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A new type of force sensor

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Abstract

A new type of force sensor isproposed, mainly based on standard machine parts. The sensor is made of two spring discs, positioned in mirror one to another and joined together by means of electron beam welding. A sensitive element in shape of a rectangle for example is placed between the spring discs. To design the sensor geometry finite element analysis (FEA) was applied to simulate the mechanical strains and stresses in the force sensor and to improve the sensor characteristics by placing the strain gauges on the maximum strain positions. Calibration tests were performed using a testing machine with dead loads to evaluate the linearity, hysteresis and creep.

Keywords: force sensor, load cell, finite element analysis, thin film strain gauges, electron beam welding

1. Force Sensor Design

Out of the variety of standard machine parts some of them are adequate for sensor purposes, hence we chose bolts, screws and spring discs. In this paper, we propose a spring disc sensor. We used commercial spring discs (Christian Bauer GmbH) of the special stainless steel type DIN 1.4568 with known physical and mechanical properties. We designed a model of two spring discs and one intermediate element as the sensitive element of the sensor, in order to realize a force sensor of a nominal force of 100 kg. The sensitive element of the sensor has different geometries and it is made of a sheet of steel from the same material. This sensitive element was cut by means of a laser. The finite element method was used to study the strain stress distribution and to optimize the sensor geometry. The manufactured sensors were statically calibrated using a dead-weight testing machine with a maximum load of 125 kg.

2.1 Materials And Methods

To realize the force sensor we chose two types of spring discs (figure 1) with the following dimensions [3]; a thin spring disc D_e=35,5 mm x D_i=18,3 mm x t=1,25 mm and lo=2,25 mm, and a thick spring disc D_e=35,5 mm x D_i=18,3 mm x t=2 mm and lo=2,80 mm.

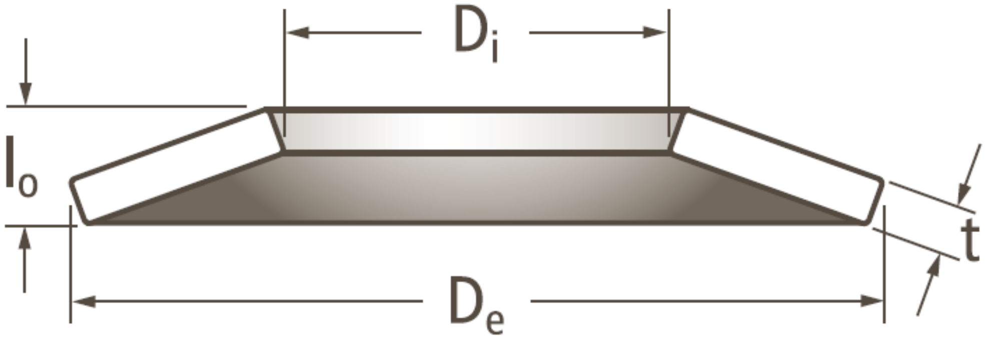
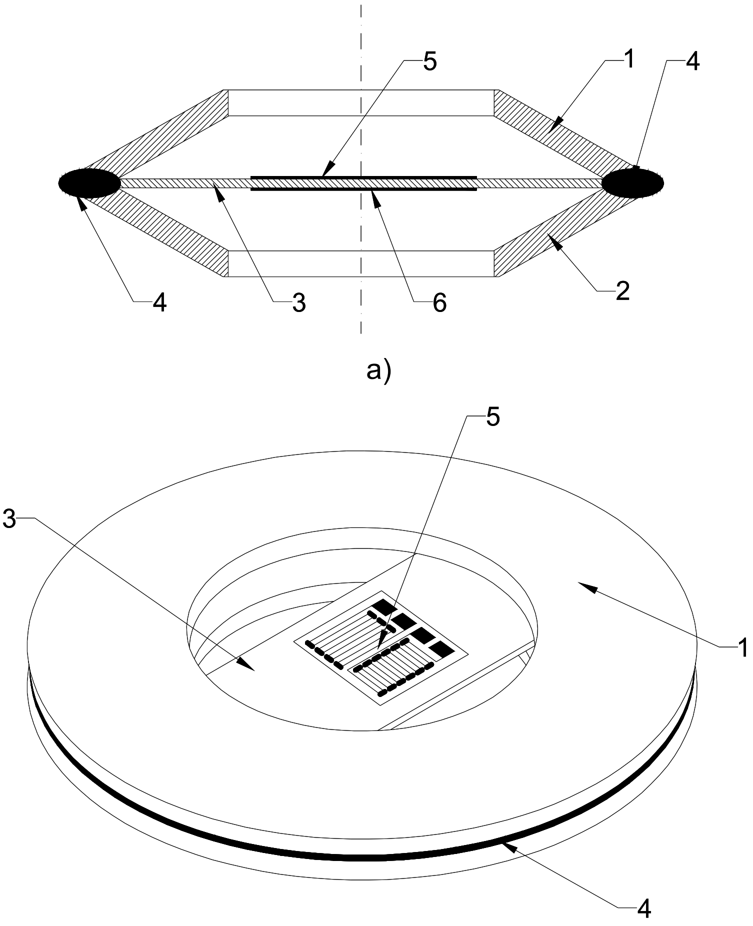


