Section 5. Machinery construction

https://doi.org/10.29013/EJTNS-22-6-62-68

Mikhalev Aleksandr Vasilievich,
sixth-year undergraduate,
Bauman Moscow State Technical University,
Department of Lifting and transport systems

DEVELOPMENT OF THE LOAD PIN FOR THE CRANE SCALES

Abstract. The development of a load pin for crane scales is presented. A load pin with a vertical wall and a load pin with a through hole were used as prototypes. Determination of the values of the parameters of the design of the load cell was carried out on the basis of the criteria of manufacturability, strength, and accuracy. The method of finite element analysis based on the ANSYS environment is applied. As a result of parametric modeling, a new design of a load pin with increased performance characteristics has been developed.

Keywords: crane scales, load pin, the load cell sensitivity, finite element analysis, machine parts computer modeling.

1. Introduction

Crane scales (suspended) are designed for commercial weighing of cargo when used together with a general-purpose lifting crane equipped with a hook suspension.

The scheme of using crane scales is as follows (Figure 1): crane scales are suspended on the crane's lifting device by a shackle in which the load sensor is fixed, a hook is attached to the sensor, which is used, in turn, similarly to the crane's hook suspension.

Various methods of load measurement are known: optics polarizing [1], piezoelectric [2], fiber-optic [3], etc. In crane scales, the generally accepted method of load measurement today is with a strain gauge [4]. The method is based on the principle of converting mechanical stress arising in the load sensor into a proportional electrical signal formed by changing the electrical resistance of the sensing element during its deformation.

Figure 1. Examples of crane scale designs

The main element determining the metrological characteristics of crane scales is a load sensor – load cell. Crane scales use S-shaped load cells, tension load cells and load pins. Crane scales with a load pin, considered in this paper, have a number of operational and technological advantages.

The purpose of this work is to develop the design of the load pin for crane scales. The following requirements are imposed on the design:

- Manufacturability;
- Providing the necessary strength;
- Provision of metrological characteristics corresponding to the required accuracy class of the device as a whole.

The manufacturability of the design should be ensured through the use of simple shapes and a minimum number of transitions to reduce the number of manufacturing operations, the use of solutions that reduce the accuracy requirements to equipment used for machining and reduce the number of necessary equipment and tools, as well as implemented without the use of special equipment.

The strength is provided by the geometry of the sensor and the material used, its thermal and chemical treatment. The factor of safety must be at least 2.5.

High indicators of metrological characteristics are realized by increasing the sensitivity of the sensor. The sensitivity is directly proportional to the stress at the place of the sticker of the sensing element, therefore, it is necessary to ensure the maximum possible stress at the place of the sticker of the strain gages, while fulfilling the strength requirement. In addition, the load measurement error is also affected by the stress distribution at the place of the strain gauge sticker. The strain gauge has the ability to average stress over the foil area. Nevertheless, the steeper the stress gradients, the higher the averaging error [5]. In this work, the difference of no more than 20% between the maximum and minimum stress at the place of the strain gauge sticker is considered permissible.

Well-known designs used in modern devices were adopted as analogues for the development of a new design of the strain gauge.

