Overview of Load Cells

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ABSTRACT

This paper discusses highlights; basic information regarding strain gauge based load cells, classification of these load cells and also throws a light on some of the new ways of designing these load cells. The force measurement system and its salient features have been briefly discussed. From its history to the current development, an extensive overview of force measuring instruments (force sensors) has been given. Briefly, so far, different types of force sensors have been discussed.

Keywords-- Load Cells, Force Measurement

INTRODUCTION

Force is a measure of the interaction between objects, mass is a measure of the content of matter in an object, weight is the force of gravity acting on an object, and load usually refers to the force acting on a surface or an object. It takes many forms, including short-range atomic force, electromagnetic force and gravity. Force is a vector with direction and magnitude. The SI unit of force is Newton (N); it is defined as the force that imparts a kilogram of mass to 1 meter per second.

Force Measuring System

The force measurement system consists of a transducer and related instruments. The transducer is subjected to the force to be measured, and some final change of the element is measured by the associated instrument. The instrument can power the transducer in some way, and it can also process the output of the transducer before the sensor displays it on an indicator to be read by the user. Strictly speaking, a transducer device receives a physical stimulus nd changes it to another measurable physical quantity through a known relationship.

Load Cells

Load cells are very commonly used for force measurement. Many load cells use flexible load-bearing components or component combinations. The force applied to the elastic element causes it to flex, which is then sensed by the auxiliary sensor, which converts it into a measurable output. The output can be in the form of electrical signals, such as strain gauges and linear variable differential transducer (LVDT) type load cells, or mechanical indicators, such as verification rings and spring scales. This kind of transducer is usually called an elastic device and constitutes the main body of all commonly used load cells. There are many different elastic transducer elements, but usually they are composed of rings, cylinders or beams. It has been found that dial gauge type load cells or strain gauge load cells have been widely used in different applications in different ranges (from a few Newton to mega Newton). This capability has made these load cells the most reliable medium for measuring force for decades [1-4].

Strain Gauge Load Cells

These are the most common load cells and are a clear example of elastic devices. Each unit is based on an elastic element that incorporates many resistance strain gauges. The geometry and elastic modulus of the element determine the magnitude of the strain field generated by the force. Each strain gauge responds to the local strain at its location, and the force measurement depends on the integration of these individual strain measurements [5-6].

The rated capacity of strain gauge load cells ranges from 5 N to more than 50 MN. They have become the most widely used of all force measurement systems and can be used as a force transmission standard with high-resolution digital indicators as shown in Figure 1.

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Figure 1: *A range of industrial load cells.*

Elastic Element Shape

Elastic Element Shape used in a load cell depends on many factors, including the force range to be measured, size limitations, and final performance and production costs. Figure 2. Explain the different elastic elements and give the typical rated capacity in Table 1. Each element is designed to measure the force acting along its main axis and is not affected by other forces (such as side loads). The arrows in the figure indicate the main axis of each element [7].

