A new technique for high-fidelity cutting technology for hydrate samples

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Introduction—pressure maintaining transfer device

Fig. 1 Marine hydrate sampler

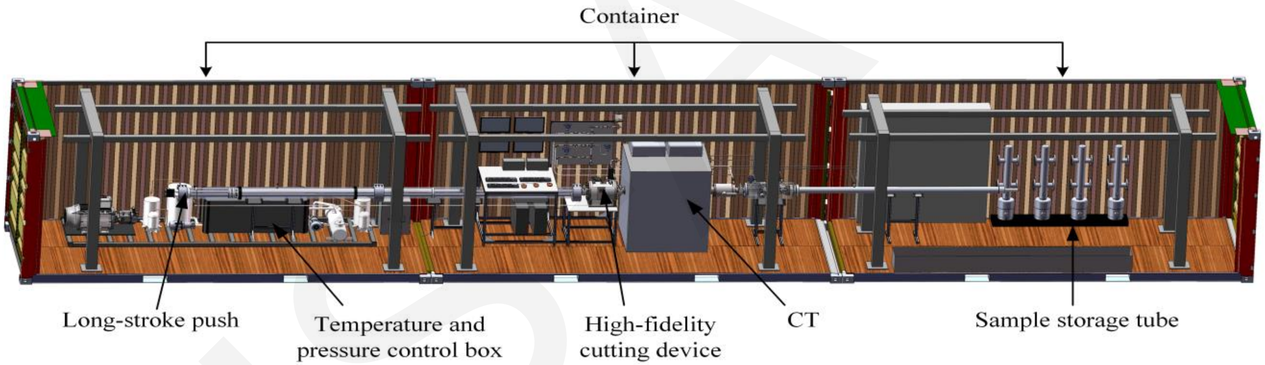


Fig. 2 Overall pressure maintaining transfer device

Drilling for samples is a conventional technique in marine resource exploration and geological investigation. Taking natural gas hydrates as an example, sampling natural gas hydrate to obtain relevant parameters can provide theoretical support for its commercial exploitation.

Designing a high-fidelity cutting device is one of the difficulties in hydrate samples pressure-holding transfer. Given the shortcomings of PCATS, our team has developed a new set of core pressure-maintaining transfer devices. Its structure is shown in Fig. 2.

