Study of Resistance Strain-resistor Torque Sensor Based on Simscape Environment

Xin-hua LIU¹, Zhi-TANG²*, Feng-chun LIU³, Jing-jing FAN⁴ and Shuai LIU⁵

¹China North Engine Research Institute, Tianjin, China
²China North Engine Research Institute, Tianjin, China
³China North Engine Research Institute, Tianjin, China
⁴Purepower Technology Co., Ltd, Tianjin, China
⁵Purepower Technology Co., Ltd, Tianjin, China

*Corresponding author

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Abstract. In order to resolve the problems of the torque sensor, including the principles and structure can not be reflected, the measurement results to be idealized and the noise can't be presented in the MATLAB/simulink simulation environment. The simulation model of train-resistor Torque Sensor consists of three modules: the strain axis module to realize transformation the torque to the strain, bridge module including four strain gauges, bridge output voltage. The model output is 0 to 5V voltage, measurement results contain Gaussian distribution errors, which make simulation system to better reflect the real objects, at the same time for more detailed study of the torque sensor and pave the way.

Introduction

Torque sensor becomes the focus of technology development in industries. The preloading tools and equipments need the torque sensor to provide a signal, which is very important and directly affects the controlling results. Some tools such as electrical wrenches, screwdrivers, and automotive Electric Power Steering-(EPS) system, according to torque sensor, can be controlled by online detection of working shaft torque to achieve automatically operational purpose of industrial process.

The resistance strain-resistor is glued to the specified position of the object surface. The resistance changes by the strain produced by the elastomer forced. By the bridge and measuring circuit, the strain is converted to electrical signal (voltage, current, frequency, etc), to be measured the torque value. The strain-resistor torque sensor is cheap, easy operation, high measurement precision. At the same time, the torque sensor is widely used. Therefore, research of strain-resistor torque sensor is valuable.

The research of torque sensor based on matlab/simscape has special function. The simulation model can reflect the measurement principle of current sensor, which have a more specific structure, and can reflect the measurement errors. The model consists of three modules: the strain axis module to realize transformation the torque to the strain, bridge module including four strain gauges, bridge output voltage. Through the experiments, the simulation system can reflect the actual object accurately, and can provide torque sensor model for various environmental use.

Simulation Model of Strain-resistor Torque Sensor

The torque sensor is measured by the strain of the torsion axis[3]. The model has no load effect on the original mechanical part. The results of the measurement including a noise of Gauss distribution, and the mean and variance of the measurement can be adjusted. The output of the sensor is a 0 to 5 voltage.

The formula is as follows:
\[ V_{out} = \frac{T \times 5}{(T_{\text{max}} - T_{\text{min}})} \]  

(1)

**Model Principle Overview**

The sensor is added a shaft connecting to the mechanical transmission path based on the principle of strain. The shaft is produced strain by torque. The strain gauge is attached to the surface of the shaft\(^4\), and the resistance changes when the strain is changed. The strain gauge is connected in the bridge circuit. The Fig. 1 is model diagram.

Figure 1. Model diagram.

**Design Model**

The model is built according to the principle of the strain-resistor torque sensor. The model consists of three modules: the strain axis module to realize transformation the torque to the strain, bridge module including four strain gauges, bridge output voltage. The internal structure of model is shown in Fig. 2. The model includes two physical interfaces that can be strung into the torque point and two physical interface of the output voltage results. The output voltage of the model contains the errors of Gauss distribution.

Figure 2. Internal Structure of Three Modules.

**Analysis of Resistance Strain Gauge**

**Strain of Shaft Under Torque**

Fig. 3 reflects the stress state of the surface of elastic shaft\(^5-7\). By the analysis, only by the effect of torque, axial and axial direction of 45 degrees is the maximum stress, while axial and axial direction of the degree of -45 is the minimum stress. They are\(^8-9\):

\[ \sigma_{\text{max}} = \frac{M}{W_p} = \frac{16M}{\pi D^3} \]  

(2)

\[ \sigma_{\text{min}} = -\frac{M}{W_p} = -\frac{16M}{\pi D^3} \]  

(3)
The strain of the strain-resistor:

\[ \varepsilon_+ = \sigma_{\text{max}} / E = \frac{16M}{\pi ED^3} \]  
(4)

\[ \varepsilon_- = \sigma_{\text{min}} / E = -\frac{16M}{\pi ED^3} \]  
(5)

The absolute value as follows:

\[ \varepsilon = \frac{16M}{\pi ED^3} \]  
(6)

Where, \( \varepsilon \) is the strain value, \( M \) is the Strain axis torque, \( D \) is strain axis diameter, \( D \) is the young modulus of strain axis, \( W_p \) is the torsional modulus of axial section.

