MULTI-COMPONENT FORCE AND TORQUE BALANCES FOR WIND TUNNELS

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Abstract: Starting from the German experience in the field of electrical measurement of mechanical quantities, one of the top application is the six-component measuring of the aerodynamic load torsor. For these complicated mechatronic devices, which have to measure six widely different components with the same relative accuracy, a complex mechanical and electrical analysis has been performed concerning the optimum positioning and connecting of the strain gauges, in order to increase the sensitivity and to compensate the disturbing influences. Four original strain gauged multicomponent balances for scale model testing were designed and manufactured having in view the improvement of the road vehicle and aircraft performances. Concrete data are shown in the four figures and tabularly summarized.

1. Introduction

The simultaneous measurement and analysis of the various aerodynamic forces and moments acting on aircraft and vehicle models along their axes require special balances with utmost precision and remaining robust in severe experimental conditions such as in wind tunnels. In the world of physical variables strain could be a measure of force and/or torque. The multi-component transducers (3 forces, expressed in Newton and 3 couples, expressed in Newton x meter) based on strain gauges offer many advantages: compactness, ease of use, remote-controlled measurement option, reliability, etc [1].

2. Applications

The most complex application is the six-component measuring of the aerodynamic load torsor (drag, side and lift forces, respectively roll, pitch and yaw moments). Four innovative strain gauged balances are presented in this paper. Their very different capacity ranges for the four models are shown in Table 1.

Force [N] / Torque [Nm]	Model I	Model II	Model III	Model IV
DRAG $X \equiv F_X$	7,100	1,000	2,600	2,850
SIDE $Y \equiv F_Y$	6,100	1,000	1,000	9,650
LIFT $Z \equiv F_Z$	7,600	1,000	1,300	14,700
ROLL $L \equiv M_X$	550	100	150	320
PITCH $M \equiv M_Y$	1,000	100	2,600	820
YAW $N \equiv M_Z$	850	100	150	760

Table 1. Capacity ranges for the six-component balances.

Innovative solutions replace the complicated "pyramidal" ones, based on independent strain gauge force transducers, with one-piece or assembled elastic structures, and *optimized by numerical methods* [2]. It is a complex *sensorization*, demonstrated on four personal applications, very different from Dantec, Onera, Rollab, Schenck and many other models.

Some specific particularities for the elastic elements of strain gauged force transducers [4] are applied in this work, *the sensor being the heart of the measurement system*.

After a world-wide comparison, four original solutions are presented: three of integral construction (I, II and IV), and one assembled variant (III). The first model (Fig. 1) is the simplest one, inspired by a Japanese model of "pillar" with square cross section, but having only two perpendicular holes. In the next cases the precise analytical design is not possible, so the numerical one - utilizing *the finite element method (FEM)* - is the best option.

