

Strain gauged elastic elements for force and related quantities measurement

Dan Mihai Stefanescu (Romanian Measurement Society, Sos. Vitan-Barzesti 11, Bucharest – 75669, E-mail: stefidanro@yahoo.cm)

Abstract

Force, Mass, Pressure, Acceleration, Vibration and other mechanical quantities are strongly connected by their physical formulas, by their like measurement principles and – last but not least – by the complex scientific program of the jointly 20th TC3, 3rd TC16 & 1st TC22 IMEKO Conference, held in Merida, Mexico, in November 2007. Force as an important mechanical quantity has a privileged position inside the Asian “planetary system” of units or atop the “Newton apple tree” suggesting SI units system. Force can be measured with a lot of elastic elements using various measurement principles. Among them those based on strain gauges as resistive transducers are predominant. Three complex and spectacular applications concerning Force and associated quantities measurement are shown in three different environments: solid, liquid and air.

Key words: Force, related quantities, elastic elements, strain gauges, SI units.

1. Introduction

Force is strongly connected with other mechanical quantities (Mass, Pressure, Acceleration) by physical relations. All these measurands are able to be determined by the same kinds of elastic elements and measurement principles, most often using strain gauges.

Based on the author's works in this inter- and multidisciplinary field, three complex applications concerning Force and related quantities measurements in three different environments (solid, liquid and air) are presented in this paper.

2. Force Within the International System of Units

There are two suggestive representations of measurement units' interconnection within the approved International System: Asian SI units like a “planetary system” (Fig. 1) and European SI units like a “Newton apple tree” (Fig. 2).

基本單位與導出單位關係圖 Derivation of Base Units

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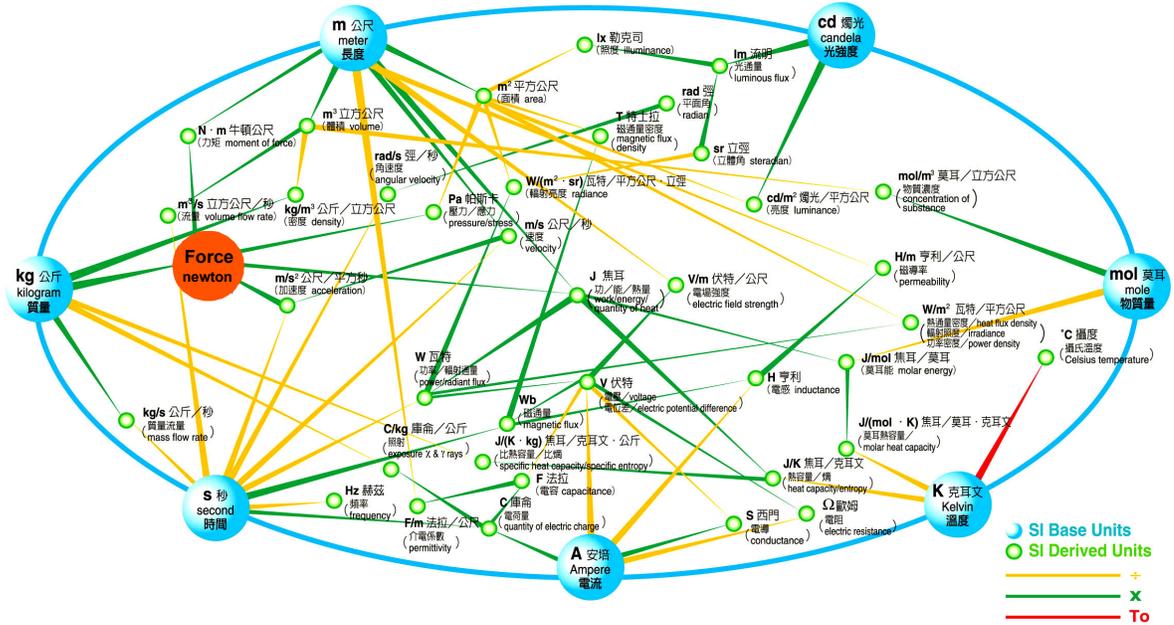


Fig. 1. Asian derivation of base units.

