Development of automated monitoring safety system of the forklift DP 3510

S N Kostarev$^{1,2,3,4}$, K A Sidorova$^5$, N A Tatarnikova$^2$ and O V Kochetova$^3$

$^1$Perm Military Institute of National Guard Troops of the Russian Federation, 1 Gremjachij log St., Perm, Russia, 614030
$^2$Perm State Agrarian-Technological University named after academician D N Prianishnikov, 23, Petropavlovskaja St., Perm, Russia, 614990
$^3$Perm Institute of the FPS of Russia, 125, Karpinskogo St., Perm, Russia, 614012
$^4$Perm National Research Polytechnic University, 29, Komsomolski Avenue, Perm, Russia, 614990
$^5$Northern Trans-Ural SAU, 7, Republic St., Tyumen, Russia, 625003

E-mail: iums@dom.raid.ru, sidorova.clavdija@yandex.ru, atarnikova.n.a@yandex.ru

Abstract. In this article, the problem of ensuring the safe operation of the forklift truck is analyzed, as well as the development of an automated monitoring system for preventing the occurrence of accidents in the territory of warehouses, enterprises and organizations using special transportation equipment. A model of the DLE system has been developed: Truck loader driver (D), Auto-loader (L), Environment (E). Hazard sources during loading operations are identified. Based on the analysis of the necessary and sufficient conditions for the transition of system states, an instrumental security assessment model has been developed that is used in the synthesis of a finite state machine. A ladder circuit and a forklift driver's console have been developed, implemented on the Omron software and hardware system. The developed on-board computer for the forklift truck takes into account the load of the mechanisms when lifting the load and, if it is necessary, generates an alarm or blocking mechanisms in a dangerous situation.

1. Introduction
Accidents during the operation of forklifts often occur due to insufficient operator training. The nature of forklift accidents is different. The most common incidents are turning the forklift over (42%), squeezing between the forklift and another surface (25%) and hitting between two machines (11%). Occasionally a forklift can hit a person (10%) or a person may be injured because of being hit by a load falling from a fork. More than 55% of all accidents occur at manufacturing plants and at construction sites. Implementation of the on-board computer on loaders DP 3510 will help make work safer [1,2].
2. Equipment and devices used in studies
In the research, the authors used controller OMRON. The operator’s panel is connected to controller OMRON. The simulation of the developed project was performed using the CX-Programmer and CX-Designer software.

3. The results of the study and their discussion

3.1. Identification of the safe state of the system
A comprehensive automated control system to ensure the safety of the forklift truck is defined as a complex system designed to protect the process of the forklift truck from external and internal sources of security threats, as well as to prevent the causes and conditions for the occurrence of damage [3].

Automated monitoring of the technical condition of the forklift truck operation allows us to assess the safety of the system’s performance quickly, and in the presence of faults, issue a “danger” signal or block a further increase in load. Automated monitoring of the state of the safe operation of the forklift truck consists of measuring the actual values of parameters characterizing the state of the system at the time of observation and comparing the indicated values with the passport data of the forklift truck. The control system provides for checking the safety of the forklift, and in the event of danger - warning the operator about the occurrence of adverse situations of damage [4].

The choice of the minimum required number of monitored parameters that carry sufficient information about the safe state of the system at any time is determined by the following factors:

- Firstly, the technical documentation contains a list of monitored parameters that must be checked in order to ensure safe operation of the forklift when used as intended;
- Secondly, when monitoring (measuring) electrical and other parameters not provided for by technical documentation, parameters are selected within the framework of the operator’s use of a methodology that takes into account the specifics of the tasks and properties of the control object [5].

When choosing monitored parameters, the following practical considerations are also taken into account:

- Parameters that have a mutual functional or correlation relationship should be excluded from consideration;
- Operating parameters for which tolerances are set, beyond which is a manifestation of obvious hazardous states of the system.

To assess the safety, consider the following system: Truck loader driver (D), Auto-loader (L), environment (E) (DLE) (figure 1).

![Figure 1. The relationship between the sets of elements of the system DLE: R – relations reflecting the connections of the system sets; U – control; Z – disturbances.](image)

2
The relationships between the elements of the system will be defined by the binary relations $R$ (1), which can be understood as functional relations, preferences, followings and others, reflecting the essence of the relationship [6]:

$$
\begin{align*}
DR_{DL}, & \quad ER_{ED}, \quad LR_{LD}, \\
DR_{DE}, & \quad ER_{EL}, \quad LR_{LE}.
\end{align*}
$$

(1)

The safety of a DLE system as a whole depends on its properties, which change during loading and unloading operations:

$$
C_L = F_L[C_L^D, C_L^E], \quad C_E = F_E[C_E^D, C_E^E], \quad C_D = F_D[C_D^D, C_D^E].
$$

(2)

The nature of changes in these properties during the operation of the DLE system deteriorates, as a rule. Therefore, to build dependencies of real state changes in the DLE system, it is necessary to know some functional $3$, which would determine the safe state of the DLE system and its properties:

$$
C_{DLE} = 3 [C_L, C_D, C_E].
$$

(3)

3.2. Sources of danger during loading operations

We will classify hazards into several groups:

- Factors possessing physical energy are associated with the work of moving machines and mechanisms, causing noise and vibration;
- Factors with chemical energy are associated with the operation of the engine-diesel and lead to increased gas pollution and dustiness of the air.

As the main monitoring parameters, we take the values of four factors that significantly affect the safety of the process of the forklift. This is the oil pressure in the hydraulic system, the weight of the lifted load, the height of the load lifting and the displacement of the load from the forklift truck.

