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NEW AUTOMATIC IMPULSE EXTINGUISHING DEVICE

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Abstract. A simple way to increase the extinguishing water surface area is to atomize water into fine drops. The smaller drops are developed, the better use of water properties can be implemented and less water is consumed in fire fighting. The automatic impulse extinguishing is created. The main aim of the investigation is to develop the approach to investigate the dynamic and hydrodynamic processes in the extinguishing device. The mathematical model of the extinguishing device is presented, where the flow of liquid and gas and the interaction of liquid with the gas are taken into account. The flow of fluids in a hydraulic system is described by a system of equations of a hyperbolic type, which is solved by a characteristics method. An instance of the mathematical simulation of the activity of extinguishing device is shown.

Keywords: extinguishing device, gas, liquid, dynamics, numerical methods.

1. Introduction

The extinguishing systems comprise systems designed for the supply of the extinguishing materials (extinguishants) to fight fires.

Water has been the most available and the most frequently used extinguishing material since times remembered. Water is distinguished for its distinctive physical and chemical qualities.

For instance, it is noted for its heat absorption characteristics that the majority of the natural substances lack.

For many years people have been trying to find better ways of delivering water to the scene of an accident and using it in the most effective way in fire fighting. It is not infrequent that damage resulting from inefficient application of water exceeds that done by fire to the burned down property and other valuables.

Water used in fire fighting tends to leak out and pollute the environment and severely deteriorate the ecological conditions in general. Although various up-to-date pumps, hoses, nozzles and sprayers are used to extinguish fires, water-based fire extinguishing technologies have not reached the top level of performance.

Even using the modern centrifugal pumps, it is not possible to prevent water spillage on the scene of a fire accident.

In fact, this leaking water is not involved in fire extinction but is being contaminated and wasted. This is due to the fact that part of this water fails to absorb the entire possible heat and tends to evaporate. This is also explained by the high tension of the water surface, which does not allow it to penetrate into the burning substances. It is evident that the more we will atomize the water, the more of the surface area we will be able to obtain from the same volume of water, which will directly contact with the fire heat and thus water properties will be used more efficiently.

For instance, if water was poured as if from the bucket, its features would be used only at 5 % efficiency.

Thus, the increase of the surface area of the extinguishing water augments the efficiency of the water consumption as well.

The simple way to increase the extinguishing water surface area is to atomize water into fine drops. The smaller drops are developed, the better use of water properties can be implemented and less water is consumed in fire fighting. The pressure energy of the pressurized and out-flowing water through the opening (i.e. fire nozzle) is transformed into jet kinetic energy. If we use the energy of the compressed air or other gases to eject water from the nozzle (instead of the compressed water energy) the jet speeds could be much faster.

The water droplet speed within the jet sprayed out in an ordinary way reaches tens m/s, while using the compressed air energy the water droplet speed can reach hundreds m/s. Furthermore, because of such speeds, water spray is atomized into fine droplets due to the air resistance (even up to 2 microns in diameter).

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Consequently, the extinguishing water cover area enlarges as well as the water efficiency. The devices with such properties can be usable in portable version.

This is very important to extinguishing small fires. Small fires by statistics reach more than 50 % of all fires. When water is supplied in fine droplets, it is possible to reach the use of all of its properties as close as 100 %. In addition, the factor of the possible damage of the property and other valuables by water flooding is eliminated completely: facilities that are not within the extinguishing area remain safe from being flooded.

The majority of fires could be addressed while using portable effective extinguishing devices.

An automatic hydraulic and pneumatic nozzle consists of a water chamber (1), a compressed air chamber (2), a fast response valve (3), a fast response valve automatic control mechanism (4), and compressed air and water sources. The water chamber (1) is supplied from water source or reservoir; the compressed air chamber (2) is supplied from the compressed air source or reservoir.

