DYNAMIC CHARACTERISTICS OF PNEUMATIC WALL-CLIMBING ROBOTS

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Keywords: wall climbing robot, pneumatic drive system, pneumatic scheme, control algorithm.

Abstract. Researches of dynamic and functional characteristics play important part of knowledge about behaviour of mechanical systems including robots. All basic platforms of wall climbing robots are working in dynamic conditions so quality of functional processes depends essentially on influences of driving robot masses motion. Functional characteristics present dependency on time of such mechanical parameters like velocity, acceleration, position of pneumatical drives of wall climbing robots. External disturbances may be in the form of step function or harmonic function, so response times of moving parts characterize their dynamic behavior. Suggested pneumatic scheme includes vacuum generators of ejector type, pneumatic drives for main transport motion of two platforms, vacuum contact devices drives, rotation motion drives, electro-pneumatic valves, sensors and transducers. Control systems based on microcontroller and information-measuring feedback loop. Two types of pneumatic wall climbing robots with vacuum contact devices are under consideration - with payload capacity 50 kg and 30 kg. Time-velocity and time-acceleration curves were obtained for piston’s move out and pull in for both of robots with payload capacity 30 kg and 50 kg. The same characteristics were obtained for central and external platforms of wall climbing robots.

ДИНАМИЧЕСКИЕ ХАРАКТЕРИСТИКИ ПНЕВМАТИЧЕСКИХ РОБОТОВ ВЕРТИКАЛЬНОГО ПЕРЕМЕЩЕНИЯ

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Ключевые слова: робот вертикального перемещения, пневматическая система приводов, пневматическая схема, алгоритм управления.

Аннотация. Исследования динамических и функциональных характеристик играют важную роль при изучении работы механических систем, в том числе роботов вертикального перемещения. Конфигурации базовых платформ роботов вертикального перемещения, которые работают в динамически изменяемых средах, зависят от выполняемых технологических операций и от полезной нагрузки, которую могут нести роботы. Функциональные возможности роботов зависят от таких технических характеристик, как скорость, ускорение, положение пневматических приводов на корпусе роботов. Внешние возмущения могут быть представлены в виде ступенчатой функции или гармонической функции, поэтому время отклика движущихся частей характеризует их динамическое поведение. Предлагаемая пневматическая схема включает в себя вакуумные генераторы эжекторного типа, пневматические приводы для поступательного движения двух транспортных платформ, приводы вакуумных контактных устройств, приводы вращения, вакуумные контактные устройства, электропневматические клапаны, датчики и преобразователи. Управление роботов было построено на основе микроконтроллера и информационно-измерительной системы с обратными связями. Рассматриваются два типа пневматических роботов вертикального перемещения с вакуумными контактными устройствами, грузоподъемностью 50 кг и 30 кг. Были получены графики зависимости скорости от времени, а также ускорения от времени необходимых для выдвижения и втягивания поршня пневматического цилиндра осуществляющего перемещение роботов с грузоподъемностью 30 кг и 50 кг. Те же характеристики были получены для пневматических цилиндров приводов вакуумных контактных устройств используемых на центральной и внешней платформе роботов.

1. Design of the wall climbing robot

The use of robotic complexes for performing inspection, technological task on a vertical surface in machinery, nuclear, oil and gas industry or maintenance of a high-rise building is gaining increasing development. Robotic complexes with an ability for the vertical movement are considered as a mechatronic technological system designed to perform tasks in hard-to-reach places that are characterized by high temperature, gas contamination, radiation, explosiveness, insufficient information about the environment and objects. The need to perform work at high altitudes, underground and underwater conditions, makes appropriate requirements on the robot. These requirements include an increased mobility, maneuverability, reliability and the maximum possible autonomy of motion [1-3].

The developed wall climbing robot (Fig. 1) is intended for repair and maintenance of a vertical and horizontal surfaces. The robot delivers technical equipment to the working area and performs the following technological operations: welding, machining, cleaning, grinding, milling, inspection, flaw detection. The robots of such a type can be used to operate on different types of tanks, hulls of ships, power complex and objects of nuclear power plants and on other structures with large continuous surfaces.

