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Investigating the operation of electrical machines with computerised laboratory activities*

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The paper outlines a course on electrical machines designed for pre-university education. The first part of the laboratory exercises is concerned with the principles of operation of motors and generators while the second part of the exercises highlights empirical studies of the efficiency of small DC motors, low-power transformers, etc. Some example experiments supported by a low-cost data acquisition system are described in the paper. The laboratory exercises described were introduced through workshops for pre-service and inservice teacher training programmes. The teachers involved responded positively and confirmed that they can apply the experiments in their teaching practice.

Keywords: teacher training; electrical motors; electrical generators; electrical transformers; data acquisition; efficiency of machines; data analysis; computerised laboratory

INTRODUCTION

WITHIN GENERAL EDUCATION, technology education in Slovenia is incorporated in the final years of primary education (11–15 year old pupils). Some years ago, when the curriculum for primary schools was changed, optional subjects such as Electrotechnics, Robotics and Electronics were introduced. While the interest of pupils in robotics and electronics is continuously increasing, more classical topics about electrical machines and devices are less attractive. As a result pupils do not choose Electrotechnics as a subject and even in-service teachers do not attend the seminars.

Different activities worldwide tend to make the study of science and technology more popular, such as organising summer camps, competitions in robotics, after school activities at secondary schools, etc. [1–3]. At the Faculty of Education, University of Ljubljana, work has been done to progress the skills and knowledge of trainee teachers of technology. In order to improve the competence of teachers to increase the interest of their pupils towards science and technology, we have modified some of the courses to become more contemporary and to make them more applicable in the teachers' practice.

One such course is Electrotechnics, introducing the fundamentals of electrical engineering, carried out in the second year of the trainee teachers' course programme. A teacher training course cannot be arranged in a similar way to that in an engineering school. Within the very limited time available for the course (one semester course comprising 45 hours), the students need to get enough practical experiences with the electrical machines and devices so that they can later apply it in their teaching practice. Laboratory exercises are therefore based on low-cost, small electrical devices such as bicycle dynamos, small DC motors, stepper motors and low power transformers. The exercises were developed within the ComLab pilot project running under the Leonardo da Vinci programme [4]. They are based on quantitative analyses built around a multi-purpose data acquisition (DAQ) system that is also used in the school science laboratories [5, 6].

LABORATORY EXERCISES ON ELECTRICAL MACHINES

Laboratory exercises introducing the principles of electrical machines were developed by a group of six students, all trainee teachers of technology. These students were asked to prepare the first draft versions of the experiments. One set of exercises was focused on some basic principles of the operation of motors and generators while other exercises highlighted empirical studies of the efficiency of electrical motors, generators and transformers. The students' task was to design the experiments using only low-cost devices. For the first version of the exercises the only appliances available were stop-clocks, meters and standard electrical instruments. After analysing the results of experiments, the exercises were modified and improved in order to obtain more reliable results. In most cases, the students proposed simpler versions of the experimental set-up. For example, to determine the efficiency of a DC motor, it was proposed that

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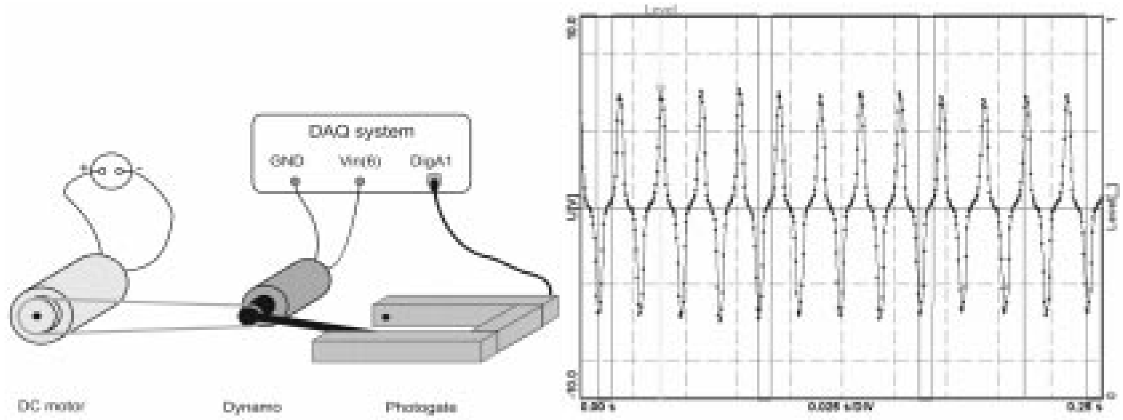