In the Asian system of measurement units, presented like the solar system, one can regard the Force like the Sun, the primordial element. One can observe the perfect “alignment” of Mass, Force [$F = m \cdot a$, where a is acceleration] and Pressure [$p = F / A$, where A is area].

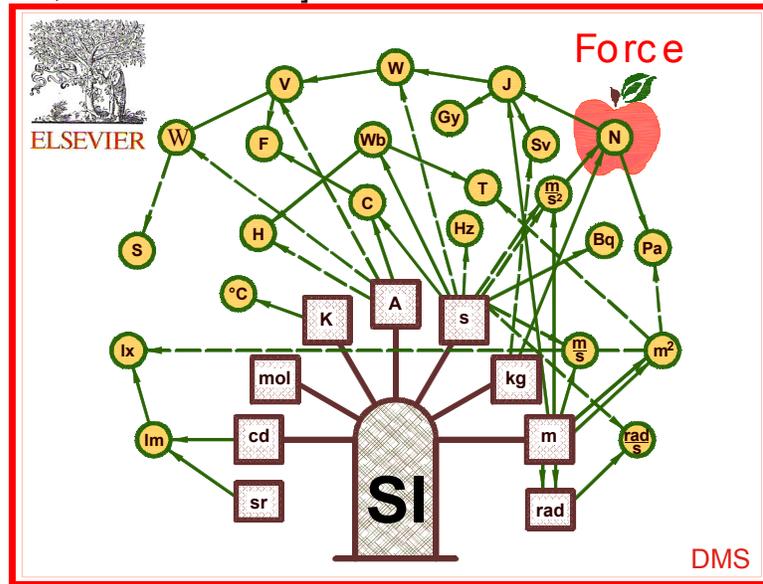


Fig. 2. International System of basic units.



Fig. 3. Dr. Dan Mihai Stefanescu under Korean “Newton apple tree”, June 2004.

However, in the European system of measurement units, the Force, as a derivative unit, is placed atop of a complicated hierarchic scheme, suggestively represented by a tree. There are some “Newton's apple trees” all over the world; the Korean one is presented in Figure 3.

3. Measurement Principles for Mechanical Quantities

The most widely used methods for mechanical quantities are based on a dozen of basic measurement principles, presented in the Table 1.

Table 1.

Measurement principles for mechanical quantities.

Mostly used measurement principles for mechanical quantities	
1 Resistive – Strain gauges	7 Galvanomagnetic (Hall effect)
2 Inductive	8 Vibrating wires
3 Capacitive	9 Micro-resonators
4 Piezoelectric	10 Acoustic (SAW, radiation)
5 Electrodynamic – EMFC	11 Gyroscopic
6 Magnetoelastic	12 Optoelectronic

Among these measurement principles those based on strain gauges as resistive transducers are predominant.

4. Elastic Elements for Force and Related Quantities Measurement

There are 12 principal types of elastic elements useful for strain gauging technology: 1 - Stretched/compressed column; 2 - Stretched/ compressed tube; 3 - Bent lamella (cantilever beam); 4 - Bent and/or torsioned shaft; 5 - Middle bent bar with embedded ends; 6 - Shearing strained profile; 7 - Bent yoke; 8 - Bent ring; 9 - Bent membrane; 10 - Compressed torus; 11 - Axis symmetrical element; 12 - Volumetric element.

Their selection criteria for the best electrical measurement of mechanical quantities have been analyzed in [1], and the appropriate methods for increasing the force transducers sensitivity have been presented in [2].

