Development of a Stand for Studying Control Systems of a Nonlinear Dynamic Object

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Abstract

Classical nonlinear objects which are studied in the control theory are: ball on beam, ball on plate, inverted pendulum and its different variations. Laboratory stands, which present stabilization control systems of this objects are widely used. The main advantage of such systems is a high demonstrativeness, resulting in fairly simple understanding of principal differences between various control laws: classical, adaptive, fuzzy and other types of controllers. In this paper, the ball on the plate laboratory bench design is considered.

1 INTRODUCTION

In the modern world, devices with a stabilization system are widespread. They are used not only in all branches of industry to a greater or lesser extent, from agriculture to high-precision production of electronic components, but also in everyday life. That is why the study of various stabilization systems is an obligatory part of the training of students studying automatic control systems at the St. Petersburg State Electrotechnical University (ETU).

Currently, discipline "Automatic Control Theory" consists of several interrelated components, theoretical in form of lectures, practical and laboratory courses. Each of which is necessary for better understanding in the subject of study and its better understanding.

During the laboratory course, significant part of the laboratory studies is devoted to the modeling and development of various control systems. However, these systems are only mathematical models and are not connected to any real physical objects. Despite the obvious importance of getting skills of various objects mathematical models development, without comparing the resulting model with the results of actual experiments it is rather difficult to appreciate the quality of the system. In order to change this situation, the use of physical layouts of such dynamic system as ball-plane one is provided.

2 LABORATORY BENCH CONSTRUCTION

The first stage of development of the laboratory stand is the development of its construction. After analyzing the various existing designs [1-2], a variant, which is shown in Figure 1, was chosen.

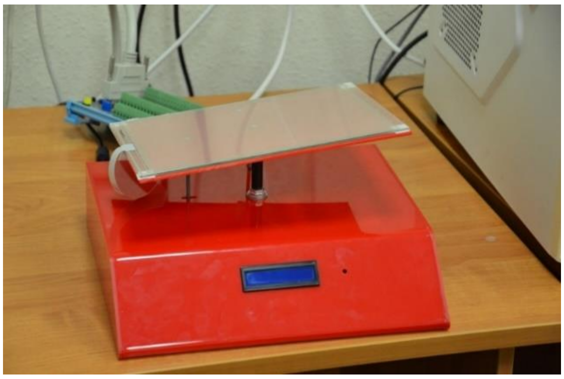

Fig. 1 Laboratory bench

The stand design is a fixed base and a movable plane connected with each other by means of a support with a cardan gear at one end [3]. Moving of a plane in space is carried out by a system of mechanical links and two servomotors. There is a lever on the motor shaft, the end of which is connected with a mechanical rod. At the other end of the rod there is a ball joint which is placed in the mounting located on the inner panel of the stand.

Figure 1 shows not only the general view of the stand, but also its structural elements, such as the support of the inclined plane and a part of the mechanical rod to the left of the support.

There is a liquid crystal screen on the front panel of the stand , which allows to display up to 16 characters in each of the two lines. It is intended to use the screen to display the values of some system parameters in real time or to display a menu for controlling the device.

As the material from which the structural elements are made acrylic glass was selected. The choice of this material is contingent on properties. Acrylic is characterized by its electrical insulation properties, long service life, low weight with high strength, it is also easily processed.

3 HARDWARE

The next stage of the development of the stand is the selection of components of its hardware. The elements are shown in Figure 2.

It was decided to use a resistive screen as a sensor for transmitting information about the position of the ball [4]. The screen is connected to a personal computer by USB cable and recognized as a device type of mouse. The signal about the coordinates of the ball on the screen is send to the input of the control system of the stand, developed in the environment MATLAB Simulink.

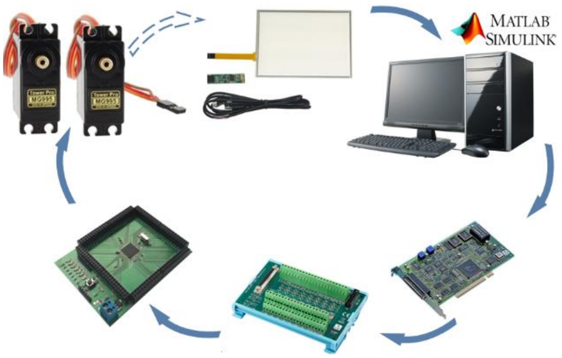

Fig. 2 Hardware of the bench

The system processes the input signal and generates output one, arriving at the PCI- 1711U board. In order to obtain an analog signal corresponding to the output signal of the system, the PCLD 8710 terminal board compatible with the PCI-1711U is used. The choice of these components is due to the fact that they have 16 potential analog inputs and two analog outputs. For operation with two servos, two separate analog outputs must be used.

To control servo drives, the microcontroller PIC24FJ256GB110 is used. The ADC module of microcontroller converts the analog signal to a corresponding value digital signal.

On the basis of this, the microcontroller generates PWM signal, the duty cycle of which depends on the magnitude of the output signal of control system. In this way, the motor shaft is rotated by a certain angle, that leads to a change in the position of the inclined plane.

