TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 62, Issue III, September, 2019

AUTOMATIC FIRE EXTINGUISHING SYSTEM USING "T", "Z", "O" LETTERS TECHNIQUE BASED ON A PARALLEL STRUCTURE

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Abstract: *This paper presents an automatic system based on a parallel structure that can be used to optimize firefighting using the technique of letters „T", „Z", „O". The system, which is in the CAD optimization stage, uses electrically driven linear actuators to direct the water jet, so that the water consumption is reduced, the material damage is minimized without affecting the efficiency of the extinguishing operation.*

Key words: *Fire extinguish, automatic system, parallel structure, kinematic simulation*

1. INTRODUCTION

Water is the most important fire extinguisher resource because it is available in large quantities and at a low price, compared to other extinguishing agents. Water has interesting physical properties from the perspective of firefighting. It can be encountered both solid and liquid or gaseous. Among the most important properties, it can be listed: freezing temperature - 0 ℃, boiling temperature - 100℃, specific heat of water in solid state (ice) - 2.09 kJ/kgK, the specific heat of the liquid water at 15 ℃ – 4,18 kJ/kgK, the specific heat of the water in the gaseous state at 700 ℃ – 2 kJ/kgK, latent melting heat (melting enthalpy) – 334 kJ/kg, latent heat of water vaporization - 2260 kJ/kgK, superficial tension at 18 ℃ (liquid-air) - $73mN/m$.

Water is not harmful in its normal state, as a result of its decomposition it does not lead to the formation of dangerous products and is harmless in contact with most materials, at least in short term. However, substances that are toxic, corrosive can dissolve in water.

Due to the use of water as extinguishing agent, several consequences can occur which can affect the safety of people, it may cause damage to their homes or to the environment.

When a large amount of water is used to extinguish a fire, part of it is vaporized, but most of it is drained, in most cases, into the sewerage network, which cannot cover the entire amount. On the other hand, according to studies conducted by D. Stridsman & J. Andersson & I. Svedung [1], water spillage can be a major problem when dangerous chemicals are involved in the fire, or when large quantities of water are discharged for a long period of time. Thus, according to T. Lundmark [2], during the extinguishing of a fire in which a large amount of old car batteries burned, the waste water failed to put out the fire, but it led to the water mixing with the acid existing in the batteries that has elapsed. This was found by measuring the pH of the water, which dropped to a value of 1.9.

After the discharge of the water at the site of an intervention, it can reach the collection network for wastewater treatment, in pipes water collection located on the surface, or may leak into the ground either outside the building or in its interior, at the basement level.

It is indicated that the volume of water that flows after the extinguishing of a fire is as small as possible, its drainage in a large quantity indicating the low efficiency of the fire extinguishing operation. Thus, if the distance between the discharge pipe and the fire is large, a high flow value and a small conical angle must be used for the water jet to reach the respective area. This will lead to a high value of the water distribution in the area where the jet comes into contact with the fire, and then the hose will have to be maneuvered energetically, due to the high flow rate, to cover the largest surface of the fire. In the area where the water jet comes into contact with the fire, the water will be in excess, which can be seen through the amounts of water accumulated in certain areas at ground level, thus demonstrating that the extinguishing was not effective, as shown in Figure 1 [3].

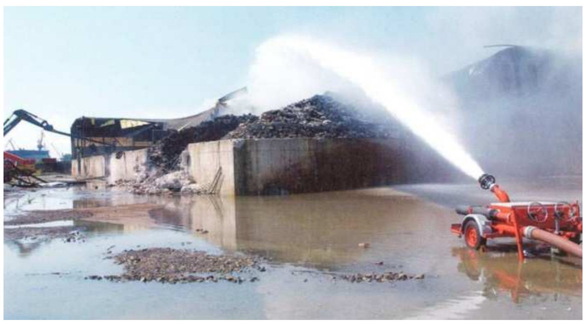

Fig. 1. Areas of accumulated water that prove that the water has not been used effectively

The complexity, the dynamics and the large number of interventions carried out over time to extinguish the fires, have led to the use of different methods to make the use of water more efficient, the use of water as extinguishing substance acquiring a variety of forms. The first method is to use different types of jets discharged over the burned space, namely compact or sprayed at different conical angles, the discharge can be continuous or in the form of impulses.