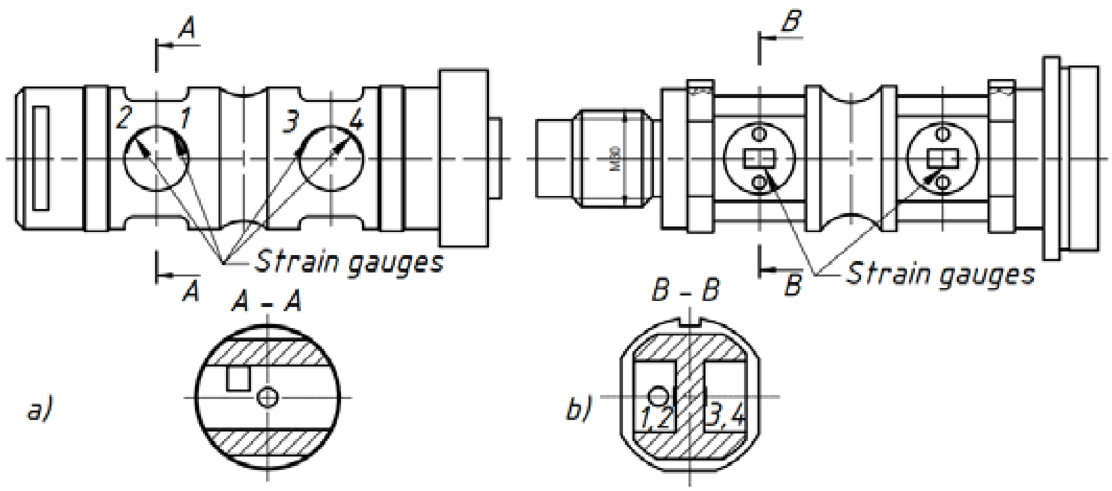


Figure 2. Samples of load pins. a) Sample 1; b) Sample 2

Their main difference is in the design of the section intended for the sticker of the sensitive element. In the first sample (Figure 2 a), it is glued to the cylindrical surface of the through hole. In the second sample (Figure 2 b), it is glued to a vertical wall in a blind hole. In [6], the advantages of a design with a vertical wall were studied and it was noted that the first design, which has a number of technological advantages relative to the second, does not meet the metrological requirements for crane scales. Therefore, it was decided to develop a design with just such a cross-section in the place of the sticker of the sensitive element, although this reduces the manufacturability during production.

Table 1 shows the results of comparing the stress in the places of the strain gages for the two compared designs of the load pins.

Table 1. – Average stress in design sections, MPa

	Sample 1, MPa	**Sample 2, MPa**
Place of the strain gauge 1	205	132
Place of the strain gauge 2	165	132
Place of the strain gauge 3	210	140
Place of the strain gauge 4	169	140
Central section	239	275

It is necessary to investigate the influence of design features and find a combination of their values that would ensure a stress level at the places of the strain gauge sticker comparable to the second sample, which is 200–220 MPa. However, at the same time it needs to have a vertical wall in the design section, thanks to which the manufacturability of the strain gauge sticker increases and their initial sensitivity is preserved.

2. Methodology

In the manufacture of strain gauges, the most common material is 40X Steel or its analogue AISI 5135. This material is characterized by the following physical properties (after heat treatment): tensile strength – 750 MPa and Brinell hardness – 235 [7].

The supports for the load pin are the surfaces of its contact with the shackle. The load is applied from the side of the hook in the middle section of the load pin. At the first stage, the geometry was changed in the SolidWorks modeling environment [8]. Each design change was followed by its calculation by the finite element method in the ANSYS software package [9].

Due to the high rigidity in comparison with the rigidity of the load pin, the shackle was modeled simplistically (Fig. 3). At the same time, friction (with a coefficient of friction 0.2) between the corresponding elements was taken into account in the contact zone of the shackle and the load pin, affecting the distribution of force between the elements.

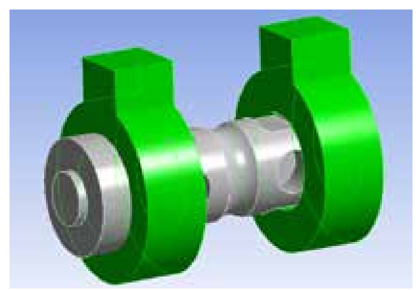


Figure 3. Shackle modeling

The assumption was made about the uniform application of the load along the surface of the groove of the strain gauge (Figure 4).

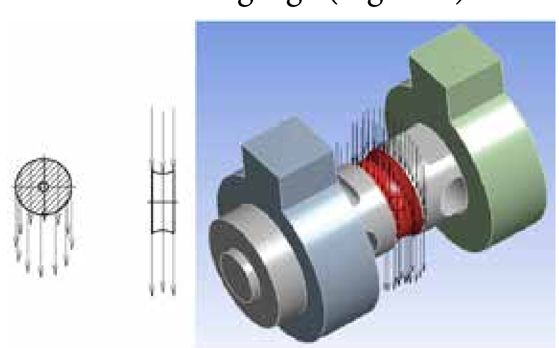


Figure 4. Application of the load modeling

It distorts the results of the calculation of stress at the place of application of the load, but does not affect the accuracy of the calculation at the place of the sticker of the strain gauges. Additionally it simplifies the calculation due to the absence of a contact problem. The load value is 49 kN, which corresponds to a load of 5 tons.