Table 2

illustrates the possibilities of using the twelve types of elastic elements for tensometric (strain gauge) measurement of mechanical quantities:

Mechanical quantities	Elastic elements types											
	1	2	3	4	5	6	7	8	9	10	11	12
Acceleration			x						x			x
Displacement			x	x	x		x		x			
Force	x	x	x	x	x	x	x	x	x	x	x	x
Mass			x		x	x	x		x	x	x	
Pressure		x	x		x				x	x		
Torque	x		x	x		x		x				
Vibration			x		x		x		x			x

It can be observed that, on the horizontal axis, Force, that has a central position among the mechanical quantities, which are associated in alphabetical order, can be measured with each of the kinds of usual elastic elements. Force is "followed" by Mass and then by the other quantities, nearly equally frequent.

On the vertical axis, the cantilever beams (type 3), can be used for the measurement of all the physical quantities existing in the Table 2. It is "followed" by the membranes (type 9) and by the bent bars fixed at the both ends (type 5).

Therefore, the most significant "crossing" is that one between the Force (among the mechanical quantities) and the cantilever beam (among the elastic elements).

Figure 4 presents the classical cantilever beam together with two models of slotted cantilevers analyzed by the finite element method [3].

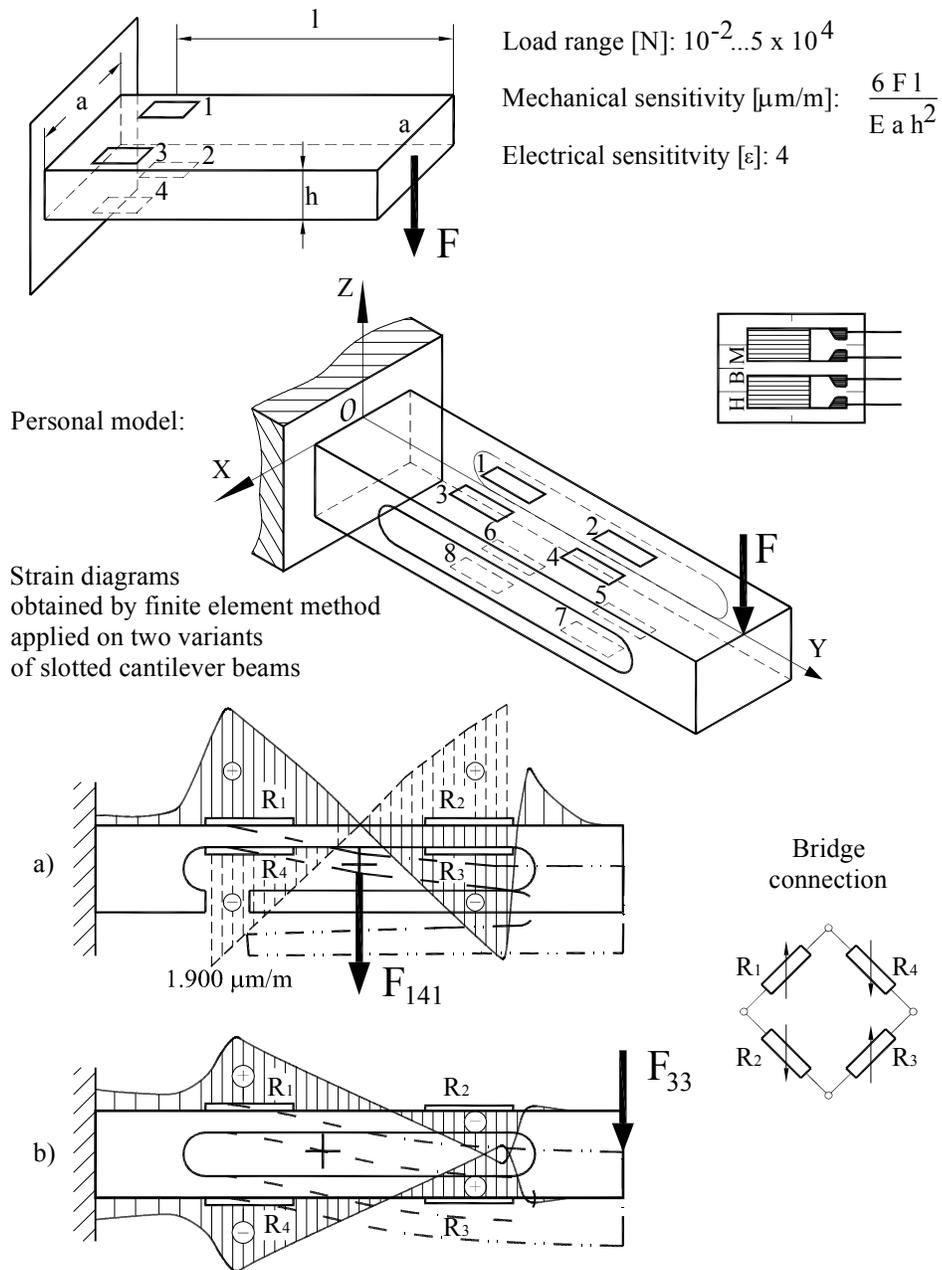


Fig. 4. Cantilever beam type of elastic element.

Apparently, the volumic elastic element, (type 12) has a reduced sensibility, but the use of semiconductor materials (e.g. silicon), increases the sensibility by two orders of magnitude and makes it able to be used with good results in the dynamic measurements (acceleration, vibrations).

5. Applications

Three applications concerning force and associated measurands are shown in three different environments: solid, liquid and, respectively, air.

5.1. Stand for Determining Stiffness and Friction Moment at the Ball Screws.

In the schematic diagram from Figure 5 is presented the stand achieved for the determination of the stiffness and friction moment at the ball screws [4]. The ball screw 2 is fastened between the ends 1, which permit the rotation drive of the screw. The part 3 is a slide with fastening device of the nut, with guiding on the stand frame.

At the stiffness test the screw is blocked against rotation and the nut is loaded with a known force F , by means of a hydraulic device 8, while the distortion δ of the nut is being sensed by an electronic transducer for displacement 4 and indicated by the strain gauge bridge 9.

At the friction moment test, the nut travels when the screw is rotating. The measurement of the resistive moment M , which appears at the screw rotating stimulated by motor 7, owing to the friction between screw and nut, is made by means of a torque transducer 5, inserted between motor and screw, through a coupling device 6. The corresponding indication is read on the strain bridge 10.

