Software implementation of hydraulic shock numerical computation in the pressure hydraulic systems without protection devices

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Abstract: - This paper presents software for calculus of hydraulic shock phenomenon in pressure hydraulic systems without protection device. The program is written in Java programming language and responds to the following requirements: easy management of several projects, easy introduction, editing and change of data entry, and proper display of the program output: the hydraulic load and speed for every moment of time. To numerical solve the equations of the hydraulic shock phenomenon we apply the method of characteristics. The output data are the values of speeds and hydraulic loads of the sections along the pipeline, elements that can assess system behavior in a given situation.

Key-Words: - hydraulic shock (water hammer), pressure hydraulic system, method of characteristics, software, flowchart, graphical interface.

1 Introduction

Nonpermanent regime of fluid motion is a normal case of hydraulic operation. In a pressurized pipeline system fugitive is the change in hydraulic parameters for the pipe ends or maneuvering through a valve situated somewhere on the pipe. Examples of situations where the motion is non-permanent regime: water enters (exits) in (from) a pipe (a) reservoir whose level changes over time, water is pushed into a pipe under pressure and centrifugal pump while the pump speed changes, move the water pipe to a turbine rotor to the turbine regulator flow turbine flow etc. change over time.

Switching from one operating mode to another is fast enough, a fugitive moving phase, which occurs due to change in operating conditions existing in one or more points in the system.

In phase liquid movement may be slow or fast variable, depending on whether the disturbance and initial conditions, the elastic characteristics of liquid and that the hydraulic system and protective devices.

Theoretically, there is no precise boundary delimitation between the two movements. It is estimated that in situations where boundary conditions change is a time that is more than twenty times during the natural light through that pipe, then quickly move can be considered variable and study the movement be taken into account fluid compressibility and elasticity system [2].

$$T_m \leq 20\frac{l}{c} \qquad (1)$$

where l is the length of pipe, c - elastic wave propagation speed (velocity). Otherwise, the movement is slowly varying and can be considered incompressible fluid.

Closing valves in steady speed, the actual closing be done in the last time (about 10-15% during the maneuver T_m), the previous condition is:

$$T_m \leq 200\frac{\mathrm{l}}{\mathrm{c}} \qquad (2)$$

The movement is characterized by rapidly varying amplitude and high frequency pressure oscillations, whose conduct is heavily influenced by fluid compressibility and elasticity of the material the pipe is made. Mass transport in fast-moving variable is negligible.

Usually the rapidly variable movement of liquids in pressure pipes is called hydraulic shock or water hammer or undulation.

In analyzing the phenomenon of hydraulic shock must be taken into account the liquid compressibility and pipe wall elasticity. Otherwise (incompressible fluid and wall), the kinetic energy of the liquid mass suddenly stopped will change over into mechanical work when the motion is practically null. In these conditions are developed forces, respective pressures extremely high.

In the initial phase of oscillations generation, the viscosity effect of internal forces can be considered negligible, but must be considered later, being the case of oscillation damping due to dissipation of mechanical energy [22].

Into hydraulic system the fluid movement, the variable slow motion has the pressure amplitude and low frequency pressure oscillations, but with significant mass transport, fluid compressibility and elasticity of the material is made pipe can be neglected in the calculation of flow and pressure variations.

Slow motion variable hydraulic pressure is called oscillatory motion.

Rapidly regime may bring claims of the system by changing speeds and especially pressures, leading to the very different values from those of the permanent regime.

The movement of liquids in pipes determines the appearance of overpressure several times or ten times bigger than the pressure of state system and leads to the destruction of installation [2].

Hydraulic shock is therefore an excess (alternate positive and negative) addition to the pressure of the permanent regime and independent from this pressure.

Because the hydraulic shock phenomenon damages the operation of installation and requires sizing pipe installations, the phenomenon is limited to a portion of the pipe as short, by inserting an air chamber or a surge tank, usually with free water level, like a large section capillary tube.

Therefore the study of nonpermanent state is very important and it is most often a prerequisite for the proper design of a hydraulic system and its operation.

2 Mathematical model

2.1 The differential form of fundamental equations

The fundamental equations of hydraulic shock phenomenon are:

- continuity equation

$$\frac{dh}{dt}+\frac{c^2}{g}\frac{dv}{dx}+\frac{\lambda v|v|}{2gd}=0 \tag{3}$$

- dynamic equation

$$\frac{dh}{dx}+\frac{1}{g}\frac{dv}{dt}=0 \tag{4}$$

where: v is speed, h-hydraulic load, c-the propagation speed of elastic waves, g-gravity acceleration, $\frac{\lambda v|v|}{2gd}$ - the friction.

