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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.

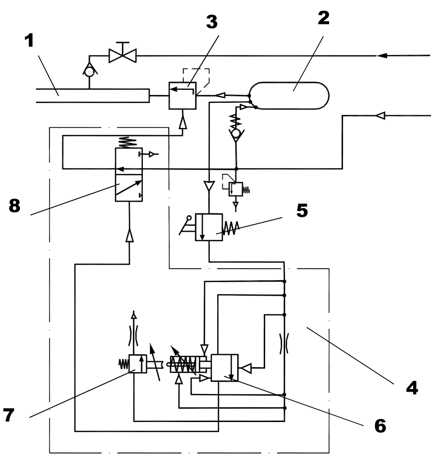

Fig. 1. Schematic view of automatic hydraulic and pneumatic nozzle

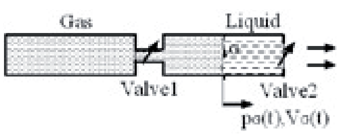

Fig. 2. Diagram of extinguishing device

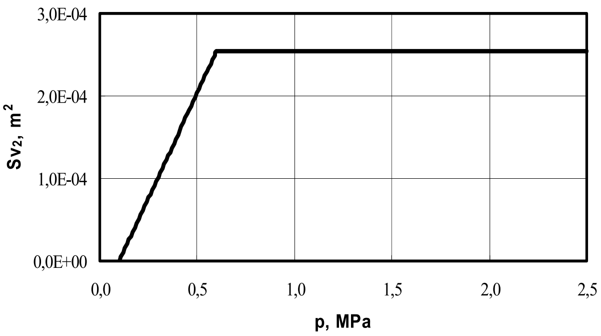

Fig. 3. Dependence of cross-section area of the second valve on pressure

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:

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

$$\{u\}_g^T = \left[p_g \;\; v_g \right];$$

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

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

$$\{u^T\} = [p \;\; v];$$

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

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:

$$c_g = \sqrt{\gamma RT};$$

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

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:

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

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):

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

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

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:

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

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:

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

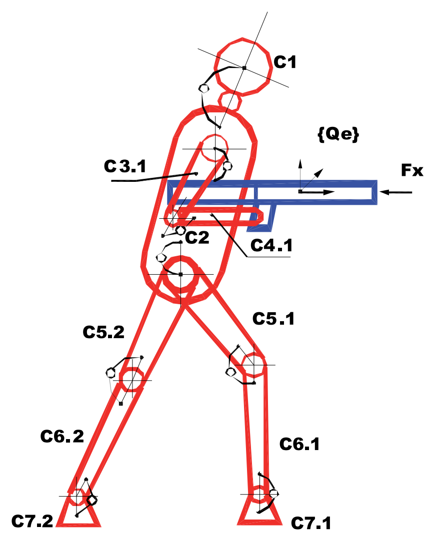

Fig. 4. Diagram of forces acting on the extinguishing device and fireman

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

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.

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.

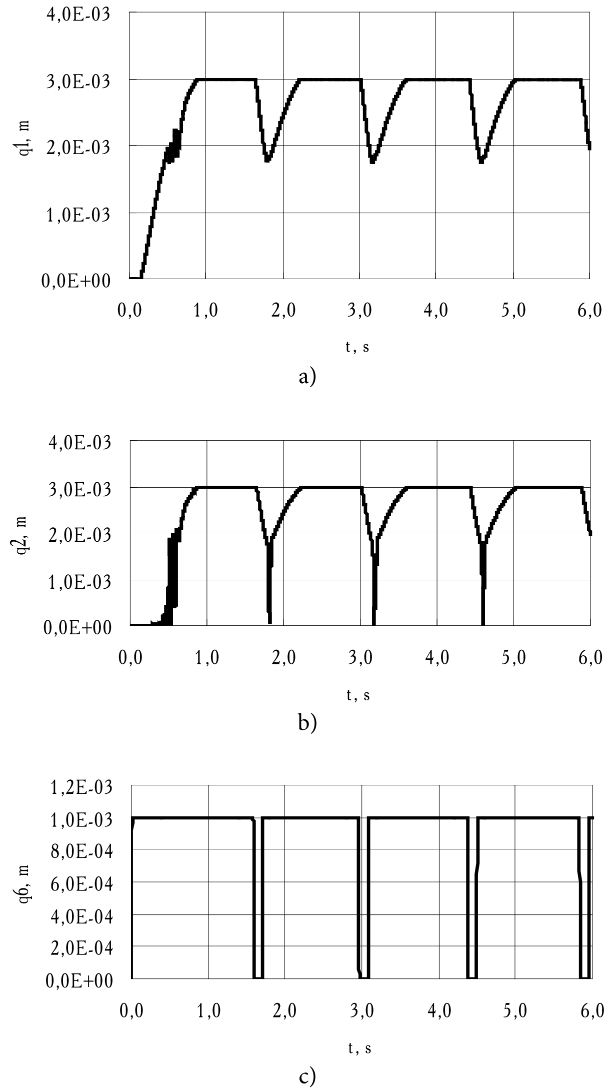

Fig. 5. Dependence of displacements of valves of automatic control mechanism upon time: a – first mass of valve 6; b – second mass of valve 6; c – fast response valve 3

- At the end of a pipeline of the extinguishing device the maximum velocity of liquid reaches 60 m/s.

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INVESTIGATION OF HYDRODYNAMIC PROCESSES OF THE EXTINGUISHING DEVICE

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Abstract. The main aim of the investigation is to develop an approach to investigate hydrodynamic processes in the extinguishing device. The mathematical model of the extinguishing device is presented where the flow of fluid and gas and the interaction of liquid with gas are taken into account. The flow of fluid 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 extinguishing device is shown. The dependence of recoil force is obtained.

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

1. Introduction

Extinguishing systems comprise systems designed for the supply of extinguishing materials (extinguishants) to fight fires. Water is 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 natural substances lack. For many years people have been trying to find better ways of delivering water to the scene of an accident and to use it in the most effective way in fire fighting. It is not infrequent that damages resulting from inefficient application of water exceed those 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 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 water surface which does not allow it to penetrate into the burning substances. It is evident that the more we 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 were 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. A simple way to increase the extinguishing water surface area is to atomize water into fine drops. The smaller the drops are developed, the better use of the 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 through the nozzle (instead of the compressed water energy) the jet speeds will 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 air resistance (even up to 2 microns in diameter). Consequently, the extinguishing water covered area enlarges as well as the water efficiency. The devices with such properties can be usable in portable version. That is very important for 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.

The extinguishing device based on the use of the compressed air energy for ejecting extinguishing water could be expressed as follows (Fig 1):

- Compressed air compartment is filled up from the air container;
- Water compartment is filled up from the water tank;
- When the fast reaction valve is opened, compressed air and water compartments get merged;
- Water being under air pressure is ejected within a very short time (from several to several tens of mili-seconds) to the focus of fire;
- Further on the process is repeated from the beginning.

Studies of such extinguishing technologies have not been completed yet and need to be further updated and tested. The main parts of the investigation are:

- Process of extinguishing (water) media delivery to fire;

Recoil of the extinguishing device during operation.

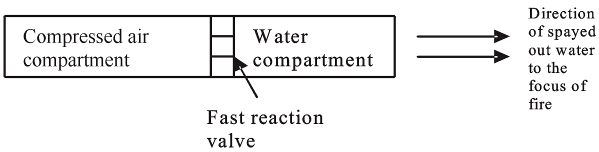

Fig 1. Principle scheme of the extinguishing device based on the use of compressed air energy

2. Mathematical model of the extinguishing device

The extinguishing device consists of two chambers (air container and water compartment) and two valves. The first valve is a fast reaction valve. The second valve opens when pressure reaches particular 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.

A dynamic model of the extinguishing device is shown in Fig 2. In the air container the pressure is $p_1(t)$ and the volume of air container is V_1.

Cross-section area Sv_1 of the first valve is function of time (Fig 3). Cross-section area Sv_2 of the second valve depends on pressure $p(t, x = L)$ (Fig 4). In the second air volume $V_2(t)$ the pressure is $p_2(t)$. The second air volume and water compartment

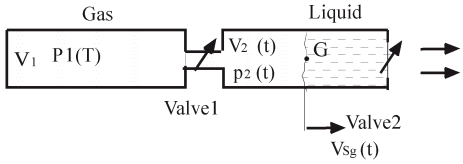

Fig 2. Diagram of the extinguishing device

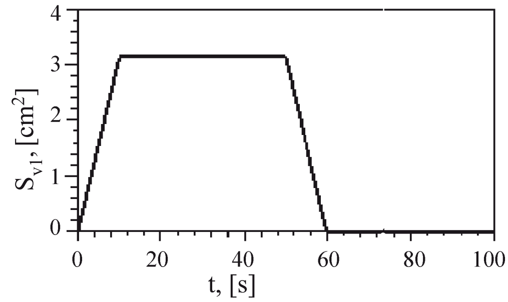

Fig 3. Cross-section area of the first valve

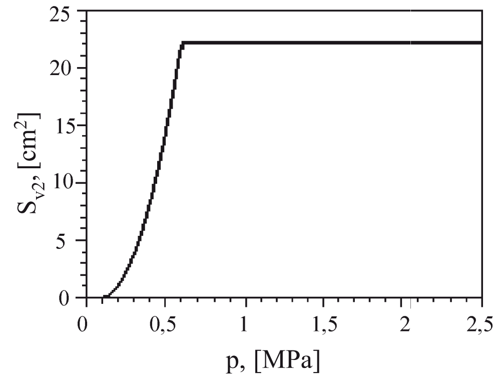

Fig 4. Cross-section area of the second valve

are separated by surface G (see Fig 2). According to the first law of thermodynamics the whole thermal energy moved with gas is spent for the change of internal energy and for the work of the expansion of gas in volume.

The change of pressure of constant volume ($V_1 = const$) of air container is determined from the following equation:

$$\frac{dp_1}{dt} = -\frac{\gamma R T_1}{V_1} G_{12}, \tag{1}$$

where G_{12} is mass charge of gas (air), determined by the formula Sen-Venan and Vencel [1]:

$$G_{12} = \mu_1 S_{v1} p_1 K_1(T_1)\varphi\left(\sigma = \frac{p_2}{p_1}\right);$$

$$K_1\ (T) = \sqrt{\frac{2\gamma}{(\gamma-1)RT_1}};$$

$$\varphi(\sigma)=\sqrt{\sigma^{\frac{2}{\gamma}}-\sigma^{\frac{\gamma+1}{\gamma}}}\,, \qquad (2)$$

S_{v1} is cross-section area of the first valve; μ_1 is factor of the charge; γ – ration of specific heat; R – gas constant; T – temperature.

The change of pressure of the second volume is determined from the following equation:

$$\frac{dp_2}{dt} = \frac{\gamma RT_1}{V_2(t)}G_{12}-\frac{\gamma p_2}{V_2(t)}\frac{dV_2}{dt}\,, \qquad (3)$$

where $V_2(t)=V_{20}+Sx_G$; V_{20} is initial volume; S is cross-section area; x_G is coordinate of point G (see Fig 2).

The liquid movement is considered as one-dimensional, i.e. all local velocity is equal to average velocity and unsettled. Velocity and pressure depend on longitude coordinate and time. Such liquid movement is characterized by the wave of increased and reduced pressure which spreads from the place of change in each pressure vibration cross-section and in deformation of pipeline walls.

The movement and continuity equations of viscous, compressible fluid in a pressure pipe have the following form [1–3]:

$$\frac{\partial}{\partial t}[S(x)\rho]+\frac{\partial}{\partial x}[S(x)\rho v]=F_1(x), \qquad (4)$$

$$\frac{\partial}{\partial t}[S(x)\rho v]+\frac{\partial}{\partial x}\left[S(x)\left(p+\rho v^2\right)\right]=F_2(p,v), \qquad (5)$$

where ρ is density of liquid.

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

$$[A]\left\{\frac{\partial u}{\partial t}\right\}+[B]\left\{\frac{\partial u}{\partial x}\right\}=\{f\}, \qquad (6)$$

where

$$[A]=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix};\quad [B]=\begin{bmatrix}v & a^2\rho\\ \frac{1}{\rho} & v\end{bmatrix},\ \{u\}^T=[p,v], \qquad (7)$$

v, p – speed and fluid pressure; a is sound velocity in the liquid with a certain amount of gas, which is stored in the elastic pipeline, is equal to:

$$a=\sqrt{\frac{K(p)/\rho}{1+\frac{K(p)\cdot d}{E\cdot e}+\frac{\varepsilon}{\gamma}\left[\frac{K(p)}{\gamma p}-1\right]}}\,, \qquad (8)$$

where $K(p)$ – bulk modulus of elasticity of liquid, ρ – density of liquid, E – modulus of elasticity of a pipeline, d – internal diameter of a pipeline, e – thickness of a wall of a pipeline, γ – index of adiabatic process, ε – ratio of gas volume in the liquid and the total volume of liquid (mixture).

Differential equations of liquid movement in the cylinder are solved by a characteristic method [1, 2]. The main idea of the characteristic method is the fact that unknown variable speed and liquid pressure at instant moment of time $t+\Delta t$ are determined according to these parameters at the moment of time (Fig 5).

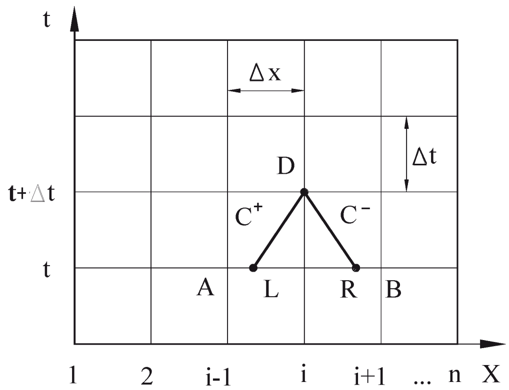

Fig 5. Circuit of liquid parameters determination of point D

Equating the determinant of matrix (13) to zero, we shall receive the equation:

$$\left|[B]-[A]\frac{dx}{dt}\right|=0 \qquad (9)$$

which allows to determine $\frac{dx}{dt}$ derivative which determines characteristic direction. If this equation has n various real roots $dx/dt=\lambda_i$ (i = 1, 2), the initial system of the differential equations is referred to as hyperbolic. The inclination tangent λ_i to the characteristic depends not only on coordinates, but also on solution $\{u\}$.

Inserting expressions $[A]$ and $[B]$ from matrices (7) into equation (9) and having solved it, we receive three equations of characteristics

$$C^+:\frac{dx}{dt}=v+a\,;\ C^-:\frac{dx}{dt}=v-a\,. \qquad (10)$$

Compatibility conditions of characteristics are equal to [4–6]:

$$C^+:\frac{dv}{dt}+\frac{1}{a\rho}\frac{dp}{dt}=\frac{f_1}{a\rho}+f_2, \qquad (11)$$

$$C^-:\frac{dv}{dt}-\frac{1}{a\rho}\frac{dp}{dt}=-\frac{f_1}{a\rho}+f_2\,, \qquad (12)$$

$$\{f\}=\left\{\begin{matrix} 0 \\ -\frac{\tau\Pi(x)}{S(x)\rho}-a_x \end{matrix}\right\}, \quad (13)$$

where τ – shear stresses on the inner surface of pipeline; a_x – acceleration along x axis; $S(x)$ and $\Pi(x)$ are cross-section area and perimeter of pipeline.

Pressure and velocity at point D at the moment of time are determined from nonlinear algebraic equation system

$$C^+ : \Phi_1 = v_D - v_L + \frac{1}{2}(p_D - p_L)[r_{1L} + r_{1D}] - \frac{\Delta t}{2}[r_{2L} + r_{2D}] - \frac{\Delta t}{2}[r_{3L} + r_{3D}] = 0, \quad (14)$$

$$C^- : \Phi_2 = v_D - v_R - \frac{1}{2}(p_D - p_R)[r_{1R} + r_{1D}] + \frac{\Delta t}{2}[r_{2R} + r_{2D}] - \frac{\Delta t}{2}[r_{3R} + r_{3D}] = 0, \quad (15)$$

where $r_1 = \frac{1}{\rho a}$; $r_2 = -a^2 \rho v \frac{dS}{dx} / S$;

$$r_3 = -a_x - \frac{\Pi\lambda(Re)v|v|}{8S};$$

$$\lambda(Re)=\begin{cases} \frac{75}{Re}, when \quad Re \le 2320; \\ \frac{0,31464}{Re^{0,25}}, when \quad Re > 2320, \end{cases} \quad (16)$$

$\lambda(Re)$ is coefficient of pressure losses along a pipe.

The system of equations (2) and (3) is solved by Newton method:

$$[J]_i \{\Delta Y\}_i = -\{\Phi(Y)\}_i, \quad (17)$$

where $\{Y\}^T = [p_D, v_D]$; $\{\Phi\}^T = [\Phi_1, \Phi_2]$.

The potential energy of the gas in a high-pressure volume is transformed to kinetic energy of the liquid. For accuracy the simulation of the interaction of the gas with liquid in the case of interaction is considered (Fig 6). At point G pressure p_{SG} and velocity v_{SG} are determined from the system of equations (3) and (15). The x coordinate of point G is determined from the following expression:

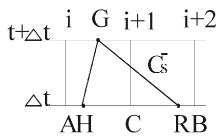

Fig 6. Circuit of liquid parameters determination at point G

$$x_G(t+\Delta t) = x_H(t) + \Delta t v_{SG}. \quad (18)$$

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 7.

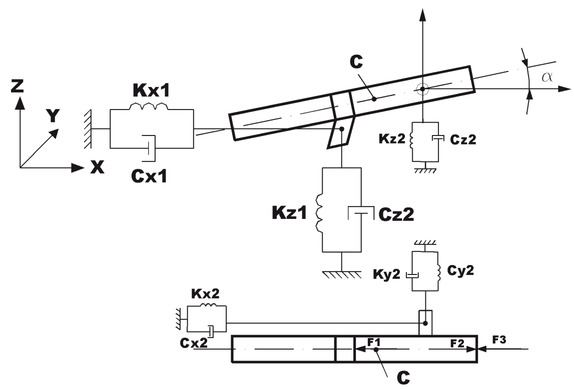

Fig 7. Diagram of forces acting on the extinguishing device

The system of equation describing the extinguishing device is as follows:

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = \{F(t, p, v)\}, \quad (19)$$

where $[M], [C], [K]$ are matrices of mass, damping, stiffness, respectively; $\{q\}, \{\dot{q}\}, \{\ddot{q}\}$ are vectors of displacement, velocity and acceleration, respectively; $\{F(t, p, v)\}$ is vector of forces and moments.

3. Numerical results

An example of the extinguishing device is considered. The following data of the extinguishing device were used: the length of water compartment is 0,420 m, the volume of air container is equal to $1,5 \cdot 10^{-3}$ m^3, initial pressure in the air container is 2,50 MPa, inner diameter of water compartment is equal to 0,060 m. Time integration step is equal to $2,0 \cdot 10^{-6}$ s. The length of water compartment is divided in to 84 elements [7].

The simulation results of hydrodynamic parameters are given in Fig 8.

The forces acting on the extinguishing device are shown in Fig 9 and Fig 10.

The displacement and velocity of the extinguishing device are shown in Fig 11 and Fig 12.

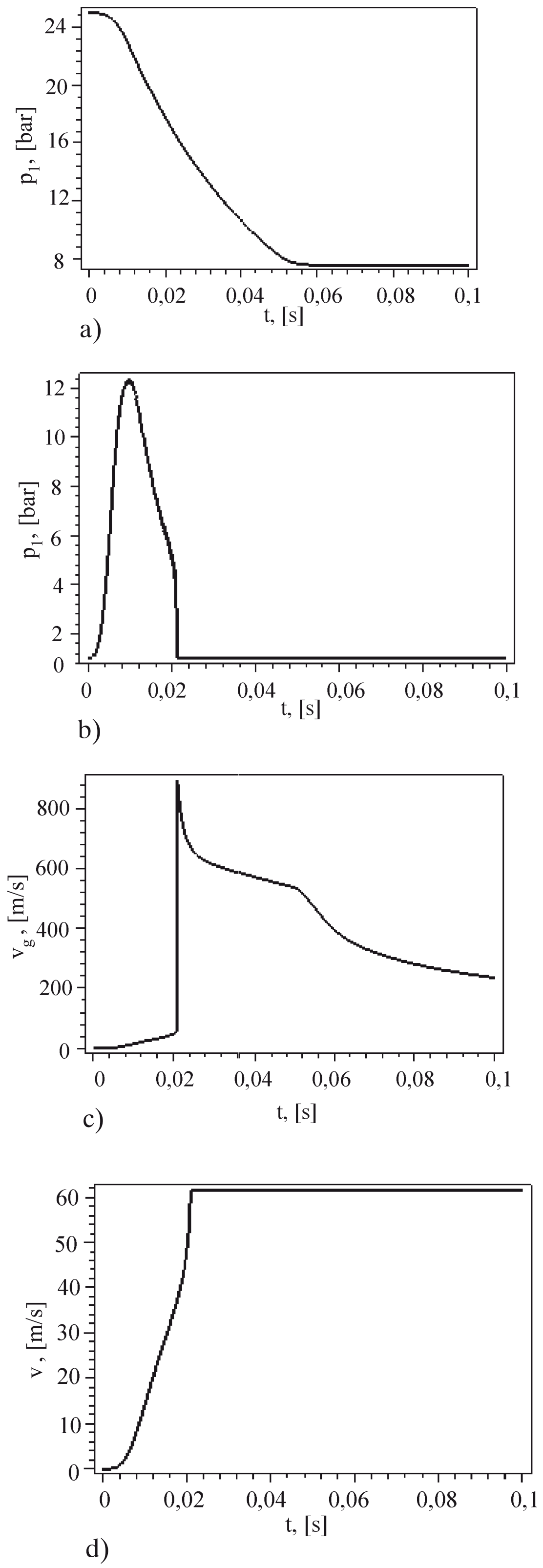

Fig 8. The parameters of the extinguishing device:

a – change of pressure in the air container;
b – change of air pressure in the second volume;
c – change of liquid velocity at the point G;
d – change of liquid velocity at the end of pipeline

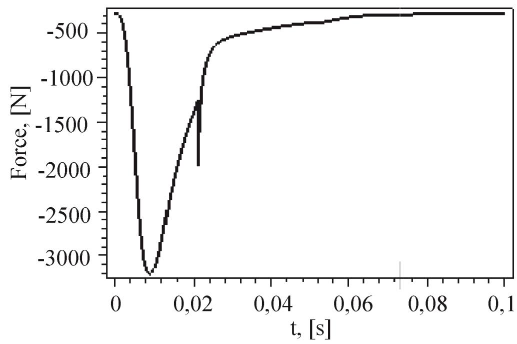

Fig 9. Dependence of pressure and jet-propolsion force upon time

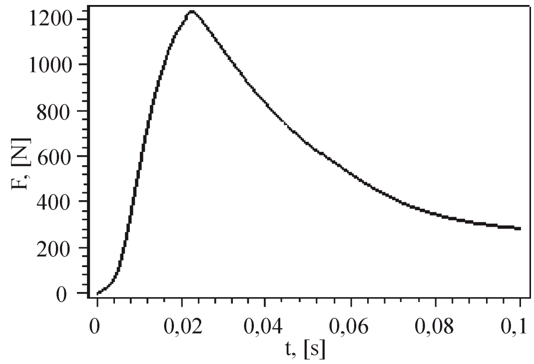

Fig10. Dependence of recoil force upon time

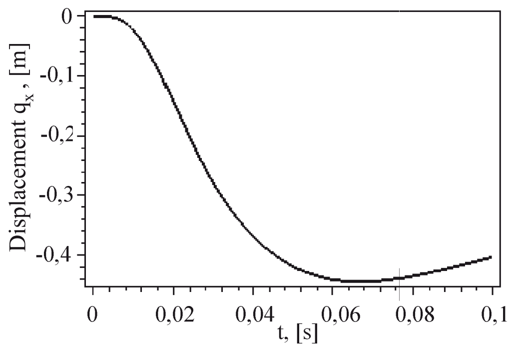

Fig 11. Displacement of extinguishing device

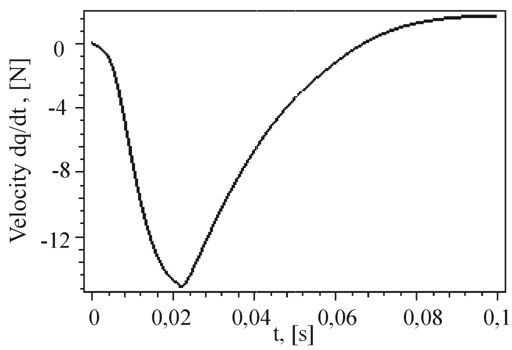

Fig 12. Velocity of the extinguishing device

4. Conclusions

1. A new approach to 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.

2. Differential equations describing hydrodynamic processes inside the extinguishing device help analyze the movement of liquid and gas better and more precisely.

3. At the end of a pipeline of the extinguishing device the maximum velocity of the liquid when initial pressure is equal to 2.5 MPa reaches 60 m/s.

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HYDRODYNAMIC PROCESSES OF THE IMPULSE FIRE EXTINGUISHING

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The main aim of the investigation is to develop approach to investigate hydrodynamic processes in the extinguishing device. The mathematical model of extinguishing device is presented, where the flow of fluid and gas and the interaction of liquid with the gas are taken into account. The flow of fluid 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-extinguishing device is shown. The dependence of recoil force is obtained.

Keywords: *extinguishing device, gas, liquid, dynamics, recoil force, numerical methods*

1. INTRODUCTION

Extinguishing systems comprise systems designed for the supply of the extinguishing materials 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 damages resulting from inefficient application of water exceed those 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 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 atomise 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 were 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 atomise water into fine drops. The smaller the drops are developed, the better use of the 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 a jet kinetic energy. If we use the energy of the compressed air or other gases to eject water through 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 atomised into fine droplets due to the air resistance (even up to 2 microns in diameter). Consequently, the extinguishing water cover area enlarges as well as the water efficiency.

The devices with such properties can be usable in portable version. That is very important in 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.

The extinguishing device based on the use of the compressed air energy for ejecting extinguishing water could be expressed as follows (Fig. 1):

- Compressed air compartment is filled up from the air container;
- Water compartment is filled up from the water tank;
- When the fast reaction valve is opened, compressed air and water compartments get merged;
- Water being under air pressure is ejected within a very short time (from several to several tens of milli-seconds) to the focus of fire;
- Further on the process is repeated from the beginning.

Studies on such extinguishing technologies have not been completed yet and need to be further updated and tested. The main parts of investigation are as follows:

- Process of extinguishing (water) media delivery to fire;
- Recoil of the extinguishing device during operation.

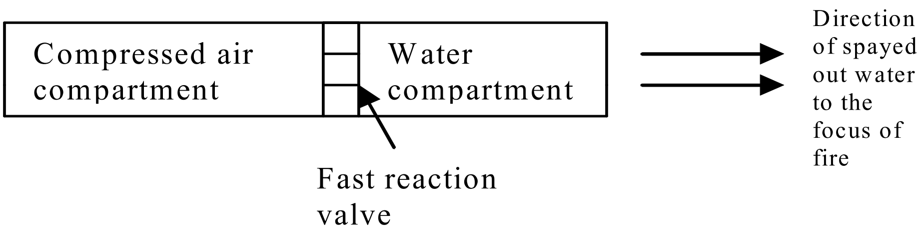

Figure 1. *Principal schema of the extinguishing device on the use of the compressed air energy*

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 fast reaction valve. The second valve opens when pressure reaches particular pressure. When the fast reaction valve begins to open the second chamber divides in two volumes. In the first volume there is high pressure of air and in the second volume there is high pressure of water.

Dynamic model of the extinguishing device is shown in the Fig. 2. In the air container the pressure is $p_1(t)$ and the volume of air container is V_1.

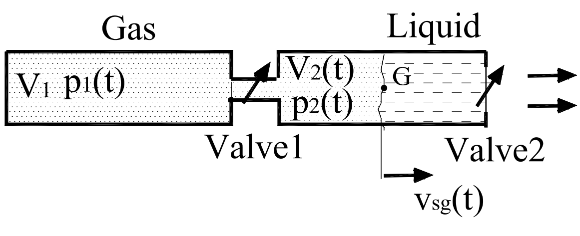

Figure 2. *Diagram of extinguishing device*

Cross-section area Sv_1 of the first valve is function of time (Fig. 3). Cross-section area Sv_2 of the second valve depends on pressure $p(t, x = L)$ (Fig. 4). In the second air volume $V_2(t)$ the pressure is $p_2(t)$. The second air volume and water compartment is separated the surface G (see Fig. 2). According to the first law of thermodynamics, whole thermal energy moved with gas is spent for change of internal energy and for work of expansion of gas in a volume.

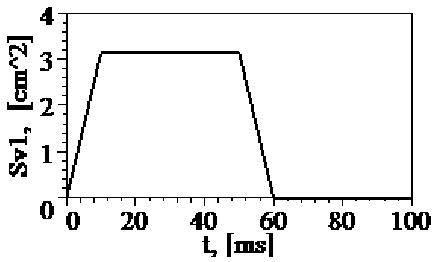

Figure 3. *Cross-section area of the first valve*

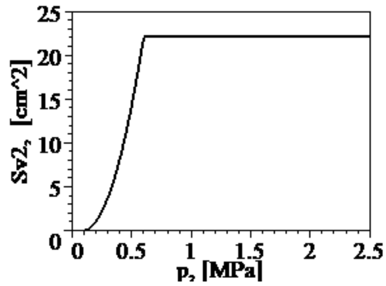

Figure 4. *Cross-section area of the second valve*

The change of pressure of constant volume ($V_1 = const$) of air container is determined from the following equation:

$$\frac{dp_1}{dt} = -\frac{\gamma R T_1}{V_1} G_{12}, \tag{1}$$

where G_{12} is mass charge of gas (air), determined on the formula Sen-Venan and Vencel [1]:

$$G_{12} = \mu_1 S_{v1} p_1 K_1(T_1) \varphi\left(\sigma = \frac{p_2}{p_1}\right); \quad K_1(T) = \sqrt{\frac{2\gamma}{(\gamma - 1) R T_1}};$$

$$\varphi(\sigma) = \sqrt{\sigma^{\frac{2}{\gamma}} - \sigma^{\frac{\gamma+1}{\gamma}}}, \tag{2}$$

S_{v1} is cross-section area of first valve; μ_1 is factor of the charge; γ – ration of specific heat; R – gas constant; T – temperature.

The change of pressure of the second volume $V_2(t)$ is determined from the following equation:

$$\frac{dp_2}{dt} = \frac{\gamma R T_1}{V_2(t)} G_{12} - \frac{\gamma p_2}{V_2(t)} \frac{dV_2}{dt}, \tag{3}$$

where $V_2(t) = V_{20} + S x_G$; V_{20} is initial volume; S is cross-section area; x_G is coordinate of point G (see Fig. 2)

The liquid movement is considered as one-dimensional, i.e. all local velocity is equal to average velocity, and unsettled. Velocity and pressure depend on longitude coordinate and time. Such liquid movement is characterized by the wave of increased and reduced pressure that spreads from the place of change in each pressure vibration cross-section and in deformation of pipeline walls.

The movement and continuity equations of viscous, compressible fluid in pressure pipe have the following form [1, 2, 3]

$$\frac{\partial}{\partial t}[S(x)\rho] + \frac{\partial}{\partial x}[S(x)\rho v] = F_1(x), \tag{4}$$

$$\frac{\partial}{\partial t}[S(x)\rho v] + \frac{\partial}{\partial x}\left[S(x)\left(p + \rho v^2\right)\right] = F_2(p, v), \tag{5}$$

where ρ is density of liquid.

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

$$[A]\left\{\frac{\partial u}{\partial t}\right\}+[B]\left\{\frac{\partial u}{\partial x}\right\}=\{f\}; \tag{6}$$

where

$$[A]=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix};\ [B]=\begin{bmatrix}v & a^2\rho\\ \frac{1}{\rho} & v\end{bmatrix},\ \{u\}^T=[p,v], \tag{7}$$

v, p – speed and fluid pressure; a – sound velocity in the liquid with a certain amount of gas, which is stored in the elastic pipeline, is equal to:

$$a=\sqrt{\frac{K(p)/\rho}{1+\frac{K(p)\cdot d}{E\cdot e}+\frac{\varepsilon}{\gamma}\left[\frac{K(p)}{\gamma p}-1\right]}}, \tag{8}$$

where: $K(p)$ – bulk modulus of elasticity of liquid, ρ – density of liquid, E – modulus of elasticity of a pipeline, d – internal diameter of a pipeline, e – thickness of a wall of a pipeline, γ – index of adiabatic process, ε – ratio of gas volume in the liquid and the total volume of liquid (mixture).

Differential equations of liquid movement in the cylinder are solved by characteristics method [1,2]. The main idea of characteristics method is the fact that unknown variable speed and liquid pressure at instant moment of time $t+\Delta t$ is determined according to these parameters at a moment of time (Fig. 5).

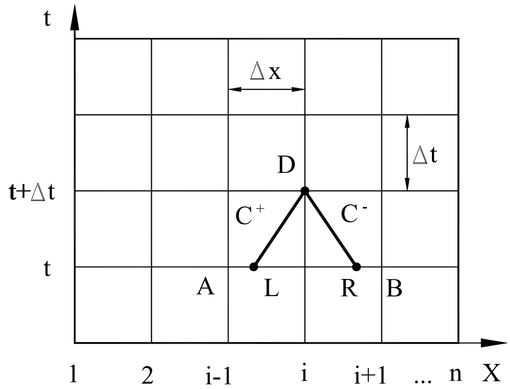

Figure 5. *Circuit of liquid parameters determination of point* D

Equating the determinant of matrix (13) to zero, we shall receive the equation:

$$\left|[B]-[A]\frac{dx}{dt}\right|=0, \tag{9}$$

which allows determining $\frac{dx}{dt}$ derivative that determines characteristic direction. If this equation has *n* various real roots $dx/dt=\lambda_i$ $(i=1,2)$, the initial system of the differential equations is referred to as hyperbolic. The inclination tangent λ_i to the characteristic depends not only on coordinates but also on solution $\{u\}$.

Inserting expressions $[A]$ and $[B]$ from matrices (7) into equation (9) and having solved it, we receive three equations of characteristics

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Compatibility conditions on characteristics are equal to [4, 5, 6]:

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$$\{f\} = \begin{Bmatrix} 0 \\ -\dfrac{\tau\Pi(x)}{S(x)\rho} - a_x \end{Bmatrix} \tag{13}$$

where τ are shear stresses on the inner surface of pipeline; a_x – acceleration along x axis; $S(x)$ and $\Pi(x)$ are cross-section area and perimeter of pipeline.

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where $r_1 = \dfrac{1}{\rho a}$; $r_2 = -a^2 \rho v \dfrac{dS}{dx} / S$;

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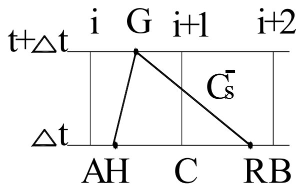

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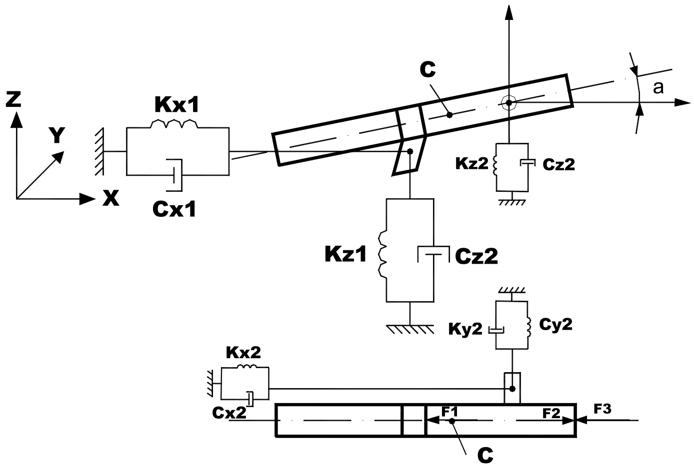

Figure 7. *Diagram of forces acting on the extinguishing device*

3. NUMERICAL RESULTS

An example of the extinguishing device is considered. The following data of the extinguishing device were used: the length of water compartment is 0.420 m, the volume of air container is equal $1.5 \cdot 10^{-3}$ m^3, initial pressure in the air container is 2.50 MPa, inner diameter of water compartment is equal 0.060 m. Time integration step is equal $2.0 \cdot 10^{-6}$ s. The length of water compartment is divided in the 84 elements.