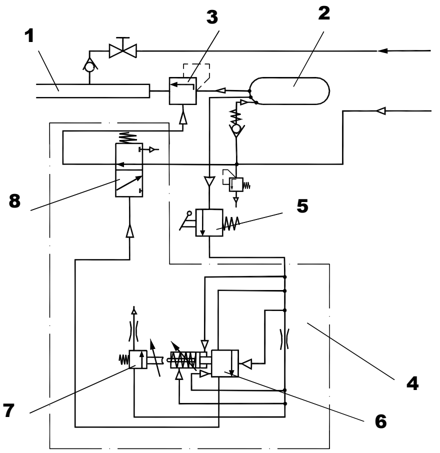

Fig. 1. Schematic view of automatic hydraulic and pneumatic nozzle

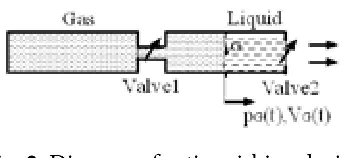

Fig. 2. Diagram of extinguishing device

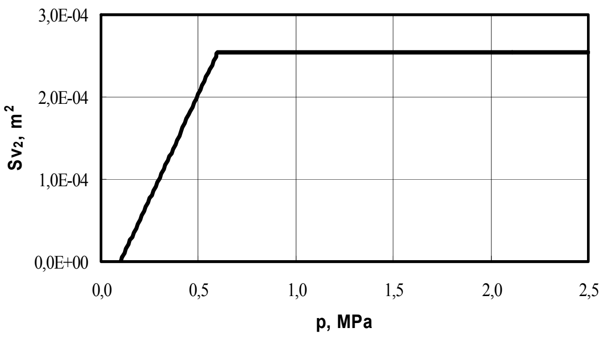

Fig. 3. Dependence of cross-section area of the second valve on pressure

The expanding air expels water from the water chamber (1) due to that water jet is divided into fine droplets. After having activated the fast response valve automatic control mechanism (4) the process is repeated constantly and water jets are ejected in series Fig. 1 (Bogdevičius and Suslavičius 2007).

2. Mathematical model of extinguishing device

The extinguishing device consists of two chambers (air container and water compartment) and two valves. The first valve is the fast reaction valve. The second valve opens when the pressure reaches a particular amount of pressure. When the fast reaction valve begins to open, the second chamber divides into two volumes. In the first volume there is high pressure of air and in the second volume there is high pressure of water. The dynamic model of the extinguishing device is shown in Fig. 2.

Cross-section area S_{v1} of the first valve is the function of time. Cross-section area S_{v2} of the second valve depends on the pressure $p(t, x = L_2)$ (Fig. 3). The second air volume and water compartment are separated by the surface G (Fig. 2). According to the first law of thermodynamics, the whole thermal energy moved with gas is spent for the change of the internal energy and for the work of the expansion of gas in a volume.

The continuity and movement equations of viscous and compressible fluid in a pressure pipe have the following form (Bogdevičius 1991, 1999, 2000; Bogdevičius *et al.* 2004):

$$\frac{\partial}{\partial t}\big(S(x)\rho\big)+\frac{\partial}{\partial x}\big(S(x)\rho v\big)=0, \tag{1}$$

$$\frac{\partial}{\partial t}\big(S(x)\rho v\big)+\frac{\partial}{\partial x}\Big(S(x)\big(p+\rho v^2\big)\Big)+ \Pi(x)\tau+\rho S(x)a_x+\rho g S(x)\sin(\theta)- p\frac{\partial S(x)}{\partial x}=0, \tag{2}$$

where: ρ, v are density and velocity of fluid, (gas and liquid); τ is tangential liquid stress at the inner surface of a pipeline; $S(x)$ is the cross-section area of a pipeline; $\Pi(x)$ is the perimeter of the cross- section of a pipeline.

An equation of one-dimensional movement of gas and liquid can be written as the system of quasi-linear differential equations:

$$\frac{\partial\{u\}_g}{\partial t}+[B]_g\frac{\partial\{u\}_g}{\partial x}=\{f\}_g; \tag{3}$$

$$\frac{\partial\{u\}}{\partial t}+[B]\frac{\partial\{u\}}{\partial t}=\{f\}, \tag{4}$$

where:

$$[B]_g=\begin{bmatrix} v_g & c_g^2\rho_g \\ \dfrac{1}{\rho_g} & v_g \end{bmatrix}; \tag{5}$$

$$\{u\}_g^T = \begin{bmatrix} p_g & v_g \end{bmatrix};$$

$$\{f\}_g = \begin{Bmatrix} -\dfrac{c_g{}^2 \rho_g v_g}{S(x)} \dfrac{\partial S(x)}{\partial x} \\ -g\sin(\theta) - \dfrac{\lambda(\mathrm{Re},\Delta)|v_g|v_g}{2D} - a_{gx}(t) \\ +\dfrac{p_g}{\rho_g S(x)} \dfrac{\partial S(x)}{\partial x} \end{Bmatrix};$$

$$[B] = \begin{bmatrix} v & c^2\rho \\ \dfrac{1}{\rho} & v \end{bmatrix}; \qquad (6)$$

$$\{u^T\} = \begin{bmatrix} p & v \end{bmatrix};$$

$$\{f\}^T = \begin{Bmatrix} -\dfrac{c^2 \rho v}{S(x)} \dfrac{\partial S(x)}{\partial x} \\ -g\sin(\theta) - \dfrac{\lambda(\mathrm{Re})|v|v}{2D} - a_x(t) + \\ \dfrac{p}{\rho S(x)} \dfrac{\partial S(x)}{\partial x} \end{Bmatrix},$$

