Precision Control of Dynamic Objects: Main Problems and Decisions

V.A. ZHMUD¹,*, L.V. DIMITROV² and H. ROTH³

¹Novosibirsk State Technical University, 6300027, str. Prospekt K. Marksa, h.20, Novosibirsk, Russia
²Technical University of Sofia, 1000, Boulevard Kliment Ohridski 8, Sofia, Bulgaria
³University of Siegen, D-57068, Siegen, Germany

*Corresponding author

Keywords: Automatics, Accuracy, Regulator, Feedback, Identification, Control.

Abstract. The precision automatic control systems (PACS) provide high-precision control of output values of controlled objects with the help of negative feedback loop. They differ from convenient automatic control systems (ACS) due to highest demands to the accuracy. Typically, the allowed value of the error of control is less than 0.0001%, while the convenient ACS which provide control with the error inside the 0.1% are considered as rather accurate ones. Most known PACS are used in the laser technology (for precise stabilization and measuring) and in electronic industry (for precise control of mechanic movements). For their developing, the competence in the two relative field of technology is necessary. Namely, the developer should be good specialist in feedback control systems (automatics) and in metrology (theory of measuring). This paper gives main directions of the researches for these purposes, main problems and their decisions.

Introduction

The object models are always approximate. Hence, the result of the regulators calculations can be not relevant. The newest methods for the decision of these problems are based on the computer aided numerical optimization of the feedback. For the numerical optimization, any level of the complexity of the object mathematical model is not the problem with software like VisSim. Developer tools include modern methods for the constructing of the cost functions for the optimization process, new structures of regulators, smart decision for decreasing of overshooting, oscillations and other problems of transient response of the system. The main problem is static accuracy. The second important problem is the equivalence of the process in simulating based on mathematical models and in reality. This problem has been resolved with some fruitful patented idea.

General Concept of Precision Automatic Control Systems

Any PACS is built around the controlled object and contains the following main parts.

1. A modulating element called “drive”.
2. An analyzing device called “sensor”.
3. The electrical part for providing stability and accuracy of control: it can be called “regulator” or “controller”. If the required mathematical model of the regulator is found, its implementation is easy.

Typical Schemes of PACS

The generalized scheme of the automatic control system is shown in Figure 1.
There are many factors affecting the object. For a linear object, the mathematical model of the system in the Laplace transform field is such as Fig. 2 shows.

\[
Y(s) = \frac{W_1(s)W_2(s)}{1 + W_1(s)W_2(s)W_3(s)} [V(s) - W_3N(s)] + \frac{1}{1 + W_1(s)W_2(s)W_3(s)} H(s)
\]

The denominator of all the transfer functions occurring in this equation is the same. The feedback regulator can be calculated with the following structure, shown in Fig. 3.

If the transfer function of the reverse branch \(W_3(s)\) is equal to unit, and the product of the transfer functions of the object and the regulator is large value, i.e. \(W_1W_2 = W_p >> 1\), we obtain
\[
Y(s) = \frac{W_p(s)}{1 + W_p(s)} [V(s) + N(s)] + \frac{1}{1 + W_p(s)} H(s)
\]

(2)

\[
Y(s) = V(s) + N(s)
\]

Hence under this condition and in the absence of measurement noise, the output signal repeats the input signal and does not depend on the disturbance. On this principle, the operation of all control systems in the loop with negative feedback is based.

Demands to the Feedback Loop

The requirements for the system are formulated, as a rule, based on the technical characteristics that an object in the system should possess. As a rule, the following demands are required:

1. Zero or negligible small static error. For example, it can be formulated mathematically:

\[
\lim_{t \to \infty} y(t) = v(t)
\]

2. A small overshoot that does not exceed a preset value, as a percentage of the value of the task jump that caused this overshoot. In particular, there may be a requirement for no overshoot.

3. Short duration of the transient process until a certain level of error is reached. For example, the time to reach a relative error of 5% can be set:

\[
t > t_{0.05} \Rightarrow |e(t)| < 0.05 v(t)
\]

4. Absence of oscillations, or their small number, or the ratio of the amplitude of the next oscillation to the amplitude of the previous one (damping index).

5. No reverse overshoot. The reverse overshoot is the output of the output signal in the direction opposite to the prescribed direction of this value.


Structure for the Regulator Optimization

A possible structure for optimization is shown in Fig. 4. To optimize the regulator, it is required to apply a structure containing the system model and a number of auxiliary modules. The model of the system includes a regulator and an object, and other specific blocks can also be included.

In addition to the system model, the structure should contain:

1. Means of formation of test signals.
2. Means of indicating the results of optimization.
3. Means (unit) for calculating the cost function.
4. Means of formation of initial values of parameters.
5. Optimization tool (performing the analysis of the value function, calculating new parameters, analyzing new values and deciding on further steps – continuing the search or stopping it).

Various algorithms for finding the minimum can be applied. The correctness of the choice of the optimization method depends on the properties of the problem: the best method for one task may be the worst or inapplicable for another task.
Tools of the Cost Functions

The cost function in general form is written in the form of a functional:

$$\Psi(T) = \Theta \sum_{i=1}^{M} \psi_i(t) dt$$

Here $\Theta$ is the duration of the simulated transient process. We propose [1]:

$$\psi_1(t) = |e(t)| t$$

$$\psi_2(t) = \max \{0, x(t) - 1, 1\}$$

Here the function $\max \{0, f\}$ is limiter:

$$\max\{0, f\} = \begin{cases} 0, & \text{if } f < 0 \\ f, & \text{if } f \geq 0 \end{cases}$$

This cost function is relevant only for the development of a single step action. Another and more effective way to suppress fluctuations in the transient process is the use of the error growth detector [1]:

$$\psi_3(t) = \max \{0, e(t) \frac{de(t)}{dt}\}$$

To provide the usability of the result it is useful to propose that object in reality is slower than in fact [2]. It can be achieved with additional delay link during the optimization procedure. It is proved that in this case the result is more relevant because in reality, the object model is identified with mistakes in the high-frequency field, and this correction removes this disadvantage.

In many cases, the choice of the sensor is difficult because different sensors have different advantages and disadvantages. The method for regulator calculation has been developed and tested which allows combine the advantages of several sensors (speed, accuracy and so on) and exclude their disadvantages. The similar decision has been proposed and used in real PACS for combining of the advantages of several drivers and remove their disadvantages from the resulting system.
Control of Balancing Robot with Feedback Using Imperfect Sensors of Position and Acceleration (Results)

The theoretical and practical results of this research are used in the many precise systems, such as laser frequency stabilization, temperature control and so on.

One of the newest developments is balancing robot [4]. The dimensions and appearance of the robot can be evaluated from Fig. 5. At the website [5] there is a video, which shows the work of the developed robot in the working off the disturbance, which is administered by the asymmetrical placement of its cargo. It can be seen that the robot successfully fulfils this hindrance, without losing balance, as Fig. 6 shows.

Conclusion

The researches gave the following results

2. Theoretically based and practically proven methods for combining of the advantages of several sensors and several drivers with the exclusion of their disadvantages.
3. Practical feedback system with the highest accuracy.
4. Control of mechanic objects with the smallest dynamic error.

Literature References