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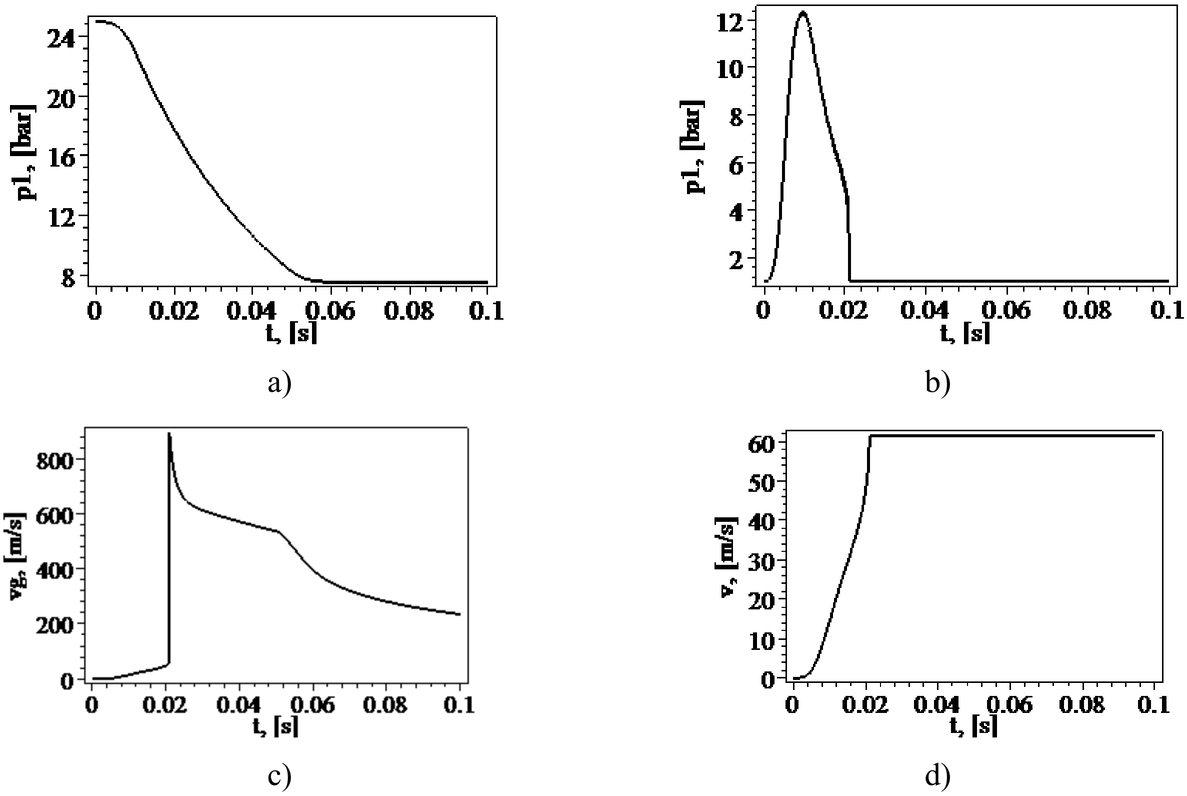


Figure 8. *The parameters of the extinguishing device: a – change pressure in the air container; b – change air pressure in the second volume; c – change liquid velocity at the point G ; d – change liquid velocity at the end of pipeline*

The forces acting on the extinguishing device are shown in the Fig. 9 and Fig. 10.

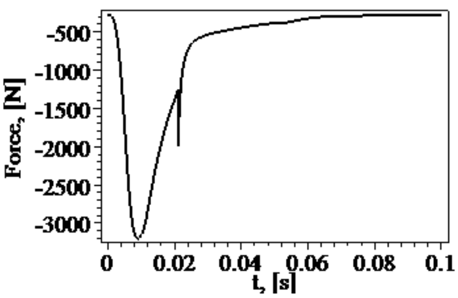


Figure 9. *Dependence of pressure and jet propulsion force upon time*

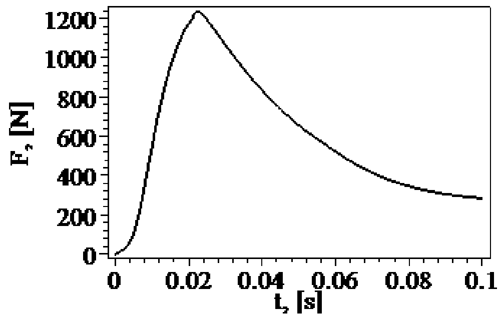
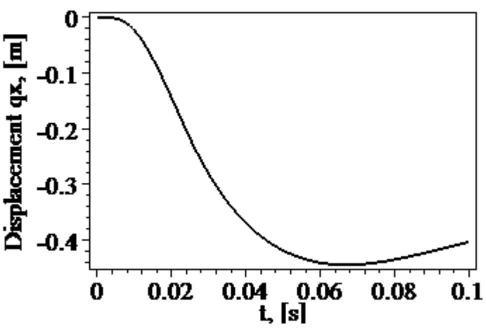


Figure 10. *Dependence of recoil force upon time*

The displacement and velocity of the extinguishing device are shown in the Fig. 11 and Fig. 12.



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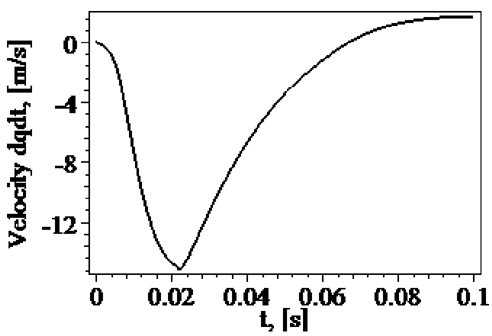

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4. CONCLUSIONS

A new 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 liquid. Differential equations, describing hydrodynamic processes inside the extinguishing device, help analyse the movement of liquid and gas better and more precisely. At the end of a pipeline of the extinguishing device the maximum velocity of liquid when initial pressure is equal 2.5 MPa reaches 60 m/s.

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IMPROVEMENT OF TECHNICAL PARAMETERS OF FIRE VEHICLES AND EQUIPMENT

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Abstract. The improvement of the technical parameters of the fire vehicle implemented in a few groups is presented. Each parameter of these groups has a respective impact on the following features of the fire vehicle. The deficiencies of the main fire vehicles under operation, the improvement of the fire vehicles vacuum systems and extinguishing systems are presented.

Keywords: fire vehicles; vacuum systems; impulsive extinquishing technologies.

1. Introduction

Approximately 11-14,000 fires occur in Lithuania annually because of weather conditions. However, over the last eleven months in 2002 alone, 20152 fires broke out resulting in damages worth of 25,939611 Lt, although factual losses seem to amount to larger numbers as the damages related to the perturbations of production and other business activities have not been taken into account. This substantial increase of fires and the number of damages done therewith have been preconditioned both by inadequate human economic activities and sharp changes of the weather.

In addition, common tendencies and experiences of other countries testify to the fact that with the increase of human activities fire threats grow as well. Fires pollute the environment heavily and have a negative impact on human health. It is evident that the quicker the fires are put out, the less damage is done.

The goal of the fire and rescue services rests on rescuing human lives and property in the event of fires and other emergencies. Fire vehicles constitute technical means that enable fire services to ensure efficient performance of their functions. It is evident that technical specifications of the fire vehicles have a crucial impact on fire fighters' work efficiency. The immediacy of fire and rescue operations being rendered depends on the technical parameters of the fire and rescue equipment including the fire vehicles. The speed factor in emergencies plays the highest importance. Analyses of fire casualties indicate that 60 % to 70 % of people perish from the intoxication emitted by fire gases within the first stage of fire (up to 5-6 minutes from the beginning of the fire) [1]. Material damages due to fires have an immediate connection to the duration of the fire burning itself. According to research studies done in Great Britain, the reduction of the fire burning time by 1 minute can drop the number of fatalities in fires by 5,3 %. Therefore, technical specifications of the use of the fire vehicle in terms of the time factor have a crucial impact on putting out fires.

A case of fire fighting or elimination of an accident can be estimated by the time factors as follows:

$$T = T_d + T_v + T_p + T_{ges}, \quad (1)$$

here T – total response time, T_d – departure time of a fire vehicle from the fire station upon reception of an emergency call, T_v - driving time needed to reach the scene of an accident, T_p – preparation time for a fire vehicle and fire equipment to respond, T_{ges} – fire fighting time.

T_d depends on how quickly the fire vehicle is able to leave the garage, i.e. on the reliability and rapidity of its start-up and the brake system as well as on its convenience for the fire fighters to quickly get into it. *Tn,* driving time to the scene of an accident depends on the maximum driving speed that the fire vehicle can develop, on its dynamic specifications and mobility, off-highway driving properties and stability, as well as on its qualities of being informative and discernable to the people round about including distance to the accident as well as roadway and traffic conditions.

T_p time depends on what kind of equipment is installed in the fire vehicle and how fast such equipment and its aggregates can be prepared for and put into operation.

T_g time depends on technical specifications of the fire fighting equipment, availability of the extinguishing materials as well as approaches and intensity of supply of the fire extinguishing materials.

By assessing the constituent parts of the time factor in fire fighting and technical parameters of the fire vehicles, which influence fire extinguishing, three main groups can be distinguished, such as:

- Chassis.
- Fire body construction, body, and containers of the extinguishing materials.
- Special aggregates and equipment.

Each parameter of these groups has a respective impact on the following features of the fire vehicle: ability to arrive quickly and safely to the scene of an accident; capacity of carrying the necessary number of the fire fighters, equipment and the extinguishing materials; being able to efficiently supply extinguishing materials or ensure implementation of the required operations using specific aggregates. Consequently, the improvement of the technical parameters of the fire vehicle can be implemented in the following ways:

- By improving or changing the chassis base in the fire vehicle;
- By advancing or changing the fire vehicle body, equipment sections and containers designed for the extinguishing materials;
- By changing a pump, equipment, or any other specific aggregate, and by installing or using supplementary measures, which can improve fire extinguishing.

2. Deficiencies of the Main Fire Vehicles Under Operation

Manufacturers endeavor to select optimal technical parameters for the fire vehicles being made. However, due to the specific application of the fire vehicles the wear of their aggregates and other components tends to be very uneven.

While on duty the fire vehicles do not put on too many kilometers and their mileage is quite low in comparison with that of the transport vehicles, however, their operating mode is rather heavy and the operation time of such vehicles seem to come up to 11–30 years. During the entire duty period of the fire vehicle its worn-out aggregates and components need to be replaced more than once. Moreover, some its parameters tend to fail to meet the new requirements over the long period of operation.

Years ago the firefighters handled only fires. Nowadays they have to carry out various rescue operations that call for the need to make use of the supplementary equipment, which fails to be properly placed in the old-type vehicle bodies. New technologies require the change of the old components. It is not unusual that after long years of its operation manufacturers stop producing some of the aggregates or components to be replaced, therefore, it turns to be vital to search for the new alternative solutions. All this becomes crucial in view of ensuring further use of the old fire vehicles as in as much the acquisition of the new up-to-date equipment seems to be problematic due to the lack of financial resources.

Currently, the State Fire and Rescue Service runs 700 units of fire and rescue automobiles and special vehicles. Even 80 % of the main fire vehicles have been manufactured in the former Soviet Union, and they fail to be noted for their reliability and endurance. The deficiencies of such fire vehicles may be differentiated as follows: 70 % of the total vehicle deficiencies come to special aggregates and body constructions, out of which 24 % make up vacuum system and 18 % fire-pump breakdowns. The rest of 30 % of the deficiencies amount to the basic chassis, out of which 12 % come to transmission aggregates and 8 % to traffic security system failures respectively.

A matter of great concern is that all the fire vehicles mounted on GAZ or ZIL mark chassis have carburetor engines that consume A-80 gasoline, whereas in other countries the chassis of such fire vehicles are equipped only with more fuel-efficient diesel engines. It would be rational to implement economical-technical calculations concerning the costs of replacing carburetor engines with the diesel ones in such fire vehicles, which are envisaged to be operated for the next several years.

As we have mentioned before, the most acute issue to deal with lies in the centrifugal fire pumps filling vacuum systems as well as in the failures of the fire pumps them-selves including corrosion and rupture of both bodies and tanks. The replacement of these systems with the new ones or the improvement of the current ones would result in both significant upgrade of their technical specifications and extension of their operating time.

3. The Improvement of the Fire Vehicles Vacuum Systems

Before delivering extinguishing fluids, centrifugal fire pumps have to be filled up within the shortest possible time. Currently, the most common vacuum systems are used to ensure immediate fill-up of the pumps. The performance of the vacuum systems is based on sucking air out of the centrifugal pumps and the suction hoses attached to it. The air suction results in rarefaction (vacuum), whereas water being under atmospheric pressure fills up both suction hoses and centrifugal pumps.

Here are the following principal characteristic parameters of the vacuum systems:

- maximum vacuum pressure is gained;
- geometric suction height;
- time-span needed for sucking air both from the pump and connection hoses.

The maximum geometric suction height depends on the maximum vacuum pressure being formed. The sizes of the system gaps and seal couplings have an impact on the formation of the maximum vacuum pressure. Regrettably, all vacuum systems have the same deficiency, i.e. the geometric suction height cannot exceed 10 meters, and taking into consideration losses within the system the maximum suction height actually comes up only to 7 – 8 meters.

All fire vehicles produced in the former Soviet Union have been equipped with the same vacuum systems without any exceptions. These systems consume energy of the exhaust gases emitted from the engines to produce vacuum. An overall layout of such a vacuum system is presented in Fig 1.

These vacuum systems do not require transmission train and they are not provided with turning, scrolling and reversible motion parts, they are easily mountable as well. However, they have the following essential deficiencies:

- Corrosion of both the vacuum apparatus valves and its body metal surfaces being exposed to hot exhaust gases emitted from the engine;
- Big noise while in operation;
- Possible increased concentration of the exhaust gases within the working premises of the driver/operator;
- Formation of the uplift of the exhaust gases up to 0,2 Mpa;
- System failure to function autonomously;
- Lower vacuum pressure is formed in comparison with other vacuum systems in use (Table 1).

The basis of the vacuum system consists of the pump type being used. Upon analysis of the parameters and characteristics of the pumps used in the vacuum systems, it has been determined that it would be the most effective way to use membrane or piston suction pumps. The transmission train is required while operating these pumps. It is common practice in western countries to use the propeller-shaft of the pump gear or the shaft of the centrifugal pump itself in order to operate the suction pump. This means that the vacuum pump will function only in case the centrifugal pump keeps turning. However, oil-seals and seals of the centrifugal pumps equipped in GAZ and ZIL-type fire vehicles are not designed to operate without water for longer periods. Therefore, it is impossible to use the pump transmission for revving up suction pumps in the fire vehicles provided with PN 40UA and PN 40UV pumps. In this case one of the solutions rests an applying an electric engine of the direct current supplied from the vehicle batteries to rev up the membrane or piston suction pumps. It is quite simple to mount this suction pump on any area of the fire vehicle (Fig 2).

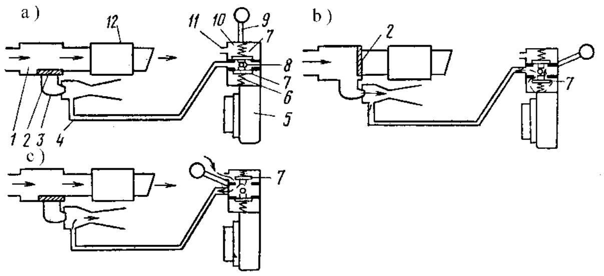

Fig 1. Vacuum systems using energy of engine exhaust gases. a)- Position in "off" mode, b) Water suction, c) Emptying of vacuum system, 1 – Body of vacuum apparatus, 2 – Valve, 3 – Injector, 4 – Coupling of centrifugal pump with injector's vacuum chamber, 5 – Centrifugal pump, 6 – Spring, 7 – Valve, 8 – Eccentric, 9 – Handle, 10 – Vacuum valve, 11 – Opening, 12 – Muffler for exhaust gases

Fig 2. Piston suction pump driven by electromotor

Table 1. Comparable data and parameters of vacuum systems

Parameter	With gas injectors	With membranepumps	With piston pumps	With rotary vane pumps
Vacuum pressure gained, MPa	0,074	0,09	0,09	0,09
Maximum geometric suction height, m	7	8	8	8
Energy source	Engine exhaust gas	Gear of centrifugal pump	Gear of centrifugal pump	Electric engine of direct current
Operation	Manual	Manual or automatic	Manual or automatic	Manual
Negative impact on environment,vehicle aggregates or operator	Impact on vehicle engine andoperator	No impact	No impact	Impact onenvironment

Suction pumps to be produced in an experimental way with 0,00021m3 operating capacity and equipped with a 1,3 kW electric motor starter engine are shown in Fig 2. These piston pumps are meant both to improve the performance of the vacuum systems of the used fire vehicles and to save the recourses for it is not necessary to start up the engine in order to perform a pump leakage test.

4. Change of Body Constructions of AC 40(130)63B and AC 40(131)137-type Fire Vehicles

The body constructions of the fire vehicles of AC 40(130)63B and AC 40(131)137 types have been manufactured for several decades without any remarkable changes. Their main deficiencies are the following:

- Insufficiency of space to place supplementary rescue equipment;
- highly intensive corrosion of body and tank;
- covers of body sections do not shut securely and they become unsafe at work place when in an open position.

Every year more construction bodies of these types of the fire vehicles tend to become unusable due to deep metal corrosion, although their chassis could keep operating for a much longer time. Different possibilities have been considered to solve this problem. For example, it has been speculated to assemble one fire vehicle out of two, to replace the most worn-out parts of the body and to change the entire body with all of its components included. It is not always possible to rationally use all the aggregates and components by mounting one fire vehicle out of two. Replacing the most worn-out parts, we fail to eliminate any of the deficiencies mentioned above. Therefore, in view of improving the characteristics of the fire vehicles being used and prolonging their operational time, the priority has been given to the change of the entire body construction. These are the following requirements for the fire vehicle construction body:

- New body constructions and parts shall not reduce active and passive safety of the fire vehicles.
- Body constructions and parts shall not exceed such dimensions, total weight and axial load of the fire vehicle as designed by the manufacturer.
- Configuration of the compartments of the new body shall be fit for the necessary supplementary equipment to place.
- Body and tank shall be produced from rustproof materials or covered by a reliable anticorrosive coating.
- Blind-like aluminum made doors shall be used instead of compartment covers.

Such body constructions that met these and other additional requirements have been manufactured and mounted on the fire vehicles. An overall view of the fire vehicle equipped with a new body construction is depicted in Fig 3.

Fig 3. Overall view of the fire vehicle AC 40(130) 63B equipped with a new body construction

The body of the fire vehicle consists of a sub-frame; elastic suspension of the sub-frame (after getting rid of cramps); a frame of the body onto which aluminum plates are fixed by gluing; a tank and foamer container both produced of polypropylene; compartments equipped with blind-like aluminum doors; elements for the fixation of the equipment.

New body constructions of such types improve the following characteristics of the fire vehicles:

1. Enlargement of the body size by 0,6 m^3 allows to load more equipment.
2. Body, water tank and foam container are corrosion proof, because they are produced of rustproof materials.
3. Blind-like aluminum doors ensure safe seal of the equipment compartments, they have an aesthetic look and improve working conditions around the vehicle.
4. Elastic suspension of the body sub-frame allows avoiding undesirable tensions within the body constructions.

5. Improvement of Extinguishing Systems

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 damages resulting from inefficient application of water exceed those 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.

The core of the modern extinguishing systems of the fire vehicles is made from the fire pumps or other equipment designed to supply fire-extinguishing materials. The fire pump characteristics define the application of the equipment. Properly selected equipment enables to effectively make use of the properties of the fire pumps. As the time factor in fire fighting is essential, it is evident that the sooner the supply of the extinguishing materials is launched, the more efficient operation of fire fighting will evolve.

One of the ways to accelerate the beginning of fire fighting is to provide available systems of the fire vehicle with a fast response hose reel. The fast response hose reel allows the fire fighters to start the water supply as soon as the water pump is put into operation without wasting time for connecting hose lines. In addition, the fast response hoses are relatively light and much easier to handle. Research studies done in Great Britain have proven that the shortest fire fighting time has been gained by using the fast response hose reels [1]. However, as the fast response hose reels are of smaller diameters (19–38 mm), they are inclined to higher hydraulic losses. Furthermore, in order to ensure the required intensity of supplying the extinguishing materials, higher pressure is needed to operate fast response hose reels.

Therefore, combined (high/low pressure) pumps are used to operate fast response hose reels as they can reach the maximum pressure of 2–5 MPa. High-pressure nozzles are combined with the high-pressure 1–2 l/s capacity hoses. Then we wonder if it is possible to use the fast response hoses in the old fire vehicles whose fire pumps are capable of reaching the pressure of 1MPa only. The answer is affirmative; it can be done. The only condition is that it is vital to select hoses and nozzles of appropriate parameters. More than several times we have noticed that the incorrect selection of the equipment with inappropriate specifications has failed to bring the results expected. With a view of applying fast response hoses in old fire vehicles, it is essential to have a quality nozzle-sprayer of about 2 l/s capacity capable of operating efficiently under low pressures (0,3–0,4 MPa) [2]. For the determination of the fire hose parameters, the following formula can be used [3]:

$$FL = CQ^2L \, , \tag{2}$$

here: FL – hydraulic losses within the hose, kPa; C – hose hydraulic resistance coefficient; Q – capacity in hundreds l/min; L – length of hoses in hundreds m (mostly up to 60 m).

Completed calculations indicate that the diameter of the fast response hose should be not less than 25 mm. The mounting of such a hose on the fire vehicle is depicted in Fig 4.

Extinguishing possibilities of the fire vehicle can be improved significantly by using the fire pumps with better characteristics. However, it is the rotating engine that defines the use of the fire pump. It is not uncommon that even the manufacturers sometimes fail to properly tune up the conformity parameters of the engine and the fire pump, such as their outputs, rotary moments, and the number of revs. Therefore, the same fire vehicles equipped with different pumps can have different supplying features of the extinguishing materials. After replacing exiting fire pumps of type PN40 in old fire vehicles with the new fire pumps that meet up-to-date parameters, the possibility to use the advanced extinguishing system becomes real. Modern fire pumps are very expensive (price per item comes up to 20–50,000 Litas). Thus, their thorough technical and economical analysis and studies should be done before making the selection and using them.

Fig 4. Mounting of the fast response hose on the fire vehicle with the new body construction

Even using 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 were poured as if from the bucket, its features would be used only at 5–10 % 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 the drops are developed, the better use of the water properties can be implemented and less water is consumed in fire fighting. The following ways are designed in order to better atomize the water that is being supplied for fire fighting:

1. To use special nozzles-sprayers that can atomize water into small drops much better.
2. To increase the pressure of the water supplied, which is being atomized much better while flowing through the nozzle.
3. To reduce tension forces of the water surface.

In the first case using modern nozzles it is possible to obtain 0,3mm drop sizes within the water jet under the pressure of 0,4-0,7 MPa. It is quite complicated to further atomize the water into smaller drops without increasing pressures. Therefore, instead of the single-stage centrifugal pumps, multi-stage are used in the fire vehicles. The pressure of the supplied water is increased from 1MPa to 4MPa. In particular cases volumetric (membrane and piston) pumps are used and the pressure is increased up to 6-20MPa. Under higher pressure the water is atomized better and thus less water is needed. However, under higher pressures (up to 20 MPa) it is impossible to supply bigger quantities of water, as the forces of the nozzles reaction increase and the fire fighters would fail to cope with such forces [4–5]. Furthermore, the small quantity of water, which is well-atomized and under the high pressure, turns into a fog. The water droplets constituting this fog are too small and lack sufficient kinetic energy, thus they may be easily blown away from the focus of the fire by the fire gases.

In the third case different chemicals that reduce the water surface tension forces are used. Such chemicals are called foams or moisteners. Such water with less surface tension forces not only can be atomized better, but also it can penetrate better into the burning surfaces. However, quality foams are quite expensive, and they are basically used for producing the foams meant to extinguish substances that are lighter than water. Recently the newly discovered CAFS systems have been used more broadly. The CAFS is the Compressed Air and Foam Extinguishing System. The principle of the system is based on water and foam mixture, which aerated with compressed air, produces high quality and stable foam, which is being delivered through hoses and nozzles to fire fighting. A special foam of type "A" is used to form the mixture and only 0,1–1 % water concentration is required, whereas the ordinary concentration for the foam comes to 3-6 %. The water – foam mixture is mixed with air in proportion 1:7. Therefore, hoses filled up with the foam are light, as they contain more air than liquids. The main scheme of the CAFS system is submitted in Fig 5.

While using the CAFS system, the extinguishing efficiency increases by 3–5 times compared with extinguishing with plain water [6–7]. The efficiency is reached due to the fact that water is being sustained within stable foams and does not leak out of the fire place (e.g., while using a solid water jet, up to 90 % of water leaks out from the fire place without any extinguishing effect. In order to ensure the functioning of the system, an air compressor, a foam dosage device, a water pump and devices for pressure regulation are required. The systems can be either an autonomic one provided with an individual motor, a compressor and other devices, or it can be the pump powered by the fire vehicle and transmission. As the CAFS systems use water very economically, there is no reason to load the fire vehicles with the large containers of the extinguishing materials. Upon mounting the CAFS systems onto the existing fire vehicles, it would be possible to reduce the volume of the water tanks and to increase the number of the equipment that is taken out and is necessary for various rescue operations. The new fire vehicles equipped with the CAFS systems could be smaller and of higher mobility. However, in order to define both the efficiency of the systems and the optimal parameters

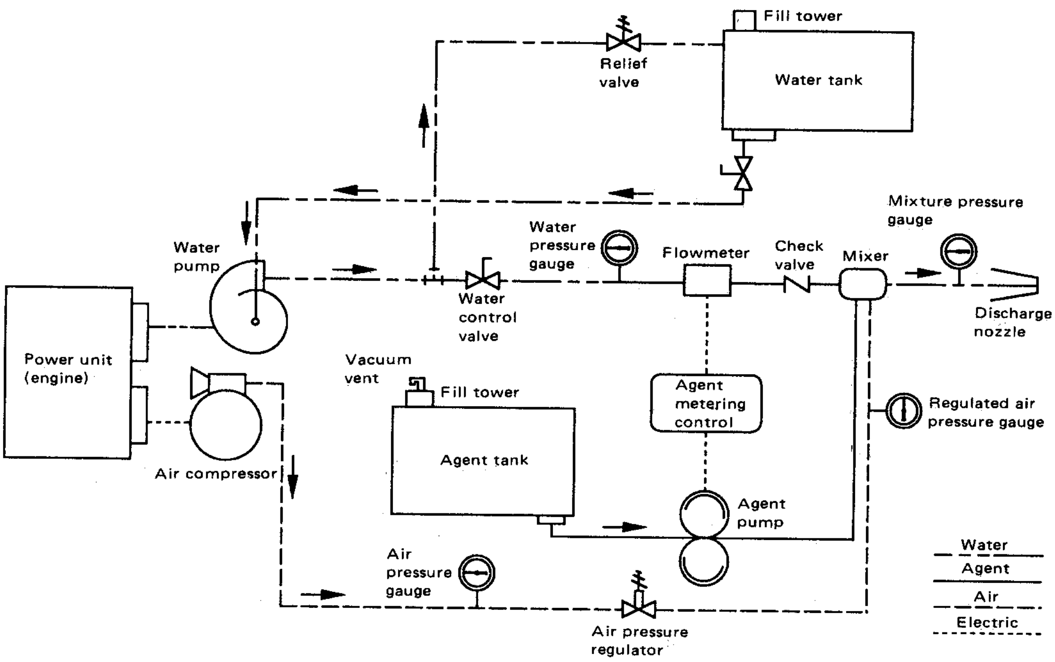

Fig 5. The main scheme of CAFS system

within appropriate fire vehicles, further analyses and practical tests are required, as the extinguishing costs may get higher when the system is being used improperly.

Having analyzed the facts mentioned above, with a view to improve the technologies of supply of the extinguishing materials, the search for the unconventional ways have become important. Today the water is chiefly supplied for extinguishing via volumetric and centrifugal pumps by using its hydraulic liquid characteristics. 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 through the nozzle (instead of the compressed water energy) the jet speed 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 speed, water spray is atomized into fine droplets due to the air resistance (even up to 2 microns in diameter). Consequently, the extinguishing water covered area enlarges as well as the water efficiency. In Table 2 and Fig 6 you can see droplet sizes, their number as well as the covered area obtained when water volume is one 1 litre [8–9].

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 smaller and higher mobility fire vehicles, as large water tanks would not be necessary. Currently, the fire services of some countries have been introducing impulsive extinguishing technologies based on the use of the compressed air energy for ejecting extinguishing water. The general principle of its functioning is shown in Fig 7.

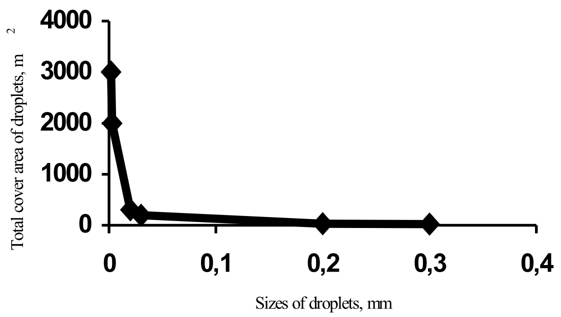

Fig 6. Dependence of the total covered area of 1litre water volume droplets on their diameter size

Table 2. Diameters of water droplets, their number and the total surface area obtained from 1 litre water volume

Droplet diameters, mm	Droplet number	Total surface, m^2
0,3	$7,1\times10^{7}$	20
0,2	$2,4\times10^{8}$	30
0,03	$7,1\times10^{10}$	200
0,02	$2,4\times10^{11}$	300
0,003	$7,1\times10^{13}$	2000
0,002	$2,4\times10^{14}$	3000

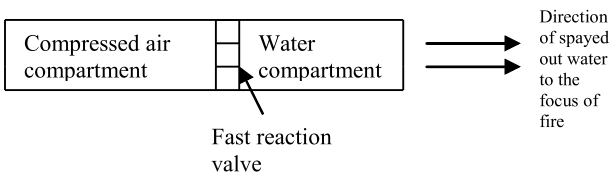

Fig 7. Principle scheme of the impulsive nozzle

Impulsive nozzles function in the following order:

- Compressed air compartment is filled up from the air container;

- Water compartment is filled up from the water tank;

- When the fast reaction valve is opened, compressed air and water compartments get merged;

- Water being under air pressure is ejected within a very short time (from several to several tens of mili-seconds) to the focus of fire;

- Further on the process is repeated from the beginning.

Studies on the impulsive extinguishing technologies have not been completed yet and need to be further updated and tested. However, even now they allow us to use the properties of the extinguishing water more efficiently and to reduce the response time.

6. Conclusions

1. The improvement of the technical parameters of the fire vehicle can be implemented in the following ways:

- By improving or changing the chassis base in the fire vehicle;
- By advancing or changing the fire vehicle body, equipment sections and containers designed for the extinguishing materials;
- By changing a pump, equipment, or any other specific aggregate, and by installing or using supplementary measures, which can improve fire extinguishing.

2. The replacement of centrifugal fire pumps filling vacuum systems with the new ones or the improvement of the current ones would result in both the significant upgrade of their technical specifications and the extension of their operating time.

3. Piston pumps with 0,00021 m^3 operating capacity and equipped with a 1,3 kW electric motor starter engine are meant both to improve the performance of the vacuum systems of the used fire vehicles and the save recourses.

4. The impulsive extinguishing technologies have

not been completed yet and need to be further updated and tested. They allow us to use the properties of the extinguishing water more efficiently and to reduce the response time.

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THE HYDRODYNAMICS BEHAVIOUR OF AUTOMATIC EXTINGUISHING SYSTEM

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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 fluid 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 extinguishing device is shown.

KEY WORDS

Extinguishing device, gas, liquid, dynamics, numerical methods

NOMENCLATURE

a_x : acceleration along x axis
a_{gx} : acceleration of gas along x axis
$C\,(Re,\,v)$: function
c_g, c : sound velocity in the gas and liquid
d : internal diameter of a pipeline
E : modulus of elasticity of a pipeline
e : thickness of a wall of a pipeline
$\{\mathrm{F}(t,p,v)\}$: vector of external forces and moments
F_{aero} : air resistance force
f_{mv} : force
f_{pv} : function
G_{in} : input mass flow
G_{out} : output mass flow of gas (air)
$[\mathrm{J}]$: Jacobian matrix,
$K\,(p)$: bulk modulus of elasticity of liquid
L_2 : length of pipeline (second chamber).
$[\mathrm{M}]$: matrix of mass
m_v : mass of fast response valve automatic control mechanism
N : number of drops
p; p_g : pressure of fluid; pressure of gas
p_v : pressure in the chamber of fast response valve automatic control mechanism
Q : thermal quantum

$\{q\}$	:	vector of displacement
$\{\dot{q}\}$; $\{\ddot{q}\}$	:	vector of velocity; vector of acceleration
R	:	gas constant
$S(x)$	:	cross section area of a pipeline
S_{v1}	:	cross-section area of the first valve
S_{v2}	:	cross-section area of the second valve
T	:	temperature of fluid
v; v_g	:	velocity of fluid; velocity of gas
ε	:	ratio of gas volume in the liquid
γ	:	index of adiabatic process
$\varphi(\sigma)$	:	piecewise flow function
μ_1	:	orifice discharge coefficient
ρ; ρ_g	:	density of fluid; density of gas
σ_{cr}	:	critical pressure ratio
τ	:	tangential liquid stress
$\Pi(x)$	:	perimeter
$\{\Psi\}$	:	vector of Lagrange multipliers
$\{\Phi\}$	:	vector of constraints

INTRODUCTION

The Extinguishing systems comprise systems designed for the supply of the extinguishing materials (extinguish-ants) 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 damages resulting from inefficient application of water exceed those 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 were 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 a jet kinetic energy. If we use the energy of the compressed air or other gases to eject water through 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). 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.

Scheme of an automatic hydraulic and pneumatic nozzle is presented in Figure 1 [1,2].

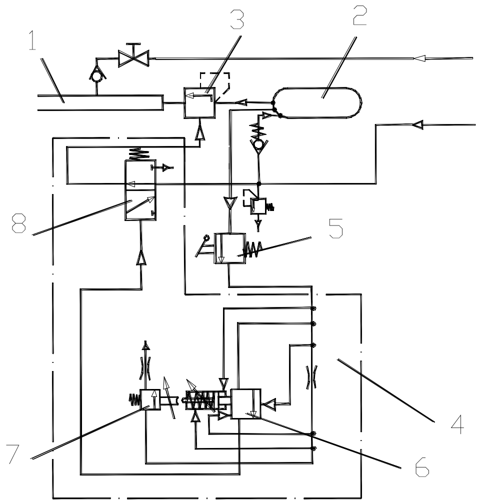

Figure 1 Scheme of automatic hydraulic and pneumatic

nozzle

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. 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) process is repeated constantly and water jets are ejected in series. The fast response valve automatic control mechanism (4) has three valves (6,7 and 8).

The water drops move with the velocity V_1, absorb the environment heat with temperature T_a and steam in the same breath (Figure 2).

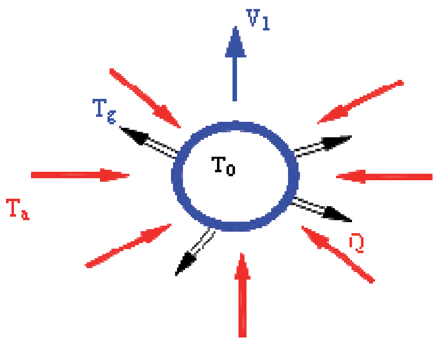

Figure 2 Scheme of drop thermal interchange

The change of thermal flow is directly proportional for the number of drops:

$$\frac{dQ}{dt} = C(Re, v)N^{5/3} \tag{1}$$

The dependence surface area of one litre water drops from the drops diameter in Figure 3 is presented.

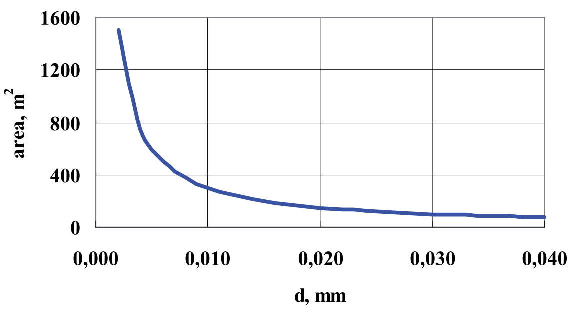

Figure 3 Dependence between surface area of drop and its diameter

II. 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 particular pressure. When the fast reaction valve begins to open, the second chamber divides in two volumes. In the first volume there is a high pressure of air and in the second volume there is a high pressure of water.

The dynamic model of the extinguishing device is shown in the Figure 4. 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 $p(t, x = L_2)$ (Figure 5). The second air volume and water the compartment is separated by the surface G (Figure 4).

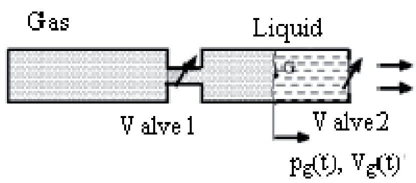

Figure 4 Scheme of extinguishing device

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.