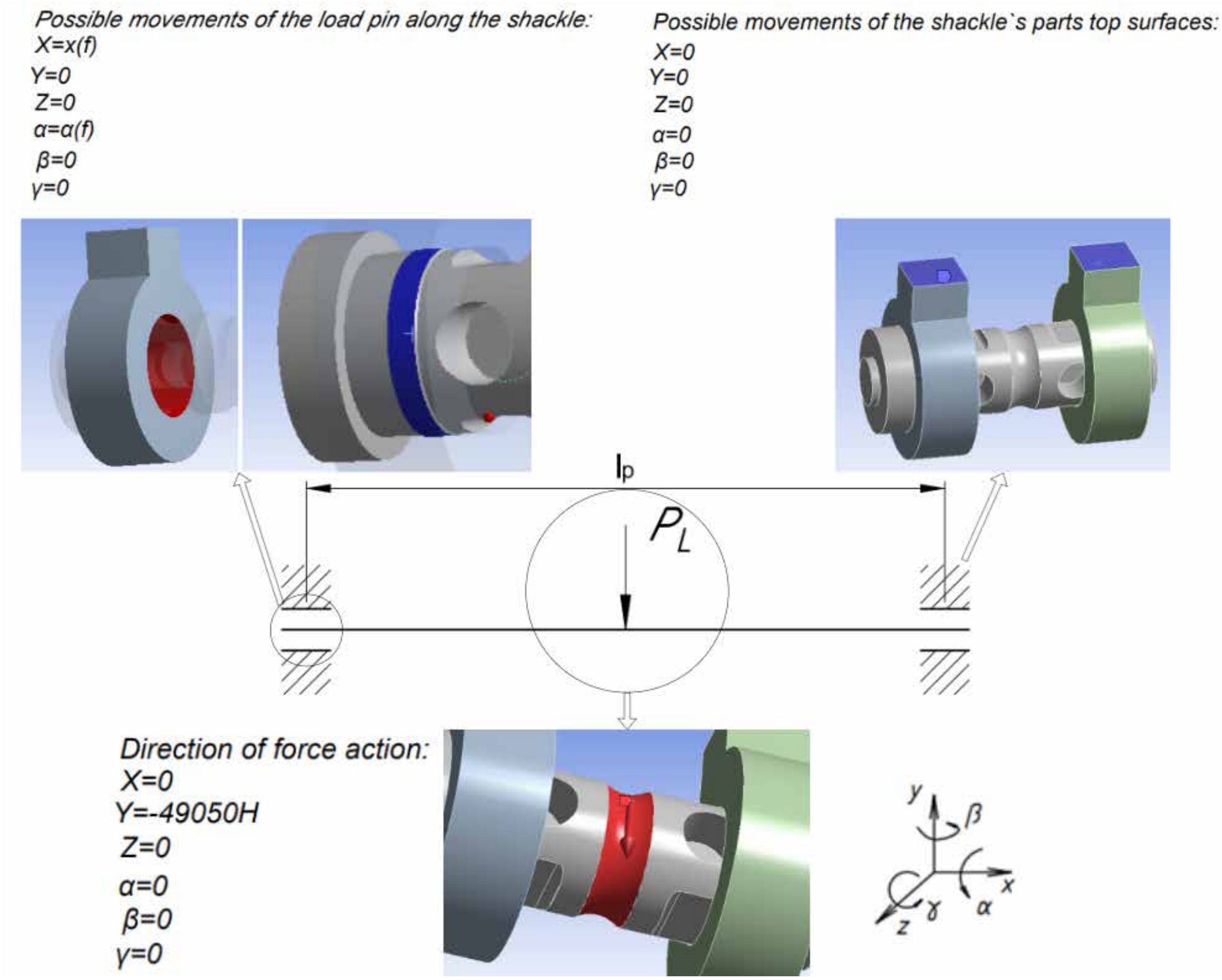


Figure 5. Calculation scheme. P_L – load from the weight of the cargo, container and load-grabbing device; l_p – the distance between the midpoints of the load pin supports

The design scheme for the load pin can be represented as follows: a two-support beam, to which a point load is applied in the middle, the beam supports are two seals at the edges of the beam with the possibility of longitudinal movement taking into account the friction force (Figure 5).

