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A Review of Concept of Force Measurements between the Past and Today

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Abstract: Force measurement is of fundamental importance to many industrial sectors. Product liability and safety issues demand that force measurements are traceable to national standards. Competitive advantage can be gained from accurate force measurement. For force measurement, some measuring systems with specific criteria are required. Force measurement systems can involve a number of different physical principles but their performance can be described by a number of common characteristics and terms, and the behavior of a system or transducer can be expressed graphically as a response curve - by plotting the indicated output value (e.g. voltage) from the system against the force applied to it. The developed techniques for force measurements are discussed through this paper. This review of research literatures has documented the advantages and disadvantages of different systems. Attention should be directed to the future needs to overcome the disadvantages of some of them. *Copyright © 2011 IFSA.*

Keywords: Force, Development, Measurements.

1. Introduction

It is imperative to define the difference between force, mass, weight and load. In summary, force is a measure of the interaction between bodies. It takes a number of forms including short-range atomic force, electromagnetic, and gravitational forces. The SI unit of force is the Newton (N). Newton is defined as the force which would give to a mass of one kilogram an acceleration of one meter per square second. Mass is a measure of the amount of material in an object, the SI unit of mass is the kilogram (kg). Kilogram is defined to be equal to the mass of the international prototype kilogram mass held at the International Bureau of Weight and Measures (BIPM). Weight is the gravitational

force acting on a body, it is taken to mean the same as mass and measured in kilograms. Load usually means the force exerted on a surface or body. It is a term frequently used in engineering to mean the force exerted on a surface or body [1].

2. Type of Forces

2.1. Force Concept

In physics, the concept of force is used to describe an influence that causes a free body to undergo acceleration. Force can also be described by intuitive concepts such as a push or pull that can cause an object with mass to change its velocity or which can cause a flexible object to deform. Forces which do not act uniformly on all parts of a body will also cause mechanical stresses, a technical term for influences which cause deformation of matter. Newton's second law can be formulated to state that an object with a constant mass will accelerate in proportion to the net force acting upon [2].

Before Newton, the tendency for objects to fall towards the Earth was not understood to be related to the motions of celestial objects. Today, this acceleration due to gravity towards the surface of the Earth is usually designated as \vec{g} and has a magnitude of about 9.81 meters per second squared (this measurement is taken from sea level and may vary depending on location), and points toward the center of the Earth. This observation means that the force of gravity on an object at the Earth's surface is directly proportional to the object's mass. Thus an object that has a mass of m will experience a force:

$$\vec{F} = m\vec{g}$$

2.2. Force Models

2.2.1. Electromagnetic Force

The electrostatic force was first described in 1784 by Coulomb as a force which existed intrinsically between two charges. Meanwhile, the Lorentz force of magnetism was discovered to exist between two electric currents. The connection between electricity and magnetism allows for the description of a unified electromagnetic force that acts on a charge. This force can be written as a sum of the electrostatic force (due to the electric field) and the magnetic force (due to the magnetic field). Fully stated, this is the law:

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}),$$

where \vec{F} is the electromagnetic force, q is the magnitude of the charge of the particle, \vec{E} is the electric field, \vec{v} is the velocity of the particle which is crossed with the magnetic field (\vec{B}).

2.2.2. Nuclear Force

There are two "nuclear forces" which today are usually described as interactions that take place in quantum theories of particle physics. The strong nuclear force is the force responsible for the structural integrity of atomic nuclei while the weak nuclear force is responsible for the decay of certain nucleons into leptons and other types of hadrons.

2.2.3. Non-fundamental Forces

2.2.3.1. Normal Force

The normal force is the repulsive force of interaction between atoms at close contact. The normal force, for example, is responsible for the structural integrity of tables and floors as well as being the force that responds whenever an external force pushes on a solid object.

2.2.3.2. Friction

Friction is a surface force that opposes relative motion. The frictional force is directly related to the normal force which acts to keep two solid objects separated at the point of contact.

