The Use of Argos2D software and Arduino Microcomputer in Teaching Hydromechanics

MICHAL RUZICKA
STEPAN MAJOR
PAVEL CYRUS
Department of Technical Education, Faculty of Education
University Hradec Králové
Rokitanského 63, Hradec Králové 500 03
CZECH REPUBLIC
michal.ruzicka@uhk.cz, s.major@seznam.cz, pavel.cyrus@uhk.cz)

Abstract: - This lecture is devoted to problematic of exploit of Agros2D software in education. The software Agros2D is software primarily devoted to the learning of FEM (Finite Element Method). The software Agros2D is a multiplatform for the solution of partial differential equations. The system uses Hermes2D library. This software is freeware available for use at no monetary cost, making them ideal for use in education. 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 hydromechanics and experimental mechanics

Key-Words: - Technical Education, Finite Element Method, Argos2D, Hydromechanics, Arduino, Bernoulli's principle

1 Introduction

In the case of natural and technical sciencises and engineering in order to describe real problems the partial differential equations are used. These complicated systems of equations are solved using finite element method. Currently number of simulation programs base FEM method is used, and many of than used friendly interface. These programs do not require advanced knowledge of mathematics, at least in the case relatively simple tasks. Such programs have very good graphical interface, which allows creating two or three dimensional models. The process of solutions of physical model includes these stages: creating of model, meshing, solving and analysis of results. Students learn to use these programs in schools. In the learning this problems often is used e-learning and project-based learning [1,2,3,4,5].

First lecture of FEM analysis [5,6,7,8] in mechanics typically is devout familiarization with the software interface [5,6,8]. In following lectures students are preparing models and they are looking for a solution of problems. Student´s knowledge from the first lesson can be tested by online questionnaire assessment with multiple choice test [1,5,8]. However, this part of the course is quite minor. This lecture is alsoo used for creating files and problems problems associated with it, because the FEM programs are working with very large files when running and saving; be sure that your local drive has space for it. The most important part of the course consists of tasks in which students creates models, that describes typical engineering problems. The first lecture is devout to the analysis of two dimensional truss structure such as bridge truss. This is example of structural analysis. Other tasks are dedicated to the „Plane Stress Bracket“, also this problem is example of 2-Dimensional object. Subsequently students pass to the problems which require 3-dimensional modeling. Also this tasks is example of simple structural analysis. In order to practice and master this part of course student musts 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, NonLinear Analysis, Buckling, NonLinear Materials. The reason why it was chosen just this, and no other order is a logical sequence of steps involving models to be closed to the reality. Whereby, the student can use one original model, which are connected to other parts.

2 Teaching Hydromechanics

An important part of the mechanics course is also hydromechanics or fluid mechanics. In teaching hydromechanics 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 flew 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 flew 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. 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.

3 Teaching Robotics and Arduino

Arduino is both open source software and hardware developed by Arduino company, resp. Smart Projects company [9,10,11]. The Arduino are different types or models of single-board microcontrollers and microcontroller kits 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. The Arduino was especially developed for education. Arduino is used for 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 used considerable number of different boards both official boards produces by Smart Projects company or compatible such as Freeduino or Freeduino and futher more (It is not possible enumerate all). Most of these units are based on the processor ATmega328. The basic and most often used official boars are (the processor is listed in bracket, if the it is used other processor than ATmega328): Arduino Micro (ATmega32U4), Arduino Nano, Arduino Nano, Arduino Uno, Arduino Leonardo (Atmega32U4), Arduino Mini, Arduino Mega (ATmega1280), Arduino Robot, Arduino Esplora and other.

The Arduino used number of sensors and detectors not only to measure basic electrical quantities such as electric current or voltage, but also more sofisticated senzore such as ultrasonic ranging sensor for non-contact measurement functionality with a ranging or different types motion sensors or triple axis accelerometers [10]. Also, sensors for measurement humidity and temperature of environment are available. In this article Arduino was used for Bernoulli's principle teaching, so flew sensors were used. Sensors based on Ventury meter are also available for Arduino an these sensors can be used Flow rate in combination with other sensors for distance measurement.