where: v_g, p_g and v, p are velocity and pressure of gas and liquid, respectively; c_g, c are sound velocity of the gas and liquid, which is stored in the elastic pipeline and is equal to:

$$c_g = \sqrt{\gamma R T};$$

$$c = \sqrt{\frac{\frac{K(p)}{\rho}}{1 + \dfrac{K(p)d}{Ee} + \dfrac{\varepsilon}{\gamma}\left(\dfrac{K(p)}{\gamma p} - 1\right)}}, \qquad (7)$$

where: $K(p)$ is the bulk modulus of elasticity of liquid; ρ is the density of liquid; E is the modulus of elasticity of a pipeline; d is internal diameter of a pipeline; e is the thickness of a wall of a pipeline; γ is the index of adiabatic process; ε is the ratio of gas volume in the liquid and the total volume of liquid (mixture); T is the temperature of fluid; a_{gx}, a_x are the acceleration along x axis, respectively.

The change of pressure in the volume is determined by the following equation:

$$\frac{dp}{dt} = \frac{\gamma R T}{V}\left(G_{in}(p, p_{in}) - G_{out}(p, p_{out})\right) - \frac{\gamma p}{V}\frac{dV}{dt}, \qquad (8)$$

where: G_{in} is the input mass flow; G_{out} is the mass flow of gas (air), determined by the formula of Sen-Venan and Vencel (Богдявичюс 1997):

$$G_{out}(p, p_{out}) = \begin{cases} \mu_1 S_{v1}(t) K_1(T) p \varphi\left(\sigma = \dfrac{p_{out}}{p}\right) & \text{if } p \ge p_{out}, \\ \mu_1 S_{v1}(t) K_1(T) p_{out} \varphi\left(\sigma = \dfrac{p}{p_{out}}\right) & \text{if } p_{out} > p, \end{cases}$$

$$K_1(T) = \sqrt{\frac{2\gamma}{(\gamma - 1) R T}}, \qquad (9)$$

where: S_{v1} is the cross-section area of first valve; μ_1 is the orifice discharge coefficient; R is gas constant; T is the temperature of gas in the air container. To take account of the subsonic and sonic flow, the piecewise flow function $\varphi(\sigma)$ is defined as follows:

$$\varphi(\sigma) = \begin{cases} \sqrt{\left(\dfrac{2\gamma}{\gamma - 1}\right)\left(\sigma^{\frac{2}{\gamma}} - \sigma^{\frac{\gamma+1}{\gamma}}\right)}, & \text{if } \sigma_{cr} < \sigma \le 1, \\ \sqrt{\gamma\left(\dfrac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}}}, & \text{if } 0 < \sigma \le \sigma_{cr}, \end{cases} \qquad (10)$$

where σ_{cr} is the critical pressure ratio given by:

$$\sigma_{cr} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}.$$

The diagram of forces acting on the extinguishing device when out-flowing water through the opening (i.e. fire nozzle) valve is shown in Fig. 4.

The recoil force acting along the extinguishing device axis is equal to:

$$F_x = -S_{v1}(p_1 - p_2) + (S_2 - S_{v2}) p_{lyq}(x_G) - F_{aero}; \qquad (11)$$

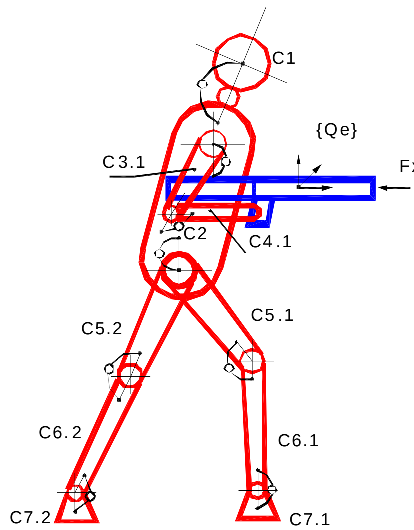

Fig. 4. Diagram of forces acting on the extinguishing device and fireman

$$F_{aero} = \begin{cases} \frac{1}{2}\rho S_{v2} v_{2,}^2 & \text{if} \quad x_G \le L_2, \\ \frac{1}{2}\rho_{gas} S_{v2} v_{2,}^2 & \text{if} \; x_G > L_2, \end{cases}$$

where: ρ_{gas} is the density of gas; L_2 is the length of pipeline (second chamber).