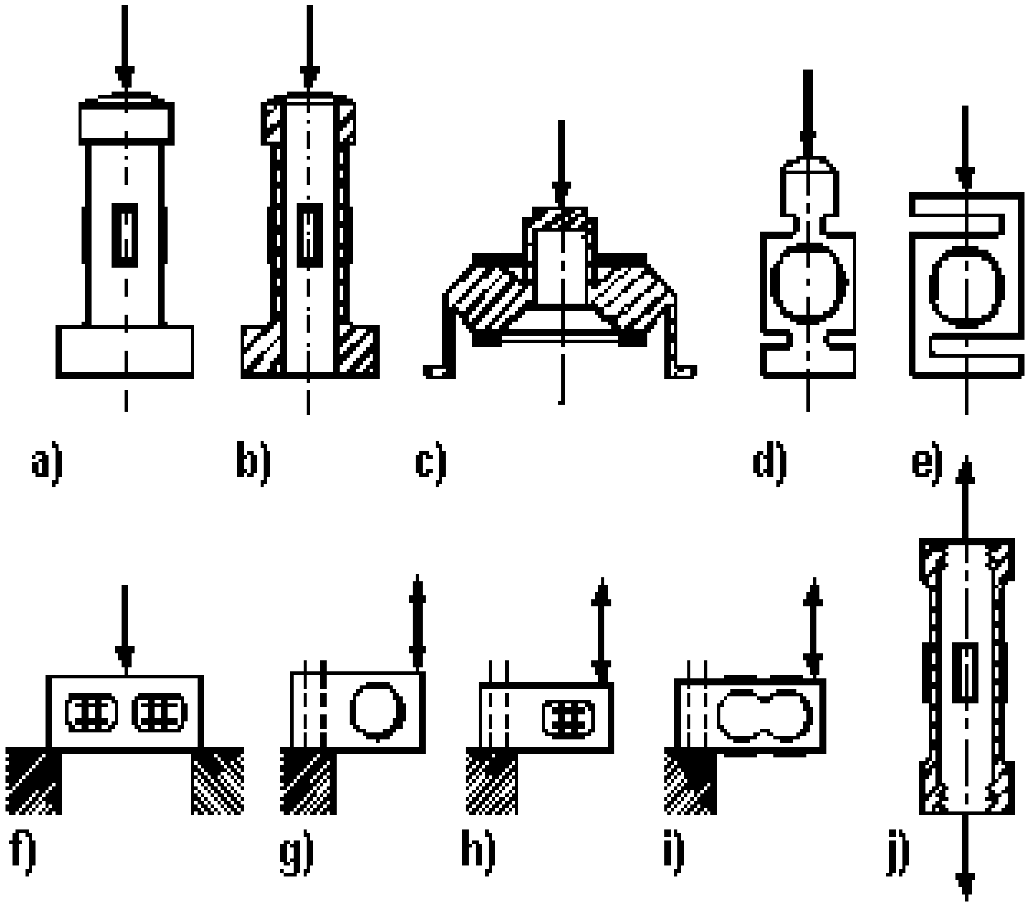

Figure 2: *Elastic Element Shape.*

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Table 1: *Elastic Element Capacity.*

a) Compression cylinder	50 kN to 50 MN
b) Compression cylinder (hollow)	10 kN to 50 MN
c) Annular ring	1 kN to 5 MN
d) Ring	1 kN to 1 MN
e) S-shaped steel (Bending or shearing)	200 N to 50 kN
f) Double-ended shear beam	20 kN to 2 MN
g) Double bending beam (simplified)	500 N to 50 kN
h) Shear beam	1 kN to 500 kN
i) Double bending beam	100 N to 10 kN
j) Tension cylinder	50 kN to 50 MN

The material used for elastic elements is usually tool steel, stainless steel, aluminum or beryllium copper, the purpose is to show a linear relationship between stresses (force) in the working range It has low hysteresis and low creep strain (output). There must also be a high degree of repeatability between force cycles to ensure that the load cell is a reliable measuring device [8]. In order to obtain these characteristics, the material is usually subjected to special heat treatment. This can include heat treatment cycles below zero for maximum stability [9].

Electrical Resistance Strain Gauges

All resistance strain gauges can be regarded as a certain length of conductive material, such as wires. When the wire is pulled within its elastic limit, its length increases as the diameter decreases and the resistance changes. If the conductive material is bonded to the elastic element under strain, the change in resistance can be measured and used to calculate the force based on the calibration of the device [10].

Wheatstone Bridges

Many load cells use strain gauges in a four-arm Wheatstone bridge configuration, whose role is to increase and decrease the power grid. The Wheatstone bridge compensates for temperature effects and eliminates signals caused by external forces. These circuits consist of a complete four-arm bridge with at least one precision strain gauge in each arm. Powering the bridge requires a stable excitation of 5 to 20 volts. A simplified version of a strain gauge load cell using a Wheatstone bridge is shown in Figure 3. The strain gauges used in Wheatstone bridges all have the same resistance value, which will form a balanced bridge application when there is no load. When a load is applied to the load cell, the strain gauge deforms, thereby changing its resistance, thereby forming an unbalanced bridge, which causes the output voltage to be proportional to the applied load. The load applied to the load cell in Figure 3 stretches the tensiometers (T1 and T2) while the pressure gauges (C1 and C2) compress. Then, the output voltage will be sent to the signal conditioner through the signal wires (+S and -S) to convert the output voltage into force values (lb, N, kg, etc.). Factors such as temperature, the length of the wire used to complete the circuit, and the placement of strain gauges will all affect the resistance in the bridge, resulting in errors in the measured value. In precision load cells, these effects can be compensated by adding resistance to the bridge [11-14].