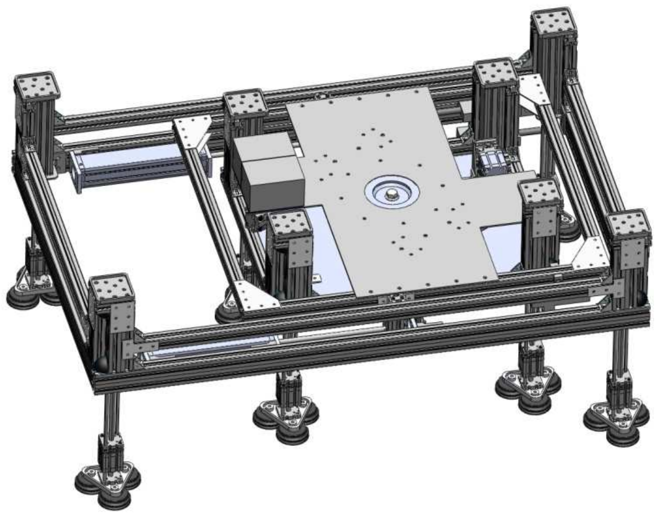

Fig. 1. General view of wall climbing robot

The drive system of the developed wall climbing robot includes a movable platform rigidly attached to the pneumatic cylinders, piston rod, which is connected to the pneumatic cylinders of the drive mechanisms of the external gripper group (suction cups). These clamps are attached to the supports connected to the piston rods of the pneumatic cylinders of the extension of the platform grippers. The pneumatic cylinders of the central group of grippers, which also hold the platform on a vertical and horizontal surface, are attached to the movable platform. These clamps are fastened to the supports connected to the piston rods of the pneumatic cylinders of the grippers of the central group of the platform. Each leg of the robot is equipped with two types of pneumatic cylinders. This leg design provides an ability to change the length of the rod to overcome obstacles with different heights. During the movement on a vertical wall robot uses the actuators with a small stroke of the rod, since there is a predominantly flat surface with a small obstacles. The horizontal surfaces may involve the need to overcome high obstacles, to handle them two types of drives are used at once. The motion of the robot consists of successive fixation on the surface of the central and the external group of the gripping devices. The grippers provide adhesion to the vertical and horizontal surfaces, both in the air environment and in the water environment. Fixation on the surface is carried out by creating a sufficient level of vacuum in the gripper (suction cup). Each rotation movement of the robot is limited to a constant discrete value due to the pneumatic construction of the turning node. Rotation is possible in two directions: clockwise or counterclockwise.

The control algorithm determines the operating mode for the drive system of the transport module. This algorithm implements actuations of the drivers, gripper drive system and the platforms.

The pneumatic scheme of the robot (Figure 2) contains the following elements.

1. The vacuum generators that creates vacuum in vacuum grippers designed to fix external and central platforms of the robot on a vertical or horizontal surfaces.

2. The pneumatic actuators for the extension of the gripping devices that carry out the motion of the vacuum grips of the central platform during the movement along the vertical surfaces.

3. The pneumatic actuators for the extension of the gripping devices that carry out the motion of the vacuum grips of the outer platform during the movement along the vertical surfaces.

4. The pneumatic actuators for the extension of the gripping devices that carry out the motion of the vacuum grips of the central platform during the movement along the horizontal surfaces.

5. The pneumatic drives for the extension of the gripping devices that carry out the motion of the vacuum grippers of the outer platform during the movement along horizontal surfaces.

6. The pneumatic motion drives that move the external platform relative to the position of the central platform and vice versa.

7. The pneumatic drives of the turning unit that performs the rotational movements of the outer platform relative to the central platform and vice versa.

8. The electro-pneumatic valve delivers compressed air to the corresponding cavities of the pneumatic motion drives.

9. The vacuum grippers that fix the external and central parts of the robot on vertical or horizontal surfaces

10. The air preparation unit contains a filter-dehumidifier, a pressure reducing valve to maintain a given level of pressure at the outlet of the air preparation device, and a pressure gauge to monitor the pressure level of the robot as well as an electronic pressure sensor to monitor the pressure level in the operator control systems.

