The development of active control to improve the efficiency of product quality problems solving machining

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Abstract The paper presents the results of the development and implementation of a promising system of active quality control of products for machining operations in the context of mass production of automotive vehicles.

Keywords: quality; active quality control systems; automotive industry

1. Introduction

A typical block diagram of the active control system for grinding process control, presented in Figure 1, consists of the active control device (ACD) itself, a sensor that monitors the current allowance for the workpiece (D₁), a grinding machine. The presence of ACD does not guarantee the constancy of the size of the products produced during processing due to the presence of a large number of disturbing factors affecting the system formed by the active control device with a sensor, a machine and the workpiece [5-7]. These factors include fluctuations in the temperature of the workpiece, ambient air and coolant, allowance of blanks and material properties of the blanks, gradual wear of the measuring tips (except when using non-contact sensors). Attempts to account for and compensate for the maximum possible number of disturbing factors in the ACD led only to a significant complication of the design and cost of the control itself, the need to involve highly qualified specialists for its maintenance, as well as a decrease in the reliability of the instrument itself. In this regard, such self-adjusting systems are not widely used in industry [1-3]. In addition to the ACD, a post process gage (PG) with a sensor (D2) is often used. Depending on the complexity of the part being monitored and the quality requirements imposed, such devices also come in a wide variety of modifications, from simple hand-held brackets to complex stands or semi-automatic devices. PG is used in order to obtain objective measurements of the machined part, due to the presence of disturbing factors. According to the results of the control parts on the control pane, the machine operator can adjust the current setting level of the ACD, if necessary. Thus, a similar structure of the organization of active control can be called two-circuit. The first circuit is formed by the ACD, a sensor for monitoring the current allowance and a grinding machine, and the second circuit is a control panel with a sensor for monitoring the current size. Feedback on the results of control is carried out with such an organization only through the machine operator [4].
Figure 1  Typical block diagram of the organization of active control for the process of round grinding

Processing of the part is performed on a grinding machine. The feed rate of the \( V_C \) of the grinding wheel varies in accordance with the processing step of a given algorithm. The size of the part \( L_1 \) is converted by the sensor \( D_1 \) into an electrical signal \( U_{L1} \) and is fed to the ACD. The ACD compares the current \( U_{L1} \) signal with the threshold values used in the control algorithm. As a result, control signals \( U_y \) are formed, which determine the stages of the processing cycle (and, consequently, the change of the grinding wheel feed speed), as well as the moment the grinding wheel is removed from the part. At the end of processing, the operator controls the part on the PG, obtaining the objective size of the part \( L_2 \). In case of a large deviation of the \( L_2 \) size from the nominal value, the operator may amend the ACD. However, in order to increase the efficiency of the controls, it is not enough to have a sufficiently accurate instrument or complex that would display the result of the part control, for example, on an analogue scale, or on a digital indicator, it is necessary to realize the possibility of additional processing of measurement information.

2.  Main part

Traditionally, the improvement of controls at the organization of the workplace of the machine operator described above was carried out by improving the means of postoperative control. Electronic controls were introduced, including multichannel systems that provide the machine operator with information on all the geometrical parameters of a part that had to be checked at the same time [8-9]. Also relevant is the issue of creating a database in which the entire array of monitored measurements is stored, with the time and date of the survey being saved. The formation of a database allows you to track the dynamics of changes in the state of the process, which is especially convenient when carrying out process improvements, such as the use of new materials, processing tools or processing modes. With well-implemented plan of control operations with a clear frequency of their conduct, the task of detecting the moment of occurrence of a “special” cause of variability, which brings the process out of a steady state, is greatly facilitated. At the same time, for ease of use, it is advisable not only to display the results in text format, but to provide an opportunity for graphical presentation of information using control charts of averages and ranges \( \bar{X} - R \) or mean and standard deviations \( \bar{X} - S \) [3, 4].