4 CONTROL SYSTEM

Since it is intended to use the developed stand for educational purposes of laboratory studies on the control theory course, it was necessary to develop a control system using the MATLAB Simulink environment. In order to be able to track the signals of the system directly during the work of the bench, it was decided to use the core of Simulink Desktop Real-Time for real-time operation.

When this package is installed in the Simulink block library, a section with the same name appears containing blocks that allow to work with analog, discrete signals, various devices or interfaces in real time. The structure diagram of the developed control system is shown in Figure 3.

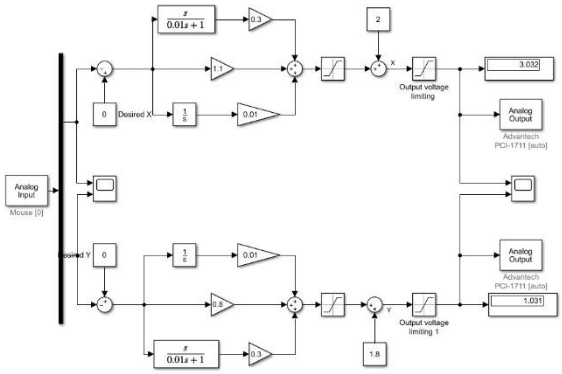

Fig. 3 Controller block diagram

The input signals of this system are the coordinates of the ball on the plate [5-6]. Transfer them to the system is carried out through the interface block "Analog input", which is included in the library Simulink Desktop Real-Time. The resistive screen transmits a signal to the system through two channels corresponding to the X and Y coordinates of the object.

Blocks "Desired X" and "Desired Y" act as the master of the system. They can be performed as constants determining the coordinates of the point where the ball should be hold, or time-varying, for example, the impact of the sinusoidal type.

Control error, which is the difference between the current value and the required one, is fed to the PID-controller input. Signal which was received at the output of the controlleris applied to the input of the saturation block. This block limits the magnitude of the maximum angle of inclination of the plane. This restriction is necessary in order that the reaction of the servo to the control signal, at large values of the control error, does not lead to the rolling of the ball from the plane.

The next element of the structural diagram is an adder, which, in addition to the signal from the output of the saturation unit, becomes a certain constant value. This value is necessary for setting an approximate horizontal position at the start of the stand work. The following output voltage limiting blocks are necessary to limit the magnitude of the control action in the range from 0 to 5. This step is necessary because the input and output signals of the control system are analog signals. For correct operation of the hardware of the stand, it is important to observe the requirements for the input voltages for each circuit element prescribed in the technical specification.

5 CONTROL SYSTEM ANALYSIS

As it was said before, the developed control system can perform the positioning task of the ball at a certain point of the inclined plane, and also realize the trajectory specified by the cosine and sine functions. The results of the work of the stand in the performance of the above tasks are shown in the figures below. Figure 4 shows the object trajectory performing the task of positioning the ball in the center of the screen.

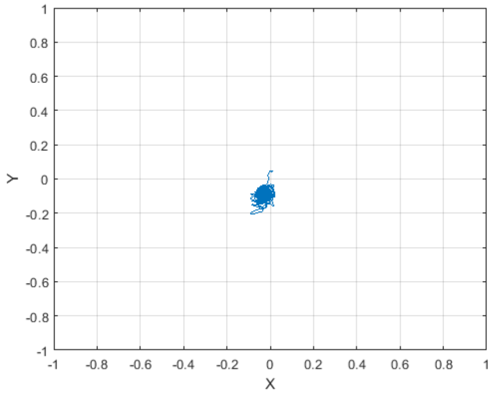

Fig. 4 Center positioning task

The system successfully performs the task . However, the object is held not in the center of the screen, but at a point offset along the Y and X axes. This offset can be explained by imperfection of the control system, the selected hardware components of the stand or by the device itself in space.

Maximum deviation from the given point for the X and Y axes is about 8%.

To estimate the system's efficiency, it is also necessary to assess its ability to resist external disturbances, such as pushing the ball with the hand, removing the ball from the platform and lowering it to the screen at another point, changing the position of the stand in space. The results of experiments in which the actions described above on the object on the plane are performed below.

First of all, the case of an external impact in the form of moving the ball by hand to one of the edges or corners of the plane is considered (Figure 5).

This chart shows that the system tends to hold the ball at the same point of the screen as and in the case with the absence of an external disturbance (Figure 4), which indicates the system's performance. Obviously, there is some static error, which explains the displacement of the positioning point relative to the center of the screen. Maximum deviation from the given point for the X and Y axes is about 7%.

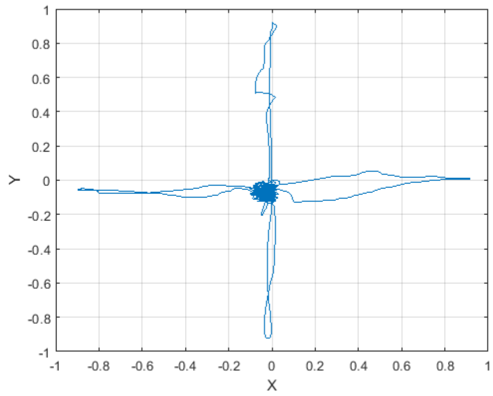

Fig. 5 Center positioning task with external impacts

More complex for processing control system is an external disturbance in the form of deviation of the ball to one of the four corners of the screen. A graph showing the movement of the ball under such external disturbances is shown in Figure 6.