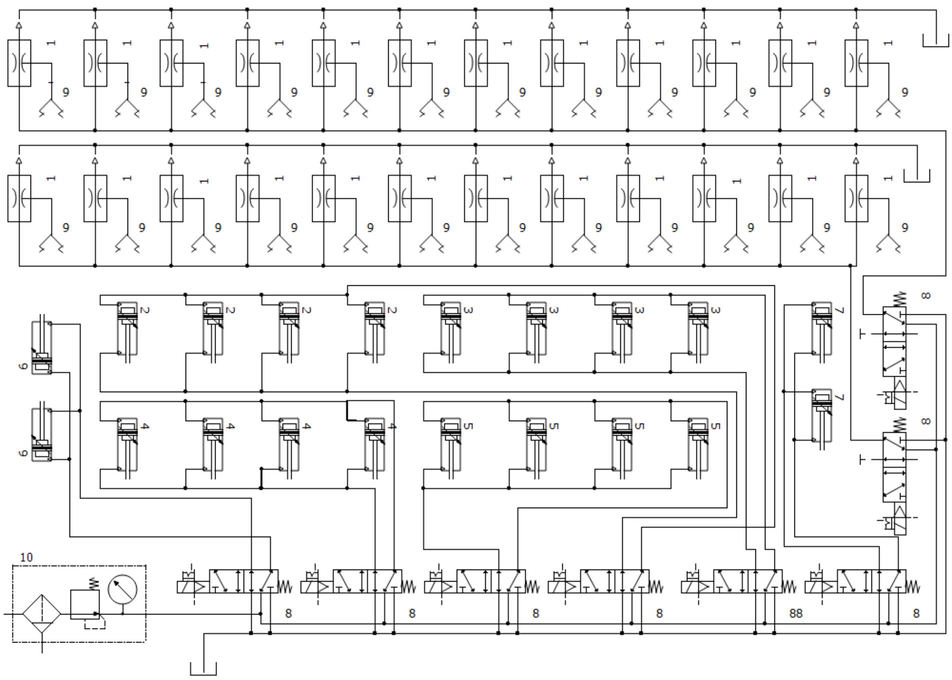

Fig. 2. Pneumatic scheme of the robot

2. Experimental studies of the wall climbing robot drives

The introduced robot samples with pneumatic drives are high-performance technical devices. Obviously, the problem to increase the velocity of the wall climbing robot is inextricably linked with the operation speed of the pneumatic drives. However, the authors' experience in the design of high-speed pneumatic actuators indicates that the increase in the operation speed of the pneumatic cylinders by the increase in the capacity of the throttles on the exhaust is ineffective [4-7]. One reason for this is a significant mass of the control object (moving platform). The mass of the robot is 100kg. The high speed requirement for the movement leads to the need to search for an effective methods of braking the control object at the end of the stroke of the pneumatic cylinder. Braking system will limit the velocity of the piston near the cylinder cover to the safe value. Otherwise, the significant impacts occur, which not only shorten the life of the pneumatic actuators, but also cause the robot to detach from the surface under the influence of the dynamic loads. For the same reason, it is necessary to limit the resulting accelerations of the robot in order to reduce the dynamic loads that arise during the transportation of the platform to a safe level.

Typical examples of the speed and acceleration dependences on time of the piston motion in a pneumatic cylinder with a diameter of 63 mm with a stroke of 250 mm, the passing rod with the use of built-in braking system and the control object with mass of 50 kg are shown in Fig. 3.

From the consideration of the graphs presented in Fig. 3, it follows that the piston travel time does not exceed 1 sec, however the inertial loads acting on the robot reach 2000 N.

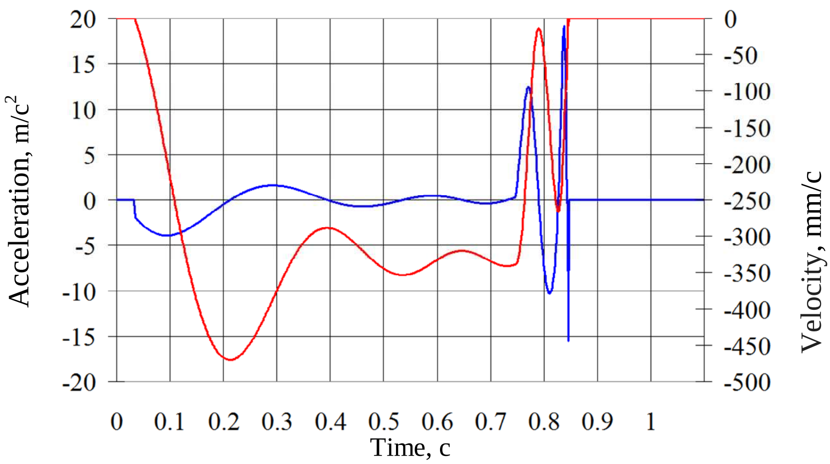

Fig. 3. Graph of the dependence of the speed and acceleration of the piston on time when retracting the rod

An example processes of moving the horizontal platform with a mass of 50 kg in the horizontal direction and moving an external platform having a mass of 30 kg by means of cylinders with a diameter of 50 mm when the robot is positioned on a vertical surface during a two-stage braking are shown in Fig. 4 and 5 respectively.

