

LABORATORIES OF INSTRUMENTATION FOR MEASUREMENT

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Credits

Contents

(texts, videos, animations, simulations, photographs, drawings and schematics)

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Revision of the English version

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ISBN

978-972-8025-67-0

Editora UP

Série Electrónica, 3

Reitoria da Universidade do Porto
Praça Gomes Teixeira,
4099-002 Porto



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Cosmotrónica

...when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.

Sir William Thomson, Lord Kelvin (1824-1907)



To the memory of António Restivo
who has not had the time to write his
Fluid Mechanics, which would have
been conceptual but containing,
surely, many practical case studies

Maria Teresa Restivo

To Ângela

Fernando Gomes de Almeida

To my parents

Maria de Fátima Chouzal

To my parents

Joaquim Gabriel Mendes

To my wife Rosário

António Mendes Lopes

July 2007

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Preface

The creation of knowledge is one of the essential components of the University mission. But it is fundamental that this knowledge should not be kept imprisoned within the institution itself. It must be transmitted so that society can benefit from it.

The University of Porto, striving to be in the front line of universities at international level, claims full allegiance in its mission to these two components. The publication of results of the work developed by members of our academic community is a source of enjoyment to U.Porto for the contribution it brings to the fulfilment of its mission.

Such publication deserves even higher prominence when it fills existing gaps in the available literature, while simultaneously opening excellent prospects for the dissemination of know-how, technologies and techniques not only to our own students but also to the public at large.

The multimedia edition of "Laboratories of Instrumentation for Measurement" fully satisfies these requisites, deserving therefore our warmest applause, appreciation and incentive.

This publication also possesses two special features that increase its added value. On one hand, it presents experimental and laboratory activities with an approach as close as possible to reality, even offering remote access to experiments, providing to the reader an excellent tool for learning laboratory techniques and methodologies. On the other hand, the adoption of electronic

format makes this work more easily available to a wider public.

The authors should be highly praised for their initiative, as well as for all the sustained effort that culminated in this publication.

This e-book fulfils every condition to be a success and hence to contribute to the prestige and the standing of U.Porto, being therefore worthy of its full acknowledgment.

José Carlos D. Marques dos Santos
RECTOR

Prologue

The publication of this e-book on "Laboratories of Instrumentation for Measurement" is most welcome given the scarcity of technical literature on this topic. It is also very timely because when dealing nowadays with large classes it is very difficult to provide to the students direct contact with well-structured hands-on experimental measurements in real labs.

This user-friendly e-book presents to higher education students in engineering, physics, bioengineering and other related areas, a first overview of some of the most common measurement techniques, offering a close approximation to the real laboratory environments which they may encounter at a later stage in their studies.

Since Mechanics is an area of natural relevance for instrumentation and measurement, it is extensively covered by the e-book material, with emphasis on specific topics such as force, displacement, strain, temperature, velocity and dimensional measurements and proximity detection. Electronics is another important area of significant diversity and complexity and an interesting link is established in this work between physical quantities and electronics, leading to a natural introduction to data acquisition and control systems. A very remarkable and unique feature of this e-book is the access to remote and virtual experiments, which is in itself a novelty not only in national terms but also at international level.

This interactive and easy to use e-book presents many examples and simulations being ideally suited for engineering students, technicians and professionals, as well as for those of other experimental scientific fields.

Joaquim Silva Gomes
PROFESSOR OF MECHANICAL ENGINEERING (FEUP)

Foreword

Instrumentation is vital for the design and implementation of measuring, monitoring and actuation systems and in data acquisition and processing, playing nowadays a fundamental role in many technological areas, as well as in those of certification, control and information.

The increasing demand of experimental accuracy in all scientific areas makes Instrumentation for Measurement a crucial component, particularly in higher education curricula with a strong technological element, being also essential at research and development level.

The objectives of the present work are:

- to stimulate hands-on activity;
- to contribute to the uniform use of concepts and definitions based on the International Vocabulary of Metrology;
- to introduce the user to the manipulation of equipment and devices for experimental tasks and to methods and procedures for measuring physical quantities of general relevance;
- to promote the critical appraisal of measurement results;
- to explore the working principles and characteristics of the sensors and transducers more commonly used in laboratory and industrial applications;
- to clarify important features of signal conditioning and transmission and data acquisition and processing;
- to introduce the concept of virtual instrumentation together with web monitoring and actuation by providing access to remote experiments.

Nowadays printed technical manuals are often complemented with the inclusion of a CD-Rom. In the present case taking into account that “what I hear, I forget; what I see, I may remember; what I experience, I know for life”, the authors decided to adopt a completely electronic format which allows a more efficient and harmonious integration of a wide range of contents: text, images, sketches, videos, animations, simulations and remote experiments. The text can be easily printed if required.

