Automation of inspection of rolling stock at a maintenance point using a robotic complex

Gennady G. Kiselev[1], *Alexander* L. Zolkin[2*], *Alexey* S. Bityutskiy[3], and *Mikhail* R. Bogdanov[4]

[1]Samara State Transport University (SSTU), Samara, 443066, Russia
[2]Computer and Information Sciences Department, Povolzhskiy State University of Telecommunications and Informatics, Samara, 443010, Russia
[3]"Invent Technology" LLP, Almaty A10E5P4, Kazakhstan
[4]Departament of Mathematics, Moscow Polytechnic University, 38 Bolshaya Semenovskaya Street, Moscow, 107023, Russia

Abstract. The article discusses the need to improve the efficiency of freight cars operation by introducing modern technologies in the maintenance process. To improve the quality of technical inspection of rolling stock at the maintenance point, it is offered to introduce a robotic complex capable of autonomously conducting technical inspection and diagnostics of rolling stock. Structurally, the robotic complex includes: chassis; manipulator; automation, control and data transmission system; diagnostic equipment; power unit. The possibility of using various diagnostic tools, vision systems, non-contact scanning sensors is considered. The functions of the complex are to pass through the inspection positions, identify malfunctions, accumulate information about the technical condition of the car with the transfer of information to the fleet operator or maintenance point.

1 Introduction

Maintenance of the rolling stock is considered to be the primary task facing the car economy. The integrity of the cars and their trouble-free use in operation is formed at the proper level by technical maintenance. However, apart from the early detection of damage, in today's competitive economy, it is essential to ensure that the downtime duration is kept to a minimum. In this regard, it is obvious that the critical technical condition of parts and elements of cars is established to ensure early troubleshooting and minimize financial costs.

Undoubtedly, to some extent, in order to focus attention on resolving issues in the field of coordinating the trouble-free running of trains and reducing the adverse impact of the "human factor" on the established process, a subsequent modernization of the mechanism for the maintenance and repair of cars is required, focused on improving the quality of maintenance service. For this reason, the importance of using diagnostic equipment and non-destructive testing methods in the maintenance of rolling stock is progressing [1].

An exceptionally paramount circumstance, which largely determines the quality of the inspection, determines the level of personnel qualification. Use of modern machinery and

* Corresponding author: alzolkin@list.ru

equipment, implementation of advanced technologies and creation of innovative products on their basis must be supported by the high qualifications and professionalism of railway workers [2].

2 Problem statement

In order to be aware of the technical condition of the rolling stock, the inspectors perform an organoleptic inspection of the running gear, including measuring the dominant parameters of the examined components of the car using a measuring tool and templates, at the same time, tapping the cast elements and running gear of the car [3].

When examining the rolling stock, it is necessary to control in detail the supporting elements of the car bogies, since the violation of their integrity along the route in all cases leads to tragic events. The root cause of the violation of the integrity of the casting is the promotion of existing cracks, presence of casting shells that were not detected during the production and maintenance of the cars. The current technology of visual inspection of the rolling stock and their running parts leads to time costs, the amount of which is largely due to the preparedness, professionalism and responsibility of the car inspector-repairer [4].

3 Research questions

In most cases, cracks form in the area that is inaccessible to the view of cars (bearing surfaces of the thrust bearing, inclined bearing surfaces of the bolster, bearing surfaces of the side frames). Responsibility for undetected defects in such sections lies with the car inspectors-repairers.

Therefore, the issue of improving the quality of maintenance of rolling stock at PTO, reducing or eliminating the human factor when inspecting units and elements of cars remains relevant. Many researchers in Russia and abroad are developing to introduce information technologies into the process of monitoring the state of infrastructure, the operation of railway enterprises, including stations, the purpose of which is to increase the overall efficiency of railway transport [5].

4 Materials and methods

The robotic complex is an automatic device, in order to perform a variety of mechanized actions, which functions according to a given algorithm, performing the functions of personnel in the course of work, characterized by the cardinal technical capabilities of the employee, and the implementation of such capabilities is carried out using all kinds of equipment [6].