2.2.3.3. Elastic Force and Hooke's Law

An elastic force acts to return a spring to its natural length as shown in Fig. 1. An ideal spring is taken to be massless, frictionless, unbreakable, and infinitely stretchable. Such springs exert forces that push when contracted, or pull when extended, in proportion to the displacement of the spring from its equilibrium position. This linear relationship was described by Robert Hooke in 1676, for whom Hooke's law is named. If Δx is the displacement, the force exerted by an ideal spring equals:

$$\vec{F} = -k\Delta\vec{x},$$

where k is the spring constant (or force constant), which is particular to the spring. The minus sign accounts for the tendency of the elastic force to act in opposition to the applied load.

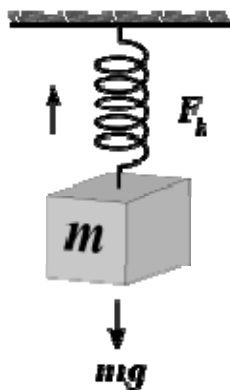


Fig. 1. Spring model for elastic force.

2.2.3.4. Rotations and Torque

Forces that cause extended objects to rotate are associated with torques as indicated in Fig. 2.

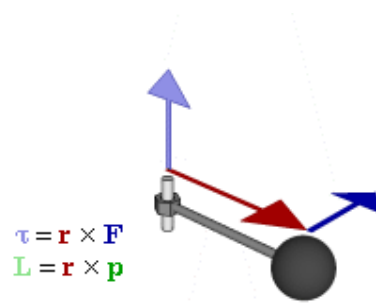


Fig. 2. Rotating force model.

Mathematically, the torque on a particle is defined as the cross-product:

$$\vec{\tau} = \vec{r} \times \vec{F},$$

where

\vec{r} is the particle's position vector relative to a pivot;

\vec{F} is the force acting on the particle.

Torque is the rotation equivalent of force in the same way that angle is the rotational equivalent for position, angular velocity for velocity, and angular momentum for momentum [2].

3. Force-measurement System

The SI unit of force is the Newton (symbol N), which is the force required to accelerate a one kilogram mass at a rate of one meter per second squared, or $\text{kg} \cdot \text{m} \cdot \text{s}^{-2}$.

A complete force-measurement system has two parts; a sensor or signal-producing system and an indicating system. The sensor system contains elements which have measurable attributes, the magnitudes of which have a correspondence to the magnitude of the applied force, e.g., the deflection of a ring, the state of strain at one or more locations on the element, etc. With the exception of elastic proving rings, commercial sensing systems are usually sealed units, the details of which are proprietary to the manufacturer. Ordinarily, the indicating system, which quantitatively displays the signal from the sensing system, is also essentially a 'black box'.

There are a variety of electronic indicating systems which can be used with strain-gage-type sensing systems. Such systems ordinarily have provisions for a 'zero' adjust (A_z) and for an amplifier gain adjust (G) relative to a span reference (S) or relative to some particular load. The span reference (S) may be a bypass resistor inserted across one arm of the sensing bridge, an internal calibration network or a ratio device which is external to the system. Most proving rings use a fixed-gain mechanical amplifier with no 'zero' adjust. Since no two sensing systems have exactly the same characteristics, and since amplifier-gain settings are arbitrary, all force measurement systems must be calibrated, i.e., subjected to known forces in order to establish the correspondence between the applied load, x , and the numerical output of the indicating system, y , for a particular amplifier-gain setting. In addition to the 'known' applied forces, there are a number of perturbing effects which can cause observable changes in the response of a force-measurement system [3].

3.1. Force Transducers

There are many types of force transducer/load cell and they are used with instrumentation of varying complexity. In designing or specifying a force measurement system for an application, it is useful to understand the basic operation of the transducer to be used and also their broad operating characteristics. Load cell designs can be distinguished according to the type of output signal generated (pneumatic, hydraulic, electric) or according to the way they detect weight (bending, shear, compression, tension, etc.)

3.1.1. Strain Gauge Load Cells

These are the most common type of force transducer, and a clear example of an elastic device. Each cell is based on an elastic element to which a number of electrical resistance strain gauges are bonded. The geometric shape and modulus of elasticity of the element determine the magnitude of the strain field produced by the action of the force. Each strain gauge responds to the local strain at its location, and the measurement of force is determined from the integration of these individual measurements of strain. The rated capacities of strain gauge load cells range from 5 N to more than 50 MN. They have become the most widespread of all force measurement systems and can be used with high resolution digital indicators as force transfer standards [4, 5]. The point of weakness for some strain gauge load cell types are that the strain gauges are exposed and require protection.

