

**TECHNICAL COUNTERMEASURES RESEARCH ON DEEP SEA
SHIPWRECK WATER CUTTING ENGINEERING**

Shengxiong Xue, Zhengwen Chen, Qile Ren, Yongqiang Wang, Songlin Cao, Caihong Han,
Di Zhang
Hefei General Machinery Research Institute, Anhui Province Key Laboratory of General
Machine Composite Material Technology
Hefei, Anhui, China

ABSTRACT

The emergency disposal method for deep sea shipwreck which contains fuel and liquid hazardous chemicals is firstly to discharge the loaded liquid. This aim is to create a safe condition before salvage. As for this engineering, this paper introduced the first step technical method for shipwreck salvage engineering. That is to use water cutting equipment to cut a 1-2 square meter rectangular or circular hole for underwater ship outer hull. And then install special equipment in the inner ship hull for drilling, plugging and pumping liquid. For 6000 meter deep sea shipwreck water cutting engineering, the whole set of cutting equipment is proposed to submerged and cooperated with ROV robot. The overall conception and working aim of deep sea shipwreck water cutting equipment was analyzed. And types and parameters of pre-mixed abrasive water cutting was also analyzed. The key technology of submarine pump, sand mixing container and water cutting head were summarized. Series of test development and the key nodes were designed. The above technical countermeasures are the whole process implementation plan for this set of deep-sea shipwreck water cutting equipment.

1. ENGINEERING BACKGROUND

At present, the shipping industry in China and the world has developed greatly. As the density of ships increases rapidly, the risk of ship accidents is increasing. When a deep sea shipwreck accident occurs, in order to discharge and recycle dangerous chemicals from the shipwreck carrying or loading, it must be adopted emergency disposal such as opening, drilling, plugging and pumping liquid for shipwreck [1-2]. As for double hulls of shipwreck outer and inner hulls, breaking and opening operation of shipwreck outer hull is the first step of emergency disposal procedure, that is to create a safe precondition for other shipwreck salvage procedures.

Water cutting is a mature and advanced technology developed both domestic and overseas during nearly twenty years [3-4], it has many technical advantages. Because of its no selectivity for the cut material, water cutting processing is widely used in application. Water cutting is a cold processing and does not produce any thermal accumulation effect. It has characteristics of high cutting quality and cutting speed. Furthermore, it can be realized to remote control and program operation. So it is quite suitable for a large amount of cutting application.

The deep sea environment is quite harsh, and the underwater depth of the shipwreck is hundreds of meters or even thousands of meters. Therefore, the salvage engineering operation for deep sea shipwreck is quite difficult. It needs higher short time efficiency for shipwreck outer hole opening, and it needs breaking and opening equipment to meet higher adaptability requirements of deep sea operation conditions. Water cutting technology can use seawater as the working medium, it can be realized remote operation especially with the development of ROV (Remote Operated Vehicle) technology [5-6], and water cutting technology has become the preferred technology for deep sea shipwreck outer hull breaking and opening salvage. However, there is not any application report around the world about a whole set of equipment submerged into deep sea for shipwreck water cutting. In 2008, the Norway company has used water cutting technology to cut Russian Kursk submarine under the Barents Sea. But this water cutting equipment was still running above the seawater. This paper introduced Chinese technology countermeasures of 6000 meters deep sea shipwreck water cutting engineering which has already been implemented.

2. DESIGN & SCHEME RESEARCH

2.1 Overall Conception and Working Aim of Deep Sea Shipwreck Water Cutting Equipment

On the premise of adapting to deep sea environment, shipwreck water cutting equipment is to form a stable and reliable water jetting conditions. And it is to achieve functions of straight line cutting, large diameter circular cutting, large square hole cutting and so on. It is also to complete the ship outer hull forming hole cutting, ship hull stiffened plates and bars attachment cutting. Then the shipwreck is applied to other special equipments close to inner hull for hole drilling, plugging and oil pumping operations and so on.

To achieve the above goals, deep sea shipwreck water cutting application should face technical problems as follows.