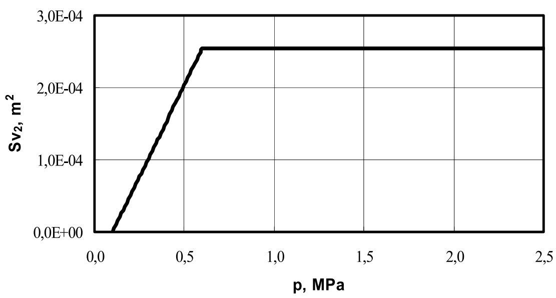

Figure 5 Dependence of cross-section area of second valve on pressure

The continuity and movement equations of viscous and compressible fluid in pressure pipe have the following form [3-7]:

$$\frac{\partial}{\partial t}[S(x)\rho] + \frac{\partial}{\partial x}[S(x)\rho v] = 0 \tag{2}$$

$$\frac{\partial}{\partial t}[S(x)\rho v]+\frac{\partial}{\partial x}\left[S(x)\left(p+\rho v^2\right)\right]+\Pi(x)\tau+ \\ +\rho S(x)a_x+\rho g S(x)sin(\theta)-p\frac{\partial S(x)}{\partial x}=0. \quad (3)$$

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

$$\frac{\partial \mathrm{u}_g}{\partial t}+\mathrm{B}_g\frac{\partial \mathrm{u}_g}{\partial x}=\mathrm{f}_g, \quad (4)$$

$$\frac{\partial \mathrm{u}}{\partial t}+\mathrm{B}\frac{\partial \mathrm{u}}{\partial t}=\mathrm{f} \quad (5)$$

where $\mathrm{B}_g=\begin{bmatrix} v_g & c_g^2\rho_g \\ \frac{1}{\rho_g} & v_g \end{bmatrix}$; $\mathrm{U}_g^T=\left[p_g, v_g\right]$;

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

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

sound velocities c_g and c is equal to:

$$c_g=\sqrt{\gamma RT}; \qquad c=\sqrt{\frac{K(p)/\rho}{1+\frac{K(p)\cdot d}{E\cdot e}+\frac{\varepsilon}{\gamma}\left[\frac{K(p)}{\gamma p}-1\right]}}.$$

The change of pressure of the volume is determined from the following equation:

$$\frac{dp}{dt}=\frac{\gamma RT}{V}\left(G_{in}(p,p_{in})-G_{out}(p,p_{out})\right)-\frac{\gamma p}{V}\frac{dV}{dt}, \quad (6)$$

G_{out} is determined on the formula Sen-Venan and Vencel [1]:

$$G_{out}(p,p_{out})=$$

$$=\begin{cases} \mu_1 S_{v1}(t)K_1(T)p\varphi\left(\sigma=\frac{p_{out}}{p}\right) & if\ p\ge p_{out} \\ \mu_1 S_{v1}(t)K_1(T)p_{out}\varphi\left(\sigma=\frac{p}{p_{out}}\right) & if\ p_{out}>p \end{cases}, \quad (7)$$

$$K_1\ (T)=\sqrt{\frac{1}{RT}}. \quad (8)$$

To take account of the subsonic and sonic flow, the piecewise flow function $\varphi(\sigma)$ is defined as follows:

$$\varphi(\sigma)=\begin{cases} \sqrt{\left(\frac{2\gamma}{\gamma-1}\right)\left(\sigma^{\frac{2}{\gamma}}-\sigma^{\frac{\gamma+1}{\gamma}}\right)}, & if\quad \sigma_{cr}<\sigma\le 1 \\ \sqrt{\gamma\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}, & if\quad 0<\sigma\le\sigma_{cr} \end{cases} \quad (9)$$

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

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

The dynamics model of the fast response valve automatic control mechanism (4) (Figure 1) consists of four masses and eight chambers with variable pressures.. The system of equation of fast response motion valve automatic control mechanism have the following form:

$$m_{vi}\frac{d^2 q_{vi}}{dt^2}=f_{mv,i}\left(q_v,\dot{q}_v,p_v\right)\quad (i=1,..,,4), \quad (10)$$

$$\frac{dp_{vj}}{dt}=f_{pv,j}\left(q_v,\dot{q}_v,p_v\right),\quad (j=1,...,6). \quad (11)$$

For quality work fireman have forces acting on the extinguishing device when out flowing water through the fire nozzle. The main force is recoil force. The dynamics model of fireman is created. The fireman with the extinguishing device is considered as multi-body system. The dynamics model consists from eleven rigid bodies.

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

$$F_x=-S_{v1}(p_1-p_2)+(S_2-S_{v2})p_{lyq}(x_G)-F_{aero}, \quad (12)$$

$$F_{aero} = \begin{cases} \frac{1}{2}\rho S_{v2} v_{2,}^2 \quad if \quad x_G \le L_2 \\ \frac{1}{2}\rho_{gas} S_{v2} v_{2,}^2 \quad if \ x_G > L_2 \end{cases} \tag{13}$$

The system of equations describing the movement of the extinguishing device and fireman is as follows [8]:

$$\begin{bmatrix} [M] & [J]^T \\ [J] & [0] \end{bmatrix} \begin{Bmatrix} \{\ddot{q}\} \\ \{\Psi\} \end{Bmatrix} = \begin{Bmatrix} \{F(q,\dot{q},t)\} \\ \{U(q,\dot{q})\} \end{Bmatrix}. \tag{14}$$

There:

$$\{U(q,\dot{q})\} = -\frac{\partial}{\partial\{q\}^T}\left(\left[\frac{\partial\{\Phi\}}{\partial\{q\}^T}\right]\{\dot{q}\}\right)\{\dot{q}\} - 2\left[\frac{\partial^2\{\Phi\}}{\partial\{q\}^T\partial t}\right]\{\dot{q}\} - \frac{\partial^2\{\Phi\}}{\partial t^2}, \tag{15}$$

$$[J] = \left[\frac{\partial\{\Phi\}}{\partial\{q\}}\right]. \tag{16}$$

III. THEORETICAL ANALYSIS

An example of the extinguishing device is considered. 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 2.0 MPa, the inner diameter of the water compartment is equal to 0,025 m. The time integration step is equal to $2.0 \cdot 10^{-6}\, s$.

Dependences of displacements of fast response valve automatic control mechanism upon time first mass is presented in Figures 7a.

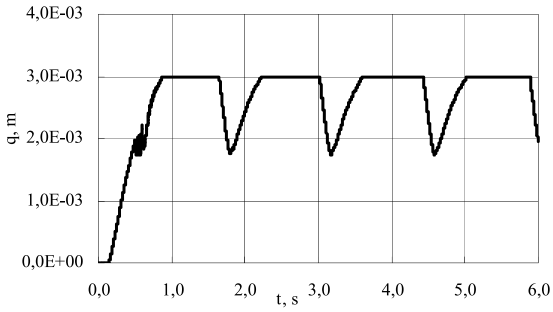

Figure 7a Dependences of displacements: first mass

The displacements of valves of the automatic control mechanism upon time fast response valve 3 are shown in the Figure 7b.

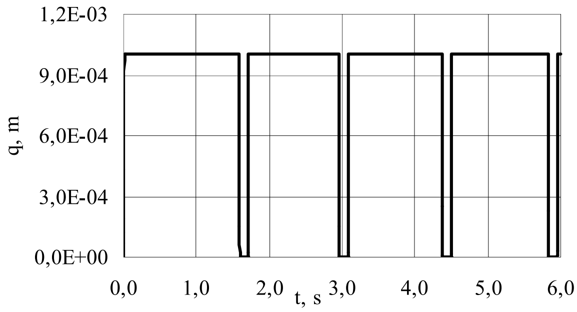

Figure 7b Dependences of displacements: fast response valve 3

The pressures in the chambers of valves of the automatic control mechanism are shown in the Figure 8. The forces acting on the extinguishing device are shown in the Figure 9.

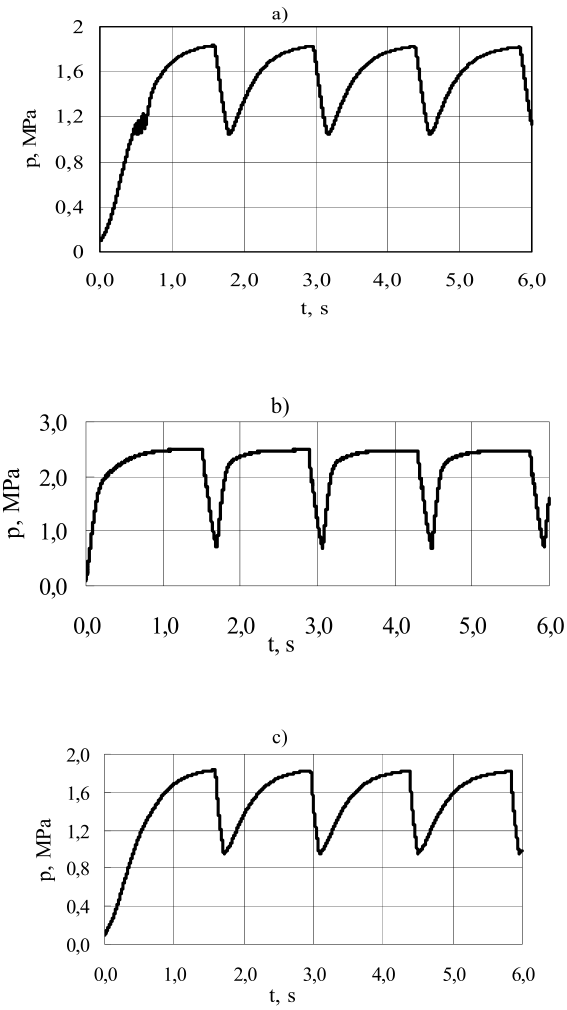

Figure 8 Dependences of pressures: a) first chamber; b) chamber of fast response valve (3) Figure 1 c) compressed air chamber (2) Figure 1

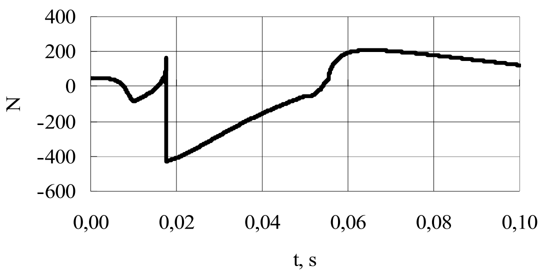

Figure 9 Dependence of recoil force upon time

In the Figure 10 are shown distribution of the cloud of water drops in the different moments of time.

a)

b)

c)

Figure 10 Distribution of the cloud of drops of water

IV. CONCLUSION

A new automatic impulse extinguishing 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 valves. At the end of a pipeline of the extinguishing device the maximum velocity of liquid reaches 60 m/s.

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Investigation the dynamic process of automatic impulse extinguishing

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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 fluid 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 extinguishing device is shown.*

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

I. Introduction

The Extinguishing systems comprise systems designed for the supply of the extinguishing materials (extinguish-ants) 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 damages resulting from inefficient application of water exceed those 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 were 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 a jet kinetic energy. If we use the energy of the compressed air or other gases to eject water through 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). 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

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source or reservoir; the compressed air chamber (2) is supplied from the compressed air source or reservoir. 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) process is repeated constantly and water jets are ejected in series fig. 1.

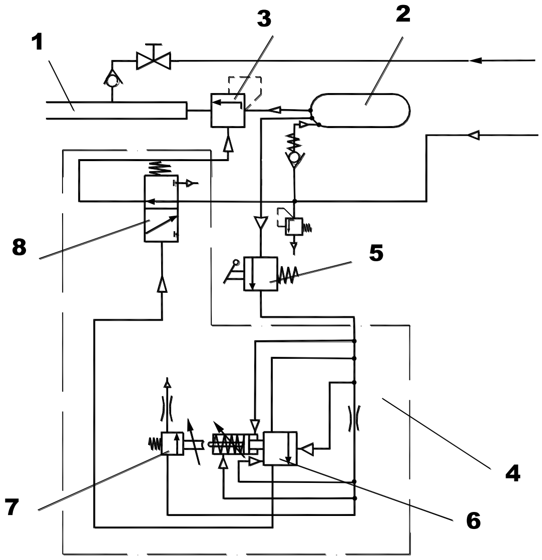


Fig.1. Schematic automatic hydraulic and pneumatic nozzle

II. 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 particular pressure. When the fast reaction valve begins to open, the second chamber divides in two volumes. In the first volume there is a high pressure of air and in the second volume there is a high pressure of water.
The Dynamic model of the extinguishing device is shown in the fig. 2.

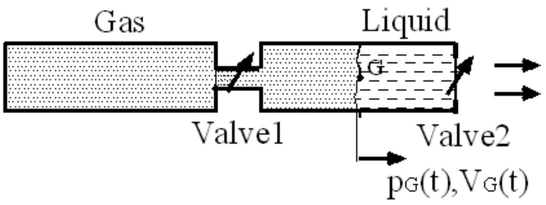


Fig.2 Diagram of extinguishing device

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 the compartment is 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.

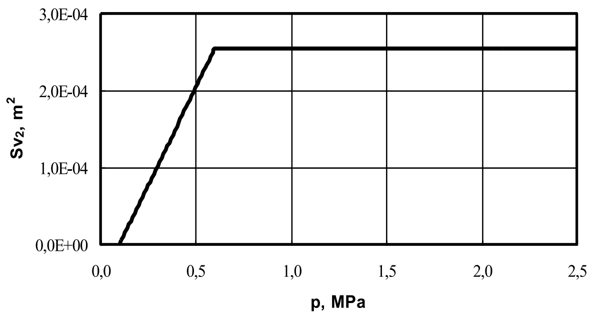


Fig.3. Dependence of cross-section area of second valve on pressure

The continuity and movement equations of viscous and compressible fluid in pressure pipe have the following form:

$$\frac{\partial}{\partial t}\left[S(x)\rho\right]+\frac{\partial}{\partial x}\left[S(x)\rho v\right]=0\,, \qquad (1)$$

$$\frac{\partial}{\partial t}\left[S(x)\rho v\right]+\frac{\partial}{\partial x}\left[S(x)\left(p+\rho v^2\right)\right]+\Pi(x)\tau+\rho S(x)a_x+$$
$$\rho g S(x)\sin(\theta)-p\frac{\partial S(x)}{\partial x}=0\,, \qquad (2)$$

where ρ, v are density and velocity of fluid, (gas and liquid); τ is tangential liquid stress in 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 quasi-linear differential equations:

$$\left[A_g\right]\left\{\frac{\partial u_g}{\partial t}\right\}+\left[B_g\right]\left\{\frac{\partial u_g}{\partial x}\right\}=\left\{f_g\right\}; \qquad (3)$$

$$\left[A\right]\left\{\frac{\partial u}{\partial t}\right\}+\left[B\right]\left\{\frac{\partial u}{\partial x}\right\}=\left\{f\right\}, \qquad (4)$$

where $\left[A_g\right]=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}$; $\left[B_g\right]=\begin{bmatrix}v_g & c_g^2\rho_g\\ \frac{1}{\rho_g} & v_g\end{bmatrix}$; (5)

$$\{u_g\}^T = [p_g, v_g];$$

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

$$[A] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}; \quad [B] = \begin{bmatrix} v & c^2 \rho \\ \dfrac{1}{\rho} & v \end{bmatrix}; \qquad (6)$$

$$\{u\}^T = [p, v];$$

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

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

$$c_g = \sqrt{\gamma RT}; \qquad c = \sqrt{\dfrac{K(p)/\rho}{1 + \dfrac{K(p)\cdot d}{E \cdot e} + \dfrac{\varepsilon}{\gamma}\left[\dfrac{K(p)}{\gamma p} - 1\right]}}; \qquad (7)$$

where: $K(p)$ – the bulk modulus of elasticity of liquid, ρ – the density of liquid, E – the modulus of elasticity of a pipeline, d – internal diameter of a pipeline, e – the thickness of a wall of a pipeline, γ – the index of adiabatic process, ε – 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 – the acceleration along x axis, respectively.
The change of pressure of the volume is determined from the following equation:

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

where G_{in} is the input mass flow; G_{out} is the mass flow of gas (air), determined on the formula Sen-Venan and Vencel [1]:

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

$$K_1(T) = \sqrt{\frac{1}{RT}}; \qquad (9)$$

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 the fig.3.

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

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

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

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

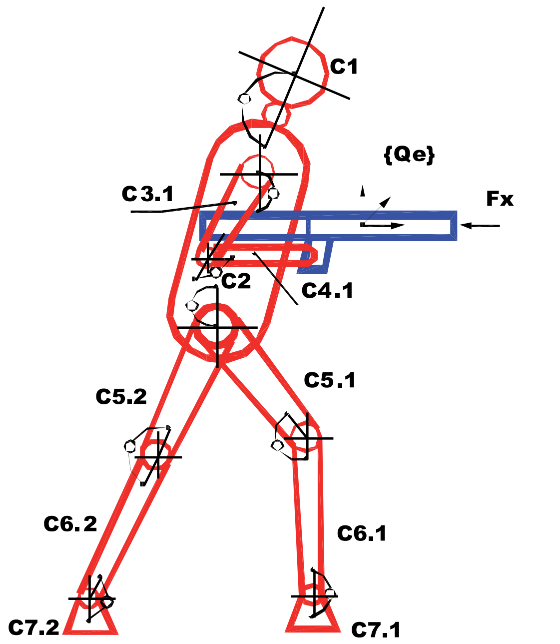


Fig.3 Diagram of forces acting on the extinguishing device and fireman

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

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

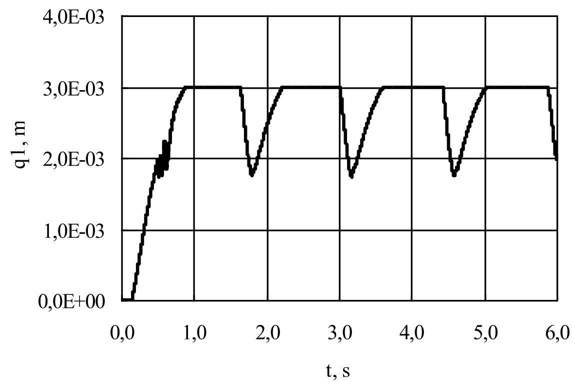
where $[M]$, $[\Phi]$ are the matrices of mass and the Jacobian matrix, respectively; $\{q\},\{\dot{q}\},\{\ddot{q}\}$ are vectors of displacement, velocity and acceleration, respectively; $\{F(t,p,v)\}$ is vector of external forces and moments; $\{\Psi\}$ is vector of Lagrange multipliers; $\{U(q,\dot{q})\}$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

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

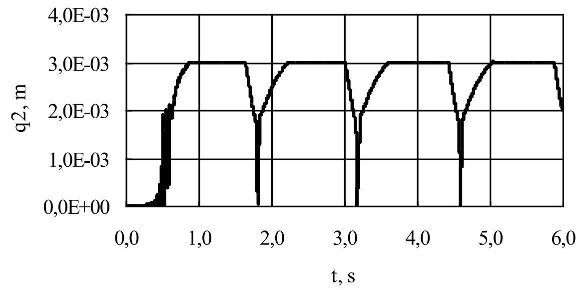
$\{\Phi\}$ is vector of constraints.

III. Theoretical analysis

An example of the extinguishing device is considered. 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 automatic control mechanism are shown in the fig.4. The pressures in the chambers of valves of the automatic control mechanism are shown in the fig.5.



a)



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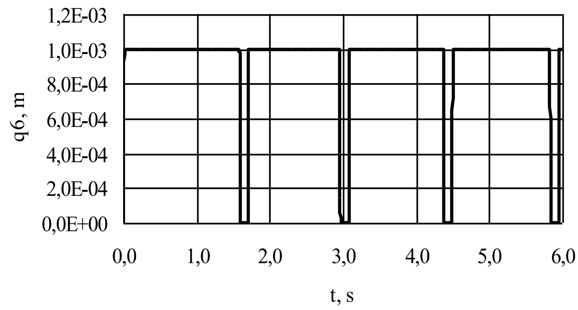
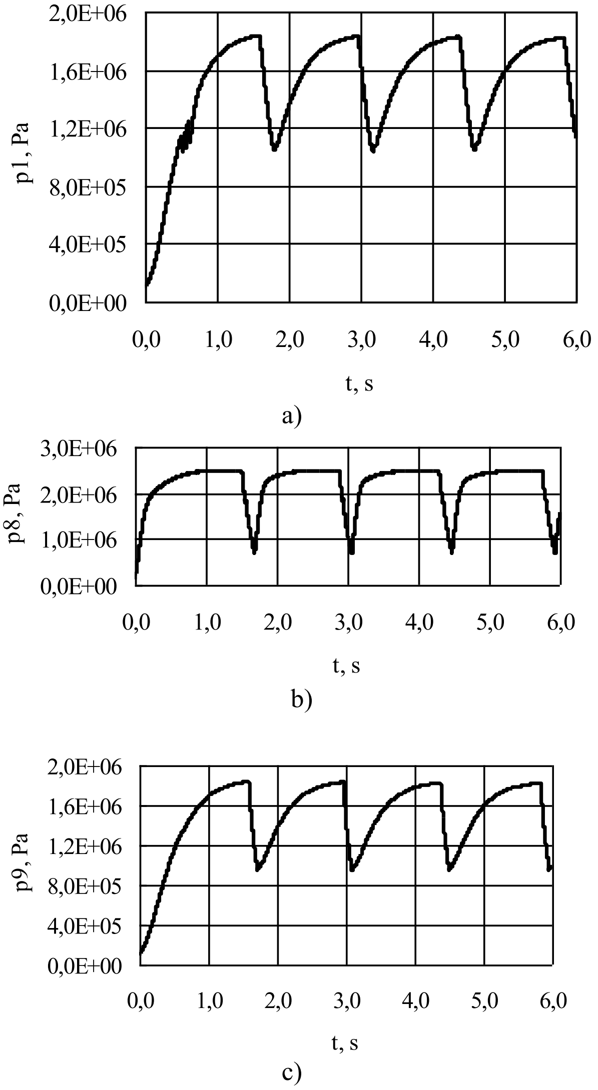


c)

Fig.4. Dependences 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



Fig, 5. Dependences of pressures in the chambers of valves of automatic control mechanism upon time: a – chamber of valve 6 ; b – chamber valve 3; c – chamber 2

V. Conclusion

A new automatic impulse extinguishing 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 valves. At the end of a pipeline of the extinguishing device the maximum velocity of liquid reaches 60 m/s.

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FULL PAPERS OF THE 9TH INTERNATIONAL CONFERENCE

INVESTIGATION OF HYDRODYNAMIC PROCESSES OF THE EXTINGUISHING DEVICE

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Abstract. The main aim of the investigation is to develop approach to investigate hydrodynamic processes in the extinguishing device. The mathematical model of extinguishing device is presented, where the flow of fluid and gas and the interaction of liquid with the gas are taken into account. The flow of fluid 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 extinguishing device is shown. The dependence of recoil force is obtained.

Keywords: extinguishing device, gas, liquid, dynamics, recoil force , numerical methods

1. Introduction

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 damages resulting from inefficient application of water exceed those 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 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 were 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 the drops are developed, the better use of the 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 a jet kinetic energy. If we use the energy of the compressed air or other gases to eject water through 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). Consequently, the extinguishing water cover area enlarges as well as the water efficiency. The devices with such properties can be usable in portable version. That 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.

The extinguishing device based on the use of the compressed air energy for ejecting extinguishing water could be expressed as follows (see figure 1):

- Compressed air compartment is filled up from the air container;
- Water compartment is filled up from the water tank;
- When the fast reaction valve is opened, compressed air and water compartments get merged;
- Water being under air pressure is ejected within a very short time (from several to several tens of mili-seconds) to the focus of fire;
- Further on the process is repeated from the beginning.

Studies on such extinguishing technologies have not been completed yet and need to be further updated and tested. The main parts of investigation are:

- Process of extinguishing (water) media delivery to fire;
- Recoil of the extinguishing device during operation.

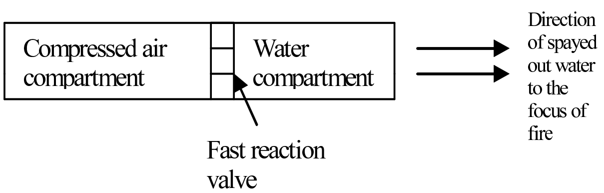


Fig 1. Principal schema of the extinguishing device on the use of the compressed air energy

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 fast reaction valve. The second valve opens when pressure reaches particular pressure. When the fast reaction valve begins to open the second chamber divides in two volumes. In the first volume there is high pressure of air and in the second volume there is high pressure of water.

Dynamic model of the extinguishing device is shown in the figure. 2. In the air container the pressure is $p_1(t)$ and the volume of air container is V_1.

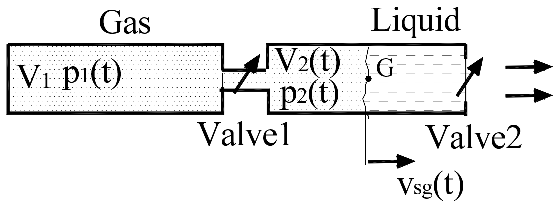


Fig 2. Diagram of extinguishing device

Cross-section area Sv_1 of the first valve is function of time (see figure 3). Cross-section diameter d_{V2} of the second valve depends on pressure $p(t, x = L)$ (see figure 4). In the second air volume $V_2(t)$ the pressure is $p_2(t)$. The second air volume and water compartment is separated the surface G (see figure 2). According to the first law of thermodynamics, whole thermal energy moved with gas is spent for change of internal energy and for work of expansion of gas in a volume.

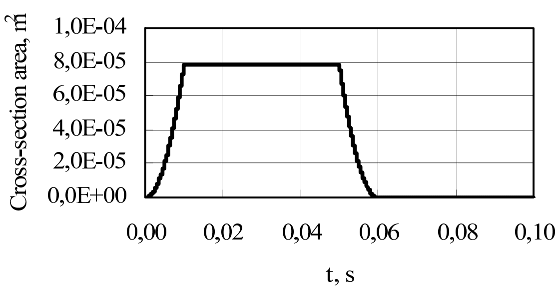


Fig 3. Cross-section area of first valve

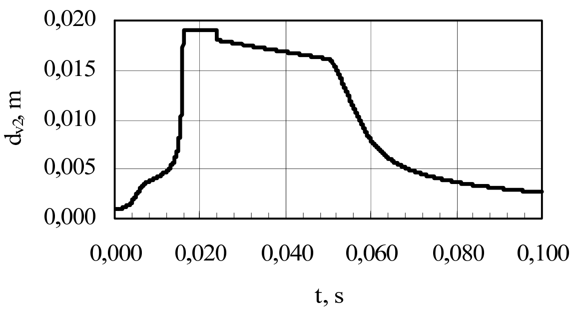


Fig 4. Cross-section diameter of second valve

The change of pressure of constant volume ($V_1 =$ *const*) of air container is determined from the following equation:

$$\frac{dp_1}{dt} = -\frac{\gamma RT_1}{V_1}G_{12}, \quad (1)$$

where G_{12} is mass charge of gas (air), determined on the formula Sen-Venan and Vencel $[1]$:

$$G_{12} = \mu_1 S_{v1} p_1 K_1(T_1)\varphi\left(\sigma = \frac{p_2}{p_1}\right);$$

$$K_1(T) = \sqrt{\frac{2\gamma}{(\gamma-1)RT_1}};$$

$$\varphi(\sigma) = \sqrt{\sigma^{\frac{2}{\gamma}} - \sigma^{\frac{\gamma+1}{\gamma}}}, \quad (2)$$

S_{v1} is cross-section area of first valve; μ_1 is factor of the charge; γ – ration of specific heat; R – gas constant; T – temperature.

The change of pressure of second volume $V_2(t)$ is determined from the following equation:

$$\frac{dp_2}{dt} = \frac{\gamma RT_1}{V_2(t)}G_{12} - \frac{\gamma p_2}{V_2(t)}\frac{dV_2}{dt}; \quad (3)$$

where $V_2(t) = V_{20} + Sx_G$; V_{20} is initial volume; S is cross-section area; x_G is coordinate of point G (see figure 2)

The liquid movement is considered as one-dimensional, i.e. all local velocity are equal to average velocity, and unsettled. Velocity and pressure depend on longitude coordinate and time. Such liquid movement is characterized by the wave of increased and reduced pressure which spreads from the place of change in each pressure vibration cross-section and in deformation of pipeline walls.

The movement and continuity equations of viscous, compressible fluid in pressure pipe have the following form [1,2,3]

$$\frac{\partial}{\partial t}[S(x)\rho] + \frac{\partial}{\partial x}[S(x)\rho v] = F_1(x), \quad (4)$$

$$\frac{\partial}{\partial t}[S(x)\rho v] + \frac{\partial}{\partial x}\left[S(x)\left(p + \rho v^2\right)\right] = F_2(p,v), \quad (5)$$

where ρ is density of liquid.

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

$$[A]\left\{\frac{\partial u}{\partial t}\right\} + [B]\left\{\frac{\partial u}{\partial x}\right\} = \{f\}; \quad (6)$$

where

$$[A] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix};\ [B] = \begin{bmatrix} v & a^2\rho \\ \frac{1}{\rho} & v \end{bmatrix},\ \{u\}^T = [p,v], \quad (7)$$

v, p – speed and fluid pressure; a is sound velocity in the liquid with a certain amount of gas, which is stored in the elastic pipeline, is equal to:

$$a = \sqrt{\frac{K(p)/\rho}{1 + \frac{K(p)\cdot d}{E\cdot e} + \frac{\varepsilon}{\gamma}\left[\frac{K(p)}{\gamma p} - 1\right]}}; \quad (8)$$

where: $K(p)$ – bulk modulus of elasticity of liquid, ρ – density of liquid, E – modulus of elasticity of a pipeline, d – internal diameter of a pipeline, e – thickness of a wall of a pipeline, γ – index of adiabatic process, ε – ratio of gas volume in the liquid and the total volume of liquid (mixture).

Differential equations of liquid movement in the cylinder are solved by characteristics method [1,2]. The main idea of characteristics method is the fact that unknown variable speed and liquid pressure at instant moment of time $t + \Delta t$ is determined according to these parameters at a moment of time (see figure 5).

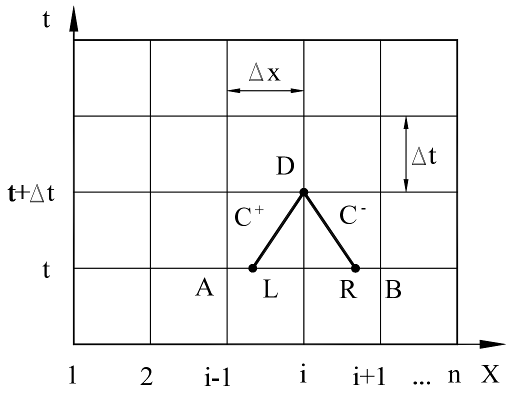


Fig 5. Circuit of liquid parameters determination of point

Equating the determinant of matrix (13) to zero, we shall receive the equation:

$$\left|[B] - [A]\frac{dx}{dt}\right| = 0, \quad (9)$$

which allows to determine $\frac{dx}{dt}$ derivative, which determines characteristic direction. If this equation has n various real roots $dx/dt = \lambda_i$ ($i = 1,2$), the initial system of the differential equations is referred to as hyperbolic.

The inclination tangent λ_i to the characteristic depends not only on coordinates but also on solution $\{u\}$.

Inserting expressions $[A]$ and $[B]$ from matrices (7) into equation (9) and having solved it, we receive three equations of characteristics

$$C^+ : \frac{dx}{dt} = v + a \; ; \quad C^- : \frac{dx}{dt} = v - a \, . \tag{10}$$

Compatibility conditions on characteristics are equal to [4,5,6]:

$$C^+ : \frac{dv}{dt} + \frac{1}{a\rho}\frac{dp}{dt} = \frac{f_1}{a\rho} + f_2 \; ; \tag{11}$$

$$C^- : \frac{dv}{dt} - \frac{1}{a\rho}\frac{dp}{dt} = -\frac{f_1}{a\rho} + f_2 \; ; \tag{12}$$

$$\{f\} = \left\{ \begin{matrix} 0 \\ -\dfrac{\tau \Pi(x)}{S(x)\rho} - a_x \end{matrix} \right\} , \tag{13}$$

where τ are shear stresses on the inner surface of pipeline; a_x – acceleration along x axis; $S(x)$ and $\Pi(x)$ are cross-section area and perimeter of pipeline.

Pressure and velocity in point D at the moment of time is determined from nonlinear algebraic equation system

$$C^+ : \Phi_1 = v_D - v_L + \frac{1}{2}(p_D - p_L)[r_{1L} + r_{1D}] - \frac{\Delta t}{2}[r_{2L} + r_{2D}] - \frac{\Delta t}{2}[r_{3L} + r_{3D}] = 0 \; ; \tag{14}$$

$$C^- : \Phi_2 = v_D - v_R - \frac{1}{2}(p_D - p_R)[r_{1R} + r_{1D}] + \frac{\Delta t}{2}[r_{2R} + r_{2D}] - \frac{\Delta t}{2}[r_{3R} + r_{3D}] = 0 \, , \tag{15}$$

where $r_1 = \dfrac{1}{\rho a}$; $r_2 = -a^2 \rho v \dfrac{dS}{dx} / S$;

$r_3 = -a_x - \dfrac{\Pi \lambda(\mathrm{Re}) v |v|}{8S}$;

$$\lambda(\mathrm{Re}) = \begin{cases} \dfrac{75}{\mathrm{Re}}, \textit{when} \quad \mathrm{Re} \le 2320; \\ \dfrac{0{,}31464}{\mathrm{Re}^{0{,}25}}, \textit{when} \quad \mathrm{Re} > 2320; \end{cases} \tag{16}$$

$\lambda(Re)$ is coefficient of pressure losses along pipe.

The system of equations (2) and (3) is solved by a Newton method:

$$[J]_i \{\Delta Y\}_i = -\{\Phi(Y)\}_i , \tag{17}$$

where $\{Y\}^T = [p_D, v_D]$; $\{\Phi\}^T = [\Phi_1, \Phi_2]$.

The potential energy of a gas in a high-pressure volume is transformed to a kinetic energy of the liquid. For accuracy simulation of interaction of the gas with liquid case of interaction is considered (see figure 7). In the point G pressure p_{SG} and velocity v_{SG} the liquid are determined from a system of equations (3) and (15). The x coordinate of point G is determined from the following expression:

$$x_G(t + \Delta t) = x_H(t) + \Delta t v_{SG} \, . \tag{18}$$

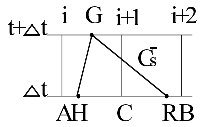


Fig 6. Circuit of liquid parameters determination of point G

The diagram of forces acting on the extinguishing device when out-flowing water through the opening (i.e. fire nozzle) valve is shown in then figure 7.

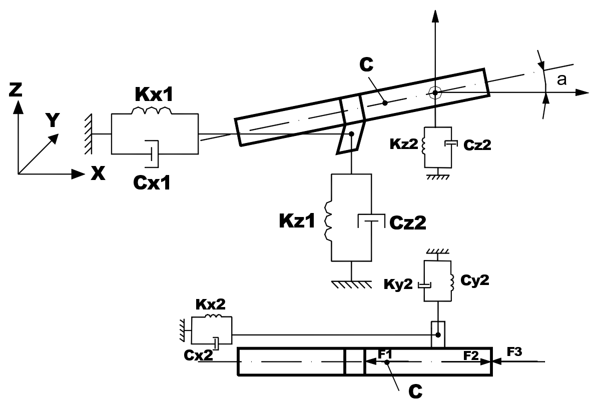


Fig 7. Diagram of forces acting on the extinguishing device

System of equation describing the extinguishing device is as follows

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = \{F(t, p, v)\}, \tag{19}$$

where $[M], [C], [K]$ are matrices of mass, damping, stiffness, respectively; $\{q\}, \{\dot{q}\}, \{\ddot{q}\}$ are vectors of displacement, velocity and acceleration, respectively; $\{F(t, p, v)\}$ is vector of forces and moments.

Today's state of research of the destruction of concrete using hand-guided drill and chisel hammers is well-proven concerning the unit tool-machine. An enormous increase in the quality of these tools was achieved during the last years and decades due to the steady optimisation of the mechanics, electronics, control, pneumatics etc., e.g. by the electro-pneumatic principle (Doepper) [1].

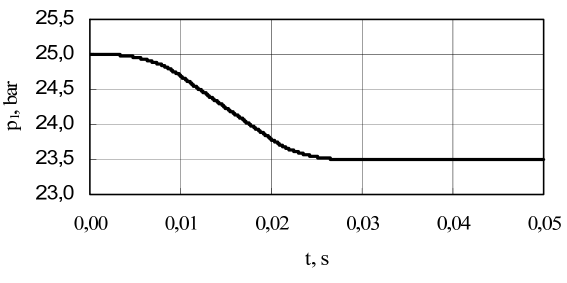
While the optimisation of the machine (drill and chisel hammer) including the machine-tool interface has reached a state that can hardly be improved yet, the optimisation of the interface tool-concrete is still in an initial stadium. It is for this reason that this study attempts to improve the tool-concrete interface, which has so far not been considered or only to a small extend [2].