Introduction—pressure maintaining transfer device

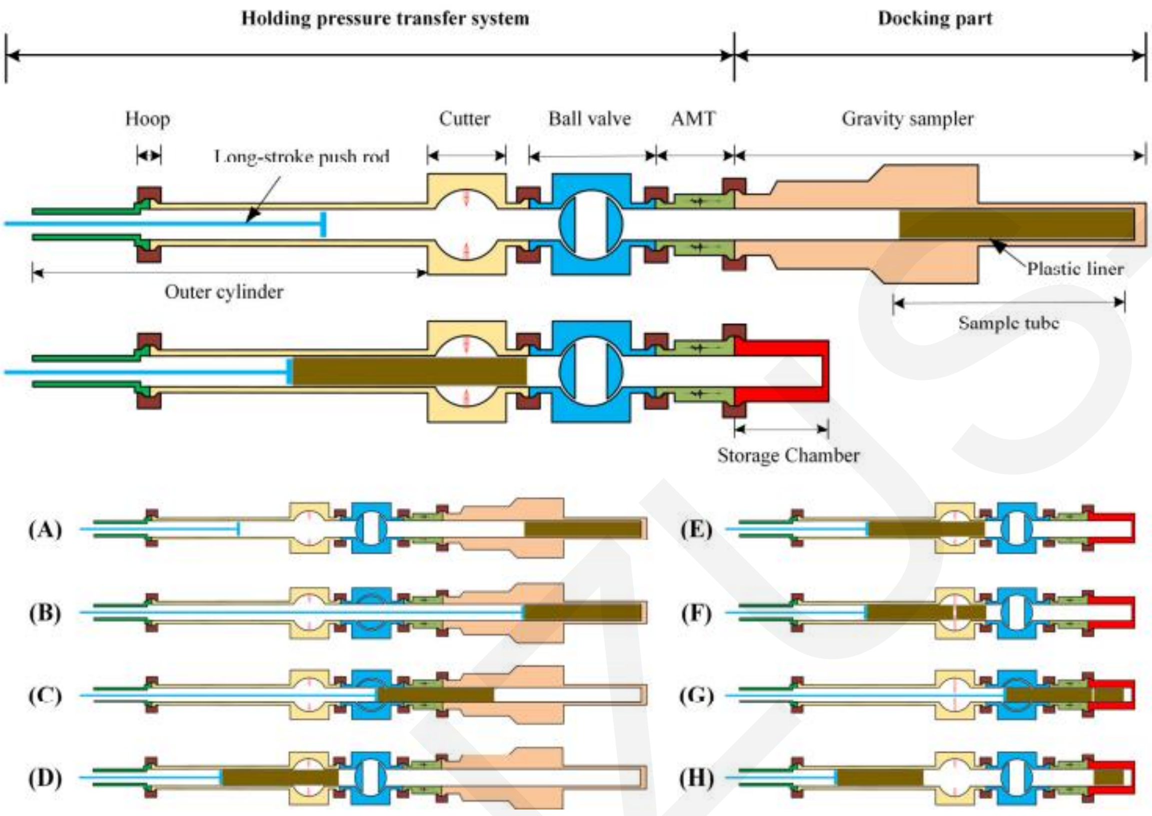


Fig. 3 Hydrate sample processing of the hydrate samples pressure-holding transfer system

A: Connect the gravity sampler and the deep-sea sample high-fidelity processing system via a hoop, turn on the temperature and pressure holding device, and adjust the temperature and pressure of the deep-sea sample processing system to the same point as the sampling point.

B: Open the ball valve to connect the gravity sampler with the deep-sea sample high-fidelity processing system, start the long-stroke push device, push the grab rod to the sample tube joint, and rotate the grab rod to make the connection between the two secure.

C: Maintaining the same temperature and pressure, retract the gripper to the CT, reduce the speed, and rotate the gripper while opening the CT for scanning to obtain the internal structure of the sample.

D: Wait until the CT scan is complete, continue to retract the gripper with the sample tube to the high-fidelity sample cutting device, and stop retracting. Then close the ball valve.

E: Open the hoop and disconnect the gravity sampler from the deep-sea sample high-fidelity processing system. Then the sample storage compartment is connected to the deep-sea sample high-fidelity processing system.

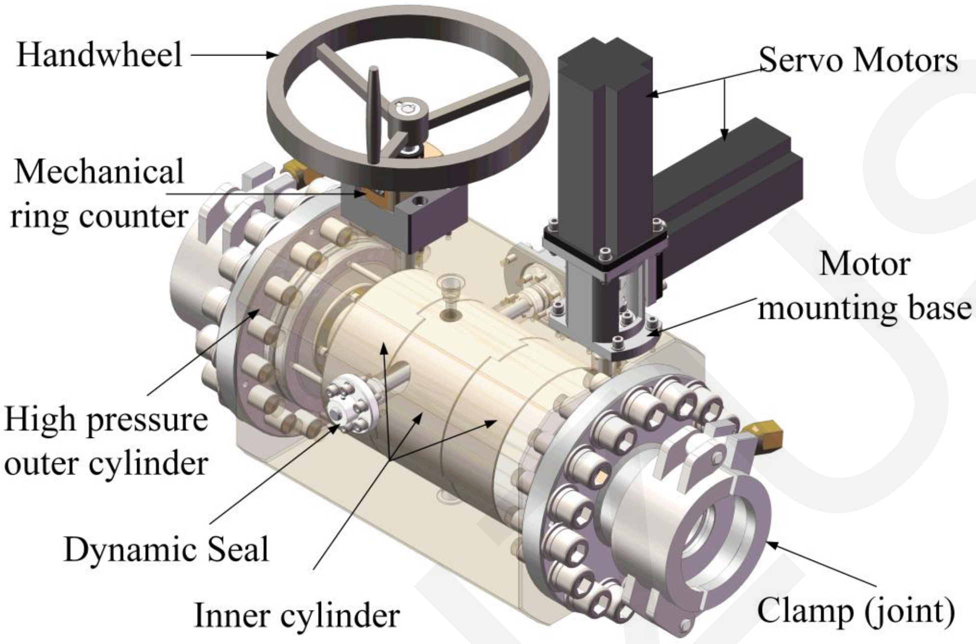
F: Hold the long-stroke pushing device still, open the clamping mechanism of the deep-sea sample high-fidelity cutting device to fix the sample tube, and open the cutting mechanism to cut the sample tube.