- 1) It should be to produce high parameters of water jetting in deep sea for effectively cutting 15mm thick of ship steel hull.
- 2) Cutting area should be as large as possible and meet operation requirements of other special equipments for shipwreck inner hull drilling, plugging and liquid pumping.
- 3) Because the abrasive used for water cutting is limited carried, the once work time under water is about 30min.
- 4) It should be realized to remote water cutting operation in deep sea environment.
- 5) As for 6000 meters deep sea, it needs to overcome ultra high confining pressure negative impact on the submerged water jetting.
- 6) Deep sea environment adaptability of shipwreck water cutting equipment.

To deal with the above problems, the technical scheme of deep sea shipwreck water cutting engineering includes as follows. Considering the resistance influence on water jetting produced by 6000 meters ultra high confining pressure and water cutting equipment operation reliability easily ensured in low limit section of water cutting pressure, pre-mixed abrasive jetting technology which is increased to 100-140MPa from the current level of pressure 50-60MPa. It can avoid complex structure and deep sea operation inadaptability of common mixed abrasive jetting technology. To meet requirements of forming large area cutting operation and remote control automatic water cutting, the whole set of water cutting equipment is cooperated with and powered by underwater ROV robot. Water cutting head is equipped with special adsorption guide component which is designed and installed on ship outer hull. It is to achieve self water cutting two-dimensional along the adsorption guide which is remote controlled by ROV, and the head's travel speed can be adjusted. In order to achieve higher cutting efficiency under water, the whole set of deep sea shipwreck water cutting equipment is optimized to extremely match the parameters of pre-mixed abrasive mixing vessel, ultra high pressure pump flow, water cutting head, water cutting time, water cutting speed and water cutting volume. A series of tests such like ground test, underwater test, pressure resistance simulation test and deep sea simulation test [7] are carried to explore the adaptability of the whole water cutting equipment. On the basis of the above technical scheme, the working aim of shipwreck water cutting equipment is to cutting a 1-2m² rectangular or circular large hole in the outer of the shipwreck hull.

2.2 Scheme of Deep Sea Shipwreck Water Cutting Equipment

The key technologies of deep sea shipwreck water cutting equipment: to develop ultra high pressure pre-mixed abrasive water cutting device, make the water cutting head travelling and cutting along the adsorption guide component has been installed on ship outer hull, integrate the whole set of equipment and submerge into the deep sea, and effectively cooperate with ROV and complete ship outer hull water cutting. The whole set of deep sea shipwreck water cutting equipment includes as follows.

- 1) Ultra high pressure sea water submarine pump unit shown in **Figure 1** is considered a generating device for ultra high pressure water jetting. The whole sea water submarine pump unit is an integrated frame unit and submerged into deep sea. In the deep sea environment, this main submarine pump of unit is a reciprocating pump to pressurize seawater and it is driven by a hydraulic motor which is powered by an underwater ROV robot.



Figure 1. Ultra high pressure sea water submarine pump unit

- 2) The pre-mixed abrasive mixing system uses 80 mesh garnet as abrasives. It is composed of abrasive mixing switch valve and two abrasive mixing vessels which are one work and one backup. This mixing system is used for storage abrasive and bearing 100-140MPa of ultra high pressure. And then it forms pre-mixed abrasive water jetting through abrasive mixing switch valve and abrasive nozzle.
- 3) Ultra high pressure water cutting executive device shown in **Figure 2** is the executive mechanism of deep sea shipwreck water cutting equipment. It contains water cutting head, adsorption guide component, driving mechanism, hose lines, etc. It matches and realizes fast connection with ROV interface. The water cutting executive device is wholly independent, which is suitable for engineering requirements of cutting shape and size. It is self stable adhesive to ship outer hull and combined with water cutting head. The driving mechanism controls water cutting head travelling along adsorption guide and keep the best target distance of water cutting. The water cutting head is remote controlled and to achieve two-dimensional direction operation. Abrasive mixing switch valve is also remote controlled to achieve switching function for abrasive water jetting.



