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Contact Type Thread Tester for Tap Inspection Automation

Jeonghyeon Kim[1], Sangwon Choi[1], Jaekuk Choi[1], Dongsun Lim[1] and Jonghoek Kim[1*]

[1] Department of Electrical Engineering, Hongik University,
Sejong, 30016, Korea (kmjh3983@gmail.com)
* Corresponding author: Jonghoek Kim, email: jonghoek@hongik.ac.kr

Abstract: In this paper, we introduce a contact type thread tester which can automatically sort out bad thread holes. The existing non-contact type testers used eddy current, camera, ultrasonic, etc. However, non-contact type testers are vulnerable to noise. In this paper, a contact type inspection method is used to sort out the defects of the thread by measuring the reverse torque that occurs while tightening the bolt and threaded holes. This tester is insensitive to noise, such as vibration. We can inspect a thread hole regardless of the size of the hole. Also, the tester automatically aligns bolt and thread hole positions in order to remove the positional error. The tester checks the size of the thread hole using a camera, and automatically carries out the inspection with the optimum torque associated to the hole size. In addition, we develop a smartphone application to control the tester remotely.

Keywords: Thread, Defect, Inspection, Automation, Reverse torque

1. INTRODUCTION

A contact type thread tester is a device for automatic inspection of the thread condition of a thread hole. If the bolt and thread hole have different threads, then they cannot be joined exactly. In the process of making thread holes, defects in threads may occur, and the inspection is conducted on the thread holes to sort out these defects.

The inspection methods are divided into non-contact inspection technology and contact inspection technology. A non-contact type method commonly uses an eddy current, an ultrasonic[1][2], and a camera[3][4][5][6][7]. However, non-contact type testers are vulnerable to noise.

Non-contact inspection technology has the advantage of identifying varied defects in a time-efficient way. However, it is expensive and has the disadvantage of reacting sensitively to the surrounding environments, such as temperature, magnetic field, and vibration. Especially, the eddy current method has difficulty in discriminating thread defection of a hole whose size is below M3.

On the other hand, contact-type inspection technology is not only inexpensive, but also insensitive to surrounding environments. It can inspect various thread holes, regardless of hole size.

Contact-type inspection technique is considered in this study. A hole defect is detected by measuring the reverse torque the motor measures during the inspection of the thread hole.

During the inspection, the bolt and thread hole can be moved for some reason, such as vibration. As the number of inspections increases, the alignment error between the bolt and thread hole may increase, and the accuracy of the inspections may decrease.

This paper uses a camera to remove the alignment error of the bolt and thread hole. Also, the camera checks the size of the thread hole automatically, and sets the optimum torque to improve the inspection accuracy. As far as we know, this automatic calibration and control has not been considered in the literature on thread testers.

To change the settings of the tester, the smartphone application is developed so that users can easily control the device without the help of a professional engineer. After the test is done, the setting and test results are sent to the server through the HTTP. Then, users can monitor the test results in real time.

The followings are novelty of the proposed contact-type inspection method：

- We use a simple structural design that changes the rotational motion of the motor into the axial motion in the main frame.

- Remove the thread hole position error automatically using a calibrator and a camera.

- Using the camera, we check the size of the thread hole automatically and carry out the inspection with the torque which is optimal for the hole size. In this way, users can inspect the thread holes of various sizes robustly.

- The smartphone application allows to set torque, the number of turns, and speed of rotation remotely. Data are accumulated by storing the results of the inspection on the server.

2. AUTOMATION CONTROL SYSTEM DESIGN

2.1 Inspection algorithm

The algorithm for the thread tester is shown in Fig. 1. Before the test begins, users set the turns and torque of the servo motor. When the test starts, the tester inspects the thread while rotating by the number of turns, as set in the tester. During this process, if the reverse-torque is bigger than a certain threshold, then it indicates defects in the thread hole. Thereafter, the tester reverses to its initial position.

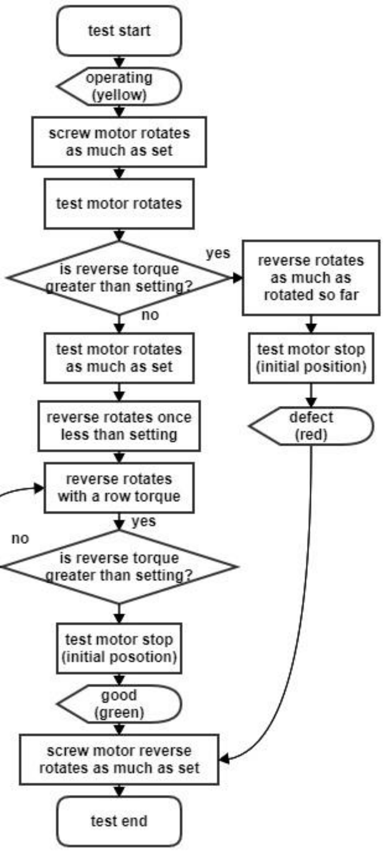

Fig. 1 Inspection algorithm

2.2 Calibrator algorithm

In this paper, we use the contact-type inspection to identify defects of the thread holes. For an accurate inspection, the x and y coordinates of the thread hole must align with the bolt on the tester. If they do not align, then additional reverse torque may occur when the bolt and thread hole get tightened. In this case, the accuracy of the test may be compromised.