Basic test were performed with the standard chisel forms flat and pointed chisel with the aim of improving the manual destruction of concrete. Considering the findings about the crack and fracture characteristics of the concrete under impact loading during the chiselling process, possibilities of the optimisation of the chisel cutting edge were investigated. A fundamental precondition for the basic tests was to look at every single impact in detail, i.e. the accurate quantitative recording of the transmitted energy and the investigations about the energy shares. This was achieved building a self-developed drop-test device and a friction-force test device [3].

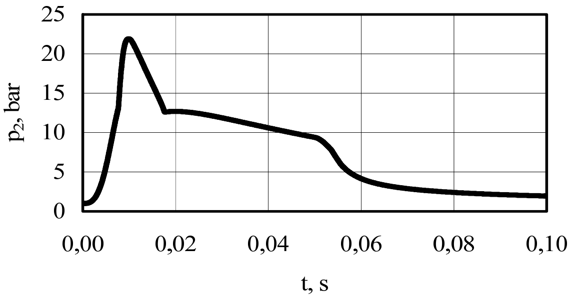
3. Numerical results

As an example of the extinguishing device is considered. The following data of the extinguishing device were used: the length of water compartment is 0.30 m, the volume of air container is equal $1.5\cdot10^{-3}$ m^3, initial pressure in the air container is 2.50 MPa, inner diameter of water compartment is equal 0.030 m. Time integration step is equal $2.0\cdot10^{-6}$ s. The length of water compartment is divided in the 62 elements.

The simulation results of hydrodynamic parameters are given in the figure 8.



a)



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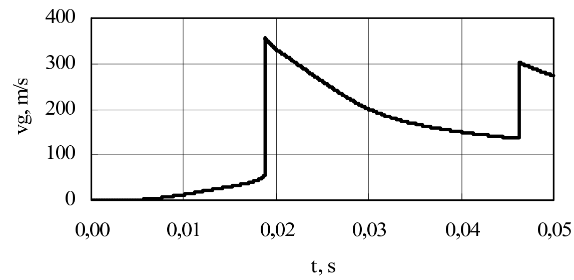

c)

Fig 8. The parameters of the extinguishing device:
a – change pressure in the air container; b – change air pressure in the second volume; c – change liquid velocity at the point G

The forces acting on the extinguishing device are shown in the figure 9.

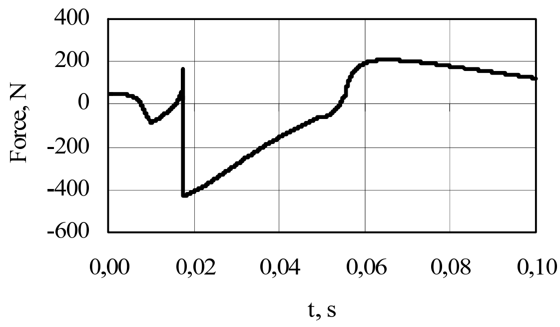

Fig 9. Dependence of recoil force upon time

The displacement and velocity of the extinguishing device are shown in the figure 10 and figure 11.

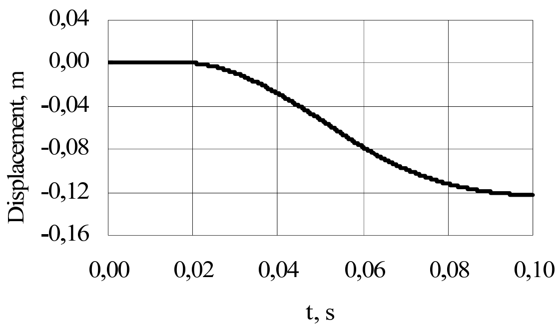

Fig 10. Displacement of extinguishing device

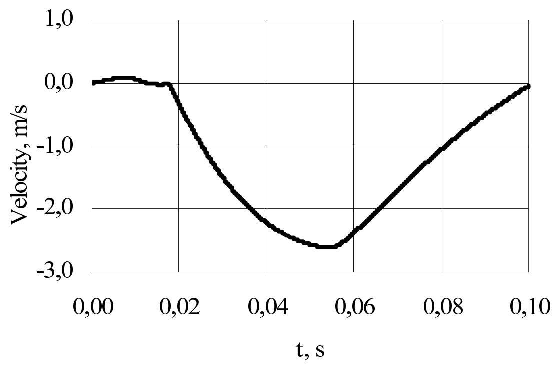

Fig 11. Velocity of extinguishing device

4. Conclusions

A new 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. Differential equations, describing hydrodynamic processes inside the extinguishing device, help analyze the movement liquid and gas better and more precisely. At the end of a pipeline of the extinguishing device the maximum velocity of liquid when initial pressure is equal 2.5 MPa reaches 60 m/s.

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INVESTIGATION OF HYDRODYNAMIC PROCESSES OF THE AUTOMATIC IMPULSE EXTINGUISHING

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Abstract: *The simple way to increase the extinguishing water surface area is to atomize water into fine drops. The smaller the drops are developed, the better use of the water properties can be implemented and less water is consumed in fire fighting. The main aim of the investigation is to develop approach to investigate hydrodynamic processes in the extinguishing device. The mathematical model of extinguishing device is presented, where the flow of fluid and gas and the interaction of liquid with the gas are taken into account. The flow of fluid 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 extinguishing device is shown. The dependence of recoil force is obtained.*

Keywords: *extinguishing device, gas, liquid, dynamics, recoil force , numerical methods*

1. INTRODUCTION

Extinguishing systems comprise systems designed for the supply of the extinguishing materials (extinguish-ants) 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 damages resulting from inefficient application of water exceed those 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 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 were 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 the drops are developed, the better use of the 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 a jet kinetic energy. If we use the energy of the compressed air or other gases to eject water through 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). Consequently, the extinguishing water cover area enlarges as well as the water efficiency. The devices with such properties can be usable in portable version. That 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.

The extinguishing device based on the use of the compressed air energy for ejecting extinguishing water could be expressed as follows:

- Compressed air compartment is filled up from the air container;
- Water compartment is filled up from the water tank;
- When the fast reaction valve is opened, compressed air and water compartments get merged;
- Water being under air pressure is ejected within a very short time (from several to several tens of mili-seconds) to the focus of fire;
- Further on the process is repeated from the beginning.

Studies on such extinguishing technologies have not been completed yet and need to be further updated and tested. The main parts of investigation are:

- Process of extinguishing (water) media delivery to fire;
- Recoil of the extinguishing device during operation.

The repeating process of the extinguishing device could be obtained by using an automatic hydraulic and pneumatic nozzle.

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. 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) process is repeated constantly and water jets are ejected in series Figure 1.

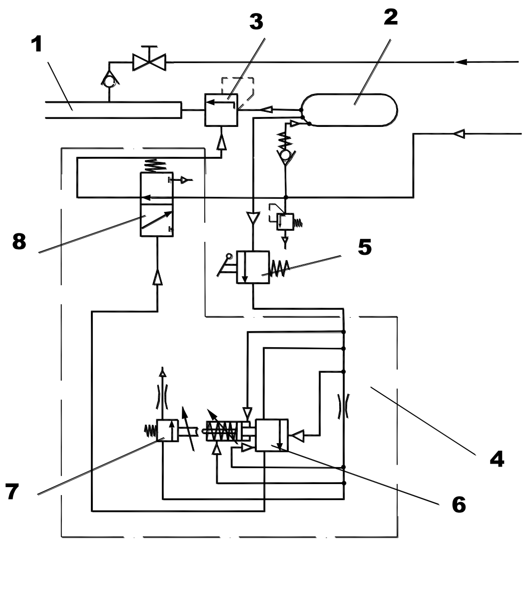


Figure 1. Schematic automatic hydraulic and pneumatic nozzle

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 fast reaction valve. The second valve opens when pressure reaches particular pressure. When the fast reaction valve begins to open the second chamber divides in two volumes. In the first volume there is high pressure of air and in the second volume there is high pressure of water.

Dynamic model of the extinguishing device is shown in the Figure 2. In the air container the pressure is $p_1(t)$ and the volume of air container is V_1.

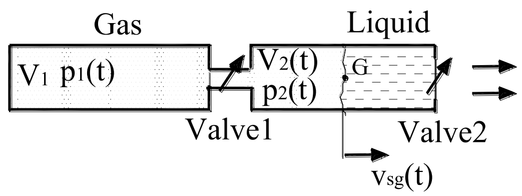


Figure 2. Diagram of extinguishing device

Cross-section area S_{v1} of the first valve and is function of time (Figure 3). Cross-section area S_{v2} of the second valve depends on pressure $p(t, x = L_2)$ (Figure 4). In the second air volume $V_2(t)$ the pressure is $p_2(t)$. The second air volume and water compartment is separated the surface G (Figure 2). According to the first law of thermodynamics, whole thermal energy moved with gas is spent for change of internal energy and for work of expansion of gas in a volume.

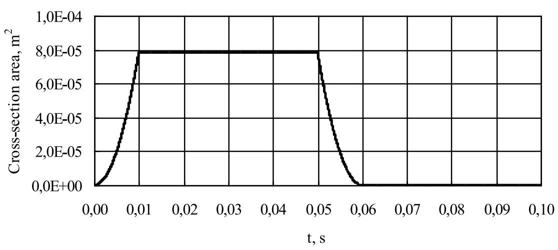


Figure 3. Dependence of cross-section area of first valve on time

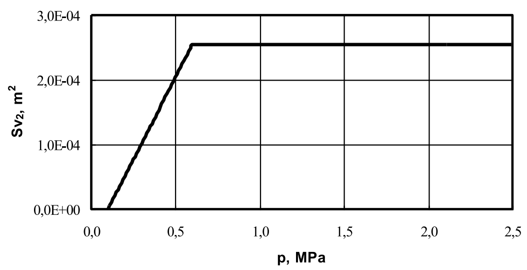


Figure 4. Dependence of cross-section area of second valve on pressure

The change of pressure of constant volume ($V_1 = const$) of air container is determined from the following equation:

$$\frac{dp_1}{dt} = \frac{\gamma R T_1}{V_1}\left(G_{1in}(p_1) - G_{12}(p_1, p_2)\right) \qquad (1)$$

where $G_{1in}(p_1)$ is input mass flow; G_{12} is mass flow of gas (air), determined on the formula Sen-Venan and Vencel [1]:

$$G_{12}(p_1, p_2) = \begin{cases} \mu_1 S_{v1}(t) K_1(T_1) p_1 \varphi\left(\sigma = \dfrac{p_2}{p_1}\right) & if\ p_1 \geq p_2 \\ \mu_1 S_{v1}(t) K_1(T_1) p_2 \varphi\left(\sigma = \dfrac{p_1}{p_2}\right) & if\ p_2 > p_1 \end{cases}$$

$$K_1\ (T_1) = \sqrt{\frac{1}{R T_1}}\ ; \qquad (2)$$

S_{v1} is cross-section area of first valve; μ_1 is orifice discharge coefficient; γ is ratio of specific heats of gaseous medium; R is gas constant; T_1 is temperature of gas in air container. To take account of the subsonic and sonic flow, the piecewise flow function $\varphi(\sigma)$ is defined as follows:

$$\varphi(\sigma) = \begin{cases} \sqrt{\left(\dfrac{2\gamma}{\gamma - 1}\right)\left(\sigma^{\frac{2}{\gamma}} - \sigma^{\frac{\gamma+1}{\gamma}}\right)} & if\ \ \sigma_{cr} < \sigma \leq 1 \\ \sqrt{\gamma\left(\dfrac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} & if\ \ 0 < \sigma \leq \sigma_{cr} \end{cases} \qquad (3)$$

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

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

The change of pressure of second volume $V_2(t)$ is determined from the following equation:

$$\frac{dp_2}{dt} = \frac{\gamma R T_1}{V_2(t)} G_{12}(p_1, p_2) - \frac{\gamma p_2}{V_2(t)}\frac{dV_2}{dt} - \frac{\gamma R T_1}{V_2(t)} G_{23}(p_2), \quad (4)$$

where $G_{23}(p_2)$ is output mass flow of gas to medium,

$$G_{23}(p_2) = \begin{cases} G^*{}_{23}(p_2)\ \ if\ x_G > L_2 \\ 0\ \ if\ x_G \leq L_2 \end{cases};$$

$$G^*{}_{23}(p_2) = \begin{cases} \mu_2 S_{v2}(p_2) K_1(T_1) p_2 \varphi\left(\sigma = \dfrac{p_\infty}{p_2}\right) & if\ p_2 \geq p_\infty \\ \mu_2 S_{v2}(p_2) K_1(T_1) p_\infty \varphi\left(\sigma = \dfrac{p_2}{p_\infty}\right) & if\ p_\infty > p_2 \end{cases}$$

$V_2(t) = V_{20} + S x_G$; V_{20} is initial volume; S is cross-section area; x_G is coordinate of point G (Figure 2).

The liquid movement is considered as one-dimensional, i.e. all local velocity are equal to average velocity, and unsettled. Velocity and pressure depend on longitude coordinate and time. Such liquid movement is characterized by the wave of increased and reduced pressure which spreads from the place of change in each pressure vibration cross-section and in deformation of pipeline walls.

The movement and continuity equations of viscous, compressible fluid in pressure pipe have the following form [1,2,3]

$$\frac{\partial}{\partial t}[S(x)\rho] + \frac{\partial}{\partial x}[S(x)\rho v] = F_1(x), \qquad (5)$$

$$\frac{\partial}{\partial t}[S(x)\rho v] + \frac{\partial}{\partial x}\left[S(x)\left(p + \rho v^2\right)\right] = F_2(p, v), \qquad (6)$$

where ρ is density of liquid.

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

$$[A]\left\{\frac{\partial u}{\partial t}\right\} + [B]\left\{\frac{\partial u}{\partial x}\right\} = \{f\}; \qquad (7)$$

where

$$[A] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}; \qquad [B] = \begin{bmatrix} v & a^2\rho \\ \dfrac{1}{\rho} & v \end{bmatrix},$$

$$\{u\}^T = [p, v], \qquad (8)$$

v, p - speed and fluid pressure; a is sound velocity in the liquid with a certain amount of gas, which is stored in the elastic pipeline, is equal to:

$$a = \sqrt{\frac{K(p)/\rho}{1 + \dfrac{K(p)\cdot d}{E \cdot e} + \dfrac{\varepsilon}{\gamma}\left[\dfrac{K(p)}{\gamma p} - 1\right]}}\ ; \qquad (9)$$

where: $K(p)$ – bulk modulus of elasticity of liquid, ρ – density of liquid, E – modulus of elasticity of a pipeline, d – internal diameter of a pipeline, e –

thickness of a wall of a pipeline, γ – index of adiabatic process, ε – ratio of gas volume in the liquid and the total volume of liquid (mixture).

Differential equations of liquid movement in the cylinder are solved by characteristics method [1,2]. The main idea of characteristics method is the fact that unknown variable speed and liquid pressure at instant moment of time $t+\Delta t$ is determined according to these parameters at a moment of time (Figure 5).

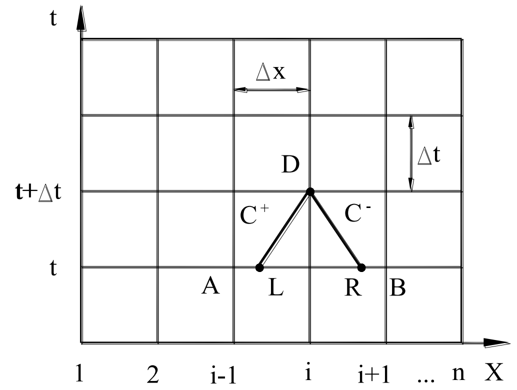


Figure 5. Circuit of liquid parameters determination of point D

Equating the determinant of matrix (8) to zero, the equation is obtained:

$$\left|[B]-[A]\frac{dx}{dt}\right|=0 \tag{10}$$

which allows to determine $\frac{dx}{dt}$ derivative, which determines characteristic direction. If this equation has n various real roots $dx/dt=\lambda_i$ ($i=1,2$), the initial system of the differential equations is referred to as hyperbolic. The inclination tangent λ_i to the characteristic depends not only on coordinates but also on solution $\{u\}$.

Inserting expressions $[A]$ and $[B]$ from matrices (8) into equation (10) and having solved it, three equations of characteristics are obtained

$$C^+ : \frac{dx}{dt}=v+a\,; \qquad C^- : \frac{dx}{dt}=v-a \tag{11}$$

Compatibility conditions on characteristics are equal to [4,5,6]:

$$C^+ : \frac{dv}{dt}+\frac{1}{a\rho}\frac{dp}{dt}=\frac{f_1}{a\rho}+f_2, \tag{12}$$

$$C^- : \frac{dv}{dt}-\frac{1}{a\rho}\frac{dp}{dt}=-\frac{f_1}{a\rho}+f_2, \tag{13}$$

$$\{f\}=\left\{\begin{matrix}0\\ -\frac{\tau\Pi(x)}{S(x)\rho}-a_x\end{matrix}\right\}. \tag{14}$$

where τ are shear stresses on the inner surface of pipeline; a_x - acceleration along x axis; $S(x)$ and $\Pi(x)$ are cross-section area and perimeter of pipeline.

Pressure and velocity in point D at the moment of time is determined from nonlinear algebraic equation system

$$C^+ : \Phi_1=v_D-v_L+\frac{1}{2}(p_D-p_L)[r_{1L}+r_{1D}]-\frac{\Delta t}{2}[r_{2L}+r_{2D}]-\frac{\Delta t}{2}[r_{3L}+r_{3D}]=0\,, \tag{15}$$

$$C^- : \Phi_2=v_D-v_R-\frac{1}{2}(p_D-p_R)[r_{1R}+r_{1D}]+\frac{\Delta t}{2}[r_{2R}+r_{2D}]-\frac{\Delta t}{2}[r_{3R}+r_{3D}]=0 \tag{16}$$

where $r_1=\frac{1}{\rho a}$; $\qquad r_2=-a^2\rho v\frac{dS}{dx}/S$;

$$r_3=-a_x-\frac{\Pi\lambda(Re)v|v|}{8S};$$

$$\lambda(Re)=\begin{cases}\frac{75}{Re}, when \quad Re\le 2320;\\ \frac{0{,}31464}{Re^{0{,}25}}, when \quad Re>2320;\end{cases} \tag{17}$$

$\lambda(Re)$ is coefficient of pressure losses along pipe.

The system of equations (15) and (16) is solved by a Newton method:

$$[J]_i\{\Delta Y\}_i=-\{\Phi(Y)\}_i, \tag{18}$$

where $\{Y\}^T=[p_D,v_D]$; $\{\Phi\}^T=[\Phi_1,\Phi_2]$.

The potential energy of a gas in a high-pressure volume is transformed to a kinetic energy of the liquid. For accuracy simulation of interaction of the gas with liquid case of interaction is considered (Figure 6). In the point G pressure p_{SG} and velocity v_{SG} the liquid are determined from a system of equations (4) and (16). The x coordinate of point G is determined from the following expression:

$$x_G(t+\Delta t)=x_H(t)+\Delta t v_{SG}\,. \tag{19}$$

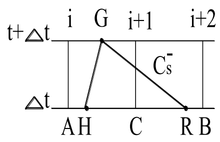


Figure 6. Circuit of liquid parameters determination of point G

The diagram of forces acting on the extinguishing device when out-flowing water through the opening (i.e. fire nozzle) valve is shown in then Figure 7.

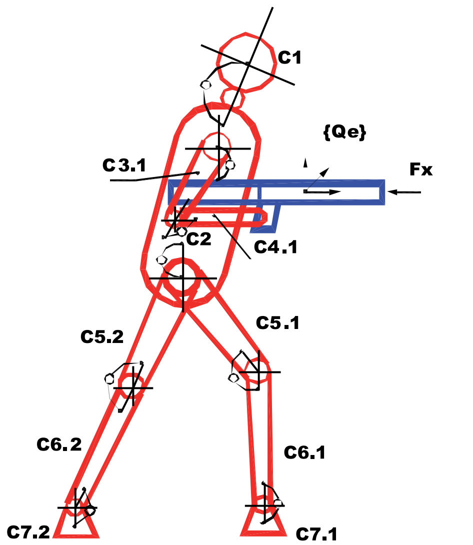


Figure 7. Diagram of forces acting on the extinguishing device and fireman

The recoil force acting along extinguishing device axis is equal:

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

$$F_{aero} = \begin{cases} \frac{1}{2}\rho S_{v2} v_2^2 & if\ x_G \le L_2 \\ \frac{1}{2}\rho_{gas} S_{v2} v_2^2 & if\ x_G > L_2 \end{cases}$$

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

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

$$\begin{bmatrix} [M] & [\Phi]^T \\ [\Phi] & [0] \end{bmatrix} \begin{Bmatrix} \{\ddot{q}\} \\ \{\Psi\} \end{Bmatrix} = \begin{Bmatrix} \{F(q,\dot{q},t)\} \\ \{U(q,\dot{q})\} \end{Bmatrix} \qquad (19)$$

where $[M]$, $[\Phi]$ are matrices of mass and Jacobian matrix, respectively; $\{q\}, \{\dot{q}\}, \{\ddot{q}\}$ are vectors of displacement, velocity and acceleration, respectively; $\{F(t,p,v)\}$ is vector of external forces and moments; $\{\Psi\}$ is vector of Lagrange multiplier; $\{U(q,\dot{q})\}$ is vector,

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

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

3. NUMERICAL RESULTS

As an example of the extinguishing device is considered. The following data of the extinguishing device were used: the length of water compartment is $0.410\,\mathrm{m}$, the volume of air container is equal $1.5\cdot10^{-3}$ m^3, initial pressure in the air container is 2.50 MPa, inner diameter of water compartment is equal $0.0250\ m$. Time integration step is equal $2.0\cdot10^{-6}$ s. The length of water compartment is divided in the 82 elements.

The simulation results of diameter of second valve is given in the Figure 8.

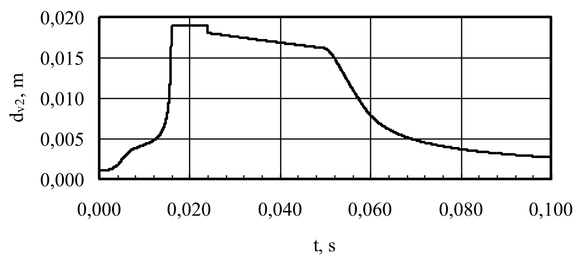


Figure 8. Dependence of diameter area of second valve on time

The simulation results of hydrodynamic parameters are given in the Figure 9.

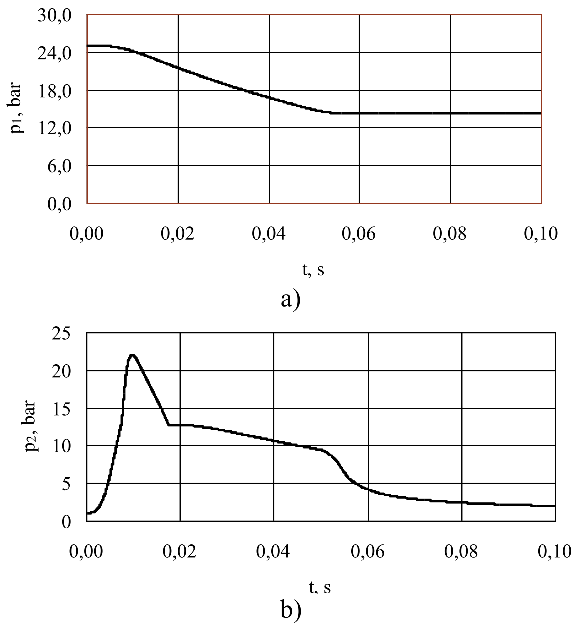
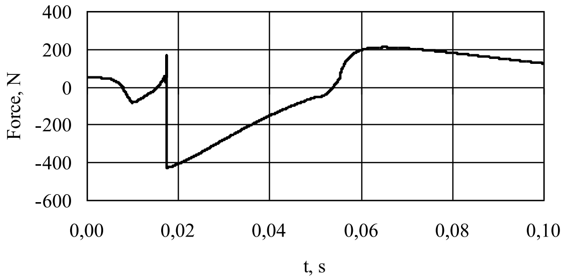
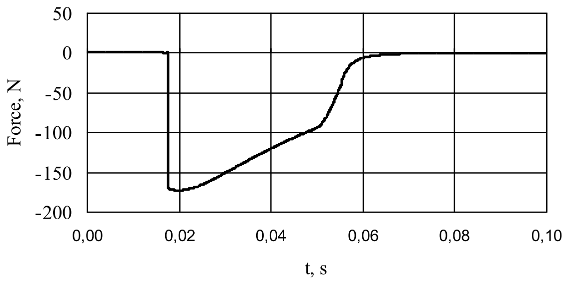


Figure 9. The parameters of the extinguishing device:
a – change pressure in the air container;
b – change air pressure in the second volume

The forces acting on the extinguishing device are shown in the Figure 10.



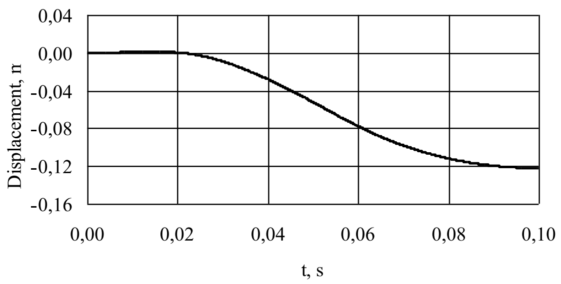
a)



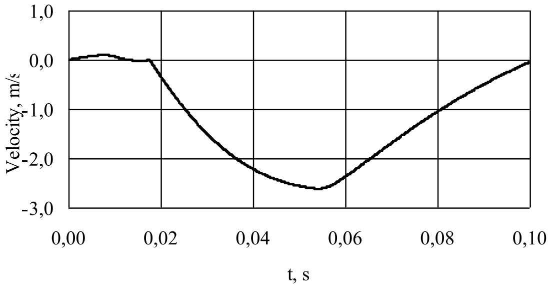
b)

Figure 10. Dependence of total force upon time: a – total force; b - recoil force

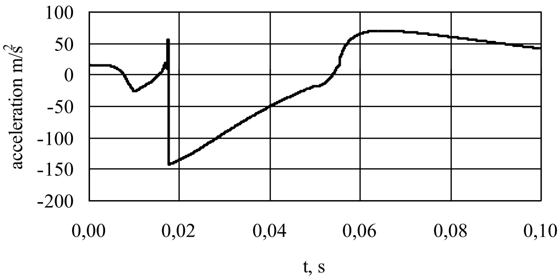
The displacement, velocity and acceleration of the extinguishing device are shown in the Figure 11.



a)



b)



c)

Figure 11. Displacement, velocity and acceleration upon time: a – displacement; b – velocity; c - acceleration

5. CONCLUSIONS

A new 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. Differential equations, describing hydrodynamic processes inside the extinguishing device, help analyze the movement liquid and gas better and more precisely. At the end of a pipeline of the extinguishing device the maximum velocity of liquid when initial pressure is equal 2.5 MPa reaches 120 m/s. The recoil forces of the extinguisher device have been evaluated more precisely.

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Investigation of Hydrodynamic Processes of the Extinguishing Device Evaluating Interaction Between Gas and Liquid

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Abstract

The main aim of the investigation is to develop an approach to investigate hydrodynamic processes in the extinguishing device. The mathematical model of the extinguishing device is presented, where the flow of gas and liquid and the interaction of gas and liquid are taken into account. The flow of fluid 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 extinguishing device is shown.
KEY WORDS: e*xtinguishing device, gas, liquid, dynamics, numerical methods*

1. Introduction

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 damages resulting from inefficient application of water exceed those 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 modern centrifugal pumps, it is not possible to prevent water spillage on the scene of a fire accident. 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 the drops are developed, the better use of the 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 a jet kinetic energy. 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. The devices with such properties can be usable in portable version. That 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%.

2. Mathematical Model of Extinguishing Device evaluating Interaction between Gas and Liquid

The extinguishing device consists of two chambers (air container and water compartment) and two valves. The first valve is fast reaction valve. The second valve opens when pressure reaches particular pressure. When the fast reaction valve begins to open the second chamber divides in two volumes. In the first volume there is high pressure of air and in the second volume there is high pressure of water. The simplex mathematical model of extinguishing device is presented in the [1]. In this article the complex mathematical model of extinguishing device is presented.

The dynamic model of the extinguishing device is shown in the Fig. 1.

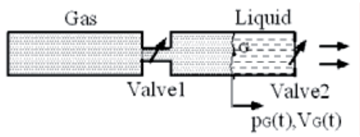


Fig. 1 Diagram of extinguishing device

The gas and liquid movement are considered as one-dimensional, i.e. all local velocity is equal to average velocity, and unsettled. Velocity and pressure depend on longitude coordinate and time. Such gas and liquid movement are characterized by the wave of increased and reduced pressure which spreads from the place of change in each pressure vibration cross-section and in deformation of pipeline walls.

The continuity and movement equations of viscous, compressible fluid in pressure pipe have the following form:

$$\frac{\partial}{\partial t}\left[S(x)\rho\right]+\frac{\partial}{\partial x}\left[S(x)\rho v\right]=0\,, \qquad 1)$$

$$\frac{\partial}{\partial t}\left[S(x)\rho v\right]+\frac{\partial}{\partial x}\left[S(x)\left(p+\rho v^2\right)\right]+\Pi(x)\tau+\rho S(x)a_x+\rho g S(x)\sin(\theta)-p\frac{\partial S(x)}{\partial x}=0\,, \qquad 2)$$

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

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

$$\left[A_g\right]\left\{\frac{\partial u_g}{\partial t}\right\}+\left[B_g\right]\left\{\frac{\partial u_g}{\partial x}\right\}=\left\{f_g\right\}; \tag{3}$$

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

here
$$\left[A_g\right]=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix};\ \left[B_g\right]=\begin{bmatrix}v_g & c_g^2\rho_g\\ \dfrac{1}{\rho_g} & v_g\end{bmatrix}; \tag{5}$$

$$\left\{u_g\right\}^T=\left[p_g, v_g\right];\left\{f_g\right\}^T=\left[-\frac{c_g{}^2\rho_g v_g}{S(x)}\frac{\partial S(x)}{\partial x},-g\,sin(\theta)-\frac{\lambda(Re,\Delta)\left|v_g\right|v_g}{2D}-a_{gx}(t)+\frac{p_g}{\rho_g S(x)}\frac{\partial S(x)}{\partial x}\right]; \tag{6}$$

$$[A]=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix};\quad [B]=\begin{bmatrix}v & c^2\rho\\ \dfrac{1}{\rho} & v\end{bmatrix}; \tag{7}$$

$$\{u\}^T=[p,v];$$

$$\{f\}^T=\left[-\frac{c^2\rho v}{S(x)}\frac{\partial S(x)}{\partial x},\ -g\,sin(\theta)-\frac{\lambda(Re)|v|v}{2D}-a_x(t)+\frac{p}{\rho S(x)}\frac{\partial S(x)}{\partial x}\right], \tag{8}$$

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

$$c_g=\sqrt{\gamma RT}\ ;\qquad c=\sqrt{\frac{K(p)/\rho}{1+\dfrac{K(p)\cdot d}{E\cdot e}+\dfrac{\varepsilon}{\gamma}\left[\dfrac{K(p)}{\gamma p}-1\right]}}\ ; \tag{9}$$

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

Differential equations of fluid movement in the pipeline are solved by characteristics method [2,3]. The main idea of characteristics method is the fact that unknown variable speed and liquid pressure at instant moment of time $t+\Delta t$ is determined according to these parameters at a moment of time (Fig. 2).

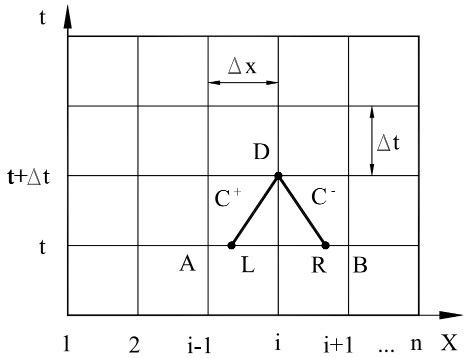


Fig. 2 Circuit of liquid parameters determination of point D

Equating the determinant of matrix (13) to zero, we shall receive the equation:

$$\left|[B]-[A]\frac{dx}{dt}\right|=0 \tag{10}$$

which allows to determine $\frac{dx}{dt}$ derivative, which determines characteristic direction. If this equation has n various real roots $dx/dt=\lambda_i$ ($i=1,2$), the initial system of the differential equations is referred to as hyperbolic. The inclination tangent λ_i to the characteristic depends not only on coordinates but also on solution $\{u\}$.

Inserting expressions $\lfloor A_g \rfloor$, $\lfloor B_g \rfloor$ and $[A]$, $[B]$ from matrices (5) and (7) and having solved it, we receive two equations of characteristics

$$C_g^+:\ \frac{dx_g}{dt}=v_g+c_g;\qquad C_g^-:\ \frac{dx_g}{dt}=v_g-c_g \tag{11}$$

$$C^+:\ \frac{dx}{dt}=v+c;\qquad C^-:\ \frac{dx}{dt}=v-c \tag{12}$$

Compatibility conditions on characteristics are equal to [5]:

$$C_g^+ :\ \frac{dp_g}{dt}+c_g\rho_g\frac{dv_g}{dt}=f_{g1}+c_g\rho_g f_{g2}\,; \tag{13}$$

$$C_g^- :\ \frac{dp_g}{dt}-c_g\rho_g\frac{dv_g}{dt}=f_{g1}-c_g\rho_g f_{g2}\,; \tag{14}$$

$$C^+ :\ \frac{dp}{dt}+c\rho\frac{dv}{dt}=f_1+c\rho f_2\,; \tag{15}$$

$$C^- :\ \frac{dp}{dt}-c\rho\frac{dv}{dt}=f_1-c\rho f_2\,; \tag{16}$$

$$\{f_g\}^T=[f_{g1},f_{g2}]=\left[-\frac{c_g{}^2\rho_g v_g}{S(x)}\frac{\partial S(x)}{\partial x}, -g\,sin(\theta)-\frac{\lambda(Re,\Delta)v_g|v_g}{2D}-a_{gx}(t)+\frac{p_g}{\rho_g S(x)}\frac{\partial S(x)}{\partial x}\right]; \tag{17}$$

$$\{f\}^T=[f_1,f_2]=\left[\frac{c^2\rho v}{S(x)}\frac{\partial S(x)}{\partial x},\ -g\sin(\theta)-\frac{\lambda(Re)v|v|}{2D}-a_x(t)\right]. \tag{18}$$

here τ are shear stresses on the inner surface of pipeline; a_x - acceleration along x axis; $S(x)$ and $\Pi(x)$ are cross-section area and perimeter of pipeline.

Pressure and velocity in point D at the moment of time is determined from the nonlinear algebraic equation system:

$$C_g^+ :\ \Phi_{g1}=p_{gD}-p_{gL}+\frac{1}{2}(\rho_{gD}c_{gD}+\rho_{gL}c_{gL})(v_{gD}-v_{gL})-\frac{\Delta t}{2}(r_{g1L}+r_{g1D})-\frac{\Delta t}{2}(r_{g2L}+r_{g2D})=0\,; \tag{19}$$

$$C_g^- :\ \Phi_{g2}=p_{gD}-p_{gR}-\frac{1}{2}(\rho_{gD}c_{gD}+\rho_{gR}c_{gR})(v_{gD}-v_{gR})-\frac{\Delta t}{2}(r_{g1R}+r_{g1D})+\frac{\Delta t}{2}(r_{g2R}+r_{g2D})=0\,; \tag{20}$$

$$C^+ :\ \Phi_1=p_D-p_L+\frac{1}{2}(\rho_D c_D+\rho_L c_L)(v_D-v_L)-\frac{\Delta t}{2}(r_{1L}+r_{1D})-\frac{\Delta t}{2}(r_{2L}+r_{2D})=0\,; \tag{21}$$

$$C^- :\Phi_2=p_{gD}-p_{gR}-\frac{1}{2}(\rho_D c_D+\rho_R c_R)(v_D-v_R)-\frac{\Delta t}{2}(r_{1R}+r_{1D})+\frac{\Delta t}{2}(r_{2R}+r_{2D})=0\,, \tag{22}$$

here
$$r_{g1}=f_{g1}=-\frac{c_g{}^2\rho_g v_g}{S(x)}\frac{\partial S(x)}{\partial x}\,;$$

$$r_{g2}=\rho_g c_g\left(-g\,sin(\theta)-a_{gx}-\frac{\lambda_g(Re,\Delta)v_g|v_g|}{2D}+\frac{p_g}{\rho_g S(x)}\frac{\partial S(x)}{\partial x}\right); \tag{23}$$

$$r_1=f_1=-\frac{c^2\rho v}{S(x)}\frac{\partial S(x)}{\partial x}\,;$$

$$r_2=\rho c\left(-g\,sin(\theta)-a_x-\frac{\lambda(Re,\Delta)v|v|}{2D}+\frac{p}{\rho S(x)}\frac{\partial S(x)}{\partial x}\right); \tag{24}$$

$$\lambda_g(Re)=\begin{cases}\left(\dfrac{0{,}556}{\lg(Re/7)}\right)^2, \text{when} \quad Re\le 2320;\\ 0{,}10\left(\dfrac{\Delta}{D}+\dfrac{100}{Re}\right)^{0{,}25}, \text{when} \quad Re>2320;\end{cases} \tag{25}$$

$$\lambda(Re)=\begin{cases}\dfrac{75}{Re}, \mathit{when} \quad Re\le 2320;\\ \dfrac{0{,}31464}{Re^{0{,}25}}, \mathit{when} \quad Re>2320;\end{cases} \tag{26}$$

$\lambda\ (Re,\Delta)$, $\lambda(Re)$ are coefficients of pressure losses along pipe; Δ - roughness of inner surface of pipeline.

