Research on response characteristics of weighing sensor of mixing vessel under medium and long period surge

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Abstract. Under surge condition, the composite motion of heave, roll, pitch, sway and surge occurs in the concrete mixing vessel, which affects the measurement accuracy of the load cell. Taking the S-shaped load cell as the test object, the measurement accuracy of the load cell under the condition of complex force field is tested by using the six degree of freedom test platform to simulate the medium and long period surge sea conditions. The test results show that: the measured value of the load cell is affected by the sway acceleration, the surge acceleration and the heave acceleration, and is positively correlated with them; when the meaningful wave height is 1m and the average zero crossing period is 6~10s, the direct weighing accuracy of the concrete mixing vessel can not meet the requirements of the domestic standard.

1. Introduction

As an important tool of concrete production on water, the market demand is huge. According to statistics, the maximum pouring volume of concrete on water of Changtai Yangtze River Bridge is 84738m³, the maximum daily pouring volume is 1403m³, the design water pouring volume of Brazilian Salvador Bridge is 428623m³ and the maximum daily pouring volume is 2500m³. The production efficiency and quality of concrete mixing vessel directly affect the construction period and quality of the bridge. The production efficiency and quality of concrete mixing vessel are mainly affected by surge conditions. According to the practice of civil construction management in Japan, the allowable wave height of water concrete operation is 0.7m. The construction data of Taiwan Golden Gate Bridge project also require that the allowable wave height of concrete on water shall not be greater than 0.7m, all of which are to avoid adverse effects on concrete production. Therefore, it is of practical significance to study the influence of the force field on the load cell of the concrete mixing vessel under the condition of medium and long period surge.

Under the surge condition, the concrete mixing ship produces the compound motion of heave, sway, pitch, roll and pitch, and the concrete material weighing sensor bears the force in different directions. Based on the Cartesian coordinate system of ship deck, the force equation of load cell is equation (1).
In ideal condition, the resistance strain gauge of load cell is in uniaxial stress state, and the stress direction is completely consistent with the axial direction of the strain gauge. The voltage output characteristic curve equations are equation (2) and equation (3).

\[ V = K_s |\mathbf{F}| \]  

\[ K_s = k \left[ 1 + \frac{4lA}{zbl} \left( 1 + \mu_r \right) \frac{E_w}{E_T} \right] \]  

\( k \) is the strain sensitivity coefficient of strain resistance wire, \( t \) is the thickness of strain gauge adhesive layer, \( b \) is the length of strain transfer band, \( z \) is the effective substrate width, \( A \) is the cross-sectional area of the resistance wire, \( l \) is the base length, \( \mu_r \) is the Poisson's ratio of the adhesive, \( E_w \) is the elastic modulus of resistance wire, \( E_T \) is the elastic modulus of adhesive.

Within the sensor range, the load cell output characteristics keep good linearity under the action of axial force. After bearing radial force, the axial direction of the strain gauge is not consistent with the stress direction, the stress and strain of the sensor change nonlinearly, and the voltage output characteristic curve of the strain gauge changes nonlinearly. This nonlinear change is related to many factors, such as the structure of the sensor, the arrangement of the strain gauge, the angle and size of the radial force and so on. Therefore, it is of practical significance to study the influence of the force field on the load cell of the concrete mixing vessel under the condition of medium and long period surge.

2. Experimental process

2.1. Experimental basis

Based on the measured data of Haili 801 crane ship of CCCC Second Navigation Engineering Bureau Co., Ltd. in the construction sea area of China Malaysia friendship bridge, the acceleration characteristics of ship under medium and long period surge price adjustment are obtained. Haili 801 has a length of 80m, a width of 30m, a depth of 6m and a design draft of 3.1m. The overall parameters of the ship are similar to those of the mixing ship.

According to the measurement data of Haili 801 during the construction of China Malaysia friendship bridge in the sea area from August 2016 to October 2016, the wave period is 8~10 seconds, and the meaningful wave height is 0.6~1.3 meters. The curves of sway acceleration, surge acceleration and heave acceleration with time are shown in figure 2. The range of sway acceleration, surge acceleration and heave acceleration is -0.349~0.414 m/s², 0.069~0.079 m/s² and -0.324~0.258 m/s² respectively.

\[
\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_x + \mathbf{G}
\]
2.2. Experimental device

2.2.1. Acceleration simulation of medium and long period surge

Acceleration simulation of medium and long period surge. The 6-DOF test platform (Wuhan MTC-6DOF-C1) of Wuhan mute Technology Co., Ltd. can simulate the acceleration in all directions in Cartesian coordinate system, and the main parameters are shown in table 1.