3.1.2. Piezoelectric Crystal

When a force is exerted on certain crystalline materials, electric charges are formed on the crystal surface in proportion to the rate of change of that force. To make use of the device, a charge amplifier required to integrate the electric charges to give a signal that is proportional to the applied force and big enough to measure. These piezoelectric crystal sensors are different from most other sensing techniques in that they are active sensing elements. No power supply is needed and the deformation to generate a signal is very small which has the advantage of a high frequency response of the measuring system without introducing geometric changes to the force measuring path. Extremely fast events such as shock waves in solids, or impact printer and punch press forces can be measured with these devices when otherwise such measurements might not be achievable. Piezoelectric sensors operate with small electric charge and require high impedance cable for the electrical interface. It is important to use the matched cabling supplied with a transducer.

3.1.3. Measuring Force through Pressure

The hydraulic load cell is a device filled with a liquid (usually oil) which has a pre-load pressure. Application of the force to the loading member increases the fluid pressure which is measured by a pressure transducer or displayed on a pressure gauge dial via a Bourdon tube. Measurement uncertainties of around 0.25 % can be achieved with careful design and favorable application conditions. Uncertainties for total systems are more realistically 0.5 % to 1 %. The cells are sensitive to temperature changes and usually have facilities to adjust the zero output reading, the temperature coefficients are of the order of 0.02 % to 0.1 % per °C.

3.1.4. Other Types of Force Measuring System

3.1.4.1. Elastic Devices

The loading column is probably the simplest elastic device, being simply a metal cylinder subjected to a force along its axis. In this case the length of the cylinder is measured directly by a dial gauge or other technique, and an estimate of the force can be made by interpolating between the lengths measured for previously applied known forces. The proving ring is functionally very similar except that the element is a circular ring, and the deformation is usually measured across the inside diameter. These transducers have the advantage of being simple and robust, but the main disadvantage is the strong effect of temperature on the output. Such methods find use in monitoring the forces in building foundations and other similar applications.

3.1.4.2. Magneto-elastic Devices

The magneto-elastic force transducer is based on the effect that when a ferromagnetic material is subjected to mechanical stress, the magnetic properties of the material are altered and the change is proportional to the applied stress. The rated capacities of these devices are in the range from 2 kN to 5 MN [6].

3.2. Selection Criteria for Force Transducers

There are different styles of Force transducers/Load cells. Load cell selection in the context of trouble free operation concerns itself primarily with the right capacity, accuracy class and environmental protection.

3.2.1. Capacity Selection

Overload is still the primary reason for load cell failure, although the process of selecting the right load cell capacity looks easy and straightforward on first sight. Capacity selection requires a fundamental understanding of the load related terms for load cells as well as the load related factors associated with systems. The load related terms for load cells are: load cell measuring range, safe load limit, ultimate overload and safe side load. A load cell will perform within specifications until the safe load limit (the maximum load that can be applied without producing a permanent shift in the performance characteristics beyond those specified; specified as a percentage of the measuring range i.e. 150 %) or safe side load limit (the maximum load that can act 90° to the axis along which the load cell is designed to be loaded at the point of axial load application without producing a permanent shift in the performance beyond those specified; specified as a percentage of the measuring range i.e. 100 %) is passed. Beyond this point, even for a very short period of time, the load cell will be permanently damaged. The load cell may physically break at the ultimate load limit.

3.2.2. Accuracy

Load cells are ranked, according to their overall performance capabilities into differing accuracy classes. Some of these accuracy classes are related to standards which are used in legal for trade weighing instruments, while others accuracy classes are defined by the individual load cell manufacturer.

3.2.3. Environmental Protection

No area of load cell operation causes more confusion and contention than that of environmental protection and sealing standards. In the absence of such standards, most manufacturers have adopted the International Protection system (IP/IEC 529 or EN 40.050) or National Electrical Manufacturers Association Standards (NEMA publication 250) [7].

