

Energetical and Informational Aspects in Transducers

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Abstract – The paper presents definitions and characteristics of the sensors and transducers used in electrical measurement of mechanical quantities, with emphasis on related energetical and informational processes that conjointly take place within them. Various aspects of the energy information conversions are attentively treated, constituting, together with several improved representations, a significant contribution to understand the electrical measurements. Finally, an original application is described: a multicomponent strain gauged balance illustrating the complexity of information transducer (IT) process in order to transform the aerodynamic loading into precisely defined electronic output signals.

Keywords: sensors / transducers, energy conversion, signal processing, Wheatstone bridge, electrical measurement of mechanical quantities.

I. TERMINOLOGY AND DEFINITIONS

In accordance with the international terminology of metrology, *sensor* is a device that responds to a physical stimulus, such as thermal energy or pressure, by producing a signal, usually electrical; *transducer* is a device for *converting energy* from one form to another for the purpose of measurement of a physical quantity or for *information transfer* [1].

In other words [2]: *Sensor* is the primary sensitive element that enables a first conversion of the measurand applied to its input (for instance, the strain gauge – abbreviated SG – bonded on the elastic element – EE); the *transducer* is the assembly [3] in which the *sensor* is mechanically installed and electrically connected (Fig. 1,a).

The practical illustration of this definitions is given in Figure 1,b.

When the “supporting / interrogating” energy domain is added, this two-dimensional representation (input – output) (Fig. 1,a) can be extended to three dimensions. The 3D *transducer space* represents the input signal in its primary energy form along the conventional X-axis, the output energy along the Y-axis and the support energy along the Z-axis.

Energetical and informational aspects of measurement process, that usually are “interweaved”, will more widely be developed in the next chapters.

II. ENERGETICAL ASPECTS IN THE TRANSDUCERS CLASSIFICATION

Transducers can be classified in terms of Information and Energy according to the transduction principle involved and the form of the measurand [4].

Peter Stein has proposed in 1963 an energetical classification in the so-called “*transducer space*” [5] in which the energy domains are classified with the memory aiding acronym COMETMAN: **C**hemical (or molecular), **O**ptical (or radiation), **M**echanical (including gravitation and mass), **E**lectrical, **T**hermal, **M**agnetic (including electrical and atomic forms), **A**coustic (often integrated in the mechanical group) and **N**uclear energy forms (which do not strictly belong to the classical transducers).

For practical reasons (easier representation), in 1969 Lion [6] has maintained only the first six domains, and adopted the term “signal domain”, better expressing such conversions than “energy domain”. Information contained in each of the six domains can be converted to any other domain.

An interesting three-dimensional representation of the *sensor / transducers cube* has been proposed by Middelhoek & Noorlag (Delft University of Technology) in 1981 and then developed by Usher and Keating (Cybernetics Department, Reading University, UK) in 1996 [7].

Four categories of transducers are shown in this 3D representation (Fig. 2):

- *self-generators* input transducers – the most important are five (having electrical output), shown as rhombuses;
- *actuators* – the most important (having electrical input) are shown as squares;
- *six modifiers* (in which electronic signal is converted, processed and modified) are represented as small circles;
- *modulators* – represented by points in 3D space, the Z-component being the modulating (signal) input. There are evidently 216 modulators in all; the most important are those for which both input and output energies are electrical (shown by dots on the central vertical line).

Self-generating transducers therefore lie in the X-Y plane. With the six forms of energy represented on the axes there are 36 combinations, of which six are

modifiers (having the same form of energy at both input and output). They are also known as “active” transducers (e.g. piezoelectric ones), while the *modulating* ones are called “passive”, in which an energy flow supplied by an energy source is modulated by the measurand, e.g. carrier frequency amplifier conditioning a strain gauged force transducer (SGFT).

Force is a widespread mechanical measurand, and its applying modifies the electric, magnetic, acoustic and / or optical properties of specific materials [8]. The key component within the measurement system is the transducer, which can use various measurement principles or methods.