The equation (3) and (4) may be replaced by two systems of equivalent ordinary differential equations:

– for direct characteristic:

$$C^{+}\begin{cases}\dfrac{dh}{dt}+\dfrac{c}{g}\dfrac{dv}{dt}=0\\[2mm]\dfrac{dx}{dt}=c\end{cases} \tag{5}$$

– for the reverse characteristic:

$$C^{-}\begin{cases}\dfrac{dh}{dt}-\dfrac{c}{g}\dfrac{dv}{dt}=0\\[2mm]\dfrac{dx}{dt}=-c\end{cases} \tag{6}$$

If the friction is taken into account, relations (5) and (6) become:

$$C^{+}\begin{cases}\dfrac{dh}{dt}+\dfrac{c}{g}\dfrac{dv}{dt}+\dfrac{c}{g}\dfrac{\lambda v|v|}{2d}=0\\[2mm]\dfrac{dx}{dt}=c\end{cases} \tag{7}$$

and

$$C^{-}\begin{cases}\dfrac{dh}{dt}-\dfrac{c}{g}\dfrac{dv}{dt}-\dfrac{c}{g}\dfrac{\lambda v|v|}{2d}=0\\[2mm]\dfrac{dx}{dt}=-c\end{cases} \tag{8}$$

2.2 The method of characteristics

Currently, the method of characteristics is the most widely-used method in the practical calculus of hydraulic shock by numerical simulation.

There are some advantages of this method. Among the advantages we mention:

- the accuracy of calculations is higher than the other methods, by keeping into account the terms with small share equations of motion;
- it's easier to handle the limit conditions and to program the complex pipes;

- loss of hydraulic load can be concentrated or uniformly distributed, showing the easer handling of the limit conditions.

This method presents a single disadvantage: the access to a computer system is necessary, so knowledge of a programming language is required.

To solve numerically the systems for a simple (ordinary) pipe (5) and (6), the length of pipe is divided into N equal sections, the length is $\Delta x = \frac{l}{N}$ and the time pitch is $\Delta t = \frac{\Delta x}{c}$.

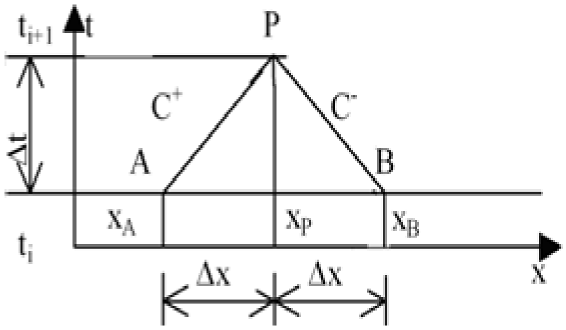

Fig. 1 Defining characteristic curves

Integrating the first equation from system (7), along direct characteristic C^+ between two points A and P (Fig. 1) we obtain:

$$\int_{h_A}^{h_P} dh + \frac{c}{g}\int_{v_A}^{v_P} dv + \frac{c\lambda}{2gd}\int_{t_A}^{t_P} v|v|dt = 0 \qquad (9)$$

which becomes:

$$h_P - h_A + \frac{c}{g}(v_P - v_A) + \frac{c\lambda}{2gd} v_A|v_A| \Delta t = 0 \qquad (10)$$

The second equation of the system (7), acquires the form:

$$x_P - x_A = c(t_P - t_A) \qquad (11)$$

Similarly, for the reverse curve we obtain the following relations:

$$h_P - h_B - \frac{c}{g}(\mathrm{v_P} - \mathrm{v_B}) - \frac{c\lambda}{2gd}\mathrm{v_B}|\mathrm{v_B}|\Delta t = 0 \qquad (12)$$

$$x_P - x_B = -c(t_P - t_B) \qquad (13)$$

Using equations (10), (11), (12) and (13) for the entire pipe, by dividing it into sections for calculation we obtain a network of features, which provides solutions to equations in each node of the network (Fig. 2). We start from known initial conditions for $t = T_0$, so we know the values of h and v in all sections of calculation, specifying the time of calculation and using the relations (10) and (12), the characteristic lines that pass through the initial sections are crossing in other sections.

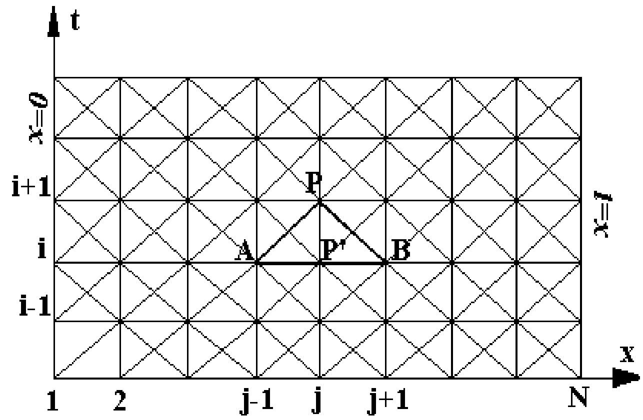

Fig. 2 Rectangular network characteristics

With the scheme from Fig.2, for calculating the speed and hydraulic load in any section j, and solving the equations (10), (12) and we get:

$$\mathrm{v}_{j,i+1} = \frac{1}{2}\left[v_{j-1,i} + v_{j+1,i} + \frac{g}{c}\left(h_{j-1,i} - h_{j+1,i}\right) - \frac{\lambda \Delta t}{2d}\left(v_{j-1,i}|v_{j-1,i}| + v_{j+1,i}|v_{j+1,i}|\right)\right] \qquad (14)$$

respectively

$$h_{j,i+1} = \frac{1}{2}\left[h_{j-1,i} + h_{j+1,i} + \frac{c}{g}\left(v_{j-1,i} - v_{j+1,i}\right) - \frac{c\lambda\Delta t}{2gd}\left(v_{j-1,i}|v_{j-1,i}| - v_{j+1,i}|v_{j+1,i}|\right)\right] \qquad (15)$$

where the first subscript from the relation (15) is for section position and the second for time.

