Development of reliability testing device for grating encoder

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Abstract. The technical index of a reliability testing device for grating encoder is determined based on the analysis of the working condition and fault cause of the grating encoder, and the overall scheme of the test device is designed. The support and mechanical structures of the operation fixture and loading device and the monitoring system of the test device are designed based on a modular design. The upper computer software is developed using LabVIEW, and the programming frame and the control interface are introduced. Reliability test is performed to verify the feasibility of the reliability testing device, and the degradation path of the predetermined degradation index is obtained.

1. Introduction
Grating encoder is a digital angle measuring device that combines optics, mechanics, and electricity. It is a sensor that can convert a physical quantity, such as rotation angle position, angular displacement, and angular speed, into electrical signals. Given the high measurement accuracy, small size, wide measurement range, and other advantages of grating encoders, they are widely used in the industry, national defense, and aerospace [1-3]. In particular, they have been widely used in the measurement link of feedback control for the angular displacement components of computerized numerical control (CNC) machine tools. Despite the huge production and sales of grating encoders in China, the market share has been dominated by foreign brands for many years, especially in the field of CNC machine tools. The main reason for this is the low reliability level of local grating encoders and the high failure rate [4, 5]. Therefore, the reliability of local grating encoders must be improved to help increase the market share effectively.

The reliability of products is mainly assessed through reliability testing by which defects in design, processing, manufacturing, and so on, especially in the electronic and aerospace fields, are identified. Ding et al. performed reliability test of two propellants to determine the ignition reliability of a pulsed plasma thruster [6]. Shao et al. proposed a reliability test design planning model based on potential defect exposure gain [7]. Zou et al. proposed a road simulation accelerated reliability test method for the key components of double-clutch transmission, which improves the test efficiency and accuracy [8]. At present, there are few researches on the reliability test of encoders. Zhu et al. adopted the method of accelerated test for grating encoder to solve the problem that it is difficult to obtain significant test data in a short time [9]. A reliability test device is
necessary to investigate the reliability of a product. Reliability data could be collected for fault analysis through the operation of the test device.

As a composite system, a grating encoder has the characteristics of mechanical, optical, and electronic systems. In addition to a complex structure, its working condition is often multidimensional. This paper proposes to build a grating encoder reliability test device considering these characteristics. The development of a laboratory reliability test can effectively avoid the shortcomings of field tracking test, shorten the test period, reduce the test cost, control the test conditions, and obtain more reliability data. At present, the related equipment can only be used for the basis stage of idle operation and cannot be called a reliability test bench in a strict sense due to the limited research and development capability and load data.

Therefore, the research and development of a reliability test device for grating encoder testing is necessary, thereby motivating the potential fault. Based on the analysis of fault reasons, suggestions and measures are proposed.

2. Overall design

2.1. Technical requirement

To develop a reliability test device for grating encoders that simulates condition loading, the impact of the environmental stress mechanism on grating encoders must be researched first. A complete grating encoder consists of three parts namely optical, mechanical, and electronic components, which are affected by stresses, such as temperature, humidity, and vibration, during operation [10].

For example, temperature changes cause the ageing of optical and electronic devices and the inconsistency of temperature characteristics [11]. The combined effect of temperature and humidity results in the entry of water molecules into the interior of the encoder, which results in the ion migration of electronic devices under the effect of electrical stress and the degradation of insulation performance [12]. Alternating vibration stress damages the precision shaft of encoders, which causes angular measurement deviations between the grating and the grating disk and leads to pitch, yaw, and torsion, resulting in the decrease of the moiré fringe signal quality [13, 14]. Therefore, the technical indicators of encoders developed in this paper are determined as follows:

1. To improve test efficiency, reliability tests should be performed simultaneously for 12 grating encoders.
2. The maximum test speed of grating encoders is 10000 rmp.
3. The vibration frequency is 10–500Hz, and the highest acceleration of vibration is 10 g.
4. The loading range of temperature is -40°C–+150°C, and the temperature change rate between -40 °C and +80 °C is 1 °C/min on the average.
5. The loading range of relative humidity is 20%–98%.

2.2. Designing scheme

According to the above technical requirements, the test device can be determined, which is mainly composed of a supporting and driving unit, a stress loading unit, and a monitoring and controlling unit. The supporting and driving unit is used to support and fix the encoder, and different type of encoders can be assembled through different fixtures. The stress loading unit involves the loading of working stresses such as temperature, humidity, and vibration. Temperature and humidity are loaded through a temperature and humidity testing chamber, and vibration stress is achieved by the vibration table. The monitoring and control unit is used to monitor the actual stress value acted on the encoder and the performance index value of the grating encoder being tested. The structure of system design is shown in figure 1, the design scheme of system is shown in figure 2, and the Physical diagram of the device is shown in in figure 3.