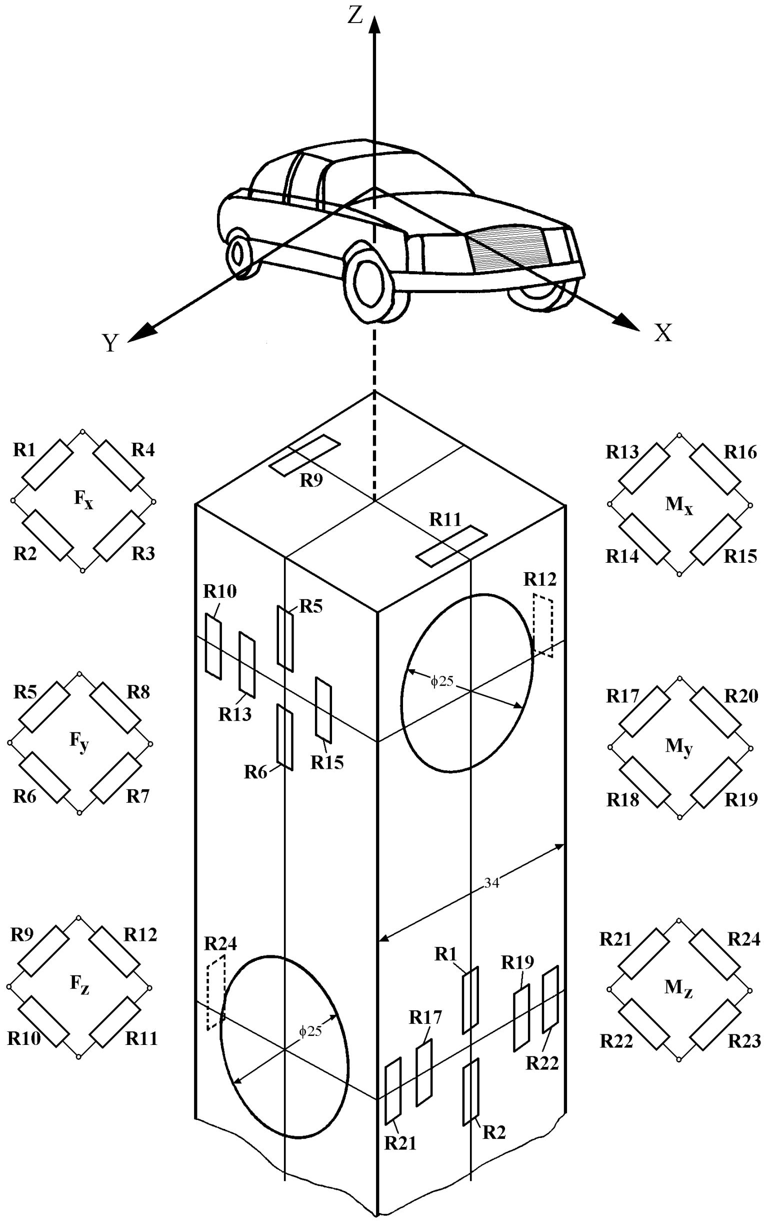

Fig.1 Vertical tensometric pillar for measuring three forces and three couples.

The second model (Fig. 2), also integral, develops the first one. The reduced space requires the adoption of a more "compact" solution utilized in Robotics, as in [9]. It is an one-piece balance the first five components of which should be analytically assessed based on some simplifying hypotheses. For the last component (N) the finite element calculation is imposed being also useful for the study of the simultaneous load application and of the component interactions. The sensor flexible element is calculated by means of FEM using the IMAGES (Interactive Microcomputer Analysis of General Elastic Structures, Celestial Soft, 1984) - 3D program. About 600 eight-node tri-dimensional solid finite elements were used. Based on an original computing programme for strains ε (SV-01) the assessed values at the rated loads in the location points of strain gauges are the ones grouped in Table 2.

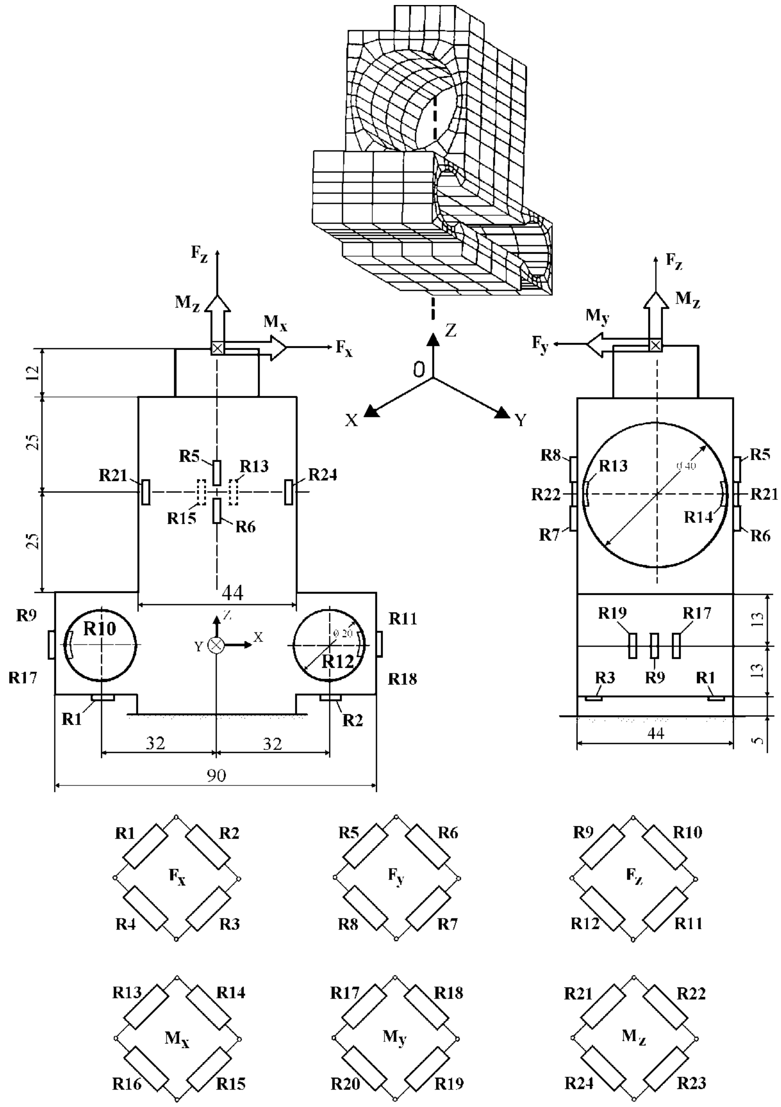

Fig. 2 Compact six-component strain gauged balance.