Specific examples of *energetical transformation* are given in [9] and their names are written on the connection arrows in Figure 3. Our focus is electro-mechanical and it is “localized” in the lower right corner. In this reversible process, a bidirectional force transducer can be seen as a sensor from the mechanical input to the electrical output or, alternately, as an actuator (referring to the opposite direction).

The “measuremen” (and women) prefer to classify transducers according to some variable parameters (resistance, inductance, capacitance), and then to add transducers generating voltage, charge or current, and other sensing devices not included in the previous categories.

The classification according to conversion principle is often used since the transducer performance is mainly determined by the physics of the underlying principle of operation. Many authors have tried to build up comprehensive and consistent classifications during the last quarter of century, among them White [10], Middelhoek [11], Fraden [12] and Regtien [13].

We propose a most general systematization of the electrical methods for measuring mechanical quantities, introducing 12 classes [2]: resistive, inductive, capacitive, piezoelectric, electromagnetic, electrodynamic, magneto-elastic, galvanomagnetic (Hall effect), vibrating wire, resonant, acoustic, and gyroscopic. This classification includes solid state, MEMS, NEMS as well as smart transducers.

III. INFORMATION PROCESSING IN FORCE MEASUREMENT

An information transducer can be viewed as an unidirectional chain consisting of three parts (Fig. 4,a): an input part (identification), a processing part (modification) and an output part (presentation) [14].

Transducers can be viewed as energy and information converters at the same time. The incoming energy contains the desired signal (the so-called *latent information parameter* [13]) and is converted to a different form of energy. This process contains a series (or sequence) of changes having in view to achieve an end result (or output).

The following conversion steps during the energetical / informational processes may be identified as from [15] and connected with Figure 1,c:

- i. The first *information transducer* is the “primary sensing element” [16].
- ii. *Type C (conversion)* in which only a loading variation does mechanical work, changing the stored potential energy and the strain pattern in the stretched-compressed elastic element (EE).
- iii. The outer region of the EE has bonded strain gauges (SGs) whose resistances depend on strain, i.e. piezo-resistive effect (*Type P – property of material*).
- iv. The next step of information transduction is a *Type M (modulation) process*, which occurs within the Wheatstone bridge.

The Wheatstone bridge is a single device that combines the two transduction processes, symbolized by the merged symbol, *PM*:

- *mechanical-to-electrical conversion*, i.e. relative variation of length (or specific deformation) to relative variation of resistance (its intrinsic resistivity);
- *signal conditioning* by the Wheatstone bridge.

The entire process could be synthetically defined as an information *Type CPM (conversion by property modulation)*, in this case *strain sensing*, which is elasto-electric.

Force transducers are frequently used as part of a measurement or control system, for example in rolling mills. Figure 4,b shows the *signal / energy data flow* in such a system [17]. In addition to the acquisition of information carried out by a transducer, a measurement requires the processing of that information and the presentation of the result in order to make it perceptible to human senses.

Transducer information must have two attributes to be useful [15]:

- describes a measurable attribute of the physical world external to the IT system;
- is distinguishable from noise (random signals).

Thus we can define transducer information as the useful signal (describing an attribute of a measurand) that is distinguishable from a noise background.

Tom Imerito (Science & Technology Communications, Pittsburgh) concludes about measurement terminology [18]: A *sensor detects* (as an input transducer) a non-electrical force, a *transducer converts* it into electrical signal, and an *actuator performs* a mechanical action.

In Mechatronics and Robotics the *sensor* detects the environment, while the *transducer* delivers the control signals to the main operation unit. Other interesting details on sensor technologies and digital signal processing (DSP) for smart sensors, as well as pertinent interpretations are given in [19].

An original application combining energy conversion and information transducer is described in the next chapter, namely a multicomponent strain gauged balance.

IV. MULTICOMPONENT STRAIN GAUGED BALANCE FOR WIND TUNNEL

Most of the modern force transducers use load cells which convert an applied force into the deformation (hence strain) of an elastic element. Evolving from one-component load cells for force and weight measurement, an original 6-component balance for aircraft models tested in a supersonic wind tunnel [20] is shown in Figure 5. The axial force is measured by four short lateral arms close to the middle of the balance inside. The other five components are measured in two symmetrical sections, each consisting of a casing with three beams. This complex structure was designed by means of finite element analysis.

