

Project-based Learning in Basic Course of Technical Physics: Computer-controlled Experiments and Agros2D Modeling

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Abstract: - This paper is deals with exploit of Arduino microcomputers and finite element software Agros2D in basic course of hydromechanics. The Arduino is software and many hardware components and microcomputers developed for teaching robotics. The Arduino microcomputers such as UNO can be used to control experiments and also for subsequent data processing. In the case of hydromechanics, the microcomputer can used to control valves and flow-sensors in experimental devices intended to study fluid dynamics. This device was developed by students and its possibilities are discusses in the article. Because real liquids are compressible as well as material of pipeline is deformable. The system allows study effect flow rate of compressible liquid and other problems. Students can use software based on Finite Element Method for analysis of behaviour of these effects. The Agros2D was chosen as suitable for students. This software was primarily developed for the educational purpose. This tool is utilized in learning of Finite Element Method. This software is able to solve complex problems described by partial differential equations. Both of these tools are appropriate for project-based learning, which form the basis for technical education. Experience shows that the students are interested in learning. Results of student tests shows, that the participants on this form of project-based learning achieve much better results in both, theoretical and practical tests (in mechanics, physics, informatics).

Key-Words: - Educational software, Computer-controlled experiment, Flow mechanics, Thermomechanics

1 The Current State of the Problem

1.2 Finite Element Method at School

In the case of natural sciences, mechanics and engineering the partial differential equations are utilized for description of complex problems. These complicated systems of equations are solved using finite element method (in the following text, we will use the abbreviation FEM). Currently number of simulation programs based on FEM method is used in practice. Many are distinguished by friendly interface. These suitable interfaces do not require advanced knowledge of mathematics, at least in the case relatively simple tasks. Such user-friendly graphical interface allows creating two or three dimensional models purely on the basis of intuitive steps. Such process of solutions of physical model includes these stages: creating of model, meshing, and solving. The final step is then analysis of results. Students learn to use these programs in not only at university, but also on high schools focused

on technology or natural sciences. In the learning this problems is often used e-learning (as in all subjects oriented on computer utilization) and project-based learning [1,2,3,4,5].

Students usually meet FEM for the first time in technical graphics lessons. Today, probably all professional CAD programs used for mechanical components modeling some FEM solver. This solver allows basic strength analysis. An example of such software is SolidWorks. This software is widely used at technically oriented high schools. The second most commonly used software is Autodesk Inventor. FEM solvers that are part of these two programs do not allow more complicated work with the FEM model, as a transformation of networks or sub-modeling. The students usually get acquainted with software devices designed primarily for FEM simulation first at university. Due to high prices of professional computational software such as ANSYS, the educational institutions prefer

freeware programs such as FEMINA. An example of these programs developed for educational purposes is Agros2D software. The system is based on Hermes2D library. This device is freeware available for use at no monetary cost, making them ideal for use at school and in universities. This program can also be used for creating simulations used in teaching. In doing so, these simulations can be used effectively even, if the students are not at all acquainted with FEM method. In this article is special interest dedicated to the use for analysis of experiments realized within teaching of hydromechanics at our university.

Especially subjects related to the teaching of finite elements method are mechanics and applied mathematics. The knowledge acquired by students in these two courses, is further utilized in the design exercises. The students usually get acquainted with the FEM software interface in the first lesson [5,6,7,8]. After the students get acquainted with software interface, they will start preparing models (this is an activity close to their skills obtained by technical graphics lessons). and they are looking for a solution of problems. Student's knowledge from the first lesson can be tested easily by online questionnaire assessment with multiple choice test [1,5,8]. However, this part of the course is quite minor. The FEM solvers are working with very large files when running, therefore software user must be sure that your local drive has space for it and he must be able to work with this files. Therefore, first lecture is also devoted to problematic such as creating.

The most important part of the course consists of tasks in which students creates model that describes typical engineering problems.

One of the first tasks, that is solved by student's analysis of two dimensional truss-structure such as bridge truss. This is example of structural analysis. Following lectures are dedicated to the problem of „Plane Stress Bracket“, also this task is example of 2-Dimensional object. Subsequently students pass to the problems which require 3-dimensional modeling. In order to practice and master this part of course student must solve about ten examples of this type. After finishing this basic lecture, students begin with complicated problems in this succession: “Effect of Self Weight”, “Distributed Loading”, “Vibration”, “Buckling”, “Non-Linear Behavior of Materials” and “Non-Linear Analysis”. The reason why it was chosen just this sequence of tasks is logical sequence of steps involving models to be

start from easiest problem to the tasks describing more complicated reality. Whereby, the student can use one original model, which is connected to other parts.