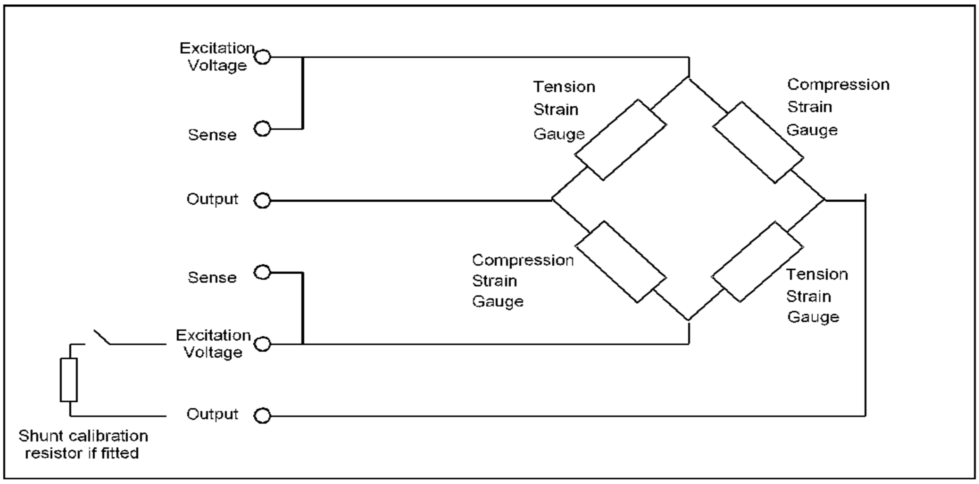

Figure 3: *The Basic Arrangement of the Four Strain Gauges in the Load Cell.*

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The most commonly used materials for making strain gauges are copper-nickel, nickel-chromium, nickel-chromium-molybdenum and platinum-tungsten alloys, which are usually called their brand name. There are various resistance strain gauges available for various applications, some of which are described below. Each strain gauge is designed to measure strain along a well-defined axis so that it can be properly aligned with the strain field.

Foil Strain Gauges

Foil strain gauges are the most widely used type. Several examples are shown in Figure 4. Compared with all other types of strain gauges, it has significant advantages and has been used in most precision load cells. It is composed of a metal foil pattern mounted on an insulating backing or carrier. The pattern is formed by bonding a thin rolled metal foil of 2 µm to 5 µm thickness to a 10 µm to 30 µm thick backing plate. The measurement grid pattern including the terminal lugs is made by photolithography.

The production technology used is similar to that used in the integrated circuit manufacturing industry, and is very suitable for automation, so the unit cost is low. Typical backing materials are epoxy resin; polyamide and glass fiber reinforced phenolic resin. The backing provides electrical insulation between the foil and the elastic element, is easy to handle, and has an easy-to-bond surface. Sometimes an adhesive layer is attached to the back of the gauge, thereby reducing the amount of processing and time required. Epoxy or epoxy-derived backing materials are difficult to handle due to their brittleness, but due to their superior performance, especially in terms of creep and low moisture absorption, they are superior to polyamide plastics, so they are preferably used for high-precision load cells.

Now, various foil gauges are available on the market for use by transducer designers and general users.