In view of two conflicting energetical requirements, the choice went to the Hottinger's Y series foil strain gauges with standard resistances as follows:

- 120 Ω – to satisfy the space restrictions;
- 350 Ω – in order to reduce energy consumption and heat dissipation of the six Wheatstone bridges with four or eight “active” strain gauges.

This integral solution offers the best relation between capacity and volume, since the interplay sensing between forces and/or moments is accurately specified by calibration, using specific computation programs. It is a suggestive example which illustrates the IT process complexity while transducing the multicomponent aerodynamic loading into well-defined electronic output signals.

V. CONCLUSIONS

As shown in the preceding chapters, energetical and informational aspects are tightly interlaced; they are for the first time analyzed and interpreted in this manner, in the context of transducers used for electrically measuring mechanical quantities.

All measurable physical quantities may be characterized by their content of information, expressed in terms of binary units (bits), which depends on the accuracy level associated to the measured value. The higher is this accuracy, the larger is its information content. The measuring or sensing process makes this information available; it is not created by the measurement process. The transducer (sensor) should deliver the output quantity with an information content close to the input one's; it is obvious that the transduction process itself is accompanied by a certain loss of information, due to the errors added to the transferred signal. A good transducer will cause a minimal loss of information, since its intrinsic errors are low.

The decomposition of a sensing process into its sequence of elemental transduction processes (ETPs) is an illustration of “hierarchies of processes, linked together to provide a communication channel” [15].

Concluding, an information transduction exists, meaning the mapping or *transformation of information*

from one form to another; and also, at the same time, a *conversion of the form of energy* that carries this information. signals.

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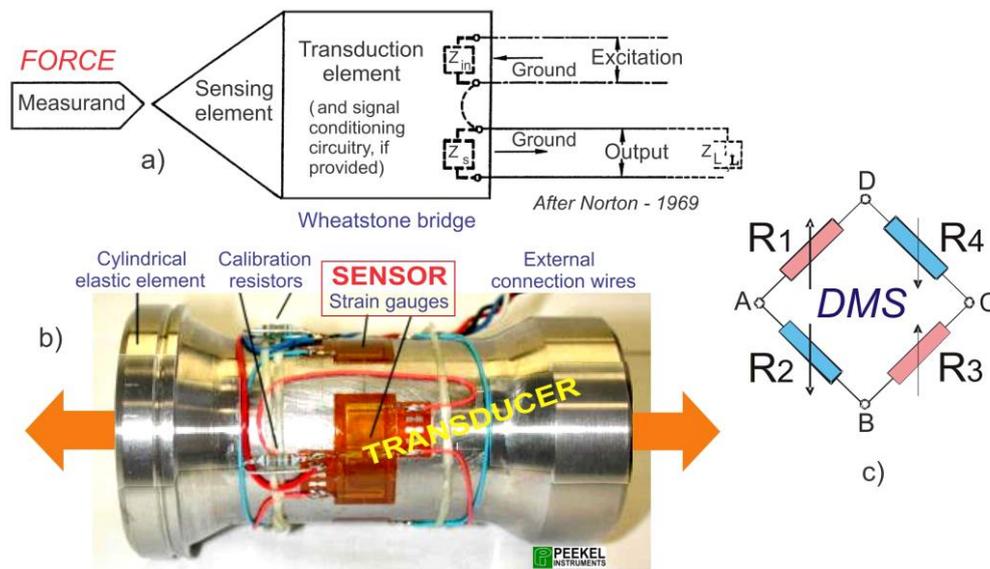


Fig. 1 – The different significances of sensor and transducer: a) block diagram as a “standardized” representation [3]; b) industrial achievement (by Peekel) of a strain gauged force transducer (SGFT); c) Wheatstone bridge connection for bonded strain gauges