For the first three parameters, the maximum values are defined in the “DP 3510 Operation Manual”: oil pressure – 18 MPa, load weight – 3500 kg, lifting height – 3300 mm.

3.3. Necessary and sufficient conditions for changing the state of system security

The manifestation of the dangerous properties of the elements of the DLE system is due to the presence of sources of danger. Sources of danger are described by two parameters:

- The power of the hazard source ($c$) is the amount of energy that the hazard source can emit;
- Time of hazardous exposure ($\tau$) – duration of excess power.

A necessary condition for the transition from one state to another of the DLE system is the power of the source of danger, and a sufficient exposure time (table 1). To assess the safety and the study of the additive effect of various sources of danger, we will transform the parameters characterizing the deviation of the parameters of permissible values of ($d$) from the real ones:

$$
\begin{align*}
\left| \frac{c_i - c}{c_i^d} \right| & \quad \left| \frac{\tau_i - \tau}{\tau_i^d} \right|
\end{align*}
$$

(4)

Table 1. Necessary and sufficient conditions for the transition of states of the system DLE.

| Safe condition | Dangerous condition | Condition accidents |
|----------------|---------------------|---------------------|
| $C^S = \begin{cases} 
  c < c^d \\
  \tau < \tau^d
\end{cases}$ | $C^O = \begin{cases} 
  c \geq c^d \\
  \tau < \tau^d
\end{cases}$ | $C^P = \begin{cases} 
  c > c^d \\
  \tau > \tau^d
\end{cases}$ |

3
The formalization of the space of the parameters of the hazard source $i$ allowed us to estimate the degree of security of the system DLE (5):

$$\theta_i = \begin{cases} 
\frac{1}{2} \left( c_i^d - c_i^e + \tau_i^d - \tau_i^e \right), & \text{at } \left( c_i < c_i^d \right) \wedge \left( \tau_i < \tau_i^e \right); \\
0, & \text{at } \left( c_i \geq c_i^d \right) \vee \left( \tau_i > \tau_i^e \right).
\end{cases} \quad (5)$$

3.4. Construction of a ladder circuit for monitoring the status of a forklift
As hardware-software maintenance controller Omron [7] has been chosen. The programming language of the OMRON CP1L controller was relay-contact logic (IEC61131-3). Necessary logic elements are entered for the description of the column of work of the loader based on controller Omron (table 2).

| In-X | Bit Address in controller RAM | Notation | Data Memory DM | Explanation |
|------|-------------------------------|----------|----------------|-------------|
| X0   | C10 2.01                      | P        | 200            | 210 Oil pressure |
| X1   | C10 3.01                      | W        | 201            | 211 Cargo weight |
| X2   | C10 4.01                      | S        | 202            | 212 Load shift |
| X3   | C10 5.01                      | H        | 203            | 213 Lift height |
| X4   | C10 0.11                      |          |                | Run         |
| X5   | C10 0.13                      |          |                | Stop        |

| Out-Y | Bit Address in controller RAM | Notation | Data Memory DM | Explanation |
|-------|-------------------------------|----------|----------------|-------------|
| Y0    | C10 0.11                      | A        |                | Turn on the system |
| Y1    | C10 0.12                      | B        |                | Outrigger job |

Fragments of the ladder monitoring and control of the forklift truck are shown in figures 2–4.

**Figure 2.** Conditional operators.  
**Figure 3.** Setting maximum parameters.  
**Figure 4.** Emergency signal.
The console for the automated monitoring system of the lift truck operator was designed using CX-Designer [8]. The console interface should display the state of the system's security parameters. In case of exceeding the parameters, a red light on the dangerous state of the lift truck operation will be displayed on the console (figure 5).

Figure 5. Onboard computer.

The description of work of the circuit of management is resulted by the loader in table 3.

**Table 3. Description of operation of the loader control circuit.**

| Description of work               | LD | Operator panel |
|-----------------------------------|----|----------------|
| Press the power button            |    |                |
| Exceeding the permissible load weight |    |                |
Conclusions

In the work of forklift trucks, human factors are the most common cause of accidents. Lack of knowledge or poor concentration of the operator’s attention results in overturning or serious damage to forklift trucks, equipment, cargo, or large-scale disruption of logistic flows. The proposed automated control system for the safe condition of the forklift truck is designed to prevent such incidents. The system will help the operator to prevent dangerous situations, minimize the risk of accidents and comply with safety at work.

References

[1] Zhang Z, Li P, Huang J and Li T 2012 Design of a new fault detection system for auto-loader Advanced Materials Research 503-504 1322-5
[2] Wang G H and Jiao Q L 2013 Research on fault injection technique for auto-loader based on PLC Advanced Materials Research 706-708 1163-6
[3] Yang F, Li G, Li H and Zhao D 2006 Journal of Huazhong University of Science and Technology (Natural Science Edition) 34 29–31
[4] Cheng H H and Penkar R 1994 Stacking irregular-sized packages by a robot manipulator IEEE International Conference on Robotics and Automation 2 959-66
[5] Grogg D 1989 Chilton's instruments & control systems 62 (6) 89–90
[6] Kostarev S N and Sereda T G 2017 Development of software and hardware models of monitoring, control, and data transfer to improve safety of downhole motor during drilling IOP Conference Series: Earth and Environmental Science 87(3) 032016
[7] Watanabe K and Arao Y 1995 Omron’s creative information system Long Range Planning 28 (2) 39–48
[8] Kostarev S N, Sereda T G 2018 Microclimate Control System Development IOP Conference Series: Materials Science and Engineering 450 (6) 0620139