A robotic arm is a mechanism that replaces the activity of an employee, including a means of influencing environmental conditions, i.e. a mechanical arm. A mechanical arm (manipulator) is an executing mechanism that simulates the functioning of a human arm in the required large range of volumes of progression or reduction of its dimensions and performance.

The robotic arm is capable of containing from one to a plurality of manipulation modules. In the joints, the components of the manipulator have the ability to turn and make translational movements. The size of certain components is able to transform through sliding mechanisms. The worker's hand is modeled in a grip format that can be two-fingered or multi-fingered. The grip is specialized in order to implement various kinds of manipulations: gripping and transferring meters of special equipment for control, components, fixtures and other items.

The relocation mechanism allows the robotic arm to move and is implemented on tracks or wheels.

The manipulators located on the chassis are in contact with the surrounding reality and objects that are manipulated or that the robot-manipulator needs to go around as an obstacle in the implementation of the task.

The information converters placed on the manipulators and vehicles of the robot provide the possibility of a reference point in space when performing the functions of inspecting the rolling stock. The converted signals from the sensors are fed to the control unit (mechanism) of the robotic complex.

Sensors for various purposes and the physical principle of operation, installed on the manipulators and the chassis of the robot, record and transmit information about the position of the device, surrounding objects, the relative position of the object of action of the robot, and etc. Thermal sensors can be used (to determine the temperature of objects and ambient air), location, allowing to determine the speed of movement and the relative position of objects, optical (artificial vision), sensors that signal interaction (contact), dynamic sensors for measuring power characteristics (forces and moments) during technological operations, and etc.

5 Results

Since the sensors (corresponding signal converters and sensors) provide the sensitivity of the manipulation robot, it is possible for the complex to operate taking into account the changing environment. Wherein, logical devices process information and form control signals transmitted to the manipulators and the chassis of the robotic complex. That is, due to the possibility of adapting to the external environment, which is partially changing, the objects of the robot's action can be located and oriented in space arbitrarily.

At the maintenance point (PTO), it is offered to use a robotic self-propelled complex designed to carry out inspection operations and detect malfunctions of freight cars, which is shown in Figure 1.

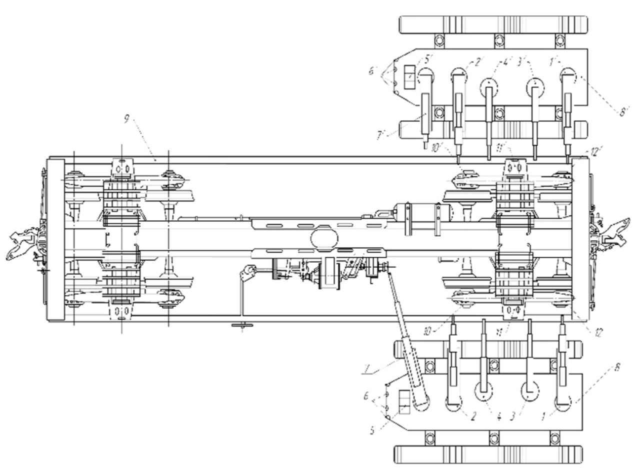

Fig. 1. Robotic complex for maintenance of freight cars: 1 and 1', 2 and 2' – a mobile device for a car inspector; 3 and 3', 4 and 4' – eddy current flaw detector; 5 and 5' - recording equipment (video camera); 6 and 6' – ultrasound sensors; 7 and 7' – manipulator providing brake release; 8 – robotic tool; 9 – the object of inspection – a freight car; 10 and 10', 11 and 11', 12 and 12' – freight car inspection positions according to the regulatory and technical documentation.

Robotic complex, includes: video camera; ultrasonic sensors; brake release manipulator; mobile device for a car inspector; eddy current flaw detector and hardware and software device of the robotic complex.

Functionally, the complex is designed to inspect the rolling stock by positions, detect faults. In addition, information about the technical condition of the car is stored and transmitted to the workstation of the fleet operator or maintenance point [7].

