Assessment of the Use of Robotic Equipment for Extinguishing Fires at Oil Refining Enterprises

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Abstract. The analysis of the assessment of the control of robotic equipment as one of the ways to effectively extinguish fires at oil refineries is carried out. A comparative analysis of the advantages of robotic firefighting equipment from combined fire fighting vehicles has been carried out. The calculation of the economic efficiency of using robotic technology is presented. The profitability of using robots in production is determined. The effectiveness of the introduction of LUF-60 instead of combined extinguishing fire trucks at oil refining enterprises has been substantiated.

1. Introduction

In any production activity, fires lead to large losses associated with equipment failure, the unsuitability of premises for the further implementation of the technological process, as well as injury and death of workers. One of the problems associated with fires in the oil industry is the domino effect, as fires can spread to neighboring installations, which can lead to large losses [1]. Ensuring a high level of fire safety is one of the main requirements at oil refineries. This is achieved by a set of measures, including the introduction of new fire extinguishing methods. A large number of studies have been carried out on this topic in various industries [2–6]. In connection with violations of fire safety rules, accidents at installations, malfunctions of electrical equipment at the facilities of the oil industry, fires occur annually, resulting in the loss of human lives and large material damage. Zhou J et al. argue [7] that large industrial fires contribute to high casualties, material loss, environmental pollution, and significant social impact. Peter Okoh and Stein Haugen In the study of major accidents in the 21st century, it is noted [8] that most cases associated with major damage to structures occurred as a result of fire and explosion.

Today, the most promising way to extinguish technological equipment using robotic technology can be identified. Fires occurring at oil refineries pose a significant threat to the life of both the employees of the enterprise and the firefighters. Whereas robotic equipment for extinguishing a fire can be used in conditions of increased temperature, reduced visibility, high concentration of toxic combustion products, and low oxygen concentration. According to Chee Fai Tan et al. the use of fire extinguishing with the help of mobile robots can reduce the direct contact of the firefighter with hazardous factors of the fire [9]. At the same time, Alhaza T. confirm the effectiveness of using robotics in extinguishing fires [10]. Along with this [11–15], they also note that the use of robots to extinguish fires is a new and effective solution. Consequently, increasing the level of fire safety of oil
refining facilities is an important part of ensuring the protection of the population from man-made threats, and the use of robotics is one of the effective solutions to achieve the result.

2. Materials and methods
One of the most promising methods of extinguishing fires at technological installations and reservoirs of oil refining complexes is the use of specialized robotic equipment LUF-60, which can operate in close proximity to the fire site [16]. Fire robots are capable of making it easier for a robot to extinguish fires or completely replace a person.

Robots are used in the oil industry to extinguish the following objects [17]:
- apparatuses for oil refining, tanks, tanks and pipelines with flammable substances that pose a threat of explosion or spill of flammable and flammable liquids;
- technological installations, emergency shutdown of which is impossible for technical reasons;
- flare combustion of gases or liquids that flow out of installations and pipelines under pressure;
- apparatuses, equipment, installations and pipelines that are heated to high temperatures according to the conditions of the technological process;
- tanks with petroleum products (surface extinguishing).

The LUF-60 robot is equipped with a fire monitor and is capable of delivering water or foam to a distance of 60 meters at a speed of 2400 l/s [18]. The robot is distinguished by its maneuverability and the ability to quickly respond to changes in the situation in the event of a fire or an emergency due to the tracked platform. The fan of the LUF-60 robot can work both for pressurization and for air suction in order to clean ventilation systems.

For rescue operations, the LUF-60 robot is equipped with special hydraulic equipment, namely a winch. The pulling force of the winch is 40 kN, the rotation speed is 10 m/min, the cable length is 30 m, and the rope diameter is 8 mm. Control is performed manually remotely [19].

There is a multifunctional system for attaching various devices [20, 21]:
1. Mini crane for lifting loads up to 600 kg., Which is controlled locally or remotely;
2. Ventilation or smoke exhaust system. Fan power provides productivity 6 m$^3$/s. It is also possible to put on the LUF-60 one more additional fan with a capacity of 16,66 m$^3$/s.
3. Special railway platform for moving along the tracks, as this fire robot is used to fight fires in tunnels on the railways.

Advantages of the LUF-60 robot:
- small dimensions and the presence of metal caterpillar tracks for movement, which allow the robot to drive close to the fire;
- large radius of fire extinguishing agent supply;
- movement and control of the robot using the remote control at a distance of up to 300 m;
- movement with the help of an electric motor, while there are no costs for fuel and lubricants, which, in the event of damage to the mechanism, would contribute to the rapid spread of fire;
- movement with the help of an electric motor, while there are no costs for fuel and lubricants, which, in the event of damage to the mechanism, would contribute to the rapid spread of fire;
- there are cameras and optical devices designed to track the progress of the fire;
- high mobility and weight allow you to successfully climb and descend stairs with an incline of up to 30°;
- a compact or atomized jet of water can be supplied, in which a "curtain of water mist" is created, consisting of the smallest water droplets;
- the diameter of the monitor's barrel of the robot is several times larger than the diameter of the monitor's barrel of a fire truck, therefore, the robot localizes the fire in a shorter time;
- increased accuracy of supply of fire extinguishing agents to the fire site, which allows to reduce unnecessary spills and reduce material damage from fire;
- ventilation of premises and deposition of smoke by sprayed water.
3. Results and discussion

In order to clearly demonstrate the economic efficiency of the implementation of the LUF-60 fire robot at oil refineries. We will also calculate the payback period of the robot, in which we compare the costs of a combined fire fighting vehicle and a LUF-60 robot per year.