Fig. 1. Apparatus for the laboratory exercise with a bicycle dynamo (left) and typical experimental signals captured from a computer screen (right), where U is the induced voltage and Level is the signal from the photo-gate.

the motor should lift a known mass vertically to get the mechanical power rather than measuring torque and rotational speed. However, it was obvious that using only a meter and stop-clock, it was not possible to ensure that the speed was constant, and there was an inherent lack of accuracy of the instruments. To obtain more consistent results, a multi-purpose DAQ system for the PC was incorporated [7] as well as two sensors: a sonic distance sensor and a photogate [8]. The PC was used to sample data as well as to analyse the data using standard spreadsheet software. In most cases, the result of the analyses was to measure the efficiency of the device under different conditions.

After the exercises had been refined, they were introduced into a regular laboratory course in the second year of pre-service technology teachers at the Faculty of Education, University of Ljubljana, initially in the school year 2004/2005. Altogether there were 11 laboratory exercises. Thirty-five students were divided into two smaller groups, one group of 15 and one group of 20 students.

To illustrate the laboratory course, some typical exercises are outlined below, while more technical assessment details, such as experimental conditions, photographs of the apparatus, measurement examples, video clips and analyses of experimental data in Excel are available on the Web [9].

OPERATION OF BICYCLE DYNAMO

The shafts of a bicycle dynamo and a DC motor are coupled through an elastic strap. The motor is connected to a DC generator to rotate the shaft of dynamo. A bar is fixed at the shaft of the dynamo to chop the light beam of a photogate. The signal from the photo-gate as well as the induced voltage at the output of the dynamo is sampled by the DAQ system (see Fig. 1, left). The students' task is to determine a relationship between the rotation speed of the dynamo and the amplitude of the induced signal. Moreover, they explore the ratio between the frequency of the output AC signal and the shaft frequency. A typical signal captured from the computer screen is shown in Fig. 1, right.

In a second version of the experiment with the bicycle dynamo, the motor is removed and the dynamo is connected to an AC generator with variable amplitude and fixed or variable frequency. The students observe that the shaft of dynamo does not rotate after being connected to the AC source, it just trembles. However, if one turns the shaft by hand in either sense, the shaft starts to rotate. The students ascertain that the frequency of shaft rotation does not depend on the amplitude of the voltage or on the loading of the shaft (torque).

Furthermore, students observe that the shaft frequency depends only on the voltage frequency and that the ratio between the frequency of the AC signal and the shaft frequency is constant and has the same value as when the dynamo has the role of a generator (the ratio in Fig. 2 is 4:1). To conclude the exercise, students use a magnetic compass to determine the number of magnetic poles in the rotor inside the dynamo.

EFFICIENCY OF A DC GENERATOR

In this experiment a simple DC motor with gears is used as a DC generator. A known resistor R_L is

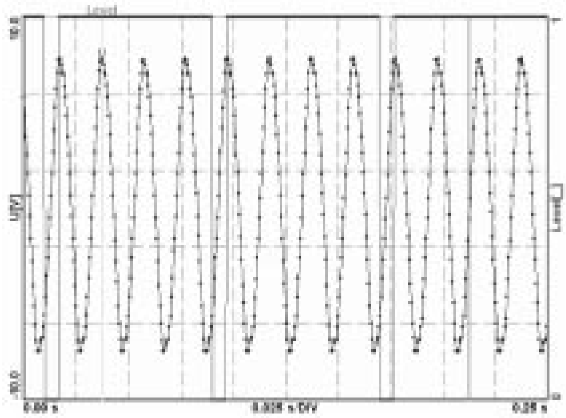

Fig. 2. Experimental signal from a bicycle dynamo taking the role of a synchronous motor, where U is the voltage from an AC generator and Level is the signal from the photo-gate.

