SSRG International Journal of Mechanical Engineering
ISSN: 2348 – 8360 / https://doi.org/10.14445/23488360/IJME-V9I5P102

Volume 9 Issue 5, 9-13, May 2022


*Original Article*

# A Mathematical Treatment to Find the Maximum Downward Displacement of the Free End of a Binocular type Bending Beam Load Cell for Correct Alignment of Overload Stoppers

Chinmay Vinay Rajguru

*Department. of Mechanical Engineering, Lokmanya Tilak College of Engineering, Koperkhairane, Navi Mumbai, India.*

Received: 11 March 2022 Revised: 01 May 2022 Accepted: 15 May 2022 Published: 24 May 2022

***Abstract –*** *Load cells, also known as force transducers, have a variety of applications in industry as well as in R and D work of science and technology. The cantilever beam load cell, also known as binocular type or single point load cell, is most suitable for light capacity static weighing and inline-check weighing systems. The part of the load cell which incorporates binocular structure is called the "spring element." This type of structure generates a large strain close to the maximum allowable Strain of the foil-type strain gauges for maximum load. The maximum strain level is present just above and below the hollow portions of the spring element. The foil-type strain gauges are attached in these areas to get maximum output signal. When a load is applied at its free end, the binocular type load cell undergoes 's' type deformation, and the horizontal flat portions near the fixed and free end become parallel. For research purposes, a commercially available binocular type aluminum- alloy load cell of 20 kg capacity is taken. It contained four 'Cu-Ni' foil-type strain gauges. Specifications of the load cell and strain gauges are obtained from the manufacturer. This data is used to perform simple mathematical calculations which specify the magnitude of maximum downward displacement of the loaded end of the load cell. Overload stoppers mounted below the loaded end can then be conveniently adjusted to utilize the maximum capacity of the load cell while protecting it from overloads and shock loads.*

***Keywords –*** *Bending beam load cell, 'Cu-Ni' strain gauges, Overloading, Sensitivity, Spring element.*

## 1. Introduction

The binocular type bending beam load cell has become well established in various commercial and industrial applications. It is typically constructed from high-grade aluminum alloy and has revolutionised the small platform scale and retail scale market. Advances in design, wide capacity range, and enhanced sealing techniques have allowed the product to become increasingly used in an industrial environment. Such load cells offer simplicity in design, high performance, and low cost. Simplicity in mounting and facility of overload protection is another advantage of these binocular type load cells.

**Fig. 1 Binocular type bending beam load cell**

**(https://www.piestingservices.com)**

This research paper presents a mathematical treatment to find the maximum downward displacement of the free end of a binocular type load cell for the correct alignment of overload stoppers.

Before mathematical derivations, let us consider the types of overloading and their prevention by using overload stoppers.

### *1.1. Overloading of load cells*

Most commercial binocular type load cells are designed to withstand certain overload. Two types of overloads are specified.

#### *1.1.1. Safe overload*

It is the maximum load that can be applied to a load cell without causing permanent damage to its performance specifications. It is specified as a percent of maximum load. Generally, it is 120 %. For example, if a load cell is rated at 20 kg, its safe overload will be 20 * 120 % = 24kg.

#### *1.1.2. Ultimate overload*

It is the maximum temporary load that can be applied to a load cell without causing structural failure. It is generally 150 % of its rated value. For 20 kg capacity load cell, ultimate overload value will be 20 * 150 % = 30 kg.

### *1.2. Shock loads*

Load cells can withstand certain shock loads also. A shock load is considered safe if its peak value is less than 120 % of the rated load cell capacity.

## 2. Materials and Methods

### *2.1. Use of overload stoppers*

Overloads above the safe overload rating may permanently affect the accuracy and performance of the load cell. Similarly, shock loads having peak values above 120 % of rated load cell capacity may also affect the calibration, and such shock loads should be avoided. To avoid overloading and shock loading effects, the overload stoppers are mounted below the free end of the load cell. These overload stoppers are set in such a way that they come into operation around 10 % above the maximum capacity of the weighing system. Care should be exercised when setting overload stoppers, so they do not become traps for small debris or process material. Lock nuts should be used to secure the overload stoppers (Fig. 2)

The following steps are considered in sequence to find theoretically maximum downward displacement of the free end of the selected load cell.

