Development of a Measuring System Based on LabVIEW for Angular Stiffness of Integrative Flexible Joint

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Abstract. In order to meet the need of development of integrative flexible joint, this paper presents a higher precision measuring system for angular stiffness test of integrative flexible joint. The main parts of the system include PC, precision motorized goniometric stage, precision motorized rotary stage and high accuracy torque sensor. The measuring and control program is developed on the platform of LabVIEW. The measuring system developed has angular resolution at 0.000320 (about 1”) theoretically in determining the angular displacement of the joint round its equatorial axis and torque accuracy at 0.005 mN·m. The developed program, which presents a friendly GUI, can implement the data acquisition and processing, measuring procedure automatically. In comparison with other measuring devices with similar purposes, the measuring device can improve the measuring efficiency and accuracy distinctly while has advantages of simple configuration, low cost and high stability.

1. Introduction

The dynamically tuned gyro (DTG) is a kind of inertial guidance meter with moderate accuracy. The flexible joint is its key component for the performance of DTG is mainly dominated by the quality of the joint [1]. The rotor is attached to its spindle by the flexible joint and is allowed to have 2 DOF round its equatorial axes. The angular stiffness is a vital performance parameter because the appropriate value of the stiffness is a principal premise to realize “dynamic tuning”. The angular stiffness is defined as:

\[ K = \frac{M}{\theta} \]  

(1)

Where \( K \), angular stiffness; \( M \), the moment around equatorial axis; \( \theta \), the corresponding angular displacement under \( M \).

Usually, the measuring of angular stiffness has two ways: static measurement and dynamical measurement. The static way directly uses the equation (1) to calculate the stiffness \( K \) by measuring the loaded moment \( M \) and the corresponding angular displacement \( \theta \) (or loaded force and linear displacement). For example, the conventional measurement by hanging standard weight is one kind of static way [2]. But this method has disadvantages of many handwork and low efficiency. What’s more, the measuring accuracy depends on how the operator uses it skillfully. In order to improve the measuring effect, some researchers studied automated measurement. Ao Ming-wu presented an automated measuring device which mainly includes force sensor, displacement sensor and computer system [3]. Long You-xi designed a measuring device based on micro-computer which uses micro-
displacement mechanism and standard spring sheet to put load on the specimen. The angular
displacement was obtained indirectly by a displacement sensor, and the loading force was calculated
by the deformation value of the sheet [4]. Zhou Qi introduced an automated measurement which used
micro-displacement stage and elastic sheet to realize micro-moment load. The micro-displacement
was measured to calculate angular displacement of the specimen [5].

The dynamical measurement of the angular stiffness of flexible joint complies with the relationship
of the resonant frequency \( \omega_n \), the stiffness \( K \) and the moment of inertia \( J \) (see the equation (2)). This
method only measures the resonant frequency \( \omega_n \) usually while calculates the moment of inertia \( J \)
using analytical mechanics [6]. Therefore, its measurement accuracy is not satisfied though it has good
efficiency.

\[
\omega_n = \sqrt{K / J}
\]  

(2)

Because the flexible joint usually has small profile and weak stiffness. It is easy to be deformed and
difficult to be positioned and clamped during measuring process. The present measuring methods of
the angular stiffness of the flexible joint commonly has low efficiency and dissatisfactory precision.

Compared with the combinative flexible joint, the integrative flexible joint (see figure 1) can bring
smaller drifting error and longer life. Meanwhile it gives harder requirements on measurement of
angular stiffness. For example, the rotational angular of the joint rotating round its equatorial axis is
limited within 15°.

2. Measurement principle

Here the measurement principle for measuring the angular stiffness belongs to the static measurement,
i.e. the equation (1) is used here to get the stiffness. The scheme shown as figure 2 is designed to get
\( M \) and \( \theta \). The torque sensor is mounted on a goniometric stage which can swing within certain rang of
angle, and the center axis of the sensor is set to align with the rotating axis of the goniometric stage. A
loading bar, which contacts the top surface’s margin of the specimen, is assembled with the measuring
spindle of the sensor. Thus, the loading bar will rotate the same angle when the goniometric stage
swings, meanwhile the loading bar brings moment load to the specimen and compels it to rotate round
its equatorial axis. The moment value can be obtained by the torque sensor directly and the angular
displacement of the specimen can be calculated according to the relationship of the loading radius of
the specimen and the arm of the loading bar. The specimen is clamped to a rotary stage by a chuck.
Thus, the four quadrant positions of the specimen can be loaded to measure angular stiffness.

Figure 1. Integrative flexible joint.

Figure 2. Measurement scheme.
3. Configuration of the measuring system

3.1. Hardware
The hardware of the measuring system are made up of high accuracy torque sensor, precision motorized goniometric stage, precision motorized rotary stage, precision manual stage, measuring jigs, loading bar, base plate, linking plates, coupling, step motor controller, sensor interface and PC. The main components are shown in figure 3(a). Figure 3(b) is a photo of the real measuring device.