With these relations we calculate quantities v and h, step by step in all sections at the j and i +1, depending on the corresponding known sizes of the preceding i.

The initial data of the problem are used for the first step of calculation. Using numerical methods for calculating virtually water hammer, Courant condition must be used in the following form:

$$\Delta t \le \frac{\Delta x}{c} \tag{16}$$

where sections of calculating length and speed are chosen different variables (air content in water of different diameter sections of calculation, etc.).

Duration of pressure wave propagation between sections of calculation is the same. Because at the time and a characteristic direct and reverse cross, the sections chosen account, choose a minimum time step and common to all sections of the pipeline [11]:

$$\Delta t_{\min} = \frac{\Delta x_{\min}}{c_{\max}} \tag{17}$$

This calculation will find new sections required for calculation of intermediate sections, achieving a network with fixed nodes and auxiliary nodes (Fig. 3 and Fig. 4).

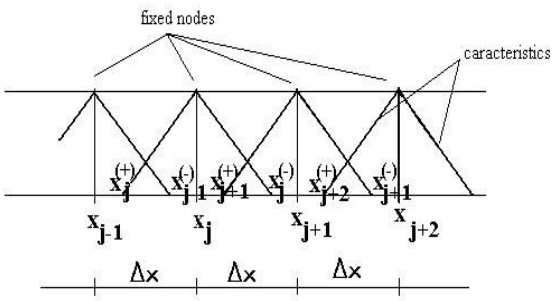

Fig. 3 Network with fixed and auxiliary nodes

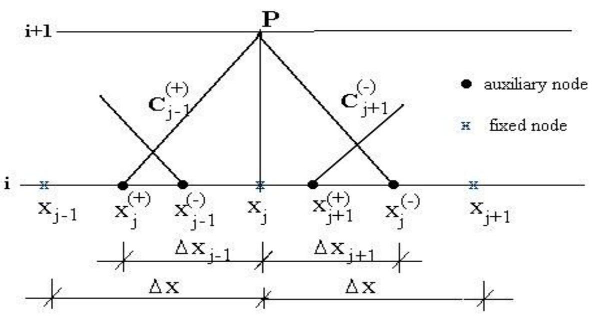

Fig. 4 Detail network nodes

By interpolation (Fig. 5), which is usually linear in supporting nodes, we obtain the following relations for h:

$$h_{j,i}^{(+)} = h_{j-1,i} + k_{j-1}^{(+)}(h_{j,i} - h_{j-1,i}) \tag{18}$$

$$h_{j,i}^{(-)} = h_{j+1,i} + k_{j+1}^{(-)}(h_{j,i} - h_{j+1,i}) \tag{19}$$

and for speed:

$$v_{j-1,i}^{(+)} = v_{j-1,i} + k_{j-1}^{(+)}(v_{j,i} - v_{j-1,i}) \tag{20}$$

$$v_{j+1,i}^{(-)} = v_{j+1,i} + k_{j+1}^{(-)}(v_{j,i} - v_{j+1,i}) \tag{21}$$

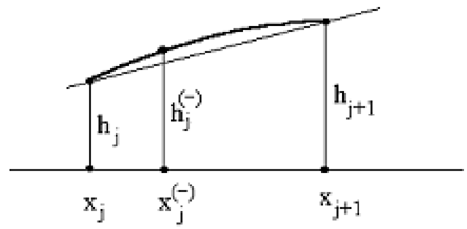

Fig. 5 Interpolation of h

The coefficients k are calculated with the formula:

$$\begin{aligned} k_{j-1}^{(+)} &= \frac{\Delta x - \Delta x_{j-1}}{\Delta x} = 1 - \frac{\Delta x_{j-1}}{\Delta x}, \\ k_{j+1}^{(-)} &= 1 - \frac{\Delta x_{j+1}}{\Delta x} \\ \Delta x_{j-1} &= c_{j-1}\Delta t_{\min}, \\ \Delta x_{j+1} &= c_{j+1}\Delta t_{\min} \end{aligned} \tag{22}$$