(1) To prove that per unit change in resistance of a strain gauge in a binocular type load cell specifies the sensitivity of the load cell in millivolt per volt.

i.e. Δ R / R = Sensitivity of the load cell in mV / V.

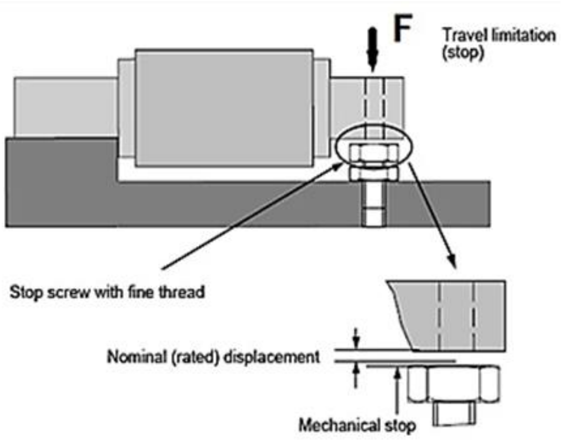


**Fig. 2 Overload stoppers arrangement of cantilever load cell**

**(https://www.hbm.com)**

(2) To find the value of maximum Strain in a strain gauge of the selected load cell by using the gauge factor formula.
(3) To find the change in length of a 'Cu – Ni' strain gauge used in the selected prototype load cell under maximum load conditions.
(4) To find the maximum downward displacement of the free end of the prototype load cell using the Pythagoras theorem.

## 3. Results and Discussions

### *3.1. Proof of Step 1*

(1) To prove R / R = Sensitivity of the load cell in mV / V. Sensitivity of a load cell: It is the ratio of a load cell's output signal voltage (mV) to its excitation potential (V) under maximum load conditions.

Let us consider a commercially available binocular type load cell containing 'Cu-Ni' strain gauges. The manufacturer in the calibration certificate provides specifications of the load cell and 'Cu-Ni' strain gauges. The gauge factor of 'Cu-Ni' strain gauges used in the prototype load cell is 2, and the sensitivity of the load cell is 3 mV/ V.

In this binocular type bending beam load cell, four 'Cu-Ni' type strain gauges are connected in the Wheatstone bridge configuration, as shown in the following circuit diagram.

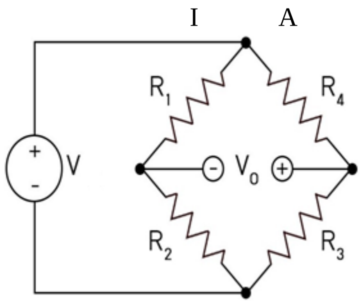


**Fig. 3 Wheatstone bridge in a load cell (https://en.wikipedia.org)**

Let V be the excitation potential in volts (Fig.3). All the strain gauges are of identical resistance values.

i.e. $R_1 = R_2 = R_3 = R_4 = R$. Under the no-load condition, the Wheatstone bridge circuit is balanced, and output signal voltage $V_o$ is zero volts. The equivalent resistance of the Wheatstone bridge is R.

∴ Total current I = V / R ………. (i)

∴ Current through $R_1$ and $R_2$ = Current through $R_4$ and $R_3$

This current is I / 2 = V / 2R ……… (ii)

When a maximum load is applied, $R_1$ and $R_3$ undergo maximum tension, whereas $R_2$ and $R_4$ undergo maximum compression.

