Structural design and performance analysis of elastomer for robot wrist force sensor

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Abstract. The robot wrist force sensor is a force sensor installed at the junction of the robot's claw and the arm, as one of the important sensors in intelligent robot systems. As a carrier of strain type elastic past wrist force sensor of strain gauge, its importance is self-evident. For an industry to design a flexible cantilever beam wrist force sensor body structure series robot, the selection of materials are described, has carried on the modeling, set constraints and load using finite element analysis software ANSYS, finally inspected the strain diagram of the elastomer and has carried an the strength and rigidity check. The analysis results show that the elastic structure has good mechanical properties, and the strain gauge is large, which is in line with the requirements of the robot.

1. Introduction
The robot wrist force sensor is a force sensor installed at the joint of the robot's claw and the arm. It can detect the magnitude and direction of the force that the robot is in contact with or touch the external environment, and provides force information for the robot control [1]. The wrist force sensor is one of the most important sensors in the intelligent robot sensing system. It can provide multi-dimensional force/torque information in three-dimensional space at the same time. It has high detection precision, high rigidity and simple calculation. The importance of elastomer as one of the robotic wrist force sensors is self-evident. At present, the elastic structure of the wrist force sensor is mostly resistance strain type, and the resistance strain measurement is the main measurement method of the six-dimensional force/torque sensor. This paper introduces an elastic structure of wrist force sensor suitable for RBT-6T/S03S industrial series joint robot, and uses ANSYS software to simulate its mechanical properties. The analysis results show that the elastic structure has good mechanical properties. The sensitivity is high, and the strain gauge is attached to each beam, so that the real-time measurement of the force condition can be realized, which is in accordance with the requirements of the robot.

2. Elastomer structure design

2.1 Selection of basic styles of elastomer structure

The strain-type wrist force sensor has a variety of elastic body structures such as cantilever beam, double-end fixed beam type, octagonal ring type and thin-walled cylinder type [2, 3]. In order to
compare the performance of the above various elastomer structures, sensitivity $\beta$ and static stiffness $K$ are introduced here. Sensitivity is the strain value of the elastomer component under the action of unit force. The calculation formula is:

$$\beta = \varepsilon / F$$  \hspace{1cm} (1)$$

In the above formula: $\varepsilon$ is the amount of deformation of the elastomer under the action of the force value $F$.

The static stiffness is the reciprocal of the total deformation of the elastic element under the action of the unit force, that is, the force required to produce the unit displacement in the direction of the force. The calculation formula is:

$$K = F / f$$  \hspace{1cm} (2)$$

In the above formula: $f$ is the total amount of deformation produced by the elastomer under the force value $F$.

It can be seen from the above formulas that for elastomeric components, increasing their sensitivity and static stiffness are contradictory. This solution to the contradiction can only make a reasonable choice based on careful analysis of the actual working conditions of the sensor[4].

Table 1. Performance index of commonly used elastomer components

| Name              | Double-ended fixed beam | Truss beam | Cantilever beam | Octagonal ring (vertical direction) | Octagonal ring (tangential) |
|-------------------|-------------------------|------------|-----------------|-------------------------------------|----------------------------|
| Sensitivity $\beta$ | $3L / 4Ebh^2$           | $3L / 4Ebh^2 / L / Ebh^2$ | $1.09R / Ebh^2$ | $2.18L / Ebh^2$                     |                            |
| Static stiffness $KS$ | $16Ebh^3 / L^3$         | $16Ebh^3 / L^3 / Ebh^3 / 4L$ | $Ebh^3 / L^3 / 0.715$ | $R^3Ebh^3 / 3.768$                 |                            |

It can be seen from Table 1 that the elastic body of the cantilever beam structure has the highest sensitivity when the size parameters of the elastomer are the same, but the static stiffness is the lowest. Considering that the test robot's claws have a bearing capacity of only 25N, the static stiffness standard of the cantilever beam can fully meet the actual requirements for this topic, so the accuracy should be the selection standard. Therefore, an elastic body of a cantilever beam structure is selected.