G: Wait for the sample tube to be cut. Open the ball valve and push forward the sample section to be cut as required into the sample storage compartment.

H: Retract the gripper and close the ball valve. The sample section to be cut is already in the storage compartment. Close the valve in the sample storage compartment and disconnect the clamp. The cutting is completed in one step. Repeat the above steps to cut the sample section again.

Mechanical structure design

- **Overall design of the high-fidelity cutting device**



(1) Working pressure: 30 MPa;
(2) Operating temperature: 2–4 °C;
(3) Pressure and temperature fluctuation during transfer: ≤10%;
(4) Single cutting time: ≤3 min;
(5) No sample contamination from cutting operations;
(6) Controllable cutting process and calculable cutter position.

Fig. 4 High-fidelity cutting device

Mechanical structure design

- **Internal structure composition**

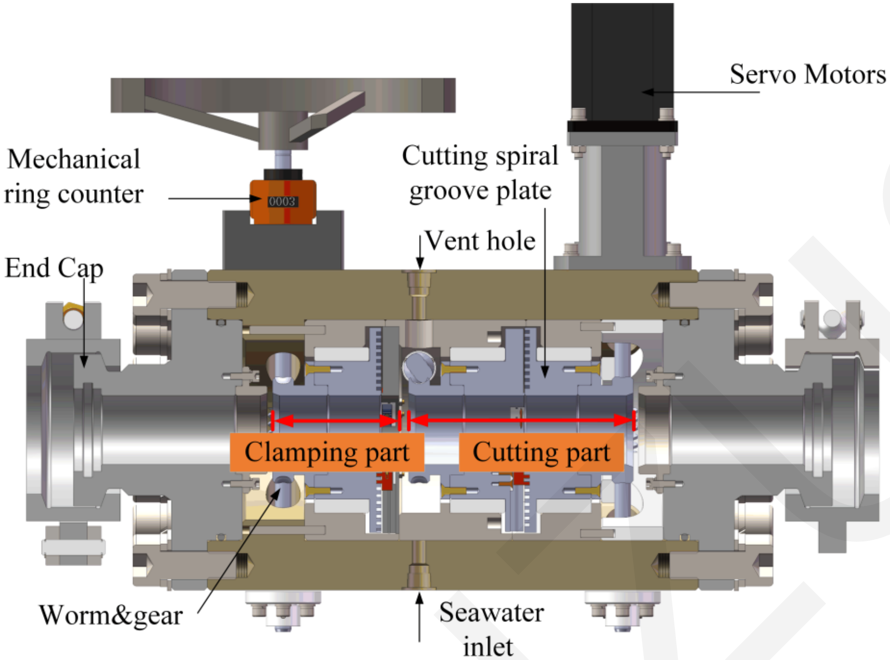


Table 1 Parameters of the high-fidelity cutting device

Parameter	Description
Total length of high-fidelity cutting device, *L* (mm)	618
Total width of high-fidelity cutting device, *M* (mm)	548
Total height of high-fidelity cutting device, *H* (mm)	518
Main materials of other parts	17-4PH
Alternating current (AC) servo motor model	DEL ECMA-J10807SS
High performance motion control type AC servo drive	DELTA ASD-A2-0743-M
Power of high-fidelity cutting device, *P* (W)	1500
Input voltage, *U* (V)	380