The systems of equations (18, 19) and (20, 21) are solved by a Newton method:

$$[J_g]_i\{\Delta Y_g\}_i=-\{\Phi_g(Y_g)\}_i\,, \tag{27}$$

$$[J]_i\{\Delta Y\}_i=-\{\Phi(Y)\}_i\,, \tag{28}$$

Here
$$\{Y_g\}^T=[p_{gD},v_{gD}];\ \{\Phi_g\}^T=[\Phi_{g1},\Phi_{g2}];\ \{\Phi\}^T=[\Phi_1,\Phi_2].$$

The potential energy of a gas in a high-pressure volume is transformed to a kinetic energy of the liquid. For accuracy simulation of interaction of the gas with liquid case of interaction is considered (Fig.3).

Movements of gas and liquid in pipeline, where discretization steps are Δx_d and Δx, and limits of gas and liquid interaction are considered. Depending on the position of the limit of gas and liquid interaction in a pipeline, there can be three cases of gas and liquid interaction.

Fig. 3 Circuit of gas and liquid parameters determination of the point G

First case of the interaction (Fig 4 a.)

$$x_{gi} \le x_{gH} \le x_j, \text{ and } x_{gi} \le \left(q_H + \dot{q}_H \Delta t\right) \le x_j, \tag{29}$$

The parameters of gas and liquid flows as well as coordinate of their interaction at the moment of time $t+\Delta t$, i.e. parameters of gas and liquid flows of point G are determined.

The conditions of compatibility, equations of these characteristics and equations of gas and liquid charge balance on characteristics C_g^+ for gas and on characteristics C^- for liquid are written. Then the system of equations, from which the parameters of gas and liquid flow can be determined at the moment of time $t+\Delta t$:

$$\begin{cases} C_g^+: \ \Phi_{g1} = \Phi_{g1}\left(p_{gG}, v_{gG}\right) = 0 \\ C^-: \Phi_2 = \Phi_2\left(p_G, v_G\right) = 0 \\ \Phi_3 = S_{gG} v_{gG} - S v_G = 0 \\ p_{gG} = p_G \end{cases} \tag{30}$$

Pressures and velocities of gas and liquid in the points i and j at the moment of time $t+\Delta t$ are determined:

$$p_{gi}^{t+\Delta t} = \left(\frac{p_{gG}^{t+\Delta t} - p_{gi-1}^{t+\Delta t}}{x_{gG} - x_{gi-1}}\right)\left(x_{gi} - x_{gi-1}\right) + p_{gi-1}^{t+\Delta t}; \ v_{gi}^{t+\Delta t} = \left(\frac{v_{gG}^{t+\Delta t} - v_{gi-1}^{t+\Delta t}}{x_{gG} - x_{gi-1}}\right)\left(x_{gi} - x_{gi-1}\right) + v_{gi-1}^{t+\Delta t};$$

$$p_j^{t+\Delta t} = \left(\frac{p_{j+1}^{t+\Delta t} - p_G^{t+\Delta t}}{x_{j+1} - x_G}\right)\left(x_j - x_G\right) + p_G^{t+\Delta t}; \ v_j^{t+\Delta t} = \left(\frac{v_{j+1}^{t+\Delta t} - v_G^{t+\Delta t}}{x_{j+1} - x_G}\right)\left(x_j - x_G\right) + v_G^{t+\Delta t} \quad 31)$$

Pressures, velocities and x coordinate of gas in the point F_1 at the moment of time t are determined:

$$x_{gF1} = \frac{1}{1+\Delta t a_{1g}}\left[x_{gG} - \Delta t\left(v_{gi-1} + c_{gF1} - a_{1g} x_{gi-1}\right)\right]; \ a_{1g} = \frac{v_{gH} - v_{gi-1}}{x_{gH} - x_{gi-1}};$$

$$v_{gL} = a_{ig}\left(x_{gL} - x_{gi-1}\right) + v_{gi}; \ p_{gL} = a_{2g}\left(x_{gL} - x_{gi-1}\right) + p_{gi};$$

$$a_{2g} = \frac{p_{gH} - p_{gi-1}}{x_{gH} - x_{gi-1}}; \ x_{gG} = x_{gH} + \Delta t v_{gH}. \tag{32}$$

Pressures, velocities and x coordinate of liquid in the point F_2 at the moment of time t are determined:

$$x_{F2} = x_G - \Delta t\left(x_{F2} - c_{F2}\right); \ v_{F2} = \frac{1}{1+\Delta t a_{1S}}\left(v_H + \Delta t a_{1S}\left(c_{F2} + v_H\right)\right);$$

$$p_{F2} = a_{2S}\left(x_{F2} - x_H\right) + p_H; \quad a_{1S} = \frac{v_{j+1} - v_H}{x_{j+1} - x_H}; \quad a_{2S} = \frac{p_{j+1} - p_H}{x_{j+1} - x_H}; \tag{33}$$

Second case of the interaction (Fig. 4 b.)

$$x_{gi} \le x_{gH} \le x_j, \text{ and } \left(q_H + \dot{q}_H \Delta t\right) < x_{gi}, \tag{34}$$

The pressure and velocity of gas and liquid in the point G at the moment of time $t+\Delta t$ are determined using system of equations (30).

Pressures and velocities of liquid in the points $j-1$ and j at the moment of time $t+\Delta t$ are determined:

$$p_{j-1}^{t+\Delta t} = \left(\frac{p_G^{t+\Delta t} - p_{j+1}^{t+\Delta t}}{x_G - x_{j+1}}\right)\left(x_{j-1} - x_{j+1}\right) + p_{j+1}^{t+\Delta t}; \ v_{j-1}^{t+\Delta t} = \left(\frac{v_G^{t+\Delta t} - v_{j+1}^{t+\Delta t}}{x_G - x_{j+1}}\right)\left(x_{j-1} - x_{j+1}\right) + v_{j+1}^{t+\Delta t}. \tag{35}$$

$$p_j^{t+\Delta t} = \left(\frac{p_G^{t+\Delta t} - p_{j+1}^{t+\Delta t}}{x_G - x_{j+1}}\right)\left(x_j - x_{j+1}\right) + p_{j+1}^{t+\Delta t}; \quad v_j^{t+\Delta t} = \left(\frac{v_G^{t+\Delta t} - v_{j+1}^{t+\Delta t}}{x_G - x_{j+1}}\right)\left(x_j - x_{j+1}\right) + v_{j+1}^{t+\Delta t}. \tag{36}$$

Pressures, velocities and x coordinate of liquid in the point F_2 at the moment of time t are determined by using (33) expressions.

<u>Third case of the interaction (Fig. 4 c.)</u>

$$x_{gi} \le x_{gH} \le x_j, \quad \text{and} \quad \left(q_H + \dot{q}_H \Delta t\right) > x_{gi+1}, \tag{37}$$

The pressure and velocity of gas and liquid in the point G at the moment of time $t+\Delta t$ are determined using system of equations (30).

Pressures and velocities of gas in the points i and $i+1$ at the moment of time $t+\Delta t$ are determined:

$$p_{gi}^{t+\Delta t} = \left(\frac{p_{gG}^{t+\Delta t} - p_{gi-1}^{t+\Delta t}}{x_{gG} - x_{gi-1}} \right)\left(x_{gi} - x_{gi-1}\right) + p_{gi-1}^{t+\Delta t}; \quad v_{gi}^{t+\Delta t} = \left(\frac{v_{gG}^{t+\Delta t} - v_{gi-1}^{t+\Delta t}}{x_{gG} - x_{gi-1}} \right)\left(x_{gi} - x_{gi-1}\right) + v_{gi-1}^{t+\Delta t};$$

$$p_{gi+1}^{t+\Delta t} = \left(\frac{p_{gG}^{t+\Delta t} - p_{gi}^{t+\Delta t}}{x_{gG} - x_{gi}} \right)\left(x_{gi+1} - x_{gi}\right) + p_{gi}^{t+\Delta t}; \quad v_{gi+1}^{t+\Delta t} = \left(\frac{v_{gG}^{t+\Delta t} - v_{gi}^{t+\Delta t}}{x_{gG} - x_{gi}} \right)\left(x_{gi+1} - x_{gi}\right) + v_{gi}^{t+\Delta t}; \tag{38}$$

Pressures, velocities and x coordinate of gas in the point F_1 at the moment of time t are determined:

$$x_{gF1} = \frac{1}{1+\Delta t a_{3g}}\left[x_{gG} - \Delta t\left(v_{gi} + c_{gF1} - a_{1g} x_{gi}\right)\right]; \quad a_{3g} = \frac{v_{gH} - v_{gi}}{x_{gH} - x_{gi}};$$

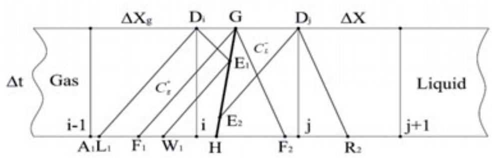
$$v_{gF1} = \frac{1}{1+a_{3g}}\left[a_{3g}\left(x_{gG} - x_{gi}\right) + v_{gi} - a_{3g} c_{gF1} \Delta t\right]; \quad p_{gF1} = a_{4g}\left(x_{gF1} - x_{gi}\right) + p_{gi};$$

$$a_{4g} = \frac{p_{gH} - p_{gi}}{x_{gH} - x_{gi}}. \tag{39}$$

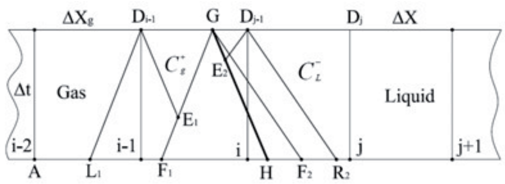
Pressures, velocities and x coordinate of liquid in the point F_2 at the moment of time t are determined:

$$x_{F2} = x_G - \Delta t\left(x_{F2} - c_{F2}\right); \quad v_{F2} = \frac{1}{1+\Delta t a_{1S}}\left[v_H + \Delta t a_{1S}\left(c_{F2} - v_{F2}\right)\right];$$

$$p_{F2} = a_{2S}\left(x_{F2} - x_H\right) + p_H. \tag{40}$$



a)



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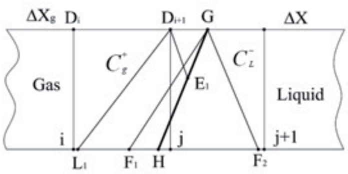


c)

Fig. 4 Cases of gas an liquid interaction: a – first case, b – second, c – third case

3. Numerical Results

As an example of the extinguishing device is considered. The following data of the extinguishing device were used: the length of water compartment is 0.300 m, the volume of air container is equal to $1.5 \cdot 10^{-3}$ m^3, initial pressure in the air container is 2.50 MPa, inner diameter of water compartment is equal to 0.0250 m and . 0.030 m. Time integration step is equal $2.0 \cdot 10^{-6}$ s. The length of gas pipeline is divided in 200 elements and of water compartment is divided in 62 elements. The second valve opens when pressure reaches particular pressure Fig. 5. Fig. 6 illustrates the change pressure in the air container in the middle point. The changes pressure and velocity of liquid in the contact point G is shown in the Fig. 7 and Fig. 8.

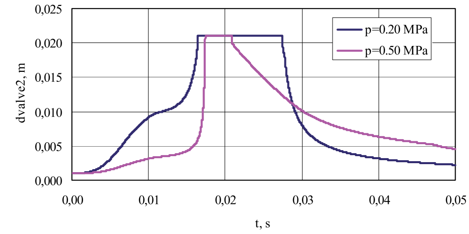


Fig. 5 Diagram of change diameter of second valve with different pressure

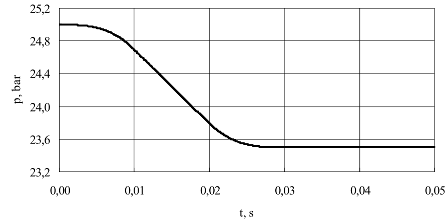
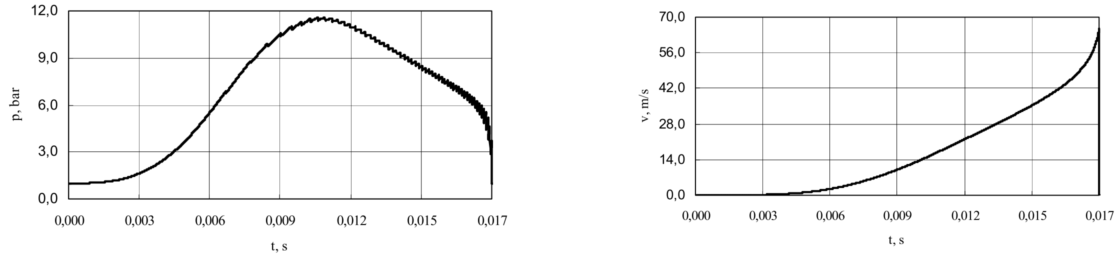
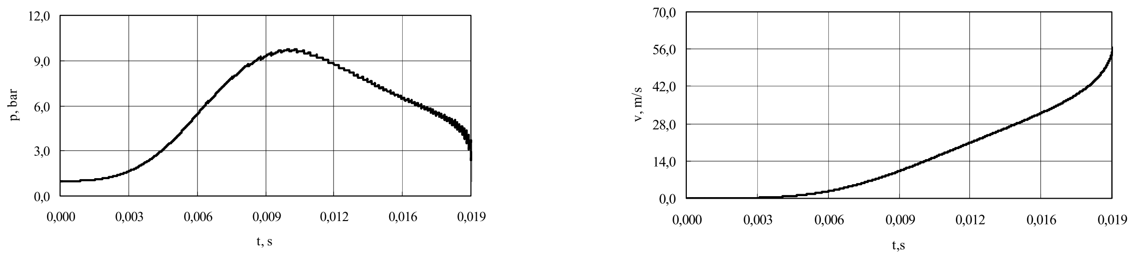


Fig. 6 Diagram of change pressure in the middle point of the air container



a) b)

Fig. 7 The parameters of the extinguishing device, diameter of pipeline is 0.0250 m : a – change pressure; b – change liquid velocity



a) b)

Fig. 8 The parameters of the extinguishing device, diameter of pipeline is 0.030 m : a – change pressure; b – change liquid velocity

4. Conclusions

A new 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 and interaction between gas and kiquid.

Differential equations, describing hydrodynamic processes inside the extinguishing device, help analyze the movement liquid and gas better and more precisely.

At the end of a pipeline of the extinguishing device the maximum velocity of liquid when initial pressure is equal 2.5 MPa, length of pipeline is 0.300 m and diameter of pipeline are 0.025 m and 0.030 m reaches 64 and 48 m/s, respectively.

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FOREWORD

The first international conference Transport Means was held in 1997 and then it became annual scientific forum in which the most relevant scientific and practical problems of transport engineering were analyzed.

9th International conference Transport Means 2005 continues nine years long tradition and takes place at Kaunas University of Technology and Klaipėda University on 20th – 21th October 2005.

The aims of the conference are to share the latest topical information on the issues of transport mean; engineering and transport technologies, to develop international relations of Lithuanian professionals in the science of transport as well as to get students interested in the transport research.

The themes of the reports presented in the plenary session and those taking place in the sections reflect the most important moments of today's transport system development:

- Design, development, maintenance, and exploitation of automobiles;
- Specifics of traffic transportation infrastructure;
- Repairs and exploitation of railway transportation means;
- Problems of development and control of railway transportation infrastructure;
- Construction and manufacture of air transportation means;
- Problems of water transportation development on local and international level;
- Specifics of mechanisms of transportation means;
- Implementation of advanced transportation technologies;
- Development of defense technologies.
- Ways of intellectualization of transport systems.

In the invitations to the conference, sent four months before the conference starts, the instructions how to prepare reports and how to model the material of the reports are provided as well as the deadlines for the reports are indicated.

Those who wish to participate in the conference should send the texts of the reports that meet the relevant requirements under indicated deadlines. Each report must include: a short description of the idea or technique being presented, a brief introduction orienting to the importance and uniqueness of the submission, a thorough description of research course and comments on the results.

The submissions are matched to the expertise according to the interests and are forwarded to the selected rewievers.

Scientific - editorial committee revises, groups the properly prepared reports according to theme and designs the conference program.

Prof. habil.dr. V. Ostaševičius

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Hydrodynamic Process in the Extinguishing Device

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Abstract

The main aim of the investigation is to develop approach to investigate hydrodynamic processes in the extinguishing device. The mathematical model of extinguishing device is presented, where the flow of fluid and gas and the interaction of liquid with the gas are taken into account. The flow of fluid 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 extinguishing device is shown.
KEY WORDS: *Extinguishing device, gas, liquid, dynamics, numerical methods*

1. Introduction

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 damages resulting from inefficient application of water exceed those 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 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 were 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 the drops are developed, the better use of the 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 a jet kinetic energy. If we use the energy of the compressed air or other gases to eject water through 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). Consequently, the extinguishing water cover area enlarges as well as the water efficiency. The devices with such properties can be usable in portable version. That 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.

The extinguishing device based on the use of the compressed air energy for ejecting extinguishing water could be expressed as follows (Fig. 1):

- Compressed air compartment is filled up from the air container;
- Water compartment is filled up from the water tank;
- When the fast reaction valve is opened, compressed air and water compartments get merged;
- Water being under air pressure is ejected within a very short time (from several to several tens of mili-seconds) to the focus of fire;
- Further on the process is repeated from the beginning.

Studies on such extinguishing technologies have not been completed yet and need to be further updated and tested. The main parts of investigation are:

- Process of extinguishing (water) media delivery to fire;
- Recoil of the extinguishing device during operation.

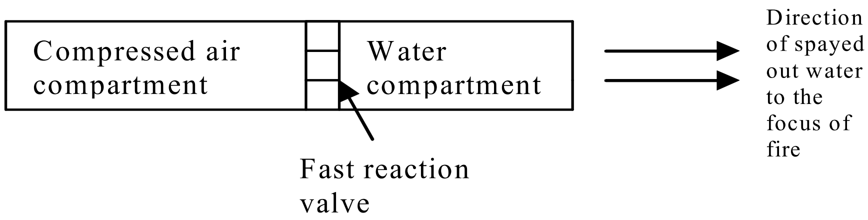


Fig.1 Principle schema of the extinguishing device based on the use of the compressed air energy

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 fast reaction valve. The second valve opens when pressure reaches particular pressure. When the fast reaction valve begins to open the second chamber divides in two volumes. In the first volume there is high pressure of air and in the second volume there is high pressure of water.

Dynamic model of the extinguishing device is shown in the Fig. 2. In the air container the pressure is $p_1(t)$ and the volume of air container is V_1.

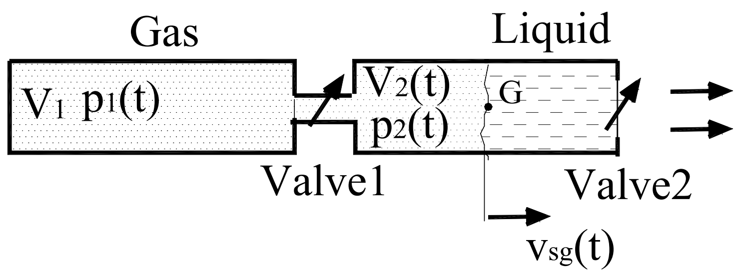


Fig.2 Diagram of extinguishing device

Cross-section area Sv_1 of the first valve is function of time (Fig.3). Cross-section area Sv_2 of the second valve depends on pressure $p(t, x = L)$ (Fig.4). In the second air volume $V_2(t)$ the pressure is $p_2(t)$. The second air volume and water compartment is separated the surface G (see Fig. 2). According to the first law of thermodynamics, whole thermal energy moved with gas is spent for change of internal energy and for work of expansion of gas in a volume.

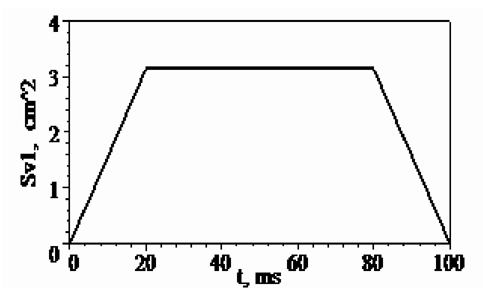


Fig.3 Cross-section area of first valve

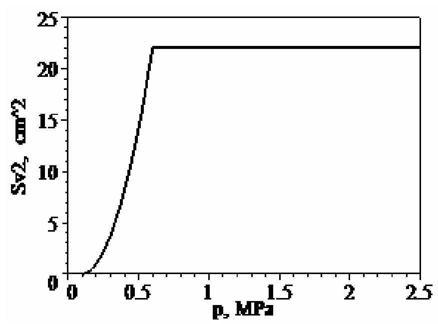


Fig.4 Cross-section area of second valve

The change of pressure of constant volume ($V_1 = const$) of air container is determined from the following equation:

$$\frac{dp_1}{dt} = -\frac{\gamma R T_1}{V_1} G_{12} \qquad (1)$$

here G_{12} is mass charge of gas (air), determined on the formula Sen-Venan and Vencel $[1]$:

$$G_{12} = \mu_1 S_{v1} p_1 K_1(T_1)\varphi\left(\sigma = \frac{p_2}{p_1}\right);$$

$$K_1\ (T) = \sqrt{\frac{2\gamma}{(\gamma-1)RT_1}}\ ; \quad \varphi(\sigma) = \sqrt{\sigma^{\frac{2}{\gamma}} - \sigma^{\frac{\gamma+1}{\gamma}}}\ , \tag{2}$$

S_{v1} is cross-section area of first valve; μ_1 is factor of the charge; γ - ration of specific heat; R - gas constant; T - temperature.

The change of pressure of second volume $V_2(t)$ is determined from the following equation:

$$\frac{dp_2}{dt} = \frac{\gamma RT_1}{V_2(t)} G_{12} - \gamma p_2 \frac{dV_2}{dt}; \tag{3}$$

here $V_2(t) = V_{20} + Sx_G$; V_{20} is initial volume; S is cross-section area; x_G is coordinate of point G (see Fig. 2)

The liquid movement is considered as one-dimensional, i.e. all local velocity are equal to average velocity, and unsettled. Velocity and pressure depend on longitude coordinate and time. Such liquid movement is characterized by the wave of increased and reduced pressure which spreads from the place of change in each pressure vibration cross-section and in deformation of pipeline walls.

The movement and continuity equations of viscous, compressible fluid in pressure pipe have the following form

$$\frac{\partial}{\partial t}[S(x)\rho] + \frac{\partial}{\partial x}[S(x)\rho v] = F_1(x), \tag{4}$$

$$\frac{\partial}{\partial t}[S(x)\rho v] + \frac{\partial}{\partial x}\left[S(x)\left(p + \rho v^2\right)\right] = F_2(p, v), \tag{5}$$

here ρ is density of liquid.

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

$$[A]\left\{\frac{\partial u}{\partial t}\right\} + [B]\left\{\frac{\partial u}{\partial x}\right\} = \{f\}; \tag{6}$$

$$[A] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}; \quad [B] = \begin{bmatrix} v & a^2\rho \\ \frac{1}{\rho} & v \end{bmatrix}, \quad \{u\}^T = [p, v], \tag{7}$$

here v, p - speed and fluid pressure; a is sound velocity in the liquid with a certain amount of gas, which is stored in the elastic pipeline, is equal to:

$$a = \sqrt{\frac{K(p)/\rho}{1 + \frac{K(p)\cdot d}{E \cdot e} + \frac{\varepsilon}{\gamma}\left[\frac{K(p)}{\gamma p} - 1\right]}}\ ; \tag{8}$$

here: $K(p)$ – bulk modulus of elasticity of liquid, ρ – density of liquid, E – modulus of elasticity of a pipeline, d – internal diameter of a pipeline, e – thickness of a wall of a pipeline, γ – index of adiabatic process, ε – ratio of gas volume in the liquid and the total volume of liquid (mixture).

Differential equations of liquid movement in the cylinder are solved by characteristics method [1,2]. The main idea of characteristics method is the fact that unknown variable speed and liquid pressure at instant moment of time $t + \Delta t$ is determined according to these parameters at a moment of time (Fig. 5).

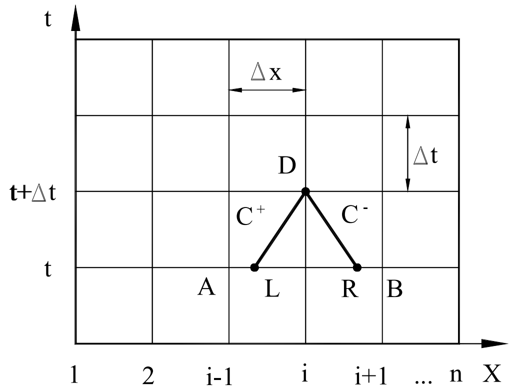


Fig.5 Circuit of liquid parameters determination of point D

Equating the determinant of matrix (13) to zero, we shall receive the equation:

$$\left| [B] - [A]\frac{dx}{dt} \right| = 0 \tag{9}$$

which allows to determine $\frac{dx}{dt}$ derivative, which determines characteristic direction. If this equation has n various real roots $dx/dt = \lambda_i$ $(i = 1,2)$, the initial system of the differential equations is referred to as hyperbolic. The inclination tangent λ_i to the characteristic depends not only on coordinates but also on solution $\{u\}$.

Inserting expressions $[A]$ and $[B]$ from matrices (7) into equation (9) and having solved it, we receive three equations of characteristics

$$C^+ : \frac{dx}{dt} = v + a \, ; \qquad C^- : \frac{dx}{dt} = v - a \tag{10}$$

Compatibility conditions on characteristics are equal to [4]:

$$C^+ : \frac{dv}{dt} + \frac{1}{a\rho}\frac{dp}{dt} = \frac{f_1}{a\rho} + f_2 , \tag{11}$$

$$C^- : \frac{dv}{dt} - \frac{1}{a\rho}\frac{dp}{dt} = -\frac{f_1}{a\rho} + f_2 . \tag{12}$$

$$\{f\} = \left\{ \begin{matrix} 0 \\ -\frac{\tau \Pi(x)}{S(x)\rho} - a_x \end{matrix} \right\}. \tag{13}$$

here τ are shear stresses on the inner surface of pipeline; a_x - acceleration along x axis; $S(x)$ and $\Pi(x)$ are cross-section area and perimeter of pipeline.

Pressure and velocity in point D at the moment of time is determined from nonlinear algebraic equation system

$$C^+ : \Phi_1 = v_D - v_L + \frac{1}{2}(p_D - p_L)[r_{1L} + r_{1D}] - \frac{\Delta t}{2}[r_{2L} + r_{2D}] - \frac{\Delta t}{2}[r_{3L} + r_{3D}] = 0 \, , \tag{14}$$

$$C^- : \Phi_2 = v_D - v_R - \frac{1}{2}(p_D - p_R)[r_{1R} + r_{1D}] + \frac{\Delta t}{2}[r_{2R} + r_{2D}] - \frac{\Delta t}{2}[r_{3R} + r_{3D}] = 0 \tag{15}$$

here $\qquad r_1 = \frac{1}{\rho a}$; $\qquad r_2 = -a^2 \rho v \frac{dS}{dx} / S$;

$$r_3 = -a_x - \frac{\Pi\lambda(Re)v|v|}{8S}; \quad \lambda(Re) = \begin{cases} \dfrac{75}{Re}, when \quad Re \le 2320; \\ \dfrac{0{,}31464}{Re^{0,25}}, when \quad Re > 2320; \end{cases} \tag{16}$$

$\lambda(Re)$ is coefficient of pressure losses along pipe.

The system of equations (2) and (3) is solved by a Newton method:

$$[J]_i \{\Delta Y\}_i = -\{\Phi(Y)\}_i, \tag{17}$$

here $\{Y\}^T = [p_D, v_D]$; $\{\Phi\}^T = [\Phi_1, \Phi_2]$.

The potential energy of a gas in a high-pressure volume is transformed to a kinetic energy of the liquid. For accuracy simulation of interaction of the gas with liquid case of interaction is considered (Fig.7). In the point G pressure p_{SG} and velocity v_{SG} the liquid are determined from a system of equations (3) and (15). The x coordinate of point G is determined from the following expression:

$$x_G(t + \Delta t) = x_H(t) + \Delta t v_{SG}. \tag{18}$$

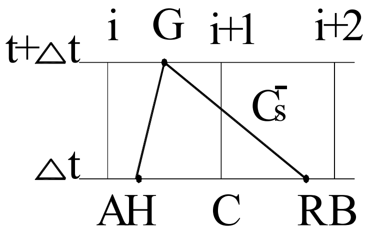
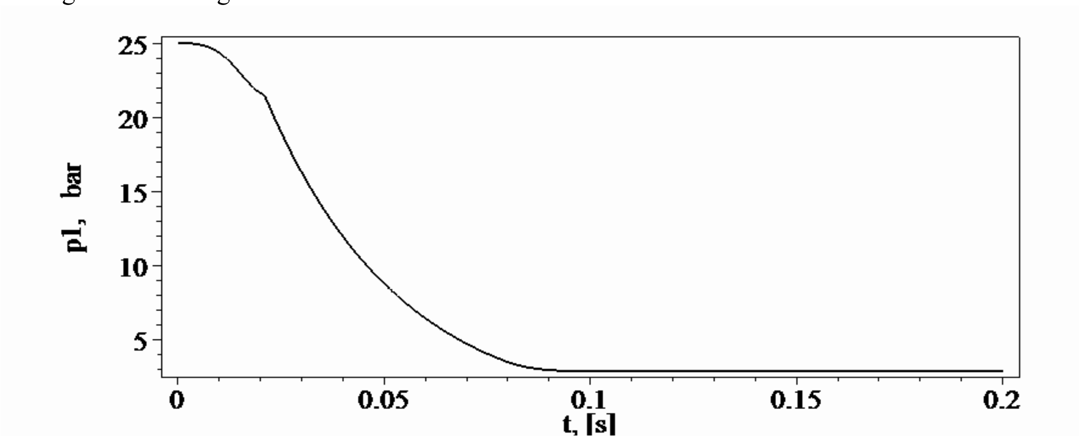


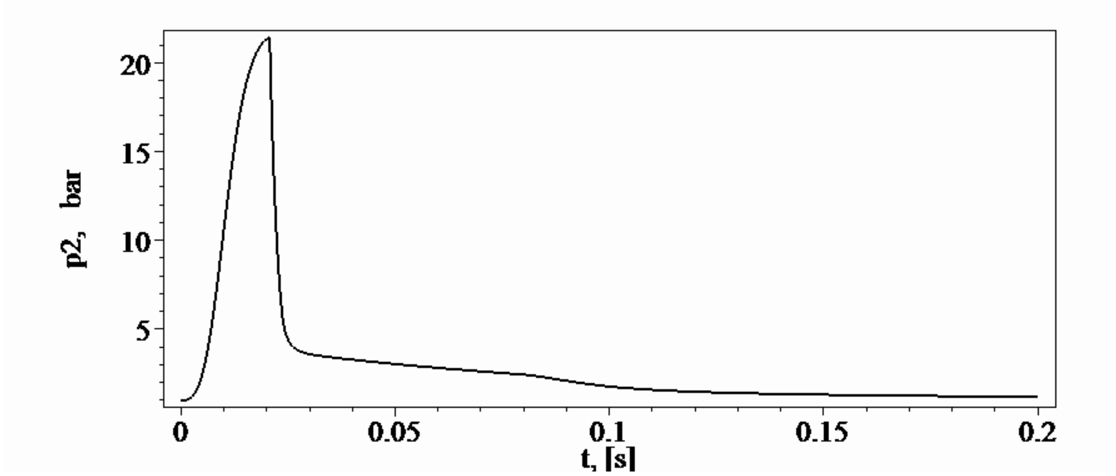
Fig.6 Circuit of liquid parameters determination of point G

3. Numerical results

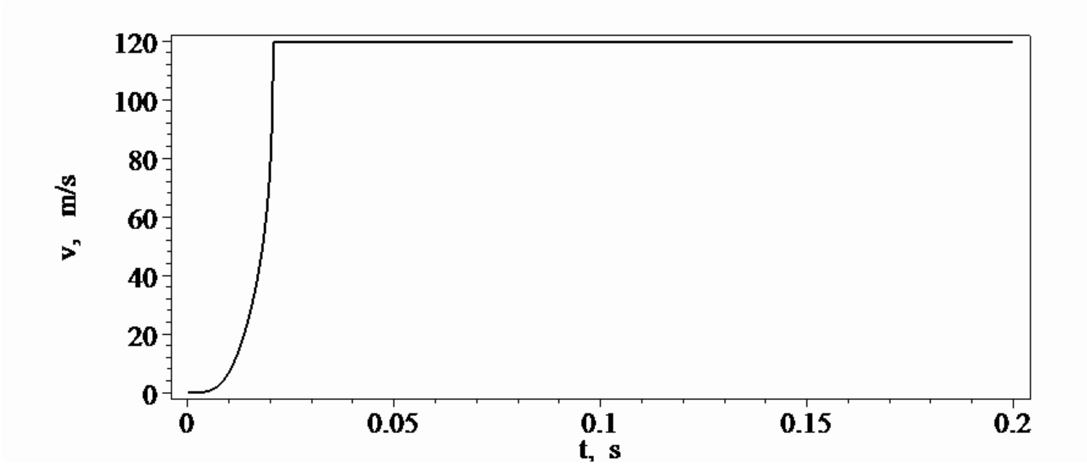
As an example of the extinguishing device is considered. The following data of the extinguishing device were used: the length of water compartment is 0.420 m, the volume of air container is equal 10^{-3} m^3, initial pressure in the air container is 2.50 MPa, inner diameter of water compartment is equal 0.060 m. Time integration step is equal $2.0 \cdot 10^{-6}$ s. The length of water compartment is divided in 84 elements. The simulation results of hydrodynamic parameters are given in the Fig. 6.



a)



b)



c)

Fig.7 The parameters of the extinguishing device : a – change pressure in the air container ; b – change air pressure in the second volume; c - change liquid velocity at the end of pipeline

4. Conclusions

A new 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.

Differential equations, describing hydrodynamic processes inside the extinguishing device, help analyze the movement liquid and gas better and more precisely.

At the end of a pipeline of the extinguishing device the maximum velocity of liquid when initial pressure is equal 2.5 MPa reaches 120 m/s.

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TRANSBALTICA-03

**4-osios tarptautinės konferencijos,
įvykusios Vilniuje 2003 m. balandžio 10-11 d.,
MOKSLINIŲ PRANEŠIMŲ RINKINYS**

**4-th International Conference,
which was held inVilnius in April 10-11, 2003,
PROCEEDINGS**

Vilnius "Technika" 2003

Išvados

Kelio nelygumus aprašius funkcijomis ir suskirsčius geležinkelio kelio ruožus pagal nukrypimų periodus (sandūriniame kelyje ekstreminių reikšmių periodai yra kas 8,33 m ir 12,5 m, o besandūriniame kelyje – 6,25 m, ir 12,5 m), be to žinant šių nukrypimų maksimalias reikšmes, matuojamas kelmačiu vagonu, kiekviename iš šių kelio ruožų galima pakankamai tiksliai aprašyti kelio virpesius ir nustatyti nepageidaujamus greičius, kuriems esant virpesių amplitudės, pagreičiai tampa didžiausi.

Palyginus skaičiavimo rezultatus, gautus taikant dinaminį modelį, su eksperimentų metu gautais rezultatais, galima daryti tokias išvadas:

1. Modelis reaguoja į tuos pačius kelio nelygumus kaip ir realus vagonas;
2. Modelis efektyviai gali būti naudojamas modeliuojant vagono ir kelio sąveiką.

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Summary

Types of railway irregularities are overviewed and influence of roughness on dynamics of the rolling-stocks is discussed. Dynamical model of the passenger wagon is created applying ANSYS software. For evaluation of precision of the dynamical model values of roughness for the function describing the railway are obtained from the data band of the wagon for railway measure. Results of analysis are obtained applying the created dynamical model and during the practical experiments and they are illustrated by the diagrams.