2.2 Elastomer structure design and material selection

Among the elastic structures of the cantilever structure, the cross-floating cross-beam structure is the most typical one and the most widely used. Therefore, we use the cross-floating cross-beam structure elastomer as the deformation component of the wrist force sensor.

According to the size of the wrist structure of our laboratory robot, the designed elastic body is shown in Figure 1. When performing the elastic body analysis, we think that the base and the center platform are ideal rigid bodies. When the deformation of the floating beam is greater than 20 times the deformation of the main beam, the deformation of the main beam can be neglected, and the main beam can be simplified into a cantilever beam structure for analysis.
At present, the elastomer materials of the wrist force sensors used in domestic and foreign robots mostly use LY12 hard aluminum and 40Cr. Because LY12 hard aluminum is cheap and easy to process, its specific gravity is only about one-third of 40Cr. Therefore, the elastomer material of the sensor is LY12 hard aluminum alloy. The main mechanical properties of LY hard aluminum are shown in Table 2.

### Table 2. Mechanical properties of LY hard aluminum

| Brand | Elastic Modulus $E$ ($N/m^2$) | Shear modulus $G$ ($N/m^2$) | Density $\rho$ ($kg/m^3$) | Poisson's ratio $\mu$ | Yield Strength $\sigma_y$ ($N/m^2$) |
|-------|-------------------------------|----------------------------|---------------------------|-----------------------|----------------------------------|
| Sensitivity $\beta$ | $7.2 \times 10^{9}$ | $2.7 \times 10^{9}$ | $6L/Ebh^2$ | 0.33 | $3.4 \times 10^{3}$ |

3. Analysis of mechanical properties of elastomer

In recent years, with the rapid development of computers, the analysis of sensors using computers with high-speed computing capabilities has been widely adopted. The use of finite element method for structural analysis is a very effective means. In this paper, the finite element analysis of the developed wrist force sensor elastomer is carried out by ANSYS analysis software, and its mechanical properties are mainly studied[5-7].

3.1 Establishment of Elastomer Finite Element Model

The elastomer structure used in this paper as a whole is formed by one-time processing of LY12 hard aluminum alloy. This structure can greatly improve the rigidity and sensitivity of the sensor. In this paper, the SOLID95 high-precision solid element in ANSYS is selected as the simulation unit. The intelligent mesh division control makes eachline on the main beam of the elastic body divided into 15 points. The rest is automatically divided by ANSYS. The final finite element model is 44,145 Nodes, 26,454 elements. The solid modeling model of the elastomer in ANSYS and the results of the meshing are shown in Figure 2.
3.2 Setting constraints and applying loads

After meshing, the elastic model is constrained. The base of the elastic body is connected with the arm of the robot. It is connected by four bolts and can be regarded as a rigid connection. Therefore, the bottom of the elastomer model should be set to have zero degrees of freedom. Next, apply a concentrated force/torque to the elastomer model.

According to the force measurement requirements of the sensor and the actual force of the robot wrist, six typical working conditions are determined here: through the coordinate origin, respectively, in the X, Y, Z direction and around the X, Y, Z directions on the elastomer. The concentrated force and moment of the cross beam are: Fx, Fy, Fz, Mx, My, Mz. In force/torque loading, the coordinate origin is set at the center of the center station. Due to the symmetrical structure of the elastomer, the deformation and strain of the elastomer under the action of Fx, Fy and Mx, My are similar. Therefore, we only analyze Fx, Fz and Mx, Mz here.

In the actual work of the wrist force sensor, the elastic body is connected with the four claws on the center table and the robotic claws, so that the force of the claw is transmitted to the elastic body of the sensor through four bolts, so the force/torque loading should be The corresponding positions of the four bolts of the center table (Note: the four holes on the center table are the bolt hole positions) apply a single-dimensional force and moment, set the positive direction of the coordinate axis to be positive,
and the torque direction is judged by the right hand rule. By looking at the solution strain map, we can understand the stress and strain distribution of the elastomer.