1.2 Using computer-controlled experiments in teaching

During the last few decades, as manufacturing costs have decreased electronic devices, relatively complex electronic measuring devices are also used in the basic course of physics. These measuring devices are able to communicate with PC or those devices are directly controlled by computer. Unfortunately, most of these school laboratories are devoted purely to electricity and magnetism or their technical applications. An example of such a laboratory is described in paper [9]. This illustration of computer-aided educational laboratory is devoted to student's familiarization with problematic of photovoltaic cells.

Perhaps most common example of computer aided school laboratory that is devoted to others problems, than electricity is laboratory equipped software IP COACH. This software was developed by CMA (Centre for Microcomputer Applications) purely for educational purposes. Also, CMA itself was founded by science educators of the University of Amsterdam with goal to improve science education with innovative and attractive technology. This software has been made possible to implement prefixed format for every laboratory exercises used in the curriculum at high school or at base physics course at university. One great advantage of this solution is that students do not have to pay attention to system scaling and calibration. Detailed textbooks were published about this software. These textbooks contain many tasks for students with exact instructions and explanation of physical phenomena [10].

1.3 Robotics and Arduino at school

Nowadays, emphasis is placed on the robotics teaching. Recently a number of inexpensive learning platforms have emerged in the world, such as Raspberry Pi. One of these resources is particularly widespread and its advantage is modular character. This tool is Arduino. This name is used for both, open source software and hardware developed by Arduino company, respective Smart Projects company [11,12,13]. There is a whole range of Arduino microcontrollers and microcontroller kits. These microcontrollers differ in performance and

other parameters, as well as in use. These single-board microcontrollers for building digital devices and interactive objects that can control small robots or different type of contrivance mechanism based on stepper motors and the sensors for measurement of physical quantities. These tools are most often known due to their use on various walking robots. However, all these sensors can be effectively utilized in the school laboratory to teach physics.

The Arduino was especially developed for education, therefore is optional for utilization in basic course of programming and robotics. The software Arduino is freeware and Arduino hardware components are mostly cheap. So cheap, that it is possible to be used by students at home.

The Arduino software can work on considerable number of different boards both official boards produces by Smart Projects company or compatible such as Freeduino or Freeduino and further more (It is not possible enumerate all). Most of these units are based on the processor ATmega328. The basic and most often used official boards are (the processor is listed in bracket, if the it is used other processor than ATmega328): Arduino Micro (ATmega32U4), Arduino Nano, Arduino Nano, Arduino Mini, Arduino Mega (ATmega1280), Arduino Uno, Arduino Leonardo (Atmega32U4), Arduino Robot, Arduino Esplora and other.

The Arduino used number different of measurement devices and detectors not only to determine basic electrical quantities such electric-current or voltage, but also more sophisticated measurement instruments such as ultrasonic ranging detector for non-contact measurement and obstacles detection. There are also, for example different types motion sensors or two and triple axis accelerometers [11,12]. Also, sensors for measurement humidity and temperature of environment are available. In this article Arduino was used for Bernoulli's principle teaching, so flow sensors were used. Sensors based on Ventury tube principle are also available for Arduino and these sensors can be used for low rate measurement in combination with other sensors for distance measurement.

2 Hydro and Thermo-Mechanics in Basic Course of Physics

2.1 Hydromechanics course at school and it's principal experiments

An important part of the basic physics course is also hydromechanics or fluid mechanics [14,15]. When

hydromechanics is taught, the students are first acquainted with difference between incompressible and compressible fluid. The hydromechanics can be divided in the hydrostatics and hydrodynamics. In the case of hydrodynamics for compressible flow only qualitative description is taught. This is because quantitative description of these problems is possible only by using higher mathematics. On the other hand, in the case incompressible flow the mathematical description is significantly simpler and more comprehensible to students. In the case of hydrostatics are physical laws taught also for gases.