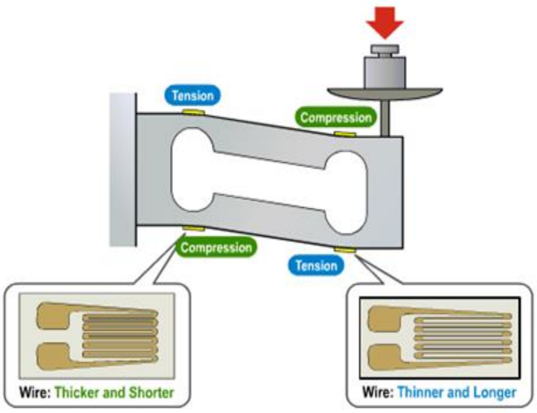


**Fig. 4 'S' type deformation of binocular type load cell**

**(https://en.wikipedia.org)**

Ideally, the resistance change in all four strain gauges is numerically equal. $R_1$ and $R_3$ undergo tension, and their resistance increase. (fig.4)

Let new value of $R_1$ be R + Δ R

i.e. $R_1$\` = R + Δ R ……… (iii)

Similarly $R_3$\` = R + Δ R……. (iv)

$R_2$ and $R_4$ undergo compression, and their resistance decreases.

Let the new value of $R_2$ be R – Δ R

, i.e., $R_2$\` = R – Δ R …….. (v)

Similarly, $R_4$\` = R – Δ R …….. (vi)

It is obvious that branch currents remain constant.

∴ Branch current = I / 2 = V / 2R …….. (vii)

∴ Voltage drop across $R_1$\` = $V_1$ = (V / 2R)(R + Δ R)

…… [From (iii) and (vii)]

Similarly voltage drop across $R_4$\` = $V_2$ = (V/ 2R) (R – ΔR)

[From (vi) and (vii)]

Now Wheatstone bridge is in unbalanced condition.

∴ Output voltage = $V_o = V_1 - V_2$

∴ $V_o$ = [(V/2R) (R+ΔR)-(V/2R) (R-ΔR)]

= (V/2R) (R+ΔR-R+ΔR)

= (V/2R) (2ΔR)

= VxΔR/R

∴ $V_o$/V = ΔR/R ……………. (viii)

Sensitivity of the prototype load cell = 3mV / V

Sensitivity = Output signal voltage/excitation voltage = $V_o$/V

= 3mV / V = 0.003V / V = 0.003 ….. (ix)

∴ Sensitivity = $V_o$/V = ΔR/R = 0.003 = 3mV / V…. (x)

[From (viii) and (ix)]

∴ Per unit change in resistance of a strain gauge (ΔR/R) specifies the sensitivity of the binocular load cell.

### 3.2. Proof of Step 2

(2) To find the value of maximum Strain in a strain gauge of the selected load cell by using the gauge factor formula:
Gauge factor: Definition: Gauge factor is defined as the ratio of fractional change in electrical resistance of the strain gauge to the fractional change in its length (Strain).

G.F = (ΔR/R)/ε

ΔR/R = Fractional change in electrical resistance of a Strain gauge.
ε = Strain in the strain gauge.

More is the value of the gauge factor; the greater the sensitivity of the strain gauge.

The selected load cell contains four 'Cu-Ni' strain gauges, each having a gauge factor of '2'. The sensitivity of the load cell is 3 mV / V.

Sensitivity of the binocular type load cell = Fractional change in resistance of the strain gauge

= ΔR/R = 3 mV / V = 0.003….. From(x)
Gauge factor (G.F) = 2

Substituting these values in the gauge factor formula;

G.F = (ΔR/R) / ε
2 = 0.003/ ε
∴ ε = 0.003/2 = 0.0015
∴ Maximum strain in the strain gauge is 0.0015
i.e1500 micro-strain.
∴ ε = 1500με

### 3.3. Proof of Step 3

(3) To find the change in length of a 'Cu-Ni' strain gauge used in the selected binocular type load cell under maximum load conditions.

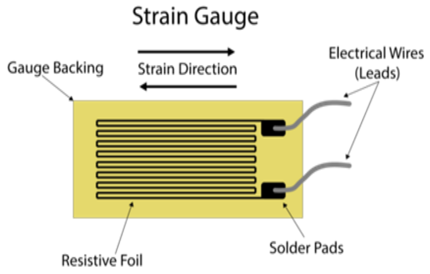


**Fig. 5 'Cu-Ni' strain gauge of 3.5mm length**

The length of a 'Cu-Ni' strain gauge in the selected load cell is 3.5 mm. The manufacturer provides the value. The maximum Strain in the strain gauge is 1500 με, i.e., 0.0015 ε …… From proof of step 2

Formula: Strain (ε) = ΔL/L. Substituting the values,
0.0015 = ΔL/3.5mm
∴ ΔL = 0.0015 x 3.5mm = 0.00525mm
= 0.00525 x 1000 µm
= 5.25 µm
∴ΔL = 5.25 µm

This value represents the maximum elongation or compression of a strain gauge of the selected load cell.