3.3. Development of the Load Cell Design Technology, Force Application Systems and New Force Measurement Techniques

3.3.1. Load Cells

In the past, the load cells are constructed using electric resistance metal foil strain gauges bonded to an elastic flexure element. The load cell is a passive analog device with continuous resolution limited ultimately by noise, due to electron motion on the order of 10^{-9} Volts (nanovolt). Therefore, practically speaking, sensitivity and stability of the electronic instrumentation used is critical when high resolution is required. High electronic gain alone will not achieve good results if the zero stability or gain stability is poor because the readings will drift with time or temperature changes. Generally, it is desired to read physical units instead of counts [8]. Modern industrial processes are digitally controlled but the majority of sensors for measuring force and weight are still transmitting analog signals (voltage or current). There are obvious benefits in generating digital signals directly from the sensors in relation to ease of integration, implementation, use, and maintenance.

For this reason, the strain gauge load cell (as mentioned in 3.1.1) with digital readout to receive the load cell output is considered the development in force measurement area. These cells convert the load acting on them into electrical signals. The gauges themselves are bonded onto a beam or structural member that deforms when weight is applied. In most cases, four strain gages are used to obtain maximum sensitivity and temperature compensation. Two of the gauges are usually in tension, and two in compression, and are wired with compensation adjustments. When load is applied, the strain changes the electrical resistance of the gauges in proportion to the load.

Other load cells are fading into obscurity, as strain gage load cells continue to increase their accuracy and lower their unit costs. Piezoresistive is similar in operation to strain gages. Piezoresistive sensors generate a high level output signal, making them ideal for simple weighing systems because they can be connected directly to a readout meter. An added drawback of piezoresistive devices is their nonlinear output [9].

Adding the LCB500 tension and compression load cell to USB sensor is one solution for the elimination of the need for an analog amplifier, power supply and display equipment making usage that much easier. The LCB500 is machined from a single block of metal, so the primary sensing element, the mountings and the case contain no welds allowing smaller dimensions and an enhanced grade of protection. The configuration of the point of measurement reduces errors caused by imperfect application of the load. The stainless steel construction is suitable for use in aggressive environments in the chemical and petrochemical industries. The standard LCB500 tension and compression load cell model has male/female threads, is a welded unit and comes with Bendix receptacle. This model is well suited for both low ranges to high range capacity applications (100-5000 lb) [10].

In the area of new sensor development, fiber optic load cells are gaining attention because of their immunity to electromagnetic and radio frequency interference (EMI/RFI), suitability for use at elevated temperatures, and intrinsically safe nature. In this work developing, there are two techniques showing promise: measuring the micro-bending loss effect of single-mode optical fiber and measuring

forces using the Fiber Bragg Grating (FBG) effect. Optical sensors based on both technologies are undergoing field trials in Japan. But, a few fiber optic load sensors are commercially available [9].

S. Mäuselein et al investigated a new type of load cell, Silicon type, with thin-film strain gauges as shown in Fig. 3. The results offer the usability of the Si LC in the range of precision measurement if temperature behavior of sensitivity and linearity are compensated [11].

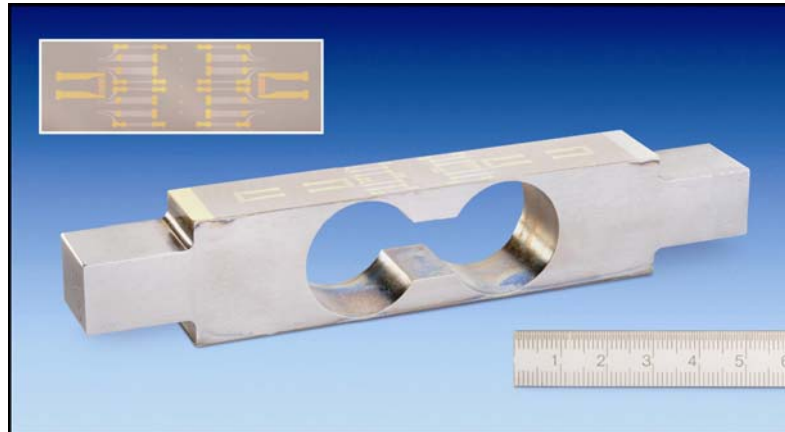


Fig. 3. Silicon Cell model.