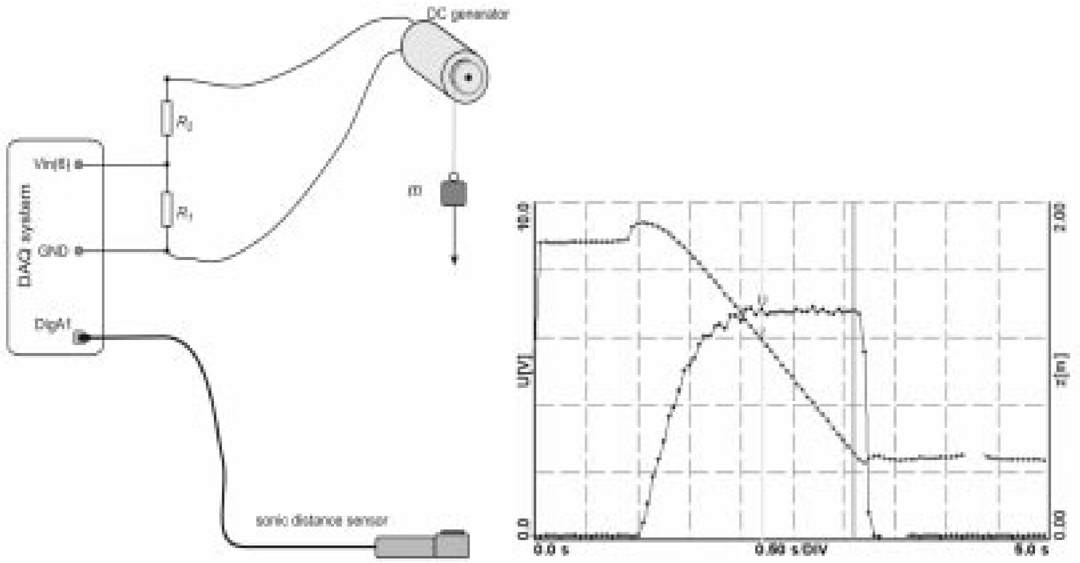

Fig. 3. Apparatus for determining the efficiency of a DC generator as a function of load resistance (left); the experimental signal indicating the position z of the mass and the induced voltage U both plotted as functions of time (right).

used as a load on the generator. The shaft of the generator rotates due to the motion of a known mass *m* moving downwards under the influence of gravity, as indicated in Fig. 3. The position of the mass is obtained using a sonic distance sensor (see Fig. 3). The DAQ system samples the induced voltage as well as the position of the mass.

Students are asked to undertake the following tasks: For a fixed mass m and different values of the load resistance R_L, they determine a time interval during which stationary conditions arise for the induced voltage and the velocity of the moving mass. From this information, for each value of R_L, they calculate the mechanical power, the electrical power and finally the efficiency. Using a standard spreadsheet programme (for example, Excel), they plot the efficiency as a function of load resistance R_L. From the curve they determine an optimal load resistance. A typical curve is shown in Fig. 4.

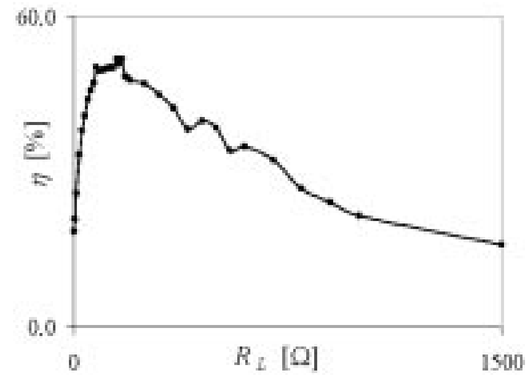

Fig. 4. Analysis of the efficiency η of the DC generator as a function of load resistance R_L.

ELECTRICALLY COUPLED DC MOTOR AND DC GENERATOR

The laboratory exercise to measure the efficiency of a DC motor is similar to the exercise on efficiency of a DC generator described above. A current through a DC motor at known voltage is sampled by the DAQ system while the motor is lifting a known mass vertically upwards. The velocity of the mass is determined using a sonic distance sensor as before.