### *3.4. Proof of Step 4*

(4) To find the maximum downward displacement of the free end of the prototype load cell using the Pythagoras theorem.
First, we have to consider the exact locations of Strain gauges on the load cell spring element. The diagrams given below indicate these locations.

**Fig. 6 Strain gauges and their locations on the spring element (https://www.precisionsensorsandsystems.com)**

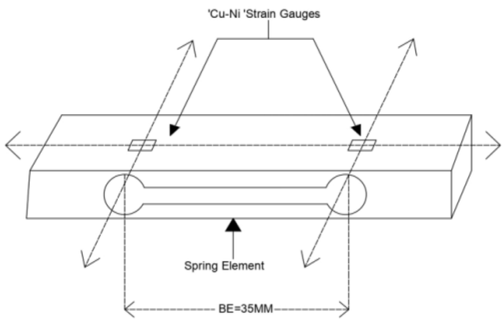


**Fig. 7 A schematic diagram of binocular spring element indicating exact locations of strain gauges**

To find the maximum downward displacement of the free end of the prototype load cell, the 'S' type deformation of the spring element is analysed. The following diagram indicates this 'S' type deformation.

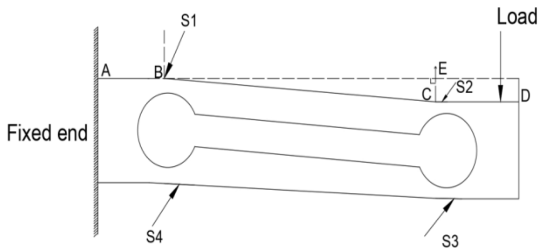


**Fig. 8 A schematic diagram showing 'S' type deformation of the binocular spring element**

As shown in the above diagram, strain gauges $S_1$ and $S_3$ undergo elongation, whereas $S_2$ and $S_4$ undergo compression when the load is applied at the free end. Due to the peculiar deformation of the spring element, surfaces AB and CD become parallel.

In our prototype load cell distance between the strain gauges is BE, which is 35mm. We have already found the maximum elongation of strain gauge $S_1$ under maximum load conditions. This value is 5.25 µm = 0.00525 mm. Consider the right-angled triangle ΔBEC.

BE = 35mm, BC = 35 + 0.00525 = 35.00525mm.To find EC.

According to Pythagoras,

$BC^2 = BE^2 + EC^2$

∴ $[35.00525]^2 = [35]^2 + [EC]^2$

∴ $1225.36752756 = 1225 + [EC]^2$

∴ $[EC]^2 = 0.36752756$

∴ EC = 0.6062 mm.

Thus the downward deflection of the free end of the selected load cell is approximately 0.6mm under maximum load conditions [20kg]. The overload protection stoppers must be set at about 0.6mm below the free end of the load cell to prevent damage to the strain gauges and load cell.

## 4. Conclusion

- The calculated value of maximum downward displacement of the free end of the selected binocular type load cell is about 0.6mm when the maximum load of 20 kg is applied. Such types of load cells are not operated up to their maximum capacity. Generally, they are used up to 80 % of their rated value. Thus the maximum safe value of load that can be applied in our prototype load cell will be 80 % of 20kg, i.e., 16 kg, and downward displacement of the free end will be 16 * 0.6/20 = 0.48 mm. Therefore overload stoppers should be aligned at about 0.5 mm below the loaded end of the load cell.

- Suppose the binocular spring element of a load cell is of sub-standard quality. In that case, the observed value of maximum downward displacement of the loaded end will differ from the calculated value. In such load cells, angular loading takes place, and the calculations as mentioned earlier become invalid. For instance, if load force 'F' is inclined to the loading hole central line at an angle of 5 º, then the force registered by the load cell is reduced by 0.4 %.