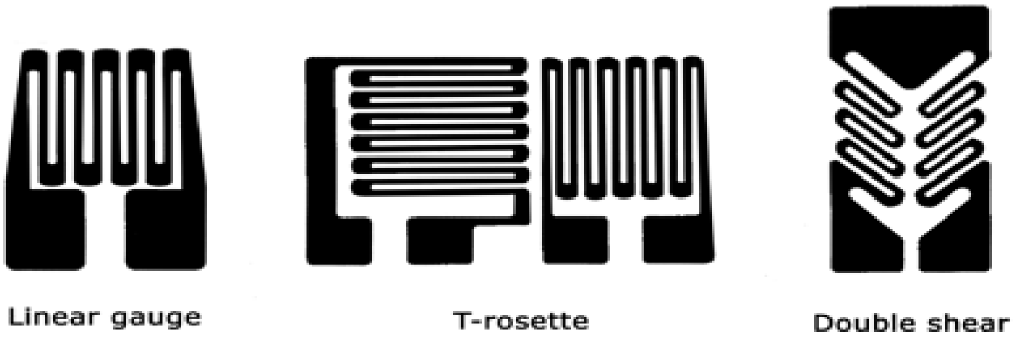

Figure 4: *Foil Strain Gauge.*

Semiconductor Strain Gauge

It is made of n or p semiconductor silicon strips. Compared with wire gauge or foil gauge, the output of semiconductor gauge is very high. The gauge factor is a measure of the output at a given strain. For semiconductors, the typical value is 100-150, and for wire and foil, the typical value is 2-4. The output of semiconductor gauges has a nonlinear relationship with strain, but they basically have no creep or hysteresis, and they have extremely long fatigue life. The high sensitivity of the meter to temperature means that the meter needs to be carefully matched on any given load cell, and they are usually matched to the computer at the time of manufacturing, but a complete sensor may still require a high level of temperature compensation. This type of gauge is widely used in "small" sensors, such as load cells, accelerometers and pressure sensors, and their sensing elements can be micro machined with a single piece of silicon.

Thin Film Strain Gauges

Thin film strain gauges are made by sputtering or evaporating metal or alloy thin films onto elastic elements. The manufacture of thin film strain gauge systems will go through multiple stages of evaporation and sputtering, and may have up to eight layers of material. There are many thin-film strain gauge load cells, covering the range from 0.1 N to 100 N in single or double bending beam configurations. Due to the manufacturing technology involved, these devices are highly cost-effective in mass production. This makes them very suitable for high-volume products such as shop scales and pressure sensors.

Wire Strain Gauges

Wire strain gauges are the original type of resistance strain gauges, although they have

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been widely replaced by inexpensive foil or film types. However, line strain gauges are still widely used in high temperature sensors and stress analysis, and can be made of a variety of materials. The diameter of the wire is usually 20 µm to 30 µm and can be bonded to the substrate using ceramic materials. It is rarely used in free form, in which the wire is wound around an insulating pin mounted on an elastic member.

The nominal resistance of the strain gauge depends on the type and application. The resistance range of wire gauge is 60 Ω to 350 Ω, the resistance of foil and semiconductor wire gauge is 120 Ω to 5 kΩ, and the resistance of film type is about 10 kΩ. Size, self-heating and power requirements are important in Selection criteria. If you want to connect multiple load cells together, matching resistance may be important.

Piezoelectric Crystal Sensor

When a force is applied to a certain crystal material, a charge is formed on the crystal surface in proportion to the rate of change of the force. In order to use this device, a charge amplifier is required to integrate the charge to provide a signal that is proportional to the applied force and large enough for measurement. To apply the piezoelectric effect , naturally grown quartz are used, but most of today artificial quartz are used. Therefore, these devices are often referred to as quartz load cells, although the term piezoelectric crystal is used more here.

These piezoelectric crystal sensors differ from most other sensing technologies in that they are active sensing elements. No power supply is needed, and the deformation of the generated signal is small, which has the advantage of the high-frequency response of the measurement system without causing geometric changes to the force measurement path.

A weighing washer is shown in Figure 5. Deflection of 0.001 mm occurs after application of 10 kN compression force. This stiffness and other inherent qualities of the piezoelectric effect achieve high frequency response (up to 100 kHz), making piezoelectric crystal sensors very suitable for dynamic measurements.

Extremely fast events (such as shock waves in solids or impact force of printers and punch pressure) can be measured with these devices; otherwise such measurements may not be possible. The electric charge of the piezoelectric sensor is very small, and needs high impedance cable as the electric interface. It is very important to use the matching cable that comes with the sensor.

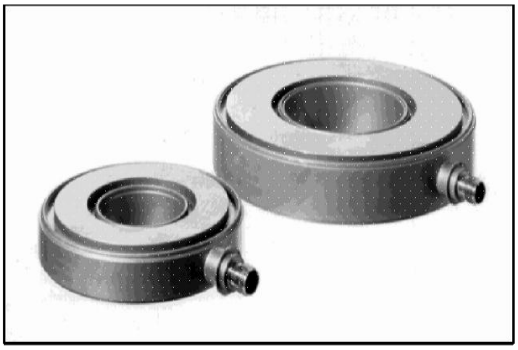

Figure 5: *Industrial piezoelectric weighing washer.*

Hydraulic Load Cell

A hydraulic load cell is a device filled with liquid (usually oil), which has a preload pressure as shown in Figure 6. Applying force to the load member will increase the fluid pressure measured by a pressure sensor or displayed on the pressure gauge dial through a Bourdon tube.

