Torque Sensors Calculation Software

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Abstract. The problem of torque control is relevant in many technological processes today. In order to better measure torque, it is appropriate to use special sensors instead of indirect control methods. The system of a circular contactless magnetoelastic torque sensor has a number of advantages over existing devices, such as strain gauge or other types of magnetoelastic sensors. However, each technological process needs to design its own magnetoelastic sensor with unique characteristics. Calculation of these characteristics is a long and complicated process, due to long equations with a large number of coefficients, which are dependent on conditions of the technological process. Output value variability, in addition, depends directly on selected parameters. It means that calculation shall be repeated in order to receive more suitable output values. The authors propose the special program that makes it easier to calculate the characteristics of this devices. This program selects the necessary values of coefficients automatically, in addition to solving the equations. It also allows users to vary different parameters of the device according to the conditions, with subsequent printing the output values on the screen. As the result, using this program, a rapid, accurate and automated calculation of a torque control device becomes possible.

1. Introduction

The problem of torque control is relevant in many technological processes, where rotational drive mechanisms are used (such as electrical drive, diesel engine, etc.). Very precise torque control could significantly increase the efficiency of such processes and reduce the components wear of their mechanical systems. It also could prevent destructive processes related to torque spikes [1].

The system of a circular contactless magnetoelastic torque sensor has many advantages. It allows using these devices in different industrial sectors, such as:

- railway transport (to develop anti-wheelslip system) [2];
- auto- and motosport (motor torque control) [3, 4];
- oil industry (to prevent torque failure and destruction of the drill pipes) [5, 6];
- shipbuilding (to control propeller thrust) [7];
- metallurgy (to control the torque of rolling mill) [8, 9];
- pulp and paper industry (for web tension control);
- agricultural industry [10].

However, for each system in these industrial sectors, the device with specific parameters is required. Calculation of these parameters is a long and complicated process, due to long equations with
a large number of coefficients. Output values variability, in addition, depends directly on selected initial and intermediate parameters. Therefore, if it is necessary to change some values, the long calculation process shall be repeated [8].

The goal of this work is to develop an application which processes all the calculations automatically and selects needed coefficients independently. All the user has to do is to assign initial conditions for coefficient selecting and to choose the overall dimensions.

The program suggests that the user should utilize the most suitable overall dimensions values, but there is often need to change them according to different circumstances (such as space limit).

2. Program interface

Figure 1 presents the application interface. It includes 4 sections with many text boxes, in which user should enter some values.

The first step is to assign the initial values of the system in “Main parameters” section. User should enter shaft diameter ($D$), torque on the shaft ($M_{\text{max}}$), shaft velocity ($n$), input voltage ($U_{\text{in}}$) and frequency ($f_{\text{in}}$) of the device values into the corresponding text boxes. Once that has been done, it would be possible to calculate the number of poles by clicking on “Calculate p”. This parameter defines the number of poles, which generate magnetic field around the shaft. Program suggests that user should have the most suitable number of poles, but this value should be assigned by user himself. The main rule is that the selected number of poles must be lower than the calculated value and it should be multiples of two. It also should be as close to the calculated value as it possible. After entering the selected number of poles, it is necessary to press the “Confirm p selected” button. An example of the number of poles calculation is shown in Figure 2.

![Figure 1](image.png)

Figure 1. The mail window of the program for calculations of the contactless magnetoelastic torque sensor.

The number of poles is calculated using the following formula:

$$p = \frac{2\pi \cdot f_{\text{in}}}{n},$$

where $f_{\text{in}}$ is the power source frequency and $n$ is the shaft velocity.

The next step is typing intermediate parameters in the “Design parameters” section that define the overall dimensions of the sensor. These parameters will be set automatically, but they could be changed depending on the circumstances. After determining design parameters, the sensor diameter should be calculated by clicking on “Calculate the sensor diameter”. Examples of sensor diameter calculation are shown in Figure 2. Figure 3 is a schematic drawing of the device with some of main and design parameters.

The device appearance depends mostly on a number of poles, and design parameters influence the dimensions of the sensor. Device models with a different number of poles are shown in Figure 4.
After geometry calculation, it is necessary to define electromagnetic parameters in the “Parameters of electromagnetic circuit” section. Let us select the shaft steel type by clicking on the relevant pull-down menu.

A design value of the exciting coil number of conductors is suggested below but should be defined as a whole number by the user. Also the detector coil number of conductors should be entered. After that coil current can be calculated by clicking on “Calculate Ic” button. The example of this calculation is given in Figure 5.
Figure 4. Models of the magnetoelastic contactless torque sensor, developed in ANSYS Maxwell: a – four-poles sensor model, b – eight-poles of an exciting coils sensor model.

Finally, the program calculates the output values in the last sector called “Output voltage calculation”. These values are electromotive forces on both output terminals of the circuit and output voltage which is the difference between these forces. The output voltage is the principal value that defines the sensor work. When one assigns the shaft torque value in the relevant text box, the output voltage changes with it as shown in Figure 6. The user should vary the shaft torque value from zero to maximum, and thus the static characteristic of the sensor can be obtained.

Figure 5. Example of electromagnetic circuit parameters calculations.

Figure 6. Example of output voltage calculation.

3. Output voltage calculations
The first thing to do for output voltage calculation is to move shaft torque into the mechanical tension on the shaft surface by the following equation:

\[ \sigma = \frac{M}{0.2D^3}, \]

where \( M \) is a shaft torque. Permeability change is calculated according to the formula:
\[ \Delta \mu = 3.7 \sigma \frac{\mu_d}{H}, \]  

where \( \mu_d \) is a differential permeability that is determined by the induction-permeability curve. Then one needs to calculate the electromotive forces on two terminals by the following equations:

\[
E_{I1} = 2\pi \cdot f_{in} \cdot \Phi_{D1} \cdot w_D, \tag{4}
\]

\[
E_{I2} = 2\pi \cdot f_{in} \cdot \Phi_{D2} \cdot w_D, \tag{5}
\]

where \( \Phi_{D1} \) and \( \Phi_{D2} \) are magnetic fluxes passing through the detector coils, \( w_D \) is a number of conductors in detector coils and \( f_{in} \) is input frequency. Magnetic fluxes are calculated by the program in the previous steps.

The last step of calculations is to find a difference between electromotive forces according to the equation:

\[
U_{out} = k_C (E_1 - E_2), \tag{6}
\]

where \( k_C \) is a rectification circuit coefficient depending on the rectification circuit and the resistance ratio of load resistors [7].

The static characteristic was obtained according to some value from examples above. This characteristic can be seen in Figure 7.

![Figure 7. Static characteristic of sensor](image)

The program is implemented on Python with Qt framework for graphic interface. For function interpolation, the program uses SciPy library [11].

4. Conclusions
This article presents the interface of the developed program that produces automatic torque sensors calculation. This calculation is based on the circular contactless magnetoelastic torque sensor system. Operability of this program was successfully tested on parameters, which describes some rotational drive mechanism.

Testing showed that results of the calculation are suitable, as can be seen in the voltage-torque characteristic which is almost a straight line.

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