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NEGATIVE STEP DYNAMIC TORQUE CALIBRATION MACHINE

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Abstract: The paper develops a negative step dynamic torque calibration machine and illustrates its working principle and critical technologies. The use of retracting actuators reduces significantly the fall time of the negative step torque, whereas air bearing yields high transfer accuracy of the dynamic torque. The experimental study is conducted and the results show that the fall time of the step torque reaches to millisecond level and the dynamic response up to 5800 Hz can be excited. Through uncertainty analysis, the expanded uncertainty of the presented calibration machine is better than 5 % (*k*=2).

Keywords: negative step torque; calibration machine; retracting actuator; air bearing.

1. INTRODUCTION

The torque sensors are extensively used in power machines in ships, automobiles and aircrafts to evaluate the performance and reliability through monitoring the torque parameter. Recently, well dynamic performance of torque sensors is required to describe the change process of torque parameter due to the high maneuverability requirement. Therefore, the study on dynamic calibration machine for torque sensors is of great significance to improve dynamic performance of automatic control system and attracts increasingly more attentions [1, 2].

Compared to the static torque calibration, the development of dynamic torque calibration machine highly depends on performance properties research, dynamic generation technology and bearing technology [3]. The excited dynamic response of torque sensors directly depends on the torque generation technology, which is the key for dynamic torque calibration research. Current research in this field is focused on three driving torque types including hammer trigger, negative step and harmonic [4]. Theoretically, the dynamic response in considerably wide frequency range can be excited by the negative step torque with extreme short fall time, which makes the negative step attracts much attention. However, the fall time of negative step torque is still long which makes the study of torque excitation machine of great interesting in the view of torque generation time.

The bearing has great influence on the sensitivity and accuracy of dynamic torque calibration machine rather than the static torque calibration machine. As the traditional bearing types, the knife-edge bearing and the rolling bearing are extensively used in static torque calibration system. However, few of these two bearings are adapted in dynamic calibration machine due to the design difficult. The air bearing comes with pure air as friction medium, which significantly reduces the friction torque rather than the rolling bearing [5, 6]. The small additive friction torque can improve the transfer accuracy of dynamic torque. Although, special design are required to make the fluctuation of air provided to the bearing steady both in pressure and temperature, which raises the design difficulty and limits the widely used in the dynamic calibration machine.

The main purpose of the paper is to develop a dynamic torque calibration machine that provides accurate dynamic performance properties for sensors under test. The retracting actuator can cut off the connection system in a short time to provide negative step dynamic torque for the calibration machine. The air bearing are used to improve the transfer accuracy. The experimental study and uncertainty analysis are also conducted to evaluate the performance of the calibration machine.

2. THEORETICAL FORMULATION

As subjected to the driving torque, the relationship between the torsional angle θ and the driving torque T meets the following second differential equation as

$$K\theta + C\dot{\theta} + J\ddot{\theta} = T \quad (1)$$

where K, C, J are respectively the torsional stiffness, damper and moment of inertia.

Thus, the transfer function of the torque sensor can be described as

$$\frac{\bar{\theta}}{T}(j\omega) = \frac{K'}{(j\omega/\omega_n)^2 + 2j\xi\omega/\omega_n + 1} \quad (2)$$

Generally, the damper ratio ξ of the torque sensor is lower than 1. Thus, the Eq. (2) can be expressed when the sensor is excited by a unit step torque $T_p = A\,\delta(t)$ as

$$\frac{\bar{\theta}}{K' A\omega_n} = \frac{1}{\sqrt{1-\xi^2}}\exp(-\xi\omega_n t)\sin(\sqrt{1-\xi^2}\,\omega_n t) \quad (3)$$

Fig.1 shows the solution of Eq. (3). It can be found that the shape of the curve depends on the natural frequency whereas the amplitude depends on the damper ratio. Therefore, the natural frequency and the damper ratio of the torque sensor can be obtained from step torque signal.

3. MACHINE CONFIGURATION AND WORKING PRINCIPLE

The working principle of the presented dynamic torque calibration machine is given as shown in Fig.3. The torque generation machine provides driving torque, which is connected to the torque sensor through connection system. The sensor is fixed on the braking system for the accuracy of torque transferred to the sensor. As the machine works, the connection system can be cut off in a rather short time, which makes the torque transferred to the sensor vanish immediately and leads to a negative step dynamic torque for the sensor. The dynamic response signal of the sensor can be collected and analyzed by the following signal process system, and then yields the dynamic parameters of the sensor.

As the dynamic torque calibration machine, the dynamic torque generation technology, the air bearing technology and control system are the critical technologies in the machine, which are respectively introduced in the following sections.

Dynamic torque generation: As mentioned above, the frequency range of dynamic response depends on the fall time of the negative step torque. Since the torque is provided by the generation machine, the fall time of negative step torque is determined by the acting time of breaking the connection system.

The retracting actuator is used in the connection system. As the actuator works, small axial force is generated and it does not act on the dynamic torque sensor. Furthermore, few additive massed is generated on the sensor, which makes the sensor keep its natural behaviour in the calibration process.

Air bearing technology: The friction torque due to the bearing used in the calibration machine has great effect on the accuracy of torque transferred to the sensor. Thus, choosing proper bearing type is of interest in the design of calibration machine.

The H-Type air bearing is selected as the main bearing in the calibration machine. For the air bearing, the carrying capacities in radial and axial directions are tough coupled, which requires comprehensive consideration in air-supply device. The pump of the thrust bearing is adapted to improve the gas pressure in radial direction resulting in high carrying capacity of the air bearing. Furthermore, it can be found from Fig.6 that the structure of H-type air bearing is considerably compact leading to its tight configuration.

Control system: The control system of the calibration machine is mainly composed of touch screen, PLC, driver, step motor, torque detection system, torque sensor and AD collection card. The operating principle of the system is shown in Fig.7. These modules involved in the control system contributing to the closed-loop system which can provide accurate control signal to the torque generation system.

4. EXPERIMENTAL STUDY

The experimental study is conducted in this section to evaluate the performance of presented calibration machine. The torque sensor calibrated by PTB was employed with torque rating 50±0.2 Nm and temperature coefficient 0.02%/℃. The temperature in the laboratory is controlled as 20±5 ℃.

Test results: The fall time of negative step torque is dominated by the retracting actuator, which determines the frequency range of dynamic response. Thus, the working time of the retracting actuators is the main performance parameter of the calibration machine. In total, 6 tests are performed to take the fall time into account and the results are listed in Table 1. It can be found that the results of fall time are generally less than 0.5 ms with average 0.428 ms and range 0.106, which confirms the consistency of negative step torque generation.

Uncertainty Analysis: The evaluation of uncertainty of the negative step dynamic torque calibration machine is conducted in the section. The uncertainty of the calibration machine is mainly composed of four components respectively caused by measurement repeatability, standard sensor, temperature and pressure fluctuation. Through analysis, the expanded uncertainty of the calibration machine is better than 5% (k=2).

5. CONCLUSIONS

A negative step dynamic torque calibration machine is developed in the paper. The signal process and control system provides control signal for steady output torque to the torque generation machine. The retracting actuator is used to cut off the steady torque within milliseconds that generates the negative step torque for the calibration machine, whereas the use of air bearing technology improves significantly the transfer accuracy of the negative step dynamic torque.

Due to the short fall time of negative step torque, the frequency of dynamic response approaches up to 5800 Hz, which can yield the dynamic performance properties of sensors under test. Through uncertainty analysis, the uncertainty of the negative step dynamic torque calibration machine is better than 5% (k=2).

6. REFERENCES

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