The torque sensor is the key component of the device. According to the requirement of the flexible joint, the maximum moment allowed to the joint is 0.15 mN·m. if the loading process includes 10 steps, and usually the sensor should have a precision parameter that is third of the minimum quantity to be measured, i.e.0.005 mN·m in this case. Thus the LORENZ-D2452 torque sensor is chose here, which has a nominal load of 0.005N·m and a accuracy class of 0.1%. Working with the LORENZ-PAX_LC-TG sensor interface, the measured torque signal can be passed to the computer using RS-232 serial port. The sensor is mounted on a precision manual stage. It can be withdrawn to a safe position to afford facilities for assembling or removing the specimen.

The goniometric stage is also a key part, which acts as a loading mechanism and also a goniometer. The TSAG10-W motorized goniometric stage is used here, which has repeatability at 0.0043° and resolution at 0.00032° (about 1'). This stage is instructed by computer via the SC300 controller.

The RSA60 rotary stage is also motorized, which is instructed by computer via the SC300 controller. Thus it rotates the specimen to the desired position. The stage has indexing repeatability at 0.01° and indexing accuracy at 0.0025°.

The SC300 step motor controller is used to control TSAG10-W stage and RSA60 stage, which has been embedded step motor driver. The control panel enables user to operate the stages easily when being offline. The controller communicates with computer via RS232 serial port, which enable the motion of two stages is programmable.

The MEGA micro chuck is selected to clamp the special jig designed for the specimen. Thus, the specimen can be loaded or unloaded conveniently.

3.2. Software
There are many choices of development platforms to develop the measuring software such as Visual C++, Visual Basic, LabVIEW and so forth. Here LabVIEW is selected. LabVIEW is a revolutionary graphical programming language developed by National Instrument. It shows a great advantages in the fields of Data Acquisition, Virtual Instrument Software Architecture, General Purpose Interface Bus,
Serial Instrument Control, Image Process, Motion Control, Data Analysis and Graph Expression. LabVIEW also offers high development efficiency. Generally using LabVIEW to develop application program can save time up to 4~10 times compared with other programming languages.

In order to finish the test automatically and conveniently, a program flow chart is written (see figure 4). Before starting the test process automatically, the specimen is fitted and clamped manually. The goniometric stage is also adjusted manually to a position where the loading bar is close to the measurement position. Then the automated measuring process starts. First it calls contact judgment module to adjust the position. The torque sensor signal is sent to computer by serial interface. The computer does data process, calculates the torque and the angle, and display them in real time. The main program judges to load or unload by the driving steps. When the whole test process is done, the program calculates the angular stiffness by fitting the value of torque and angle of each step.

The software developed is a standard windows application program which can be run in all the versions of windows. It has concise graphic user interface, most of the operations can be done by just clicking the mouse. The interface of the program is shown as figure 5. The main interface includes 5 top level menus which are basic information, communication judgment, equipment calibration, stiffness measurement and report query.

![Figure 4. Program flow chart.](image1)

![Figure 5. Measuring system interface.](image2)

### 4. Measuring experiment

There are two measuring processes. One is 1-position testing process which focuses on the repeatability of the measuring system. Another is 4-position testing process which measures the stiffness values at four quadrantal positions of the specimen. The measuring program draws a curve
on the screen during the measuring process which represent the moment \( M \) and the angular displacement \( \theta \) (see figure 5). From figure 5 we can see the curve seems as a slanting line. Thus, the slope (i.e. angular stiffness) can be obtained by using least-square method. The measuring software also provides measuring reports in detail.

Table 1 shows the measuring data during a 4-position testing process. A great deal experiments have been verified, and the similar results as table 1 are obtained. These experiment data indicate the measuring device has advantages of high accuracy, good stability and easy operation.

| Sequences | Measured stiffness: g·cm/rad (design value: 340±20) |
|-----------|-----------------------------------------------------|
|           | 0°         | 90°        | 180°       | 270°       |
| 1         | 335.4      | 323.0      | 330.4      | 322.6      |
| 2         | 338.0      | 332.1      | 336.3      | 325.8      |
| 3         | 340.0      | 332.1      | 338.9      | 325.2      |
| 4         | 339.3      | 328.2      | 330.4      | 327.8      |
| 5         | 334.1      | 326.3      | 329.7      | 326.5      |
| Average   | 337.36     | 328.34     | 333.14     | 325.18     |
| Maximum difference | 5.9 | 5.8 | 9.2 | 5.2 |
| Percent of difference | 1.75% | 1.77% | 2.85% | 1.65% |

5. Conclusion

The requirement of the angular stiffness test for integrative flexible joint is harder than that for combinative flexible joint. The developed measuring system based on labVIEW can meet the requirement with angular resolution at 0.00032° and torque accuracy at 0.005 mN·m theoretically. Computer measuring technology is adopted to automate the measuring process and data processing, which improves the measuring efficiency greatly. The experiment data indicate the developed system has advantages of high accuracy, good stability and easy operation. The developed measuring system also has a lower gross cost and is helpful for the development of integrative flexible joint.

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