After placing the train on the appropriate path of the park for inspection and its fencing, the robotic complex installed on a caterpillar base or wheels, automatically, at the command of the operator, starts moving along the train in accordance with the inspection positions. In order for the complex to stop at the right place, ultrasonic sensors are installed on the complex. Being in front of the inspection position, the device, using a video camera, reads the visible information on the car: number, date of manufacture, the last repair carried out on the car, and etc [8].

Using the installed video camera, the valve in the air distributor structure is recognized, a signal is sent to the control unit, after processing the information, the brake release manipulator is activated.

The eddy current flaw detector included in the complex provides an increase in the detection of defects in the cast parts of the bogie. Information about the absence or presence of cracks in the diagnosed parts is transmitted to the PTO.

The mobile small-sized device of the inspector-repairer of cars, shown in Figure 2, provides checking the parameters of wheel sets using sensors. Non-contact scanning with sensors allows you to identify and control the state of the wheel rolling surface, rim thickness, position of the friction wedge, position of the brake pads on the wheels, etc. The function of quickly determining the position of the device in space and relative to the nodes of the cars continuously corrects the measurement results of the tested characteristics and parameters [9].

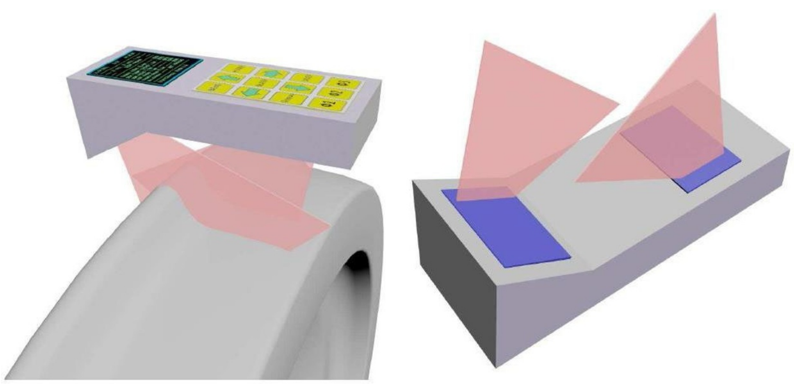

Fig. 2. Mobile small-sized device for the inspector-repairer of cars.

The hardware complex and software of the robotic device (Figure 3) perform the functions of receiving, accumulating, processing and transmitting information about the technical condition of units and elements of freight cars. In the future, the information obtained can be used in the formation of the electronic passport of the car. The information received by means of the mobile device of the inspector-repairman and flaw detectors is transmitted to the operator's workstation. In addition, the hardware-software complex is designed to locate the robotic complex at a certain control (inspection) position provided for by the regulatory and technical documentation for the operation and maintenance of freight cars.

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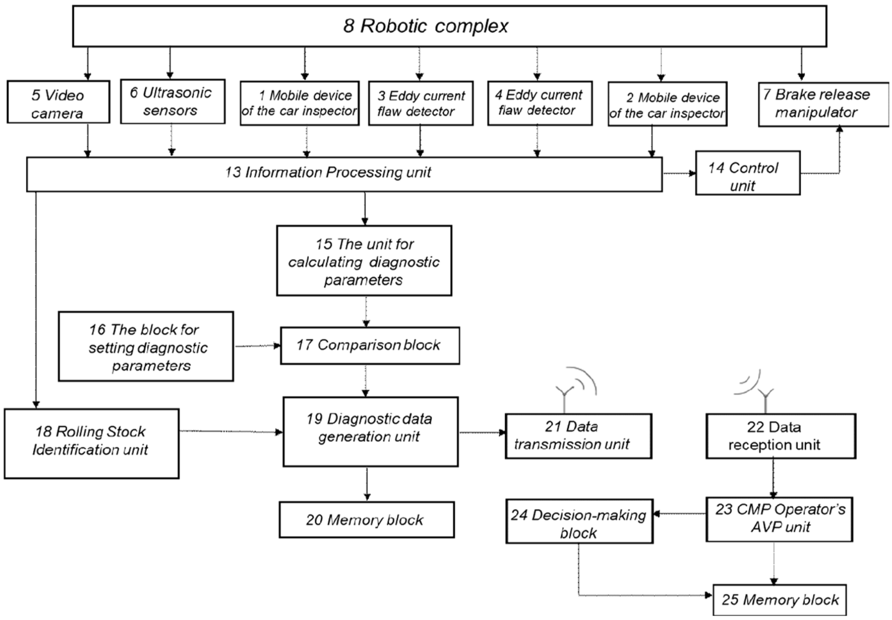