There are several techniques of water discharge in the form of impulses, such as short, long pulses, respectively "surface sweeping", the latter having the role of cooling the upper layers of hot gases [4]. The second method is given by the physical change of the diameter of the water droplets, finding that, at a value of the drop diameter of 0.3 mm, with a conical angle of the jet of 45° and a slope of the hose of 45° in front of horizontal, an efficiency of extinction of more than 75% is obtained [5]. The third method is the modification of the chemical composition of the water by adding additives, which reduces its surface tension and, implicitly, the speed of water drainage from the surface of the material to be protected or extinguished [6].

By using the compact jet, the water can be flowed horizontally or vertically, in a circle, in the shape of eight symbol or using the letter technique, which is exemplified in Figure 2.

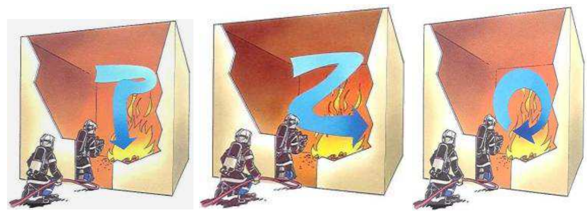

Fig. 2. Fire extinguishing using letter technique

Regarding the movement of the discharge hose, there are four main methods by which the hose can be maneuvered during the actions of water discharge, named according to the name of the letters whose model takes the form of the jet: the method of water discharge in the form of the letter „O", „T", „Z" respectively „Upside down U".

In the practical use of the letter technique, the starting point is always from top to bottom, this technique being used for rooms with floor area of up to 10 m^2 in the case of the „T" letter, 10 - 20 m^2 in the case of the letter „O"., 20-30 m^2 in the case of the „Z" letter [7]. These results are empirical and are based only on the practical experience of professional firefighters, as no scientific studies and research have been yet carried out to confirm or disprove the hypotheses.

Also, the water flow required for the discharge, respectively the analysis of the quantity of water used, are of particular importance in increasing the efficiency of the extinguishing action using the letter technique. There are several methods used to determine the water flow required for firefighting, some based on experimental data and others based on scientific principles, which depend on the value of the total thermal load of the fire compartment [8,9].

There are studies that present that the total water consumption recorded as a result of the extinguishing of fires is to a large extent, directly proportional to the area on which the fire is manifested [10].

2. STATE OF THE ART

There are very few international studies regarding the use of the virtual environment for developing equipment that can be deployed/used for managing the situations occurred in hazardous environments, without endangering responders' lives [11]. For example, the development of autonomous devices used to discharge water from a fixed position is very limited and are mostly capable to discharge water in the form of the letter „O".

In one of these studies [12], a series of experiments were carried out in a construction with a one floor (ground floor and 1st floor) that had internal stairs. At the end of which there were doors located. In these locations there had been installed bidirectional devices used to measure the amount of air driven by the jet flow. Also, the experiments have considered the water discharge was done through the door from the entrance to the building located on the ground floor, both inside and outside the building, through a hose located at about 3.6 meters from the door.

Thus, 4 experiments were performed, using different types of jets, namely: compact jet, spray jet with very narrow conical angle (below 15°) and a jet with a narrow conical angle (between 15° - 45°). The jet flow was realized in different ways, either by holding the hose in a fixed position, or by manipulating it in the form letter „O", „Z", or „upside down U", as it is illustrated in Fig 3 and 4.

Fig.3. Water discharge by holding the discharge hose in a fixed position

The fourth experiment in the test series consisted of comparing the quantities of air entrained by the automatic rotation of a discharge hose in the form of the letter „O", using a device (metronome), at speeds of 50, 100 and 150 rotations per minute, the jet stream being compact.