To determine the values of the point P in section j and time i +1 (Fig. 4), in addition to relations (10) ÷ (13), are necessary following relationships:

$$\mathrm{v}_{j,i+1} = \frac{1}{(c_{j-1} + c_{j+1})}\left[c_{j-1}v_{j-1,i}^{(+)} + c_{j+1}v_{j+1,i}^{(-)} + g\left(h_{j-1,i}^{(+)} - h_{j+1,i}^{(-)}\right) - \frac{\lambda\Delta t}{2}\left(\frac{c_{j-1}v_{j-1,i}^{(+)}\left|v_{j-1,i}^{(+)}\right|}{d_{j-1}} + \frac{c_{j+1}v_{j+1,i}^{(-)}\left|v_{j+1,i}^{(-)}\right|}{d_{j+1}}\right)\right] \tag{23}$$

$$\mathrm{h}_{j,i+1} = \frac{1}{(c_{j-1} + c_{j+1})}\left[c_{j+1}h_{j-1,i}^{(+)} + c_{j-1}h_{j+1,i}^{(-)} + \frac{c_{j-1}c_{j+1}}{g}\left(v_{j-1,i}^{(+)} - v_{j+1,i}^{(-)}\right) - \frac{\lambda\Delta t}{2g}\left(\frac{c_{j-1}v_{j-1,i}^{(+)}\left|v_{j-1,i}^{(+)}\right|}{d_{j-1}} - \frac{c_{j+1}v_{j+1,i}^{(-)}\left|v_{j+1,i}^{(-)}\right|}{d_{j+1}}\right)\right] \tag{24}$$

In previous relationships, the index (+) refers to direct feature corresponding auxiliary node, and (-) corresponding to the reverse feature.

2.3 Boundary conditions

The current practice of calculating the hydraulic shock in pressure hydraulic systems meet the following types of boundary conditions [16]:

2.3.1 End of downstream (upstream) section with the scheduled closing valve (Fig. 6).

In this case it has two equations - one describing the law of valve closure and the other the equations (10) or (12).

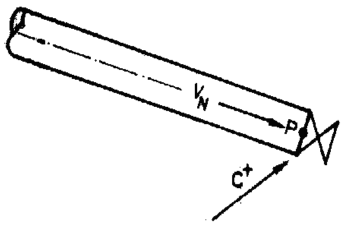

Fig. 6 The end of downstream (upstream) section with the scheduled closing valve

From equation of valve closing, the velocity $v_{N,\,i+1}$ is determined and from equation (10) results (it was considered an end section downstream):

$$h_{N,i+1} = h_{N-1,i} - \frac{c}{g}\left[\left(v_{N,i+1} - v_{N-1,i}\right) + \frac{\lambda}{2d} v_{N-1,i}\left|v_{N-1,i}\right| \Delta t\right] \tag{25}$$

2.3.2 The upstream end section (downstream) reservoir with constant level (Fig. 7).

In this case $h_{1,i+1} = h_{am} = const$ and is load of installation by the reference plane.

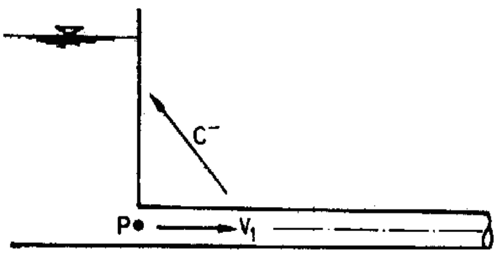

Fig. 7 The upstream (downstream) end section reservoir with constant level

From equation (12) follows (was considered upstream end section)

$$v_{1,i+1} = v_{2,i} + \frac{g}{c}\left(h_{1,i+1} - h_{2,i}\right) - \frac{\lambda}{2d} v_{2,i}\left|v_{2,i}\right| \Delta t \tag{26}$$

2.3.3 Section computing branch (Fig. 8).

Using the same notation as above, values of this section is calculated from the following system of equations:

$$v_{j_1,i+1} - v_{j_1-1,i} + \frac{g}{c}\left(h_{j_1,i+1} - h_{j_1-1,i}\right) + \frac{\lambda \Delta t}{2d} v_{j_1-1,i}\left|v_{j_1-1,i}\right| = 0 \tag{27}$$

$$v_{j_2,i+1} - v_{j_2+1,i} - \frac{g}{c}\left(h_{j,i+1} - h_{j_2+1,i}\right) + \frac{\lambda \Delta t}{2d} v_{j_2+1,i}\left|v_{j_2+1,i}\right| = 0 \tag{28}$$

$$v_{j_3,i+1} - v_{j_3+1,i} - \frac{g}{c}\left(h_{j,i+1} - h_{j_3+1,i}\right) + \frac{\lambda \Delta t}{2d} v_{j_3+1,i}\left|v_{j_3+1,i}\right| = 0 \tag{29}$$

$$v_{j_1,i+1} f_1 = v_{j_2+1,i} f_2 + v_{j_3+1,i} f_3 \tag{30}$$

where f1, f2, f3 are areas of pipe sections that determine node j.