Fig. 3. Block diagram of the hardware-software device of the robotic complex.

In order to reduce the time for monitoring and diagnosing the technical condition of units and elements of a freight car, the robotic complex is equipped with several diagnostic complexes such as "a mobile inspection device and an eddy current flaw detector, which are based on retractable rods, making it possible to examine at a distance of up to three meters with a viewing angle of 360°. For this development, a utility model patent No. 195844 dated February 6, 2020 was obtained.

The ability to perform movements of the manipulation device is largely determined by: the number of degrees of freedom of the manipulator, kinematic connections, their placement and type; maneuverability and dynamic properties of the manipulator; the main parameters and characteristics of the drives, which consist of special technical means (realizing the movement of the manipulator elements). That is, the mechanical part of the robot and its control system are determined by the composition, design and parameters (characteristics) of the drive.

Features of the technological process of the manipulator determine the following basic production and technological requirements for the quality of the drive: providing with the required accuracy of the execution of signals from the control system. To perform a separate technological operation, the coordinated movement of all drives that set the manipulator links in motion is usually required. That is, when controlling the manipulator, group operation of the drives takes place. It also requires the ability to control the speed over a wide range, the accuracy of the trajectory and the location of the robot in position. There are high demands on the adjustment of the drive for the operation of the manipulator of several links, high performance and speed.

In addition, acceleration and deceleration, high reliability under the action of loads, minimization of the mass and dimensions of the drive device must be ensured. The operational requirements include low maintenance costs and unification of units [10].

The electric variable speed drive meets the specified requirements, is characterized by small dimensions of the motors, low noise level, is fast-acting and is characterized by high accuracy and significant torque at maximum allowable speed. It also has a fairly high performance reliability. An electric drive uses the available electricity, which is converted into the required form using special converters. With an increase in carrying capacity, the mass and inertia of the electric drive increase significantly. The transformation of rotational motion into translational occurs by means of mechanical transmissions, the type of which is determined by the structural diagram of the manipulator.

Optimum characteristics have drives placed on the base. They have the smallest weight and dimensions, less energy-intensive.

To move robots and manipulators, vehicles are used, the most common and simple of which are wheeled and caterpillar mechanisms. The caterpillar movement device is used mainly with a significant mass of the robot, providing more room for maneuver.

The problem of operating moving robots and manipulators in the cold season is snow and ice, which can lead to a complete loss of device mobility. The problem can be solved by using a caterpillar mover with rubber-metal tape tracks or a wheel drive with low-pressure wide-profile tires.

6 Findings

When robotizing a technological process, the problem of determining the type and type of industrial robot that the robot must satisfy is solved. The requirements for the robotic complex are given above.

Next, a force calculation is carried out, which includes the calculation of the acting forces and moments of forces. For the nominal mode of operation, the forces due to the inertia of the object that is supposed to be manipulated, as well as the inertia of the structural elements of the manipulator, are determined. Velocities, accelerations and masses of structural units are pre-set.

The parameters characterizing the kinematics of the manipulator are set based on the requirements of the manipulator response time, type and type of drive together with the control system. Such a parameter is, among other things, the total (full) response time of the degrees of freedom T, and the speed and acceleration of the response of the degrees of freedom are determined by the type of drive and the control system of the manipulator. The dependence of speed on time can be approximated by a trapezoidal function that describes the relationship between the time of individual sections (acceleration t_a, movement at a constant speed t_y and braking t_b) with a total response time. For different types of drive and control systems, this ratio is different [11].