Fig. 5 High-fidelity cutting device

Mechanical structure design

- **Quality section guarantee method**

$$
\begin{cases}
x = \dfrac{p\cos(\theta)}{\pi} + \dfrac{p\theta\sin(\theta)}{\pi}, \\
y = \dfrac{p\sin(\theta)}{\pi} - \dfrac{p\theta\cos(\theta)}{\pi},
\end{cases}
$$

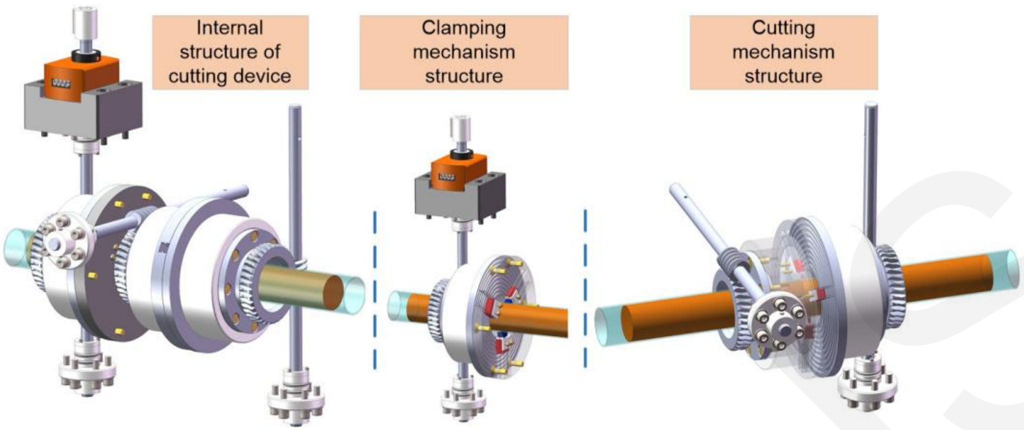


Fig. 6 Schematic realization of the high-fidelity cutting device

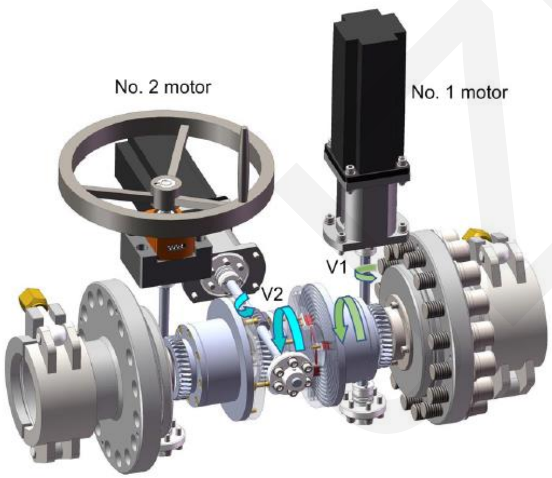


Fig. 7 Direction of rotation

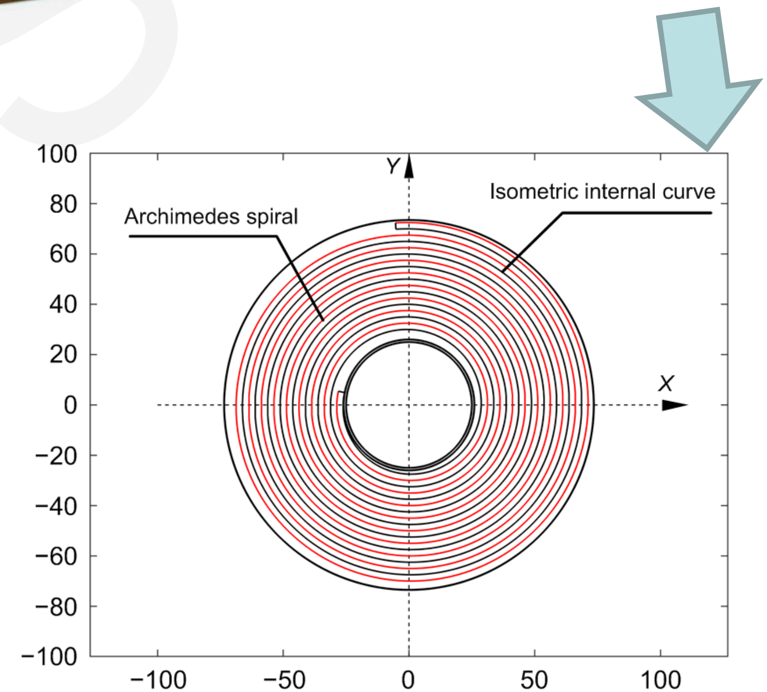


Fig. 8 Surface curve of spiral grooved plate (unit: mm)

Mechanical structure design

- **Realization of high-pressure dynamic seal and anti-silting design of the cutter**