Figure 1 – Spring disc

The force sensor (figure 2) consists of two spring disc 1, 2 positioned in mirror. Between them an elastic element 3 is placed.



a)

b)

Figure 2 – Sketch of the force sensor; a) section view, b) isometric view

We started with a rectangular plate, named type I (figure3) with the following dimensions: L=35,5 mm x l=10 mm x h=0.4 mm and: L=35,5 mm x l=6 mm x h=0,4 mm, carrying the strain gauges 5, 6, glued on both sides of the plate.

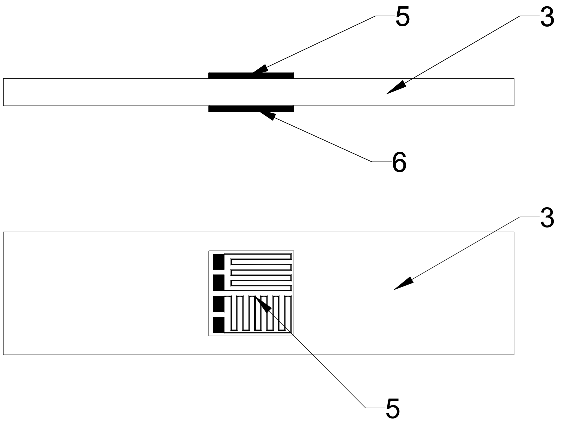


Figure 3 – Type I sensitive element

In a different design the strain gauges were placed only on one side. Other geometries based on the same spring disc were investigated as well. Type II (figure4) has a well-defined buckle with a certain radius. The strain gauges are glued on both sides of the steel sheet.

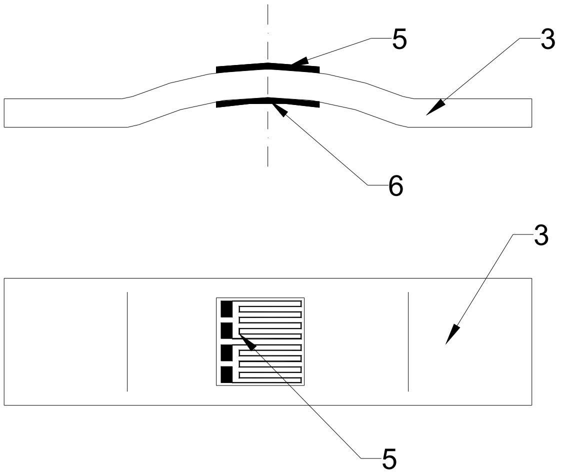


Figure 4 – Type II sensitive element

Finally we have designed a more complex geometry, type III (figure5), consisting of a ring element 7, overload protection 8 and a hole 9 for a cable.