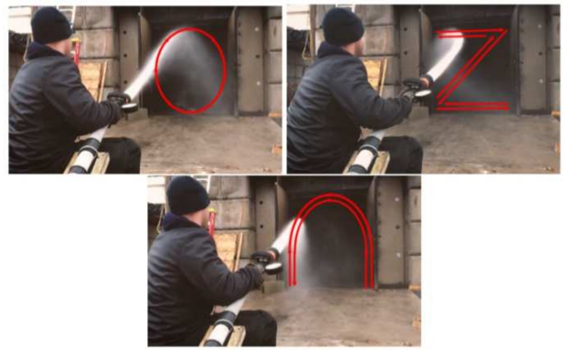

Fig. 4. Water discharge by maneuvering the discharge hose in the form of the letters "O", "Z", "upside down U"

The experiment was also carried out inside a building, at a distance of about 3.60 m from an exterior ventilation opening. It has been found that increasing the rotational speed of the hose from 50, to 100, respectively to 150 rotations per minute, while it is handled in the form of the letter "O", leads to an increase in the amount of air entrained by the water jet flow.

Considering that one of the main activities of the intervention crews performed during the execution of the extinguishing actions is the evacuation of the smoke and the ventilation of the rooms, by handling the discharge hose in different ways, a greater or lesser amount of air can be introduced.

The amount of air or smoke that can be displaced by the movement of the discharge hose is dependent on the speed at which the hose is operated (handled). The movement of the discharge hose produces the "disintegration" of the jet, that is, the faster the hose moves, the more drops are created, in this way a larger quantity of air is involved. Thus, in the case of handling the discharge hose in the form of the letter "O", by increasing the speed of movement of the hose, and by increasing the number of rotations per minute from 50, to 100, and then to 150, the amount of air displaced was higher. It has been found that if a fire-fighter tries to dislodge a quantity of air or smoke, he must increase the speed of movement of the hose, and if he does not want to move any amount of air or smoke, he must keep the hose in a position as

fixed as possible. The involvement of a large quantity of air is not influenced much by the chosen model of hose movement. Maneuvering the discharge hose in the form of the letter "O", "Z", "upside down U", or just moving the hose quickly, without a particular model, using the "spray and pray" technique, all these movements led to the formation of similar quantities of air.
Joshua G. McNeil and Brian Y. Lattimer [13] have developed an autonomous fire-extinguishing system that manifests either in a room with low visibility or with good visibility. The system contains a group of multispectral sensors, including ultraviolet and infrared stereo vision sensors, to detect and act on the fire to extinguish it.

Fig. 5. Fire extinguisher test before (a), during (b) and after (c) water discharge

The autonomous extinguishing system was used to operate on a woody fire, with the heat flow between 40 kW and 50 kW, from a distance between 2.80 m and 5.50 m and at heights between 0, 40 m and 1.30 m.
Also, an autonomous fire extinguishing system has been developed for interior compartments [14], by short-distance water discharge, based on computerized visualization, characterized by receiving real-time feedback on the size of the fire and the direction of the water discharge.

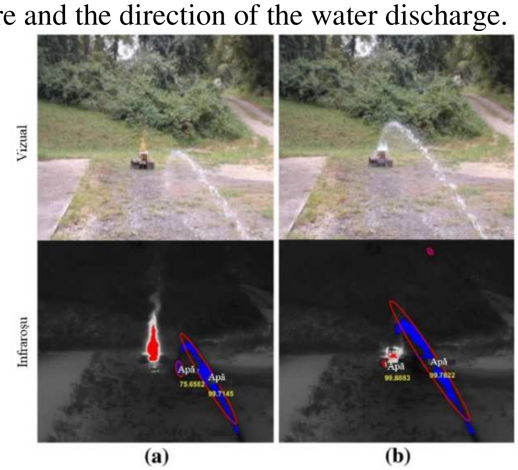

Fig. 6. Visual and infrared images with the direction of the water jet: (a) the initial direction; (b) the corrected direction, the water reaching the fire outbreak

The phases of the system include the oscillation movement of the hose, the complete control system, the visual servomechanism and the completion of the action as soon as the size of the fire decreases to zero.

3. THE TZO PLATFORM

To develop an automatic fire extinguishing system that makes use of the letter technique, a parallel structure known in the literature as the Stewart platform has been used as the starting point. This platform was originally designed in 1965 for a flight simulator and is commonly used for this purpose even today, due to the large workspace and the 6 degrees of freedom that it offers. The Stewart platform is used in areas such as automotive, aerospace, defense, transportation or manufacturing. The newest application of this platform is found in additive manufacturing where it is the second most used structure for 3D printers [15].