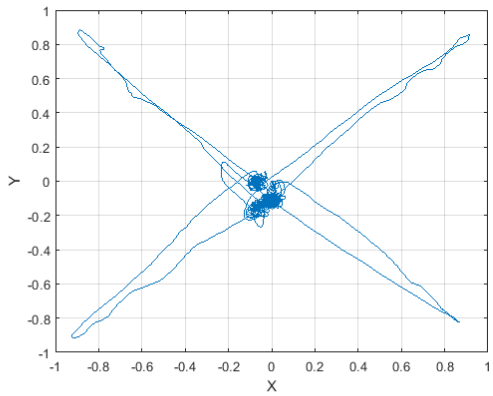

Fig. 6 Center positioning task with external impacts

It is clearly visible the change in the positioning point of the object due to the external disturbances. Nevertheless, despite the displacement of the coordinates of the point itself, the overall picture of the system's operation remains the same. Control system strives to keep the ball at a certain point and successfully copes with it. Maximum deviation from the positioning point for the X and Y axes is about 6%.

Based on the results presented above, it can be concluded that the developed system not only successfully copes with the task assigned to it but is also able to work out external impacts of a different types.

As it was said before, in addition to the task of keeping the object at a given point, the system is able to realize the movement of the ball in the plane along a certain trajectory. Further in the paper, the results of the work of the stand will be considered when it works out the motion along a circle and an ellipse.

The first case of a sinusoidal signal of the form 0.5sin(5t) as the reference signal for the X-axis motion and a signal of the form 0.3sin(5t+π/2) for the Y-axis will be considered. Such a combination of signals should lead to the fact that the ball in the plane moves along the trajectory in the form of an ellipse. The result of the system is shown in Figure 7.

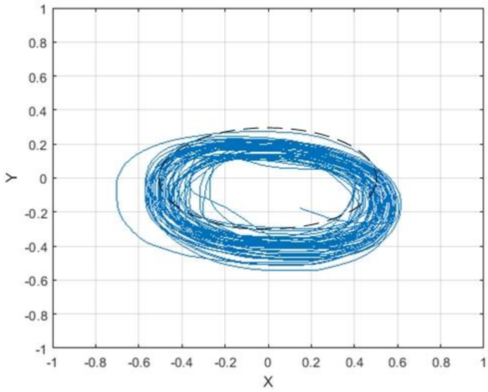

Fig. 7 Ellipse trajectory task

In this diagram, the black dotted line indicates a reference trajectory. It is evident that the object moves along an ellipse, but it is displaced relative to the center of the screen. It should be noted that the identical displacement was already encountered earlier, when considering the task of holding the ball in the center of the screen. The amplitude of the average deviation from the trajectory is about 13% for both axes.

For circle trajectory of ball motion reference signal will be used in the form of a sinusoidal signal of the form 0,4sin(5t) for movement along the X axis and a signal of the form 0.4sin(5t+π/2) for the Y axis. The chart of the ball movement according to this task is shown in Figure 8.

In this figure, the black dashed line shows the reference circle corresponding to the task. It is clearly seen how the ball moved across the screen, it is easy to determine the starting point of the trajectory and the path through which the object could move along a given curve. Obviously, there is a displacement of the point around which the movement takes place, relative to the center to the lower boundary of the screen. The magnitude of the amplitude of the average deviation from the given trajectory is 15% for the X and Y axes, which is about three fourths from the value of the average deviation when the bench is working with an elliptical trajectory.

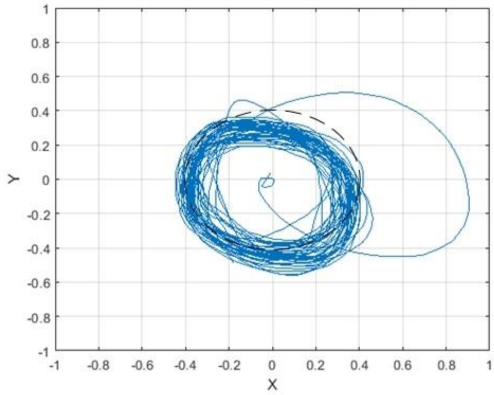

Fig. 8 Circle trajectory task

6 CONCLUSION

In this article the implementation of the ball on plate system laboratory stand is considered. Investigations of the developed control system have shown that the system is efficient and successfully performs the task of stabilizing the ball on the plate. However, carrying out the task of moving the ball along a certain trajectory, a significant deviation of its motion from a given trajectory is observed. The system is able to resist limited external disturbances without loss of stability. To improve the performance of the stand, it is planned to modify it and use other regulators (fuzzy, neural networks, adaptive) instead of PID controller.

7 REFERENCES

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