Bending Stress Measurement System and Procedure for Experimental Training of Undergraduates on Electronics and Measurement Techniques

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Abstract: - An accurate training on measurement techniques and measurement system design can be obtained by carrying out real experiments with real electronic components and circuits. The measurement system presented in this paper performs the computer aided study of the bending stress sensor. This experimental system is very useful for engineering undergraduates because they can test the theoretical knowledge about measurement techniques, sensors and transducers, signal conditioning circuits, data acquisition boards, signal processing methods and computers (hardware and software). The bending stress sensor consists of four strain gauges connected in a full-bridge circuit, and it transforms the load or force into measurable voltage change. An instrumentation amplifier and a noise suppression circuit and amplifier are designed for conditioning the output voltage of the bending stress sensor. The computer aided study of this sensor imposes a data acquisition board with a microcontroller, adequate software and a friendly user interface. The procedure for strain gauge sensor study supposes the following four stages: assignation of the measurement points, plotting the transfer characteristic of the force transducer, computing some parameters of the force transducer (zero error, differential sensitivity, relative sensitivity), weighing some objects using the strain gauge sensors. The architecture and design considerations for signal conditioning module and data acquisition board are also presented in this paper.

Key-Words: - Undergraduates, experimental training, measurement system, bending stress sensor, signal conditioning circuit, data acquisition board, computer, user interface, procedure.

1 Introduction

In the last years the authors have devoted great attention to the different aspects of the educational activity, with particular emphasis to theoretical and experimental training of the undergraduates on measurement methods, measurement systems (architecture and working mode), real instruments (features and working principle), virtual instruments, useful tools (advanced software and hardware), distance learning [1,2,3]. Therefore a number of tools have been realized in order to gradually propose to the students meaningful aspects of advanced technologies. An overview of selected tools is presented in [1], in particular a tool that takes into account the peculiarities of the unknown signal and also the effect of the noise signal superimposed to the signal to be measured.

Moreover, through the connection to a measurement system working in the lab, the remote user can have the sensation of "distant participation" [4]. This activity cannot replace a hands-on contact to the real measurement equipment; however such training can be a proper solution to the problem of preparing students to make reliable measurements close to real life [5].

Engineering undergraduates can test their theoretical knowledge about electronic circuits, sensors, measurement methods, computer (hardware and software) using the experimental systems, methods and procedures presented in [6,7,8,9].

Great attention has been devoted in the last years by the authors [4,5,10-16] to the theoretical and experimental training of the undergraduates on:

- measurement methods,
- real instruments (features and working principle),
- virtual instruments and related environment,
- useful tools (advanced software and hardware),
- distance learning.

This paper presents an experimental system for bending stress sensor studying; it is very useful in engineering education because the students apply the knowledge about sensors and transducers, signal conditioning circuits, signal processing, microcontrollers and computers, for understand how this experimental system works.

The strain gauge is a device for measuring the changes in distances between points in solid bodies that occur when the body is deformed [17,18,19]. Strain gauges are used either to obtain information from which stresses in bodies can be computed or to act as elements on devices for measuring such quantities as forces, pressure, and acceleration. The favorable factors of strain gauges are the small size and very low mass, excellent linearity over wide range of strains, low and predictable thermal effects, high stability with time, relatively low in cost, and resistance change is the circuit output. Thermal degradation, relatively low output signals, careful installation procedures and moisture effects are the main limiting factors of strain gauges. The bending stress sensor studied in this paper consists of four strain gauges connected in a full-bridge circuit, and it converts the load or force in a voltage change.

A similar experimental system is presented in [6,7] and it performs the rotary incremental encoder study: methods for resolution improvement, displacement and speed measurement methods, sense discrimination method. That system consists of one rotary incremental encoder, an IBM-PC compatible computer, an intelligent interface, a mechanical subsystem and a driving module; it illustrates how the same sensor can measure different physical variables. A soft method for resolution improvement and sense discrimination is also presented and verified in [7]. The accuracy of rotary incremental encoders is studied in [20].

2 Measurement System Architecture and Operation

The measurement system presented in this paper consists of bending stress sensor, signal conditioning module, data acquisition board, TTL/RS-232 converter, power supply and an IBM-PC compatible computer (Fig.1).

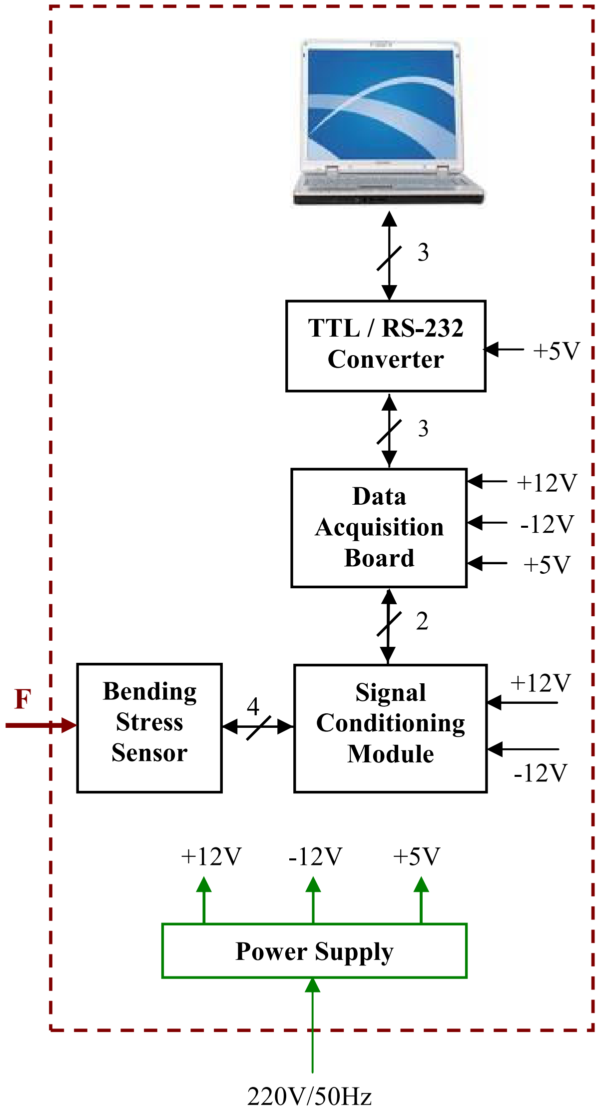


Fig. 1. Hardware architecture of the bending stress measurement system.

