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# **Development of Deep Sea Pipeline Position and Attitude Measuring Device Based on Flange Center Positioning**

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Abstract. In order to reduce the measurement uncertainty of deep sea pipeline position and attitude measuring device based on flange centre positioning, this paper evaluates the solution process of pipeline pose and proposes a positioning method based on flange centre positioning. The problem of deep water riser measurement operation is solved on the basis of reducing the uncertainty. The final design-related prototype verifies that the measurement method can effectively reduce the uncertainty based on the accuracy.

#### 1. Introduction

With the development of offshore engineering technology and the growing demand for energy, deepsea oil and gas exploration equipment and technology have also become a hot spot in the international marine engineering community. In the oil and gas fields with proven reserves of over 100 million tons in the past 10 years, marine oil and gas fields account for about 60% and half of them are in waters with a water depth of more than 500m [1-4]. This indicates that there are a lot of oil and gas resources in the vast deep waters. For the development of deep-water oil and gas, the main problems are: complex and extreme seabed environment, high pressure, and low temperature in deep water, underwater separation and production operations, and long-distance underwater return operations [5, 6]. Submarine pipelines are the most viable way for transporting offshore oil and gas worldwide [7]. Experience has shown that underwater return technology is an important technology in the process of deep sea pipeline laying, which is of great significance for the development of oil and gas [8, 9]. Considering the topographical factors of the seabed and the impact of the harsh environment of deep water, how to accurately measure the relative spatial position such as the spacing and angle between the flanges of the two seabed pipes is the main problem solved by the underwater returning technology [10-12].

#### 2. Scheme design of pipeline pose measurement device

#### 2.1. Overall structural design of the measuring device

The system is divided into five parts in modular form, including: flange docking mechanism, angle measuring mechanism, auxiliary measuring rope length detecting mechanism and auxiliary ROV. The flange docking mechanism positions and mounts the measuring device through the flange. The angle measuring mechanism includes a quadrature tilt angle and a pitch and yaw angle measuring mechanism

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for measuring the angles of the auxiliary measuring rope. The auxiliary measuring rope detecting mechanism mainly functions to detect the length of the measuring rope. The auxiliary ROV is equipped with flange cleaning tools, manipulators and winches. The main function is to assist the installation and recovery of the measuring system; the main function of the winch is to retract and tension the auxiliary measuring rope; the overall scheme of the system is shown in 'figure 1'.



Figure 1. Pipe attitude measurement system schematic

'1' is measured pipe I, '2' is butt device I. '3' is measuring device II. '4' is measuring rope. '5' is measuring device I. '6' is auxiliary ROV. '7' is docking device II and '8' is pipeline tested II.

#### 2.2. Flange docking mechanism structure design

It is the key to reduce the measurement uncertainty to ensure the accuracy of the alignment between the lead-out point of the measuring rope and the center-line of the flange or pipe. The main function of the flange docking mechanism is to provide reliable positioning accuracy and clamping force for the measuring device. The structure diagram is shown in 'figure 2'.



Figure 2. Schematic diagram of flange docking mechanism.

### 2.3. Research on sstructures of oorthogonal dip angle mmeasurement mmechanism

Since the submarine pipeline is affected by factors such as the external environment, a certain posture change occurs, that is, the pipeline actually has a horizontal swing in the horizontal plane, a pitch swing in the vertical plane, and a slight rotation about the axis. Therefore, when the measuring device is mounted by the flange docking mechanism, the rotation angle  $\beta$  with respect to the  $x_r$  axis is generated by the attitude of the flange, and the measuring device has a rotation angle  $\alpha$  with respect to the  $y_r$  axis, as shown in 'figure 3'. The orthogonal inclination measuring mechanism uses the orthogonal inclination sensor to measure the angles  $\alpha$  and  $\beta$  as shown in 'figure 4'.

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Figure 3. Pipeline actual position and orientation

Figure 4. Orthogonal inclination measuring me

The ANSYS simulation is used to solve the stress and strain of the sealed shell under the pressure, as shown in 'figure 5' (a), (b).