The thin-film SGs were applied on the upper surface of the Si Spring in the area of the thin places of the LC body by using the sputtering technology. The material of the SGs is NiCr and the thickness of the SGs amount to 250 nm. The small application area of one SG with only 0.8 mm times 1.8 mm leads to a higher sensitivity compared to glue SGs with greater application areas. The investigations result in a high reproducibility and a low hysteresis which are about one magnitude better than for conventional strain gauge load cells.

Not only the load cell development is related to the new design, but the improvement of the load cell function in force measurement is also required. Surasith Piyasin is a researcher who concentrated to improve the hollow clevis-pin type load cells. These cells are widely used in heavy-duty machinery such as crams, hoists and conveyors. He tried to determine the best geometric proportion for the load cell. He proved that the certain positions for strain gauges offer some advantage over the proportions and gauge positions. Various kinds of geometric parameters for the clevis-pin have been created. These parameters were inner diameter, outside diameter, length and height. By using the ANSYS version 5.4 finite element code for the stress analysis, he concluded that: when the hollow-bore clevis-pin is used as a strain gauge load cell, the proportions are likely to be of length to diameter ratio varying from about 2.5:1 to about 3.5:1 or perhaps 4.0:1. Also, the best results are likely to be obtained with bore to outside diameter ratio giving thick-wall proportions and, typically, of from 1/2 to 1/3 [12].

Continuing the improvement of force transducers, some researches focused on the application of heat treatments on spring elements of transducers, since this is a very effective method for attaining good performance in force measurements. Heat treatments change the microstructure of the spring material, which plays a major role in the improvement of performance characteristics of force transducers, particularly in terms of hysteresis error. Sinan Fank and Mehmet Demirkol studied the changing of the microstructure of AISI 4340 steel through the application of different heat treatments, and the subsequent measurement of the hysteresis performance of force transducers in relation to the change in the structural characteristics of the spring elements. Some of the specimens were quenched and tempered to 35, 45 and 55 HRC (Hardness Rockwell C). Some of the other specimens were

austempered to obtain a bainitic structure with 45 HRC. The remaining specimens were austenitized at a high temperature for a long time to obtain a coarse tempered martensitic structure with 45HRC hardness. The hysteresis characteristics of the force transducers were determined using a dead weight, force standard machine. The results have shown that the hysteresis characteristics of quenched and tempered specimens improved with increasing hardness. Bainite exhibited better hysteresis performance over tempered martensite at the same hardness level, while a coarse martensite structure has a detrimental effect on the hysteresis characteristics of force transducers [13].

3.3.2. Force Application Systems

In the area of using Dead Weight concept as a primary method for applying the forces, the Electronic Deadweight Tester is a modern replacement for the Conventional Deadweight Tester (CDT) which has some disadvantages by usage. In this dead weight concept, the forces applied to the sensor are generated by suspending weights of known mass in a known gravity field. Some of the CDT disadvantages are: The minimum pressure increment is limited by the minimum mass value in the mass set, so if the test gauge is of high resolution, it may not be possible to position its needle directly on a nominal test point. The second disadvantage are the alternative to setting nominal pressures on the gauge under test by loading incremental masses is to interpolate the gauge's reading, creating an opportunity for errors. Another disadvantage is, since the deadweight tester is inherently a mechanical device, there is no convenient way to automate the data acquisition. Once a test point is defined, the operator must write the data on a data sheet or manually enter it into a customized computer application [14].

Force Standard Machines (FSM's) operating with dead weights in the earth's gravitation field are the most accurate way to generate forces because the realization is traceable to the base units of mass, length and time. On the other hand, cost limitations for high capacity machines lead to technical solutions using force amplification of the direct loading by hydraulic or by mechanical lever system. The best measurement uncertainty achieved by dead weight machines is 20 ppm, while the best measurement uncertainties reached with hydraulic amplification are in the range from 100 ppm up to 500 ppm, and 50 ppm up to 200 ppm for lever system.

In Germany, in year 2001, G. Navrozidis et al evaluated new state of the art force standard machine. The fully automated force standard facility is a combined dead weight – lever amplification machine with 110 kN direct load capacity and a 10:1 lever multiplication part. The lever system is affected by disturbing moments that are caused by eccentric coupling of the masses to the lever and eccentric moment of the test transducer [15].