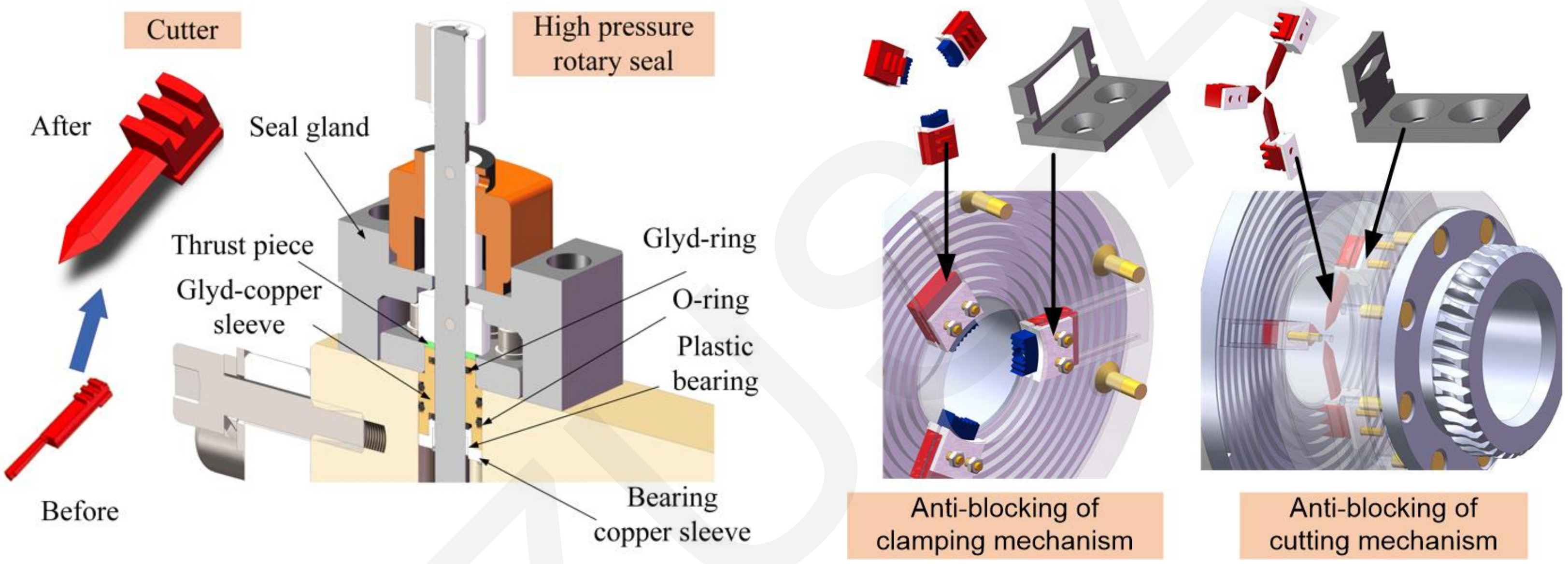


Fig. 9 High Pressure Dynamic Seal and Cutter Improvement device and anti-blocking design

Considering that the current cutting device adopts the combination of spiral groove plates and limit plates, there is a large gap between them, and chips will inevitably occur during cutting The presence of small stones and sludge in the sample makes it possible for impurities to enter the gap, leading to the tool' s rotary blockage. A set of anti-silting structures is designed separately based on spiral groove plates to prevent silt and small stones from entering the spiral groove plates and affecting cutting.

