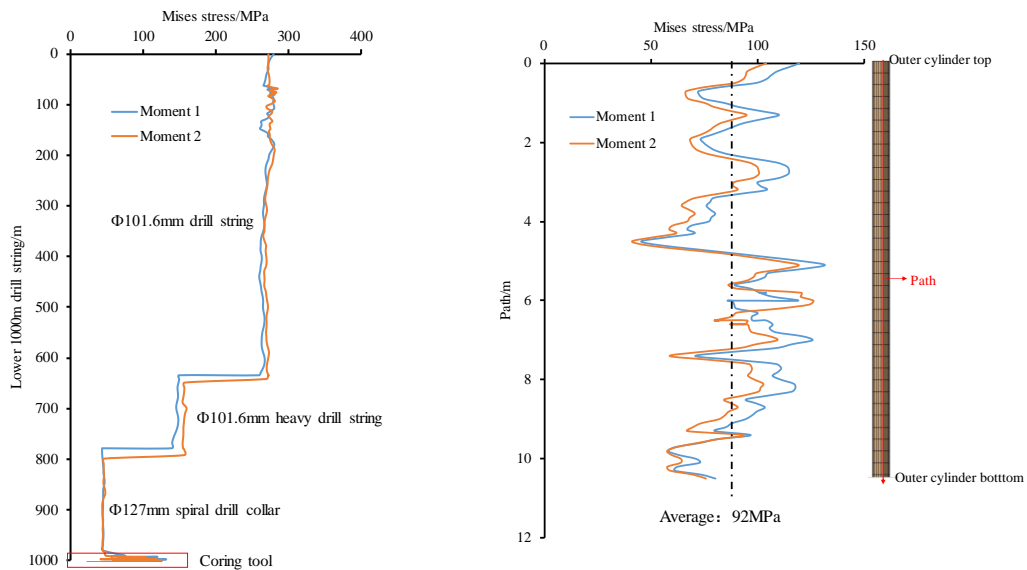
(b) Stress distribution in the outer barrel of the coring tool along the path

Fig. 4 Stress distribution of drill string and coring tool at the bottom of the core process

3.2. Analysis of entrapment process

When the core was drilled for 8m with a weight of 40kN on bit and a speed of 60rpm, the stress of the lower 1000m drill string was shown in Fig. 5, and the stress distribution law was similar to that of the tree-core process. The maximum stress was on the drilling pipe with a diameter of 101.6mm S135I on slope, and the stress value increased significantly due to the increase in weight on

bit and speed. The average stress of the outer barrel of the core tool along the path is 92MPa, the stress fluctuation is about 70MPa, and the stress level of the outer barrel of the core tool is high during the core process.



(a) Stress distribution in the lower 1000m drill string

(b) Stress distribution in the outer barrel of the coring tool along the path

Fig. 5 Stress distribution of drill string and coring tool in the lower part of the coring process

When entering the core, the core bit breaks the rock at the bottom of the hole, and the core length gradually increases. With the increase of drilling depth, the core gradually migrates upward, thus forming contact with the inner wall of the core tool, and extracting the contact force of the top position of the core over time during the core entry process, as shown in Fig. 6. It can be seen from the figure that the bit is constrained by the core hole during the initial core entry. The lateral swing amplitude of the lower position of the coring tool near the drill is small, so that the top of the core is not obviously contacted during the core entry, that is, the core integrity is high in the initial core entry stage. With the increase of core entry length, the contact force between the top of the core and the inner wall of the core tool gradually increases, corresponding to the increase in the lateral swing amplitude of the middle and upper part of the core tool, which exceeds the gap between the inner wall of the core tool and the core, and the larger contact force is easy to lead to local rock damage or the core is directly broken.

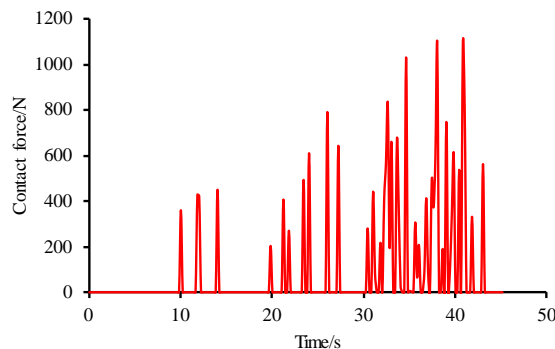


Fig. 6 Change of the contact force at the top of the core with time

When the core reaches 8m, the bending shape of the core-taking tool changes dynamically with time under the combined action of pressure, bending and torsion, resulting in the contact difference

between the inner cylinder and the core. Therefore, the core contact force cloud map at different times and the contact force on the whole core at different times are extracted, as shown in Fig. 7. It can be seen from the figure that when the core reaches 8m, The most serious contact between the inner cylinder of the coring tool and the core is basically at the position of 6.8m, and its contact force is about 1050N. The distribution of contact force also indicates that the inner cylinder of the coring tool has a high contact degree with the upper part of the core. Although the maximum contact force is at the upper part of the core, the fracture position of the core may be at the lower part of the core.