Figure 3. Axial surface stress state.

**Layout of Strain Gauge**

Fixed mode of strain-resistor are as shown in Fig. 4[10], The strain-resistor are gauge is placed in the direction of maximum tensile stress and maximum compressive stress, and combined with the full bridge circuit, the sensor sensitivity can be improved, and the temperature of the strain gauge is also influenced by the whole bridge circuit.

Figure 4. Fixed mode of strain gauge.

**Resistance of Strain Gauge**

For the length of \( l \), the resistivity is \( \rho \), the radius of the circular section resistance wire is \( r \), and the resistance is:
\[ R = \rho \frac{l}{\pi r^2} \]  

thus there are:

\[ \frac{dR}{R} = \frac{dl}{l} - 2 \frac{dr}{r} + \frac{d\rho}{\rho} \]

For wire of the Poisson's ratio is \( \mu \), there are

\[ \frac{dr}{r} = -\mu \frac{dl}{l} \]

the ordinary metal wire, ignoring the piezoresistive effect and considering

\[ \frac{d\rho}{\rho} = 0 \]

Thus, the upper type (8) is simplified as:

\[ \frac{dR}{R} = (1 + 2\mu) \frac{dl}{l} = (1 + 2\mu)\varepsilon \]

### Bridge Voltage Output

The full bridge circuit is shown in Fig. 5[11].

\[ V_o = u(\frac{R_2}{R_1 + R_2} - \frac{R_3}{R_4 + R_3}) \]

When the strain gauge has no strain, \( R_1=R_2=R_3=R_4 \), at this point \( V_0=0 \). The shaft of the applied torque makes the strain of the strain-resistor, causing the resistance change. At this point, according to the way of the strain-resistor, it should be

\[ dR_1 = dR_3 = -dR \quad dR_2 = dR_4 = -dR \]

Then:

\[ V_o = u(\frac{R_2 + dR_2}{R_1 + dR_1 + R_2 + dR_2} - \frac{R_3 + dR_3}{R_3 + dR_3 + R_4 + dR_4}) = u \frac{dR}{R} \]

In summary, the final output voltage of the bridge is

\[ V_o = u(1 + 2\mu) = \frac{16M}{\pi ED^3} \]
Parameter Settings

Table 1. Output standard.

<table>
<thead>
<tr>
<th>Common</th>
<th>Maximum torque</th>
<th>Minimum torque</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000N*m</td>
<td>-1000N*m</td>
</tr>
<tr>
<td>Voltage</td>
<td>5v</td>
<td>0v</td>
</tr>
</tbody>
</table>

Table 2. Noise.

<table>
<thead>
<tr>
<th>Noise mean</th>
<th>Noise variance</th>
<th>Noise sample times</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N*m)</td>
<td>(N*m^2)</td>
<td>(s)</td>
</tr>
<tr>
<td>0</td>
<td>100N^2*m^2</td>
<td>0.001s</td>
</tr>
</tbody>
</table>

Table 3. Axis and Strain bridge.

<table>
<thead>
<tr>
<th>Axis</th>
<th>Strain bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Elastic</td>
<td>Diameter</td>
</tr>
<tr>
<td>1000Mpa</td>
<td>0.06m</td>
</tr>
</tbody>
</table>

Test Certificate

To test the availability of the model, the experimental environment is built shown in Fig. 6. The environment includes a torque source that can generate ideal torque. At the same time, comparing the model output to the original ideal torque; the torque sensor output is 0 to 5V voltage. By analysis of the test results, Fig. 7 is the contrast chart of the test results.
Conclusions

The results of simulation and experiments show that, the model of strain-resistor torque sensor can reflect the measurement principle and the errors of the measurement. The model is considered the principle of strain-resistor torque sensor, modeling the internal structure. The model is important to further study of the sensor and its effect in system. The model consists of torque value and adjustable Gaussian distribution errors, which can better reflect the actual situation in the measurement, and more effective.

References