Gaisrinių automobilių ir jų įrangos tobulinimas

Vladimiras Suslavičius, *VGTU*, **Viktor Aladjev**, *Noosfera*

Pateiktame straipsnyje nagrinėjamos gaisrinės technikos, naudojamos priešgaisrinėse gelbėjimo tarnybose, problemos. Išnagrinėti gaisrinių automobilių techninių parametrų įtaka ir reikšmingumas atliekant gaisrų gesinimo darbus. Nuo gaisrinės ir gelbėjimo technikos, tame tarpe ir gaisrinių automobilių, techninių parametrų priklauso gaisrų gesinimo ir gelbėjimo darbų atlikimo greitis. Pateikti gaisrinių automobilių bei jų sudedamųjų dalių trūkumai. Didžiausia rūpestį sudaro gaisrinių išcentrinių siurblių užpildymo vakuuminės sistemos, pačių gaisrinių siurblių gedimai,kėbulų ir cisternų korozija. Pateiktos pagrindinės kryptys efektyviai panaudoti gaisrinius automobilius ir jų įrangą. Nurodytos priemonės kaip įvairiomis gesinimo priemonėmis racionaliai panaudoti gesinimui vandenį.

1. Įvadas

Kiekvienais metais Lietuvoje, priklausomai nuo oro sąlygų, kyla apie 14 tūkst. gaisrų. Tačiau vien tiktai per 2002 metus kilo 21237 gaisrai, padarę 30,8 mln litų nuostolių. Realūs nuostoliai yra žymiai didesni, nes nėra vertinami nuostoliai dėl gamybos ar veiklos sutrikimo. Kilę gaisrai smarkiai teršia aplinką bei daro įtaką žmonių sveikatai. Akivaizdu, kad kuo greičiau užgesinami gaisrai, tuo yra mažesni nuostoliai.

Priešgaisrinių gelbėjimo tarnybų veiklos tikslas – gelbėti žmonių gyvybes ir turtą gaisrų bei kitų ekstremalių situacijų atvejais. Gaisriniai automobiliai – tai techninės priemonės, kurias naudojant priešgaisrinės gelbėjimo tarnybos užtikrina savo funkcijų vykdymą. Gaisrinių automobilių techninės charakteristikos turi lemiamos įtakos efektyviam ugniagesių gelbėtojų darbui. Nuo gaisrinės ir gelbėjimo technikos, tame tarpe ir gaisrinių automobilių, techninių parametrų priklauso gaisrų gesinimo ir gelbėjimo darbų atlikimo greitis. Greičio faktorius ekstremaliose situacijose turi ypatingą reikšmę. Žmonių žūties tyrimai gaisruose rodo, kad 60-70% žmonių žūsta apsinuodiję gaisro dujomis pirminėje jo stadijoje (iki 5-6 min. nuo gaisro kilimo pradžios) [1]. Materialiniai nuostoliai dėl kilusių gaisrų turi betarpišką ryšį su pačio gaisro degimo trukme. Gaisro degimo sutrumpinimas 1 min., pagal atliktus tyrimus Didžiojoje Britanijoje, gali sumažinti 5,3% žuvusiųjų skaičių gaisruose. Taigi gaisrinio automobilio panaudojimo laikinės charakteristikos turi lemiamą reikšmę gaisrų gesinimui.

Gesinimas ar incidento likvidavimas gali būti įvertinamas laiko faktoriais taip:

$$T = Tiš + Tv + Tp + Tges, \quad (1)$$

čia: T - bendras laikas, sugaištas gaisro gesinimui, $Tiš$ - gaisrinio automobilio išvykimo laikas iš gaisrinės, gavus pranešimą apie nelaimingą atsitikimą, Tv - vykimo iki incidento vietos laikas, Tp - gaisrinio automobilio ir įrangos parengimo gesinimui laikas, $Tges$ - gaisro gesinimo laikas.

$Tiš$ priklauso nuo to, kaip greitai gaisrinis automobilis gali pajudėti iš garažo: ar patikimas ir greitas užvedimas, kokia stabdžių sistema, ar patogu greitai ugniagesiams sulipti. Tv vykimo laikas į įvykio vietą priklauso nuo to, kokiu maksimaliu vidutiniu greičiu galės judėti gaisrinis automobilis, kokios jo dinaminės charakteristikos, koks manevringumas, pravažumas, stabilumas, ar jis yra informatyvus ir pastebimas aplinkiniams, koks yra atstumas iki gaisro vietos, kokia kelių būklė ir eismo sąlygos. Tp laikas priklauso nuo to, kokia gaisriniame automobilyje yra įranga, kaip greitai galima ją ir agregatus parengti bei naudoti. $Tges$ laikas priklauso nuo gesinimo įrangos techninių charakteristikų, turimų gesinimo medžiagų kiekio, gesinančių medžiagų tiekimo būdų ir intensyvumo.

Įvertinus laiko faktoriaus gaisrų gesinime sudedamąsias dalis, gaisrinių automobilių techninius parametrus, turinčių įtaką gesinimui, galima suskirstyti į 3 pagrindines grupes:

- Važiuoklės.
- Gaisrinio antstato, kėbulo, gesinančių medžiagų talpų.
- Specialiųjų agregatų ir įrangos.

Kiekvienas iš šių grupių parametras atitinkamai turi įtakos tokioms gaisrinio automobilio savybėms: greitai ir saugiai atvykti į įvykio vietą; išvežti reikalingą skaičių ugniagesių, įrangos ir gesinančių medžiagų; efektyviai tiekti gesinančias medžiagas ar su specialiais agregatais užtikrinti reikalingų darbų atlikimą. Todėl gaisrinių automobilių techninių parametrų gerinimą galima vykdyti šiais būdais:

- Tobulinti arba pakeisti gaisrinio automobilio bazinę važiuoklę.
- Modernizuoti ar pakeisti gaisrinio automobilio kebulą, įrangos skyrius, gesinančių medžiagų talpas.
- Keisti siurblį, įrangą ar kitą specialųjį agregatą, įrengti ar naudoti papildomas priemones, gerinančias gaisrų gesinimą.

2. Eksploatuojamų pagrindinių gaisrinių automobilių trūkumai

Gaminant gaisrinius automobilius stengiamasi parinkti optimalius techninius parametrus. Tačiau, dėl gaisrinių automobilių panaudojimo specifikos, labai netolygiai dėvisi jų agregatai ir kitos sudedamosios dalys. Eksploatavimo metu gaisrinių automobilių ridos, lyginant su transportiniais, yra nedidelės, tačiau jų darbo režimas gana sunkus, o automobilio naudojimo trukmė sudaro 11- 30 metų. Per visą gaisrinio automobilio eksploatavimo periodą nekartą tenka keisti susidėvėjusius agregatus ir mazgus. Be to, per ilgą eksploatavimo laikotarpį kai kurie parametrai pradeda netenkinti naujų sąlygų. Anksčiau ugniagesiai tiktai gesindavo gaisrus, o dabar vykdo ir įvairius gelbėjimo darbus, kuriems atlikti reikalinga papildoma įranga, kurios talpinimui seno tipo kėbuluose nėra vietos. Atsiradusios naujos technologijos reikalauja pasenusių sudedamųjų dalių pakeitimo. Neretai po daugelio eksploatavimo metų vieno ar kito agregato ar mazgo, kurį būtina pakeisti, gamyba būna nutraukta ir tenka ieškoti alternatyvių sprendimų. Visa tai yra ypatingai aktualu senų gaisrinių automobilių tolimesniam naudojimui užtikrinti, nes naujos šiuolaikinės technikos įsigijimas dėl finansinių lėšų trūkumo yra labai ribotas.

Šiuo metu valstybinėje priešgaisrinėje gelbėjimo tarnyboje eksploatuojama per 700 vnt. gaisrinių ir gelbėjimo automobilių bei specialios paskirties transporto priemonių. Tarp pagrindinių gaisrinių automobilių net 80% yra pagaminti buvusioje Sąjungoje, kurie nepasižymi geru patikimumu ir ilgaamžiškumu. Tokių automobilių gedimai pasiskirsto sekančiai:

- 70% visų gedimų tenka specialiems agregatams ir kėbulo konstrukcijai, iš kurių 24%- vakuuminei sistemai ir 18% - gaisriniam siurbliui.
- 30% tenka bazinės važiuoklės gedimams, iš kurių 12% tenka transmisijos agregatams, 8% - eismo saugumą užtikrinančioms sistemoms.

Nemažą rūpestį kelia ir tai, kad visi gaisriniai automobiliai, sumontuoti ant GAZ ir ZIL važiuoklių, turi karbiuratorinius variklius, naudojančius A-80 markės benziną. Tuo tarpu kitose šalyse tokių klasių gaisrinių automobilių važiuoklės komplektuojamos tiktai žymiai ekonomiškesniais dyzeliniais varikliais. Būtų tikslinga atlikti dar ne vienerius metus numatomiems eksploatuoti gaisriniams automobiliams karbiuratorinių variklių pakeitimo dyzeliniais ekonominius-techninius skaičiavimus.

Kaip jau buvo minėta, didžiausių rūpesčių sudaro gaisrinių išcentrinių siurblių užpildymo vakuuminės sistemos, pačių gaisrinių siurblių gedimai, kėbulų ir cisternų korozija ir trūkimai. Pakeičiant šias sistemas naujomis ar atlikus jų patobulinimus, galima būtų ženkliai pagerinti gaisrinių automobilių charakteristikas bei prailginti tarnavimo laiką.

3. Gaisrinių automobilių vakuuminių sistemų gerinimas

Gaisriniai išcentriniai siurbliai, prieš pradedant jais tiekti gesinančius skysčius, turi būti kuo greičiau užpildyti. Šiuo metu daugiausiai yra paplitusios vakuuminės sistemos, kurios užtikrina greitą siurblių užpildymą. Vakuuminių sistemų darbas yra pagrįstas oro išsiurbimu iš išcentrinių siurblių ir su jais sujungtų įsiurbimo žarnų. Išsiurbus orą susidaro išretinimas (vakuumas) ir vanduo, veikiamas atmosferinio slėgio, užpildo įsiurbiamąsias žarnas ir išcentrinius siurblius.

Pagrindiniai vakuuminės sistemos charakterizuojantys parametrai yra:

- pasiekiamas maksimalus vakuuminis slėgis;
- geometrinis įsiurbimo aukštis;
- laikas, per kurį išsiurbiamas oras iš siurblio ir sujungimo žarnų.

Maksimalus geometrinis įsiurbimo aukštis priklauso nuo sukuriamo maksimalaus vakuuminio slėgio. Deja, visos vakuuminės sistemos turi tą patį trūkumą – teorinis geometrinis įsiurbimo aukštis negali būti didesnis kaip 10 metrų, o įvertinus nuostolius sistemose, maksimalus įsiurbimo aukštis praktiškai tesiekia tiktai 7-8 metrus.

Visuose gaisriniuose automobiliuose, pagamintuose buvusioje Sąjungoje, be išimties, buvo montuojamos vienodos vakuuminės sistemos, kuriose vakuumui sudaryti naudojama variklių išmetamų dujų energija. Tokios vakuuminės sistemos nereikalauja transmisinės pavaros, jose nėra besisukančių . slenkančio ir grįžtančio judesio dalių, jas gana paprasta sumontuoti. Tačiau jos turi ir esminių trūkumų:

- vakuuminio aparato sklendžių bei pačio korpuso metalinių paviršių, veikiamų karštų variklio išmetamųjų dujų, korozija;
- didelis triukšmas darbo metu;
- galima padidėjusi išmetamų dujų koncentracija gaisrinio automobilio vairuotojo/operatoriaus darbo vietoje;
- sudaromas variklio išmetamųjų dujų priešslėgis iki 0,2 MPa;
- neįmanomas sistemos autonominis darbas;
- sudaromas mažesnis vakuuminis slėgis, lyginant su kitomis naudojamomis vakuuminėmis sistemomis (1 lentelė).

1lentelė. Vakuuminių sistemų palyginamieji duomenys ir parametrai

Parametras	Su dujų čiurkšliniais siurbliais	Su membraniniais siurbliais	Su stūmokliniais siurbliais	Su plokšteliniais siurbliais
Išvystomas vakuuminis slėgis, MPa	0,074	0,09	0,09	0,09
Maksimalus geometrinis įsiurbimo aukštis, m	7	8	8	8
Energijos šaltinis	Variklio išmetamosios dujos	Išcentrinio siurblio pavara	Išcentrinio siurblio pavara	Elektrinis nuolatinės srovės variklis
Valdymas	Rankinis	Rankinis arba automatinis	Rankinis arba automatinis	Rankinis
Neigiamas poveikis aplinkai, automobilio agregatams ar operatoriui	Turi poveikį automobilio varikliui ir operatoriaus darbo vietai	Neturi	Neturi	Turi poveikį aplinkai

Vakuuminės sistemos pagrindą sudaro naudojamas siurblio tipas. Išanalizavus vakuuminėse sistemose naudojamų siurblių parametrus, jų savybes, nustatyta, kad geriausiai būtų naudoti membraninius arba stūmoklinius įsiurbimo siurblius. Tačiau šių siurblių darbui būtina pavara. Vakarų šalių įsiurbimo siurbliams varyti naudojami siurblio pavaros kardaninis velenas ar pačio išcentrinio siurblio velenas. Tai reiškia, kad vakuuminis siurblys dirbs tiktai tuo atveju, kai suksis išcentrinis siurblys. Tačiau GAZ ir ZIL tipo gaisriniuose automobiliuose įrengtų išcentrinių siurblių riebokšliai ir sandarinimai nepritaikyti dirbti ilgesnį laiką be vandens. Todėl gaisriniuose automobiliuose, kuriuose yra sumontuoti PN 40UA ir PN 40UV siurbliai, neįmanoma naudoti siurblio pavaros įsiurbimo siurbliams sukti. Šiuo atveju vienas iš sprendimo būdų yra membraniniam ar stūmokliniam įsiurbimo siurbliui sukti naudoti nuolatinės srovės elektros variklį, maitinamą iš automobilio elektrinių grandinių.

Žinant reikalavimus, kuriuos turi tenkinti vakuuminė įsiurbimo sistema, galima nustatyti įsiurbimo siurblio parametrus naudojantis tokia formule [2]:

$$T = 2{,}3A\frac{v}{u}lg\frac{Pa}{Po} \qquad (2)$$

čia: T – išcentrinio siurblio užpildymo laikas (ne ilgesnis kaip 45 s); A – koeficientas, nustatomas eksperimentiniu būdu ir priklausantis nuo sujungimo armatūros charakteristikų (nustatytas 3,54); v – išsiurbiamo oro tūris, kurį sudaro išcentrinio siurblio ir įsiurbiamųjų žarnų tūriai (PN40 siurblio tūris – 15,8 dm kub., įsiurbiamų 125 mm žarnų tūris iki vandens paviršiaus – 99 dm kub.); u – vakuuminės sistemos našumas, m kub./s; Pa – atmosferinis slėgis (101325 Pa); Po – liekamasis slėgis išcentriniame siurblyje (30000 Pa).

Atlikę skaičiavimus pagal formulę (2) gauname, kad įsiurbimo siurblio našumas turi būti ne mažesnis kaip 0,0095 m^3/s. Norėdami pagerinti įsiurbimo greitį 5 sekundėmis gauname, kad našumas jau turėtų būti ne mažesnis kaip 0,0107 m^3/s, o prie skaičiuojamo 35 s įsiurbimo greičio – našumas ne mažesnis kaip 0,0122 m^3/s.

Įvertinę paskaičiuotus našumus bei priemę, kad su membraniniais guminiais vožtuvais siurblių tūrinio naudingumo koeficientas tesiekia 0,85 [3], naudingumo koeficientas dėl mechaninių nuostolių sudaro 0,8, siurblys dirba išvystydamas maksimalius slėgius, gausime reikalingus elektros variklių galingumus, kurie sudarys:

- prie 45 s įsiurbimo laiko – 1257 W;
- prie 40s įsiurbimo greičio – 1396 W;
- prie 35 s įsiurbimo greičio – 1591W.
- prie 40s įsiurbimo greičio – 1396 W;
- prie 35 s įsiurbimo greičio – 1591W.

Pradėti eksperimentiniu būdu gaminti įsiurbimo siurbliai su 0,00021 m^3 darbiniu tūriu bei komplektuojami 1,3 kW galingumo elektriniu automobiliniu starteriniu varikliu. Šie stūmokliniai siurbliai pagerina senų gaisrinių automobilių vakuuminių sistemų darbą, taupo lėšas, nes siurblio hermetiškumui patikrinti nebūtina užvedinėti variklio.

4. Gaisrinių automobilių AC 40(130)63B ir AC 40(131)137 antstatų keitimas

Gaisrinių automobilių AC 40(130)63B ir AC 40(131)137 antstatai be didesnių pakitimų buvo gaminami ne vieną dešimtmetį. Jų pagrindiniai trūkumai:

- nėra pakankamai vietos papildomai gelbėjimo įrangai talpinti;
- labai intensyvi kėbulo ir cisternos korozija;
- kėbulo skyrių dangčiai nepatikimai užsidaro, o atidarytoje padėtyje - darbo vietoje yra nesaugūs.

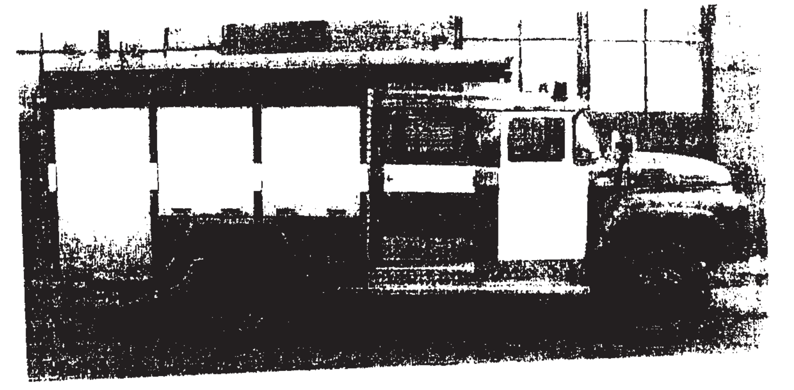
Kiekvienais metais vis daugiau šio tipo gaisrinių automobilių antstatų dėl gilios metalo korozijos tampa nebetinkami naudoti, nors važiuoklės dar galėtų tarnauti žymiai ilgesnį laiką. Problemai išspręsti buvo svarstomi įvairūs variantai: iš dviejų gaisrinių automobilių surinkti vieną; keisti

labiausiai susidėvėjusias kėbulo detales; keisti visą kėbulą kartu su jo komplektuojančiomis dalimis. Surenkant iš dviejų gaisrinių automobilių vieną, ne visada įmanomas racionalus visų agregatų ir mazgų panaudojimas. Keičiant atskiras labiausiai susidėvėjusias antstato detales, nepašaliname nei vieno aukščiau paminėto trūkumo. Todėl, siekiant pagerinti naudojamų gaisrinių automobilių charakteristikas bei prailginti jų tarnavimo laiką, nutarta pirmenybę teikti viso antstato keitimo variantui. Gaisrinio automobilio antstatui keliami reikalavimai:

- Naujos antstato konstrukcijos ir detalės neturi sumažinti gaisrinių automobilių aktyviosios ir pasyviosios saugos.
- Antstato konstrukcijos ir detalės neturi viršyti gaisrinių automobilių gamykloje nustatytų gabaritų, bendrųjų masių bei ašių apkrovų.
- Naujo kėbulo skyrių konfigūracija turi tikti reikiamai papildomai įrangai talpinti.
- Kėbulas ir cisterna turi būti gaminami iš nerūdijančių medžiagų arba būtų padengtos patikima antikorozine danga.
- Vietoje skyrių dangčių turi būti naudojamos aliumininės žaliuzės tipo durelės.

Šias ir kitas papildomas sąlygas atitinkantys antstatai buvo pagaminti ir pradėti montuoti ant senų gaisrinių automobilių. Gaisrinio automobilio su nauju antstatu bendras vaizdas pateiktas (1 pav.).

Gaisrinio automobilio antstatas susideda iš: porėmio; porėmio elastinės pakabos (atsisakius tvirtinimo apkabomis); kėbulo karkaso, prie kurio tvirtinami klijavimo būdu aliumininiai lakštai; cisternos ir putokšlio bako, gaminamų iš polipropileno; skyrių uždarymo aliumininėmis žaliuzės tipo durelėmis; įrangos tvirtinimo elementų.



1 pav. Bendras gaisrinio automobilio AC-40(130)63B vaizdas su naujuoju antstatu

Tokio tipo nauji antstatai pagerina gaisrinių automobilių charakteristikas:

1. Padidėjęs 0,6 m^3 kėbulo tūris leidžia talpinti daugiau įrangos.
2. Kėbulas, cisterna ir putokšlio bakas nebijo korozijos, nes gaminami iš nerūdijančių medžiagų.
3. Aliumininės žaliuzės tipo durelės gerai sandarina įrangos skyrius, estetiškai atrodo ir pagerina darbo sąlygas aplink automobilį.
4. Antstato porėmio elastinės pakabos dėka nesudaromi nepageidaujami įtempimai kėbulo konstrukcijose.

5. Gesinimo sistemų gerinimas

Gesinimo sistemos – tai sistemos, kurių dėka tiekiamos gesinančios medžiagos gaisro gesinimui. Taip jau yra nuo seno, kad labiausiai prieinama ir naudojama gesinimui medžiaga yra vanduo. Vanduo pasižymi ypatingomis fizinėmis ir cheminėmis savybėmis, turi tokias šilumos absorbavimo charakteristikas, kurių stinga dažniausiai gamtoje sutinkamoms medžiagoms. Daug metų žmonės bandė surasti geresnius būdus, kaip transportuoti vandenį gesinimui ir efektyviau jį panaudoti. Neretai neefektyviai naudojant vandenį gesinimui, nuostoliai dėl vandens poveikio viršija nuostolius dėl sudegusio turto ir kitų vertybių. Ištekantis iš gaisravietės naudojamas gesinimui vanduo užteršia aplinką ir smarkiai pablogina bendrą ekologinę būklę. Nors gaisrų gesinimui naudojami šiuolaikiniai modernūs įvairūs siurbliai, gaisrinės žarnos, švirkštai ir purkštuvai, tačiau gesinimo vandeniu technologijos tikrai dar nepasiekė didžiausių aukštumų.

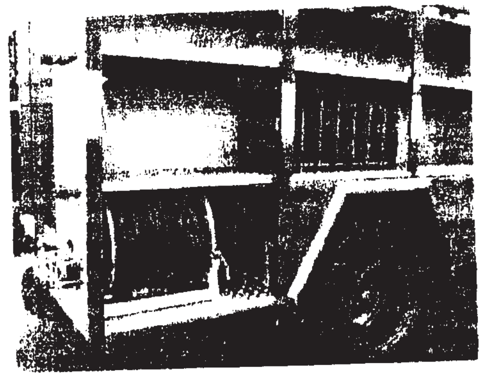
Šių dienų gaisrinių automobilių gesinimo sistemų pagrindą sudaro gaisriniai siurbliai arba kiti gesinančias medžiagas tiekiantys įrenginiai. Gaisrinio siurblio charakteristikos apsprendžia įrangos panaudojimą. Teisingai parinkta įranga leidžia efektyviau išnaudoti gaisrinių siurblių savybes. Kadangi gaisrų gesinime laiko faktorius yra ypatingai svarbus, tai akivaizdu, kad kuo anksčiau bus pradėtos tiekti gesinančios medžiagos į gaisrą, tuo pats gesinimas bus efektyvesnis. Ženkliai pagreitinti gesinimo pradžią, panaudojant esamas gaisrinio automobilio sistemas, yra įrengti automobilyje greito reagavimo žarnų ritę. Greito reagavimo žarnų ritės ugniagesiams suteikia galimybę be laiko gaišimo žarnų linijų sujungimui pradėti tiekti vandenį tuoj pat, kai tik pradeda veikti gaisrinis siurblys. Be to, greito reagavimo žarnos yra santykinai lengvos ir su jomis galima greitai manevruoti. Pagal Didžiojoje Britanijoje atliktus tyrimus nustatyta, kad naudojant greito reagavimo žarnų rites pasiekiamas greičiausias gaisrų gesinimas [1]. Tačiau greito reagavimo žarnų ritės, būdamos mažesnių skersmenų (19-38 mm), pasižymi žymiai didesniais hidrauliniais nuostoliais.

Be to, norint užtikrinti reikiamą gesinančių medžiagų tiekimo intensyvumą, darbui su greito reagavimo žarnomis būtinas didesnis slėgis. Todėl darbui su greito reagavimo žarnomis dažniausiai naudojami kombinuoti (žemo/aukšto slėgio) siurbliai, kurie gali pasiekti 2–5 MPa slėgį. Kartu su aukšto slėgio žarnomis naudojami aukšto slėgio švirkštai , kurių našumas 1-2 l/s. Kyla klausimas, ar galima naudoti greito reagavimo žarnas senuose gaisriniuose automobiliuose, kurių siurbliai išvysto tiktai 1 MPa slėgį. Galima, tiktai būtina parinkti reikiamų parametrų žarnas ir švirkštus. Nekartą teko įsitikinti, kad, parinkus neteisingų charakteristikų įrangą, laukiamo efekto nepasiekiama. Siekiant panaudoti greito reagavimo žarną senuose automobiliuose, būtina turėti gerą apie 2 l/s našumo švirkštą purkštuvą, galinti efektyviai dirbti prie žemų (0,3-0,4 MPa) slėgių [4]. Gaisrinės žarnos parametrams nustatyti galime naudoti tokią formulę [5]:

$$FL = C\,Q^2\,L, \qquad (3)$$

čia: FL - hidrauliniai nuostoliai žarnoje, kPa; C - žarnos hidraulinio pasipriešinimo koeficientas; Q - našumas šimtais l/min; L - žarnų ilgis šimtais m (dažniausiai iki 60 m).

Atlikus skaičiavimus gauname, kad greito reagavimo žarna turi būti ne mažesnio kaip 25 mm skersmens. Tokios žarnos įrengimas gaisriniame automobilyje parodytas (2 pav.).



2 pav. Greito reagavimo žarnos įrengimas sename gaisriniame automobilyje su nauju antstatu

Gaisrinio automobilio gesinimo galimybes galima ženkliai pagerinti naudojant geresnių charakteristikų gaisrinius siurblius. Tačiau gaisrinio siurblio naudojimą apsprendžia jį sukantis variklis. Neretai net gamintojai ne visada tinkamai suderina variklio–siurblio atitikimo parametrus: galingumus, sukimo momentus, apsukų skaičių. Todėl tie patys gaisriniai automobiliai su skirtingais siurbliais gali turėti ir skirtingas gesinančių medžiagų tiekimo savybes. Senuose gaisriniuose automobiliuose, pakeitus gaisrinius siurblius PN 40 šiuolaikiniais atitinkamų parametrų siurbliais, tampa įmanoma naudoti pažangiausią gesinimo įrangą. Modernūs gaisriniai siurbliai kainuoja gana brangiai (20-50 tūkst. Lt.), todėl jų panaudojimui bei atrankai būtina kruopšti techninė ir ekonominė analizė bei tyrimai.

Tačiau, net ir naudojant šiuolaikinius išcentrinius siurblius, neišvengiama gesinančio vandens ištekėjimo iš gaisravietės atvejų. Ištekantis vanduo praktiškai nedalyvauja gesinime, yra užteršiamas bei eikvojamas veltui. Tai atsitinka dėl to, kad dalis vandens nespėja priimti visos galimos šilumos ir pavirsti garais bei dėl didelio vandens paviršiaus įtempimo, kuris neleidžia jam absorbuotis į degančias medžiagas. Akivaizdu, kad kuo labiau susmulkinsime vandenį, tuo iš to paties jo tūrio gausime didesnį paviršiaus plotą, kuris betarpiškai galės kontaktuoti su gaisro karščiu ir tuo efektyviau bus išnaudojamos vandens savybės. Pavyzdžiui, jeigu į ugnį pilti vandenį kaip iš kibiro, tai jo savybės gali būti panaudotos tiktai 5-10% efektyvumu. Taigi gesinančio vandens paviršiaus ploto didinimas didina ir jo naudojimo efektyvumą. Didinti vandens paviršiaus plotą galima paprasčiausiai jį susmulkinti į atskirus mažus lašelius. Kuo mažesni lašeliai, tuo geriau išnaudojamos vandens savybės ir tuo mažiau jo reikia gaisro gesinimui. Geriau susmulkinti tiekiamą gesinimui vandenį galima šiais pagrindiniais būdais:

1. Naudoti specialius švirkštus purkštuvus, kurie žymiai geriau susmulkina vandenį į atskirus lašelius.
2. Didinti tiekiamo vandens slėgį, kuris ištekėdamas pro švirkštus geriau suskaidomas.
3. Mažinti vandens paviršiaus įtempimo jėgas.

Pirmu atveju, naudojant šiuolaikinius švirkštus purkštuvus, prie 0,4-0,7 MPa vandens tiekimo slėgių galima pasiekti 0,3 mm skersmens lašelių dydžius čiurkšlėje. Dar labiau susmulkinti vandens lašelius, nedidinant vandens tiekimo slėgius, yra gana sudėtinga. Todėl gaisriniuose automobiliuose vietoje vienapakopių išcentrinių siurblių naudojami daugiapakopiai. Tiekiamo gesinimui vandens slėgis padidinamas nuo 1 MPa iki 4 MPa. Atskirais atvejais naudojami tūriniai siurbliai (membraniniai ir stūmokliniai) ir slėgis sukeliamas iki 6-20 MPa. Prie didesnių slėgių vanduo geriau išpurslinamas ir todėl reikalingas mažesnis jo kiekis. Tačiau prie

didesnių slėgių (iki 20 MPa) neįmanomas didesnio vandens kiekio tiekimas, nes žymiai didėja švirkštų reakcijos jėgos, su kuriomis nesusitvarkytų ugniagesiai. Be to, per mažas labai gerai išpurslintas prie aukšto slėgio vandens kiekis pavirsta į rūką. Tokio rūko vandens lašeliai yra gana maži ir neturi pakankamos kinetinės energijos dėl ko jie gali būti lengvai nubloškiami gaisro dujų nuo židinio.

Trečiu atveju naudojami įvairūs chemikalai, kurie sumažina vandens paviršiaus įtempimo jėgas. Šie chemikalai vadinami putokšliais ir drėkintojais. Vanduo su mažesnėmis paviršiaus įtempimo jėgomis gali būti ne tik labiau suskaidomas, bet jis žymiai geriau įsiskverbia į degančius paviršius. Tačiau geri putokšliai nėra pigūs, todėl pagrindinai naudojami putoms sudaryti lengvesnių už vandenį medžiagų gesinimui. Nors pastaruoju metu vis plačiau naudojamos ir pripažįstamos palyginus neseniai sukurtos CAFS sistemos. CAFS (Compressed Air Foam System) - tai suslėgto oro ir putų gesinimo sistema. Darbo principas pagrįstas tuo, kad vandens ir putokšlio mišinį aeruojant suslėgtu oru gaunamos labai kokybiškos ir stabilios putos, kurios pro žarnas ir švirkštus tiekiamos gesinimui. Mišiniui sudaryti naudojamas specialus A tipo putokšlis, kurio reikalinga koncentracija vandenyje tesiekia 0,1-1% (įprasto putokšlio koncentracija siekia 3-6%) Vanens-putokšlio mišinys maišomas su oru santykiu 1:7. Todėl gaisrinės žarnos su putomis yra lengvos, nes jose daugiau oro nei skysčių.

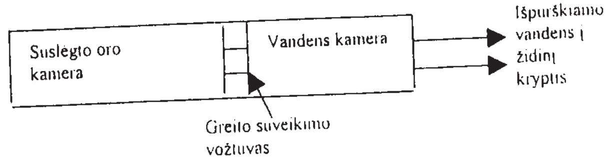
Naudojant CAFS sistemą, gesinimo efektyvumas padidėja 3-5 kartus, lyginant su gesinimu paprastu vandeniu [6]. Efektyvumas pasiekiamas dėka to, kad vanduo yra išlaikomas stabiliose putose ir visiškai neišteka iš gaisro vietos (pvz., naudojant kompaktinę ištisinę čiurkšlę net iki 90% vandens išteka iš gesinamo židinio neturėdamas gesinančio poveikio). Sistemos darbui būtina turėti oro kompresorių, putokšlio dozavimo įrenginį, vandens siurblį, slėgių reguliavimo prietaisus. Sistemos gali būti tiek autonominės, turinčios savo variklį, kompresorių, vandens siurblį ir kitus įranginius, tiek ir naudojančios esamą gaisriniame automobilyje siurblį ir jo pavarą. Kadangi CAFS sistemos labai taupiai naudoja vandenį, todėl gaisriniuose automobiliuose netenka prasmės turėti dideles talpas gesinančių medžiagų. Sumontavus CAFS sistemas esamuose automobiliuose galima būtų mažinti vandens cisternų tūrį ir didinti išvežamos reikalingos įvairiems darbams įrangos kiekį. Nauji automobiliai su CAFS sistemomis galėtų būti žymiai mažesni ir manevringesni. Tačiau šių sistemų efektyvumo ir optimalių parametrų nustatymui konkrečiuose gaisriniuose automobiliuose reikalingi tolimesni tyrimai ir praktiniai bandymai, nes neteisingai naudojant sistemas gesinimo kaštai gali net didėti.

Įvertinus paminėtus faktus bei siekiant toliau tobulinti gesinančių medžiagų tiekimo technologijas, būtina ieškoti netradicinių būdų. Pagrindinai vanduo gesinimui šiuo metu tiekiamas panaudojant jo kaip hidraulinio skysčio savybes per išcentrinius ar tūrinius siurblius. Slegiamam ir ištekančiam vandeniui pro kiaurymę (gaisrinį švirkštą) jo slėgio energija paverčiama čiurkšlės kinetine energija. Jeigu vandeniui išpurkšti pro švirkštą naudosime suslėgtojo oro ar kitų dujų energiją (vietoje pačio vandens slėgio energijos), tai galime gauti žymiai didesnius čiurkšlės greičius. Tradiciškai švirkščiamo vandens lašelių greitis čiurkšlėje sudaro apie kelias dešimtis m/s, o panaudojus suslėgto oro energiją lašelių greitis gali siekti net šimtus m/s greičius [7]. Be to, prie tokių greičių dėl oro pasipriešinimo čiurkšlė gali būti susmulkinama į žymiai mažesnius lašelius (net iki 2 mikronų skersmens). Dėl to ženkliai padidėja gesinimui naudojamo vandens paviršiaus plotas bei jo panaudojimo efektyvumas. Iš vieno litro tūrio vandens gaunami lašelių dydžiai, jų skaičius bei gaunamas paviršių plotas pateikiamas 2 lentelėje.

2 lentelė. Iš 1 l vandens tūrio gaunamų lašelių skersmenys, jų skaičius ir bendras paviršiaus plotas

Lašelių skersmenys, mm	Lašelių skaičius	Bendras plotas, m^2
0.3	$7,1x10^{7}$	20
0,2	$2,4x10^{8}$	30
0,03	$7,1x10^{10}$	200
0,02	$2,4x10^{11}$	300
0,003	$7,1x10^{13}$	2000
0.002	$2,4x10^{14}$	3000

Kai vanduo tiekiamas labai mažais lašeliais, tai galima pasiekti artimą 100% jo visų savybių panaudojimą. Be to, visiškai panaikinamas turto ir vertybių sugadinimas dėl vandens poveikio: nebūtų užliejamos vandeniu negesinamos patalpos. Daugelį gaisrų galima būtų gesinti naudojant mažesnius ir mobilesnius gaisrinius automobilius, nes nereikėtų turėti didelių vandens talpų. Šiuo metu kai kurių šalių priešgaisrinės gelbėjimo tarnybos diegia impulsinio gesinimo technologijas, kurių veikimas pagrįstas naudojant suslėgto oro energiją gesinančiam vandeniui išpurkšti. Bendras veikimo principas parodytas 3 pav.

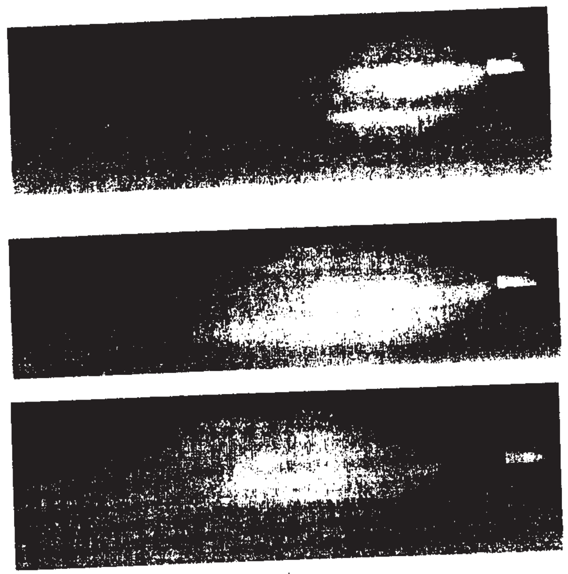


3 pav. Impulsinio švirkšto principinė schema

Impulsiniai švirkštai dirba taip:

- iš suslėgto oro rezervuaro užpildoma suslėgto oro kamera;
- iš vandens rezervuaro užpildoma vandens kamera;
- atidarius greito suveikimo vožtuvą, susijungia suslėgto oro ir vandens kameros;
- vanduo, veikiamas oro slėgio, išpurškiamas per labai trumpą laiko tarpą (nuo kelių iki kelių dešimčių milisekundžių) į gaisro židinį;
- toliau procesas kartojamas iš naujo.