When used with pressure sensors, hydraulic load cells are inherently very rigid, deflecting only about 0.05 mm under full force conditions. Although the maximum capacity is 5 MN, most equipment has a capacity of 500 N to 200 kN. The pressure gauge used to monitor the force can be placed a few meters away from the device using a dedicated liquid-filled hose.

The hydraulic load cell is independent and does not require an external power supply. They are inherently suitable for use in potentially explosive environments and can be tension or compression devices. Through careful design and good application conditions, a measurement uncertainty of about 0.25% can be achieved. The uncertainty of the entire system is actually 0.5% to 1%. The battery is sensitive to temperature changes and usually has the function of adjusting the zero output reading, with a temperature

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coefficient of about 0.02% to 0.1% per degree Celsius.

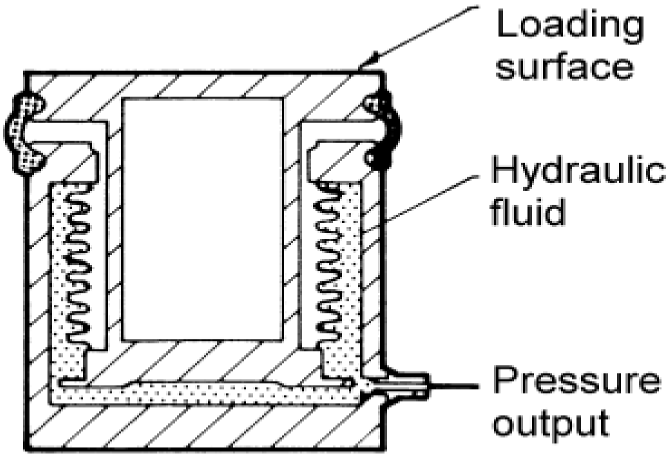

Figure 6: *Hydraulic Load Cell.*

Pneumatic Load Cell

The working principle is similar to that of the hydraulic Load Cell. This force is applied to one side of the piston or flexible material membrane and is balanced by the air pressure on the other side. The offset pressure is proportional to the force and is displayed on the pressure dial.

The sensing device includes a chamber with a tight cap. Air pressure is applied to the chamber and accumulated until it equals the force on the lid. Any further increase in pressure will lift the lid, allowing air to seep around the edges until pressure equilibrium is reached. In this equilibrium position, the pressure in the chamber represents the force acting on the cover, which can be read by a pneumatic dial indicator.

The Elastic Device

The loading column is probably the simplest elastic device. It is just a metal cylinder, which is forced along its axis. In this case, the length of the cylinder is directly measured by a dial indicator or other technique, and the force can be estimated by interpolating between the measured lengths for the previously applied known force. The inspection ring is very similar in function, except that the element is a circular ring and the deformation is usually measured along the inner diameter. These sensors have the advantage of being simple and robust, but the main disadvantage is the strong influence of temperature on the output. Such methods can be used to monitor forces in building foundations and other similar applications.

LINEAR VARIABLE DIFFERENTIAL SENSOR (LVDT)

Linear Variable Differential Sensor (LVDT) can be used in load cells to measure the displacement of elastic elements without using strain gauges. LVDT is essentially a transformer that can provide an alternating current (AC) output voltage based on the displacement of a single movable magnetic core. The lack of friction and low-quality magnetic cores can achieve high resolution and low hysteresis, which makes this device ideal for dynamic measurement applications.

Capacitive Load Cells

Capacitive load cells use capacitive sensors to sense the displacement of elastic elements. In most cases, the sensor consists of two parallel plates facing each other. The change in the length of the spring member will cause the gap between the two plates to change, which leads to a change in capacitance. For small weighing instruments such as household scales, springs can also provide parallel guidance for the platform of the scale.