Accordingly, in this paper, the position of bolt and the thread hole are aligned automatically, using a calibrator and a camera which measures the thread hole in real time.

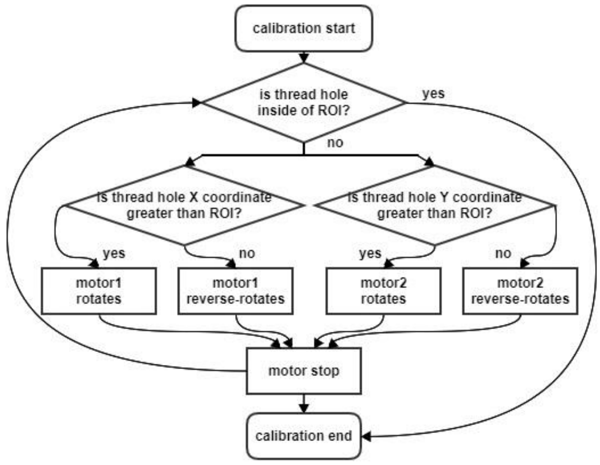

Fig. 2 Calibrator algorithm

The algorithm for calibrating thread hole position is shown in Fig. 2. Fig. 3 shows the image captured by the camera. The region of interest (ROI) is displayed as a circle. The thread hole is marked with green if it is inside the ROI, and red if it is outside. The calibrator drives the motor so that the thread hole is located inside the ROI, aligning the position of the tester's bolt and the thread hole. The calibrate machine is depicted in Fig. 17.

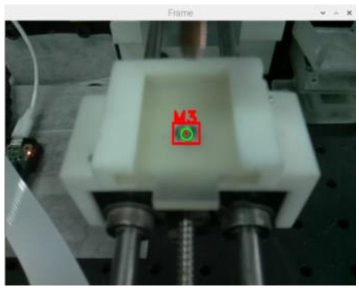

Fig. 3 ROI (Region of Interest) of calibrator. The thread hole is marked with green if it is inside the ROI, and red if it is outside.

2.3 Thread hole size determining algorithm

The algorithm for setting the optimum torque voltage for a thread hole size is shown in Fig. 4. We detect the thread hole size automatically and set the optimum torque voltage associated to the hole size. We obtain the optimum torque voltage for a thread hole size through Experiment 1.

To check the size of the thread hole, we use the template match of OpenCV. We store the templates for each hole size and detect the size of the thread hole based on how similar it is to the camera image. Then, we set the optimum torque voltage based on Experiment 1. We demonstrate the effectiveness of the auto optimum torque setting in Experiment 2.

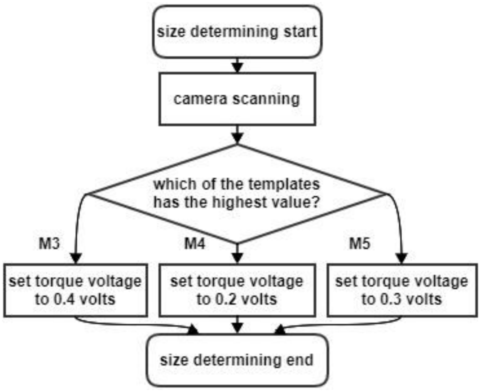

Fig. 4 Detect the thread hole size automatically

2.4 Application

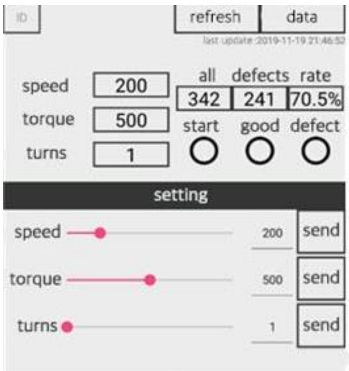

Fig. 5 Application interface

We introduce the application that is intuitive and easy to set without a professional engineer. This tester can be applied to many processes by changing the speed and torque of the tester. As the depth of a thread hole varies, the number of rotations of the tester can be set considering the varying depth. The current status of the test is selected among the following three states: 'OPERATING(yellow)', 'GOOD(green)', 'DEFECT(red)'.

After the test is done, the setting and test results are sent to the server through the HTTP.