When determining the best design of the strain gauge, the following parameters were varied (Figure 6.): the thickness of the vertical wall, the thickness of the horizontal wall, the degree of conicity.

For reasons of manufacturability, it is impractical to use a vertical wall with a thickness of less than 5 mm.

For the calculation by the finite element method, the structural elements that ensure the manufacturability of the structure were removed, since this improves the quality of the construction of the finite element grid. Accordingly, stress in areas of stress concentration caused by a sharp change in shape or size were not taken into account.

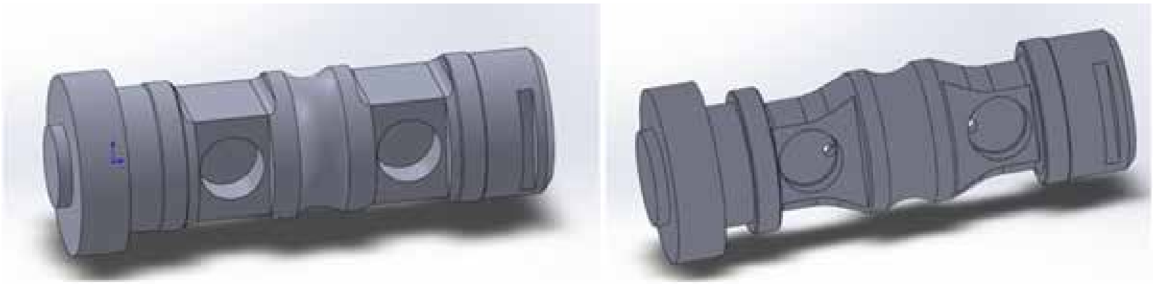


Figure 6. Illustration of the parameters to be changed

3. Results

With the initial geometry of sample No. 2, the required stress level of 200 MPa is achieved with a vertical wall thickness of 2 mm. When the horizontal wall is reduced to 5 mm, an average stress level of 212 MPa is achieved with a vertical wall thickness of 5 mm. However, the maximum stress is 412 MPa (see Table 2).

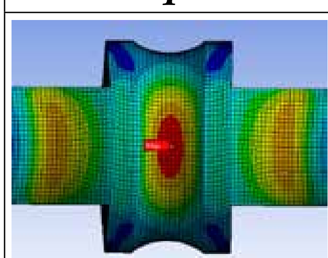
Notation for Tables 2–3: c – cylindrical middle part; k – conical middle part; w – vertical wall thickness; h – horizontal wall thickness.

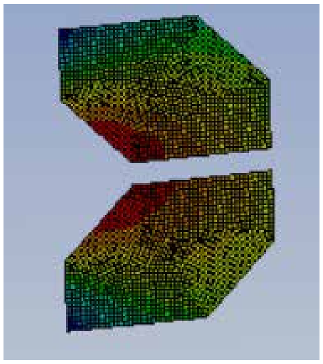
Table 2.– Calculation results of sample No. 2 with a reduced horizontal wall

Parameter	c, w=2 mm, h=10 mm	c, w=5 mm, h=5 mm
Maximum stress in the pin (horizontal wall)	313 MPa	412 MPa
Average values at the place of the strain gauge sticker	224 MPa	212 MPa
Maximum stress at the place of the strain gauge sticker	239 MPa	234 MPa
Minimum stress at the place of the strain gauge sticker	207 MPa	192 MPa

With a conicity of the middle part of the load cell 17 º, a wall thickness of 6 mm and a horizontal wall thickness of 8 mm, the average stress level was 212 MPa, and the maximum stress was 280 MPa (see Table 3).