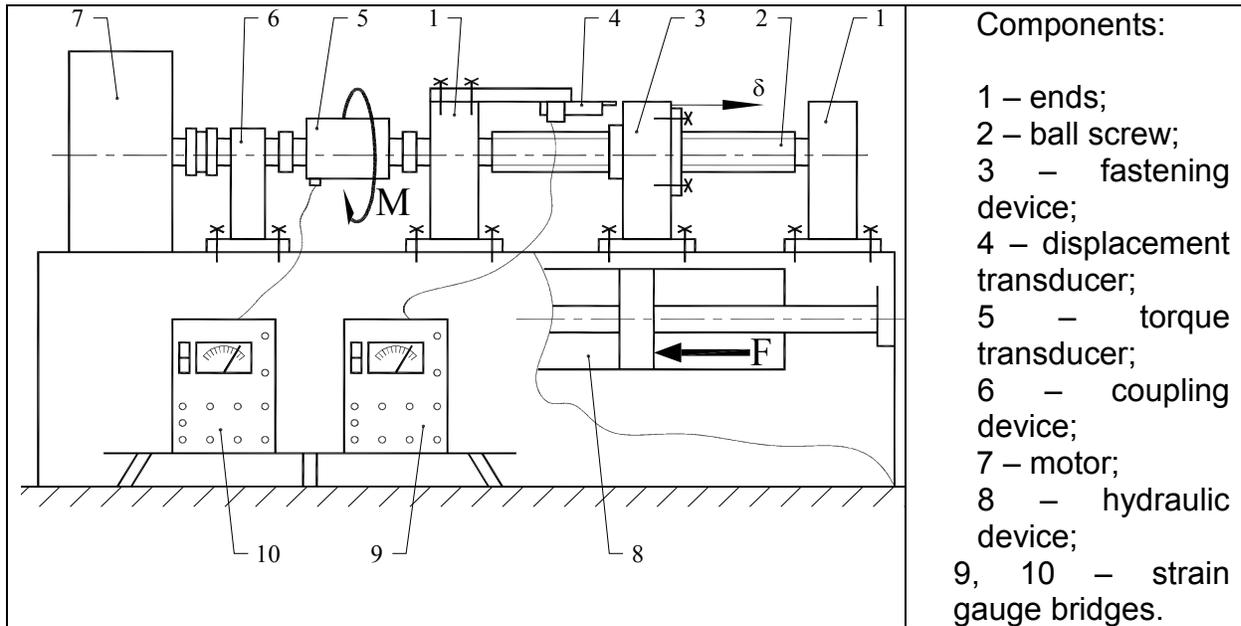


Fig. 5. Stand for determining the stiffness and friction moment at the ball screws.

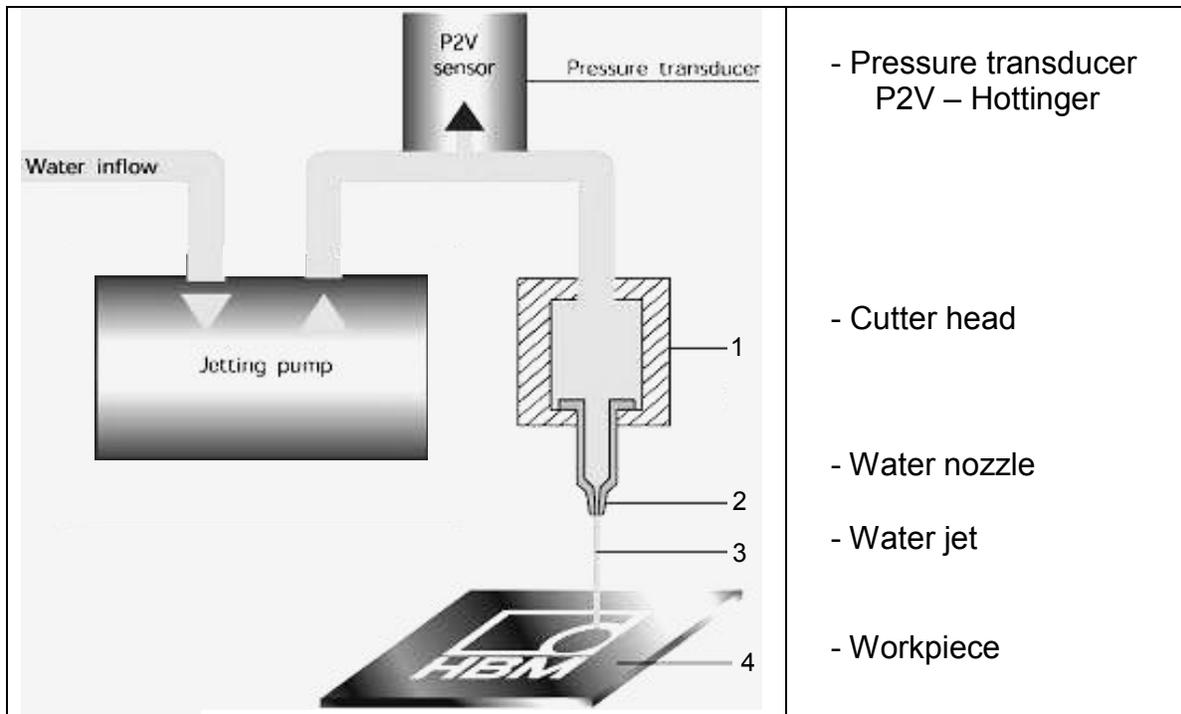


Fig. 6. The principle of waterjet cutting.