The measured stress is the force F which is transformed into differential voltage using a bending stress sensor based on strain gauges. The signal conditioning module supplies the sensor and also prepares its output differential voltage according to the requirements of the data acquisition board. This interface enables the computerized study of the bending stress sensor. A friendly user interface has been designed in order to follow the stages and steps of the sensor studying procedure.

The picture of the bending stress measurement system is shown in Fig.2.

Fig. 2. A picture of the bending stress measurement system.

This section presents the hardware configuration and some design considerations about the main electronic blocks shown in Fig.1.

2.1 Bending Stress Sensor

A load cell translates loads or forces into measurable electrical output. Strain gauges are placed in the elastic element to sense the strain induced by the load applied on the load cell.

For strain measurement, a Wheatstone bridge is formed to convert the resistance change to a voltage change. Greater sensitivity and resolution are possible when more than one gauge is used. A basic full-bridge circuit typically used in bending stress sensors is illustrated in Fig.3; four identical gauges (SG_1, SG_2, SG_3, and SG_4) are connected one to each of the Wheatstone bridge sides. The output differential voltage V_{IN} depends on the resistances of the strain gauges (R_{SG1}, R_{SG2}, R_{SG3}, and R_{SG4}) and bridge excitation (continuous voltage V_S):

$$V_{IN} = V_S\left(\frac{R_{SG1}}{R_{SG1}+R_{SG2}} - \frac{R_{SG4}}{R_{SG3}+R_{SG4}}\right). \quad (1)$$

Because the strain-initiated resistance change (ΔR_{SGi}) is extremely small for each gauge [19,21], the output differential voltage of the full-bridge circuit with identical gauges ($R_{SGi}=R_{SG}$, i=1,2,3,4) is given by

$$V_{IN} = \frac{V_S}{4}\cdot\left(\frac{\Delta R_{SG1}}{R_{SG}} - \frac{\Delta R_{SG2}}{R_{SG}} + \frac{\Delta R_{SG3}}{R_{SG}} - \frac{\Delta R_{SG4}}{R_{SG}}\right). \quad (2)$$

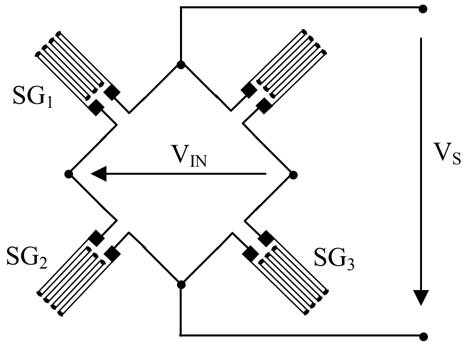


Fig. 3. Full-bridge circuit typically used in bending stress sensor.

The gauge factor K_{GF}, defined in [18,19] allows us to point out the input-output function of the bending stress sensor:

$$V_{IN} = K_{GF}\cdot\frac{V_S}{4}\cdot(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4), \quad (3)$$

where ε_i is the strain applied to the gauge SG_i.

If a positive (tensile) strain is applied to gauges 1 and 3, and the same but negative (compressive) strain to gauges 2 and 4, the output voltage will be four times larger:

$$V_{IN} = GF\cdot V_S\cdot\varepsilon. \quad (4)$$

Bending stress measurement with such 4-gauge system is illustrated in Fig.4; the strain gauges SG_1 and SG_3 are bonded on the top surface, and SG_2 and SG_4 on the bottom surface of the elastic element.

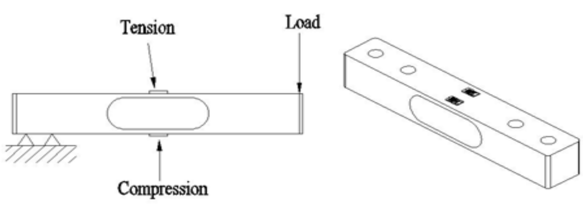


Fig. 4. Bending stress measurement.

Four resistors (for zero compensation, bridge balancing, output adjusting, and thermal sensitivity reduction, respectively) can be connected in the basic full-bridge circuit from Fig.3 to improve the strain gauge sensor performances [18,21].

2.2 Signal Conditioning Module
The hardware configuration of the signal conditioning module is illustrated in Fig.5; IA is an instrumentation amplifier (INA114), and NSCA is a noise suppression circuit and amplifier. One voltage reference and three regulators prepare the reference voltage for INA114, the excitation of the bending stress sensor ($V_S = +10V$) and the supply voltages of the instrumentation amplifier ($V_{IA}^{+} = +9V$, $V_{IA}^{-} = -9V$).