## References


[1] Abubaker M. Saeed Hamed, Mohammad Qasim Abdullah, Evaluation of Stress Concentration Factor in Steel Elastic Element of Load Cell, Journal of Scientific and Engineering Research, 4(5) (2017) 157-161.

[2] Farhad Aghili, 2010, Design of a Load Cell with Large Overload Capacity, Transducers of the Canadian Society for Mechanical Engineering, (2010) 449-461.

[3] Ivan Moller, Renato Machado de Brito, Carlos E. Pareira, Valner Jolo Brusamarello, 2010, Load cells in Force Sensing Analysis-Theory and a Novel Application, IEEE Instrumentation and Measurement Magazine, (2010) 15-19.

[4] M. Kuhnel, F. Hilbrunner, H. Buchner, G. Jager, E. Manske and T. Frohlich, 2012 Traceable determination of Mechanical parameters of binocular shaped force transducers, Imeko World Congress Metrology for Green Growth, (2012) 1-6.

[5] Seif M.Osman[1], Ebtisam H. Hasan[1], H.M. El-Hakeem[1], R.M.Rashad[2] and F. Kouta[2], Conceptual design of multi-capacity load cell, 16th International Congress of Metrology, (2013) 03002-p2 -03002-p4.

[6] Ranjeet Kumar, Sandeep Chhabra, Ajay Singh Verma, Anurag Gupta, Analysis of load cell, International Journal of Applied Engineering Research, (2018) 274-277.

[7] Mingjie Liu, Qi Zhang, Yiwei Shao, Chuanqi Liu, Yulong Zhao, Research of a novel 3D printed strain gauge type force sensor, 9th International Conference of the Chinese society of Micro-Nano Technology, (2018) 1-14.

[8] Dongil Lee, Hyun Pyo Hong, Myung Jin Lee, Chan Won Park, Nam Ki Min,A prototype high sensitivity load cell using single walled carbon nanotube strain gauges, Sensors and Actuators a physical, (2012) 120-126

[9] Joon Hyub Kim, Ji- Hoon Han, Chan Won Park, Nam ki Min, 2020, Enhancement of withstand voltage in silicon strain gauges using a thin alkali- free glass, Sensors, (2020) 1-13.

[10] John X.J. Zhang, Kazunori Hoshino, 2019, Mechanical Transducers: Cantilevers, acoustic wave sensors and thermal sensors, Molecular Sensors and Nanodevices, (2019) 311-412

[11] Ming-Hsuing Ho[1], Ping-Hui Lee and Pinning Wang, The Research of Low-profile Load Cell Design Sensitivity, iop conference series: Materials Science and Engineering, 4th International Conference on Applied Materials and Manufacturing Technology, (2018) 1-8

[12] Meng Zhang, Binbin Qiu, Maoyu Zhu, Xianquig Qu, Novel Computation method of reducing ill-posedness for structural static distributed load identification by optimising strain gauge locations, Mechanical Systems and Signal Processing , (2019) 83-110

[13] http://ametme.mnsu.edu/UserFilesShared/Equipment_Manuals/te_110/StrainGageBasedTransVishay.pdf

[14] https://www.omega.co.uk/techref/pdf/strain_gage_technical_data.pdf

[15] https://erde.netrix.se/shop/assets/shop_files/lcguide.pdf

[16] https://www.ricelake.com/media/b5mlti1q/m_us_22054_lc-wm_handbook_revb.pdf

[17] https://www.precisionss.com/

[18] https://www.vpgtransducers.com

[19] https://www.info@vijayantatechnologies.com

[20] https://www.mmrl.ucsd.edu

[21] https://www.usna.edu

[22] https://www.americanpharmaceutical.review.com

[23] https://www.flintec.com/in/weight-sensors/load-cells/strain-gauge

[24] https://tacunasystems.com/knowledge-base/an-overview-of- load-cells/

[25] https://www.engineersgarage.com/load-cell/