5.2. Waterjet Cutting Machine.

Waterjet cutting (Fig. 6) requires extremely high water pressures of 3,000 to 5,000 bar, which have to be accurately measured. HBM provides special pressure transducers and transmitters for this purpose [5].

5.3. Multicomponent Strain Gauged Balances for Testing Car and Plane Models in Wind Tunnels.

To test plane or car models inside aerodynamic tunnels, special strain gauged balances are conceived and achieved [6]. One can see such an external tensometric balance in Figure 7.

Capacity ranges are: drag force $F_x = 2,6 \text{ kN}$; side force $F_y = 1 \text{ kN}$; lift force $F_z = 1,3 \text{ kN}$; rolling moment $M_x = 150 \text{ Nm}$; pitching moment $M_y = 2,600 \text{ Nm}$; yawing moment $M_z = 150 \text{ Nm}$. The tensometric sensitivity of channels F_z and M_z has been increased using eight strain gauges instead of four, all of them being active within the Wheatstone bridges.

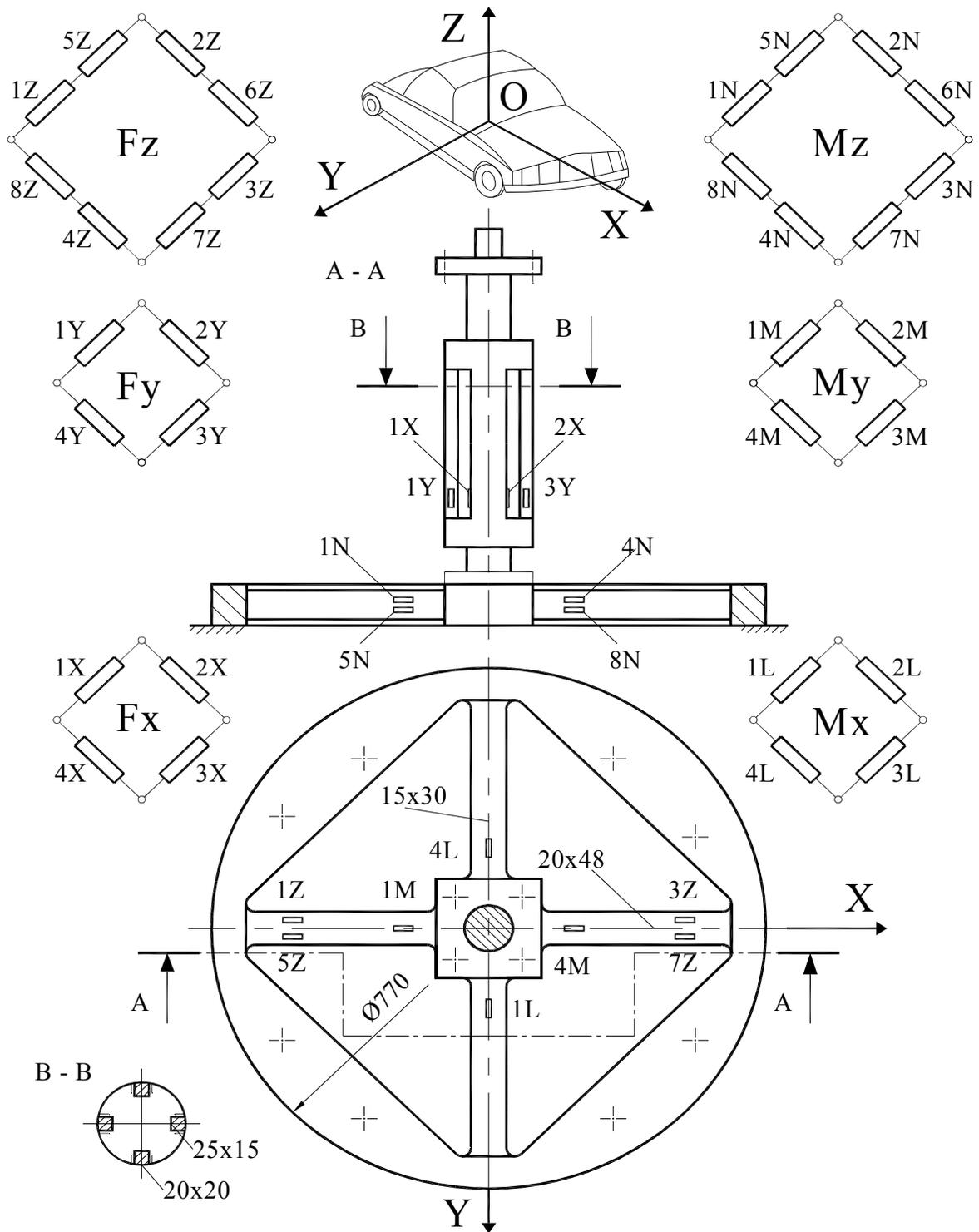


Fig. 7. Six-component strain gauged balance.

