The Investigation of Internal Turret Single Point Mooring Slip Ring Structure Design

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Abstract. Research the structure of turret mooring system slip ring abroad, for the first time in China presents a slip ring structure design, contact fatigue, finite element analysis of the key components of the brush, and through the research on the feasibility of assembly precision test equipment, main circuit resistance and withstand voltage, power frequency withstand voltage and dynamic continuous high current test of static electric slip ring in the working process and rationality.

1. Introduction
Along with the rapid growth of the national economy, China's demand for energy is also growing rapidly. As an efficient and clean energy source, natural gas will also become China's preferred alternative fuel, and it will become a key industry supported by the state. In the next few years, China's consumption of total natural gas will have more than 50% of its consumption demand from abroad, so a large amount of imported natural gas will become an inevitable trend of China's energy composition. Facing the abundant oil and gas storage resources in the deep sea of the South China Sea, the use of the internal turret single point mooring LNG-FPSO with wind vane effect is widely recognized as an oil and gas production method; In addition to the single point mooring system design technology, the electric slip ring required to connect the rotating and non-rotating oil and gas pipelines in this type of single point system is a key component of the core of the single point mooring system. At present, CNOOC's FPSO used in China's waters, its single-point mooring system and electric slip ring are all monopolized from design to processing and manufacturing, and the technical blockade is very serious [1]. This paper will propose a structural design of an electric slip ring, one of the key components in the internal turret-type single-point mooring system, thus breaking the monopoly of foreign companies that rely solely on imports and key technologies in this field.

2. The origin and characteristics of the turret-type single-point mooring system
In the early 1980s, SBM proposed a turret-style concept and installed the device in the stern of a floating storage tanker, officially applying the turret concept to practice [2]. Subsequently, the company further developed the external turret to release the riser mooring system and applied it to the development of the Jabiru oil field in the hurricane area of the northwest coast of Australia, thus opening the door to research and development of turret mooring technology [3]. The turret mooring works in the same way as other single-point mooring methods. It also fixes the FPSO to the mooring point at sea through a certain connection. It can be rotated 360° in all directions with the action of wind, waves and water flow to form a weather vane effect. In order to avoid the destructive power caused by wind and waves, the environmental load and motion response of the system under the
external disturbance of wind and waves are reduced. The turret mooring system is mainly composed of four parts: turret, liquid transmission system, turret rotation system or turntable, and interface connection system. The turret is not only the mooring point of the FPSO, but also the passageway of the riser and other umbilical system to the hull deck through the seabed. The relatively fixed characteristics of the pontoon and the deck facilities ensure that the FPSO can also be realized with the subsea wellhead under complicated sea conditions. Intermittent oil and gas transportation is the core of turret mooring technology [4, 5]. The internal turret single point mooring system is one of the three core components of the offshore FPSO system, with investment (design, manufacturing and offshore installation) accounting for approximately one third of the entire FPSO system. The FPSO hull part design and construction technology has been fully mastered in China; the FPSO upper process processing module has system integration design capability in China, but the main process processing equipment relies on imports [6].

3. Electric slip ring structure design
The electric slip ring can improve the system performance, simplify the system structure, avoid the sprain of the wire during the rotation process, and is a precision power transmission device that realizes the image, data signal and power transmission between the two relative rotating mechanisms [7]. The single-point electric slip ring is responsible for the power transmission function of the oil field. It is the core component of the oil field with FPSO as the main production body, and its reliability and safety directly affect the normal operation of the oil field [8]. For the single-point electric slip ring system, the brush and the collector ring inevitably cause contact failure during the long-term contact rotation. The first symptom of this phenomenon is the partial discharge phenomenon caused by poor contact on the two electrical contact surfaces. Once the partial discharge occurs on the contact surface, the temperature will rise rapidly in the local volume close to the surface of the medium, causing thermal fusion of the medium. Microscopically, ablation occurs on the electrical bonding surface, which makes the contact between the brush and the fixed copper ring more. Large air gaps result in the occurrence of a larger number of partial discharge phenomena, resulting in a vicious cycle that ultimately leads to failure.