### 3.3 ANSYS strain chart and result analysis

In order to facilitate the analysis results, the surface numbers of the main beam of the wrist force sensor elastomer structure are shown in Fig. 3. The main beam faces of No. 4, 8, 12, and 16, respectively, correspond to the back faces of the main beam faces.

1) \( F_z = -20N \). Since the robotic gripper used in the experiment can only carry a load of 25N, the maximum force load in the analysis here is 20N. The elastic floating beam is set to maximize the free deformation of the main beam after loading force. As shown in Fig. 4, it can be seen from the simulation analysis that the strain of the main beam except the floating beam is affected by the negative force maximum. In addition, on the four main beams of the elastic body, the faces 1, 5, 9, 13 are pressed, the faces 4, 8, 12, 16 are pulled, and the deformations caused by the tension and compression at the corresponding upper and lower positions are identical.

![Fig. 4 Strain diagram of the elastomer at \( F_z = -20N \)](image)

2) \( F_x = 20N \). As shown in Fig. 5, when the elastic body is subjected to a force of 20 N in the X direction, the main deformation concentrates on the four faces of the two main beams, the faces 2, 11 are pressed, and the faces 3, 10 are pulled. Due to the symmetry of the elastomer, it can be seen from the results that the amount of deformation at the corresponding position of the tensioned and stressed beam is the same.

![Fig. 5 Strain diagram of the elastomer at \( F_x = 20N \)](image)

3) \( M_z = 20 \times 6N.MM \). As shown in Fig. 6, when the elastic body is subjected to the 20N.MM moment in the Z direction, the main deformation concentrates on the eight faces of the four main beams, and the faces 3, 7, 11, and 15 are pressed, and the faces 2, 6, and 10 are pulled. Due to the
symmetry of the elastomer structure, it can be seen from the results that the amount of deformation at the corresponding position of the tensioned and stressed beam is the same.

Fig. 6 Strain diagram of the elastomer at Mz = 20X6N.MM

4) $M_x = 20 \times 6N.MM$. As shown in Fig. 7, when the elastic body is subjected to the 20N.MM moment in the X direction, the main deformation concentrates on the four faces of the two main beams, the faces 4, 9 are pressed, and the faces 1, 12 are pulled. Due to the symmetry of the elastomer structure, it can be seen from the results that the amount of deformation at the corresponding position of the tensioned and stressed beam is the same.

Fig. 7 Strain diagram of the elastomer at Mx=20X6N.MM

From the above ANSYS analysis results, it can be seen that when the elastic force of the wrist force sensor is subjected to the six-dimensional force, the most deformed part is on the main beam (except the floating beam), so the strain gauge should be attached to each surface of the main beam, and try to be close to the center station.

In addition, in order to judge the rationality of the elastomer design, we check the maximum stress and maximum deflection of the elastomer after the unit force/torque loading to check the stiffness and strength. The stiffness and strength check are shown in Table 3. The yield limit of the elastomer material LY12 hard aluminum alloy is $\delta_y = 360MPa$. It can be seen from the table that under the action of full-scale force/torque, the strength and rigidity of the elastomer can meet the requirements. In addition, the deformation part of the elastic body is obvious, and other interferences are less, so the elastic structure of the above design is reasonable. Meet the design requirements.
Table 3. Single-dimensional force / moment action elastomer strength, stiffness check.

| Name          | Elastic body maximum stress (Mpa) | Maximum deflection (μm) |
|---------------|----------------------------------|-------------------------|
| $F_x = 20N$   | 0.13                             | 2.47                    |
| $F_z = -20N$  | 0.83                             | 15.4                    |
| $M_x = 20 \times 6N.MM$ | 0.07                             | 1.44                    |
| $M_z = 20 \times 6N.MM$ | 0.05                             | 1.03                    |

4. Conclusion
An elastic structure of cantilever beam type wrist force sensor suitable for an industrial series articulated robot is designed. The basic form and material selection of the structure are described. Then it is modeled and set by ANSYS software. Constraint, load application, and finally check the strain diagram of the elastomer and check the strength and stiffness. The analysis results show that the mechanical properties of the elastomer are good, and the strain at the strain gage is large, which is in line with the requirements of the robot.

5. References
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