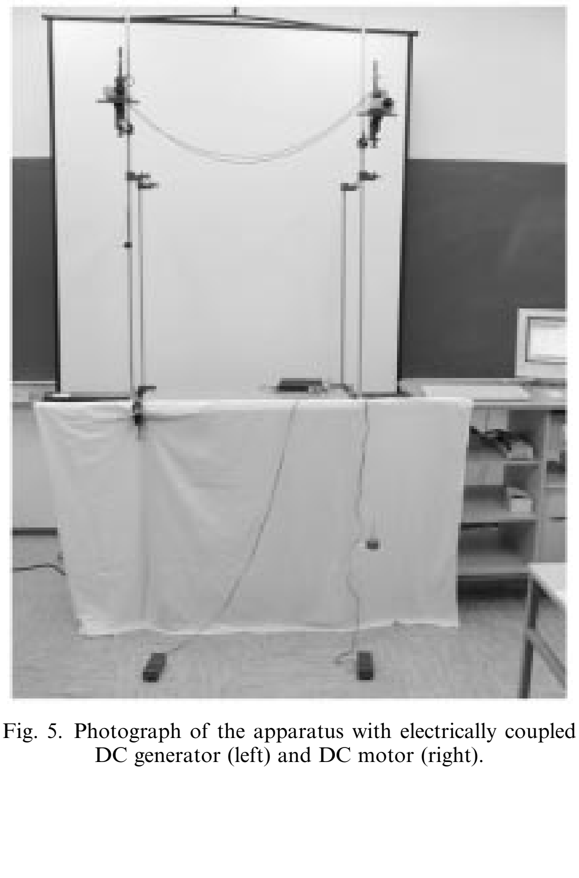

Fig. 5. Photograph of the apparatus with electrically coupled DC generator (left) and DC motor (right).

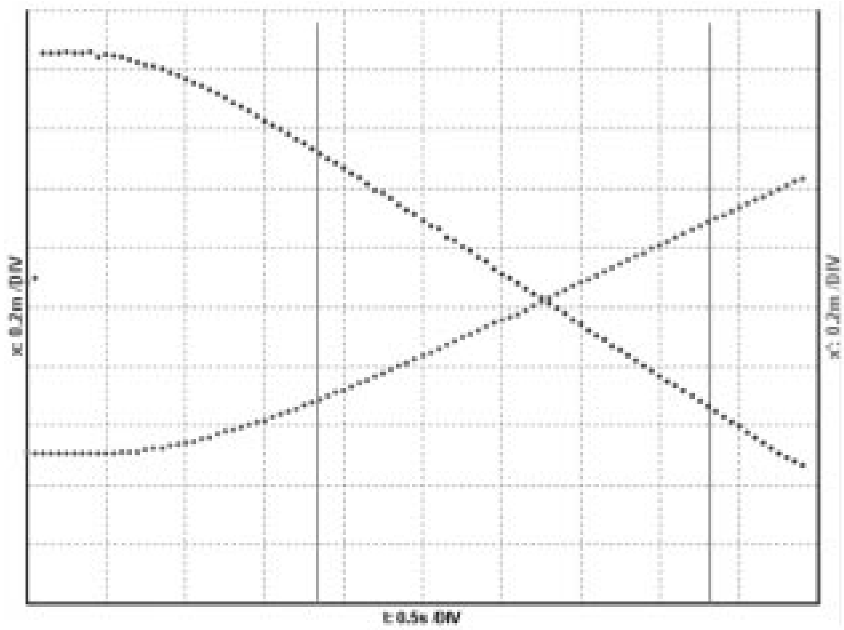

Fig. 6. Experimental signal for position x of weight driving the generator (negative slope) and position x' of weight lifted by the motor (positive slope) plotted as a function of time.

The exercise that follows combines both principles. A mass m_1 is moving downwards to rotate the shaft of the DC generator. The induced voltage is used to power a DC motor, which raises another mass m_2. Two sonic distance sensors are used simultaneously to sample the positions of both masses (see Fig. 5).