Probably most important laws or principles taught in basic course of hydromechanics or hydrodynamics is Bernoulli's principle [14,15,16]. Most simple form of Bernoulli's principle for incompressible flows is taught in the seventh class at elementary School (in Czech Republic). The teaching of this issue can be appropriately complemented by a number of illustrative experiments. We can create a model set of different tubes in which we will measure the flow. These assemblies may include different flow sensors. These sensors are used for building blocks for teaching programming and robotics at secondary schools. These schools are oriented towards mechanical and electrical engineering. It is possible to integrate robotics and mechanics and physics in a suitable way in certain student projects. In this article, we will become acquainted with the integrated teaching of Bernoulli principle, as part of the student project in robotics and technical mechanics. At the same time, we will show the use of Agros2D in education.

2.2 Thermodynamics and mechanics of gases at basic course of physics

Gases mechanics is a branch of fluid mechanics, which is devoted to ideally compressible. In reality, also the gases are not compressible in zero volume. When compressing gases, phenomena that study thermodynamics begin to appear [17]. Thermodynamics is a branch of physics concerned with heat and temperature and their relation to energy and work. Students are familiar with the three laws of thermodynamics at technical high schools. This course builds on the basic knowledge obtained in the previous study and is based on the assumptions, that students are familiar with terms such as temperature. It is then possible to interpret such phenomena as thermodynamic processes: Adiabatic process, Isothermal process, Isobaric

process and others. These processes can be implemented in a relatively simple laboratory.

3 Bernoulli's principle and Student Experiments

3.1 Introduction

Bernoulli's principle is a seemingly counterintuitive statement about how the speed of a fluid relates to the pressure of the fluid [14,15,16]. The Bernoulli's principle is closely linked with the law of conservation of energy. In reality the basic Bernoulli's equation is law of conservation for sum of potential and kinetic energy of volume unit of fluid. Bernoulli's principle can be applied to various types of fluid flow, resulting in various forms of Bernoulli's equation. In the physics different forms of Bernoulli's equation are known for different types of flow. The simple form of Bernoulli's equation is valid for incompressible flows. The Bernoulli's law in this form says that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline.

3.2 Incompressible Flows

When Bernoulli's principle is applied on the incompressible flow, e.g. liquids and gases whose density can be considered to be constant in studied region [14,15,16]. This flow is also characterised by low Mach number [14,16]. Where the Mach number can be characterised as a dimensionless quantity defined as the ratio of flow velocity past a boundary to the local speed of sound. Bernoulli originally performed his experiments only on liquids, so his equation in its original form is valid only for incompressible flow. A common form of Bernoulli's equation, valid at any arbitrary point along a streamline, is [14,15,16]:

$$\frac{v_1^2}{2} + gh_1 + \frac{p_1}{\rho} = \frac{v_2^2}{2} + gh_2 + \frac{p_2}{\rho} \quad (1)$$

where: v is the fluid flow speed at a point 1 or 2 (see indexes in eq. (1)) on a streamline, g is the acceleration due to gravity, h is the elevation of the point 1 or 2 above a reference plane, with the positive h -direction pointing upward – so in the direction opposite to the gravitational acceleration, p is the pressure at the chosen point, and ρ is the density of the fluid at all points in the fluid.

An important condition is there is no friction between fluid and pipe wall. The fluid flow is steady without turbulence. The meaning of indexes is shown at Fig. 1.

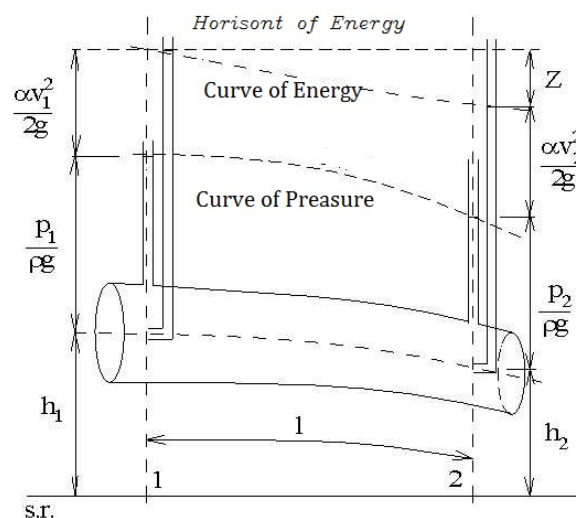


Fig.1 Fluid flow through the pipe, from the point at elevation h_1 to the point at elevation h_2 . The pipe is characterised by cross-sections S_1 and S_2

3.3 Compressible flows

The basic and the most general form of Bernoulli's equation for compressible flows can be expressed as [14,15,16]:

$$\frac{v_1^2}{2} + \int_{p_1}^p \frac{dp}{\rho(p)} + \psi(\vec{r}_1) = konst. \quad (2)$$

where p is the pressure and ρ is the density, which is a function of pressure p . The flow speed is v and ψ is the potential associated with the conservative force field, often the gravitational potential. The potential ψ is a function of position, i.e. Positioning vector \vec{r} or coordinates x, y, z . If this equation is applied to incompressible flow, the potential ψ has the same meaning as the product gh in Eq. 1.