ε (μm/m)	X	Y	Z	L	M	N
X	2,590	0	0	0	1,120	0
Y	0	1,365	0	1,070	0	0
Z	0	0	1180	0	0	0
L	0	265	0	2,760	0	0
M	1,290	0	0	0	1,990	0
N	0	0	0	0	0	2,600

Table 2. Interaction matrix for the second type of 6-component balance.

One may also notice that, among the components, only Fx and My are inter-influencing each other and Fy and Mx respectively, fact which will be taken into account in the calibration programme. The simultaneous action of the six components leads to a maximum equivalent stress of 266 MPa, very closed to the admitted one (275 MPa for 34 MoCrNi 15 steel).

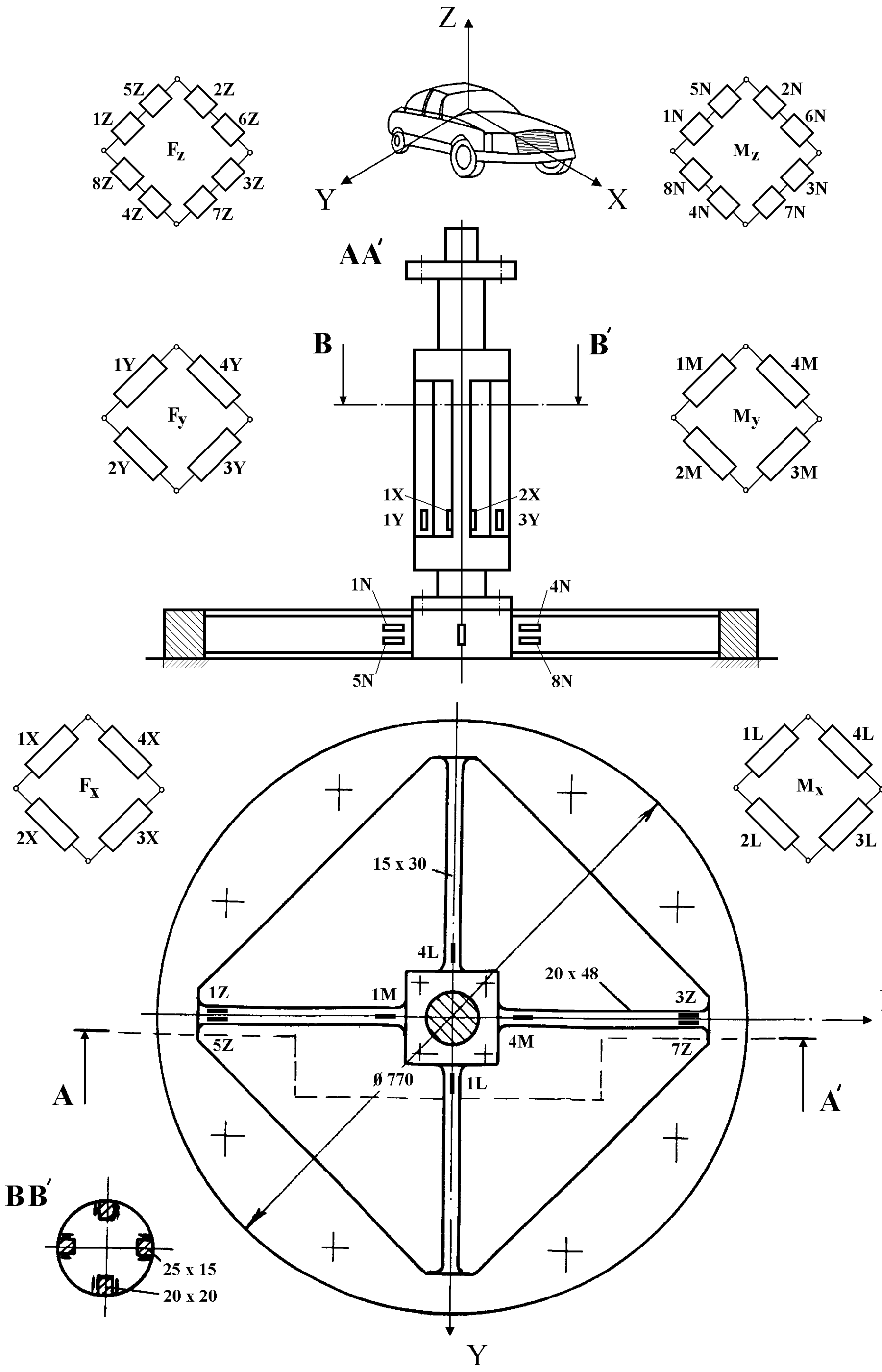

Fig.3 Composed six-component external strain gauged balance.