Optical Strain Gauges

Optical strain gauges can be formed in a manner similar to linear strain gauges by using optical fibers. The deflection of the elastic bearing member combined with the optical strain gauge will cause the length of the optical fiber to change. If a monochromatic light is used to feed two optical strain gauges that experience different strain levels, the phase difference (in half-wavelength units) between the two beams emerging from the strain gauge is a measure of the force applied.

Interferometry Optical Sensors

Interferometry optical sensors use high-resolution displacement measurement methods. The fork spring deforms under the action of this force, and the deformation is about 40 µm. The change of the fork hole is measured by a Michelson interferometer. The deforming element is made of quartz (quartz glass) that has little temperature dependence. Any residual errors can be corrected by using temperature sensors and computers. These systems have an overall performance better than 0.01% in the limited temperature range of 5°C to 40°C, and the hysteresis and creep are extremely small. An optical system based on Moiré fringe measurement has also been manufactured.

Vibrating Element

In the case of a tuning fork type load cell, the load cell consists of two parallel splines, which are connected at their ends and resonate in opposite directions. The way of vibration is similar to that of a tuning fork, and if the element is subjected to tension or compression, the resonance frequency will change. The excitation of vibration and the mutual reception of vibration signals are performed by two piezoelectric elements (see piezoelectric crystal load cell) close to the vibration node of the tuning fork. Tuning forks are usually about 25 mm long, made of Elinvar (nickel steel with 13% chromium), with a rated capacity of 8 N, a resonance frequency of 6 kHz to 7 kHz, and a linear performance of 0.01% to 0.02%

Vibrating Wire Transducer

The vibrating wire transducer consists of a tensioned ferromagnetic wire, which is excited by the drive coil into lateral vibration. Use pickup coils to detect these vibrations. Both coils have permanent magnet cores. Once the wire is excited until its resonance frequency reaches a given tension, the two coils can be connected through an amplifier to form a self-excited oscillation system to maintain it at that frequency. Each resonance frequency is a measure of wire tension and therefore the force applied at that moment. The advantage of the vibrating wire sensor is its direct frequency output, which can be processed by digital circuits without the need for an analog-to-digital converter. The vibrating wire principle is used to measure the force and strain levels of pressure sensors in civil engineering applications.

Surface Wave Resonator Load Cell

In the surface wave resonator load cell, the ultrasonic transmitter driven by alternating current is composed of comb-shaped electrodes on the quartz substrate, and emits surface acoustic waves directed according to the inverse piezoelectric effect. In accordance with the piezoelectric effect, a second system arranged in the same way converts these sound waves back to AC voltage. The arrangement of the amplifier should make the system vibrate at a natural frequency. The deformation of the spring depends on the force, which changes the frequency of the resonator.

Magneto Elastic Device

The function of the magneto elastic load cell of this is that when the ferromagnetic material is subjected to mechanical stress, the magnetic properties of the material will change, and the change is proportional to the applied stress. Due to its rugged structure, high signal level and small internal resistance, the magneto elastic load cell can be used in harsh and electrical interference environments, such as rolling mills. The rated capacity of these devices is 2 kN to 5 MN.

THE DYNAMIC BALANCE EQUIPMENT

A gyroscope force sensor utilizes the force sensitive characteristics of the gyroscope installed in the gimbal or frame system. The commercially available gyro load cell is equipped with a dynamically balanced heavy-duty rotor on the main shaft, and the rotor itself is installed in the inner frame of the two-frame system. The device has three mutually perpendicular rotating free shafts, and its origin axis is located on the center of gravity of the rotor. The force measured by the sensor is applied through the lower rotating shaft, and a pair of forces is generated on the inner frame to make the gimbal under pressure. Then the time it takes for the outer gimbal to complete a circle is a measure of the applied force. The gyroscope load cell is essentially a fast-response digital sensor, and is inherently free of hysteresis and drift.

Force balance uses a feedback circuit to compare electrical output with force input. A typical system has attached an electric coil to the force input member that works in the magnetic flux gap of the permanent magnet. The current flowing through the coil produces a restoring force that is opposite to the applied force. The displacement sensor is used to sense the displacement of the force input member, and its output is amplified and used to control the current in the coil until the restoring force accurately balances the applied force and restores the force input member to its original position. The coil current that reaches this balance is proportional to the applied force, and is measured as the voltage sensed across the resistor in series with the coil. This type of equipment has good dynamic performance, small deflection and is relatively insensitive to environmental conditions. They are inherently stable and accurate, so they are often considered as secondary standards. This type of equipment is mainly a competitor of mechanical analytical balances in quality analysis.