In the case of force standard machines with hydraulic transmission, a defined weight force acts on a piston/cylinder system in which a constant oil pressure builds up. By coupling this system with a second piston/cylinder system having a larger sectional area (pressure balance), a transmission of force by a factor $Q=A_2/A_1$ is achieved, where A_1 and A_2 are the effective areas of the two piston/cylinder systems.

Indeed the advantages of the modern automatic machines are not limited to the possibility of checking the time response of the devices under test, but even the accuracy can be generated with a small number of masses, with the relevant advantage of lower costs of mass production and calibration.

The possibility of self calibration is also important. Self calibration consists of internal mutual comparison of the forces generated by the different masses. Beside the great practical advantage of avoiding the separation of the masses from the machine for calibration, it produces a great metrological advantage. The metrological advantage of self calibration is due to the fact that forces

produced by different groups of masses are compared directly at their point of application to the force transducer. It takes, therefore, into account eventual systematic effects due to the force transfer and cancels them.

Besides force standard machines with deadweight, with lever transmission and with hydraulic transmission, there are some others procedures used. Build-up procedure is one of them. Fig. 4 indicates the base plate of buildup setup.

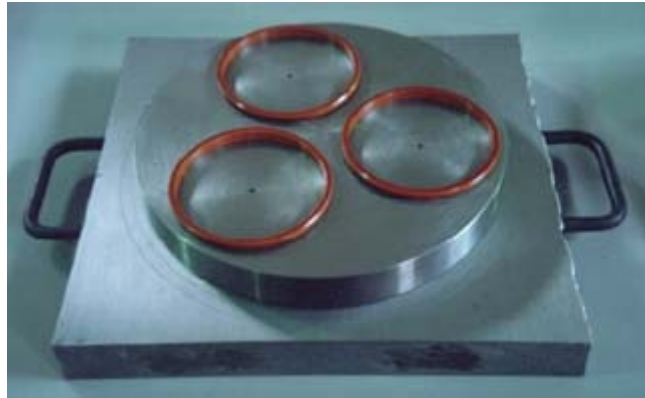


Fig. 4. Base plate of the Build-up prototype.

For very large capacities, in general above 1 MN, the "build up" procedure may be employed, consisting of comparing the dynamometer to be calibrated with one or more dynamometers linked in parallel. With the "build up" method the field of force measurement may be extended to values that would not appear possible with the use of deadweight or multiplication primary standards, at a much lower cost [16]. Incorrect positioning of a force transducer at the build-up base plate, can be a source of systematic errors for the behavior evaluation in this type of standardization system.

3.3.3. Techniques

In the field of dynamic force measurements, there are some improved techniques. One of them is discussed by Yusaku Fujii and J. D. R. Valera. They studied a novel method for accurately measuring small and steep impact force. In this method, the inertial force of a moving mass is used as the reference force applied to the material under test. A pneumatic linear bearing is used to obtain linear motion with negligible friction acting on the mass, i.e., the piston-shaped moving part of the bearing. The impact force is generated and applied to the material by collision with the mass. An initial velocity is manually given to the moving part. A corner-cube prism (CC), that forms part of the interferometer, and a metal block with a round-shaped tip (for adjusting the collision position) are attached to the moving part (made of aluminium with square pole shape); its total mass M is approximately 21.17 g. The inertial force acting on the mass is measured highly accurately using an optical interferometer. The high performance of the proposed method is shown by evaluating the viscoelasticity of a small rubber block under small and steep impact load [17].

Due to the progress achieved in micro system technology and materials science, e.g., medical technology and hardness measurement, there is an increasing need for traceable measurements in the mN range. For small force measurements, there are some difficulties raised from: (1) No National Measurement Institute supports a direct force realization linked to the International System of Units (SI) below 1 N even for static force. (2) Small force to be generated and/or measured is usually a

varying force and any dynamic calibration technique for force sensors has not been established yet. In other words, this fact means that the uncertainty evaluations both for the measured value of the small force and for the time of the measurement are very difficult. The proposed optical method is demonstrated in Fig. 5 for Micro Force Measurement according to Levitated-Mass Method, is free from these problems [18].