Figure 8 suggests a lot of Force and related quantities measurements for cars testing in order to improve their performances.

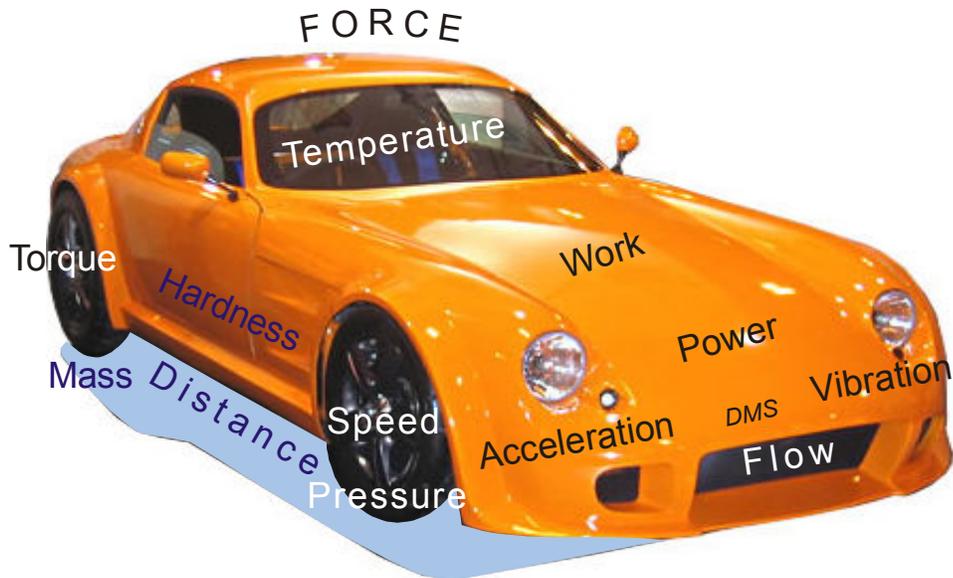


Fig. 8. Force and related quantities measurement for car testing.

Many other significant applications for electrical measurement of Force and associated mechanical quantities can be found in the emerging Handbook of Force Transducers [7].

6. Conclusions

Force has a central position among the mechanical quantities, all being connected by physical formulas and able to be measured with the same kinds of elastic elements and measurement principles, most often by strain gauges.

Based on the author's works in this inter- and multidisciplinary field, some interesting applications are shown, starting from single-component Force (and other mechanical quantities related to it) transducers and finally developing sophisticated strain gauged multi-component balances for wind-tunnels.

Reference

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