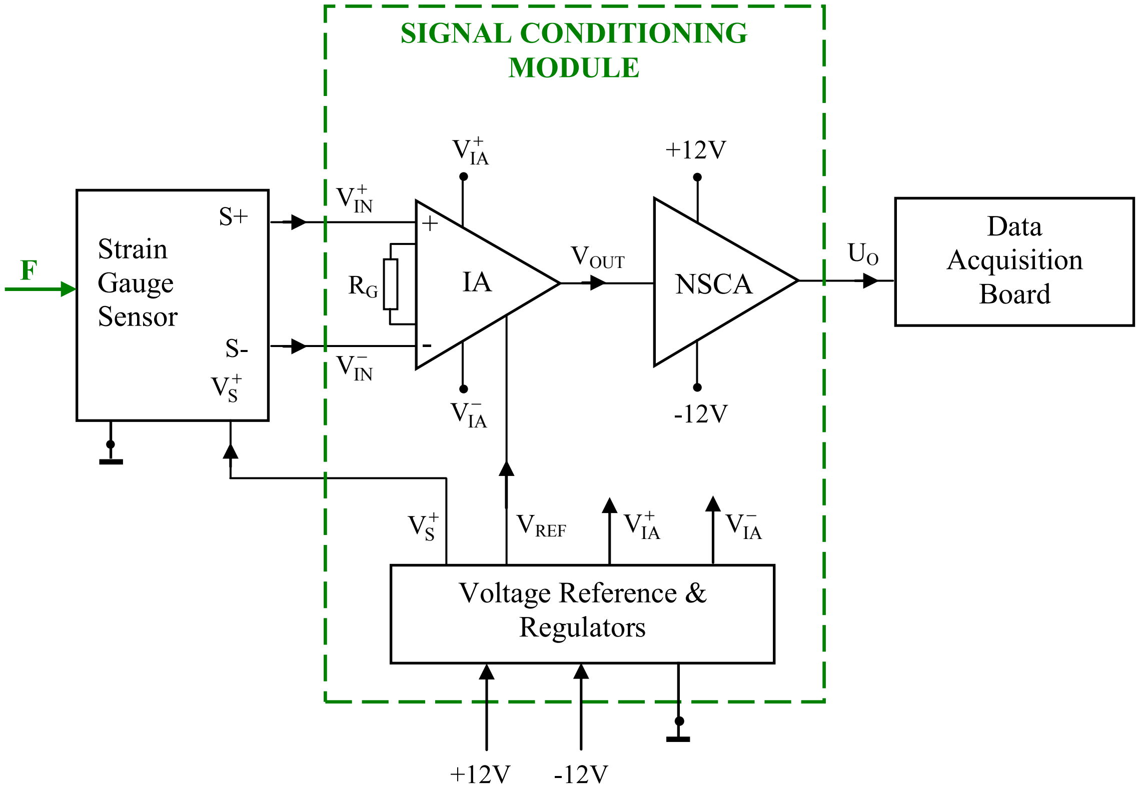


Fig. 5. Signal conditioning module.

INA114 is ideal for a wide range of applications, including bridge amplifier; its gain is set by connecting a single external resistor (R_G=100Ω in Fig.5), and the level of the output voltage (V_{OUT}) is adjusted using the reference voltage V_{REF}, as we can see from the following expression:

$$V_{OUT} = V_{IN}\left(1 + \frac{50k\Omega}{R_G}\right) - V_{REF} . \qquad (5)$$

2.3 Data Acquisition Board
The picture of the data acquisition board (in detail presented in [8,22]) is shown in Fig.6, and the block diagram is presented in Fig.7. This interface is configured around a 16-bit microcontroller from the 80C552 family – Philips Semiconductors [23,24,25]. The data acquisition board is provided with 8 analog inputs (P5.0...P5.7), 16 digital inputs/outputs (P1.0...P1.7, P4.0...P4.7) and 2 width-modulated digital outputs (PWM0, PWM1). The bi-directional bus driver assures the access to the internal data bus AD0-AD7.

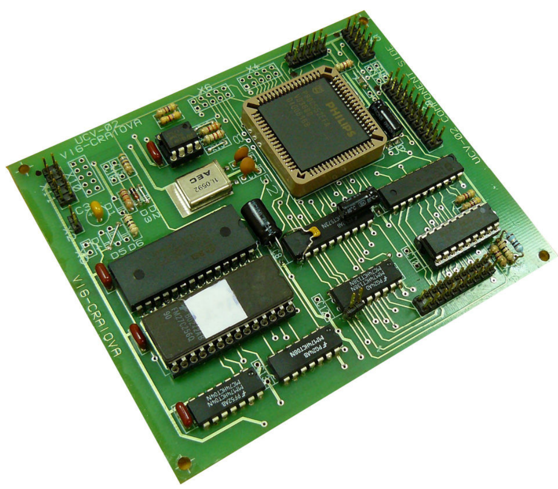


Fig. 6. The picture of the data acquisition board.