Electronic control design

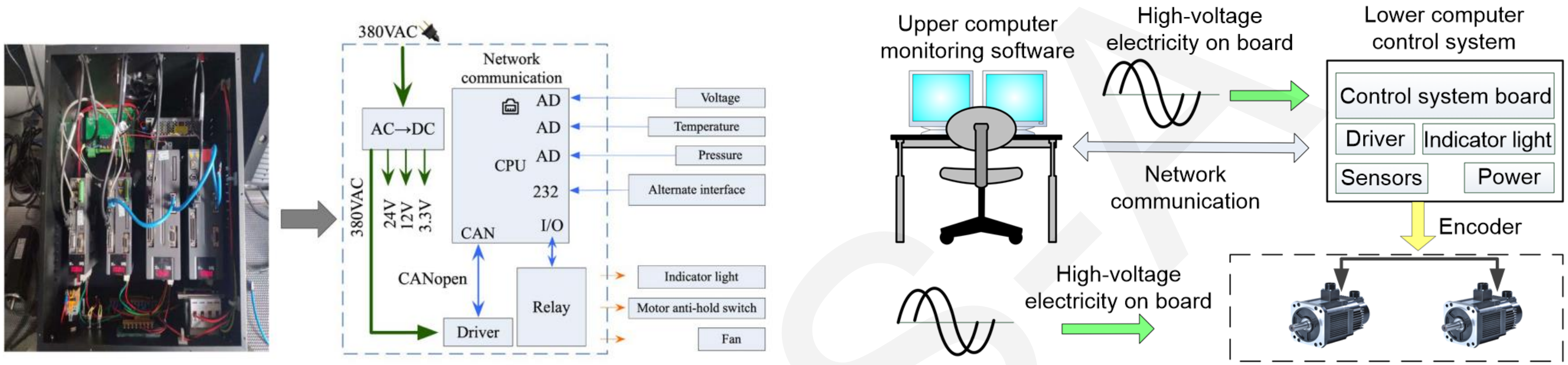


Fig. 10 Overall composition of the control system and hardware composition of industrial computer

Fig. 11 Upper computer interface

- Dynamic display region for sample handling: this dynamically displays the core sample tube position and provides position information for sample tube cutting.
- The status display for the cutting motors: this region dynamically displays the speed and torque of the cutting motor on a dial.
- Cutting control buttons: these regulate the core cutting process in the core tube by multiple control buttons for automatic control.
- Indicator light region: this displays the running status of the cutting motor, open or closed.
- Log region: the log preparation of network connection, with a text warning in case of a program operation error.

Force analysis and simulation

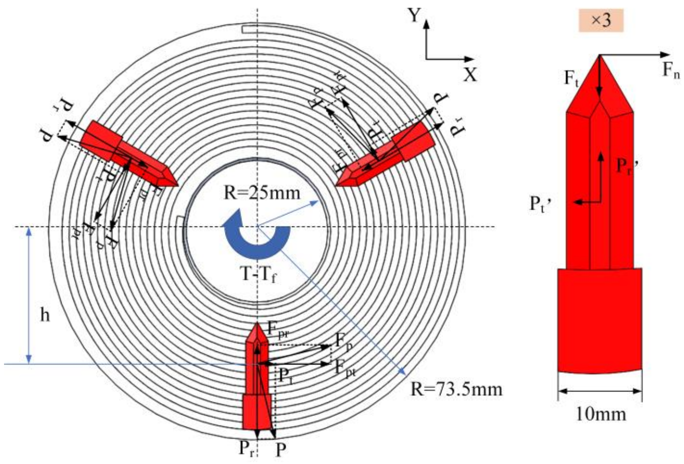


Fig. 12 Force analysis of cutters

In the upper model, θ is the helix angle (h), h is the radius of action of the disc wire plane thread, and the claw tooth arc is the reaction force of the disc screw plane thread on the effective radial driving force of the claw tooth arc, $\boldsymbol{P}$ is the magic force of the disc screw plane thread by the claw tooth arc, f is the friction coefficient of the contact surface part, $\boldsymbol{T}$ is the driving torque, $\boldsymbol{T_f}$ is the obstruction of the friction moment.