Figure 2. Ultra high pressure water cutting device cooperated with ROV

4) Ultra high pressure water cutting head is fixed travel along adsorption guide of water cutting executive device. The abrasive mixing is straightly formed before abrasive nozzle, and pre-mixed abrasive jetting is sprayed by abrasive nozzle.

3. PARAMETERS & DEVELOPMENT RESEARCH

3.1 Type and Principle of Deep Sea Shipwreck Pre-mixed Abrasive Water Cutting

Abrasive water cutting technology involves a certain amount of abrasive particles into the pure water jetting. After abrasive and water mixing, the abrasive particles can be used to impact material with high speed of water jetting. It is greatly improving the ability of water jetting penetrating material.

A common mixed abrasive water cutting technology [8-9] shown in **Figure 3** uses water nozzle to spray water jetting and forms vacuum to absorb abrasive into the mixing chamber, and finally forms liquid and solid mixing jetting to spray from the abrasive nozzle. Because the acceleration time of absorbed abrasive is short and the water jetting after sprayed is quickly put into basic stage and dissipation stage of water jetting, it caused that the kinetic energy of accelerated abrasive is limited. So the water jetting pressure of common mixed abrasive water cutting materials must be reached 200-400MPa [10].

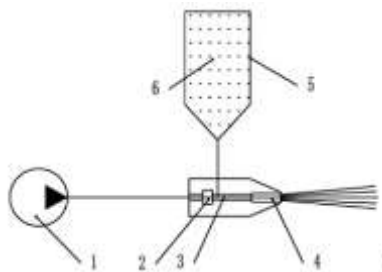


Figure 3. Principle of common mixed abrasive water cutting
1.Pump 2.Water nozzle 3.Mixing chamber
4.Abrasive nozzle 5.Abrasive tank 6.Abrasive

The shipwreck is in the extremely high confining pressure which is environment pressure. The confining pressure of deep sea shipwreck has resistance and damage to the formation and condensation of water cutting jetting. The higher the confining pressure is, the worse efficiency of water cutting jetting is. Deep sea shipwreck water cutting technology uses pre-mixed abrasive water cutting technology shown in **Figure 4**. That is, a part of ultra high pressure water (sea water) is put into abrasive mixing vessel and other ultra high pressure water is put into abrasive nozzle, abrasive and water is mixed and accelerated before abrasive nozzle, then abrasive water jetting of liquid and solid two phase jetting is sprayed from abrasive nozzle. As the abrasive is fully mixed in the water jetting and prolonged the acceleration time, the working pressure of pre-mixed abrasive water cutting is only 50-60MPa for the same cutting material. Because the pressure of pre-mix abrasive water cutting is reduced to the low level of ultra high pressure which is 100MPa of starting point,

the reliability of high pressure equipment has been greatly enhanced and the working pressure margin to overcome confining pressure of deep sea has also been improved. It is no doubt that the pre-mixed abrasive water cutting is the best technical scheme of deep sea shipwreck breaking and opening salvage.

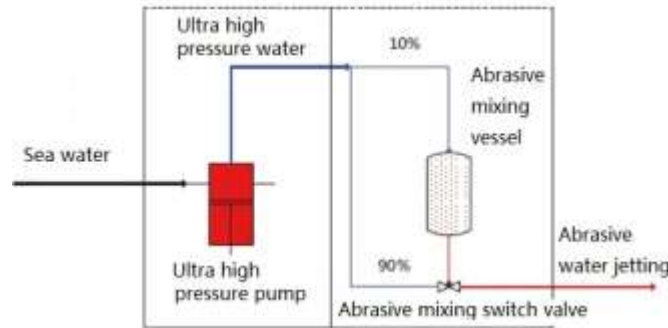


Figure 4. Principle of pre-mixed abrasive water cutting for deep sea shipwreck salvage

3.2 Working Parameters of Pre-mixed Abrasive Water Cutting in Deep Sea

It must be firstly faced harsh environment condition of 60MPa confining pressure about 6000 meters deep sea shipwreck water cutting engineering. In the domestic and foreign research and application, whether it is deep surface oil drilling or coal seam excavation, the confining pressures of these applications are both less than 1000 meters and these equipments are basically working on the ground. The real application with ultra high confining pressure environment which is under water is not common, but only there is a little application of the constraint conditions such as oil casing pressure. The direct and effective means of overcoming the confining pressure is to increase the water jetting working pressure. The author has carried out the ground experiment of pre-mixed abrasive water cutting and the experimental data are shown in **Table 1**.