The structural design of the electric slip ring of the internal turret type single point mooring system proposed in this paper can avoid the partial discharge phenomenon caused by the poor contact between the two electrical contact surfaces of the brush and the collector ring by the following two methods. (1) The elastic conductive finger is designed and installed on the brush. When the micro-surface jump occurs during the installation of the collector ring, the elastic adjustment can be made to ensure the contact area of the two electrical contact surfaces to meet the requirements of conduction and signal transmission. (2) The two guide pillars distributed in the middle and the middle of the brush form an adaptive structure for adjusting the working position of the brush along the axial direction of the guide pillar. When the collector ring has a surface jump of more than 1mm, the contact position of the brush and the collector ring can be automatically adjusted. The above two methods can effectively avoid the occurrence of partial discharge phenomenon caused by poor contact between the brush and the collector ring from the elastic adjustment and the displacement adjustment.

Figure 1. Offshore oil 113 original single point electric slip ring.
3.1. Brush assembly structure design

3.2. Elastic contact conductive finger contact static analysis
Since the model is symmetrical and reduces the amount of calculation, one-half model is used for analysis. The tetrahedral element is used for discretization, and the model grid is set to a size of 0.0002m, which is divided into 95,904 nodes and 61,145 cells. According to the actual fixed state of the brush, the lower end of the brush constrains all degrees of freedom [9]. Since the structure has symmetrical features, in order to reduce the amount of calculation, 1/2 of the model is analyzed, and symmetric planes are applied with symmetric constraints. Set the upper plate to contact the spring piece with a coefficient of friction of 0.1.
For the overall analysis and calculation of the elastic contact conductive finger, the maximum stress appears at the position where the spring piece is in contact with the bottom end, and the maximum stress value is 96.1MPa. The maximum stress value of the spring piece is 24.6MPa, and the maximum stress value of the bottom plate is 96.1MPa. It can be seen from the stress distribution cloud diagram that the bottom steel plate is subjected to more stress.

4. **Brush overall fatigue analysis**

The model is discretized in a tetrahedral unit, and the model grid is set to a size of 0.001 m, which is divided into 892138 nodes and 291347 units. The round copper plate is simplified into two upper and lower rings, which are in contact with the spring piece and have a friction coefficient of 0.1. According to the actual working state of the brush, the left end of the brush constrains all degrees of freedom. Set the upper and lower rings to contact the spring piece with a friction coefficient of 0.1. Fixed constraint at A: upper and lower rings at B, constraining its radial and axial degrees of freedom, releasing the circumferential freedom to release its rotational freedom; at C, rotating the circle around the center of the ring, the speed is 6circles/12h; At E, respectively, a displacement constraint of 1.5 mm is applied to the ring.
Two events were set during the analysis, two loads (rotation, 1.5 mm displacement load), and ANSYS fatigue analysis was counted by rain flow counting. First, find the magnitude of the stress from large to small. The maximum stress amplitude is: load 1 of event 1 and load 1 of event 2: stress amplitude = (E1L1 - E1L2) / 2 = 55.088 MPa; 51.263 MPa corresponds to the number of times on the fatigue curve (permissible number of times is 0.1E9 times); the actual number of cycles is 0.1E5 times, so the damage coefficient is 0.1E5/0.1E9=0.0001. The second largest stress amplitude is: load 1 of event 2 and load 2 of event 2: stress amplitude = (E1L1-E1L2)/2 = 29.071 MPa; 41.011 MPa corresponds to the number of times on the fatigue curve (permissible number of times is 0.1E9 times); the actual number of cycles is 0.59E6 times, so the damage coefficient is 0.59E6/0.1E9=0.0059 cumulative damage coefficient is 0.0001+0.0059=0.006<1.

5. Assembly accuracy test of collector ring
Since the collector ring is used as the power and information input component, the rotation speed and the rotation time in the work are irregular, and the assembly accuracy has an extremely important influence on the service life of the brush. The test checks that all parts of the collector ring and the brush are installed on the test tool and the bolts are fastened. The flatness of the collector ring on the installation is detected by a dial indicator. The maximum deviation position appears at the third collector ring. The deviation value is 0.8mm<1mm to meet the test requirements.
Figure 7. Schematic diagram of the detection position.