Moreover, given the contributions of neuro-linguistic programming to education, the authors find that the format adopted is adequate to the diversity of psychological and learning profiles of the large target audience of the developed materials.

Finally, the authors' intention to further explore other topics within Laboratories of Instrumentation for Measurement makes the electronic edition the ideal option for easy and economic updating.

"Laboratories of Instrumentation for Measurement" comprises 13 modules. Each one presents a clearly defined learning objective, the essential concepts and a step-by-step guide for performing the experimental activity, various complementary multimedia contents and a final synthesis. The set of open questions that closes each module is intended to provide formative assessment. The authors would like to encourage the users to undertake their own analyses and further elaboration of additional questions as an excellent way to achieve deeper learning.


The authors also hope to contribute to the dissemination of experimental activity in engineering education and to facilitate the conception, tuning and exploration of experimental systems for laboratory training. The full technical description of the equipment is provided to make the setups easily reproducible. In addition the access to remote experiments has been made available.

The authors

Acknowledgments

The authors gratefully acknowledge:

- Editora UPorto for fully supporting this edition and Dr. Sara Ponte for its coordination;
- Universidade do Porto for having created the conditions for the initial development of what became the present work and Prof. José Ferreira Gomes, former Vice-Rector, for having trusted us;
- Dr. Lígia Ribeiro for helping at various stages;
- Engenheiro Carlos Sousa and Engenheiro José Almacinha for many discussions of metrological concepts;
- The referees;
- Prof. José Couto Marques for the revision of the English version;
- Prof. Joaquim Silva Gomes for providing the Prologue;
- Prof. Marques dos Santos for the permanent incentives and valuable suggestions and for having found the time to write the Preface;

 To the sponsors

Our sincere thanks go to you all.

Chapter index

I Use of generic laboratory equipment

Objectives

This module reviews the use of generic laboratory equipment, namely multimeters, oscilloscopes, function generators, frequency meters and DC power supplies.

Experimental procedure

Synthesis and acquired knowledge

After the conclusion of this module, the user should be able to manipulate the main functions of digital multimeters, digital oscilloscopes, function generators, frequency meters and stabilized power supplies.

At the end of this module the user should be able to answer these questions:

1

When using a 2- or 4-wire resistance measuring equipment, in which case will you get a higher resistance value? What means the difference between the measured values in the two cases?

2

How do you insert a multimeter in a circuit for measuring a voltage?

3

How do you insert a multimeter in a circuit for measuring a current?

4

What is the frequency range of on equipment?

II Dimensional measurement

Objectives

This module deals with measurements of external and internal dimensions, depths, angles and screw threads, using, to that effect, well known mechanical instruments, namely: callipers, external, internal and depth micrometers, dial indicators, protractors and screw thread gauges. It is also demonstrated how a dial indicator can be used in a dimensional verification procedure.

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module, the user should be familiar with current analogue and digital mechanical instruments for dimensional measurement. The user should also be able to identify the digital communication capabilities available in some of these instruments.

At the end of this module the user should be able to answer these questions:

1 Which type of measurement (absolute or differential) is performed with an analogue calliper?

2 Which device should be used for measuring a $\phi 40h7$ shaft and checking if it is within the tolerance limit?

3 Which device should be used for measuring a $\phi 100H14$ opening and checking if it is within the tolerance limit?

4 Which device should you use to measure the angle between two faces of a piece?

III Data acquisition

Objectives

This module presents an introduction to data acquisition systems using hardware and LabVIEW graphical software from National Instruments™.

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module, the user should be able to manipulate A/D conversion systems and to develop basic applications in LabVIEW graphical software for DC and AC signal acquisition, taking in account the importance of main parameters such as input range, conversion resolution and sampling rate. At the end of this module the user should be able to answer these questions:

1

Analogue transducers usually present nonlinearity greater than 0.1%. Supposing that the conversion range is similar to the transducer output range, what should be the acquisition resolution so that the accuracy of the measurement is not influenced?

2

What relation should exist between the AC signal frequency and the acquisition sampling rate to ensure a correct digitizing of an AC signal?

3

Consider the acquisition card NI 6008 USB. Choose the right range and sampling rate to acquire the signal $y(t) = 2 + 3 \sin 100\pi t$. Justify.