CONCLUSION

This paper discusses the basic knowledge related to force measuring instruments and force realization systems. The force measurement system and its salient features have been briefly discussed. From its history to the current development, an extensive overview of force measuring instruments (force sensors) has been given. Briefly, so far, different types of force sensors have been discussed.

REFERENCES

1. "The information center for sensors and data system", Available at http://www.sensorland.com
2. Qandil, A., & Zaid, A. I. (2015), "Considerations in the design and manufacturing of a load cell for measuring dynamic compressive loads", In *2015 Power Generation System and Renewable Energy Technologies (PGSRET)* (pp. 1-6). IEEE, Available at https://ieeexplore.ieee.org/abstract/document/7312209
3. How to select a load cell, [online] Available at https://www.lcmsystems.com/resources/how-to-select-a-load-cell
4. Seif. M. Osman., Ebtisam H. Hasan., H. M. El-Hakeem., R.M.Rashad and F. Kouta., "Conceptual design of multi capacity load cell", *16th International Congress of Metrology*, pp. 2-3, Available at https://www.researchgate.net/publication/269207332_Conceptual_design_of_multi-capacity_load_cell
5. Joseph H.Antkowiak., Joseph J. Rencis(1994), "Geometric nonlinearities in design of force transducers", *Advances in Engineering Software Elesvier publications* pp. 12-15, Available at https://doi.org/10.1016/0965-9978(94)90069-8
6. Chang, Y. S., & Lin, T. C. (2013), "An optimal g-shaped load cell for two-range loading", *Engineering in agriculture, environment and food*, Volume *6*, Issue 4, pp. 172-176, Available at https://www.jstage.jst.go.jp/article/eaef/6/4/6_172/_article/-char/ja/
7. Fan-She Lin., Tshen-Chan Lin., (2007) "Design of a G-shaped load cell for two range weighing application", *International Agricultural Engineering Journal*, pp 80-84, Available at https://www.researchgate.net/publication/289701236_Design_of_a_G-shaped_load_cell_for_two-range_weighing_application
8. Jocelyn M. Kluger., Themistoklis P. Sapsis., Alexander H. Slocum. (2016), "A high-resolution and large force-range load cell by means of nonlinear cantilever beams", *Elsevier publications ,Precision Engineering* Volume Issue 43, pp.,241-256, Available at https://doi.org/10.1016/j.precisioneng.2015.08.003
9. Kluger, J. M., Slocum, A. H., & Sapsis, T. P. (2017), "Ring-based stiffening flexure applied as a load cell with high resolution and large force range", *Journal of Mechanical Design*, Volume *139*, *Isssue* 10, Available at https://doi.org/10.1115/1.4037243
10. Osman, S. M., Kumme, R., El-Hakeem, H. M., Löffler, F., Hasan, E. H., Rashad, R. M., & Kouta, F. FORCE TRANSDUCER WITH DIFFERENT CAPACITIES, Available at https://www.imeko.org/publications/wc-2015/IMEKO-WC-2015-TC3-069.pdf
11. IMEKO World Congress(2015) "Measurement in Research and Industry", *Prague, Czech Republic*, Available at https://www.imeko.org/index.php/imeko-news-events/world-congresses/356-imeko-xxi
12. Mr. S. M. Ghanvat., Prof. H. G. Patil., "Shape Optimization of 'S' Type Load Cell Using FiniteElement Method" International Journal of Engineering Innovation & Research, Volume 1, Issue 3, 310-315.
13. Kolhapure, R., Shinde, V., & Kamble, V. (2017), "Geometrical optimization of strain gauge force transducer using GRA method". *Measurement*, Volume *101*, pp.111-117, Available at https://doi.org/10.1016/j.measurement.2017.01.030
14. Durairaj, M., Sudharsun, D., & Swamynathan, N. (2013), Analysis of process parameters in wire EDM with stainless steel using single objective Taguchi method and multi objective grey relational grade. *procedia Engineering*, Volume *64*, pp.868-877, Available at https://doi.org/10.1016/j.proeng.2013.09.163

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