The ring element 7 is designed to house the electronic parts for amplification, temperature compensation, linearization, etc.

The elements of the sensor were joined together using electron beam welding. A special device was built to fix the different components of the sensor during welding. The structure was fixed and rotated while the spot of the beam melted the joining zone. A couple of experiments were performed to establish the optimal parameters of the welding process.

At first we simulated a single spring disc and applied different forces. We registered no significant differences between the finite element results and the data of the catalogue. The spring disc has a nonlinear elastically behavior. The force was applied in steps onto the inner diameter on the spring while the outer diameter could extend freely.

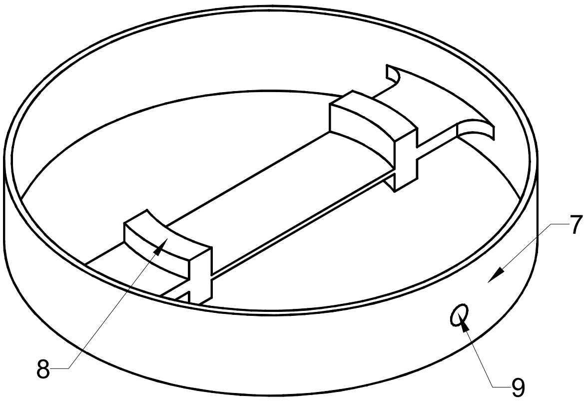


Figure 5 – Type III sensitive element

2.2 Theoretical Approach – Finite Element Analysis

The second step was to simulate the two spring disc arrangement without the sensitive element. We took care of the influences of the joining zone. The models had around 30.000 nodes. In a final step the complete sensor geometry was simulated. We considered different widths of the sensitive element and different types of sensitive elements as described above. The maximum force applied in the simulations was 1250N.

3. Experimental Tests

Some force sensors were built up and tested on a static dead-load machine. We measured the linearity, sensitivity, hysteresis and creep by loading the sensors to an output of 2 mV/V or 2000 µm/m. The strain gauges were placed and glued at the locations determined by finite element method. The force was applied directly onto the sensor using a bearing ball to secure a vertically applied force. Measurements were performed at room temperature and 50°C.

4. Results and Discussion

The depth of the joining zone has a big influence on the rigidity and hence the sensitivity of the sensor. We simulated joining zone depths of 0.08 to 1mm and as a consequence the sensor sensitivity decreases by a factor of approx. 10.

Different types of sensitive elements as described above were simulated and measured. For type I elements two different widths of the plate, 10 mm and 6 mm were tested. In this case there are two possibilities to realize the joining: Welding only the width of the plate or 360^o around. The output signals were calculated [4] based on the strains in defined regions of the simulations, where the strain gauges are to be positioned.

Table 1 summarizes the finite element results for sensitive elements with 6 mm width. The stress represents the maximum von Mises stress localized in the welding zones. Sensitivities were calculated using tension and compression strains localized on the sensitive element. All simulated models presented in the table 1 are 360^{o} welded.

Table 1 – Simulation and experimental results

Nr.	Spring disc	Element Type	Welding angle	Welding	Stress MPa	Sensitivity mV/V	
						FEA	Experimental
1	Thin	I	360^{o}	EBW	440	0.278	0.8
2	Thin	II	360^{o}	EBW	507	0.515	1.1
3	Thick	I	360^{o}	EBW	512	0.12	0.2
4	Thick	II	360^{o}	EBW	240	0.63	0.7
5	Thick	III	360^{o}	EBW	300	0.67	0.8

In the case of the thick spring disc the simulation and experimental results are comparable regarding the sensitivity. Big differences occur with thin spring discs presumably due to the influences of the welding zone. We observed some dilatation and deformations after the welding process due to the heat and cooling process. Using element types II and III the sensitivity of the sensors increased while the von Mises stress in the welding zone decreased (table 1).