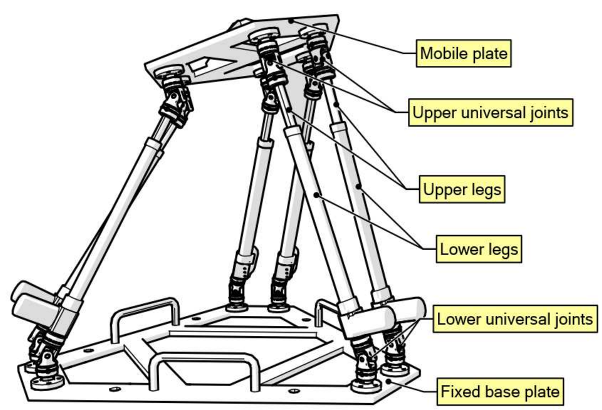

Fig. 7. Stewart platform

The platform has two bases, a fixed one and a movable one (Fig. 7) connected with 6 active legs whose length changes dynamically.
The base is considered as a reference frame work and it has a xyz reference system attached while the mobile platform has the x`y`z reference system attached. In order to define the orientation of the mobile platform towards the base, the Euler angles are used: ψ (rotation

around z axis - yaw), θ (rotation around y axis - pitch) and φ (rotation around x axis - roll).
In these conditions, the coordinates of a point on the mobile platform relative to the fixed base are (see Fig. 8):

$$P = i`x + j`y + k`y = ix + iy + kz \quad [1]$$

Where:

$$x = OA - BC = x`cos\psi - y`sin\psi \quad [2]$$
$$y = AB + PC = x`sin\psi - y`cos\psi \quad [3]$$
$$z = z` \quad [4]$$

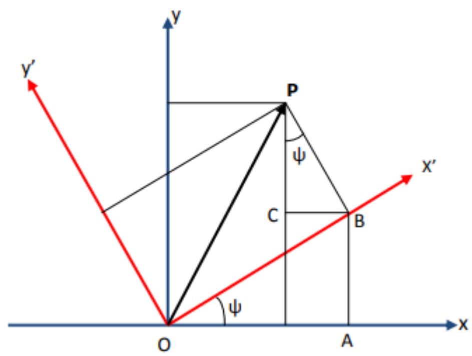

Fig. 8. The geometric relationship between the mobile and the fixed platform of the Stewart platform

The relationship between the two reference systems is given by:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R_z(\psi,\theta,\varphi)\begin{bmatrix} x` \\ y` \\ z` \end{bmatrix} \quad [5]$$

Where:

$$R_z(\psi) = \begin{pmatrix} cos\psi & -sin\psi & 0 \\ sin\psi & cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad [6]$$

$$R_y(\theta) = \begin{pmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{pmatrix} \quad [7]$$

$$R_x(\varphi) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos\varphi & -sin\varphi \\ 0 & sin\varphi & cos\varphi \end{pmatrix} \quad [8]$$

To determine a point the relationship [5] becomes [9]:
Starting from the equation above [9] it is possible to determine the working space of the mobile platform as the geometrical set of points that the platform can reach. Once the workspace has been defined, the platform`s actuation and control system can be started. This is normally done using a fairly complex system of equations which can be automated using snap tools.
The approach proposed in this paper is to model the platform in Matlab, followed by a dynamic simulation in SimMechanics and Delmia V5-6.
Thus after a dimensioning of the platform and a preliminary simulation in SimMechanics the platform is modeled in Delmia V5-6 which is then kinematically simulated to determines the working space required to perform the letters from the TZO technique ("T", "Z", "O" " upside down U ”) used in efficient fire extinguishing.
For the geometrical dimensioning of the platform and the drive system, Matlab and the libraries dedicated to the calculation and simulation of the Steward platform are used (Fig. 9).
Using the KinematicsSolver class functions from the SimScape Multibody, a kinematic analysis is performed to verify that the dimensions of the legs and the ratio between the fixed and the moving base allow reaching points that define the letters used in the TZO technique (Fig. 10). 3D simulation of the Steward platform and the drive system based on linear electric motors is performed in Matlab using SimScape Multibody (Fig. 11).