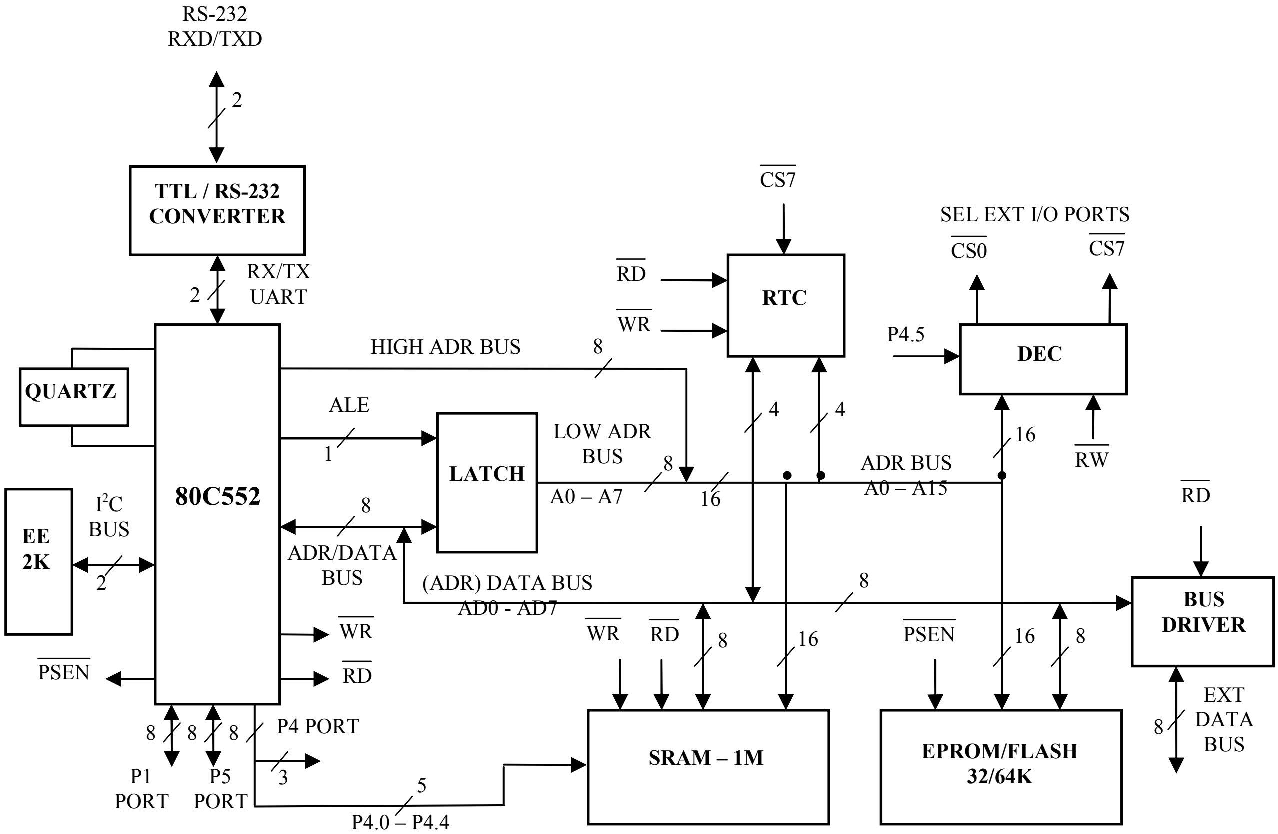


Fig. 7. Data Acquisition Board

The address demultiplexer (DEC) forms selections for the ports that will be connected to the internal bus and a memory register (LATCH) is used for A0...A7 bits of the multiplexed address/data bus. In Fig.5, RTC is the real-time clock, and TXD, RXD are the communication lines between the data acquisition board and TTL/RS-232 converter (shown in Fig.1). The hardware resources of this interface enable engendering of some digital or analog commands and also the acquisition of many digital or analog signals for computing some variables or parameters [8].

The program modules, at the data acquisition board level, are written in the assembly language and C for 80C552 microcontroller. Many possibilities exist for using this flexible and versatile data acquisition board in various industrial applications and laboratory platforms [6,8,22].

The students can learn to use microcontrollers even if 80C552 is not very fast (because it is older generation). Other data acquisition board may be then easy configured around a new microcontroller, more efficient in applications.

The TTL/RS-232 converter transforms the output voltage of the data acquisition board into other voltage according to the requirements of the IBM-PC compatible computer. The computer performs the signal processing and a friendly user interface enables the bending sensor study in accordance with the procedure that will presented in the next section.

3 Procedure for Bending Stress Sensor Study and Experiments

The procedure for bending stress sensor study supposes the following four stages [9,26]:

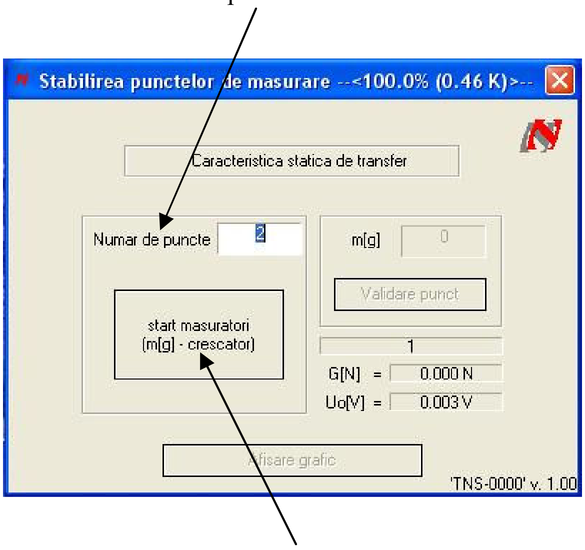
- assignation of the measurement points;
- plotting the transfer characteristic of the force transducer;
- computing some parameters of the force transducer;
- weighing some objects using the bending stress sensor.

3.1 Assignation of the Measurement Points

Each measurement point has two coordinates in the plane (G,U_O); U_O[V] is the output voltage of the signal conditioning module, and G[N] is the gravitation force of the object put on the sensor table. The user must choose the number of the measurement points, each one defined through its coordinates in the plane (G,U_O). Many test weights must be used for the assignation of the measurement points

The steps of this stage of the sensor study procedure are presented in this section. Fig.8 illustrates the dialog window that appears when the student accesses the main program.

Number of measurement points



Start measurements button

Fig. 8. The dialog window that appears when the student accesses the main program.

a) The student must specify the number of the measurement points (minimum 2 and maximum 10); this number is 2 in Fig.8. If the introduced number is not between 2 and 10, an error message is displayed (Fig.9).
b) The user presses then the "Start measurements" button (Fig.8).
c) Without any object on the sensor table, the displayed weight is m[g]=0 and it is the real weight of the tested object. The student must validate this first measurement point by pressing the "Point validation" button. (Fig.10, where 6 is the number of measurement points). The coordinates G[N] and U_O[V] of this point are then displayed in the appropriate fields.
d) The undergraduate must put the first test weight on the sensor table and then he must introduce its real weight (m[g]) in the appropriate field.