3. HARDWARE CONFIGURATION

Hardware is divided into an approach machine, test machine, calibrate machine. And, the test machine is divided into motor parts, rotation parts, buffer parts, and bolt parts.

3.1 Approach machine

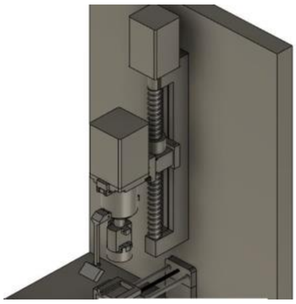

Fig. 6 Approach machine

The approach machine allows bolts in the tester to come in contact with the thread hole. This hardware contains motors and ball screws. The approach machine controls the distance of moving up and down, by changing the number of rotations of the motor.

3.2 Test machine

Fig. 7 Test machine

The test machine is necessary to perform both rotational and vertical motion during the inspection of threads.

1) Motor parts

Fig. 8 Servo motor

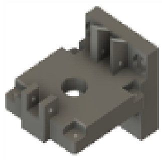

Fig. 9 Motor shield

Servo motor used in this paper can measure reverse torque and can control rotation speed and torque. The motor operates according to the algorithm in Fig. 1 in link with the PLC. Motor shield in Fig. 9 ensures that the motor and the approach machine are connected to each other.

2) Rotation parts

Fig. 10 Main frame

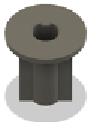

Fig. 11 Rotary shaft

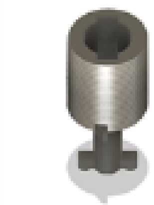

Fig. 12 Test shaft

Rotation parts transform the rotary motion of a motor into the axial motion. The motor combines with the rotary shaft in Fig. 11 to transfer the rotational motion of a motor into the axial motion. The rotary shaft combines with the test shaft in Fig. 12. Thus, the test shaft follows the main frame thread in Fig. 10.

Fig. 13 barriers for setting the initial position

We build the small barriers on the main frame and on the rotary shaft, so that the shaft can return to its initial position after the inspection is done. Those barriers prevent the initial position of the shaft from having a position error due to inertia or motor encoder problems. While the shaft returns to the initial position, it rotates half a turn less than the return rotation value which is set initially. Thereafter, the motor rotates with small torque and stops when a reverse torque is applied due to the barrier on the main frame. This method reduces the strain on the protection barrier and is able to correct the initial position error.

3) Buffer parts

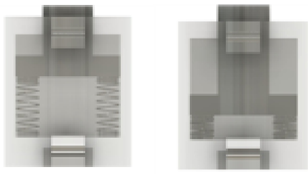

Fig. 14 Buffer

The buffer in Fig. 14 combines with a test shaft of the rotation parts. There may be cases where the test thread hole is not aligned with the tester axis slightly, as depicted in Fig. 15.

To resolve this slight misalignment problem, we insert springs into the buffer in Fig. 14, so that the test shaft is buffered. In this way, the tester has some flexibility and can perform inspection, even in the case where the hole is not aligned slightly as shown in Fig. 15.

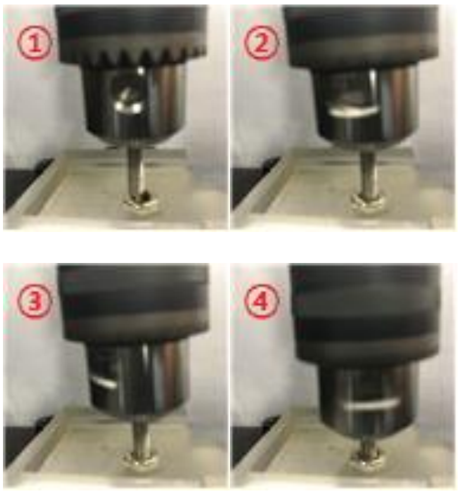

Fig. 15 Flexibility of the tester against slight misalignment problems

4) Bolt parts

Fig. 16 Drill chuck shield

Drill chuck shield shown in Fig. 16 combines with the bottom of the buffer and the drill chuck. The drill chuck allows for inspection of the thread hole with varying diameters.

3.3 Calibrate machine

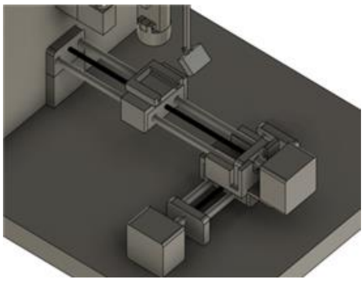

Fig. 17 Calibrate machine

The calibrate machine is used for aligning bolt and thread hole position. It calibrates the thread hole position error using the algorithm in Fig. 2.