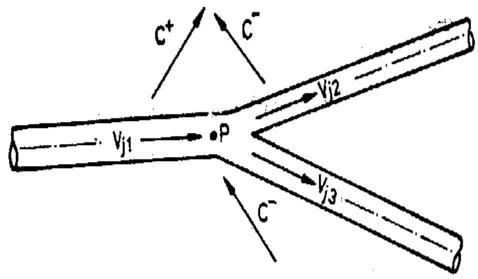

Fig. 8 Y-pipe calculation

2.3.4 Section of pipe union (Fig. 9).

As with the previous system resolved four equations:

$$v_{j_1,i+1} - v_{j_1-1,i} + \frac{g}{c}\left(h_{j_1,i+1} - h_{j_1-1,i}\right) + \frac{\lambda \Delta t}{2d} v_{j_1-1,i}\left|v_{j_1-1,i}\right| = 0 \tag{31}$$

$$v_{j_2,i+1} - v_{j_2-1,i} + \frac{g}{c}\left(h_{j,i+1} - h_{j_2-1,i}\right) + \frac{\lambda \Delta t}{2d} v_{j_2-1,i}\left|v_{j_2-1,i}\right| = 0 \tag{32}$$

$$v_{j_3,i+1} - v_{j_3+1,i} - \frac{g}{c}\left(h_{j,i+1} - h_{j_3+1,i}\right) + \frac{\lambda \Delta t}{2d} v_{j_3+1,i}\left|v_{j_3+1,i}\right| = 0 \tag{33}$$

$$v_{j_1,i+1} f_1 + v_{j_2+1,i} f_2 = v_{j_3+1,i} f_3 \tag{34}$$

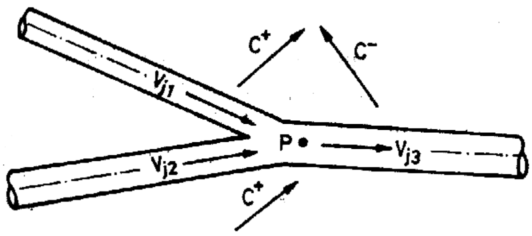

Fig. 9 Connection section calculation

2.3.5 Section of pipe flow calculation (fig. 10).

It's the case of pipe with liquid leakage due to broken pipe or a flow-controlled sampling.

To calculate the size, $v'_{j,i+1}$ $v''_{j,i+1}$, v_s and $h_{j,i+1}$ using equations (10) ÷ (13) and this specific case the following equations.

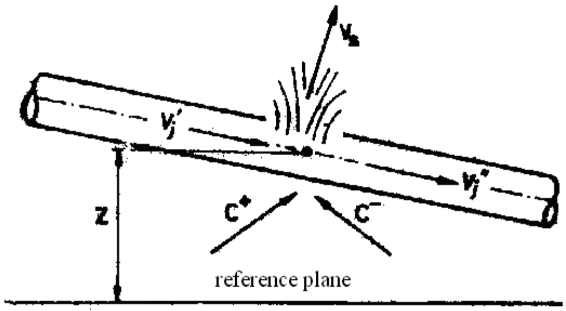

Fig. 10 Section of pipe leakage calculation

$$v_{s,i+1} = \sqrt{2g\left(H_{j,i+1} - Z_j\right)} \qquad (35)$$

$$\mathrm{v}'_{j_1,i+1} f_1 = \mathrm{v}''_{j,i+1} f_1 + \mathrm{v}_{s,i+1} f_s \qquad (36)$$

where v_s is the speed in the section of pipe leakage and f_s - sectional area of leakage.

2.3.6 Pump or turbine calculation section (Fig. 11).

To calculate the size $\mathrm{v}'_{j,i+1}$, $\mathrm{v}''_{j,i+1}$, $\mathrm{h}'_{j,i+1}$, $\mathrm{h}''_{j,i+1}$ and $\Delta\omega$ it has five equations, two of the form (10), (12) and the following relationships:

$$v'_{j_1,i+1} f_1 = v''_{j,i+1} f_2 \qquad (37)$$

$$\Delta\omega = \mp \frac{M_f}{J} \Delta t \qquad (38)$$

$$H_{util,i+1} = H'_{j,i+1} - H''_{j,i+1} = f(Q) \qquad (39)$$

where we used the usual notations: $\Delta\omega$ is rotation speed decrease (increase) of pump (turbine), M_f – brake moment given by the water flow through the pump (turbine) and $I = \dfrac{GD^2}{4g}$ - moment of inertia of rotating parts, where G - rotor weight, D - diameter. As shown, use the form feature turbo pump $H = f(Q)$.

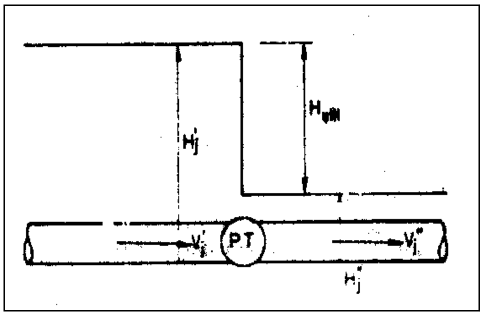

Fig. 11 Pump or turbine calculation section

2.3.7 Calculation section with sudden changing (Fig. 12).

It is the case of a sudden changing of calculation section, changing of pipe diameter, passing from left calculation section with the parameters $d_j^{(s)}$, $\lambda_j^{(s)}$, $c_j^{(s)}$ to the section with the parameters $d_j^{(d)}$, $\lambda_j^{(d)}$, $c_j^{(d)}$.