After a couple of seconds, the speeds of both masses become constant (Fig. 6). Calculation of the efficiency of the system is straightforward: $(m_2v_2)/(m_1v_1)$. Students start with a fixed mass m_1 driving the generator and vary the mass m_2 that is lifted by the motor. As in the previous cases, they plot how the efficiency of the coupled systems depends on one variable—the mass m_2 in this case (Fig. 7, left). While the curve that is obtained in this case is usually as expected, it is not so trivial to predict dependence of velocity v_1 (speed of the mass that drives the generator) as a function of velocity v_2 (speed of the mass lifted by the motor) as seen on Fig. 7, right.

RESULTS AND DISCUSSION

Laboratory exercises on electrical machines, designed for pupils aged 11 to 15, need to be straightforward, but still effective and similar to real technological procedures. It is also important that the teachers feel confident while pupils carry out the exercises. Finally, the required apparatus should not be costly. Examples in the course are therefore based on electrical devices that can be purchased in practically any technical store: a bicycle dynamo, two DC motors with gears, a low-power transformer (say 230 V on primary coil, 2×18 V on secondary coils) and a small stepper motor. The rest of the equipment is commonly available in school laboratories: AC

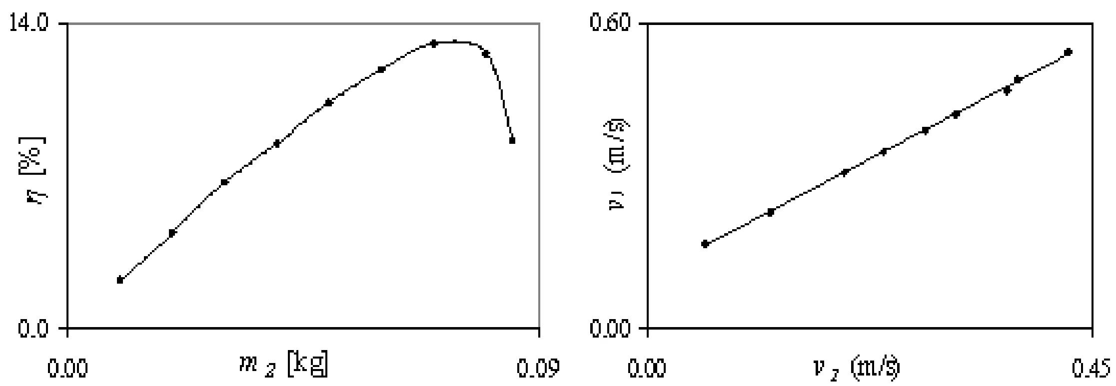

Fig. 7. Analyses of the efficiency η of electrically coupled system as a function of mass m_2 lifted by the motor (left), the dependence of the speed v_1 of the weight driving the generator on the speed v_2 of lifted weight (right).

and DC generators, weights, wires, resistors, coils, magnets, etc. The data acquisition system (DAQ system), sonic distance sensors and photo-gates are not compulsory. However, this instrumentation essentially improves the quality of results, less time is needed to perform the experiments and students are observed to be more motivated. Presenting and analysing the sampled data within spreadsheet software may also contribute some commonly applicable skills to the students.

The experience of the first year was that the class of 35 students preformed the laboratory exercises very well. They did not have any practical or theoretical problems as far as the principles of operation of motors and generators were concerned. Some problems were observed when doing those exercises highlighting empirical studies of the efficiency of electrical motors, generators and transformers. For example, during the exercise on the efficiency of a DC generator, students did not place and orient the sonic distance sensor correctly, so while the mass was dropping down, the sampled data was noisy or even inappropriate. One of the more difficult tasks encountered by students was how to chose an optimal mass and how many and which load resistances to use to obtain an adequate curve for the efficiency. On examining the laboratory reports of the first group of students, it was observed that some students had not chosen a suitable interval of load resistances so that they could not determine the optimal load resistance. Some students had trouble manipulating the software for data acquisition, typically they did not chose the proper sampling frequency and number of samples.

