TEACHING OPTICS WITH LIMITED EQUIPMENT

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ABSTRACT

When there is a scarcity in equipment for teaching optics, some alternative way should be found to maintain the students' ability to cope with practical situations. It is assumed that creativity and innovative attitude may help them derive solution of real problems.

In our department, optics is taught through lectures and through a thesis for students choosing optics as their final project. Topics of the thesis are selected such that no delicate equipment is needed yet important principles of optics are involved.

For the lecture, special assignment related to patents is given. In one type of the assignment, each student is required to find a patented invention in optics and to formulate any thinkable improvement or modification of the invention. In another type, each student is asked to study several patents about a certain subject in optics and then to propose his own invention.

Keywords: education; patents; measurement.

1. INTRODUCTION

Education in optics generally needs sets of equipment with which major optical principles can be demonstrated and various experiments can be practiced. This is especially true in the education for engineering students who in their future career would work with technical problems. However, adequate optical components and instrumentation are not always available, yet the students are still expected to acquire the ability to handle practical situation.

In this paper we present an alternative approach to such a problem. Rather than bringing the students in contact with extensive optical hardware, which is not always possible, we propose that the content of the education is designed such that it includes a significant effort to enhance the students' creativity. It is assumed that innovative attitude may help them solve actual problems in their job.

The description of this approach starts in Section II with a summary of the curriculum representing the education environment where the proposed idea is applied. Its implementation is subsequently discussed in Section III together with several examples.

2. CURRICULUM

The Department of Engineering Physics at the Bandung Institute of Technology was established as an undergraduate engineering education program. It concerns mainly with finding solution of technical problems that are based on multiple physical variables and phenomena. The program duration is 4 years comprising 144 credits, where 130 credits

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are allocated for compulsory courses and 14 credits for elective lectures. Included in the compulsory requirement is a thesis work (final project, 5 credits) in the final year. Elective courses and thesis work are selected from the options offered in the department.

The current options comprise among others instrumentation and control, building physics and acoustics. Optics is embedded in instrumentation and control; the main purpose of offering optics is to support measurement and instrumentation through the non contact way. In this regard a fourth year student should take a compulsory lecture titled Laser and Fiber Optics (3 credits), and may join Optical Techniques (2 credits) as an elective course.

In Laser and Fiber Optics, the students learn various aspects of laser such as the principles of laser generation, laser resonator, beam properties, applications in interferometry and holography. Light guiding properties of optical fibers, attenuation and dispersion, applications for communication and sensors, are given also in this lecture. On the other hand, optical principles and their use in equipment and technical applications are the theme for Optical Techniques. Discussed topics include depth of field of a lens, ray tracing, moirè pattern, speckle interferometry, diffraction and its application.

Since approximately a decade the education has been extended with a master program in instrumentation and control, as well as with a doctoral program. In the master program, Laser and Optical Instrumentation (2 credits) is offered as an elective course. About 15 students enroll for the master program each year. The number is around 75 new undergraduate students per year, and presently there are about 10 doctor candidates in the department.

A good practice in education is presenting demonstration as a support for the lecture, especially when it involves a relatively new comprehension and when the students are expected to deal with a lot of hardware in their future work. In addition, laboratory and experiment works would be extremely useful. Experiences with relevant equipment will contribute to the students' ability to handle real problems.

With this in mind, various laboratory works are organized for the first, second, and third year students. In these study levels the courses are not yet very specialized so that the laboratory experiments involve certain common components and instruments. Exchange and reallocation of the equipment are possible during the execution of the yearly program.

In the fourth year, however, the courses have become more specialized and the equipment attached to each course is more or less unique. Then any equipment scarcity may obstruct the effort to build the students' competence. To solve this problem, we assume that creativity and innovative attitude may (to some extent) compensate the insufficient experience with the hardware. This is especially the case when the work environment is also not well equipped.

3. ASSIGNMENT AND THESIS

3.1 Assignment

Solving various problems related to the subject matter of the lecture is a task normally given to the students in the form of home assignment or class exercises. The problems could cover calculation to find numerical answers, written discussion to present a narrative solution, or a design consideration. According to our approach mentioned previously about enhancing the creative attitude, in addition to the normal lecture tasks we have given also to the students of Laser and Fiber Optics since several years other assignment. There are two general types of this special assignment, both are related to patents in optics.

In the first type, each student is asked to search a patented invention in the field of optics from the available internet website [1]. Title of the invention is up to the students to choose according to their interest. Based on the selected patent, the student must propose any improvement or modification that he or she thinks is possible with that particular invention. Two weeks are given as the time allocation.

Evaluation of the collected answers is based mainly on the good understanding of related optical phenomena and on the originality of the idea. Considered somewhat less importantly is the feasibility of the practical implementation, since the students do not have enough opportunity to test the proposed improvement. Many surprising ideas have been observed, although some incorrect principles are found as well. Post discussion during the lecture can supply the clarification and further remarks, which are expected to bring all the assignment scheme closer towards the targeted objective.