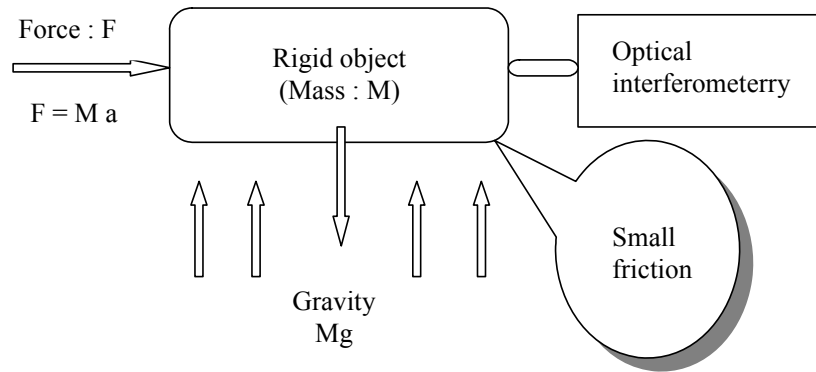


Fig. 5. Levitated-Mass Method.

Another trend for measuring the small force is described in Fig. 6 by Stefan Niehe at 2003. He has evaluated metrological characteristics for a new force measuring facility for the range from 10 mN to 10 N consisting of a piezoelectric adjustment unit and a precision compensation balance [19].

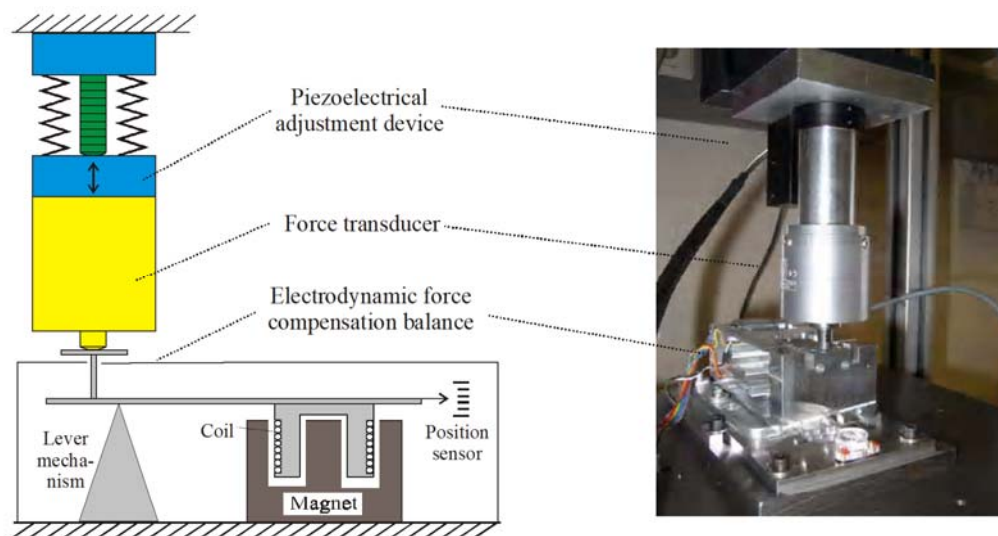


Fig. 6. Measuring facility.

It essentially consists of a piezoelectric ID fine adjustment unit with an integrated capacitive feedback sensor and a precise electrodynamic compensation balance with lever mechanism. The force transducer to be investigated is screwed overhead, together with the fine adjustment device, and traced by the coarse adjustment unit to contact the balance. When the fine adjustment device travels downwards, the force transducer presses the load receptor of the balance downwards. A piston sensor records the movement of the lever arm, and the balance automatically changes the current through a coil rigidly connected to the lever arm. The action of force on this current – carrying coil in a magnetic

field procedures a counterforce and thus ensures resulting to the initial position by the piston sensor. The force – proportional coil current is a measured of the balance. By variation of the piezoelectrically produced translation, the force transducer can be loaded in compression with different forces which are recorded by the balance.