Currently, it is common practice for manufacturers of measuring and measuring equipment to provide remote access to a specific device, for example, via a local network with the ability to view accumulated measurements. Depending on the location of the equipment (compactness or strong dispersal of controls), technical and economic capabilities of the enterprise, three types of data transmission channel are used:
- wire line, for example, via the “Ethernet” communication channel;
- special electronic card or Flash card;
- radio channel.

The organization of a communication channel using a wired line to a local network, although it has a high cost for its initial installation, is compensated for by low maintenance costs and is the best option for compact placement of monitoring equipment. There are situations that one or several workplaces are removed from the total set of devices; in this case, the data transfer can be realized by means of a Flash card, with the subsequent transfer of the obtained data to a centralized database. Depending on the conditions of production and the equipment used, as well as with a compact arrangement of controls, the local network can be implemented through a radio channel.

The connection of the postoperative control device to the corporate network of the production site is often realized via the “Ethernet” communication channel, which ensures data transfer at speeds up to 100 Mbps. In this case, each device is assigned a unique IP address (or less often the network name of the device, which is typical for small productions when the number of devices is small) in the network environment. As a result, it is possible to promptly analyze the “flow” of the technological process at a specific workplace, thereby identifying “bottlenecks” and promptly introduce corrective measures.

With this approach, it became possible to track trends that are slowing in time due to deep statistical processing using variance, regression analysis. Further development of postoperative control tools was carried out, mainly due to the improvement of computer technologies and the development of the software used. This made it possible to perform the simplest statistical processing of the measurements taken directly at the workplace of the machine operator. At the same time, the structure of the control system is improved by increasing the number of feedbacks used, as shown in Figure 2.

![Figure 2](image)

**Figure 2**  Block diagram of the active control system with the statistical processing of the control results

As practice shows, in order to effectively realize the benefits of statistical analysis, it is necessary to minimize additional labor costs on the part of the operating personnel — a machine operator, a controller, or a setup man. The traditional maintenance of paper control charts with the introduction of controlled parameters by hand, followed by simple calculations, demonstrated its unviability. In this regard, only the automation of the process of collecting and building control charts can have a positive effect. All this together allowed us to provide all interested stakeholders of the process with objective information on the quality of the products on the basis of which it is possible to develop coordinating actions that improve and stabilize the entire process.

However, the means of active control were also improved, but independently of the postoperative control, by improving the software, processing modes, by installing additional sensors. But at the same time, the connection between the means of active and postoperative control was carried out only through the machine operator. The efficiency of the introduction of adjustments (adjustments) of which into the processing program largely depended on the quality of the parts produced on the machine. This is the main drawback of such a structure of controls. Despite the positive effect of the introduction of statistical processing of information at the stage of postoperative control, it’s not all information that comes into
consideration, but only a part of it, i.e. specific sample of parts. Therefore, the effectiveness of the introduced corrections largely depends on the frequency of sampling and their volume. Moreover, the sampling frequency should be carefully regulated. On the one hand, in order to better track the state of the technological process, the frequency of sampling should be as often as possible, on the other hand, the laboriousness of the control procedure and the time for its execution greatly increase, especially when monitoring parts of complex configuration.

Solving the problem of lagging information occurring in such an organization can be achieved by improving the means of active and postoperative control based on a two-loop active control system. The main advantage of this structure is the tracking of the state of the technological process directly at the pace of the technological process by the active control system. The modern level of development of computer technology allows you to form ACD on the basis of an industrial computer, and thanks to advanced software, it is possible to obtain information on each processed part. Since the collection of information about the parameters and conditions of the part processing, as well as all the related information is performed in the part processing cycle, there is no loss of monitoring time, and the procedure itself is automated and does not require additional actions by the machine operator. With such an organization, there is no lag in information from a timely undetected reason destabilizing the technological process, since the dynamic size of each processed part is taken into account, on the basis of which the processing cycle is controlled. As a result, you can create a map of the dynamic dimensions of the parts, which allows you to display information on the entire set of parts. In this case, the moment of occurrence of the “special” cause of variability, which derives the technological process of their stable state will be identified in a timely manner, thereby preventing the release of defective products. All this is done in the ACD, which forms the first or main circuit of the system. PG in this case forms the second or additional circuit of the system. The block diagram of such an organization of active control in this case is presented in Figure 3.