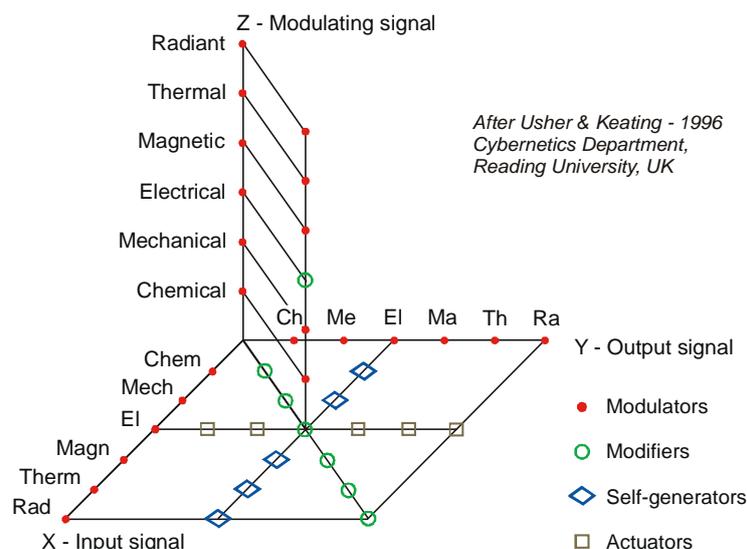


Fig. 2 – A modified 3D representation of the transducers’ “cube”, with its “electrical heart” in the center

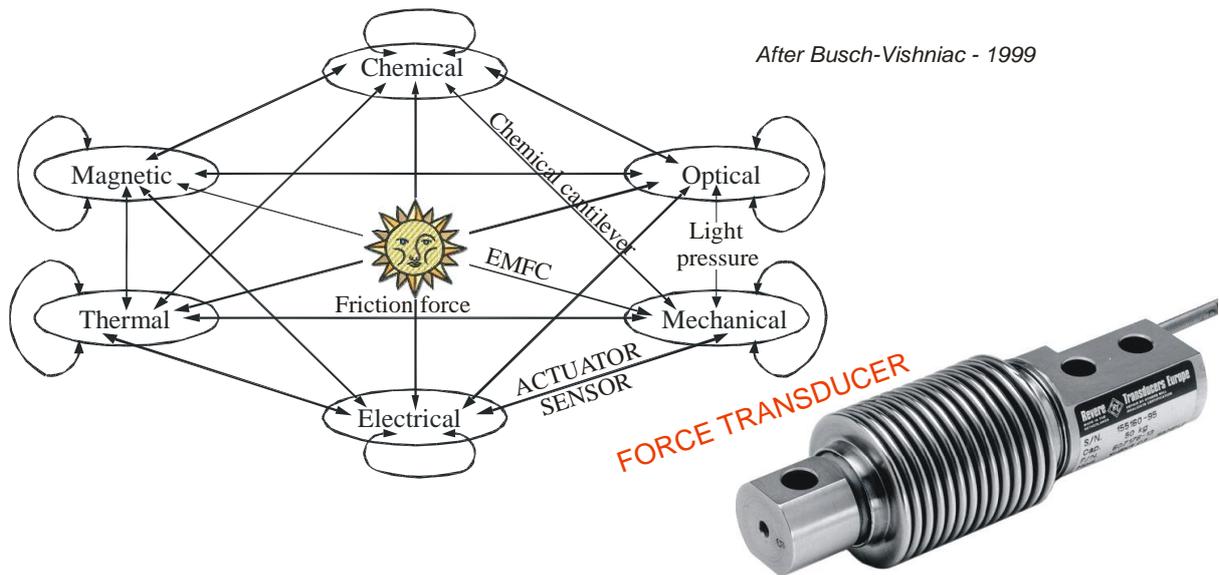
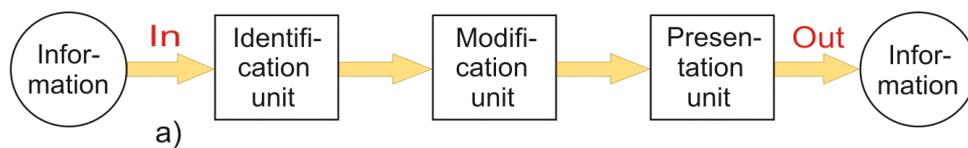
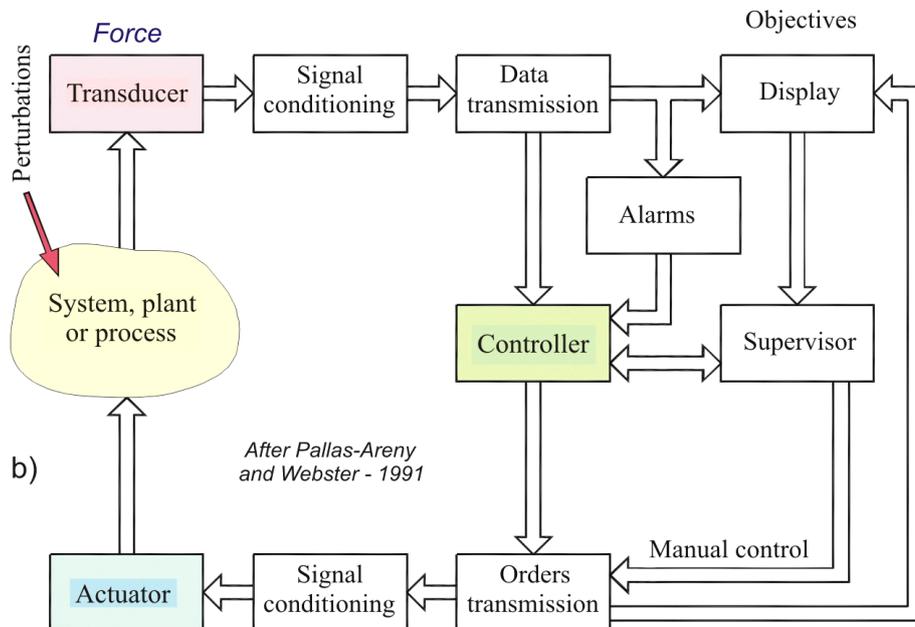