The System of equations describing the movement of the extinguishing device and fireman is as follows:

$$\begin{bmatrix} [M] & [J]^T \\ [J] & [0] \end{bmatrix} \begin{Bmatrix} \ddot{q} \\ \zeta \end{Bmatrix} = \begin{Bmatrix} F(q,\dot{q},t) \\ u(q,\dot{q}) \end{Bmatrix}, \qquad (12)$$

where: $[M]$, $[J]$ are the matrices of mass and the Jacobian matrix, respectively; $\{q\}$, $\{\dot{q}\}$, $\{\ddot{q}\}$ are vectors of displacement, velocity and acceleration, respectively; $\{F(t, q, v)\}$ is vector of external forces and moments; $\{\zeta\}$ is vector of Lagrange multipliers; $u(q, \dot{q})$ is vector:

$$\{u(q,\dot{q})\} = -\frac{\partial}{\partial\{q\}^T}\left(\left[\frac{\partial\{\Phi\}}{\partial\{q\}^T}\right]\{\dot{q}\}\right)\{\dot{q}\} - 2\left[\frac{\partial^2\{\Phi\}}{\partial\{q\}^T\partial t}\right]\{\dot{q}\} - \frac{\partial^2\{\Phi\}}{\partial t^2},$$

where $\{\Phi\}$ is vector of constraints.

3. Representation of results

An example of the extinguishing device is considered. The presented dynamic model of automatic impulse extinguishing is solved with *Maple* software (Аладьев, Богдявичюс 2001).

The following data of the extinguishing device were used: the length of the water compartment is 0.25 m, the volume of the air container is equal to $V_1 = 1.5 \cdot 10^{-3}$ m^3, the initial pressure in the air container is 2.50 MPa, the inner diameter of the water compartment is equal to 0.0250 m. The time integration step is equal to $2.0 \cdot 10^{-6}$ s.

The displacements of valves of the automatic control mechanism are shown in Fig. 5.

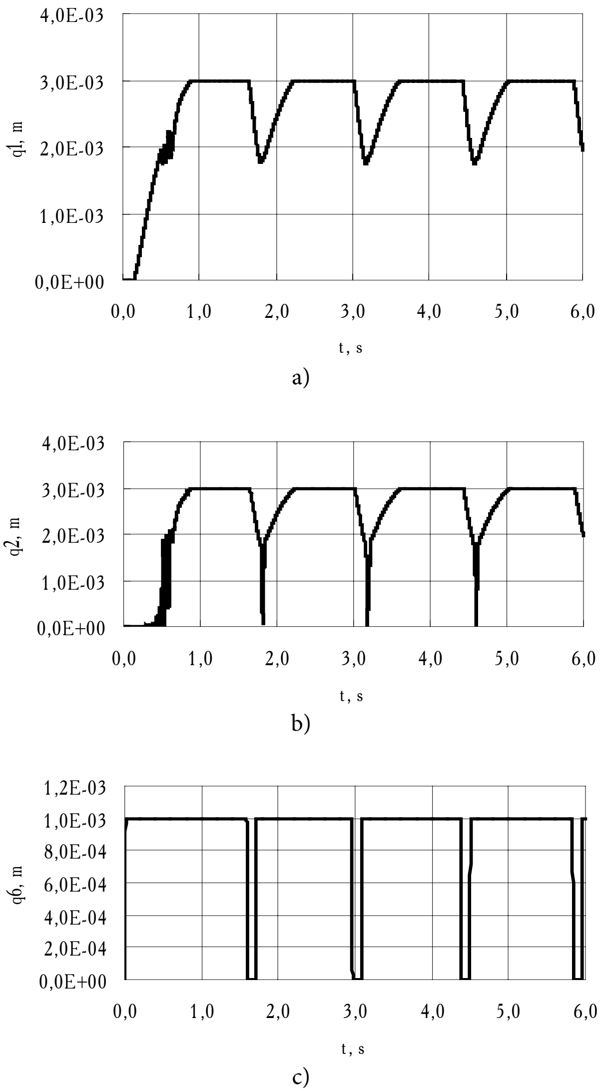

Fig. 5. Dependence of displacements of valves of automatic control mechanism upon time: a – first mass of valve 6; b – second mass of valve 6; c – fast response valve 3

4. Conclusions

- A new automatic impulse extinguishing device is created.
- The approach for simulating hydrodynamic processes of the extinguishing device has been developed.
- The composed mathematical model of the extinguishing device takes into account wave motion of a liquid.
- The differential equations, describing hydrodynamic processes inside the extinguishing device, help analyze the movement of liquid and gas better and more precisely.
- The period of vibration of fast response valve is about 1.4 s and this time can be regulated by changing stiffness of the valves.
- At the end of a pipeline of the extinguishing device the maximum velocity of liquid reaches 60 m/s.

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