By analysing the outcomes of the 'modernised' course in comparison with the course performed earlier using traditional instrumentation, we were able to identify some technical advantages. The support of a personal computer during data sampling as well as in the analysis process has enabled the students to repeat the experiment for different situations; for example, efficiency was examined as a function of a variable parameter. Similar laboratory experiments performed without a DAQ system were not sufficiently accurate to determine during what time interval the speed was constant. Such work was also very time-consuming.

Interviews were also carried out with the students, most of whom responded very positively. They indicated strong approval of the modernisation of the electrical machines laboratory exercises and the introduction of the DAQ system and sensors enabling instantaneous results on the computer screen. Furthermore, they appreciated the possibility of analysing the data while performing the exercises, instead of spending a lot of time analysing the data in the traditional way afterwards. The interdisciplinary character of the exercises was also highlighted—the students indicated a preference for more such science-integrated laboratory practice as they find it effective in the learning process. The students were also asked to suggest how the exercises might be improved. In addition to some very useful technical points, they suggested two significant proposals. The first was to have a preliminary introduction on how to use the DAQ system—an issue that we are addressing in the current school year (2005/06). The second was a wish to receive more detailed instructions about the laboratory procedures such as what weights to take, what load resistances to use, etc. This second point did not meet with the approval of the curriculum design team. We intentionally did not provide the exact information requested, since students in Slovenian schools traditionally perform laboratory exercises by following more or less 'cook-book style' laboratory instructions. With these 'novel' laboratory exercises, we also tried to introduce some didactical methods emphasising creativity, project based work and the need to give students an insight into methods of scientific research. Since the computerised laboratory course saved considerable time compared with traditional laboratory work, we would like to use this time not to increase the quantity of the exercises, but rather to improve their quality. Laboratory exercises introducing inquiry and research principles are believed to be a productive direction for development.

A kind of 'side result' of these exercises on electrical machines was an increased interest on the part of students to decide to choose electrical engineering topics for their diploma theses. A student of the final (fourth) year of the programme decided to prepare an apparatus to demonstrate models of typical electrical motors. He developed a three-phase microcontrollerbased function generator with variable phase shift and variable voltage frequency. Using the function generator, models of three-phase, two-phase and single-phase AC synchronous and asynchronous motors were developed.

In order to introduce such laboratory practice to schools, we organised a one-day workshop for a group of 16 in-service teachers. The teachers responded positively and indicated that they could incorporate the experiments in their teaching practice. The outcome of this workshop was that, in the current school year, three pilot schools have proceeded to introduce the exercises to pupils aged 14 to 15.

We need to stress that technology education in Slovenia is incorporated in the final years of primary education (12–15 year old pupils) from 6th to 8th grade as a compulsory subject; while from 7th to 9th grade, students may choose optional subjects such as Electrotechnics, Robotics and Electronics. Although there is an increasing interest of pupils in robotics and electronics, schools prefer to offer foreign languages and other more socially-oriented optional subjects. As reported by in-service teachers, the main reason for such a situation is financial—schools are not prepared to invest large sums of money in equipment for optional subjects. It is of major importance, therefore, to offer low-cost equipment for laboratory exercises. In a similar manner to the case of the exercises on electrical machines described in this paper, we prepared low-cost solutions for the course in Robotics. A radio-controlled electric cart costing about 10 Euros was modified to act as a mobile robot. We added some sensors, mounted an inexpensive microcontroller circuit programmed using shareware software and changed it into an 'intelligent car'.

CONCLUSIONS

Further dissemination of the school laboratory practices that have been described to Slovenian schools depends on many rather complex issues. A very obvious one is that most schools in Slovenia are not appropriately equipped for such laboratory exercises. Even if this were not the case, most in-service teachers are not sufficiently qualified to handle DAQ systems, sensors, software, multimedia material, computer simulations, etc. As mentioned earlier, an important question is how to modify the traditional didactical approach of most of the teachers so that they can confidently undertake laboratory exercises with their pupils.

In-service teacher training programs for larger number of teachers combined with the financing of schools to purchase the required equipment falls, of course, outside the scope of this paper. Since the Slovenian government has declared its intention to provide more attention and finances for science and engineering education, the newly developed laboratory course outlined here may still reach more schools.

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