$\boldsymbol{P_r}$ is the required cutting radial force, which can also be obtained according to the cutting analysis. By combining the equations, the torque required by the motor can be obtained. The servo motors are selected according to the torque, and other factors (such as control method, power supply voltage, rated power, etc.) that are required.

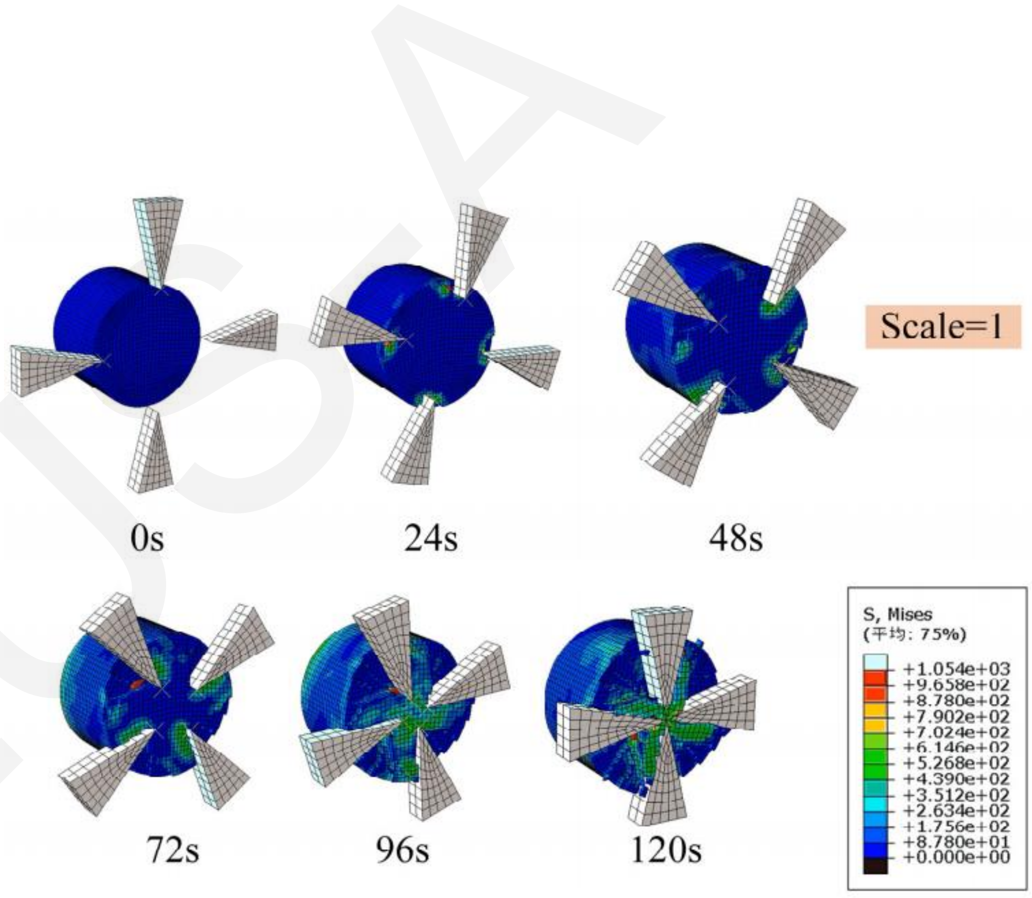


Fig. 13 Single cutting simulation

Experiment and conclusion

Fig. 14 cutting device and the cutting section of in-situ sample tubes

The equipment designed in this study can be used for high-fidelity cutting of deep-sea samples, thus providing important technical guarantees for the study of hydrates. It significantly supports research on marine energy and marine sediment cores. The hydrate is disturbed as little as possible, and is maintained as far as possible at its in-situ state.