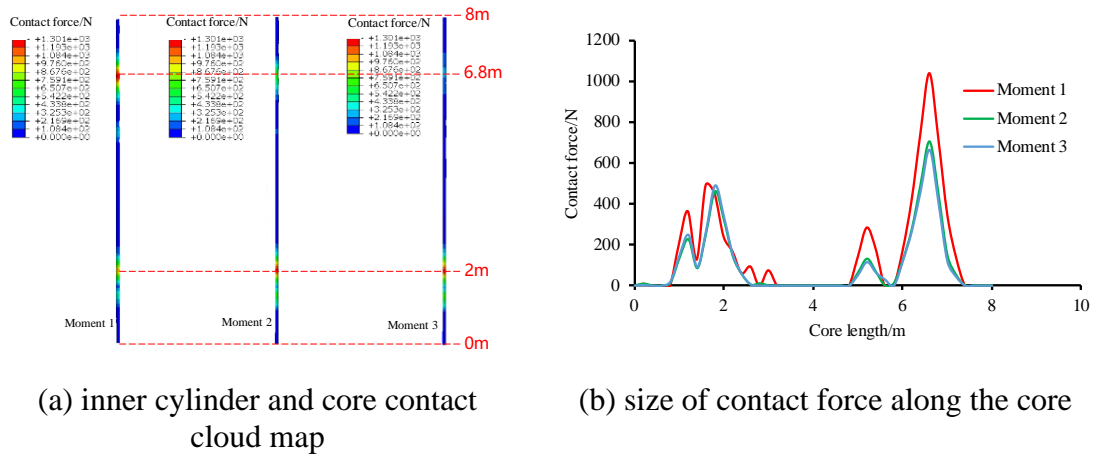


Fig. 7 The contact between the core and the inner barrel of the coring tool when the core is 8m

The inner diameter of the inner barrel is 86mm, the core diameter in the model is 80mm, and there is a gap of 3mm between the inner barrel and the core on the left and right. The transverse movement of the inner barrel at different positions during the core-taking process is shown in Fig. 8. The transverse swing amplitude of the inner barrel at 4m position is close to 3mm, so the contact degree at this position is low. The transverse oscillation displacement of the inner cylinder at the position of 8m exceeds 3mm at some times, so there is obvious contact collision with the core. The assembly uses a 166mm centralizer and the drill bit is constrained by the core hole, so the core tool bends the most in the middle and upper part of the assembly, which increases the length of the drill and puts the lower core at a higher risk of fracture, consistent with field knowledge.

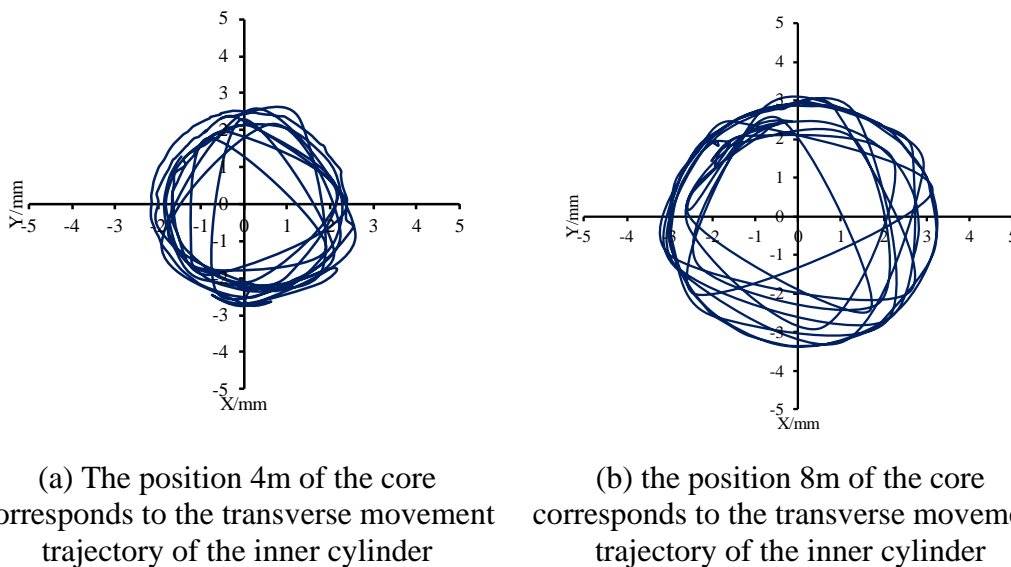


Fig. 8 Movement tracks of the inner barrel of the coring tool at different positions when the core is 8m

4. CONCLUSION

- (1) When using 20kN bit weight and 45rpm tree core, the core hole expansion rate is 2.5%, and the average stress of 140mm core tool outer barrel is 53MPa. With the interaction between bit weight, rotational speed and core, the stress and fluctuation range of the outer barrel of core tool increase.
- (2) When the core is driven for 8m at 40kN bit weight and 60rpm, the contact position between the inner cylinder and the core changes due to the difference in the bending position of the core tool during dynamic drilling process, but the contact position between the inner cylinder and the core is concentrated in the area of 5-7m, with the maximum contact force around 6.8m and the size of about 1050N.
- (3) The coring bit is constrained by the coring hole and the centralizer is used at the top of the centralizer, which makes the upper part of the coring tool bend and swing greatly, and the contact collision with the core is serious, resulting in a high risk of the lower part of the core being directly broken.

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