Measured linearity errors (figure6) are about 5 % with a hysteresis of about 5 %. The experimental results are different for various sensor devices. The best measured value for the linearity error was approx. 2 % which is in contradiction to the calculated value of approx. 0.5 %. Best results were obtained with sensors using type III of sensitive elements.

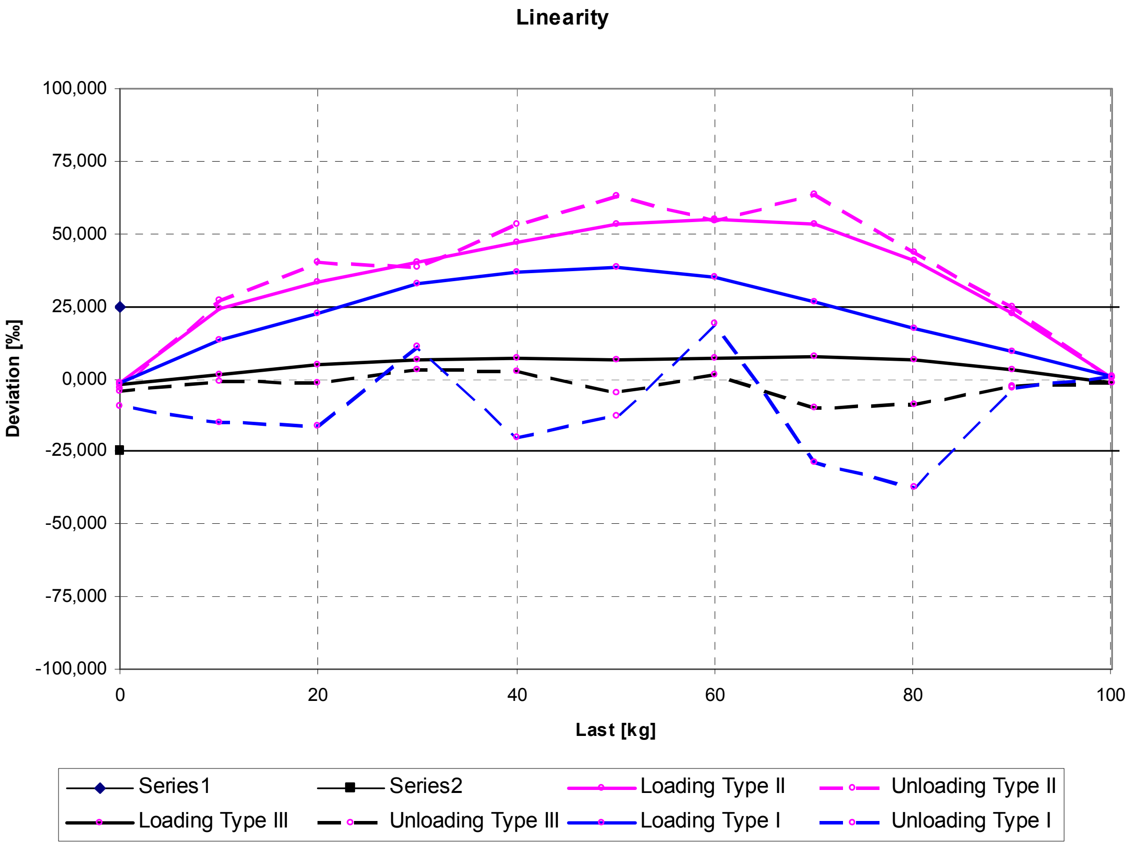


Figure 6 – Linearity error plot

5. Conclusion

We propose a new type of force sensor consisting of two spring discs and a sensitive element joined by welded. The finite element method was used to evaluate the strain stress distribution and to optimize the sensor geometry. The sensor was statically calibrated using a dead load machine. The finite element analysis, optimization and testing process allow us to conclude that the sensor has a high potential on the force sensor market. We will apply resistance welding in the future to get a better-defined welding zone. The sensitive element can be modified in such way to permit the use of thin film strain gauges sputtered on ceramic plates.

References

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