Table 1. Collector ring installation test (0.01mm).

| Detection position     | 1   | 2   | 3   | 4   | 5   | 6   | Maximum difference |
|------------------------|-----|-----|-----|-----|-----|-----|--------------------|
| Collector ring 1       |     |     |     |     |     |     |                    |
| Upper surface value    | 25  | 45  | 60  | 60  | 70  | 40  | 45                 |
| Lower surface value    | 52  | 38  | 20  | 22  | 7   | 40  | 45                 |
| Collector ring 2       |     |     |     |     |     |     |                    |
| Upper surface value    | 67  | 95  | 100 | 100 | 103 | 87  | 36                 |
| Lower surface value    | 107 | 82  | 75  | 84  | 79  | 95  | 32                 |
| Collector ring 3       |     |     |     |     |     |     |                    |
| Upper surface value    | 38  | 11  | 80  | 75  | 35  | 84  | 73                 |
| Lower surface value    | 150 | 175 | 105 | 100 | 150 | 95  | 80                 |
| Collector ring 4       |     |     |     |     |     |     |                    |
| Upper surface value    | 60  | 35  | 42  | 50  | 20  | 23  | 40                 |
| Lower surface value    | 66  | 102 | 90  | 80  | 112 | 111 | 46                 |

6. Main loop resistance and withstand voltage test
The ZRY-III contact resistance tester is used to perform resistance detection on the inner loop of the electric slip ring to meet the requirements. For comparison with the main loop resistance after the temperature rise test. Then, as shown in the Figure 8, the two ends of the contact resistance tester are respectively connected to the input and output terminal, the contact resistance tester is started, the current of 100A is passed, the resistance value of the loop is detected, and the resistance value of each loop is detected according to IEC62271-1-6.4 High-voltage switchgear and control equipment specifications, the detection values are shown in Table 2.

Figure 8. Main circuit test position.
Table 2. Main loop resistance detection (μΩ).

| Loop     | Ambient temperature | Resistance |
|----------|---------------------|------------|
| Loop A   | 17.8                | 181.6      |
| Loop B   | 17.8                | 188.5      |
| Loop C   | 17.8                | 184.6      |
| Loop D   | 17.8                | 117.7      |

7. Power frequency withstand voltage test
The BN90B portable current booster (INPUT: 220V/22.7A, OUTPUT: 5V/1000A) millivoltmeter and power frequency test booster were used to perform phase-to-phase and phase-to-phase withstand voltage tests. Connect the two ends of the portable current booster to the input and output line terminals of the measured phase, and gradually increase the output current. If there is burning, the power will stop immediately. When the current rises to 315A, 347A, 473A, the two ends of the millivoltmeter are respectively measured at the inlet and outlet terminals. The test data is shown in Table 3.

Table 3. Current-carrying voltage drop detection.

| Voltage drop (mV) | Current | Loop A | Loop B | Loop C | Loop D |
|-------------------|---------|--------|--------|--------|--------|
| 315A              | 55.6    | 62.4   | 74.6   | 55.6   |
| 347A              | 60.8    | 68.3   | 77.1   | 61.3   |
| 473A              | 79.5    | 90.3   | 94.3   | 81.3   |

| Voltage drop (mV) | Calculated resistance (μΩ) |
|-------------------|-----------------------------|
| 315A              | 176.5                       |
| 347A              | 198.1                       |
| 473A              | 222.2                       |

8. Dynamic and static continuous high current test
(1) Static continuous high current test
Connect the collector ring, the brush and the double-fed converter type high current generating device, and connect the wiring according to the test principle diagram. The output end of the inverter is connected to the line terminal, and the three-phase collector ring is shorted together. The double current converter type high current generating device supplies a large current to the circuit, and the current is gradually increased to a rated current of 315 A, and the long-term stable operation is maintained. Observe the change in current waveform at any time during operation. At the same time, the temperature of each part during the operation of the electric slip ring is measured and recorded by an infrared temperature measuring instrument.