IV Bridge circuits

Objectives

This module presents the use of LCR bridge circuits in the determination of inductance, capacitance and resistance. Simultaneously, some physical phenomena are analysed that induce changes to these characteristics. This fact is the base of the working principle of a large number of transducers. The Wheatstone bridge is then used in the static measurement of resistance. Finally, the transfer functions of a Wheatstone bridge circuit are experimentally obtained and analysed for large and small variations of resistance.

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module, the user should be able to identify some working principles of passive transducers, whether of resistive, inductive or capacitive type. He should distinguish the bridge circuit transfer functions for large and small changes of the integrated elements. They should also be able to determine the linearity and sensitivity of the bridge circuit and to evaluate the measurement system resolution.

At the end of this module the user should be able to answer these questions:

1 What are the advantages of using a bridge circuit to determine an impedance change?

2 How can you determine the average sensitivity of a bridge circuit?

3 How can you determine the nonlinearity (error of linearity or linearity) of a bridge circuit?

4 Does the normalized characteristic of a bridge circuit change with the values of its components?

V Mounting strain gauges

Objectives

In this module the procedure for mounting a strain gauge on an aluminium beam is described, following the sequence considered appropriate to guarantee a correct performance for strain gauge installation on metals.

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module the user should be able to explain the operating principle of an electrical resistance strain gauge, to apply the mounting technique for instrumentation of test specimens with these sensors and to carry out the final electrical test. He should also be able to identify the most important parameters in the selection of a strain gauge.

At the end of this module the user should be able to answer these questions:

1

Which type of strain gauge should be used for measuring the strain state at a point on the surface of a loaded body in which the principal directions are unknown?

2

How can you reduce the influence of temperature variation on the measurement of strain caused by mechanical stress on a steel piece?

3

How do you test the correct installation of a strain gauge?

VI Use of strain gauges

Objectives

This module discusses the use of strain gauges in the measurement of strain. Additionally some common techniques associated with resistance strain gauge instrumentation will be applied.

VI Use of strain gauges

Basic concepts

Measuring circuit

Temperature effect compensation

**3-wire method:
lead wire effects**

Other considerations

Synthesis and acquired knowledge

After the conclusion of this module, the user should be able to use electrical resistance strain gauges for the determination of strain, as well as to identify the associated signal conditioning. He should also be able to determine the sensitivity of the various elements of the strain measurement system and the measurement resolution and to apply the compensation techniques of influence quantities as well as those for increasing the system sensitivity.

At the end of this module the user should be able to answer these questions:

1

Why may the equation $\Delta V = V_0 \frac{\Delta R_e}{4R_e}$ be used on current mechanical engineering applications?

2

How may the temperature effects be compensated for in strain measurement with strain gauges?

3

What are the advantages of using a 3-wire technique?

4

Should you use a 3-wire technique in a half or a full-bridge configuration?

VII Measurement of force and strain

Objectives

This module presents the use of strain gauges for measuring strain and determining some mechanical material characteristics (Young modulus and Poisson ratio). It also explores the use of strain gauges associated with a test specimen of a convenient geometry for measuring forces (load cells).

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module the user should be able to use resistance strain gauges for determining mechanical characteristics of a material and for force measurement, applying different signal conditioning solutions. He should also be able to create and implement an electronic weighing scale.

At the end of this module the user should be able to answer these questions:

- 1 How many sensors and signal conditioning systems (measuring bridges) do you need for measuring the Poisson ratio of a material?
- 2 How many sensors and signal conditioning systems (measuring bridges) do you need for measuring the Young modulus of a material?
- 3 When using a beam for testing a load cell why should a micrometer be used to measure the beam thickness?
- 4 In which type of load cells is the elastic element submitted to a bending moment?

VIII Measurement of temperature: resistance thermometers

Objectives

This module presents one of the techniques frequently employed in temperature measurement, based on the use of resistance thermometers. The working principle of an RTD (Resistance Temperature Detector) is first described, as well as how to determine and analyze its characteristic. Then an electronic thermometer is developed using a temperature transmitter for RTD.

Basic concepts

Synthesis and acquired knowledge

After conclusion of this module, the user should have verified the working principle of a temperature sensor of the conductor resistance type, determined its characteristic and analyzed the sensor sensitivity and the resolution of the temperature measurement system used. He should also be able to use a temperature transmitter and to develop an electronic thermometer.

At the end of this module the user should be able to answer these questions:

1

In temperature measurement the RTD is not normally mounted in a bridge circuit. Why?

2

Why is the 4-wire lead configuration used for measuring the Pt_{100} resistance?

3

What precautions should be taken with the current supply to an RTD? Why?

4

What is the typical offset of a 2-wire temperature transmitter?

IX Measurement of temperature: thermocouples

Objectives

This module covers one of the techniques frequently applied in temperature measurement, based on the use of thermocouples.