Calculation of the consumption of fuels and lubricants for a fire engine of combined extinguishing per year (Q_{ed}, l.):

\[ Q_{ed} = Q_{rse} + Q_{po} + Q_{cno} \]

where \( Q_{rse} \) – the mileage expense for one exit:

\[ Q_{rse} = \frac{L \cdot S}{100} = \frac{49 \cdot 2}{100} = 0,98 \]

where \( L \) – fuel consumption per 100 km;
\( S \) – mileage of a fire engine to the place of fire, km.

Fuel consumption for pump operation (Q_{po}, l.):

\[ Q_{po} = R \cdot k \cdot W = 0,330 \cdot 1,1 \cdot 80 = 29,04 \]

where \( R \) – diesel fuel consumption rate for a pump drive for a fire truck, which is 0.330 l / min;
\( k \) – coefficient of winter allowance;
\( W \) – pump operation time, min.

Fuel consumption for operation without load (Q_{cno}, l.):

\[ Q_{cno} = U \cdot Q = 0,150 \cdot 30 = 4,5 \]

where \( U \) – the fuel consumption for stationary operation without load, which is 0.150 l / min;
\( Q \) – engine running time without load.

The total cost for the exit is (Q_{ed}, l.):

\[ Q_{ed} = 0,98 + 29,04 + 4,5 = 32,95 \]

Consumption of fuels and lubricants with an average number of fires per year (Q_{y}, l.):

\[ Q_{y} = Q_{ed} \cdot P = 32,95 \cdot 8 = 263,67 \]

where \( P \) – the average number of fires per year.

Costs for fuels and lubricants per year (G, rub.):

\[ G = Q_{y} \cdot Z = 263,67 \cdot 47,65 = 12563 \]

where \( Z \) – the cost of 1 liter of diesel fuel, rub.

Calculation of wages of firefighters per year (N_{1}, rub.):

\[ N_{1} = H_{1} \cdot T_{1} \cdot K_{1} = 15 \cdot 21000 \cdot 12 = 3780000 \]

where \( H_{1} \) – the number of firefighters (3 shifts of 5 people each);
\( T_{1} \) – the average monthly salary of one firefighter, rub.;
\( K_{1} \) – the number of months.
Calculation of funds for the maintenance of a fire truck:
The operating costs of maintaining a fire truck per year include the following types of costs ($C_{mc}$, rub.):

\[
C_{mc} = C_d + C_o + C_{crm} + C_{fea} + C_{ee} + C_b
\]

where $C_d$ - depreciation deductions per year, rub.;
$C_o$ - overhaul, rub.;
$C_{crm}$ - current repairs and maintenance, rub.;
$C_{fea}$ - fire extinguishing agents, rub.;
$C_{ee}$ - electric energy, rub.;
$C_b$ - tires, rub.

\[
C_{mc} = 5500 + 46000 + 42000 + 185000 + 21000 + 32000 = 331500
\]

The cost of a fire truck per year is ($R_1$, rub.):

\[
R = G + N + C_{mc} = 12563 + 3780000 + 331500 = 4124063
\]

Calculation of the salary of the service personnel LUF-60 ($N_2$, rub.):

\[
N_1 = H_2 \cdot T_2 \cdot K_2 = 6 \cdot 21000 \cdot 12 = 1512000
\]

where $H_2$ – the number of firefighters (3 shifts of 2 people each);
$T_2$ – the average monthly salary of one firefighter, rub.;
$K_2$ – the number of months.

Calculation of consumption for the maintenance of the robot LUF-60:
Operating costs for maintaining the LUF-60 robot per year include the following types of costs ($C_{cr}$, rub.):

\[
C_{cr} = C_d + C_o + C_{crm} + C_{fea} + C_{ee} + C_b
\]

\[
C_{cr} = 15500 + 42000 + 32000 + 175000 + 65000 + 43000 = 372500
\]

The costs for the LUF-60 robot per year are ($R_2$, rub.):

\[
R_2 = N_2 + C_{cr} = 1512000 + 372500 = 1884500
\]

The difference between the costs of fire trucks and LUF-60 for 5 years of use ($V$, million rub.):

\[
V = (S_1 \cdot 5R_1) - (S_2 \cdot 5R_2) = (15 \cdot 5 \cdot 4,12) - (31,2 \cdot 5 \cdot 1,88) = 15,72
\]

where $S_1$ – cost of a fire truck, million rub.;
$S_2$ – the cost of the LUF-60 robot, million rub.;
$R_1$ – expenses for PA per year, million rub.;
$R_2$ – the cost of the LUF-60 robot per year, million rub.

Thus, the introduction of the LUF-60 robot at oil refineries will reduce economic costs and increase the safety level of both workers and firefighters.
4. Conclusions
The study has shown that fires are one of the dangerous factors that contribute to a large number of losses, accidents, injuries and deaths of workers. The analysis of the effectiveness of the use of specialized robotic equipment for fire extinguishing is carried out. The results of the study made it possible to determine the importance of introducing robotic technology at fire and explosion hazardous enterprises. Based on the analysis, within the framework of this work, the introduction of the LUF-60 robot is proposed. When performing the work by calculation, it was proved that the introduction of the LUF-60 robot at oil refineries will reduce costs and increase the level of fire safety. In order to be competitive in global markets and increase their profits, refineries are striving to reduce costs and improve production efficiency. With the help of robotic technology, it is possible to achieve not only production optimization, but also an increase in the level of fire safety.

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