A NEW APPROACH TO PRACTICAL TRAINING EQUIPMENT FOR MEASUREMENT

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Abstract. Students need be well trained in performing correct measurements. This paper reports on a training program in which emphasis is put on a critical attitude with respect to the whole measurement process. A meticulous analysis of the measurement environment, the measurement devices and the signal processing are prerequisites for an unambiguous interpretation of the measurement results. These skill are trained using a complete system built up in modules that can be studied separately. Error analysis is part of the training program and is performed on a real measurement.

Keywords: measurement, training, education, measurement errors.

1 INTRODUCTION

Measurement is a vital activity of designers, engineers and scientists. It is a major responsibility of a university to create an environment where students can learn how to accomplish measurements according to standardised procedures and that are credible and profitable to any other user of the measurement results.

The act of measurement is not only a matter of proper equipment and technical skills, but requires a critical attitude as well as sufficient prior knowledge towards the process that is subject to measurement. The student should always be aware of measurement errors and should quantify them in an appropriate way. The need and importance of these additional abilities should be made explicit and be trained.

Cost reduction is often a motive to move from real measurement equipment to virtual instrumentation. Of course, such virtual instruments have their benefits, also in education. Nowadays many universities use virtual instrumentation for training purposes [1-3] and profit from their flexibility, reduced routine work and the possibility of remote operation. However, a measurement takes place in the real world, and the training process needs, at least partly, be performed in the same real world.

In this contribution we present a laboratory environment that enables students to familiarise with the total spectrum of skills that are to be learned for performing correct and effective measurements. The environment comprises both measurement equipment and virtual tools for the execution of real measurements and the proper interpretation of the results.

The training course is part of the second years undergraduate program of the Faculty of Electrical Engineering at the University of Twente. Students have acquired basic knowledge on mathematics (calculus), electronics and computer programming. In parallel to the measurement course students follow courses on the physics of transducers, modelling and simulation of (dynamic) systems and on signals and (linear) systems.

2 DEVELOPING COMPETENCIES

A student, but also the experienced researcher, will always be confronted with differences between the theoretical model that describes the system under consideration, and the reality as becomes apparent by measurements. Each measurement is an experiment, and therefore closely associated to the real world. This real world is not ideal: theory does never completely describe the physical behaviour of a real process or system. There are two reasons for the discrepancy between model and measurement: a wrong model and wrong measurements. First, the model is inappropriate: it does not comprise all relevant properties that we are interested in or it is based on wrong assumptions. Secondly, the measurement contains errors, due to for instance unforeseen loading, instrument uncertainties and erroneous operation.

All of these errors might occur simultaneously, hindering a clear analysis of the situation. An important and primary competence is the ability to be conscious of all kind of errors and to identify and quantify them. This competence can be mastered by a thorough insight in the subsequent processes that make up the measurement, and a clear methodology for fault isolation and detection. Moreover, a fair assessment of the various errors should reveal the main causes of the observed deviations from the expected behaviour, leaving other possible causes to be negligible in a specific situation. As a consequence, the student must learn about all distinct system parts and their mutual interactions. Note that the system to be considered is the combination of the measurement object and the measurement instrument.

3 A THREE-STEP APPROACH

After a series of introductory lectures on theoretical aspects of a measurement system, the student's task is to perform measurements on various physical systems. Examples of such systems are: a conveyer belt transporting objects of different shape; a pipe carrying a gas flow; a moving vehicle (scale model). We confine in this paper to the gas flow in a pipe. The aim is to measure the flow velocity of the gas through the pipe.

The measurement is based on an acoustic time-of-flight method. With a pair of ultrasonic transducers positioned face to face in the pipe, at a fixed distance L, the propagation time of an ultrasonic pulse travelling from transmitter to receiver has to be measured, from which the flow velocity can be deduced (fig.1). Obviously, the measurement result is corrupted due to a variety of causes and the final result is rather inaccurate because a number of parameters is not accurately known. So, just by performing this measurement the result must be considered with great suspicion.

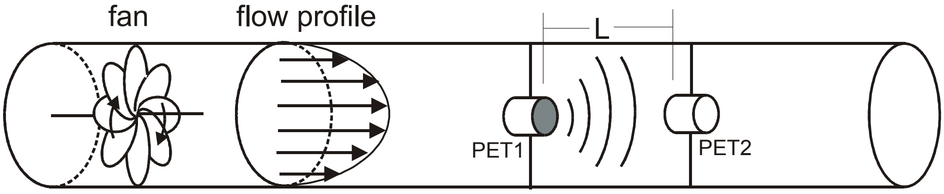

Fig. 1. The measurement of gas flow velocity using the acoustic time-of-flight method

To find the main sources of inaccuracy and to improve the overall performance of the measurement, all systems parts and every step in the measurement procedure must be considered with care. In this approach the student will investigate the system in three steps: the transducers, the signals and finally the flow system itself. This partitioning in three phases is characteristic for all measurement systems in this course. For each phase, half a day is available for the experimental work.