$$P_{RB} = R_z(\psi)\cdot R_z(\theta)\cdot R_z(\varphi) = \begin{pmatrix} cos\psi & -sin\psi & 0 \\ sin\psi & cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix}\cdot\begin{pmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{pmatrix}\cdot$$
$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & cos\varphi & -sin\varphi \\ 0 & sin\varphi & cos\varphi \end{pmatrix} cos\theta = \begin{pmatrix} cos\psi\, cos\theta & -sin\psi & cos\psi\, sin\theta \\ sin\psi\, cos\theta & cos\psi & sin\psi\, sin\theta \\ -sin\theta & 0 & cos\theta \end{pmatrix}\cdot\begin{pmatrix} 1 & 0 & 0 \\ 0 & cos\varphi & -sin\varphi \\ 0 & sin\varphi & cos\varphi \end{pmatrix} =$$
$$\begin{pmatrix} cos\psi\, cos\theta & -sin\psi\, cos\varphi + cos\psi\, sin\theta\, sin\varphi & sin\psi\, sin\varphi + cos\psi\, sin\theta\, cos\varphi \\ sin\psi\, cos\theta & cos\psi\, cos\varphi + sin\psi\, sin\theta\, sin\varphi & -cos\psi\, sin\varphi + sin\psi\, sin\theta\, cos\varphi \\ -sin\theta & cos\theta\, sin\varphi & cos\theta\, cos\varphi \end{pmatrix} \quad [9]$$

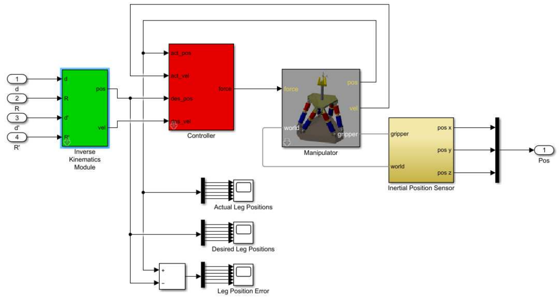

Fig. 9. Sizing and simulation of the Stewart platform in Matlab and SimMechanics

After establishing some minimal geometric dimensions, the next step was the identification and selection of the linear electric motors that will be used in the design of the platform.

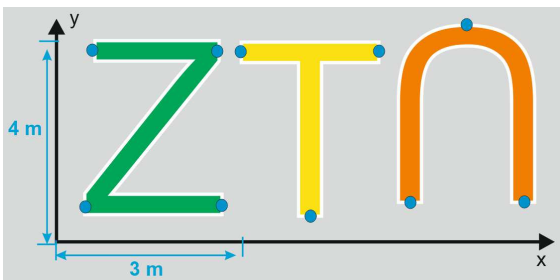

Fig. 10. The characteristic points of the letters

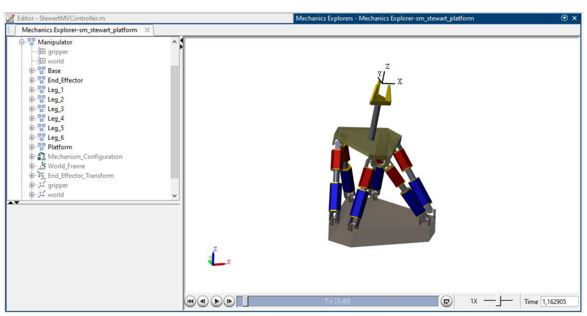

Fig. 11. Simulation of Stewart platform in SimScape Multibody

The preliminary 3D model made in Delmia V5 is shown in Figure 12, it was used in the kinematic simulation used to verify that the system can make all the letters used in the TZO technique.

The kinematic simulation of the platform provides important data such as the position of each kinematic coupling during a cycle in which a letter is performed to analyze the singularities (Fig. 13) or the volume described during a cycle (Fig. 14).