Error message:
The number of points must be between 2 and 10

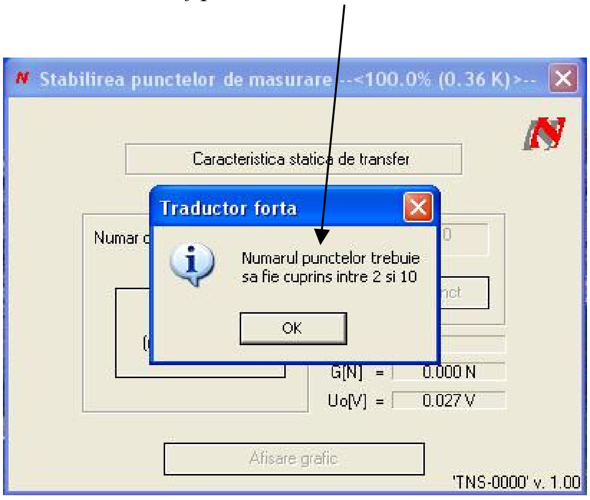
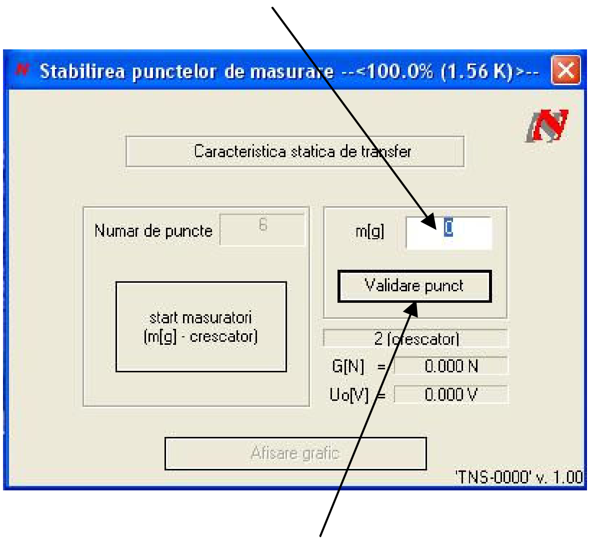


Fig. 9. The error message.

Weight of the tested object



Point validation button

Fig. 10. Validation of the first measurement point

e) The second measurement point is validated using the same "Point validation" button. The coordinates G[N] and U_O[V] of this point are then displayed in the appropriate fields.
f) Continue the point assignation until the last measurement point is validated. In Fig.11 is shown the assignation of the third measurement point.
g) Press the "Graphic displaying" button (Fig.11) for advancing to the next stage of the procedure: plotting the transfer characteristic of the force transducer.

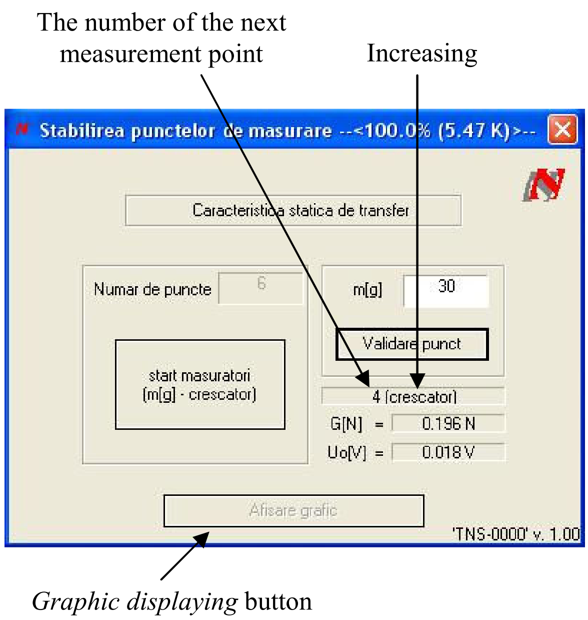


Fig. 11. The assignation of the third measurement point.

The number of the next measurement point is also displayed; this number is 4 in Fig.11. The introduced weight for the current point must be always greater than the weight for the previous point (explained as "increasing" in Fig.11).

3.2 Plotting the Transfer Characteristic of the Force Transducer

The dialog window for plotting the transfer characteristic of the force transducer is illustrated in Fig.12. Three fields can be seen in this figure:

- Transfer characteristic,
- Processing,
- Results.

The assigned measurement points are all represented in Fig.12 and denoted with 1,2,3,.. Their coordinates can be also seen in the same figure.