(2) Dynamic continuous high current test
Before the test, the inverter part of the test tool is connected first, and the inverter is started to make the collector ring start to rotate. Then carry out the same steps as the static test, and the speed of the collector ring can be changed at any time during the rotation of the tool to achieve irregular rotation.

1. Circuit breaker; 2. Contactor 1; 3. Rectifier Bridge; 4. Pre-charged power; 5. Contactor 2; 6. Doubly-fed converter; 7. Reactor; 8. PLC; 10. Circulating water cooling system; 11. Outlet section; 12. Collector ring.
Figure 9. Electrical principle of test tooling.

Table 4. Dynamic static continuous high current test (°C).

| Serial number | State          | Current | Rotating speed | Time | Brush contact temperature | Main circuit A | Main circuit B | Main circuit C | Main circuit D |
|---------------|----------------|---------|----------------|------|---------------------------|----------------|----------------|----------------|----------------|
|               |                |         |                |      | Left brush               | Right brush    | Left brush    | Right brush    | Left brush    |
| 1             | Static         | 315A    | 0              | 0.5h | 19.4 195 19.5 19.5       | 19.4 19.5      | 19.5 19.5     | 19.5 19.6      | 19.6 19.6      |
|               |                |         |                | 1h   | 19.8 19.9 19.8 19.8      | 19.9 20.0      | 19.9 20.0     | 19.9 20.0      | 20.0 20.0      |
| 2             | Static         | 347A    | 0              | 0.5h | 20.0 20.2 20.4 20.3      | 20.1 20.1      | 20.1 20.1     | 20.1 20.4      | 20.4 20.4      |
|               |                |         |                | 1h   | 21.6 21.7 22.0 21.8      | 21.8 21.7      | 21.7 20.4     | 20.4 20.3      | 20.3 20.3      |
| 3             | Dynamic (positive) | 315A | 7r/min         | 0.5h | 20.4 20.5 20.5 20.3      | 20.3 20.4      | 20.4 20.1     | 20.1 20.3      | 20.3 20.3      |
|               |                |         |                | 1h   | 22.7 22.8 22.7 22.6      | 23.0 22.8      | 22.8 20.7     | 20.7 20.8      | 20.8 20.8      |
| 4             | Dynamic (reverse) | 315A | 7r/min         | 0.5h | 20.6 20.7 20.5 20.6      | 20.6 20.8      | 20.8 20.7     | 20.7 20.8      | 20.8 20.8      |
|               |                |         |                | 1h   | 23 23.1 22.9 23           | 22.9 23.1      | 23.1 23.1     | 23.1 23.2      | 23.2 23.2      |
| 5             | Dynamic        | 315A    | Irregular change | 0.5h | 20.5 20.6 20.4 20.5      | 20.7 20.6      | 20.8 20.7     | 20.7 20.8      | 20.8 20.8      |
|               |                |         |                | 1h   | 22.7 22.8 22.6 22.7      | 22.8 22.7      | 22.7 23       | 23 22.9       | 22.9 22.9      |
|               |                |         |                | 1.5h | 23.4 23.5 23.3 23.4      | 23.5 23.4      | 23.6 23.6     | 23.6 23.6      | 23.6 23.6      |
|               |                |         |                | 2h   | 24 24.1 23.9 24           | 24.2 24        | 24.2 24.2     | 24.2 24.2      | 24.2 24.2      |
|               |                |         |                | 2.5h | 24.1 24.1 24 24.1        | 24.3 24.2      | 24.3 24.3     | 24.3 24.3      | 24.3 24.3      |
|               |                |         |                | 3h   | 24.4 24.5 24.3 24.4      | 24.6 24.6      | 24.7 24.6     | 24.7 24.6      | 24.7 24.6      |
|               |                |         |                | 3.5h | 24.9 25 24.8 24.9        | 25 25.0        | 25.1 25       | 25.1 25        | 25.1 25        |
|               |                |         |                | 4h   | 25.2 25.3 25.1 25.2      | 25.3 25.4      | 25.4 25.4     | 25.4 25.4      | 25.4 25.4      |
|               |                |         |                | 4.5h | 25.3 25.3 25.1 25.2      | 25.3 25.4      | 25.4 25.4     | 25.4 25.4      | 25.4 25.4      |
|               |                |         |                | 5h   | 25.3 25.4 25.2 25.4      | 25.3 25.4      | 25.4 25.4     | 25.4 25.4      | 25.4 25.4      |
|               |                |         |                | 5.5h | 25.4 25.4 25.3 25.3      | 25.5 25.4      | 25.4 25.4     | 25.4 25.4      | 25.4 25.4      |
|               |                |         |                | 6h   | 25.5 25.4 25.3 25.4      | 25.5 25.5      | 25.5 25.5     | 25.6 25.7      | 25.7 25.7      |
|               |                |         |                | 6.5h | 25.5 25.5 25.4 25.4      | 25.6 25.7      | 25.7 25.7     | 25.7 25.7      | 25.7 25.7      |
|               |                |         |                | 7h   | 25.4 25.5 25.5 25.4      | 25.6 25.7      | 25.7 25.7     | 25.7 25.7      | 25.7 25.7      |
|               |                |         |                | 7.5h | 25.6 25.5 25.6 25.5      | 25.7 25.7      | 25.8 25.7     | 25.8 25.7      | 25.8 25.7      |
|               |                |         |                | 8h   | 25.6 25.7 25.6 25.6      | 25.8 25.8      | 25.7 25.8     | 25.7 25.8      | 25.8 25.8      |
9. Conclusion
(1) The structure design of the electric slip ring of the internal turret type single point system is proposed, and the complete design system and detailed structural design are given.
(2) According to the actual working conditions, the finite element analysis of the brush components of the key components of the electric slip ring is carried out, and the nonlinear contact statics and fatigue life analysis of the elastic contact conductive fingers are analyzed, and the analysis results can meet the needs of use.
(3) The engineering test of assembly precision, main loop resistance and withstand voltage, power frequency withstand voltage, dynamic and static continuous high current for electric slip ring verified the practical feasibility of electric slip ring.