3.4 Experimental device

The students are preparing a functional model for the study of Bernoulli's principle. This model is prepared from two types of pipes: firmly undeformable made from hardened transparent plastics and second prepared from soft plastics with a known modulus of elasticity. The elasticity modulus was $E = 0.5$ GPa. Students have a base desk Arduino Micro with two flow sensors based on the principles of Venturi tube, and one sensor for deformation measurements. Device Assembly is

clearly visible from Fig.2. This is illustration of project-based learning of programming, mechanics and physics [18,19,20].

These flow sensors controlled by Arduino measured and record the flow speed at point 1 and 2. The deformation of diameter of elastic tube from the soft plastics is measured by deformation sensor. Also the pressure in the tubes at the point 1 and two is measured and recorded by sensors controlled by Arduino Micro.

The pressure, respectively flow speed is controlled by height of water tank over the basic plane. Also the height of the tank level is measured by the sensor controlled by Arduino Micro. The influence of water compression is very small and hardly measurable with available Equipment. Therefore, it has been decided to measure the deformation of the soft tube. And thus modify the model. The advantage is that the deformation of the tube is easily connected to the pressure changes in the pipeline by students. The grow of tube diameter is measured and the simulation is working with diameter of tube

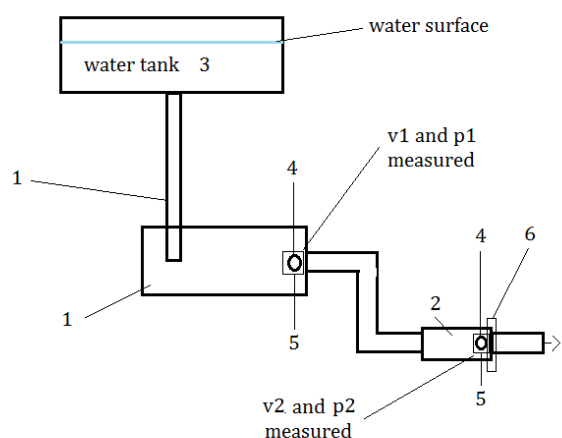


Fig. 2 Pipeline system with sensors: 1 – Tube from hard plastics, 2 – Exchangeable tube - hard plastics/ soft plastics, 3 – water tank, 4 - speed sensors, 5 – pressure sensors, 6 – deformation measurement – tube diameter and its expansion.

4 Adiabatic process and experiment

4.1 Theory of adiabatic process

The adiabatic process can be described as compression or expansion of gases without transfer of heat or matter between a thermodynamic system and environment. So we will assume such a process: an ideal gas is compressed adiabatically (no heat was added, and also no matter was added in the vessel), work is done on it and the temperature of

gas in the vessel increases. Otherwise in case of an adiabatic expansion, the gas does work and its temperature drops. These processes actually have a whole range of technical applications. For example, Adiabatic compression actually occurs in the cylinders of a car, where the compressions of the gas-air mixture take place so quickly that there is no time for the mixture to exchange heat with its environment. Further, this principle is utilized in for example in some refrigeration plants.

This process can be described in the case ideal gas by simple equation:

$$PV^n = konst. \quad (3)$$

where P is pressure, V is volume, and for this case $n = \gamma$. The process described by this form is a reversible (i.e., no entropy generation) process and process can be represented by the polytropic process equation. The parameter n can be defined as

$$\gamma = \frac{C_p}{C_v} = \frac{f+2}{f} = \frac{k_T}{k_S} \quad (4)$$

where C_p being the specific heat for constant pressure, C_v being the specific heat for constant volume, γ is the adiabatic index, and f is the number of degrees of freedom (3 for monatomic gas, 5 for diatomic gas and collinear molecules e.g. carbon dioxide). The parameters k_T and k_S are isothermal compressibility and isentropic compressibility respectively