The simplicity of production of a thermocouple and its operation principle are highlighted, as well as the techniques associated to its current use.

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module, the user should be able to explain the operating principle of a thermocouple and the reason why a thermocouple must be assembled with a carefully selected pair of conductor materials. He should also justify the importance of cold junction compensation and know how to perform it.

At the end of this module the user should be able to answer these questions:

1 Is a thermocouple a relative or absolute temperature transducer?

2 What solutions exist for performing cold-junction compensation?

3 Why may the use of thermocouples, in an industrial environment, require some caution on signal conditioning?

4 When selecting a thermocouple for a given application what parameters should be considered?

X Measurement of displacement

Objectives

In this module several experimental studies are performed using various analogue and digital displacement transducers to obtain some of their operation characteristics. The following transducer types will be used: potentiometric transducer, LVDT, incremental linear encoder, digital dial indicator and eddy current (inductive) transducer.

Basic concepts

Synthesis and acquired knowledge

In this module different types of analogue and/or digital displacement transducers, frequently used in lab and in industrial applications, are exploited. After its conclusion, the user should be able to interpret the type of a displacement transducer characteristic, analyse and quantify some parameters such as nonlinearity, sensitivity and hysteresis.

At the end of this module the user should be able to answer these questions:

1

The manufacturer lists as displacement transducer characteristics: nonlinearity $\leq 0.25\%$; supply 2V@5kHz. What does it mean?

2

Does the output signal of an LVDT, corresponding to a given core position, remain the same after a temporary interruption of the supply? Is an LVDT an absolute or a relative measurement transducer? Why?

3

What are the different elements of a displacement measurement system using a digital incremental encoder?

4

What are the different elements of the displacement measurement system of an LVDT transducer?

XI Detection of proximity

Objectives

In this module some experimental tests are conducted using several proximity detectors in order to determine some of their operation characteristics. The following detector types are considered: inductive, capacitive, photoelectric, fiber optic and reed switches.

Basic concepts

Synthesis and acquired knowledge

In this module different types of proximity detectors are used. On each setup, the characteristic of the different detectors is determined against a displacement transducer (working standard). The user should be able to assess their characteristics and how they depend on the target materials, the detection distances and the working hysteresis.

At the end of this module the user should be able to answer these questions:

1

Explain the relevance of the hysteresis when using a detector.

2

Consider the following sets of detectors and materials: {eddy current, capacitive and optical detectors, reed switches}, {steel, aluminium, nylon, polyamide, wood, copper, water, teflon, paper, glass, concrete, polished glass}. Establish the correspondence between the detectors and the materials for which they are active.

3

What is the role of the optical fibre in an optical detector?

4

Considering all the types of detectors used, which of them presents the largest detection range?

XII Measurement of angular velocity

Objectives

The objective of this module is to explain the working principle of electromagnetic and digital tachometers and to use them in the measurement of angular velocity.

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module, the users should be able to explain the working principle of digital tachometers and DC electromagnetic tachometers used in the measurement of angular velocity and to identify their main components. They should also be aware of the possibility of using different devices to measure frequency and, thereby, angular velocity.

At the end of this module the user should be able to answer these questions:

1 Does a DC electromagnetic tachometer identify the direction of rotation?

2 What parameters does the resolution of a DC electromagnetic tachometer depend on?

3 State the main components of a digital tachometer?

4 How can the rotation direction be identified with a digital tachometer?

5 What parameters does the resolution of a digital tachometer depend on?

XIII Web Monitoring and Control

Objectives

This module uses some of the experimental setups developed at the Laboratory of Instrumentation for Measurement (LIM) of Faculdade de Engenharia da Universidade do Porto (FEUP) to enhance the knowledge about physical quantity measurement and calibration procedures, applying currently existing technologies for web monitoring and control of experimental systems.

Basic concepts

Synthesis and acquired knowledge

After the conclusion of this module, the user should be familiar with the use of remote web monitoring and control systems. He should also be familiar with a temperature calibration procedure, a method to evaluate the straightness deviation of a line in a given direction on a surface and the technique for experimental determination of mechanical material characteristics, analysing specific parameters based on obtained results.

At the end of this module the user should be able to answer these questions:

1 What is a calibration procedure?

2 What characteristics should have a reference standard?

3 What reference standard has been used on the calibration procedure?

4 Describe the measuring chain under calibration.

5

Explain the concept of straightness deviation.

6

What is the Young modulus of a material?

7

What is the analytical relation between deflection and strain, for an elastic cantilever beam of rectangular cross section with a point load at the free end?