1) Image processing parts

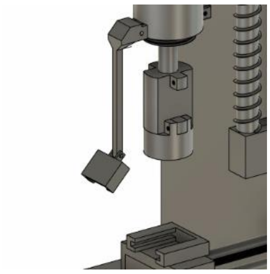

Fig. 18 Image processing parts

Image processing parts are used for checking bolt and thread hole position. Because it processes images in real time, we use Raspberry Pi, which has better graphic performance than MCU. The image processing parts are connected to the main frame of rotate parts to check the position of the thread hole in real time.

2) Calibrate parts

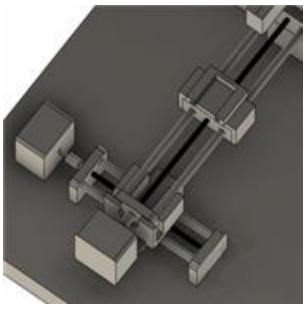

Fig. 19 Calibrate parts

Based on the images taken from the image processing parts, the calibrate part moves the thread hole to align with the bolt in the tester. Calibrate parts consists of two pairs of step motors and ball screws and are located at the bottom of the test machine. Two pairs of step motors and ball screws are installed perpendicular to each other, and each step motor is rotated so that the thread hole moves along the x and y axes. The calibrate parts are controlled using the algorithm in Fig. 2.

4. EXPERIMENT

To improve the accuracy of the test, users need to set the values of the turns and motor torque. To set those values, we checked the accuracy through various experiments. To demonstrate the effect of the settings, the accuracy experiments are carried out.

4.1 Accuracy experiment by torque

The torque setting of the motor is an important factor because it detects the reverse torque of the motor and identifies a defect. If the torque setting is too low, then a normal thread hole will be identified as having a defect. If the torque setting is too high, then a faulty thread hole will not be identified correctly.

Accordingly, we do experiments to measure the tester accuracy while changing torque. The experiments were conducted using M3, M4, M5 bolts, and thread holes. The experiments were carried out 10 times each with M3, M4, M5 bolts, and thread holes for the following four types: normal thread holes, thread-free, bad threaded, and smaller thread hole.

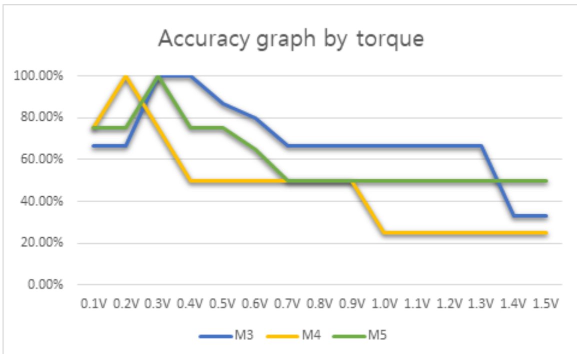

Fig. 20 Accuracy graph by torque

Test results in Fig. 20 show that M3, M4, and M5 thread holes have the highest accuracy when torque voltages are 0.3V~0.4V, 0.2V and 0.3V respectively.

4.2 Accuracy of setting the optimum torque automatically by determining thread hole size

The image processing parts of the calibrate machine detects the size of the thread hole automatically, so that the inspection can be carried out with the optimum torque voltage.

We perform the test with fixed torque voltage (0.4 V) to demonstrate the effect of setting the optimum torque. The experiments are carried out 20 times each with M3, M4, M5 bolts, and thread holes for the following four types: normal thread holes, thread-free, bad threaded, and smaller thread hole.

The test results in Fig. 21 show that the automatic setting of optimum torque by checking the size of thread hole shows higher accuracy, compared to the case where a fixed torque (0.4 V) is used.

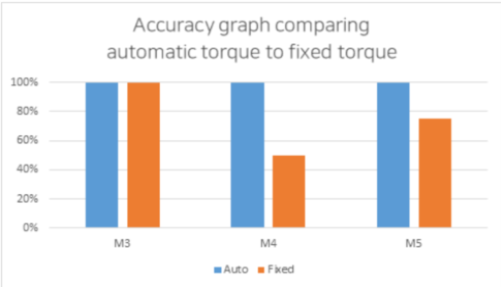

Fig. 21 Accuracy graph comparing automatic torque to fixed torque

5. CONCLUSIONS

In this paper, we propose a contact type threads tester that sorts out a defect of threads, which occurs in the process of producing thread holes.

The motor measures the reverse torque when tightening the bolt, in order to sort out defective thread holes. Setting the optimal reverse torque allows accurate inspection of various types of bad thread holes robustly.

Using a camera, the tester automatically detects the size of the thread hole and sets the optimum torque setting. Also, the tester removes the positional misalignment between bolt and thread hole, using a calibrator and a camera.

The application is developed so that users can easily change the tester settings without the help of a professional engineer. The data on inspection status are accumulated on the server, so that users can find the cause of a defect and find ways to reduce the defect rate.

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