An additional circuit is used to provide objective information about the quality of the machined part, since the size of the machined part obtained in the main circuit for several reasons (dynamic measurements, presence of coolant in the control zone, temperature fluctuations, delayed removal of the grinding wheel, etc.) certain error. As a result, the size of the part in the main contour requires some adjustment. For this purpose, the objective data obtained in the second contour are used to refine the correction coefficients of the main contour. In this case, the adjustment with the use of an additional circuit can be carried out at longer time intervals than with the traditional approach, especially with a stable technological process, which allows reducing the laboriousness of control by the operating personnel. In order to increase the reliability of the results on the controlled size in the main circuit of the active control system, it is advisable to use statistical processing of the obtained data.

![Block diagram of a two-circuit active control system with statistical processing of information](image-url)
Thus, the determination of the final removal rate of the allowance at the time of completion of processing and removal of the grinding wheel from the part at the pace of the technological process will allow you to quickly monitor the current situation and introduce corrective measures. At the same time, it is better to visualize the results obtained, for example, using control charts of averages and span, distribution histograms.

As a result, the statistical characteristics of the adopted symbols in the main circuit of the active control system will be:

- the average value of the size error:

\[ \Delta L = C_1 \Delta V_{MK} = \frac{C_1}{n} \sum_{i=1}^{n} (V_{MKi} - V_{MK_{HOM}}) = C_1 \left( V_{MK} - V_{MK_{HOM}} \right) \]  

(1)

- the magnitude of the size error values:

\[ R_{AL} = \Delta L_{max} - \Delta L_{min} = C_2 \left( V_{MK_{max}} - V_{MK_{min}} \right) \]  

(2)

where \( n \) is the number of parts in the sample.

Continuous monitoring of the quality indicators of the machined parts prevents not only the delay, but also the loss of information about the change in the state of the technological process over time. This circumstance makes it possible to recognize the early signs of the emergence of a special cause of variability until the appearance of defective products.

In this case, the additional contour of the system is used to periodically identify the coefficients \( C_i \) and \( C_2 \) in the system’s main contour:

\[ C_1 = \frac{\Delta L_2}{\Delta V_{MK}} ; \]

(3)

\[ C_2 = \frac{R_{AL}}{V_{MK_{max}} - V_{MK_{min}}} , \]

(4)

where \( \Delta L_2 \) is the size error obtained in the additional contour.

On this principle, a dual-circuit active control system is built, including the ACD as the main circuit and PG the control panel as an additional circuit.

Figure 4 illustrates the implementation of the control algorithm implemented on the basis of early detection of equipment imbalance:

- (Fig. 4 a) - point-by-point diagram of the size of the deviation of the size from the nominal value, calculated on the basis of the values of the final rate of removal of the allowance at the time of completion of processing indirectly in the pace of the technological process in the main circuit of the active control system;

- (Fig. 4 b) - the control map of medium and range (\( \bar{X} - R \) sheet), obtained by statistical processing of the point-by-point diagram for small samples, is formed in the main contour of the active control system;

- (Fig. 4 c) – the \( \bar{X} - R \) sheet for an objective assessment of the size error, formed in static conditions using an additional contour.