4 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 [12,13,14,15,16,17]. 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 ZČU (Západočeská Univerzita – 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 or under Linux (especially Ubuntu).

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 [12]. 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 (highschools). In this article the Agros2D software was used for study of and simulation of flew 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 to understanding differential equations.

4 Bernoulli's principle

Bernoulli's principle is a seemingly counterintuitive statement about how the speed of a fluid relates to the pressure of the fluid [17,18,19,20]. The Bernoulli's principle is closely locked 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.

4.1 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 [17,18,19,20]. This flow is also characterised by low Mach number [20]. Where the Mach number can bee characterised as a dimension less 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 [18,19,20]:

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

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.

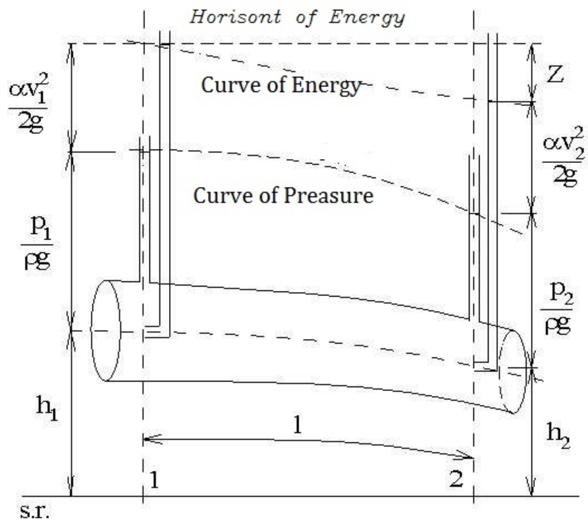

Fig.1 Fluid flow through the pipe, from the point at elevation h_1 to the point at elevation h_1. The pipe is characterised by cross- sections S_1 and S_2

4.2 Compressible flows

The basic and the most general form of Bernoulli's equation for compressible flows can be expressed as [18]:

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

where p is the pressure and ρ is the density, which is 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 function of positron, i.e Positioning vector $\vec{r}$ or coordinates $x, y. z$. If this equaton is applied on the incompressible flow, the potential Ψ has same meaning as product gh in the Eq.1.

5 Students Model of Pipeline System

The students are preparing functional model for study of Bernoulli's principle. This model is prepared from to types of pipes: Firmly undeformable made from hardened transparent plastics and second prepared from soft plastics with a known modulus of elasticity. The elastisticity modulus was E = 0.5 GPa. Students have base desk Arduino Micro with two flew sensors based on principles of Venture 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 [21,22,23,24].

These flew 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

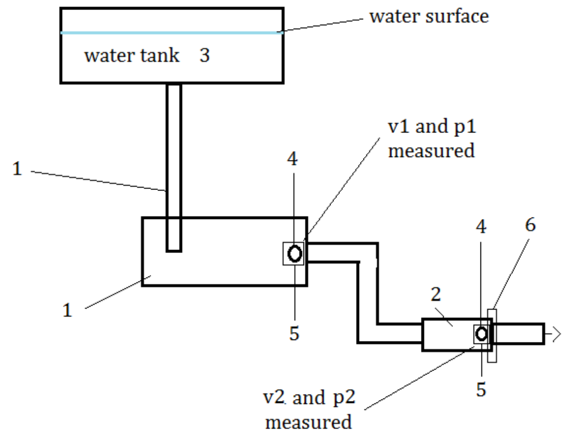

Fig. 2 Pipeline system with sensors: 1 – Tube from hard plastics, 2 – Exchangeable tube - hard plastics/ soft plastics, 3 – water tank, 4 - speed sensors, 5 – pressure sensors, 6 – deformation measuremet – tube dimater expansion.

.

6 Simulation in the Agros2D

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.

7 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. Our school will try to develop further this approach.