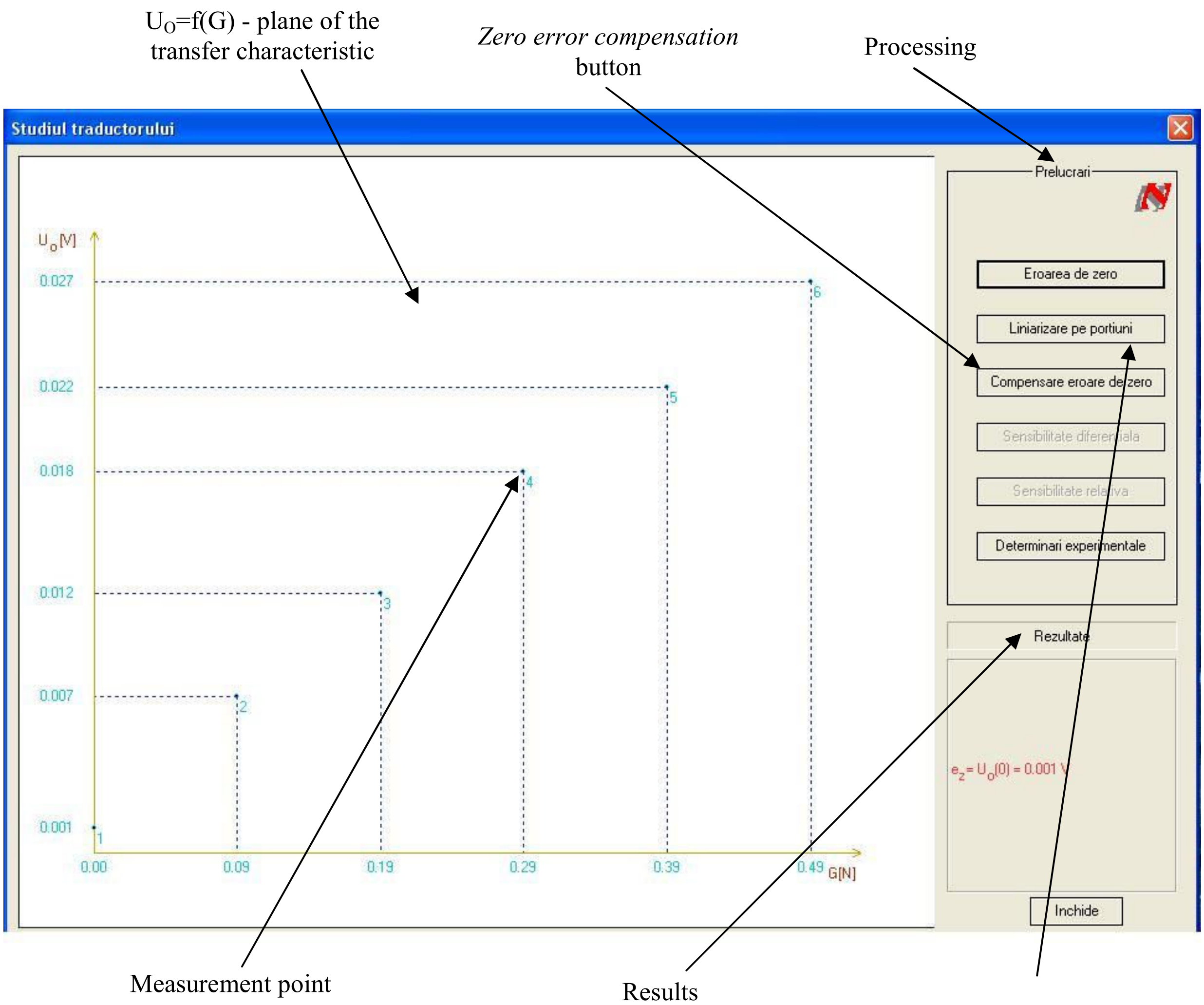


Fig. 12. The dialog window for plotting the transfer characteristic.

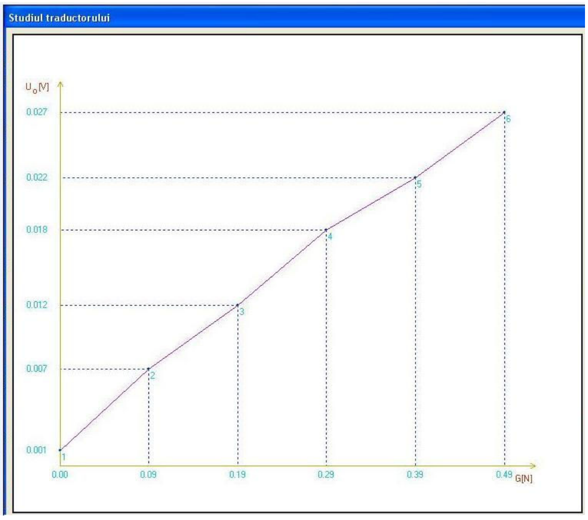


Fig. 13. Linearized transfer characteristic with zero error.

The section describes the two steps of this procedure stage.

a) The linearized transfer characteristic $U_O=f(G)$ is drawn (Fig.13) when the "Linearization" button (fig.12) is pressed.
b) The zero error of the linearized transfer characteristic becomes zero (Fig.14) if the student presses the "Zero error compensation" button (Fig.12).

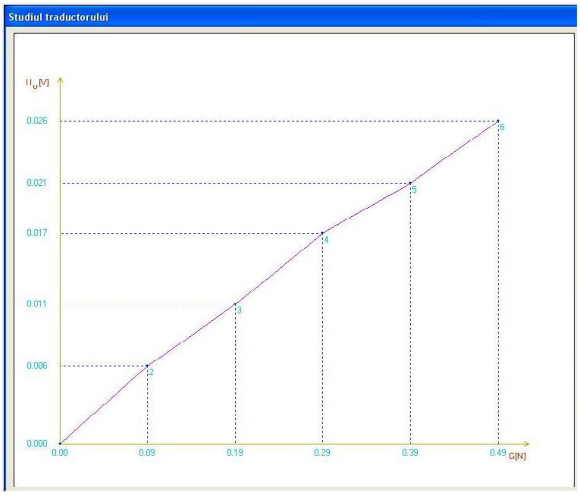


Fig.14. Linearized transfer characteristic with compensated zero error.

3.3 Computing Some Parameters of the Force Transducer

This third stage of the procedure for bending stress sensor study supposes three steps.

1) Compute and display the zero error by pressing the "Zero error" button shown in Fig.15; the computed value is displayed in the field "Results" (Fig.15).

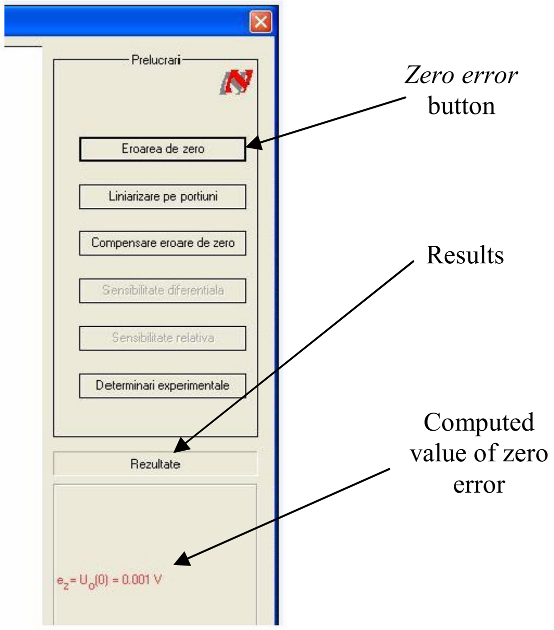


Fig.15. Dialog window for zero error.

2) Compute the differential sensitivity using the button with the same name (Fig.16). This parameter is computed for each line segment of the transfer characteristic $U_O=f(G)$ (shown in Fig.14). The differential sensitivity is given by

$$S_{i-j} = \left.\frac{DU}{DG}\right|_{i-j} = \frac{U_{O,i} - U_{O,j}}{G_i - G_j}, \tag{6}$$

for the line segment between the measurement points i and j, i>j. The minimum, maximum and ideal values of this parameter are all displayed in the field "Results" (Fig.16).