| Posture  | Velocity | Displacement | Acceleration | Accuracy |
|----------|----------|--------------|--------------|----------|
| Yaw      | ±20°/s   | ±23°         | ±200°/s²     | 0.1°     |
| Trim     | ±20°/s   | ±20°         | ±200°/s²     | 0.1°     |
| Heeling  | ±20°/s   | ±20°         | ±200°/s²     | 0.1°     |
| Heave    | ±400mm/s | ±400mm       | ±0.5g        | 1mm      |
| Swaying  | ±400mm/s | ±450mm       | ±0.5g        | 1mm      |
| Surge    | ±400mm/s | ±450mm       | ±0.5g        | 1mm      |

2.2.2. Weight and acceleration measurement

The load cell is S-type tension sensor, which is distributed uniformly in three points at 120° and installed at the bottom of the test platform. The ship attitude measuring instrument is arranged at the same position to measure the acceleration characteristics of the load cell installation position, and the sampling frequency is 10Hz. The parameters of load cell used in quality measurement are shown in table 2. After digital filtering and hardware filtering, the sampling frequency is 10Hz.

| Characteristic parameters of load cell | Parameter     | 200Kg |
|--------------------------------------|--------------|-------|
| range                                |              | 200Kg |
| Output sensitivity                   | 2.0mV/V      |       |
| Zero point output                    | ±1F.S        |       |
| nonlinearity                         | 0.03% F.S    |       |
| repeatability                        | 0.03% F.S    |       |
| creep (30 minutes)                   | 0.03% F.S    |       |

| Characteristic parameters of ship    | Project      | Resolving Power |
|--------------------------------------|--------------|-----------------|
|                                     |              |                 |
2.2.3. Experimental methods
The weight of the weight is 50kg, and the six degree of freedom test platform is applied with the compound motion of rolling, pitch, sway, pitch and heave. The motion period, amplitude and phase are set according to table 3. The ship attitude measuring instrument measures the sway acceleration, surge acceleration and heave acceleration in the state of compound motion, the weighing sensor measures the weight of the weight, and the measurement results are processed by digital filtering.

Table 3. Experimental motion parameters

| Movement posture | Amplitude | period | Phase difference |
|------------------|-----------|--------|------------------|
| Pitch            | 1°        | 10s    | 0°               |
| Rolling          | 2°        | 8s     | 90°              |
| Swaying          | 200mm     | 6s     | 0°               |
| Surge            | 200mm     | 8s     | 90°              |
| Heave            | 200mm     | 6s     | 45°              |

3. Experimental results and analysis
The range of ship attitude measurement instrument is -0.26~0.28 m/s² in sway, -0.07~0.10 m/s² in surge and -0.30~0.29 m/s² in heave. The acceleration amplitudes in all directions are close to the measured acceleration data of ship motion in medium and long period surge State. The variation range of the measured value of the load cell is 48.3~51.9kg, and the deviation range is -3.4%~3.8%. The curves of measured values of sway acceleration, surge acceleration, heave acceleration and load cell in any period of time (55s to 75s as an example) are shown in figure 3.

Figure 3. Curve of acceleration and weight with time.

According to figure 3, The mass measurement range is 48.5~51.7kg, the error range is -3%~3.4%, and the amplitude of heave acceleration is -0.22~0.28m/s². The heave acceleration directly affects the measurement result by superposition with the gravity acceleration, the direct calculation error of the symmetrical weight result is -2.2%~2.8%, accounting for 70%~80% of the weighing error, which is the main influencing factor; the range of the sway acceleration is -0.26~0.24 m/s², which affects the weighing accuracy through the lateral effect of the sensor, and produces the remaining 20%~30% measuring error together with the sensor inclination angle, the comprehensive error of the weighing
system, which is the secondary influencing factor. Within a certain range, the measured value of the load cell is positively correlated with the sway acceleration and heave acceleration; under the compound force field, there is a phase difference between the measured curve of the load cell, the sway acceleration curve and the heave acceleration curve that changes with time, and the phase difference has no obvious rule.

4. Conclusion
In order to solve the problem that the weighing accuracy of concrete mixing vessel decreases under the condition of medium and long period surge, a six degree of freedom test platform is used to simulate the medium and long period wave surge sea state, and the measuring accuracy of the weighing sensor under the combined action of transverse acceleration, longitudinal acceleration and heave acceleration is measured. The conclusions are as follows: when the meaningful wave is 1m high and the average zero crossing period is 6 ~10s, the maximum measurement error of the load cell is 3.8% due to the comprehensive influence of the sway acceleration, surge acceleration and heave acceleration, which can not meet the requirements of 5.5.2.3 of GB/T 10171-2016 building construction machinery and equipment concrete mixing station (building). The heave acceleration directly influences the weighing result of the weighing sensor by superposition with the gravity acceleration, which is the main influencing factor of the material weighing error of the concrete mixing vessel under surge condition; the sway acceleration influences the weighing result by the lateral effect of the weighing sensor, which is the secondary influencing factor by the joint action of the sensor tilt angle and the system error; the heave acceleration compensation method is adopted The formula can improve the weighing accuracy of concrete mixing vessel to a certain extent.

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