References
[1] Bai Xueping, Li Da, Fan Mo, Yi Cong, Zou Xing. Research on design method of internal turret single point mooring system [J]. Ocean Engineering, 2015, (03): 36-42.
[2] Liu Zhigang, He Yanping. Technical characteristics and development trend of FPSO turret mooring system [J]. China Ocean Platform 2006 21 (5); 1-6.
[3] Mace A. J. Hunter K. C. Disconnectable Riser Turret Mooring System for Jabiru's Tanker-based Floating Production System [J]. OTC5490, OTC'19, 1987.
[4] Christoph Vogt, Martin L. Goodman, J. A. Han. Turret Mooring System: The Key to Oil Production in the Extreme Atlantic Frontier [J]. OTC10957, OTC'31, 1999, 2(II); 241-254.
[5] LT England, A. Duggal, A. Queen, "A Comparison between Turret and Spread Moored F(P)SOs for Deepwater Field Developments", Deep Offshore Technology 2001.
[6] Liu Shengfa. Introduction of internal turret type single point mooring system [J]. Guangdong Shipbuilding, 2014, (02): 25-28+31.
[7] Xue Ping, Chen Shaobing, Liu Li. Conductive Rings and Brushes in Electric Slip Rings [J]. Optical Fiber and Cable and Its Application Technology, 2012, (01): 11-13.
[8] Liu Chaoping, Zhang Baohua, Jin Chunlei, Lu Hao, Sun Wenbo. Analysis and Research on Discharge Characteristics of Single Point Electric Slip Ring of Offshore Oil FPSO [J]. Automation and Instrumentation, 2016, (04): 32-34.
[9] Zhang Yan. Ansys Workbench 15.0 finite element from entry to proficient [M]. Mechanical Industry Press, 2014.