Table1. Ground experiment data of pre-mixed water cutting

Parameters	Experiment situation					
	200	140	100	140	100	60
Pressure(MPa)	200	140	100	140	100	60
Flow(L/min)	10	17	27	10	15	15
Power of pump(kW)	55		30	30	22	
Water cutting speed of 10mm steel plates(mm/min)	800		600	400	300	
Water cutting speed of 15mm steel plates(mm/min)	600		400	300	240	

It can be seen from experiment that the better performance for water cutting 10-15mm steel plate is under 60MPa of pressure and 15L/min of flow. With the further incensement of pressure and flow, the efficiency of steel plate cutting is higher. When the pressure increases to 140-200MPa, the efficiency of steel plate water cutting is limited.

According to the experiment results of pre-mixed abrasive water cutting on the ground and the effect of ultra high confining pressure, the parameters of deep sea shipwreck water cutting engineering are 100-140MPa of pressure and 10-15L/min of flow. The pressure is distributed as follows. 1) The normal working pressure of pre-mixing abrasive water cutting is 60MPa. 2) The remote pressure losses and the seabed working pressure margin taken into account is 20MPa. 3) The pressure to overcome ultra high confining pressure of 6000 meters deep sea is 60MPa. 4) Because the above two pressures are evaluated relatively conservative, such as 6000 meters is limit depth, 100MPa of pressure and 15L/min of flow with equal power is used as test conditions.

Resistance force caused by ultra high confining pressure is still in qualitative and not quantitative research. Although ultra high confining pressure which is static pressure can greatly improve the inlet pressure of pump unit and cannot improve the outlet pressure of pump unit, it is only benefit to save the pump unit running energy because pressure of water jetting is produced by nozzle. In a word, confining pressure of seabed water jetting is a resistance force.

3.3 Key Technology of Submarine Pump

In order to obtain a stable and reliable ultra high pressure water cutting condition, the structure of the submarine pump is designed a three-plunger ultra high pressure pump shown in **Figure 5**. The pump structure is self balanced. The main body of this pump is composed of the power end and the liquid end. The submarine pump is submerged into the seawater environment, inside and outside of the pump is loaded the ultra high confining pressure. The material of the exposed parts uses a special high strength double phase stainless steel material to ensure the bearing confining pressure. The key components such as dynamic seals etc. are corrosion resistant materials and composites. And they use sea water to lubrication. In order to apply for deep sea environment, the driving unit of the submarine pump is a hydraulic motor, its hydraulic characteristics are highly matched with the liquid characteristics of the submarine pump and 300rpm of pump rotary speed.

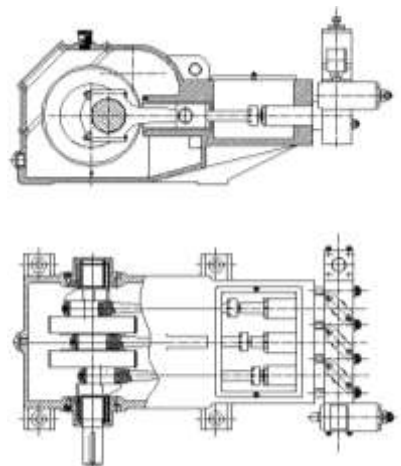


Figure 5. Structure of submarine pump

A notable feature of the submarine pump is that all rotating parts of power end are not rolling bearings, but sliding bearings and axial balancing systems. Because rolling bearings are easily to damage or even seized without oil lubrication in the seawater environment.

3.4 Key Technology of Abrasive Mixing Vessel

As ultra high pressure vessel, abrasive mixing vessel is pressurized 140MPa. It is difficult to improve the volume under this pressure. The whole set of deep sea shipwreck water cutting equipment uses two abrasive mixing vessels, every vessel is designed 25L of volume and 100kg of storage. After 30min water cutting operation using one abrasive mixing vessel, another spare abrasive mixing vessel can be switched to use according to the needs.