Figure 5(a). Sealed shell strain and stress oud1. Figure 5(b). Sealed shell strain and stress cloud It can be obtained from the analysis of simulation results, which meet the strength requirements.

#### 3. Mathematical model establishment of pipeline pose measurement system

The solution model for establishing a deep sea pipeline pose measurement system based on flange positioning is shown in 'figure 6'. The measuring devices I and II are respectively installed on the flange end faces of the tested pipes I and II, and the two flange end faces respectively correspond to the planes C and D, and the protruding points of the measuring ropes in the two measuring devices are points A and B, respectively. A and B are planes A and B and planes C and D, respectively. The central axis of the pipe of the pipe I to be tested and the planes A and C are respectively assigned to points A and Or, and the central axis of the pipe of the pipe to be tested II and planes B and D are respectively assigned to points B and O<sub>b</sub>. The absolute coordinate system  $\Omega_R$  is established with O<sub>r</sub> as the origin, and the reference coordinate system  $\Omega_1$  is established around the x-axis and the axis rotation coordinate system  $\Omega_R$  to  $\beta_r$  and  $\alpha_r$ , that is, the central axis of the measured pipe I is the axis direction of the coordinate system  $\Omega_1$ . Similarly, the absolute coordinate system  $\Omega_b$  and the reference coordinate system  $\Omega_3$  are established. The measurement system includes: a total of 9 measured values of  $\alpha_r$ ,  $\alpha_b$ ,  $\beta_r$ ,  $\beta_b$ ,  $\gamma_r$ ,  $\gamma_b$ ,  $\theta_r$ ,  $\theta_b$ and  $S_r$ , as shown in 'figure 6'.

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Figure 6. Schematic diagram of pipeline pose measurement system According to 'figure 6', Calculated by the calculation of the transition matrix:

$$\begin{cases}
O_R O_{bx} = \begin{vmatrix}
L(S\eta S\alpha_r - C\eta C\alpha_r S\gamma_r) \\
-m_2 S\Delta P C\beta_b
\end{vmatrix} \\
O_R O_{by} = \begin{vmatrix}
m_1 C\beta_r + LC\eta (C\beta_r C\gamma_r - S\alpha_r S\beta_r S\gamma_r) \\
-LS\eta C\alpha_r S\beta_r + m_2 C\Delta P C\beta_b
\end{vmatrix}$$
(1)  

$$O_R O_{bz} = \begin{vmatrix}
m_1 S\beta_r + LC\eta (S\beta_r C\gamma_r + C\beta_r S\alpha_r S\gamma_r) \\
+LS\eta C\alpha_r C\beta_r - m_2 S\beta_b
\end{vmatrix}$$

$$\begin{cases} \xi x = 90^{\circ} - \xi y \\ \xi y = \arctan(S \Delta p C \beta_{b} / (C \Delta p C \beta_{r} C \beta_{b} - S \beta_{r} S \beta_{b})) \\ \xi z = \arcsin(-C \Delta p S \beta_{r} C \beta_{b} - C \beta_{r} S \beta_{b}) \end{cases}$$
(2)

# 4. Pipeline attitude measuring device experimental scheme

4.1. Experimental prototype overall plan

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Host computer PLC Power supply Taut wire Pipe II Figure 7. Experimental measuring device

Pipes I and II are placed on the rails to move the pipe position. The pipe II can realize the horizontal and vertical swing adjustment and the vertical direction lift adjustment. During the experiment, different relative position and orientation between the pipes can be simulated by moving the pipe II and adjusting its horizontal, pitching and vertical heights.

#### 4.2. Experimental measurement step

- In step a, measure the distance between the drawstring points of the two measuring devices from the end face of the pipe, and then adjust the height of the pipe I to be equal to the pipe II, and align the two slide rails of the installed pipe. The mobile experimental platform II aligns the angle measuring mechanisms in the measuring devices I and II, and at this time, the initial data of each sensor is collected by controlling the upper computer.
- In step b, move the pipe II to different positions on the slide rail, observe and record the measurement data of each sensor on the upper computer, and measure the relative distance and angle of the two pipes as reference values by using the laser range finder and the angle measuring instrument.
- In step c, the swing cylinder piston rods are returned to the initial position, at which time the centre of gravity of the dredging robot moves forward a distance.
- In step d, use the host computer to solve the relative pose and compare it with the data directly measured by the measuring instrument. The measured data is shown in 'Table 1'.