In the first step various characteristic properties of the transducers are studied both theoretically and by experiment. Two types of transducers are considered: a piezoelectric transducer (PET) and an electrostatic transducer (EST). The properties of both types are discussed in the theoretical part of the course. Using the laboratory set-up, these properties are evaluated experimentally. Their frequency characteristics are compared and directivity plots for various frequencies are determined. Finally, the response on a burst signal has to be registered and explained.

The second step is devoted to the signals: the propagation of sound waves through the gas (with wavelength and sound speed as important parameters) and the various processing steps. Experiments must reveal the damping of sound in air, its dependency on frequency and the decay of intensity with travelled distance. Furthermore, knowing the properties of the transducers and in particular their response to a burst, the accurate determination of the time-of-flight is not trivial anymore when the signal is corrupted by noise.

The last step is the performance of the velocity measurement itself. The various error sources in the measurement system have to be identified and quantified. Questions to be answered by the student are for instance: what is the consequence of using the threshold operation, when the signal from the receiver contains noise? how will temperature changes influence the measurement result? what do you know about the radial flow distribution in a pipe? does the presence of the acoustic sensors significantly affect the original flow velocity? Obviously, some of these questions are not easy to answer by the student without additional experiments. In this example we consider the temperature dependency of the sound velocity in the gas, which can be modelled by a simple linear equation. It will become clear that accurate determination of the flow velocity from the time-of-flight requires knowledge about the fluid temperature. A separate temperature measurement allows correction of the temperature-induced error. However, a much more elegant way is to apply a measurement strategy that is essentially temperature independent. To avoid the effect of the temperature dependent sound velocity, a two-way strategy is chosen: the TOF is measured once with sound travelling with the flow and once opposing the flow, just by switching the transducers between transmitting and receiving mode. The student's task is to explore the merits of this principle.

4 MEASUREMENT SETUP

Recurrent problems with experimental training are the limited resources and the restricted learning time of the student. The first aspect is often circumvented by the use of virtual instruments and simulations only. Needless to say that this solution does not really contributes to the development of experimental skills. The question of the limited learning time can be minimised by a well-balanced combination of soft and hard tools and easily accessible tutorial aids (lecture notes, help files).

Using virtual tools, the flexibility of the measurement system is increased. The software offers the student a possibility to modify the parameters of the test signals and to quickly store and analyse measurement data. It also offers a powerful diagnostic tool. Virtual instruments introduce specific problems, that are considered to be a part of the measurement system (quantisation errors, sampling rate, limited signal window and timing errors) and therefore need to be examined by the student as well.

The measurement set-up as shown in figure 2 meets closely the requirements. It is a combination of real and virtual instrumentation, with a PC as a central control unit.

The core of the hardware is the measurement object and a pair of acoustic sensors. A digital function generator and a digital oscilloscope are indispensable tools in a training course for measurement. The piezoelectric transducers are placed at approximately 7 cm distance apart in a 50 mm diameter pipe line with antireflective material. The transducers are switchable from transmitting to receiving mode by the PC via a DAQ-board. A controllable flow source is capable of generating flows. Both the generator and the oscilloscope are connected to the PC by a GPIB bus.

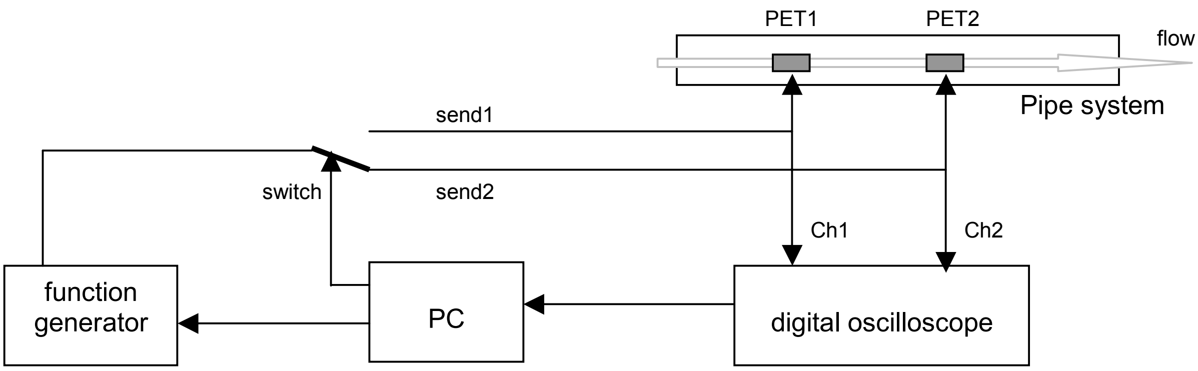

Fig. 2. Experimental setup of the flow measurement system

The core of the software is LabVIEW [1]. It is capable of controlling the oscilloscope and generator settings, reading the oscilloscope and controlling the whole measurement sequence. Once a measurement procedure has been set up, the measurement itself can be executed in a short time, and repeated an arbitrarily number of times. The latter allows also a statistical analysis of the measurement data.