A PC monitoring software is developed using LabVIEW. Before testing, various parameters can be set on the interactive interface. During testing, the parameters and their change curves are displayed in real time, and the ACCESS database is used to store the state parameters.
3. Design of mechanical structure

The mechanical structure mainly includes three parts: the supporting platform of the test device, the fixture, and the stresses loading device. The supporting platform is vertically arranged and divided into three layers. The supporting circular plate of the first layer is connected with the vibration table by bolts, and the entire test device is fixed on the vibration table. The supporting circular plate of the second and third layers are used to install and fix the encoder and the driving motor. The supporting circular plates of these two layers are provided with wiring holes to arrange the motor and the encoder circuit. The supporting circular plates are connected and fixed by supporting frames, which have a regular hexagonal distribution to ensure the structural rigidity of the test device. The mechanical structure of device is shown in figure 4.
Grating encoder is a kind of precise optical equipment. Generally, it cannot be directly and rigidly connected to the shaft of the unit under test. Instead, it is connected in an elastic soft way to avoid excessive axial movement and radial run-out, which prevents damage to the encoder’s dial and shafting. The connection method is usually a combination of hard and soft connection. In a hard connection, the encoder shaft and the user’s shaft are rigidly fixed to ensure coaxial rotation, whereas soft connection is an elastic connection between the encoder housing and the user’s equipment and is used to absorb the jitter error caused by the rotation of the user’s axis. In this paper, a fixture is designed to ensure smooth operation. The fixture consists of the spindle body, a bearing, a bushing, the outer body, the pedestal of the grating encoder, a hexagonal recessed set screw, and a housing shell, as shown in figures 5 and 6. One end of the spindle body is designed as a cone face that can be matched with the output shaft of the encoder. The fixture is connected to the loading plate through three uniformly connected posts.

To reduce the processing difficulty of the support plate and improve the compatibility and adaptability of the test device, a modular design method is adopted for the test device. The encoder with its fixture and the drive motor are connected to the same loading plate to form a loading unit. The loading unit is then fixed to a circular support plate. The connecting holes of each loading plate and each supporting plate of different stations are designed to the same size to guarantee the interchangeability of the loading unit. Each installation station of the supporting plate leaves a hole of a certain size, which is convenient for fixing the encoder with different installation methods.

4. Design of monitoring system
Two main parts should be monitored. The first part is the stress value loaded to the grating encoder being tested. Although the temperature and humidity box and the vibration table have their own sensors with a closed-loop control, their measured values deviate from the actual values of the
stresses acting on the encoder, which can lead to inaccurate test data. Therefore, the actual measured stress of the encoder requires further monitoring. The second part is the value of the output signal. The encoder tested in this paper is a sinusoidal encoder, and its output is a two-channel sinusoidal voltage signal with a phase difference of 90°. The design scheme of monitoring system is shown in figure 7.

![Design scheme of monitoring system](image)

**Figure 7.** Design scheme of monitoring system

4.1. Hardware design of monitoring system

Considering long period of reliability test for the grating encoder, the reliability of the selected stress sensor should be relatively higher. Therefore, a platinum thermal resistance temperature sensor is selected. The platinum thermal resistance temperature sensor is widely used and has a measurement accuracy that can reach 0.15°C and a measurement range that can cover -200 °C – 650 °C. The capacitive humidity sensor is selected because the moisture-sensitive capacitance of the humidity-sensitive capacitor changes with the external humidity and converts the humidity parameter into an electrical parameter.

The 3039M10 triaxial accelerometer by Dytran, which is an IEPE accelerometer with its own power amplifier and an integrated processing circuit, is selected. It has high anti-interference ability and reliability and is easy to use.