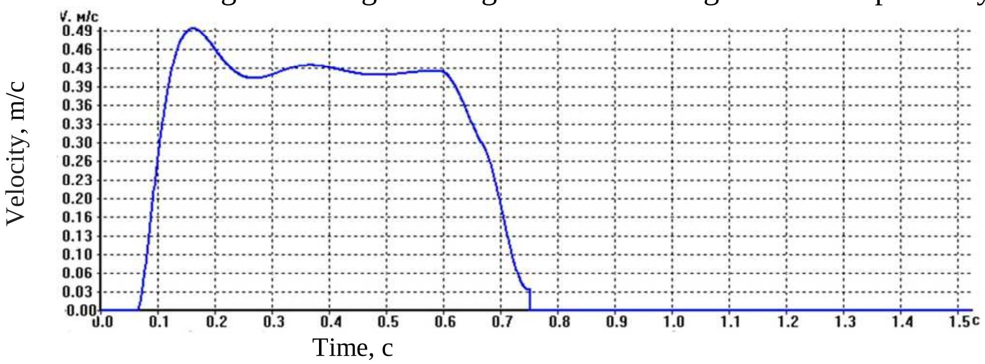

Fig. 4. Graph of the time dependence of the speed of the central platform when retracting the rod

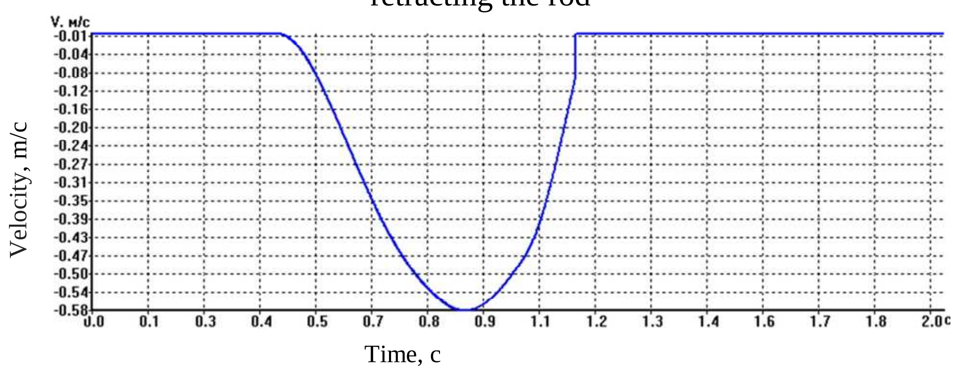

Fig. 5. Graph of the time dependence of the external platform speed on time when the rod is extended

It is important to note that during the operation of the robot the direction of its movement changes, therefore, the orientation angle of the axis of the pneumatic cylinders with respect to the horizon changes. This leads to the fact that the numerical value of the projection of the gravity vector on the cylinder axis changes and, consequently, the external force acting on the platform from gravity.

Based on the results of the conducted studies, the following conclusions are drawn: an inertial load of less than 500 N is achievable when cylinders have diameter more than 50 mm. Thus, the diameter of the cylinders of longitudinal motion drives should be selected not only by taking into account the weight of the moving platform of the robot, but by also taking into account the requirements for the dynamic properties of the motion process of a massive objects.

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Conclusion

Wall Climbing Robot with pneumatic control, driving systems and two platforms is presented. Such type of robot is intended for extreme conditions of application including nuclear power stations. The obtaining transient characteristics permitted to estimate response times of every platforms for all practical cases and to analyses vibrations. The receiving transient characteristics permitted to estimate response times for all interesting cases and to analyses vibrations.

The experimental results show that response time not increase 1 sec for piston maximum motion per one cycle. Overshooting of acceleration not increase 0,05% on maximum value.

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