Measuring component	category	2m	3m	4 m	5 m	6m	7m
$O_R O_{bx}$	Actual value(mm)	0.0	0.0	0.0	0.0	0.0	0.0
	Measurement(mm)	4.7	9.2	13.1	16.8	23.1	30.5
$O_R O_{by}$	Actual value(mm)	2000.0	3000.0	4000.0	5000.0	6000.0	7000.0
	Measurement(mm)	1994.8	3004.1	4008.3	5014.8	6016.8	7025.2
$O_R O_{bz}$	Actual value(mm)	0.0	0.0	0.0	0.0	0.0	0.0
	Measurement(mm)	-2.1	9.6	11.9	18.8	32.5	46.9
ξx	Actual value(°)	0.0	0.0	0.0	0.0	0.0	0.0
	Measurement(°)	0.2	0.3	0.6	0.9	1.0	1.1
ξγ	Actual value(°)	90.0	90.0	90.0	90.0	90.0	90.0
	Measurement(°)	89.8	89.5	89.3	89.0	89.1	88.9
ξz	Actual value(°)	0.0	0.0	0.0	0.0	0.0	0.0
	Measurement(°)	0.2	0.3	0.7	0.6	0.8	0.9

Table 1. Main parameters of hydraulic cylinder

### *4.3. Experimental measurement step*

It can be seen from 'Table 1' that the experimental error of the pipe measuring device based on the centre of the flange is smaller, and the table shows that the positioning mode can effectively reduce the uncertainty by about 30% when the centre distance between the two pipes is greater than 5 m.

# 5. Conclusion

Analysis of the data of the deep sea pipeline pose measurement system shows that the measurement method based on the flange centre positioning can reduce the error value by 30%. This experiment verifies that the measurement system can reduce the measurement uncertainty better under the premise of ensuring the measurement accuracy, and has a good application prospect.

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# References

- [1] Zhang.D.W. (2014). Discussion on the status quo of offshore petroleum engineering equipment. China Chemical Industry, 27:193-193.
- [2] Yu. X.C., Wang. C. S., Li.B. (2017). Research on pigging strategy of underwater return pipeline in Deepwater oil and gas field in South China Sea. Ocean Engineering Equipment and Technology, 4: 199-204.
- [3] Pettingill. H., Weimer.P. (2002).Worldwide deep-water exploration and production past present and future. Lead. Edge, 21:371-376.
- [4] Gao. Y.B., Li. H.Q., Chai. Y.P. (2010).Current status and trends of high-tech development in deep seas. Ocean Technology, 29: 119-124.
- [5] Shi. L. X., Li.Z.G. Zhao.D.Y. (2008). Submarine pipeline connection technology. Natural gas industry, 28: 106-108.
- [6] Wang.L.Q. Dong.J.B., Zhang.W. (2012). Design of docking equipment for deep sea pipeline. Natural gas industry, 32: 75-78.
- [7] Zhang.L. Xin.L. (2019).Thermal vertical buckling of surface-laid submarine pipelines on a sunken seabed, Ocean Engineering, 173:331-344.
- [8] Liu.F. (2018). Research on design method of sub-sea pipeline expansion and bending installation under special working conditions. Piping Technology and Equipment, 151: 34-35+39.
- [9] Pei.L. (2013).Driverless Maintenance Connection Technology of Sub-sea Pipeline. China Petroleum Machinery, 41: 57-61.
- [10] He.N., Wang L.Q., et al.(2010). Design and Simulation Analysis of Deep Sea Pipe Flange Connection Machines, Journal of Cheng University, 31: 559-563.
- [11] Korn.M. Mesineni.S., Hu.W. (2015).Modelling and simulation; sub-sea step out and tieback.In: Offshore Technology Conference, Houston, pp.3294-3303.
- [12] Yokley.J.M. Payne.C.W. (2013).Hybrid-Tieback SEAL ASSEMBLY: US20130299176.