4.2 Adiabatic process and experiments

In this paragraph, the simple and accurate experiment to determine the adiabatic coefficient γ of air is presented. This experiment with its simplicity meets the requirements on the basic school experiment. The experiment has a moderate cost since only a large glass syringe, a glass bottle with two holes and two rubber stoppers, and a common pressure gauge with corresponding output are required. The method allows one to measure experimentally the isothermal compressibility, k_T , and the adiabatic or isentropic compressibility k_S of air. The experimental setup is shown in Fig. 3. The volume changes are measured using glass syringe. The shift of syringe piston is measured by sensor and its movement is controlled by servomotor. The pressure changes were measured with pressure device on which is able import data from measurement for further analysis. The control

of the experiment was realised utilizing Arduino components.

The volume changes are measured determined from piston displacement in syringe. In this way, students are able to determined pressure increase ΔP_T and ΔP_S , the measurement under constant volume decies ΔV . Finally the parameter γ will be determined equation:

$$\gamma = \frac{\Delta P_s}{\Delta P_T} \quad (5)$$

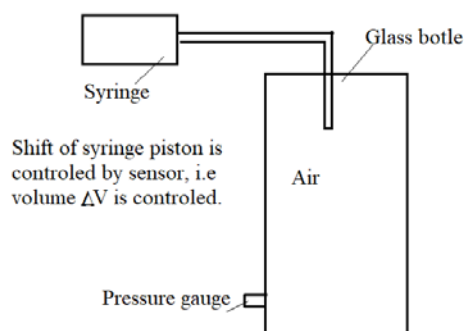


Fig. 3 The experimental device for analysis of adiabatic process.

5 Process Simulation and FEM

5.1 Description of Agros2D Software

The Agros2D software is a versatile multiplatform application designed for solution of physical fields. This platform was written in C++ and uses the Hermes2D library [21,22,23,24,25]. Hermes2d herself is based on hp-FEM (adaptive finite element method of higher order precision) to solve partial differential equations. The application is developed at the Department of Theoretical Electrical Engineering of FEL West Bohemian University in Pilsen and is distributed under the GPL license. Its principal part is a user interface serving for complete preprocessing and postprocessing of the tasks (it contains sophisticated tools for building geometrical models and input of data, generators of meshes, tables of weak forms for the partial differential equations and tools for evaluating results and drawing graphs and maps). The Agros2D is working in the operating system Windows.

The basic features of this software are coupled physical fields, that means that the user can blend two or more physical fields in one problem. specifications, our Publishing House may not be able to include your paper in the Proceedings. The Agros2D allows both Simulation and analysis of

linear and nonlinear problems [21]. The Agros2D software implements Newton's and Pickard's methods for solution of nonlinear problems. Another advantage of this software is Automatic space and time adaptivity. This feature has been taken over from Hermes2d [16]. Another important feature of the Agros2D is adaptive time stepping for transient phenomena analysis. Another, also useful functions or features of Agros2D are: utilization of Curvilinear elements, Quadrilateral Meshing and Particle Tracing.

In general, however, the starting user does not need to understand higher mathematics. The software is very user friendly. The great advantage for use in education is that the software used only two dimensions for model construction. The program can be used not only by students at university, but also by students in the secondary education (high schools). In this article the Agros2D software was used for study of and simulation of flow of incompressible and compressible liquid through Pipeline. The pipeline in the model is both firm non-deformable and flexible (deformable). This flexible pipeline is expanded by the pressure of the liquid. All these problems can be relatively easy to simulate in the program as well as high school students. Although these problems would be hardly solved by methods based on analytical methods, now it can be solved by students without understanding to komplex differential equations.

5.2 Simulation of flow in pipes

The students prepared 2D model of Pipeline system in Agros2D software: This model used as input data geometrical parameters of system especially the height of the individual tubes over the basic plane and diameter of tubes. Very important input value is the height of water surface in the water reservoir, this value was measured during the experiments. The task of FEM simulation is determine, the speed at the point 1 and 2 (These values are a function of the height of water surface in the water reservoir.), also the pressure at this two points was determined. These values are compared with measured. The influence of water compression is very small and hardly measurable with available Equipment. Experiments conducted by students show compliance 95% with FEM model.

6 Conclusion

The values measured by students are in 95% in compliance with values obtained by simulation in

Agros2D software. This is illustration of project-based learning of programming, mechanics and physics [18,18,20]. Our school will try to develop further this approach.

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