By solving the differential equation for the speed under the specified initial conditions (selected ratios $k_a = t_a/T$ and $k_t = t_t/T$, characteristic for this type of drive), the maximum possible speed v and acceleration ω of actuation of the degree of freedom are estimated. The solution to the equation will be expression (1), which establishes a mathematical relationship between the speed v and the course of the degree of mobility S:

$$S=0.5\cdot v\cdot t_a + v\cdot t_y + 0.5\cdot v\cdot t_b \tag{1}$$

Given the ratios:

$t_a= k_a\cdot T$; $t_b = k_b\cdot T$; $t_y= T- t_a - t_b$

the expression for the maximum actuation speed of the drive is (formula 2):

$$v=\frac{S}{T}\cdot\frac{1}{1-0{,}5(k_p+k_b)} \quad v=\frac{S}{T}\cdot\frac{1}{1-0{,}5(k_p+k_t)} \tag{2}$$

The maximum deceleration (acceleration during deceleration) can be estimated, respectively, by formula (3):

$$\omega=\frac{v}{t_T}=\frac{S}{T^2}\frac{1}{k_b[1-0{,}5(k_a+k_b)]} \quad \omega=\frac{v}{t_T}=\frac{S}{T^2}\frac{1}{k_t[1-0{,}5(k_a+k_t)]} \tag{3}$$

The most difficult mode of operation of the robot is the simultaneous operation of all possible degrees of mobility. It is according to this mode that the parameters of the robotic device are selected. The specificity of the robotic technological process determines the speed of the robot and its working body. This sets the data for the force calculation.

7 Discussion

Figure 4 shows a kinematic diagram with a cylindrical coordinate system for the power calculation of the manipulator: the lifting unit of the manipulator arm when using a pneumatic drive and the cyclic control system of the manipulator. The ratios of the acceleration and deceleration times with the total response time for such robots are taken within the following limits: $k_a = t_a/T = 0.2 \div 0.6$; $k_b = t_b/T = 0.03 \div 0.1$. The most difficult combination for the drive operation is a long acceleration time and a minimum deceleration time, it is from these requirements that one should proceed when developing the drive of a robotic tool, and the above ratios k_a and k_b during operation of the drive are regulated within a fairly wide range by changing the supply pressure and setting throttles. As the initial data for calculating the speed and acceleration, the ranges of movements of the degrees of freedom S_f and φ (p $_f$) required by the technological process of the robot (manipulator) and the total response time T_f.

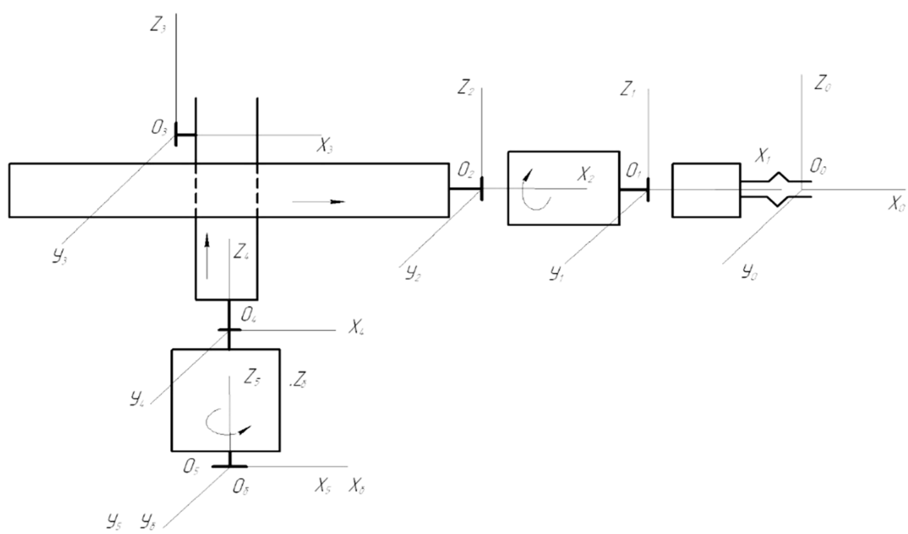

Fig. 4. Kinematic scheme for power calculation of manipulator arm lifting.