The abrasive mixing vessel is bolted to the head, and it is inclined reliably and fixed. The ultra high pressure water of deep sea shipwreck water cutting is entered from the upper end of the vessel, and the abrasive is mixed and absorbed from the bottom of the vessel. The abrasive mixing switch valve is installed in the bottom of this vessel, and the consumption of the pre-mixed abrasive is adjusted about 3kg/min. The Abrasive mixing vessel is resistant to seawater corrosion. The ultra high pressure water is entered into chamber and is mixed with dry abrasive, then it is realized realize uniform and stable supply of abrasive mixing through switch valve.

3.5 Key Technology of Water Cutting Head

After mixing the water with abrasive, the ultra high pressure abrasive water jetting is sprayed through the water cutting head. As the final executive component, it is not only subjected to seawater corrosion but also it has good abrasion resistance to the high speed abrasive water jetting. The design of water cutting head is matched with the parameters of pre-mixed abrasive water jetting. The bore of the abrasive nozzle should have a considerable ratio of length to diameter, which is conducive to the condensation and straight line of abrasive water jetting.

3.6 Series of Tests Development and Its Key Points

The whole set of deep sea shipwreck water cutting equipment and application cannot be separated from engineering test. Series of tests will play a guiding role in improving equipment development, forming commercialization and standard application. The series of tests include as follow.

- 1) Equipment performance parameters tests. It is carried out according to the test method specified by GB/T 26163 ultra high pressure water cutting machine and JB/T 6909 ultra high pressure pump. Through the performance parameters experiments of the submarine pump, abrasive mixing vessel, water cutting head, other components and the whole set of equipment, the design parameters are confirmed to achieve the expected design target.

- 2) Underwater test. It is carried out with simulation device of using deep sea shipwreck salvage. According to the emergency salvage procedure, the effect of ultra high pressure water cutting experiment in conventional tanks is gradually tested, and the operation reliability of the whole equipment under submerged conditions is confirmed by this test.
- 3) Pressure resistance simulation test. It is adopted high pressure container which is used for simulation 6000 meters deep sea confining pressure environment. This experiment is to put the components into ultra high confining pressure, the whole set of equipment pressure resistance test is depending on the overall terms and conditions. This experiment includes static pressure resistance test, dynamic pressure resistance test, performance test, remote monitoring operation of equipment components. The performance of the equipment under ultra high confining pressure condition is confirmed by this test.
- 4) Deep sea test and application. On the premise of meeting the requirements of above tests, deep sea shipwreck water cutting equipment is submerged into deep sea by the Diving salvage ship and coordinated with ROV shown in **Figure 6**. To achieve the working aim of application, the deep sea experiment is to realize the complete underwater operation such like the connection of submarine, adsorption guide laying and installation, achieve underwater power, underwater start-up and remote control for 30-50 meters, deep sea water cutting operation and so on.



a) The Diving salvage engineering ship



b) ROV robot for deep sea shipwreck salvage

Figure 6. Salvage ship and ROV

4. CONCLUSION

Pre-mixed abrasive water cutting technology of 100-140MPa is suitable for 6000 meters deep sea shipwreck water cutting engineering. Proof basis and technical scheme are convincing and feasible. Ultra high confining pressure, ultra high pressure abrasive water jetting in deep sea, abrasive mixing and control, water cutting operation are the key technical countermeasures for deep sea shipwreck water cutting engineering. The whole set of deep sea shipwreck water cutting equipment, make ultra high pressure submarine pump and ultra high pressure water cutting device coordinated with ROV as the core components of shipwreck salvage, can completely adapt to deep sea operation requirements. Series of tests including four tests are important parts of equipment development, and

they are an indispensable progressive part. It still needs to be continually modified and adjusted for above technical countermeasures in the implementation processing. Especially it is necessary to refine the design and test for underwater less action frequency and even non action.

5. ACKNOWLEDGMENTS

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