Impulsinio gesinimo čiurkšlė bei jos sklidimas parodytas 4 pav.



4 pav. Impulsinio gesinimo čiurkšlė bei jos sklidimas

Impulsinio gesinimo technologijos dar nėra pilnai ištirtos ir reikalauja tolimesnio jų tobulinimo bei bandymų atlikimo. Tačiau jau šiandien jos leidžia žymiai geriau panaudoti gesinančio vandens savybes, pagreitinti reagavimo laiką.

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Summary

The improvement of the technical parameters of the fire vehicle are implemented in few groups are presented. Each parameter of these groups has a respective impact on the following features of the fire vehicle. The deficiencies of the main fire vehicles under operation, the improvement of the fire vehicles vacuum systems and extinguishing systems are presented.

Skaitmeniniai kompiuteriniai techninių sistemų diagnostikos metodai

Vincas Valavičius, *VGTU, VPU*

Parengtas skaitmeninis kompiuterinis techninių sistemų diagnostikos metodas taikant paketus: Maple 8, MathCad 2001, Matlab 6. Analizuojama tiesinių diagnostinių matricų, metrologinių kriterijų, funkcinių charakteristikų ir dviejų klasių gedimų klasifikavimas, kvadratinių regresijos lygčių ir ekonomiškiausių režimų skaičiavimas ir analizė

1. Įvadas

Diagnozuojant transporto priemonių technines sistemas naudojami kompiuteriniai skaitiniai metodai. Simbolinių skaičiavimų programos tokios kaip Mathematika, Matlab, MathCad, Maple ir kt. sėkmingai atlieka ne tik apytikslius skaičiavimus, bet ir tikslius matematinių reiškinių pertvarkius, diferencijavimą, integravimą, bet ir tikimybinius statistinius skaičiavimus ir matematinį modeliavimą. Aktualu taikyti kompiuterinius matematinius paketus, nes jie nuolat yra tobulinami ir kaupiamos informacinės technologijos. Šiame darbe autorius pateikia sisteminę kompiuterinių paketų taikymo analizę ir svarsto galimybes taikyti parengtas technologijas transporto sistemoms diagnozuoti.

Taikant paketą Maple8 galima spręsti tiesinio programavimo uždavinius, analizuoti funkcijas ir polinomus, rengti grafinį vienmatį, dvimatį ir trimatį vizualizavimą, rašyti rezultatus į elektronines lenteles ir skaičiuoti kitus inžinerinius uždavinius. Paketas Maple8 turi ir papildomų privalumų: palengvintas darbas Internete, išplėstas grafinis vaizdavimas, pagerintas greičio ir mažesnės kompiuterinės atminties veiksmingumas, įvestas naujas XMLTools paketas veiksmingesniam darbui Internete ir galimybė taikyti standartą MathML, patobulintos diferencialinių lygčių sprendimo galimybės.

Kompiuterinis paketas Matlab6 turi daugiausia modeliavimo privalumų, bet išmokti juo dirbti yra sunkiau negu Maple. Šis paketas turi daug inžinerinių paketų, kurie tinka praktiškai visiems inžineriniams uždaviniams modeliuoti. Tai paketas Processing Toolboch tokioms komandoms organizuoti: geometrinės operacijos ir vaizdų analizė, statistika vienmatis ir dvimatis filtravimas. Taikant paketą Signal Processing galima lygiagrečiai pasinaudoti ir kitais paketais. Patogu yra taikyti paketą Image Processing dvimatėms funkcinėms charakteristikoms analizuoti ir klasifikavimo uždaviniams spręsti, panaudojant atpažinimo teoriją. Klasifikavimo charakteristikoms išskirti patogu lygiagrečiai taikyti Neural Network ir Fuzzy Logic paketus, o paramet-

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Aštuntosios Lietuvos jaunųjų mokslininkų konferencijos „Lietuva be mokslo – Lietuva be ateities“, įvykusios Vilniuje 2005 m. gegužės mėn. 12 d.,

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held on 12 May 2005 in Vilnius, Lithuania

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8-й конференции молодых ученых Литвы

„Литва без науки – Литва без будущего“, состоявшейся 12 мая 2005 года в Вильнюсе, Литва

ТРАНСПОРТ

Vilnius „Technika“ 2005

Dabartiniu metu kiekvienas Respublikos gyventojas gali rinktis bet kokią remonto įmonę, priklausomai nuo savo finansinių galimybių. Tačiau patikimai atliekami remonto darbai tik dideliuose ir specializuotuose automobilių priežiūros centruose.

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АНАЛИЗ СТАНЦИИ ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ И РЕМОНТА АВТОМОБИЛЕЙ В ЛИТВЕ

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В статье анализируется динамика роста транспортных средств и станций технического обслуживания и ремонта в Литве Также анализируется специализация станций технического обслуживания и ремонта.

NEDIDELIŲ GAISRO ŽIDINIŲ GESINIMO ĮRANGOS PARAMETRŲ TYRIMAS BEI JOS TOBULINIMAS

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1. Įvadas

Kiekvienas didesnis gaisras dažniausiai prasideda nuo nedidelių židinių, kurių savalaikis pastebėjimas bei likvidavimas turi lemiamos įtakos nuostolių nuo gaisrų mažinimui. Visiškai suprantama, kad nedidelio židinio likvidavimui reikia žymiai mažiau sunaudoti resursų, nei jau išsiplėtusio gaisro gesinimui. Kuo greičiau užgesinami židiniai, tuo geriau apsaugoma žmonių gyvybė, sveikata bei turtas nuo suniokojimo. Šiuolaikinėje visuomenėje, su pakankamai išvystytomis ryšio ir informacinėms sistemomis, atsiranda galimybės gana greitai apie pastebėtus gaisro židinius pranešti priešgaisrinėms gelbėjimo tarnyboms, kurios esant pakankamam jų išsidėstymui vietovėje gali operatyviai atvykti į įvykio vietas ir likviduoti gaisrus dar pirminėje jų stadijoje. Todėl pagal statistinius duomenis [1] daugiau kaip 50%visų kilusių gaisrų gesinama tiktai vienu švirkštu.

Pagal kitus atliktus statistinius tyrimus gaisro židinių išplitimas atvykus priešgaisrinėms tarnyboms ir jų procentas nuo bendro gaisrų skaičiaus sudarė [2]:

- iki 5 m^2 - 29 %;
- nuo 5 iki 10 m^2 - 30 %;
- nuo 10 iki 30 m^2 - 20 %;
- nuo 30 iki 100 m^2 - 10 %;
- nuo 100 iki 600 m^2 - 9 %;
- virš 600 m^2 - 2 %.

Iš pateiktų duomenų matosi, kad turint bei panaudojant efektyvias nedidelių gaisro židinių gesinimo priemones galima būtų likviduoti net apie 80 % visų kilusių gaisrų [3]. Tokių priemonių naudojimas ženkliai pagreitina priešgaisrinių gelbėjimo tarnybų reagavimą, židiniai likviduojami su minimaliais resursais. Tačiau tokios priemonės dar nėra pilnai ištirtos, nėra nustatyti optimaliausi parametrai ir reikalauja tolimesnio jų tobulinimo bei bandymų atlikimo.

2. Esamų švirkštų naudojimo nedideliems židiniams gesinti analizė

Priešgaisrinės gelbėjimo tarnybos gaisrų gesinimui tradiciškai naudoja 1-6 l/s našumo švirkštus – purkštuvus, kai vanduo gesinimui tiekiamas iš cisternos ar kito vandens šaltinio gaisriniu išcentriniu siurbliu pro sujungtas su švirkštais žarnas. Siekiant, kad būtų užtikrinamas gesinimas turi būti tiekiamas atitinkamas gesinančio vandens kiekis, adekvatus išsiskiriančiam šilumos kiekiui nuo degančio paviršiaus. Jeigu gesinančio vandens kiekis į degantį paviršių bus tiekiamas nepakankamai, tai gesinimas nevyks, nes pastoviai išsiskirs daugiau šiluminės energijos, nei jos bus sugerta. Jeigu vandens bus tiekiama per daug – tai nedalyvaujantis gesinime jo kiekis paprasčiausiai nutekės nuo gesinamo paviršiaus. A tipo (kietų produktų) gaisruose išsiskiriantis karščio intensyvumas yra nuo 95 kJ/m^2s (knygos), 245 kJ/m^2s (mediena) iki 630 kJ/m^2s (polistirolas) [4]. Įvertinant 1 l vandens savybes, teorinis gesinimui tiekiamo vandens intensyvumas apskaičiuojamas taip:

$$I = W/k\,, \tag{1}$$

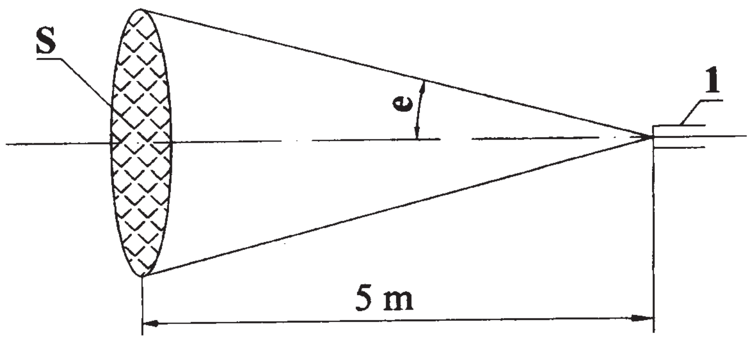
čia I – tiekiamo gesinimui vandens intensyvumas,; W – energijos išsiskyrimo intensyvumas nuo 1 m^2 degančio paviršiaus ploto, kJ/m^2s; k – 1 litro vandens kiekio energijos sugėrimas, kai vanduo kaitinamas nuo 20°C iki 100°C ir išgarinamas, $k = 2571{,}2kJ$.

Atlikus skaičiavimus pagal pateiktą (1) formulę, gauname A tipo gaisruose degant kai kurioms medžiagoms tokius vandens tiekimo intensyvumus:

- knygoms – 0,037 l/m^2s,
- medienai – 0,095 l/m^2s,
- polistiroliui – 0,245 l/m^2s.

Pagal šias reikšmes A tipo gaisruose gesinančio vandens tiekimo intensyvumo vidurkis sudaro 0,126 l/m^2s, tai tas intensyvumas, kuris turėtų būti užtikrinamas gesinant nedidelius gaisro židinius.

Siekiant įvertinti naudojamų švirkštų efektyvumą bei jų galimybes priimame vandens tiekimo intensyvumo nustatymo schemą parodytą (1 pav.). Parenkami švirkštų 1 labiausiai naudojami režimo parametrai: čiurkšlės skleidimo kampai e – 0° (kompaktinė čiurkšlė), 15° ir 30°, čiurkšlės skerspjūvio plotas S 5 m. atstumu nuo švirkšto.



1 pav. Vandens tiekimo intensyvumo pro švirkštus įvertinimo schema

Įvertinimo duomenys pateikiami (1 lentelėje).

Gautus gesinančio vandens tiekimo intensyvumo duomenis lyginant su reikalingo A tipo gaisruose vandens tiekimo į degančio paviršiaus plotą vidurkiu, galime spręsti apie įvairaus našumo švirkštų naudojimo efektyvumą. Jeigu gaunamas vandens tiekimo intensyvumas viršija vidurkį, tai sudaromos galimybės neefektyvaus vandens panaudojimo, kai jo dalis nutekėtų nedalyvaudamas gesinime. Jeigu priešingai – tai degančių objektų gesinimas būtų neefektyvus arba neįmanomas. Pagal naudingai naudojamo gesinančio vandens kiekį, išreikštą procentais, galime spręsti apie pačių švirkštų ir jo čiurkšlių efektyvumą (2 lentelė).

1 lentelė. Gesinančio vandens tiekimo intensyvumo įvertinimas naudojant skirtingo našumo švirkštus bei čiurkšles

Čiurkšlės tipas, čiurkšlės skleidimo kampas *e*	Skerspjūvio plotas S, m^2	Gesinančio vandens tiekimo intensyvumas l/m^2s					
		Švirkštai, kurių našumai, l/s					
		1	**2**	**3**	**4**	**5**	**6**
15°	5,64	0,17	0,35	0,53	0,71	0,89	1,06
30°	26,13	0,04	0,08	0,11	0,15	0,19	0,23
0° (kompaktinė)	0,11	9,09	18,18	27,27	36,36	45,45	54,54

2 lentelė. Tiekiamo pro švirkštus gesinimui vandens kiekio naudojimo efektyvumo duomenys, įvertinant reikalingą gesinimui tiekimo intensyvumo vidurkį

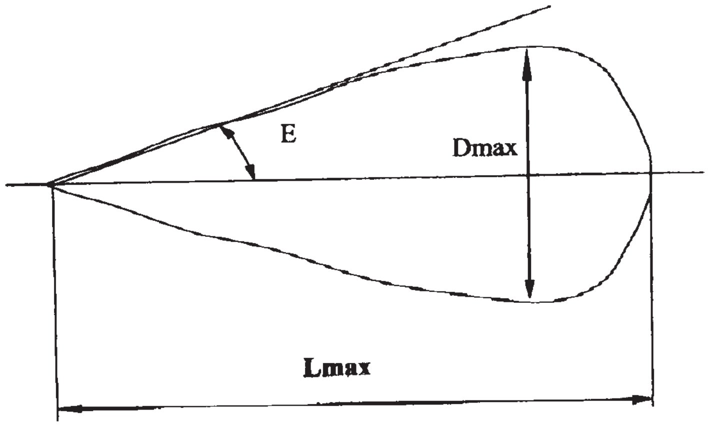
Čiurkšlės tipas, čiurkšlės skleidimo kampas *e*	Naudingai naudojamas gesinimui vandens kiekis %					
	Švirkštai, kurių našumai, l/s					
	1	**2**	**3**	**4**	**5**	**6**
15°	74	36	24	18	14	12
30°	trūksta	trūksta	trūksta	84	66	55
0° (kompaktinė)	1,2	0,7	0,5	0,3	0,27	0,23

Gauti duomenys parodo, kad nedidelių židinių gesinimui naudojamų švirkštų efektyvumas nėra pakankamas. Ypatingai neefektyvios gesinimui yra kompaktinės čiurkšlės, kurių naudojimas pateisinamas tik tais atvejais, kai reikia suardyti degančius paviršius arba tiekti vandenį didesniu atstumu. Nedidelių židinių likvidavimui labiausiai tinka kilnojamos gesinimo priemonės, naudojančios vandens išmetimui suslėgtojo oro energiją, ypatingai impulsiniai švirkštai [5].

3. Impulsinių švirkštų optimalių parametrų tyrimas

Tiekiamo gesinimui vandens panaudojimo efektyvumas priklauso ne tik nuo jo kiekio, bet ir nuo to, koks yra jo paviršiaus plotas. Kuo labiau susmulkinamas vanduo į atskirus lašelius, tuo gaunamas didesnis iš to paties vandens kiekio paviršiaus plotas, kuris gali greičiau sugerti šiluminę energiją. Praktikoje dažnai pasitaiko, kai nors ir tiekiamas vanduo reikiamu intensyvumu, tačiau su nedideliu susmulkinimu, jis nespėja sugerti galimo šilumos kiekio ir dėl to nuteka šalin. Geriausią vandens čiurkšlės susmulkinimą pasiekia impulsiniai švirkštai (net iki 0,002 mm skersmens lašelių) [5]. Šiuo metu naudojami impulsiniai švirkštai IFEX

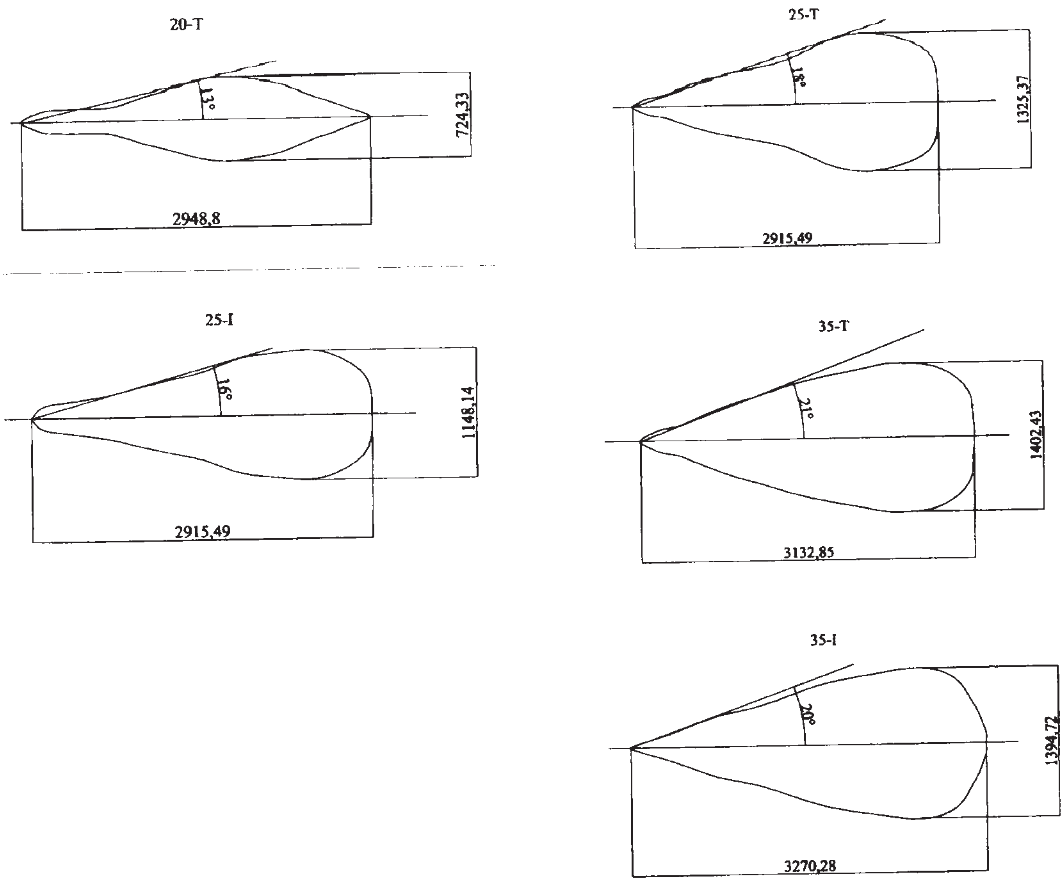
3000 vieno impulso metu gali išstumti iki 1 l vandens, kuris pavirsta į lašo formos greitai judančio rūko debesį (2 pav.).



2 pav. Impulsinio švirkšto čiurkšlės forma ir jos pagrindiniai parametrai

5 metrų atstume nuo švirkšto rūko debesies maksimalus skersmuo D sudaro 3 m, vidutiniškai tenkantis vandens kiekis gesinimo paviršiaus plotui sudaro 0,142 l/m^2. Tačiau pagal švirkšto technines galimybes toks vandens kiekis gali būti tiekiamas tik 3 s intervalais, tai yra vandens tiekimo intensyvumas sudaro tik 0,047 l/m^2s. Toks vandens tiekimo intensyvumas yra ženkliai per mažas efektyviam gesinimui, nors vandens gesinimo savybės dėl labai gero susmulkinimo išnaudojamos beveik 100 %. Taip pat gesinant nedidelius židinius, kai čiurkšlės skersmuo sudaro net 3 m nėra efektyvus, nes vandens nepatenka ant degančio paviršiaus. Siekiant geriau pritaikyti impulsinį švirkštą nedidelių židinių gesinimui, būtina sumažinti jo svorį, atatrankos jėgą, padidinti vandens tiekimo intensyvumą, sumažinti čiurkšlės skersmenį. Šiuos tikslus galima pasiekti sumažinus išstumiamo vandens kiekį pro mažesnį švirkšto antgalį vieno impulso metu, bet padidinus jų dažnį. Siekiant surasti optimalius parametrus buvo atlikti eksperimentai, kurių metu buvo naudojami skirtingo skersmens ir ilgio antgaliai, fiksuojamas čiurkšlių formavimasis ir sklidimas 0,07 s intervalais, kai impulso metu tiekiamas 0,2 l vandens kiekis. IFEX 3000 standartinis švirkšto antgalis yra 62 mm skersmens ir 345 mm ilgio. Eksperimento metu buvo naudojami tokie antgaliai: 20-T – 20 mm skersmens, 320 mm ilgio; 25-T – 25 mm skersmens, 328 mm ilgio; 25-I – 25 mm skersmens, 454 mm ilgio; 35-T – 35 mm skersmens, 326 mm ilgio; 35-I – 35 mm skersmens, 452 mm ilgio.

Eksperimento metu 5 m atstume nuo švirkšto nustatytos čiurkšlių formos ir parametrai parodyti (3 pav.) Iš gautų eksperimentinių čiurkšlių duomenų surandamas čiurkšlių maksimalus skersmuo D, skerspjūvio plotas S, vandens kiekis tenkantis gesinamam plotui C, nustatomas reikalingas vandens tiekimo našumas V (V=I/S), nustatomi reikalingi impulsų intervalai t (3 lentelė).



3 pav. Čiurkšlių formos ir parametrai

3 lentelė. Čiurkšlių duomenys bei optimalių parametrų dydžiai

Antgalio tipas	Sklaidos kampas E, °	L_{max}, m	D_{max}, m	S_{max}, m^2	C C l/m^2	V l/s	t, s
20-T	13	2,954	0,724	0,411	0,487	0,052	3,8
25-T	18	2,915	1,325	1,378	0,145	0,174	1,1
25-I	16	2,915	1,148	1,035	0,193	0,13	1,5
35-T	21	3,146	1,402	1,543	0,13	0,194	1
35-I	20	3,285	1,394	1,525	0,131	0,192	1

4. Išvados

1. Gesinimo priemonės, skirtos nedideliems gaisro židiniams likviduoti, yra ypatingai aktualios priešgaisrinėms gelbėjimo tarnyboms, nes jomis galima žymiai taupiau ir greičiau gesinti didelį gaisrų skaičių.
2. Naudojami šiuo metu švirkštai nėra efektyvus nedidelių židinių gesinimui.
3. Naudojant optimalių parametrų impulsinio švirkšto antgalius bei parenkant tinkamus darbo režimus galima ženkliai sumažinti svorį, atatrankos jėgas, užtikrinti reikiamą gesinamo vandens tiekimo intensyvumą.

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ОПРЕДЕЛЕНИЕ И УЛУЧШЕНИЕ ПАРАМЕТРОВ СРЕДСТВ, ПРЕДНАЗНАЧЕННЫХ ДЛЯ ТУШЕНИЯ НЕБОЛЬШИХ ОЧАГОВ ВОЗГОРАНИЯ

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В данной статье излагаются проблемы рационального и эффективного использования огнетушащих веществ для тушения небольших пожаров. Определены основные параметры использования имеющихся средств для тушения небольших очагов возгорания, выявлены их недостатки. Описаны полученные в ходе эксперимента результаты, установлены направления улучшения импульсных средств пожаротушения.

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Faculty of Transport Engineering

Факультет инженерии транспорта

Septintosios Lietuvos jaunųjų mokslininkų konferencijos
„Lietuva be mokslo – Lietuva be ateities",
įvykusios Vilniuje 2004 m. balandžio mėn. 29 d.,

PRANEŠIMŲ RINKINYS

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of the 7th Conference of Young Scientists of Lithuania

„Lithuania without Science – Lithuania without Future"
held on 29 April 2004 in Vilnius, Lithuania

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СБОРНИК ТЕЗИСОВ ДОКЛАДОВ

7-ой конференции молодых ученых Литвы

„Литва без науки – Литва без будущего",
состоявшейся 29 апреля 2004 года в Вильнюсе, Литва

ТРАНСПОРТ

Vilnius „Technika" 2004

THE ENGINE COOLANT INFLUENCE TO THE BUS TECHNICAL STATE
Evaldas PRIŽGINAS
Masters' student, Department of automobile Transport, faculty of Transport Engineering, Vilnius Gediminas Technical University

The influence of engine coolant quality rates to the bus technical state is being analyzed. The types of failures and suggestions to make their quantity less are offering sustaining research results.

NEDIDELIŲ GAISRO ŽIDINIŲ GESINIMO ĮRANGOS TOBULINIMAS

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1. Įvadas

Gaisras – tai nekontroliuojamas degimas, kurį siekiant sumažinti nuostolius būtina kuo greičiau užgesinti. Materialiniai nuostoliai dėl kilusių gaisrų turi betarpišką ryšį su pačio gaisro degimo trukme. Gaisro degimo sutrumpinimas 1 min., pagal atliktus tyrimus Didžiojoje Britanijoje, gali sumažinti 5,3 % žuvusiųjų skaičių gaisruose [1]. Šiuo metu priešgaisrinėse gelbėjimo tarnybose naudojama gesinimo įranga pagrindinai yra skiriama didesnių gaisrų gesinimui ir mažai yra priemonių, skirtų nedidelių židinių likvidavimui.

Taip jau yra nuo seno, kad labiausiai prieinama ir naudojama gesinimui medžiaga yra vanduo. Vanduo pasižymi ypatingomis fizinėmis ir cheminėmis savybėmis, turi tokias šilumos absorbavimo charakteristikas, kurių stinga dažniausiai gamtoje sutinkamoms medžiagoms. 1 litro vandens įkaitinimui nuo 20^{o} C iki 100^{o} C reikia 335 kJ šiluminės energijos bei dar 2257 kJ, kad jį paversti garais. Tačiau neefektyviai naudojant vandenį gesinimui, nuostoliai dėl vandens poveikio viršija nuostolius dėl sudegusio turto ir kitų vertybių. Ištekantis iš gaisravietės naudojamas gesinimui vanduo užteršia aplinką ir smarkiai pablogina bendrą ekologinę būklę, praktiškai nedalyvauja gesinime bei eikvojamas veltui. Tai atsitinka dėl to, kad dalis vandens nespėja priimti visos galimos šilumos ir pavirsti garais bei dėl didelio vandens paviršiaus įtempimo, kuris neleidžia jam absorbuotis į degančias medžiagas. Akivaizdu, kad kuo labiau susmulkinsime vandenį, tuo iš to paties jo tūrio gausime didesnį paviršiaus plotą, kuris betarpiškai galės kontaktuoti su gaisro karščiu ir tuo efektyviau bus išnaudojamos vandens savybės. Pavyzdžiui, jeigu į ugnį pilti vandenį kaip iš kibiro (mažai susmulkinus), tai jo savybės gali būti

panaudotos tiktai 5–10 % efektyvumu [2]. Didinti vandens paviršiaus plotą galima paprasčiausiai jį susmulkinant į atskirus mažus lašelius. Šiuo metu labiausiai susmulkintos vandens gesinimo čiurkšlės gaunamos panaudojus suslėgtų ir besiplečiančių dujų (oro) energiją. Tradiciškai švirkščiamo vandens lašelių greitis čiurkšlėje sudaro apie kelias dešimtis m/s, o panaudojus suslėgto oro energiją lašelių greitis gali siekti net šimtus m/s greičius. Prie tokių greičių dėl oro pasipriešinimo čiurkšlė gali būti susmulkinama į žymiai mažesnius lašelius (net iki 2 mikronų skersmens) [3]. Suslėgtojo oro (dujų) energijų panaudojimo gesinančių medžiagų tiekimo technologijos dar nėra pilnai ištirtos ir reikalauja tolimesnio jų tobulinimo bei bandymų atlikimo. Tačiau jau šiandien jos leidžia žymiai geriau panaudoti gesinančio vandens savybes, pagreitinti reagavimo laiką.

2. Suslėgtojo oro (dujų) panaudojimo gesinančioms medžiagoms tiekti principai

Suslėgtųjų dujų energiją naudojančios kilnojamos gesinimo priemonės leidžia ugniagesiams gelbėtojams vykdyti gesinimą be gaisrinio automobilio siurblio panaudojimo bei žarnų linijų pratiesimo nuo jo iki židinio. Dėl to gali būti žymiai sutrumpinamas reagavimo laikas bei užtikrinamas gesinimo ekonomiškumas.

Pats paprasčiausias suslėgtųjų dujų energijos panaudojimas stebimas gesintuvuose, kai inde su gesinančiomis medžiagomis palaikomas atitinkamas slėgis, kurio dėka atidarius čiaupą slegiamas gesinantis skystis švirkščiamas reikiama kryptimi. Tačiau tokio tipo gesintuvuose negalima išgauti didesnio vandens susmulkinimo nei naudojant gaisrinius tradicinius išcentrinius siurblius.

Žymiai pranašesnis gesinančio vandens tiekimas gali būti vykdomas, kai jo porcijos iššaunamos panaudojus suslėgtų ir besiplečiančių dujų (oro) energiją. Tokio tipo gesinimo priemonės vadinamos impulsinėmis, nes gesinančios medžiagos tiekiamos impulsais. Principinė impulsinio gesinimo švirkšto schema parodyta.

Impulsiniai švirkštai dirba taip:

- iš suslėgto oro rezervuaro užpildoma suslėgto oro kamera;
- iš vandens rezervuaro užpildoma vandens kamera;
- atidarius greito suveikimo vožtuvą, susijungia suslėgto oro ir vandens kameros;
- vanduo, veikiamas oro slėgio, išpurškiamas per labai trumpą laiko tarpą (nuo kelių iki kelių dešimčių milisekundžių) į gaisro židinį;
- toliau procesas kartojamas iš naujo.

Išpurškiamas vanduo pasiekia net 120 m/s greitį (432 km/h). Vandens porcija skrisdama tokiu greičiu sutinka didelį oro pasipriešinimą ir dėl to čiurkšlė susiskaido į labai mažus lašelius (net iki 2 mikronų dydžio) ir praktiškai virsta greitai judančiu rūku. Toks rūkas pasižymi labai geromis gesinimo savybėmis, nes labai gerai apgaubia visą aplinką, o smulkūs lašeliai greičiau absorbuoja šilumą. Tokiu pagrindu veikiantys impulsiniai švirkštai gaminami ne vienoje šalyje. Tačiau šiuo metu nėra sukurtas jų veikimo matematinis modelis, leidžiantis nustatyti optimalius parametrus.

Šiuo metu, atlikus bandymus su Vokietijos IFEX GmbH pagamintu impulsiniu švirkštu IFEX 3001 nustatyti šie privalumai:

- Labai geras išpurslinimas, kas sudaro sąlygas arti 100 % vandens gesinamųjų savybių panaudojimo.
- Naudojant suslėgtą orą „šūviui", tai yra išnaudojant oro tamprumą/spūdumą pasiekiamas labai didelis vandens dalelių greitis, kurios gerai skverbiasi į medžiagų paviršius.
- Susidaręs rūkas gerai apima visą tūrį ir aplenkia kliūtis (patenka į visas įmanomas vietas).
- Galima atlikti pavienius „šūvius" iki 1 litro vandens tūrio kas 2–3 s arba serijomis iki 0,25 litro.
- Galima purkšti vandenį laistymui be „šūvių".
- Vandenį galima naudoti su putokšliu.
- Maksimalus „šūvio" atstumas iki 16 m.

Kilnojamų gesinamų priemonių, naudojančių suslėgtojo oro energiją, bandymai parodė, kad jomis galima gesinti su 9 litrais vandens net A55 klasės gaisrus [4], kurio metu degančio paviršiaus plotas sudaro 61 m^2. Pagal atliktus statistinius tyrimus gaisro židinių išplitimas atvykus priešgaisrinėms tarnyboms ir jų procentas nuo bendro gaisrų skaičiaus sudarė [5]:

- iki 5 m^2 – 29 %;
- nuo 5 iki 10 m^2 – 30 %;
- nuo 10 iki 30 m^2 – 20 %;
- nuo 30 iki 100 m^2 – 10 %;
- nuo 100 iki 600 m^2 – 9 %;
- virš 600 m^2 – 2 %.

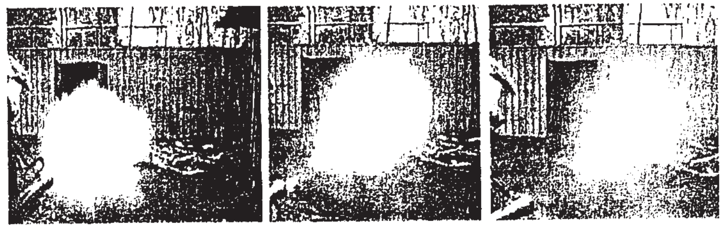
Iš pateiktų duomenų matosi, kad net apie 80% visų kilusių gaisrų galima užgesinti panaudojus efektyvias kilnojamas gesinimo priemones. Dėl to tokios priemonės daugelio atvejų įtraukiamos į priešgaisrinių gelbėjimo tarnybų greito reagavimo ar pirmos pagalbos automobilių privalomos įrangos sąrašus [6].

3. Impulsinių gesinimo priemonių optimalių parametrų nustatymas

Siekiant nustatyti jau esamo impulsinio švirkšto IFEX 3001 savybes, buvo atlikti eksperimentiniai „šūvio" fazių tyrimai bei praktiniai bandymai. Purškiamo vandens fazių tyrimui buvo panaudotas fotografinis metodas su 0,07 s intervalais tarp kadrų. Fotografinio tyrimo rezultatai pateikiami (1 pav.) ir (2 pav.).

Atliekant purškiamo vandens fotografinių tyrimų analizę nustatyta:

- Išleista iš impulsinio švirkšto vandens čiurkšlė skaidosi į smulkius lašelius ir lėtėja. Dalies vandens lašelių greitis tampa minimalus ir jie lieka laisvai sklęsti ore visame čiurkšlės judėjimo kelyje.
- Greičiausieji vandens čiurkšlės lašeliai 10 m atstumą pasiekia jau per 0,35 s laiko tarpą.
- Pagrindinė vandens čiurkšlės masė 10 m atstumą pasiekia per 0,7 s laiko tarpą



1 pav. Purškiamo vandens judėjimo fazės

2 pav. Vandens čiurkšlės judėjimo ir skaidymosi fazės

Įvertinus tyrimų ir praktinių bandymų rezultatus nustatyti tokie impulsinio švirkšto pagrindiniai trūkumai:

1. Gana nemažas švirkšto svoris (iki 8 kg), kuris ženkliai apsunkina ugniagesio gelbėtojo greito manevravimo galimybes.
2. Gana didelės švirkšto reakcijos jėgos vandens čiurkšlės paleidimo metu. Netinkamai laikant švirkštą jo naudotojas gali net traumuotis.
3. Gana ilgas švirkšto užpildymo laikas (2–3 s), tai yra laiko tarpas tarp čiurkšlių paleidimų. Dėl šių priežasčių kyla būtinybė naudoti du tokius švirkštus vieno židinio gesinimui.
4. Naudojant švirkštus uždarose patalpose (butuose) yra tikimybė, kad greitai lekiantys lašeliai nespės sugerti šilumos ir atsitrenks į sienas ar kitas

patalpas ribojančias konstrukcijas, dėl ko žymiai mažėtų gesinimo efektyvumas.

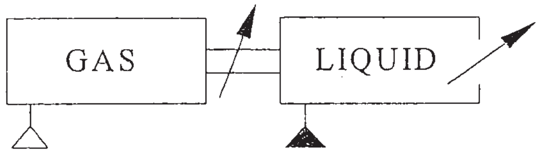
5. Švirkšto veikimas nėra efektyvus atvirose vietovėse didesniais atstumais, nors čiurkšlės maksimalus atstumas siekia iki 16 m. Smulkiai išpurslintus lašelius išnešioja oro srautai.

Įvertinus gautus rezultatus galima teigti, kad nedidelių gaisro židinių gesinimui, kurių aktualumas buvo aprašytas šiame straipsnyje, impulsinio švirkšto parametrai nėra optimalūs.

Impulsinio švirkšto, pritaikyto nedidelių židinių gesinimui, optimalių parametrų prielaidos yra sekančios:

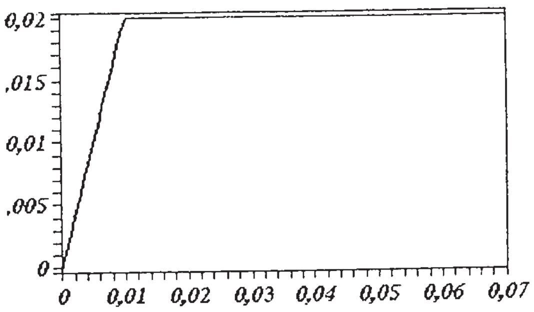
- Nedideli židiniai praktiškai gesinami esant nedideliems atstumams nuo jų, todėl optimalus čiurkšlės veikimas turi būti užtikrintas 3–6 m atstume.
- Siekiant užtikrinti gesinimą vienu švirkštu, gesinančių medžiagų tiekimo į židinius nepertraukiamumą, būtina išlaikyti ne mažesnį gesinančių medžiagų tiekimo intensyvumą (tai yra 0,25–0,3 l/s) bei sumažinti švirkšto užpildymo laiką ir padidinti čiurkšlės paleidimo dažnį.
- Sumažinti impulsinio švirkšto svorį, mažinant vandens masę čiurkšlėje bei didinant jos paleidimo dažnį.
- Sumažinti impulsinio švirkšto reakcijos jėgas mažinant vandens masę čiurkšlėje bei įrengiant kompensacinius mechanizmus.