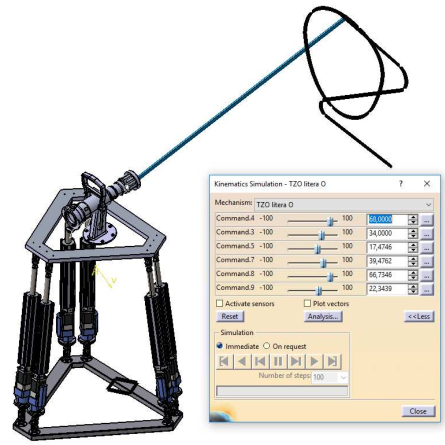

Fig. 12. Preliminary 3D model of the TZO system

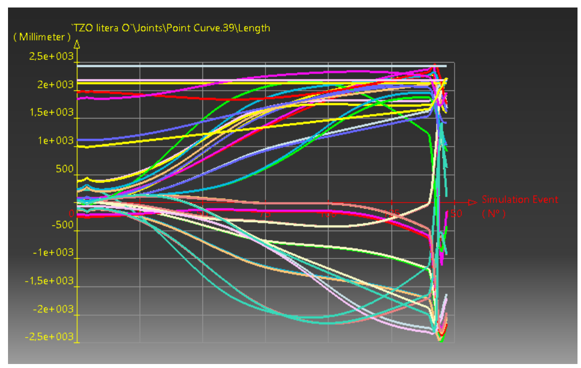

Fig. 13. The activity of the kinematic couples while defining the letter „O“

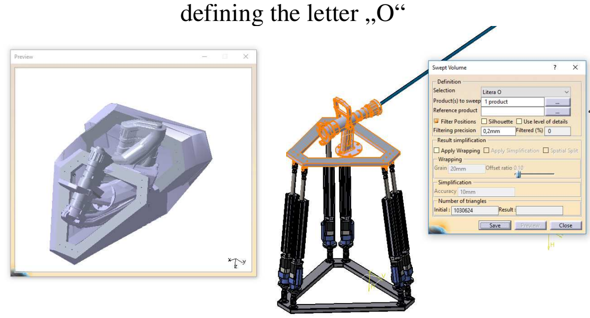

Fig. 13. The volume generated by the mobile platform during the generation of the letter „O“

4. CONCLUSION

The development of an automatic fire-extinguishing system using the technique of the „T”, „Z”, „O” letters is of particular importance, having the role of providing new information needed to understand the phenomena that occur during the fire-extinguishing process.

With this system, a series of tests can be performed, on a full scale, in order to analyze the parameters resulting from the water acting on the fire. Thus, by discharging the water jet in the form of the „T”, „Z” or „O” letters, one can measure the speed of liquidation of the fire, the reduction of the heat flow caused by the fire, the reduction of the temperature of the hot gas layer, the quantity of air displaced by jet flow and the influence of the water jet on the displacement of the smoke.

Analyzing the manner of manifestation of the fire following the use of the automatic extinguishing system for the discharge of water using the technique of the „T”, „Z”, „O” letters has the role of increasing the efficiency of the fire-extinguishing process, this having both benefits on the safety of the intervention crews, to protect people’s lives, as well as on limiting the damage caused by the fire.

The Stewart Platform is a parallel structure that allows the realization of all the letters in the TZO technique and which can be easily adapted and controlled. It can be made from heat resistant materials and powered by dust-resistant and water-resistant motors. The kinematic and dynamic simulations performed in MATLAB and Delmia V5-6 support the viability of the system. In the following steps, the linear actuators must be designed such that they can support and control a discharge system used for fire-extinguishing, an efficient remote-control system and a method of moving the platform independently must be assured for this system.

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ACKNOWLEDGEMENT

The authors would like to thank Prof. Traian Petrișor, Director of the project ExNanoMat (https://exnanomat.utcluj.ro/) for access to the Matlab software.

Sistem automat de stingere a incendiilor folosind tehnica literelor „T”, „Z”, „O” bazat pe o structură paralelă

Lucrarea prezintă un sistem automat bazat pe o structură paralelă care poate fi utilizată la optimizarea stingerii incendiilor utilizând tehnica literelor „T”, „Z”, „O”. Sistemul, aflat in etapa de optimizare CAD, utilizează actuatori liniari acționați electric pentru a dirija jetul de apă, astfel încât consumul de apă să fie redus, pagubele materiale să fie diminuate pe cât posibil fără a influența eficiența operației de stingere.

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