The NI CompactDAQ system is chosen as the acquisition system, which are shown in figures 8 and 9. The CompactDAQ system is a modular data acquisition platform in which various module crates and modules can be embedded. The crate communicates with the PC through USB, Ethernet, or WIFI. It has an NI-STC3 timing and synchronization controller that can manage multiple analog, digital, and counter measurement tasks simultaneously. NI signal flow is used by NI-STC3 to access the memory of the PC and quickly read data through the USB and the Ethernet. The crate model is cDAQ9189, which is a bus-powered Ethernet crate designed for the measurement systems of small or distributed sensors. It controls the timing, synchronization, and data transfer between the I/O modules of C Series and external hosts. The crate provides accurate and synchronized timing based on a TSN network that is suitable for long-distance high-frequency measurements. NI 9434 is selected as the capture card, which is a 4-channel dynamic signal acquisition card with a dynamic range of 102 dB and a galvanostatic piezoelectric signal conditioning of 2 mA. Four input channels can be sampled by up to 51.2 kS/s simultaneously. In addition, the module includes a built-in antialiasing filter that adjusts the sample rate automatically.
4.2. Software design of monitoring system

The software system has four functions. First, it identifies the user of the software and ensure the safety of test data. Second, it displays the output signal of the grating encoder and the effect of various environmental stresses visually. Third, it is equipped with signal processing and data analysis functions. Fourth, it records accurately and saves the observed parameters of the encoder reliability test.

To improve the inheritability and expandability of the test device, LabVIEW is adopted to develop its control system. The development follows the modular design concept, which from top to bottom can be divided into the following: login module, the main loop module of the system control, the underlying configuration module of the capture card, the data acquisition module, the filtering module, the analysis tool module, and the data storage module. The software design module is shown in figure 10.

Figure 10. Software design module

The login module guarantees the stability of the collection platform and the security of data, discriminating the user’s identity by user name and password in the login window.

The main loop module of the system control is used to identify the user’s requirements and to provide feedback based on the demand. The result of the feedback triggers the implementation of the functions of each sub-module. The main program adopts the structure pattern of looping built-in events and uses local variables to trigger each event. The bottom layer configuration module of the capture card completes the underlying hardware configuration functions, including channel creation, sampling of clock setting, start tasks, and stop tasks. The data acquisition module adopts the event structure to control the start, pause, and stop of data acquisition. The filter module improves and optimizes the system’s own filter, which can eliminate the high-frequency noise in the signal and facilitate the subsequent data processing. The analysis tool module adopts the programming idea that combines the conditional structure and the feedback node and analyzes the test data after a certain number of cycles. The data can be handled by Fourier expanded to analyze its DC component, amplitude, and phase errors. The data storage module can temporarily place the...
acquired data in an excel table for further data analysis and modeling. The software interface and the program are illustrated in figures 11 and 12, respectively.

![Monitoring interface](image1)

![Background program map](image2)

**Figure 11.** Monitoring interface  
**Figure 12.** Background program map

5. **Reliability test of grating encoder**

To verify the usability of the test device, a single step-stress test is performed on the grating encoder. The maximum temperature, which has the greatest influence on the optics and electronic circuits of the encoder, is selected as the test stress. The DC error is adopted as the monitoring index of the degradation test to collect degradation data. The temperature of the grating encoder in actual working condition is $T_0 = 25^\circ C$, and the maximum temperature is $T_m = 85^\circ C$. The temperature stress of SSADT is divided into four levels: $T_1 = 45^\circ C$, $T_2 = 60^\circ C$, $T_3 = 75^\circ C$, $T_4 = 85^\circ C$. Based on these stresses, 12 samples are tested and numbered (marked as 1, 2, ..., 12, respectively). According to the requirements of SSADT, the entire test is divided into four stages. In each stage, each level of stresses is applied to 12 encoders in sequence. The test time of each stage is 528 hours, and the total test time is 2112 hours. That is, stress level 1 is first loaded to the 12 encoders. After 528 hours, the temperature in the temperature and humidity chamber is increased to switch the stress to level 2. After 528 hours, the stress is increased again to reach stress level 3. After 528 hours of continuous testing, the temperature is increased to stress level 4, and the test is continued until terminated.

After the test, the relative value of DC deviation is selected as the Y-axis to draw the degenerative trajectory curve as shown in figure 13. It can be seen that the relative value of DC deviation have an increasing trend. In the early stages of the trial, the change was less pronounced, but the change became more pronounced later in the trial.

![Degradation curve of encoder DC drift](image3)

**Figure 13.** Degradation curve of encoder DC drift
6. Conclusion
The reliability test device of grating encoders developed in this study can simulate the working condition of the encoder in the laboratory, which addresses the insufficient research on the reliability test equipment and test technology of the grating encoders of domestic manufacturers.

A modular design method is adopted for the test device, thereby ensuring the reliability of the structure, the good accessibility of maintenance and the continuity and stability of the test. The monitoring system has increased automation and does not require a long period of time from the test personnel.

The test performed for this device shows that the developed reliability test device of grating encoders can perform the reliability test for a long time and has high durability.

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