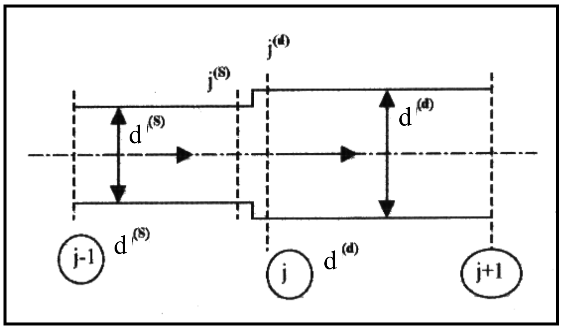

Fig. 12 Calculation scheme

$$v^{(d)}_{j,i+1} = \left\{1 + \frac{c_{j-1}}{c_{j+1}}\left(\frac{d_j^{(d)}}{d_j^{(s)}}\right)^2 + \xi\left[\left(\frac{d_j^{(d)}}{d_j^{(s)}}\right)^2 - 1\right]^2 \frac{\left|v^{(d)}_{j,i}\right|}{2c_{j+1}}\right\}^{-1} \times \left[v_{j+1,i} + \frac{c_{j-1}}{c_{j+1}} v_{j-1,i} + \frac{g\left(h_{j-1,i} - h_{j+1,i}\right)}{c_{j+1}} - \frac{\Delta t}{2}\left(\frac{c_{j-1}\lambda_{j-1} v_{j-1,i}\left|v_{j-1,i}\right|}{c_{j+1} d_j^{(s)}} + \frac{\lambda_{j+1}}{d_j^{(d)}} v_{j+1,i}\left|v_{j+1,i}\right|\right)\right] \qquad (40)$$

$$h^{(d)}_{j,i+1} = h_{j+1,i} + \frac{c_{j+1}\left(v^{(d)}_{j,i+1} - v_{j+1,i}\right)}{g} + \frac{c_{j+1}\lambda_{j+1}}{2gd_j^{(d)}} v_{j+1,i}\left|v_{j+1,i}\right|\Delta t \qquad (41)$$

$$v^{(s)}_{j,i+1} = v^{(d)}_{j,i+1}\left(\frac{d_j^{(d)}}{d_j^{(s)}}\right)^2 \qquad (42)$$

$$h_{j,i+1}^{(s)} = h_{j,i+1}^{(d)} + \xi \left[\left(\frac{d_j^{(d)}}{d_j^{(s)}} \right)^2 - 1 \right]^2 \frac{v_{j,i+1}^{(d)} \left| v_{j,i+1}^{(d)} \right|}{2g} \tag{43}$$

3 Presentation of the calculation

The presentation of the solutions of hydraulic shock problem, using numerical calculus by means of the characteristics method discussed in this paper, shows the need for the development of a computer program that automatically responds to the following requirements:

- easy management of several projects;
- easy introduction, editing and modification of data entry;
- proper display of the program output: the hydraulic load and speed every moment of time.

The program is written in Java programming language, high-level object-oriented programming language, developed by Java Soft, a group inside the Sun Microsystems company. The main characteristics are:

- Simplicity: it removes the so called benefits that may cause an ambiguous code (for instance, the multiple inheritance, the overloaded operators, etc);
- Completely object-oriented - it removes the procedural programming style;
- Dynamic language;
- Compiled and interpreted: Java source code compiles into portable byte codes that require an interpreter to execute them; this interpreter is called JRE (Java Runtime Environment);
- Robustness: it eliminates the most frequent sources of errors that may appear when writing code and it accomplishes this by removing pointers and by self-managing the memory through the instrumentality of garbage collector program that runs in background and removes those objects that aren't used anymore. A Java program that passes the compilation step will never break the system which it runs on;
- Very secure: it's one of the most secure programming language available, offering high level security tools like dynamic code checking, imposing strict rules for running programs on remote computers, etc;
- Portability: Java is an independent-platform programming language, namely, the same application can run without modifications on different systems like Windows, UNIX or Macintosh. This property brings hefty profits to companies that develop network application over the Internet.

The calculation was done to study the phenomenon of hydraulic shock in the following scheme:

- pump - pipeline - tank (PCR) without changing the section of the repression pipe;
- tank - pipe - valve (RCV) for a section of the pipeline;
- tank - pipe - valve (RCV Complex) changing the cross-section of the pipeline.

The existing data refer to the speed and hydraulic load values in sections along the pipe, by means of which we can appreciate the behavior of the system in a given situation. To solve the already mentioned objectives, the program was designed according to the logical schema in Fig. 13.