Acknowledgment: This project was prepared by finantial support *"Metoda konečných prvků a automatizace experimentu ve výuce mechaniky a technických laboratoří na katedře technických předmětů"* 18/I zč SV 2119 - pracoviště 1440.

References:

[1] M. Aparacio, F, Bacao, T. Oliveira: Cultural impacts on e-learning system success, The internet and Higher Education 31 (2016), Elsevier, pp. 58-70.

[2] C. L. McDermott, E. F. Redish, "Resource Letter: PER-1: Physics Education Research". *American Journal of Physics*. **67** (9) 1999: 755–767.

[3] R. Duit, H. Niedderer, H. Schecker (2006). "Teaching Physics". *Handbook of Research on Science Education*: pg. 606.

[4] C. L. McDermott:"Guest Comment: How we teach and how students learn---A mismatch?". *American Journal of Physics*. **61** (4) 1993: 295–298.

[5] J. Chaskalovic: *Finite Elements Methods for Engineering Sciences,* Springer Verlag, 2008

[6] O.C. Zienkiewicz, R. L. Taylor, J. Z. Zhu, *The Finite Element Method: Its Basis and Fundamentals*, Butterworth-Heinemann, 2005

[7] I. Babuska, U. Banerjee, J.E. Osborn, "Generalized Finite Element Methods: Main Ideas, Results, and Perspective". *International Journal of Computational Methods*. **1** (1) 2004:,67–103

[8] D.L. Logan, *A first course in the finite element method.* Cengage Learning, 2011

[9] M. Banzi, M. Shiloh, *Getting Started with Arduino*; 2014

[10] T. Karvinen, K. Karvinen, V. Valtokari*: Make: Sensors* Haftad, Engelska, 2014

[11] ,J. Purdum, *Beginning C for Arduino: Learn C Programming for the Arduino and Compatible Microcontroller,* Apress, 2014

[12] P. Solin, K. Segeth, I. Dolezel: *Higher-Order Finite Element Methods*, Chapman & Hall/CRC Press, 2003

[13] P. Karban, F. Mach, P. Kůs, D. Pánek, I. Doležel, I.: Numerical solution of coupled problems using code Agros2D, *Computing*, 2013, Volume 95, Issue 1 Supplement, pp 381-408

[14] P. Solin, L. Korous: Adaptive higher-order finite element methods for transient PDE problems based on embedded higher-order implicit Runge–Kutta methods, *Journal of Computational Physics,* 2012, Volume 231, Issue 4, pp 1635–1649

[15] L. Korous, P. Solin, *An adaptive hp-DG method with Dynamically-Changing Meshes for Non-Stationary Compressible Euler Equations*, Computing, 2013, Volume 95, Issue 1 Supplement, pp 425-444

[16] P. Solin, J. Cerveny, I, Dolezal: *Arbitrary-Level Hanging Nodes and Automatic Adaptivity in the hp-FEM*, Math. Comput. Simul., 2008, Volume 77, pp 117 – 132

[17] J. Kyncl, J. Doubek, L. Musálek. Modeling of Dielectric Heating within Lyophilization Process. *Mathematical Problems in Engineering*, 2014.

[18] H. Lamb, *Hydrodynamics* (6th ed.). Cambridge University Press, 1993

[19] L.D. Landau, E.M. Lifshitz. *Fluid Mechanics*. Course of Theoretical Physics (2nd ed.). Pergamon Press, 1987

[20] H. Chanson, *Applied Hydrodynamics: An Introduction to Ideal and Real Fluid Flows,* CRC Press, Taylor & Francis Group 2009

[21] T. Markham, Project Based Learning. *Teacher Librarian*, 39(2) 2011, 38-42.

[22] J.G. Greeno, *Learning in activity*. In R. K. Sawyer (Ed.), The Cambridge handbook of the learning sciences. New York: Cambridge University Press, 2006

[23] J. Dewey, *Education and Experience*, 1938/1997. New York. Touchstone.

[24] R.K. Sawyer, *The Cambridge Handbook of the Learning Sciences.* New York: Cambridge University Press, 2006.