Fig. 3 – A suggestive positioning of the six energy domains in order to represent their complex interactions and transformations between these basic energies [8]



After van Putten - 1988



After Pallas-Areny and Webster - 1991

Fig. 4 – Stages of information data flow (a) and functional block diagram of a measurement and control system joining sensing at the top and actuating at the bottom of this representation (b)

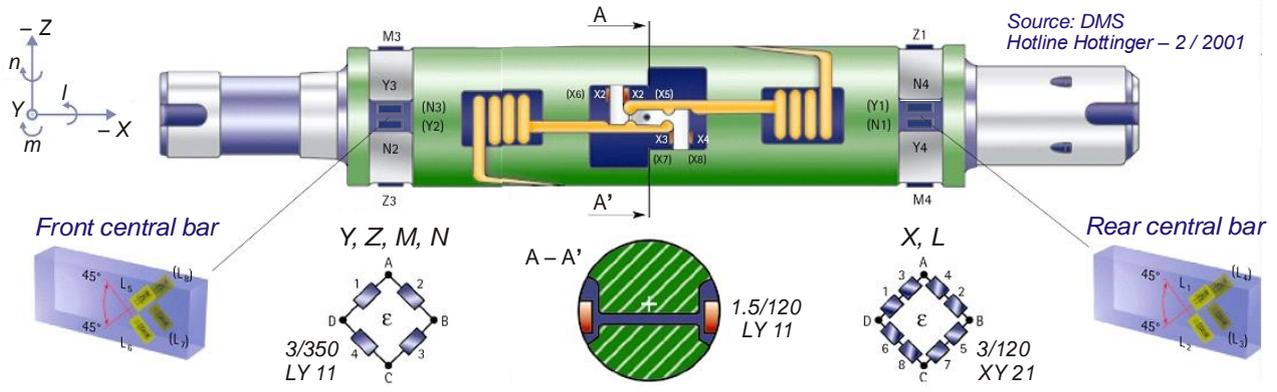


Fig. 5 – Original six-component strain gauged balance for aircraft models tested in wind tunnel