The third model (Fig. 3) is an extension of a proper robotic device [5]. This external balance, which is not subjected to space restrictions, permits the "composition" of a bar made elastic structure such as the four-spoke wheel and the four-column hub. The numerical computation model contains 18 tridimensional bar elements and 16 knots. The final version has been imposed by the equivalent stresses existing in the elastic elements and by the possibilities of technological processing. Analysing the influence of each load on the instrument readings for the other five Wheatstone bridges, one came to the conclusion that the effects are theoretically uncoupled due to the symmetrical or anti-symmetrical F - M diagrams. The tensometric sensitivity of Z and N channels was increased using eight strain gauges instead of four, all of them being active.

The first three variants may be considered as vertical ones while the last (Figure 4) is a horizontal strain gauged balance; it is an original multi-component balance for aircraft models being tested in the Romanian supersonic wind tunnel [8]. This complicated structure was developed by means of Finite Element Analysis; the loads from 722 isoparametric elements and the displacements of 1,536 nodes were calculated by computer. The elastic body of the balance was accurately machined by electroerosion from a single piece of ARMCO 17-4 PH steel and metalurgically treated to ensure an admissible tensile strength better than 400 MPa (N/mm^2). The axial force is sensed by four cantilever beams near the middle section (AA') of the internal balance; the other five components are measured in two symmetrical sections each consisting of three-bar cages. This integral solution offers the best relation between capacity and volume, since the interaction between forces and/or moments is accurately specified by calibration.

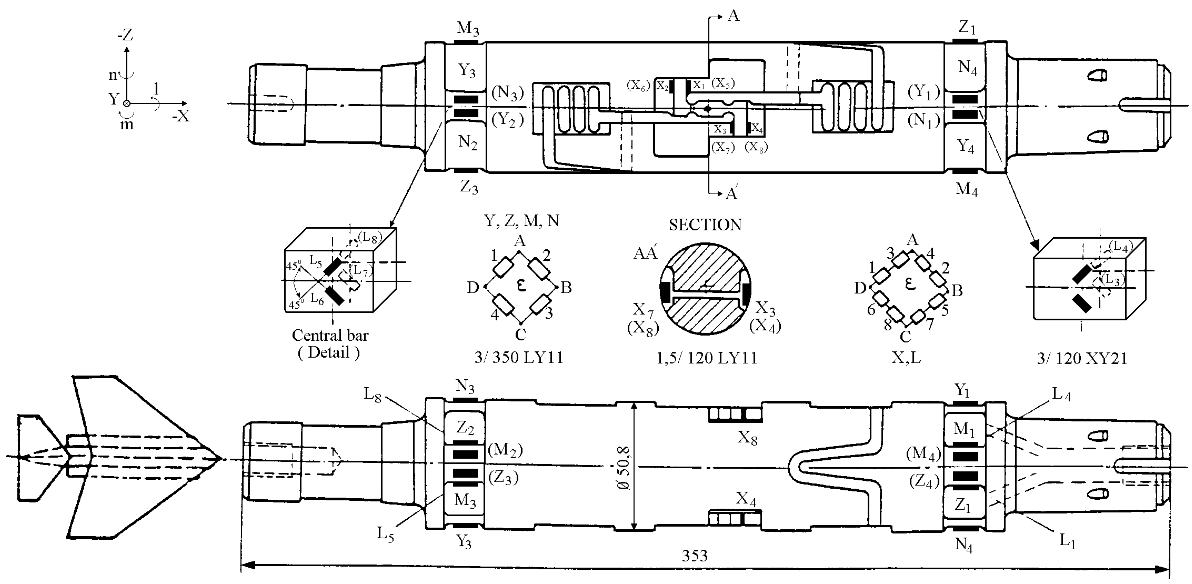

Fig. 4 Internal multi-component tensometric balance for the Romanian Wind-Tunnel.

Testing of multi-component strain gauged balances requires special benches for calibration and raises numerous force, torque and mass metrology problems, underlining the official denomination of our Technical Committee No. 3 in IMEKO. These six-component balances were verified by using an appropriate calibration procedure [6]; they have been connected, via standardized interface, to the data acquisition and control system of the trisonic wind tunnel, conducted by computer. The test determinations of strains are in good agreement with the calculated values.

3. Conclusions

The accurate measuring is, let's say, a "pylon" of the modern engineering metrology, a necessary condition in quality assurance. From very different force- and torque-balance instruments [10] the multi-component strain gauge balances for wind tunnels are the most complicated and valuable mechatronic applications. The original Romanian contributions concerning the four strain gauged balances consist in *the increasing methods of their tensometric sensitivity* [7], maintaining good structural symmetry and low interinfluences between the measured components. The know-how achieved provide the basis for *exemplary solutions for every individual from a broad spectrum of applications*, based on complex weighing cells or force sensors/ transducers [3], actually limited only by the human creativity.

4. References

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