We accept for the gripper rotation module φ1 = π; T1 = 2 s; extension module S2 = 0.8 m; T2 = 0.8 s; lift module S3 = 0.8 m; T3 = 4 s; manipulator rotation module φ4 = 3π/2; T4 = 4 s. We accept the following ratios for rotational modules between the full operation and the time of individual sections of the trapezoidal dependence: k a(1.4) = 0.3; kb(1.4) = 0.2 and translational ka(2.3) = 0.1; kb(2.3) = 0.07.

Using expressions (2) and (3), we estimate the values of the maximum possible speed and acceleration of the lift module operation: v3=0.87 m/s, ω3=12.5 m/s2.

For other modules, we similarly obtain: ω1=2.1 deg/s; ε1=5.25 deg/s2; υ2=1.09 m/s; ω2=19.4 m/s2; ω4= 1.6 deg/s; ε4=2 deg/s2.

The following coordinate systems are introduced in the kinematic scheme:

- $x_b\ y_b\ z_b$ – axes of the base coordinate system; z_b – axis directed along the axis of rotation of the manipulator; $x_b\ o_b\ z_b$ – plane located parallel to its extension;

- $x_n y_n z_n$ – coordinate system (input) for the nth module of the degree of mobility (n = 1, 2, ..., N = 5); this system is tied to the input of the module, which is structurally a fastening of the working body of the manipulator;
- x_{n+1}, y_{n+1}, z_{n+1} – coordinate system (output) of the n-th module, which coincides with the input coordinate system of the (n+1)-th module. Accordingly, the output of the module is the structural elements that ensure its fastening to a static base (it can be connected through intermediate modules or by direct connection);
- $x_o y_o z_o$ - coordinate system of the working body of the robotic tool or object of manipulation.

Let's take the axes $x_o y_o z_o$; $x_n y_n z_n$ и $x_{n+1} y_{n+1} z_{n+1}$ parallel to the corresponding axes of the base coordinate system $x_b y_b z_b$.

When developing the project for the lifting module of the manipulator (n = 3), it is assumed that the modules of the working body, rotation (n = 1) and the extension module of the manipulator (n = 2) have already been designed. Let us also assume that the following parameters of the manipulator extension module (n = 2) are found: the load at the module input from the inertia forces of the manipulated object, the manipulator working body and the module of its rotation. In the general case, the specified load can be described by a column matrix:

$$P_2 = \begin{bmatrix} P_{2x} \\ P_{2y} \\ \dots \\ P_{2\sigma} \\ \dots \\ P_{2\gamma} \end{bmatrix} = \left[P_{2x}, P_{2y}, \dots, P_{2\sigma}, \dots, P_{2\gamma}\right]^T (\sigma = x, y, z, \alpha, \beta, \gamma),$$

where the index "t" is the matrix transposition symbol.

8 Conclusion

Use of a robotic complex at a car maintenance point will reduce the time for car inspectors-repairers to inspect and identify malfunctions in rolling stock in accordance with regulatory requirements and transfer data on detected defects to the maintenance operator, which will lead to faster adjustment of the repair work schedule and transition to repairs on condition.

The offered robotic complex for implementation of the inspection and maintenance of freight cars at the maintenance point:

- ensures the identification of the rolling stock, determination and fixation of the side number of the car and further other data about the car (date of manufacture, date and place of the last repair, and etc.);
- allows to reduce the staff of inspectors-repairers;
- ensures the improvement of the quality of technical maintenance and the detection of defects in car units;
- provides a reduction in maintenance time, an increase in the productivity of PHE with an overall increase in the level of safety of technological processes.

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