In order to benefit most of the approach as outlined above, the student should be able to execute as many measurements as possible with a minimal preparation time. On the other hand, the student must obtain sufficient insight in the measurement set-up to understand the basic functions and operation. To that end, the connection of the hardware modules is part of the assignment.

To relieve the programming load most parts of the virtual measurement system have been prepared. In this phase of the teaching program students lack experience in LabVIEW for the implementation of such blocks. Moreover, most programming does not contribute to the understanding of the measurement system and is therefore prepared in advance. The virtual system is subdivided in several functional blocks, and students can arrange and connect those blocks by themselves. Fig. 3 shows an example of the virtual system. If necessary a special short instruction is included to make the students quickly familiar with this matter.

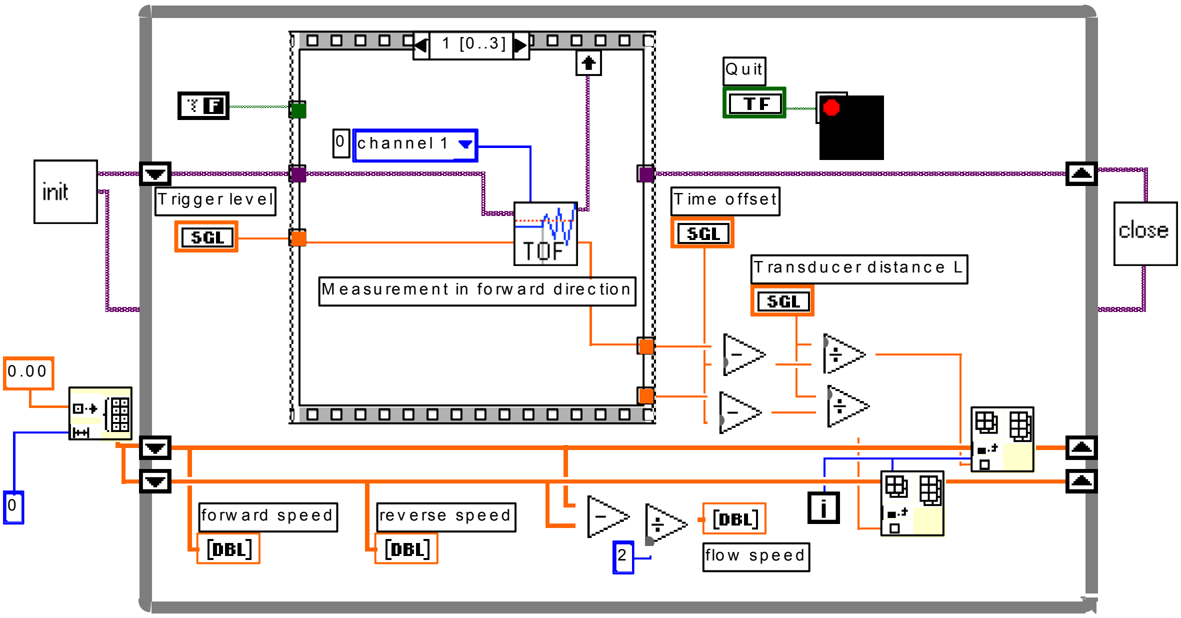

Fig. 3. Example of the virtual instrumentation for the acoustic flow measurement

Control of costs is an important aspect in the set-up of a practical training course, in particular when large groups of students must pass the whole training sequence in a restricted period of time. The construction of many duplicates of the whole measurement set-up as described would be too expensive. To allow the students work in parallel only parts of the system are duplicated. For instance, for the first step (characterisation of the transducers) a simple experimental set-up is made available consisting of a ruler with a couple of transducers that can easily be positioned and replaced. Such subsystems can be duplicated at low cost. Furthermore, some tasks can be performed completely off line, for instance the analysis of the measurement data, writing reports (in electronic format only) and the set-up of the virtual instrumentation. For these tasks, sufficient PC's are made available. Finally, all practical courses at the Department Electrical Engineering share general measurement equipment (oscilloscopes, generators, multimeters, PC's) and software packages (word processing, simulation programs, virtual tools) to further reduce the costs of the various training courses.

5 CONCLUSIONS

The three-step concept outlined in this paper has been evaluated with a small group of students and will run next year. Some of the advantages of this approach are the following. Students are forced to perform a systematic analysis and characterisation of all system parts (including errors) prior to the execution of the measurement. They are trained to acquire a critical attitude towards measurement experiments and to present measurement results in an unambiguous way. The systems have been implemented in modules, using a balanced distribution over hardware and software tools. In this way the time students need to work on line has been minimised whereas the experimental training has been maintained at an acceptable level.

The modularity of the set-up allows quick adaptation to the needs, for instance when teaching programs are changed. Possible extension are a PC-controlled flow generation (now adjustable manually by an analog voltage source) and a computer controlled heating element.

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[4] LabVIEW is a software package developed by National Instruments