Fig. 7 indicates a new trend for force measurement by hand force measurement system. B. D. Lowe et al are studying this point [20]. The system incorporates 16 to 20 thin profile conductive polymer pressure sensitive resistors attached to a thin athletic grip glove to cover the pulpar regions of the phalangeal segments and palm that contact the grasped object. The electrical responses of these sensors have been found to be linear when calibrated against applied force distributed over the sensor surface area. The active area of each sensor is circular with a diameter of 9.53 mm. The thickness of each sensor is 0.127 mm. Raw data are sampled via a pc and digitized through a 12-bit data acquisition board set to a ± 5 V range. The raw voltage data from the sensors are converted to calibrated force units and displayed in real time.



Fig. 7. Sensor placement on the force glove.

Attaching thin profile pressure/force sensors to a glove has the advantage of facilitating measurements of hand force on any grasped object, such as a hand tool, without the need to instrument the tool itself. The disadvantage of this measurement approach is that the material properties of the glove and sensor may alter the frictional conditions between the hand and the tool and may degrade tactile representation of the coupling between the hand and the tool. If these limitations are acceptable the glove-based system is a useful measurement device for characterizing hand grip contact forces in the evaluation of many hand tools. The glove system is also advantageous because of its low cost, and replaceable sensors. Through repeated use in industrial activities that involve high grip force levels we have observed damage and failure of the thin profile force sensors. These sensors are relatively inexpensive and can be replaced individually. Other commercial systems have been developed with multiple force sensing elements embedded within a single printed medium. If one of the sensing elements in this medium is damaged the entire sensor medium must be replaced – at significant cost.

4. Summary

Developments of force measurement are passed by several steps in the past and still continue in future. The classic applications, e.g. material testing and safety engineering, require force measurements extend from 1 N to 100 MN. In the aerospace industry, off-shore industry and in opencast mining, applications in the MN range dominate. In the medium force range from 1 kN to 1 MN, applications

are found in the automotive industry, in materials handling and in aviation, whereas in the textile industry and in automation and medical engineering, forces in the lower force range of up to a few kN are measured. Whilst in the past, traceability was especially required for forces larger than 1 Newton, the need for traceability of smaller forces, in the milli-, micro- and nanonewton range, is constantly increasing today [21]. Also the traceability for large force measurements (e.g. build up system) is needed.

Nowadays, the self check is one of the modern techniques in dead weight machine design. It is solving the problem for mass recalibrating, without release the masses far from the machine [22]. The smallest relative measurement uncertainties are 0.002 % for calibrations with deadweight.

The force sensors are usually mechanical elastic bodies which deform under the action of a force. Most of the time, this deformation is measured electrically, e.g., according to the metrological principle of strain gauges. There are, however, other principles (e.g. piezo-electric force transducers) which generate a charge proportional to the force. For the precision measurement of static forces, e.g. within the scope of international comparison measurements, especially strain gauge force transducers have established themselves, whereas dynamic measurements often require the use of piezo-electric force transducers.

Also, this study review reveals the advantages of some force measurement tools and disadvantages of others. Silicon load cell, for example, could be used for precision measurements which are normally the field of the electromagnetic force compensation technology. Beyond, in spite of the electromagnetic force compensation technology, the Si LCs are not limited to low and medium loads and thus they are suitable to be used as transfer standards [11]. Investigations are performed with mechanical spring made of single-crystalline silicon (S-spring) for the load cell with sputtered-on thin film strain gauges. The measurements revealed that the Silicon load cell behavior is better than the conventional metallic material load cell [23, 24]. But, it is costly use and still under development.

Forces in the nanonewton and piconewton range have already been for several years in scanning force microscopy for the high resolution measurement of surfaces. The increasing industrial use of plastic microparts which get scratched when they are measured by means of contact measurements where the measuring force is too high, has led to new challenges for quality assurance for both scanning force microscopes (SFM) and usual contact stylus instruments. A new field of application for scanning force microscopes has resulted from the development of automated force spectroscopy devices for molecular analysis. These devices can determine where active ingredients of medicaments bind to the target molecule and how strong the bond is. It is thus possible to measure forces in the piconewton range. All these measuring procedures are based on the use of soft bending test beams (cantilevers) with integrated stylus tip.

The force measurement concept is focused on the usage of the modern technique not only to measure the small forces but also to characterize the materials. Atomic force microscope on of this method to characterize the nanotribological properties [25].

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In addition, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
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