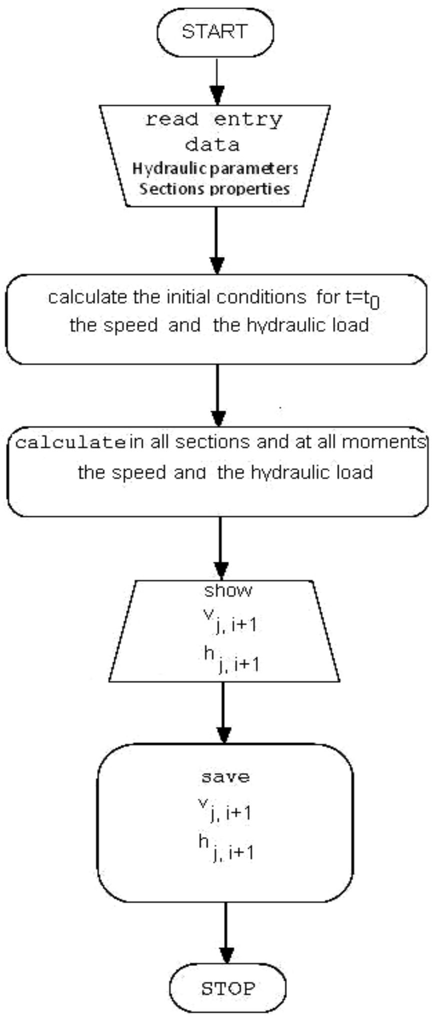

Fig. 13 Logical schema

Graphical interface (Fig. 14), which shows how easy is to use computer program, was programmed in Java.

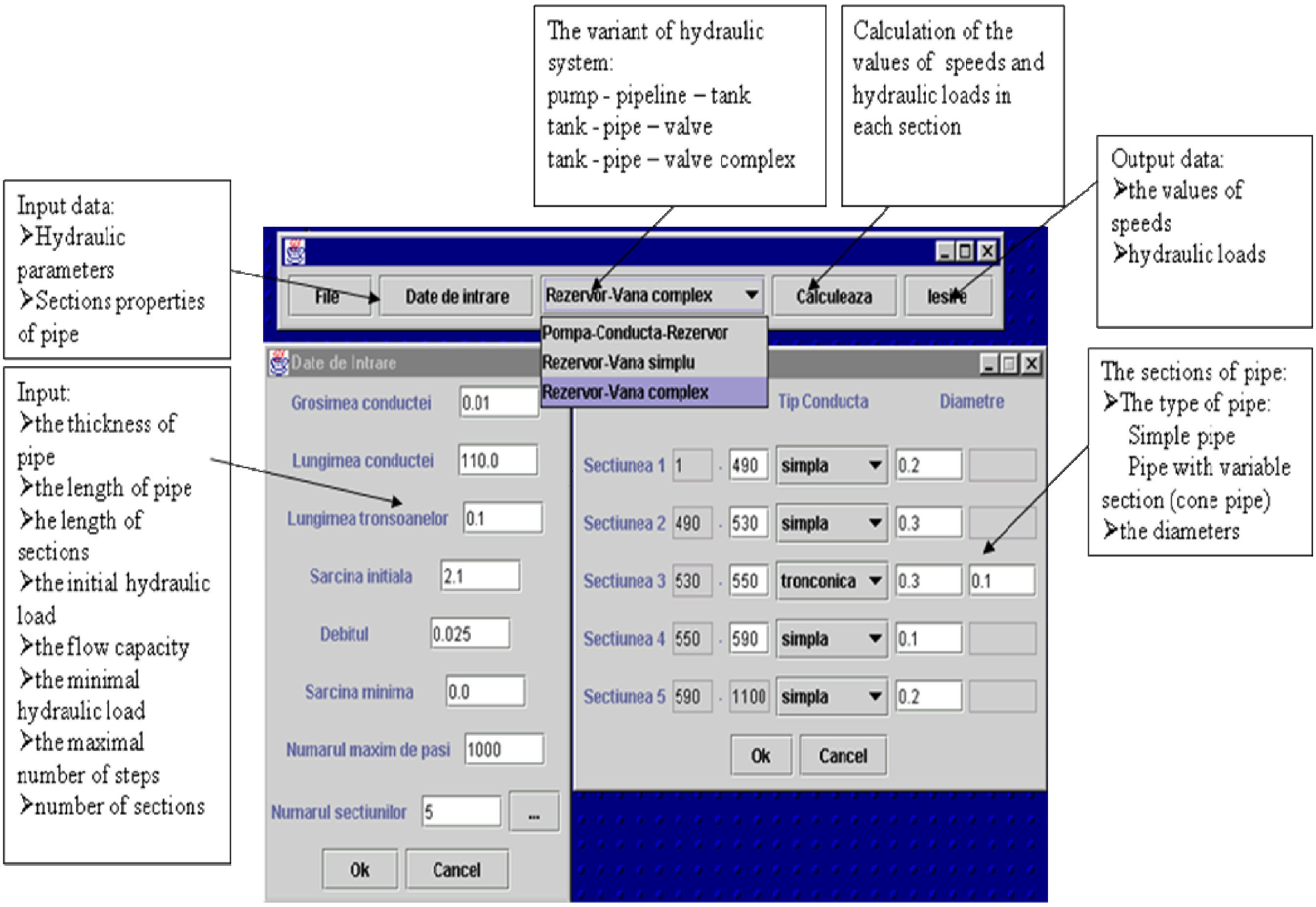

Fig. 14 Graphical interface

4 Numerical application

We consider a pumping installation with the follow parameters: the geodesic height Hg =30 m, the diameter of pipe D = 0,6m, the pumping flow Q = 0,848m^3/s, the roughness coefficient n = 0,012, the length of the calculus section $\Delta x = 80$ m.