The second type of the special assignment has a higher degree of difficulty and for this a time allocation of about four weeks is given. Here, individual student is asked to study several patents on a certain subject that may be freely chosen. Based on the patents, the student is required to formulate his own invention on the subject, limited to just one claim (as opposed to several claims in a real patent). Again, a lot of original ideas have been submitted, some of them might even be categorized as rare invention.

There are at least two considerations in choosing patents as the focal point of the assignment. First, analogous to a scientific journal article, a patent can be regarded as a prominent achievement of an inventor (or group of inventors) in producing a contribution to the international world. Review of scientific fundamentals, assessment on the currently available techniques, advantages of the proposed invention, can all be traced in the patent description. A patent document is essentially quality and information rich.

As the second consideration, the assignment is meant to give the students the awareness and the spirit of always seeking creative, unconventional solutions which would be important for their future work. It is expected also to make the students more familiar with the patent world, stimulating them to pay effort toward invention, which may eventually lead to the production of their own patents, either at present or in the future. This gives surely a beneficial contribution to the local industry and business, as well as to the engineering development.

3.2 Thesis

The main concern in the undergraduate thesis work is the synthesis of the knowledge from all lectures that have been given and its application to solve real problems. Components and instrumentation are needed to construct the necessary setup, to carry out measurements, and to do the signal processing.

In the case of limited equipment availability, we should select and prepare the topics with great care such that no delicate equipment is needed, and yet the objective could be achieved. As an illustration, in the following we present examples of thesis work done in the optics laboratory of our department. This laboratory had its start with almost empty room. In the later period, a number of self made equipment [2] fill the room.

a. Measurement of particle velocity and diameter using fiber guided laser beams

The thesis has been rewritten (with some modification) as a paper and presented at a regional meeting [3]. As the background, laser Doppler velocimeter is a useful device for measuring particle velocity and size. However, the technique requires high quality interference fringe and elaborate signal processors. Laser transit velocimeter [4] which is not based on interference became an alternative, but the setup is still rather complicated.

Hence a simple setup is proposed, which uses two parallel laser beams with a small mutual distance, directed to two respective photodetectors. A moving particle in the plane of the beams will block the laser beams one after the other and produces successive shadows at the photodetectors. From the elapsed time between the shadow pulses, the velocity of the particle can be measured. The detection of bright laser beams which are intermittently blocked places a non stringent requirement on the detector sensitivity.

Furthermore, the laser beams beyond the probe volume are guided by optical fibers so that the probe volume can be remotely located and very flexibly adjusted to the velocity direction. A schematic drawing of the setup is shown in Fig. 1.

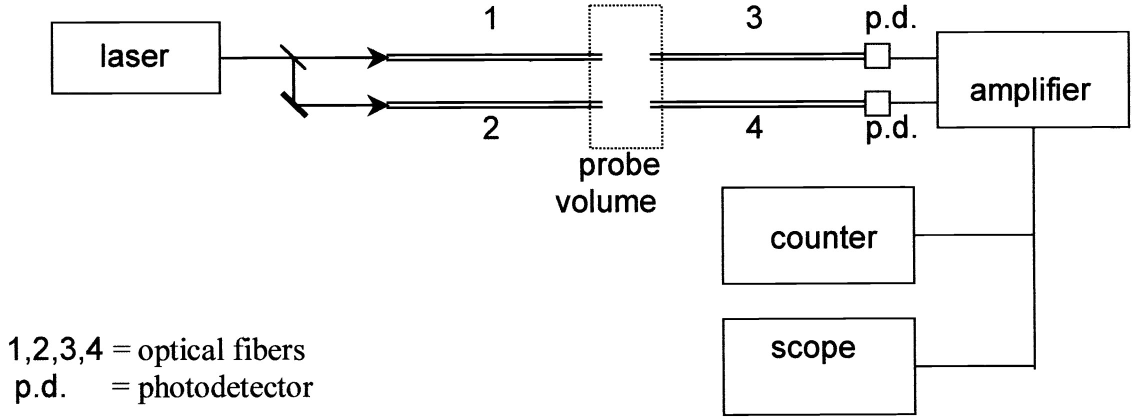

Fig.1. Setup with fiber guided laser beams.

A shadow pulse starts when the leading edge of a particle enters one laser beam, and terminates when the particle's trailing edge leaves the beam. If *d* is the beam diameter seen by a receiving fiber (*d* is practically identical to the fiber core diameter), *D* the diameter of a spherical particle and *v* its velocity, the pulse width *t* is given by

$$t = (d + D) / v \tag{1}$$

from which D can be obtained. This equation is accurate if the path made by the center of the particle intersects the beam axis, or if the particle is significantly larger than the beam.

Another method for diameter measurement is based upon the pulse height and applies for particles smaller than the core diameter d of the fibers. When a particle partially blocks the laser beam, the intensity reduction seen by the receiving fiber is proportional to the area covered by the particle cross section. The pulse height, in turn, is proportional to the intensity reduction, so we obtain

$$P = d\left[(V_0 - V_1) / V_0\right]^{1/2} \qquad (2)$$

where V_0 is the resulting signal voltage when the full intensity is received, V_1 when maximal blocking occurs, and $V_0 - V_1$ the pulse height.