3) Compute the relative sensitivity by pressing the button with the same name (Fig.17). This parameter is also computed for each line segment of the transfer characteristic with compensated zero error. The relative sensitivity is given by

$$S_{r,i-j} = \left.\frac{DU/U}{DG/G}\right|_{i-j} = \frac{\left(U_{O,i} - U_{O,j}\right)/U_{O,i}}{\left(G_i - G_j\right)/G_i}, \tag{7}$$

for the line segment between the measurement points i and j, i>j. The minimum, maximum and ideal values of this parameter are displayed in the field "Results" (Fig.17).

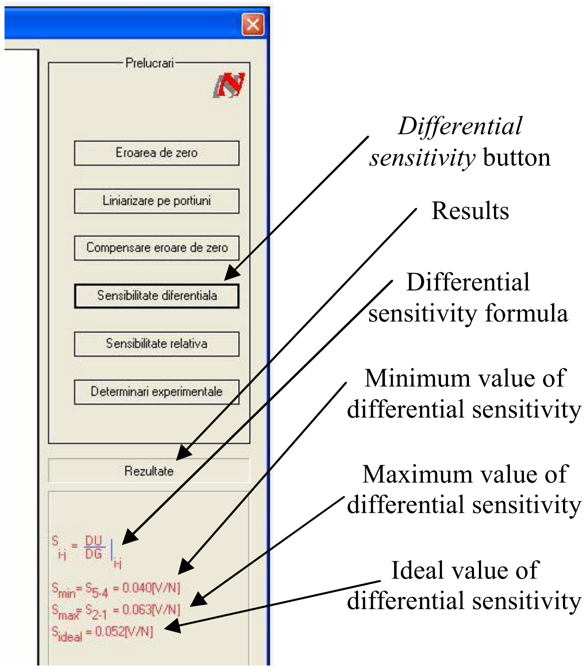


Fig. 16. Dialog window for differential sensitivity.

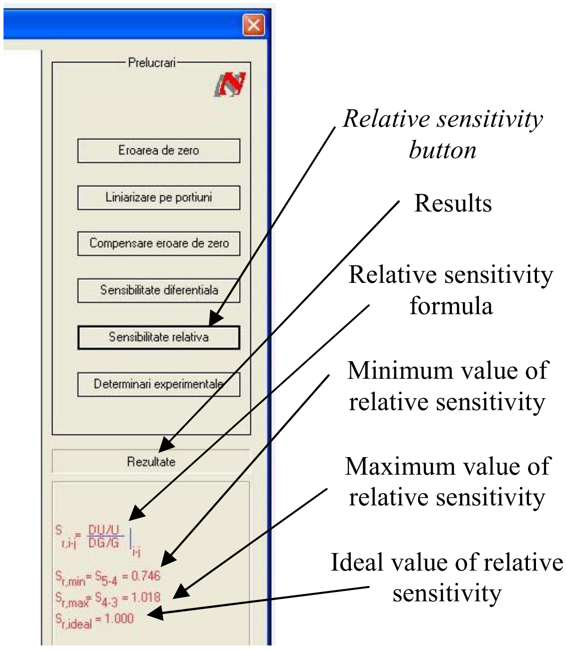


Fig. 17. Dialog window for relative sensitivity.

3.4 Weighing some objects using the bending stress sensor

This experimental system becomes an electronic weighing cell when the user presses the button "Experimental measurements" (Fig.18). There is a small table fixed on the bending stress sensor and different objects can be put on this table (Fig.2); the computer displays the mass of the weighed object (Fig.18).

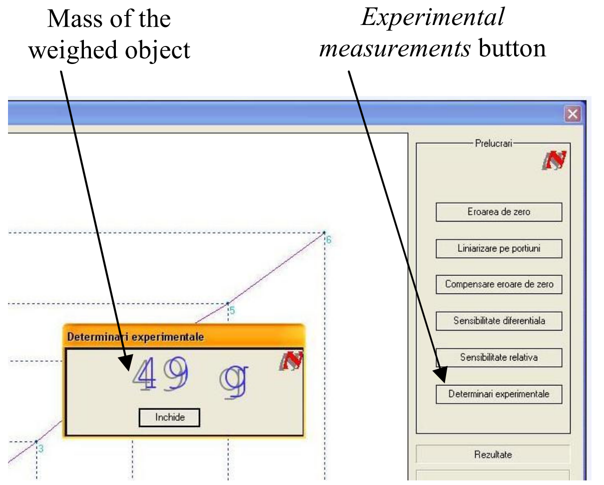


Fig. 18. Dialog window for weighing some objects.

4 Conclusion

Many authors have devoted great attention to experimental training of the engineering undergraduates on measurement techniques, signal processing and measurement system design. This experimental training supposes real experiments with real electronic components and circuits. The paper is focused on a measurement system that performs the computer aided study of the bending stress sensor. The main components of this system are the following: bending stress sensor, signal conditioning module, data acquisition board, and computer. The architecture and design consideration about each electronic module are also presented. A friendly user interface enables the assignation of the measurement points, plotting the transfer characteristic and computing some parameters of the force transducer: zero error, differential sensitivity and relative sensitivity. This experimental system becomes an electronic weighing cell for small objects. The bending stress measurement system and procedure solve practical problems because the undergraduates can apply their previous knowledge about strain gauge sensors, instrumentation amplifiers, signal conditioning circuits, microcontrollers and computers (hardware and software). Other signal conditioning circuit, data acquisition board, procedure for sensor studying or user interface may be then easy designed if the students understand how this measurement system and its electronic circuits work.

References :

[1] B. Ando', A. Ascia, S. Baglio, N. Pitrone, Experimental Training on Advanced Technologies, WSEAS Transactions on Advances in Engineering Education, Issue 8, Vol. 5, August 2008, pp. 519-528.