It is considered an accidental closing of the check ball and the closing time of the check ball is 0,1 seconds and 5 seconds.

The maximal pressure in the section situated near the pump and the time which corresponds to the maximal pressure, in the situation without protection, is 248 mH_2O, respectively 180 mH_2O.

In table 1 we presented the maximal pressure in the section situated near the pump and the time which correspond to the maximal pressure in hydraulic system without protection against the hydraulic shock.

Table 1 Values of the maximal pressure, near pump

	closing time of check ball 0,1 s	closing time of check ball 5 s
p_{max} (m H_2O)	248	180
T (s)	12,5	12,5

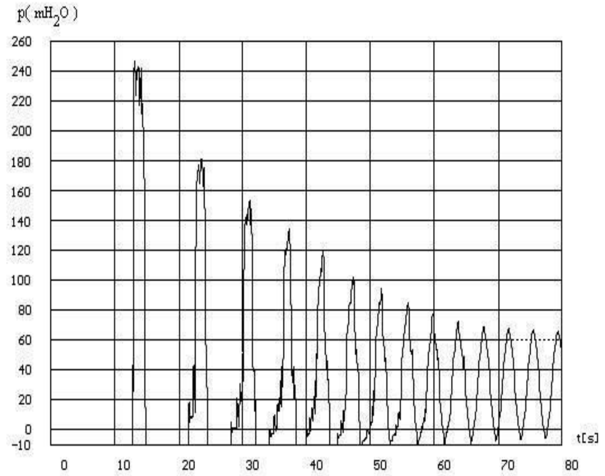

Fig. 15 Variation of pressure in time at the closing time of check ball 0,1 seconds

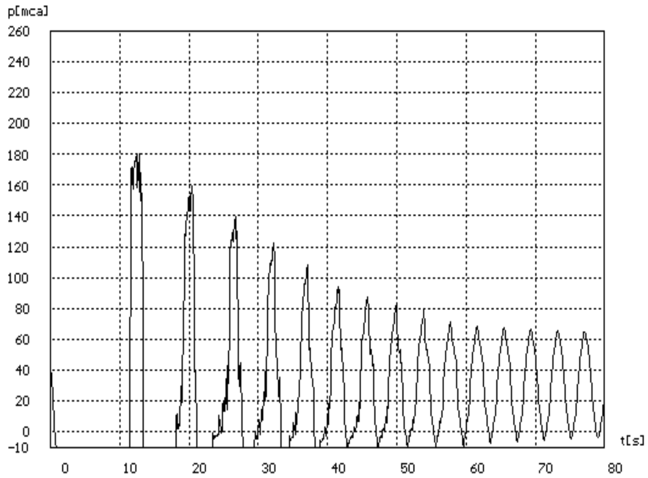

Fig. 16 Variation of pressure in time at the closing time of check ball 5 seconds

5 Conclusions

The presented software, written in Java language, allows the user to execute quickly and efficiently a complex algorithm over a large data set, having the results calculated in a short period of time (depending of the user computer resources) and registered in a text file in a specified location.

It has a graphical interface easy to apply by any user, containing the calculation of hydraulic shock phenomenon in the following scheme:

- pump - pipeline - tank (PCR) without changing the section of the repression pipe;
- tank - pipe - valve (RCV) for a section of the pipeline;
- tank - pipe - valve (RCV Complex) changing the cross-section of the pipeline.

The numerical example presents an application of this software and the results for two situation of closing of the check ball: 0,1 seconds and 5 seconds.

In the near future is aimed at expanding the software with subprograms on the situation in which hydraulic systems are provided with protection means.

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Appendix

The following symbols are used in this paper:

T_m – time of valve maneuver

l – length of pipe

v – speed (velocity)

h - hydraulic load,

c - propagation speed of elastic waves

x - distance along the pipe

t – time

p – absolute pressure

Δx - the length of the calculus section

Δt - time pitch

C^+ - direct characteristic

C^- - reverse characteristic

$\frac{\lambda v|v|}{2gd}$ - term of friction

λ - friction factor (Darcy's coefficient)

d - diameter of the pipe

g - acceleration due to gravity

$\Delta\omega$ - rotation speed decrease (increase) of pump (turbine)

M_f – brake moment given by the water flow through the pump (turbine)

I - moment of inertia of rotating parts

G - rotor weight

Q – pumping flow

H - pumping head

Subscripts

P point P at time $t+\Delta t$

A, B neighboring sections of P at the previous time t

min – minimum

max - maximum

i upstream node

j downstream node

0 steady-state condition

Superscripts

s - left calculation section

d - right calculation section

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