Impulsinio švirkšto pagrindiniai parametrai gali būti nustatomi sprendžiant hidraulinių ir pneumatinių sistemų būsenų lygtis. Impulsinio švirkšto modelio principinė schema parodyta (3 pav.).

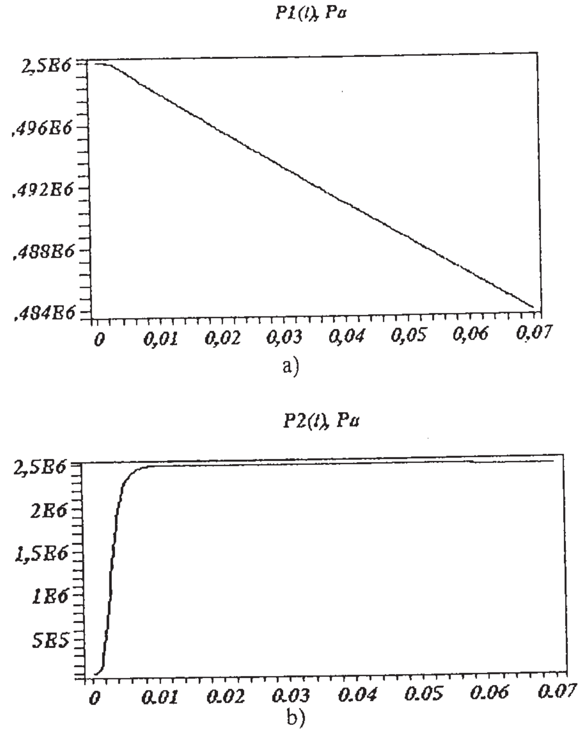


3 pav. Impulsinio švirkšto modelio principinė schema

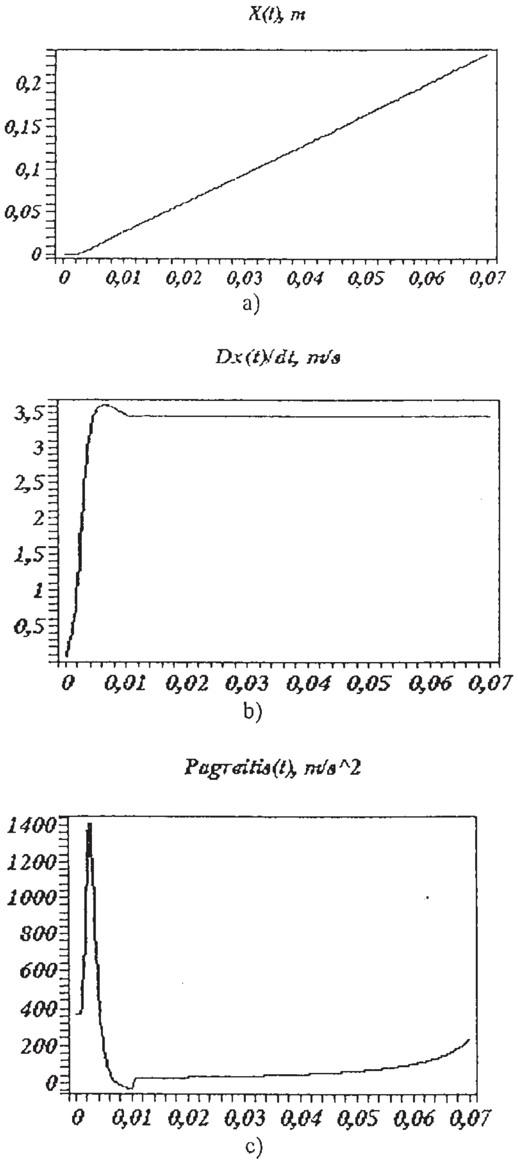
Pneumatinės kameros vožtuvo skersmens priklausomybė nuo laiko parodyta 4 pav. Dujų slėgio priklausomybės pneumatinėje ir švirkšto kamerose parodytos 5 pav. Skysčio masės poslinkis, greitis ir pagreitis parodyti 6 pav.



4 pav. Pneumatinės kameros vožtuvo skersmens priklausomybė nuo laiko



5 pav. Slėgio priklausomybės nuo laiko:
a – pneumatinėje kameroje; b – švirkšto kameroje



6 pav. Skysčio masės kinematinių parametrų priklausomybė nuo laiko:
a – poslinkis; b – greitis; c – pagreitis

4. Išvados

1. Gesinimo priemonės, skirtos nedideliems gaisro židiniams likviduoti, yra ypatingai aktualios priešgaisrinėms gelbėjimo tarnyboms, nes jomis galima žymiai taupiau ir greičiau gesinti didelį gaisrų skaičių.
2. Impulsinių gesinimų technologijų naudojimas leidžia maksimaliai išnaudoti vandens gesinančias savybes, tuo sumažinant jo poreikį bei nuostolius dėl vandens poveikio.
3. Šiuo metu naudojamų impulsinių švirkštų techninės charakteristikos nėra optimalios nedidelių gaisro židinių gesinimui.
4. Impulsinio švirkšto matematinio modelio nustatymas ir sprendimas leistų parinkti optimalius techninius parametrus.

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УЛУЧЕНИЕ ПАРАМЕТРОВ СРЕДСТВ, ПРЕДНАЗНАЧЕННЫХ ДЛЯ ТУШЕНИЯ НЕБОЛЬШИХ ОЧАГОВ ВОЗГОРАНИЯ

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В данной статье излагаются проблемы для рационального и эффективного транспортирования огнетушащих веществ для тушения небольших пожаров. Рассмотрено влияние и значение методов подачи огнетушащих средств. Описаны существующие и выявляемые недостатки применяемых установок импульсного пожаротушения. Даны методы для определения оптимальных параметров средств тушения, использующих энергию сжатых газов.

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

VGTU

TRANSPORTO INŽINERIJOS FAKULTETAS

**Penktosios Lietuvos jaunųjų mokslininkų konferencijos
"Lietuva be mokslo – Lietuva be ateities",
įvykusios Vilniuje 2002 m. gegužės mėn. 22 d.,
pranešimų medžiaga**

TRANSPORTAS

Vilnius „Technika" 2002

2. Įvertinus asfaltbetonio mišinio gamybos technologinio proceso veiksnius (medžiagų drėgnį, jų taršą, maišinio masę, maišymo ciklo trukmę, asfaltbetonio maišytuvo užduotą našumą, technologinių sietų akučių matmenis, naudojamų karštųjų frakcijų dydį ir skaičių, pradinių mineralinių medžiagų masės santykį ir bitumo kiekį) sudaryta pradinių šaltųjų mineralinių medžiagų dozatorių pradinio sureguliavimo seka. Naudojant mūsų sukurtas matematines formules ir skaičiavimo algoritmą, galima teisingiau negu iki šiol buvo daroma apskaičiuoti pradinių šaltųjų mineralinių medžiagų dozatorių našumus, leidžiančius gaminti tikslesnės ir stabilesnės sudėties asfaltbetonio mišinius.

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GAISRINIŲ AUTOMOBILIŲ TECHNINIŲ PARAMETRŲ GERINIMO BŪDAI

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1. Įvadas

Priešgaisrinių gelbėjimo tarnybų veiklos tikslas – gelbėti žmonių gyvybes ir turtą gaisrų bei kitų ekstremalių situacijų atvejais. Gaisriniai automobiliai – tai techninės priemonės, kurias naudojant priešgaisrinės

gelbėjimo tarnybos užtikrina savo funkcijų vykdymą. Akivaizdu, kad gaisrinių automobilių techninės charakteristikos turi lemiamos įtakos efektyviam ugniagesių gelbėtojų darbui. Nuo gaisrinės ir gelbėjimo technikos, tame tarpe ir gaisrinių automobilių, techninių parametrų priklauso gaisrų gesinimo ir gelbėjimo darbų atlikimo greitis. Greičio faktorius ekstremaliose situacijose turi ypatingą reikšmę. Žmonių žūties tyrimai gaisruose rodo, kad 60 – 70% žmonių žūsta apsinuodiję gaisro dujomis pirminėje jo stadijoje (iki 5 – 6 min. nuo gaisro kilimo pradžios) [2]. Materialiniai nuostoliai dėl kilusių gaisrų turi betarpišką ryšį su pačio gaisro degimo trukme. Gaisro degimo sutrumpinimas 1 min., pagal atliktus tyrimus Didžiojoje Britanijoje, gali sumažinti 5,3% žuvusiųjų skaičių gaisruose. Taigi gaisrinio automobilio panaudojimo laikinės charakteristikos turi lemiamą reikšmę gaisrų gesinimui. Optimalus funkcinis gaisrinio automobilio panaudojimas gali būti išreikštas tokia priklausomybe:

$$O = F(Ta, Ti, Tg); \quad (1)$$

čia: O – optimalus gaisrinio automobilio panaudojimas; Ta – atvykimo laikas į įvykio vietą; Ti – įrangos išskleidimo laikas; Tg – gesinimo laikas.

Atvykimo laikas į įvykio vietą priklauso nuo to, kokiu maksimaliu vidutiniu greičiu galės judėti gaisrinis automobilis, koks yra atstumas iki gaisro vietos, kokia kelių būklė ir eismo sąlygos, kaip greitai, gavus pranešimą apie nelaimę, automobilis gali išvažiuoti iš gaisrinės. Įrangos išskleidimo laikas priklauso nuo to, kokia gaisriniame automobilyje yra įranga, kaip greitai galima ją panaudoti, koks ugniagesių skaičius gali atvykti. Gesinimo laikas priklauso nuo gesinimo įrangos techninių charakteristikų, turimų gesinimo medžiagų kiekio.

Įvertinus laiko faktoriaus gaisrų gesinime sudedamąsias dalis, gaisrinių automobilių techninius parametrus galima suskirstyti į 3 pagrindines grupes:
1. Važiuoklės.
2. Gaisrinio antstato, kėbulo, gesinančių medžiagų talpų.
3. Specialiųjų agregatų ir įrangos.

Kiekvienas iš šių grupių parametras atitinkamai turi įtakos tokioms gaisrinio automobilio savybėms: greitai ir saugiai atvykti į įvykio vietą; išvežti reikalingą skaičių ugniagesių, įrangos ir gesinančių medžiagų; efektyviai tiekti gesinančias medžiagas ar su specialiais agregatais užtikrinti reikalingų darbų atlikimą. Todėl gaisrinių automobilių techninių parametrų gerinimą galima vykdyti šiais būdais:
- Tobulinti arba pakeisti gaisrinio automobilio bazinę važiuoklę.

- Modernizuoti ar pakeisti gaisrinio automobilio kėbulą, įrangos skyrius, gesinančių medžiagų talpas.
- Keisti siurblį ar kitą specialųjį agregatą, įrengti papildomas priemones, gerinančias gaisrų gesinimą.

2. Eksploatuojamų pagrindinių gaisrinių automobilių trūkumai

Gaminant gaisrinius automobilius stengiamasi parinkti optimalius techninius parametrus. Tačiau, dėl gaisrinių automobilių panaudojimo specifikos, labai netolygiai dėvisi jų agregatai ir kitos sudedamosios dalys. Eksploatavimo metu gaisrinių automobilių ridos, lyginant su transportiniais, yra nedidelės, tačiau jų darbo režimas gana sunkus, o automobilio naudojimo trukmė sudaro 11 – 30 metų. Per visą gaisrinio automobilio eksploatavimo periodą nekartą tenka keisti susidėvėjusius agregatus ir mazgus. Be to, per ilgą eksploatavimo laikotarpį kai kurie parametrai pradeda netenkinti naujų sąlygų. Anksčiau ugniagesiai tiktai gesindavo gaisrus, o dabar vykdo ir įvairius gelbėjimo darbus, kuriems atlikti reikalinga papildoma įranga, kurios talpinimui seno tipo kėbuluose nėra vietos. Atsiradusios naujos technologijos reikalauja pasenusių sudedamųjų dalių pakeitimo. Neretai po daugelio eksploatavimo metų vieno ar kito agregato ar mazgo, kurį būtina pakeisti, gamyba būna nutraukta ir tenka ieškoti alternatyvių sprendimų. Visa tai yra ypatingai aktualu senų gaisrinių automobilių tolimesniam naudojimui užtikrinti, nes naujos šiuolaikinės technikos įsigijimas dėl finansinių lėšų trūkumo yra problematiškas.

Šiuo metu valstybinėje priešgaisrinėje gelbėjimo tarnyboje eksploatuojama per 700 vnt. gaisrinių ir gelbėjimo automobilių bei specialios paskirties transporto priemonių. Tarp pagrindinių gaisrinių automobilių net 80% yra pagaminti buvusioje Sąjungoje, kurie nepasižymi geru patikimumu ir ilgaamžiškumu. Tokių automobilių gedimai pasiskirsto sekančiai:

- 70% visų gedimų tenka specialiems agregatams ir kėbulo konstrukcijai, iš kurių 24%- vakuuminei sistemai ir 18% – gaisriniam siurbliui.
- 30% tenka bazinės važiuoklės gedimams, iš kurių 12% tenka transmisijos agregatams, 8% – eismo saugumą užtikrinančioms sistemoms.

Nemažą rūpestį kelia ir tai, kad visi gaisriniai automobiliai, sumontuoti ant GAZ ir ZIL važiuoklių, turi karbiuratorinius variklius, naudojančius A-80 markės benziną. Tuo tarpu kitose šalyse tokių klasių gaisrinių automobilių važiuoklės komplektuojamos tiktai žymiai ekonomiškesniais dyzeliniais varikliais. Būtų tikslinga atlikti dar ne vienerius metus numatomiems eksploatuoti gaisriniams automobiliams karbiuratorinių variklių pakeitimo dyzeliniais ekonominius-techninius skaičiavimus.

Kaip jau buvo minėta, didžiausių rūpesčių sudaro gaisrinių išcentrinių siurblių užpildymo vakuuminės sistemos, pačių gaisrinių siurblių gedimai, kėbulų ir cisternų korozija ir trūkimai. Pakeičiant šias sistemas naujomis ar atlikus jų patobulinimus, galima būtų ženkliai pagerinti gaisrinių automobilių charakteristikas bei prailginti tarnavimo laiką.

3. Gaisrinių automobilių vakuuminių sistemų gerinimas

Gaisriniai išcentriniai siurbliai, prieš pradedant jais tiekti gesinančius skysčius, turi būti kuo greičiau užpildyti. Šiuo metu daugiausiai yra paplitusios vakuuminės sistemos, kurios užtikrina greitą siurblių užpildymą. Vakuuminių sistemų darbas yra pagrįstas oro išsiurbimu iš išcentrinių siurblių ir su jais sujungtų įsiurbimo žarnų. Išsiurbus orą susidaro išretinimas (vakuumas) ir vanduo, veikiamas atmosferinio slėgio, užpildo įsiurbiamąsias žarnas ir išcentrinius siurblius.

Pagrindiniai vakuuminės sistemos charakterizuojantys parametrai yra:

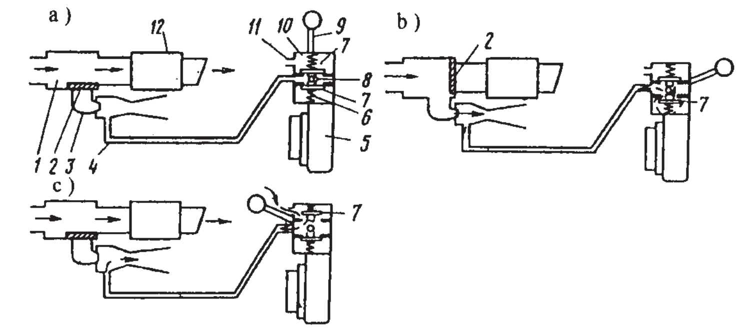
- pasiekiamas maksimalus vakuuminis slėgis;
- geometrinis įsiurbimo aukštis;
- laikas, per kurį išsiurbiamas oras iš siurblio ir sujungimo žarnų.

Maksimalus geometrinis įsiurbimo aukštis priklauso nuo sukuriamo maksimalaus vakuuminio slėgio. Maksimalaus vakuuminio slėgio sukūrimui turi įtakos sistemos tarpelių dydžiai bei sujungimų sandarumas. Deja, visos vakuuminės sistemos turi tą patį trūkumą – teorinis geometrinis įsiurbimo aukštis negali būti didesnis kaip 10 metrų, o įvertinus nuostolius sistemose, maksimalus įsiurbimo aukštis praktiškai tesiekia tiktai 7 – 8 metrus.

Visuose gaisriniuose automobiliuose, pagamintuose buvusioje Sąjungoje, be išimties, buvo montuojamos vienodos vakuuminės sistemos, kuriose vakuumui sudaryti naudojama variklių išmetamų dujų energija. Bendra tokios vakuuminės sistemos schema pateikta (1 pav.).

Tokios vakuuminės sistemos nereikalauja transmisinės pavaros, jose nėra besisukančių , slenkančio ir grįžtančio judesio dalių, jas gana paprasta sumontuoti. Tačiau jos turi ir esminių trūkumų:

- vakuuminio aparato sklendžių bei pačio korpuso metalinių paviršių, veikiamų karštų variklio išmetamųjų dujų, korozija;
- didelis triukšmas darbo metu;
- galima padidėjusi išmetamų dujų koncentracija gaisrinio automobilio vairuotojo/operatoriaus darbo vietoje;
- sudaromas variklio išmetamųjų dujų priešslėgis iki 0,2 MPa;
- neįmanomas sistemos autonominis darbas;
- sudaromas mažesnis vakuuminis slėgis, lyginant su kitomis naudojamomis vakuuminėmis sistemomis (1 lentelė).



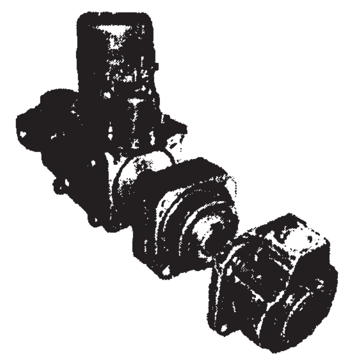
1 pav. Vakuuminės sistemos, naudojančios variklio išmetamųjų dujų energiją: a – nedarbinė vakuuminės sistemos padėtis; b – vandens įsiurbimas; c – vakuuminės sistemos ištuštinimas; 1 – vakuuminio aparato korpusas; 2 – sklendė; 3 – čiurkšlinis siurblys; 4 – išcentrinio siurblio sujungimas su čiurkšlinio siurblio vakuumine kamera; 5 – išcentrinis siurblys; 6 – spyruoklė; 7 – vožtuvas; 8 – ekscentrikas; 9 – rankena; 10 – vakuuminis čiaupas; 11 – kiaurymė; 12 – išmetamųjų dujų duslintuvas

1 lentelė. Vakuuminių sistemų palyginamieji duomenys ir parametrai

Parametras	Su dujų čiurkšliniais siurbliais	Su membraniniais siurbliais	Su stūmokliniais siurbliais	Su plokšteliniais siurbliais
Išvystomas vakuuminis slėgis, MPa	0,074	0,09	0,09	0,09
Maksimalus geometrinis įsiurbimo aukštis, m	7	8	8	8
Energijos šaltinis	Variklio išmetamosios dujos	Išcentrinio siurblio pavara	Išcentrinio siurblio pavara	Elektrinis nuolatinės srovės variklis
Valdymas	Rankinis	Rankinis arba automatinis	Rankinis arba automatinis	Rankinis
Neigiamas poveikis aplinkai, automobilio agregatams ar operatoriui	Turi poveikį automobilio varikliui ir operatoriaus darbo vietai	Neturi	Neturi	Turi poveikį aplinkai

Vakuuminės sistemos pagrindą sudaro naudojamas siurblio tipas. Išanalizavus vakuuminėse sistemose naudojamų siurblių parametrus, jų savybes, nustatyta, kad geriausiai būtų naudoti membraninius arba

stūmoklinius įsiurbimo siurblius. Tačiau šių siurblių darbui būtina pavara. Vakarų šalių įsiurbimo siurbliams varyti naudojami siurblio pavaros kardaninis velenas ar pačio išcentrinio siurblio velenas. Tai reiškia, kad vakuuminis siurblys dirbs tiktai tuo atveju, kai suksis išcentrinis siurblys. Tačiau GAZ ir ZIL tipo gaisriniuose automobiliuose įrengtų išcentrinių siurblių riebokšliai ir sandarinimai nepritaikyti dirbti ilgesnį laiką be vandens. Todėl gaisriniuose automobiliuose, kuriuose yra sumontuoti PN 40UA ir PN 40UV siurbliai, neįmanoma naudoti siurblio pavaros įsiurbimo siurbliams sukti. Šiuo atveju vienas iš sprendimo būdų yra membraniniam ar stūmokliniam įsiurbimo siurbliui sukti naudoti nuolatinės srovės elektros variklį, maitinamą iš automobilio elektrinių grandinių. Tokį įsiurbimo siurblį lengva sumontuoti, bet kurioje gaisrinio automobilio vietoje (2 pav.).



2 pav. Stūmoklinis įsiurbimo siurblys, varomas elektrinio variklio

Pradėti eksperimentiniu būdu gaminti 2 pav. pavaizduoti įsiurbimo siurbliai su 0,00021 m^3 darbiniu tūriu bei komplektuojami 1,3 kW galingumo elektriniu automobiliniu starteriniu varikliu. Šie stūmokliniai siurbliai pagerina senų gaisrinių automobilių vakuuminių sistemų darbą, taupo lėšas, nes siurblio hermetiškumui patikrinti nebūtina užvedinėti variklio.

4. Gaisrinių automobilių AC 40(130)63B ir AC 40(131)137 antstatų keitimas

Gaisrinių automobilių AC 40(130)63B ir AC 40(131)137 antstatai be didesnių pakitimų buvo gaminami ne vieną dešimtmetį. Jų pagrindiniai trūkumai:

- nėra pakankamai vietos papildomai gelbėjimo įrangai talpinti;

- labai intensyvi kėbulo ir cisternos korozija;
- kėbulo skyrių dangčiai nepatikimai užsidaro, o atidarytoje padėtyje - darbo vietoje yra nesaugūs.

Kiekvienais metais vis daugiau šio tipo gaisrinių automobilių antstatų dėl gilios metalo korozijos tampa nebetinkami naudoti, nors važiuoklės dar galėtų tarnauti žymiai ilgesnį laiką. Problemai išspręsti buvo svarstomi įvairūs variantai: iš dviejų gaisrinių automobilių surinkti vieną; keisti labiausiai susidėvėjusias kėbulo detales; keisti visą kėbulą kartu su jo komplektuojančiomis dalimis. Surenkant iš dviejų gaisrinių automobilių vieną, ne visada įmanomas racionalus visų agregatų ir mazgų panaudojimas. Keičiant atskiras labiausiai susidėvėjusias antstato detales, nepašaliname nei vieno aukščiau paminėto trūkumo. Todėl, siekiant pagerinti naudojamų gaisrinių automobilių charakteristikas bei prailginti jų tarnavimo laiką, nutarta pirmenybę teikti viso antstato keitimo variantui. Gaisrinio automobilio antstatui keliami reikalavimai:

- Naujos antstato konstrukcijos ir detalės neturi sumažinti gaisrinių automobilių aktyviosios ir pasyviosios saugos.
- Antstato konstrukcijos ir detalės neturi viršyti gaisrinių automobilių gamykloje nustatytų gabaritų, bendrųjų masių bei ašių apkrovų.
- Naujo kėbulo skyrių konfigūracija turi tikti reikiamai papildomai įrangai talpinti.
- Kėbulas ir cisterna turi būti gaminami iš nerūdijančių medžiagų arba būtų padengtos patikima antikorozine danga.
- Vietoje skyrių dangčių turi būti naudojamos aliumininės žaliuzės tipo durelės.

Šias ir kitas papildomas sąlygas atitinkantys antstatai buvo pagaminti ir pradėti montuoti ant senų gaisrinių automobilių. Gaisrinio automobilio su nauju antstatu bendras vaizdas pateiktas (3 pav.).

3 pav. Bendras gaisrinio automobilio AC-40(130)63B vaizdas su naujuoju antstatu

Gaisrinio automobilio antstatas susideda iš: porėmio; porėmio elastinės pakabos (atsisakius tvirtinimo apkabomis); kėbulo karkaso, prie kurio tvirtinami klijavimo būdu aliumininiai lakštai; cisternos ir putokšlio bako, gaminamų iš polipropileno; skyrių uždarymo aliumininėmis žaliuzės tipo durelėmis; įrangos tvirtinimo elementų.

Tokio tipo nauji antstatai pagerina gaisrinių automobilių charakteristikas:

1. Padidėjęs 0,6 m^3 kėbulo tūris leidžia talpinti daugiau įrangos.
2. Kėbulas, cisterna ir putokšlio bakas nebijo korozijos, nes gaminami iš nerūdijančių medžiagų.
3. Aliumininės žaliuzės tipo durelės gerai sandarina įrangos skyrius, estetiškai atrodo ir pagerina darbo sąlygas aplink automobilį.
4. Antstato porėmio elastinės pakabos dėka nesudaromi nepageidaujami įtempimai kėbulo konstrukcijose.

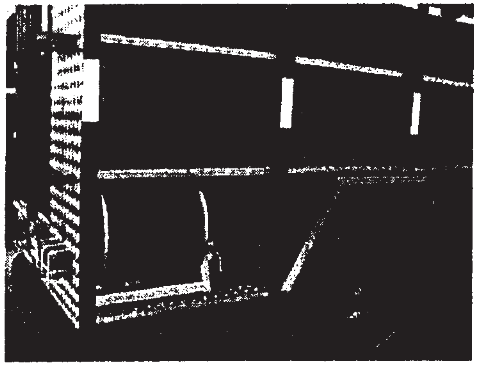
5. Gesinimo sistemų gerinimas

Gesinimo sistemos – tai sistemos, kurių dėka tiekiamos gesinančios medžiagos gaisro gesinimui. Šių sistemų pagrindą sudaro gaisriniai siurbliai. Gaisrinio siurblio charakteristikos apsprendžia įrangos panaudojimą. Teisingai parinkta įranga leidžia efektyviau išnaudoti gaisrinių siurblių savybes. Kadangi gaisrų gesinime laiko faktorius yra ypatingai svarbus, tai akivaizdu, kad kuo anksčiau bus pradėtos tiekti gesinančios medžiagos į gaisrą, tuo pats gesinimas bus efektyvesnis. Ženkliai pagreitinti gesinimo pradžią, panaudojant esamas gaisrinio automobilio sistemas, yra įrengti automobilyje greito reagavimo žarnų ritę. Greito reagavimo žarnų ritės ugniagesiams suteikia galimybę be laiko gaišimo žarnų linijų sujungimui pradėti tiekti vandenį tuoj pat, kai tik pradeda veikti gaisrinis siurblys. Be to, greito reagavimo žarnos yra santykinai lengvos ir su jomis galima greitai manevruoti. Pagal Didžiojoje Britanijoje atliktus tyrimus nustatyta, kad naudojant greito reagavimo žarnų rites pasiekiamas greičiausias gaisrų gesinimas [2]. Tačiau greito reagavimo žarnų ritės, būdamos mažesnių skersmenų (19 – 38 mm), pasižymi žymiai didesniais hidrauliniais nuostoliais. Be to, norint užtikrinti reikiamą gesinančių medžiagų tiekimo intensyvumą, darbui su greito reagavimo žarnomis būtinas didesnis slėgis. Todėl darbui su greito reagavimo žarnomis dažniausiai naudojami kombinuoti (žemo/aukšto slėgio) siurbliai, kurie gali pasiekti 2 – 5 MPa slėgį. Kartu su aukšto slėgio žarnomis naudojami aukšto slėgio švirkštai, kurių našumas 1 – 2 l/s. Kyla klausimas, ar galima naudoti greito reagavimo žarnas senuose gaisriniuose automobiliuose, kurių siurbliai išvysto tiktai 1 MPa slėgį. Galima, tiktai būtina parinkti reikiamų parametrų žarnas ir švirkštus. Nekartą teko įsitikinti, kad, parinkus neteisingų charakteristikų įrangą, laukiamo efekto nepasiekiama. Siekiant panaudoti greito reagavimo žarną senuose automobiliuose, būtina turėti gerą apie 2 l/s našumo švirkštą purkštuvą, galinti efektyviai dirbti prie žemų (0,3 – 0,4 MPa) slėgių [1]. Gaisrinės žarnos parametrams nustatyti galime naudoti tokią formulę [3]:

$$FL = CQ^2L; \quad (2)$$

čia: FL – hidrauliniai nuostoliai žarnoje, kPa; C – žarnos hidraulinio pasipriešinimo koeficientas; Q – našumas šimtais l/min; L – žarnų ilgis šimtais m (dažniausiai iki 60 m).

Atlikus skaičiavimus gauname, kad greito reagavimo žarna turi būti ne mažesnio kaip 25 mm skersmens. Tokios žarnos įrengimas gaisriniame automobilyje parodytas (4 pav.).

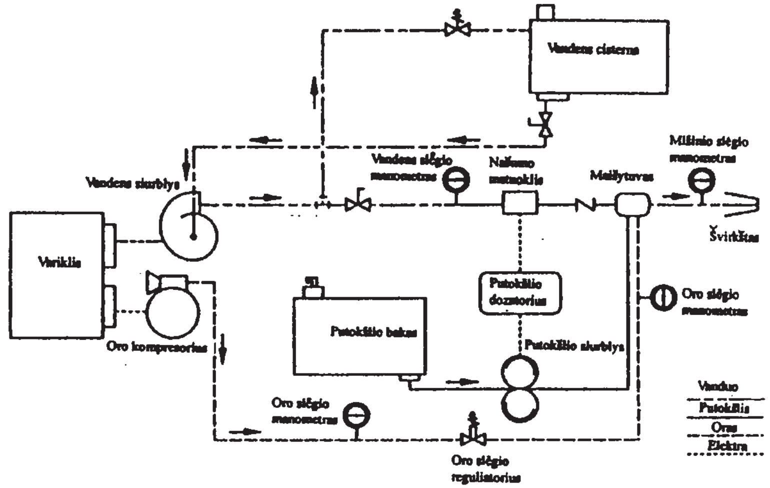


4 pav. Greito reagavimo žarnos įrengimas sename gaisriniame automobilyje su nauju antstatu

Gaisrinio automobilio gesinimo galimybes galima ženkliai pagerinti naudojant geresnių charakteristikų gaisrinius siurblius. Tačiau gaisrinio siurblio naudojimą apsprendžia jį sukantis variklis. Neretai net gamintojai ne visada tinkamai suderina variklio-siurblio atitikimo parametrus: galingumus, sukimo momentus, apsukų skaičių. Todėl tie patys gaisriniai automobiliai su skirtingais siurbliais gali turėti ir skirtingas gesinančių medžiagų tiekimo savybes. Senuose gaisriniuose automobiliuose, pakeitus gaisrinius siurblius PN 40 šiuolaikiniais atitinkamų parametrų siurbliais, tampa įmanoma naudoti pažangiausią gesinimo įrangą. Modernūs gaisriniai siurbliai kainuoja gana

brangiai (20 – 50 tūkst. Lt,), todėl jų panaudojimui bei atrankai būtina kruopšti techninė ir ekonominė analizė bei tyrimai.

Visų gaisrinių automobilių, net ir neseniai pagamintų, gesinimo savybes padidinti galima įrengiant juose CAFS sistemas, kurios vis plačiau pripažįstamos įvairiose šalyse. CAFS (Compressed Air Foam System) – tai suslėgto oro ir putų gesinimo sistema. Darbo principas pagrįstas tuo, kad vandens ir putokšlio mišinį aeruojant suslėgtu oru gaunamos labai kokybiškos ir stabilios putos, kurios pro žarnas ir švirkštus tiekiamos gesinimui. Mišiniui sudaryti naudojamas specialus A tipo putokšlis, kurio reikalinga koncentracija vandenyje tesiekia 0,1 – 1%. Vandens-putokšlio mišinys maišomas su oru santykiu 1:7. Todėl gaisrinės žarnos su putomis yra lengvos, nes jose daugiau oro nei skysčių. Principinė CAFS sistemos schema pateikta (5 pav.).



5 pav. Principinė CAFS sistemos veikimo schema

Naudojant CAFS sistemą, gesinimo efektyvumas padidėja 3 – 5 kartus, lyginant su gesinimu paprastu vandeniu. [4, 5]. Efektyvumas pasiekiamas dėka to, kad vanduo yra išlaikomas stabiliose putose ir visiškai neišteka iš gaisro vietos (pvz., naudojant kompaktinę ištisinę čiurkšlę net iki 90% vandens išteka iš gesinamo židinio neturėdamas gesinančio poveikio). Sistemos darbui būtina turėti oro kompresorių, putokšlio dozavimo įrenginį, vandens siurblį, slėgių reguliavimo prietaisus. Sistemos gali būti tiek autonominės, turinčios savo variklį, kompresorių, vandens siurblį ir kitus įranginius, tiek ir naudojančios esamą gaisriniame automobilyje siurblį ir jo pavarą. Kadangi CAFS sistemos labai taupiai naudoja vandenį, todėl gaisriniuose automobiliuose netenka prasmės turėti dideles talpas gesinančių medžiagų. Sumontavus CAFS sistemas esamuose automobiliuose galima būtų mažinti vandens cisternų tūrį ir didinti išvežamos reikalingos įvairiems darbams įrangos kiekį. Nauji automobiliai su CAFS sistemomis galėtų būti žymiai mažesni ir manevringesni. Tačiau šių sistemų efektyvumo ir optimalių parametrų nustatymui konkrečiuose gaisriniuose automobiliuose reikalingi tolimesni tyrimai ir praktiniai bandymai.

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ABS ĮTAKA EISMO SUGUMUI

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1. Įvadas

Visais laikais automobilių pasaulyje buvo pastebimas gamintojų ypatingas dėmesys saugumo klausimams. Keleivių saugumas didinamas dviem būdais: apsaugant juos nuo galimų sužeidimų avarijos metu arba įdiegiant priemones, kurios leidžia išvengti pačios avarijos. Viena iš tokių technologijų – stabdžių antiblokavimo sistemos (ABS – angliškai – anti-lock braking system). ABS buvo išrasta ir užpatentuota 1936 metais Vokietijoje. Komercinėje rinkoje ABS pasirodė 70-ųjų pradžioje, tačiau dėl techninio sudėtingumo ir didelių gamybos kaštų plačiai nepaplito. Vėliau jų naudojimas pradėjo sparčiai augti. 1990 – 1995 JAV buvo pagaminta beveik

39 milijonai automobilių su ABS. Jau 1997 m. 85% Europoje gaminamų vidutinės klasės automobilių turėjo ABS ir net 99% – didelės klasės. Gamintojai tikina, kad stabdžių antiblokavimo sistema mažina autoįvykių skaičių. Žmonės vairuodami automobilius su įrengta ABS mano, kad stabdžių antiblokavimo sistema leis jiems stabdyti greičiau ir saugiau. Būtent todėl ir kyla klausimas, ar iš tikrųjų stabdžių antiblokavimo sistema mažina autoįvykių skaičių, ar nauja technologija viską daro už mus? Šiame straipsnyje atkreipimas dėmėsis į stabdžių antiblokavimo sistemos panaudojimo automobilių transporte tikslingumą ir į jos teigiamus ir neigimus poveikius eismo saugumui.

2. ABS įtaka eismo saugumui

Automobilio ratų sukibimas su kelio paviršiumi priklauso nuo kelio ir padangos būklės, taip pat nuo ratų santykinio slydimo [1]:

$$\lambda = \frac{(v - w_{sr} \cdot r_o)}{v}; \qquad (1)$$

čia: v – automobilio greitis; w_{sr} – stabdomo rato kampinis greitis; r_o – rato laisvasis spindulys.

Išilginio sukibimo koeficientas [1]:

$$\varphi = \frac{P_{st}}{R_z}; \qquad (2)$$

čia: P_{st} – stabdymo jėga; R_z – rato normalinė reakcija.

Rato sukibimo su kelio paviršiumi išilgine kryptimi (išilginio sukibimo) koeficientas charakterizuoja stabdymo jėgą, kuri mažina automobilio greitį, o rato sukibimo koeficientas skersine, statmena rato plokštumai kryptimi – pasipriešinimą slydimui į šoną.

Idealus automobilio stabdymas yra toks, kai automobilio ratai turi geriausią sukibimą su kelio paviršiumi, tada nuolatos sekamas ratų slydimas ir pagal tai valdomas stabdymo efektyvumas [1]. Padangų sukibimo su kelio paviršiumi koeficiento priklausomybė nuo santykinio rato slydimo pavaizduota 1 pav.