Optical fiber with 1.4 mm diameter and 0.56 numerical aperture was employed. The setup was calibrated by fastening a thin rod to the axis of a motor having a known rotation speed. The velocity at several points along the rod was measured with the setup and compared to the results calculated from the rotation speed. A difference around 4% was noticed.

The simple device was then used to measure the diameter of small particles (plant seeds) dropped from a height of 10 cm. The resulting diameter values had a mean difference of 5% with respect to the results obtained using a vernier caliper.

b. Measuring the temperature of a plate with laser beam deflection

Fata morgana is a well known phenomenon which occurs when light is incident at a shallow angle (with respect to the ground) to the heated air layer above a hot ground surface. Due to refractive index gradient of the air, the light is bent in a gradual way and propagates finally to the upward direction. An observer receiving the upward going light will obtain an impression of seeing a water layer at the ground surface reflecting the light.

In the thesis [5], a similar phenomenon was applied to measure the temperature of a heated vertical plate. A narrow laser beam is sent parallel within a small distance to the plate. Due to the temperature gradient in the direct surrounding air, the laser beam will be deflected and the deflection depends primarily on the plate temperature. By measuring the deflection, the temperature can be interpreted.

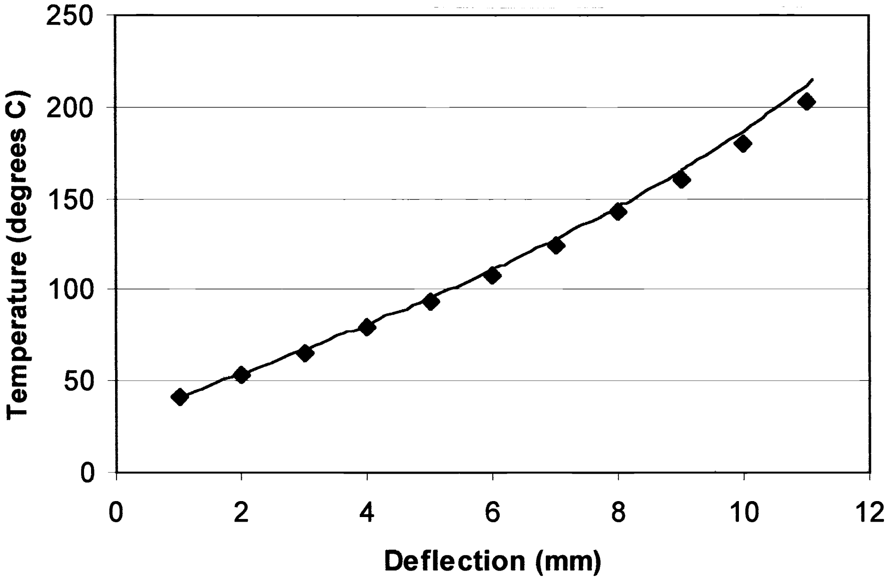

Fig. 2. Experiment results (♦) compared to the theoretical curve (——).

Result of the temperature measurement is shown in Fig. 2. The theoretical curve was computed by involving the temperature distribution due to convection around the plate, the dependence of air refractive index on its temperature, and the relation between light path and the refractive index distribution. Experiment values were obtained by sending a HeNe laser beam parallel to a heated vertical plate at an initial distance of 3 mm to the plate and 5 cm from its bottom edge. The plate had a dimension of 50 cm long and 9 cm high.

Light detector was placed at a distance of 1.5 m from the trailing edge of the plate and the temperature to be compared was measured using a thermocouple. The light detector consisted of ten short optical fibers, linearly arranged, leading to ten photodiodes. This arrangement was able to detect the spatial displacement of the laser beam.

Very good agreement between experiment and theory can be observed. In the temperature range up to 110°C, the difference was less than 2.1%; between 110°C and 220°C it was less than 4.2%. These quite accurate results were obtained just with a laser beam and a simple arrangement of photodetectors. With a somewhat more complicated theoretical analysis, in another thesis the method has been extended for a horizontal heated plate.

c. Computer based works

Theses involving work with computer have been produced also. The topics range from deformation measurement with speckle interferometer [6] to the design of a wide angle lens [7]. In the work with speckle interferometer, the computer was employed to process the speckle images, while in the lens design a ray tracing program was applied.

Work with computer has surely the advantage that one computer can do many different type of jobs, often with far reaching results. It should always be noted, however, that the good understanding and exercising of optical principles are not overwhelmed by hours of programming, formatting and other computer related activities that are often regarded by students as more exciting. Care should be undertaken to define the exact objective and to outline the underlying principles prior to offering the work to the students.

4. CONCLUSION

We have shown that although sophisticated equipment is not used, education in optics could be conducted. The keywords are creativity and unconventional solutions, which are applicable in the organizing of the education with limited equipment, as well as in contributing to the students' competence needed for their future career.

To implement the approach, the teaching staff should pay more effort and preparatory activities to look for possibly unusual schemes or subjects that involve major optical principles yet are suited to the existing condition.

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