Table 3.– The results of the calculation of the load pin with a conical middle part

Place	Parameter	k, w=6 mm, h=8 mm
1	**2**	**3**
	Maximum stress in the pin (center cross-section of the load pin)	280 MPa

1	2	3
	Average values at the place of the strain gauge sticker	212 MPa
	Maximum stress at the place of the strain gauge sticker	224 MPa
	Minimum stress at the place of the strain gauge sticker	191 MPa

4. Conclusion

Only by reducing the thickness of the vertical wall, it was not possible to achieve the required stress level. Only with a thickness of 2 mm, which is 3 mm less than the technological requirements, 200 MPa stress was achieved. This made it necessary to change the thickness of the horizontal wall. A decrease in the thickness of the horizontal wall, in turn, led to an increase in the overall stress level, which did not allow for the desired factor of safety of 2.5.

To increase the overall strength and achieve the greatest stress in the sensor sticker area, the shape of the middle part of the strain gauge was changed from cylindrical to conical, which made it possible to transfer the force from the load to the vertical wall more evenly. At the same time, the desired stress level was achieved with a vertical wall thickness of 6 mm.

The resulting shape of the load pin is inferior in terms of manufacturability to known designs. However, the developed design allows it to maintain the measuring range of the strain gauge due to a sticker on a flat wall, unlike a design with a through hole, when the strain gauge is applied to which, it deforms, taking the shape of a cylindrical surface and losing the sensitivity range.

In comparison with a similar design, while maintaining the advantage of the sensor sticker on a flat surface, the stress in the sticker area increases, that leads to an increase in the sensitivity range of strain gages in this case as well.

In the prototype of a flat-wall strain gauge, due to the fact that the shape of the middle part is cylindrical, the bending torque, increasing to the average cross-section, stress along the length of the wall distributes unevenly. The increasing cross-section along the length of the strain axis makes it possible to compensate for the change in the bending moment and obtain a more uniform distribution of stress in the wall. This is confirmed by the reduced stress spread in the vertical wall in the developed design in comparison with sample No. 2.

5. Acknowledgements

The authors wish to thank the scientific supervisor Ivanov S. D., CJSC ITC KROS for providing the material base and the staff of the Department of Lifting and Transport Systems of Bauman Moscow State Technical University for their help in conducting experiments, advice, recommendations, valuable comments and criticism.

References:

1. Fedorinin V. N., Sidorov V. I. "Polarizing optical sensors for measuring physical quantities". "Вестник СибГУТИ" (Russian).– No. 3. 2009.– P. 46–56.
2. Kikot V. V., Cheburakhin I. N., Koshkin G. A., Volkov V. S., Andreev V. G. "High-temperature piezoelectric pressure sensor with improved sensitivity based on lead-free power-ceramics." Measuring. Monitoring. Management. Control (Russian) – No. 2 (28). 2019.– P. 56–63.
3. Kleckers T., Gunther B. "Deformation Measurement: Fiber Optic Sensors from HBM". Electronics: Science, Technology, Business.– No. 1. 2008.– P. 76–78.
4. Nazukina E. N., Kleveko V. I. "Investigation of the parameters of the strain gauge for monitoring the stress-strain state of geosynthetic reinforcing materials". Modern technologies in construction. Theory and practice. (Russian).– No. 1. 2019.– P. 20–25.
5. Younis N. T. and Kang B. "Strain Gage Backing Effects on Measuring Steep Strain Gradient". Proceedings of the International Conference on Mathematics and Engineering. Honolulu, Hawaii, USA, 13–15 June. 2011.
6. Mikhalev A. V., Nazarov A. N., Ivanov S. D. "The impact of the strain gauge location on the load pin on it`s performance assessment," Seventy third russian scientific and technical conference for students, undergraduates and postgraduates with international participation (Russian).– No. 1. 2022.– P. 489–492.
7. URL: https://steelselector.sij.si/steels/37CRS4.html/ (date accessed: 01.11.2022).
8. URL: https://help.solidworks.com/ (date accessed: 02.11.2022).
9. URL: https://ansyshelp.ansys.com/ (date accessed: 02.11.2022).