[2] L. Benetazzo, M. Bertocco, F. Ferraris, A. Ferrero, C. Offelli, M. Parvis, V. Piuri, A Web-Based Distributed Virtual Educational Laboratory, *IEEE Trans. on Inst. and Meas*., vol.49, No.2, p.349, 2000.

[3] F.J. Jimenez-Leube, A. Almendra, C. Gonzales, J. Sanz-Maudes, Networked Implementation od an Electrical Measurement Laboratory for First Corse Engineering Studies, *IEEE Trans. On Educational*, vol. 44, N. 4, p. 377, 2001.

[4] B. Andò, S. Baglio, N. Pitrone, Remote Connection for Extended Availability of the Educational Lab, *Proc. of IMEKO World Congress 2001*, Budapest, 2001.

[5] B. Andò, S. Baglio, N. Pitrone, New Trend in Laboratory Sessions, *Proc. of the 12th IMEKO TC4 International Symposium*, Zagreb, 2002.

[6] D. Purcaru, E. Niculescu, I. Purcaru, Experimental Measuring System with Rotary Incremental Encoder, *WSEAS Transactions on Advances in Engineering Education,* Issue 9, Vol. 4, September 2007, pp. 180-186.

[7] D.M. Purcaru, E. Niculescu, I. Purcaru, Measuring Method Adequate for Computerized Study of Rotary Incremental Encoders, *WSEAS Transactions on Electronics, Issue 6,* Vol. 3, June 2006, pp.349-355.

[8] D.M. Purcaru, E. Niculescu, I. Purcaru., S.D. Nedelcut, System Design and Implementation for Some Technological Parameters' Measurement, *International Review of Electrical Engineering,* Vol.3, No.3, May-June 2008, pp. 573-579.

[9] D. Purcaru, E. Niculescu, C. Gordan, Electronic Measurement Systems and Procedures for Optical Encoder and Force Sensor Studying, *Journal of Electrical and Electronics Engineering,* Vol. 2, No. 2, 2009, pp.181-186.

[10] B. Andò, N. Pitrone, Distance Learning in Laboratory Sessions, *Proc. of the* XVII IMEKO World Congress Metrology in the 3rd Millennium, Dubrovnik, 2003.

[11] S. Baglio, P. Barrera, N. Pitrone, N. Savalli, Developments on Three-Phase System Measurements by Advanced Technologies, *WSEAS Trans. on Advances in Engineering Education*, Issue 2, Vol. 2, April 2005, pp. 127-134.

[12] B. Andò, S. Baglio, N. Pitrone, N. Savalli, Tools for Training on Three-Phase System Measurements, *WSEAS Trans. on Advances in Engineering Education,* Issue 6, Vol. 3, June 2006, pp. 548-553.

[13] S. Graziani, G. Nobile, N. Pitrone, N. Savalli, Education Enhancement on Three-phase system Measurements, *4th WSEAS/IASME Inter. Conf. on EE'07,* Crete, Greece, 2007.

[14] B. Andò, P. Giannone, E. Pecora, N. Pitrone, Development in Web-based Laboratory Sessions, *Proc. of IMTC 2004* , Como, Italy, 2004.

[15] B. Andò, A. Ascia, N. Pitrone, Teaching Digital Voltmeter by Advanced Technologies, *4th WSEAS/IASME Inter. Conf. on EE'07,* Crete, Greece, 2007.

[16] A. Ascia, B. Andò, S. Baglio, N. Pitrone, Teaching Advanced Technologies to Undergraduates, 5*th WSEAS/IASME Inter. Conf. on EE'08,* Crete, Greece, 2008.

[17] A. Helfrick, W. Cooper, *Modern Electronic Instrumentation and Measurement Techniques,* Prentice-Hall International Editions, 1990.

[18] F. Lackner, W. Riegler, P. H. Osanna, M. N. Durakbasa, High Precision Strain Gauge Based Sensor for Monitoring Suspension Forces at CERN, *Measurement Science Review,* Volume 8, Section 3, No. 2, 2008, pp. 46-49.

[19] I. Sinclair, *Sensors and Transducers (Third Edition),* Newness, 2001.

[20] P. Koči, J. Tůma, Incremental Rotary Encoders Accuracy, *7th International Carpathian Control Conference*, Ostrava – Beskydy (Czech Republic), 2006, pp.257-260.

[21] H. K. Tönshoff, I. Inasaki (Editors), *Sensors Applications. Vol.1 - Sensors in Manufacturing* Wiley-VCH Verlag GmbH, 2001.

[22] I. Purcaru, D. Purcaru., E. Niculescu., C. Rusu, M. Căpăţînă, Central Units in Data Acquisition Systems for Engineering Education, *Scientific Bulletin of the "Politehnica" University of Timişoara, Romania, Transactions on Electronics and Communications,* Tome 53 (67), 2008, pp. 37-41.

[23] *Philips Semiconductor Data Sheet, Integrated Circuits. XA 16-bit Microcontroller Family,* 2001.

[24] V. C. Petre, The Technician's Point of View in Microcontroller Based Measurements, *WSEAS Transactions on Advances in Engineering Education, Issue 8, Volume 3,* 2006, pp. 779-782.

[25] V. Vašek, P. Dostálek, J. Dolinay, D. Janáčová, K. Kolomazník, Microcontrollers and Modern

Control Methods, *The 2nd WSEAS International Conference on COMPUTER ENGINEERING AND APPLICATIONS (CEA'08),* 2008, Acapulco, Mexico, *Proceedings,* pp. 195-198.

[26] D. Purcaru, C. Gordan, I. Purcaru, M. Niculescu, Intelligent Measurement System with Strain Gauge Sensor for Engineering Education, *The 5th WSEAS International Conference on EDUCATIONAL TECHNOLOGIES (EDUTE"09),* 2009, La Laguna, Tenerife, Canary Islands, Spain, *Proceedings* (in press).