The moment of detection of a “special” cause is indicated on the diagram by line \( I-I \). Initially, when the technological process is in a steady state and there is no influence of the prevailing disturbing factor, or it is insignificant, in this case the value of the final removal rate of the allowance can be considered optimal within a certain range. The dynamic scatter plot (curve 1) displays the size error for each machined part. At the same time, the main contour of the system also performs traditional statistical processing using the small sample method (in this case, 3 parts per selection) at a certain time interval, as a result, a dynamic map \( \bar{X} - R \) is formed (graphs 2 and 3).
In this case, the moments of sampling in the second circuit of the system, for the formation of a static map $\bar{X} - R$ (curves 4 and 5) are performed less frequently than in the main circuit and are determined by the reasons for the long-term nature. As soon as the effect of the perturbing factor is detected, in this case it is expressed by approaching the boundary of the UCL statistical control on dynamic diagrams, both dotted (curve 1) and on the medium and span maps (curves 2 and 3). From this point on, a thorough postoperative control is performed in the additional circuit, which confirms the presence of a disturbing factor affecting the technological process, or the need to correct the algorithm used for early detection of the cause of variability in the main circuit of the system.

**Figure 4** Implementation of the two-loop algorithm based on early detection of a “special” cause of variability

Careful postoperative control is necessary because the size deviation does not immediately respond to the action of the disturbing factor [15, 17].

In this way, the quality of surface microgeometry - roughness can be assessed based on the determination of the final rate of removal of the allowance at the time of finishing the treatment. The most common qualitative method of assessing roughness, for example, comparison with a sample visually or by touch. Less often, for particularly important parts, profilometers or profilographs are used, since they require careful handling in order to obtain objective control results and certain professional skills.

Such a structure of a two-circuit active control system is universal and has a number of advantages in relation to traditional means and, depending on the tasks of a particular production, is able to realize:
- software, adaptive or optimal control algorithms;
- statistical regulation on the basis of medium and span control charts, or by means of a dynamic control chart.

In most cases, the production often use software active control with ACD. Among the main advantages are the ease of operation and adjustment, if possible, to ensure acceptable processing quality indicators for the conditions of mass engineering with a permissible deviation from the nominal value of no more than 20 microns. In cases with stricter tolerance fields in the range from 5 to 10 microns, the
required parameters can be achieved using adaptive (adaptive or self-adjusting) control devices that can compensate for the disturbing factors prevailing in their influence on the process.

A variant of the implementation of this algorithm is presented in Figure 5. With a stable state of the process, when the effect of perturbing factors is absent or compensated, the part is processed according to the following path:

\[ S_{\text{INITIAL}} \rightarrow 1 \rightarrow 2 \rightarrow V_{MK,\text{HOM}} \]  

where \( S_{\text{HAa}} \) - the value of the initial allowance of the workpiece;

\( V_{MK,\text{HOM}} \) - the value of the final rate of removal of allowance at which the nominal value of the size of the machined part is achieved.

At the same time, \( S_{\text{SC1}} \) and \( S_{\text{SC2}} \) - values of the machined part allowance at which the feed rate is switched from rough to finishing and from finishing to nursing, respectively, under conditions of a stable state of the technological process. When ACD detects the presence of a disturbing factor destabilizing the technological process, a transition to a new processing trajectory is automatically performed:

\[ S_{\text{INITIAL}} \rightarrow 3 \rightarrow 4 \rightarrow V_{MK,\text{HOM}} \]  

To implement the processing trajectory by expression (6), the command response moment is shifted when switching from finishing to nursing with a new allowance value \( S'_{\text{SC2}} \). The result of processing the new path is to achieve the nominal size of the part.

3. Conclusion

Thus, despite the tightening of tolerance fields for certain geometrical parameters of manufactured parts, early detection of causes of disorder and an attempt to compensate for the maximum number of disturbing factors, the problem remains the impossibility of obtaining parts of exactly the same size. In this regard, the sorting of the checked parts into accuracy classes is introduced, and subsequently a selective assembly is performed. It is worth noting that for many parts the width of the class reaches only a few micrometers. Because often the areas of machining parts and their subsequent assembly are often spaced relative to each other, manufactured and controlled parts must be marked. Marking in addition to the immediate task - to transfer the value of the controlled parameter for a specific part to the assembly site in order to obtain the highest possible quality of the assembled assembly, it is possible to keep track of each manufactured part and monitor the quality of manufacture.

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