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PROSPECTS OF ADAPTIVE CONTROL OF TECHNOLOGICAL SYSTEM ON THE BASE OF HEAVY MACHINE-TOOLS

The system of adaptive control of technological system is created as the integrated complex which includes a heavy machine-tool, systems of tools, system of CNC-control with the complete sets of measuring and diagnostic facilities, mathematical models of functioning of the technological system with the elements of artificial intelligence. The algorithms of work of the optimum system of adaptive control are formed with including of criteria: prime price of treatment, productivity, accuracy, quality and reliability of the system.

Keywords: adaptive control system, accuracy, heavy machine-tool, sensor

Introduction

The features of technological cycle, which are conditioned the uniqueness of equipment and technological processes of treatment on heavy machine-tools, have enterprises of heavy engineering. At treatment of large details the special technical decisions, do not inherent in other areas of engineer, are often needed. Expensive equipment brings an economic effect only in the case of guarantee of its maximal use [1÷4]. Today the question of the required exactness achievement can be considered most essential in planning new models of machine-tool equipment, as long as exactly in this area developers run into most of problems, compelling to search roundabout ways, go to the compromise that, in final analysis, tells on general quality and competitiveness of new products.

A factor of exactness is dominant in the integral estimation of economic efficiency and quality of equipment. The brief survey of market of machine-tool equipment is enough to expose the degree of influencing of exactness class of equipment on its price. Generally the cost of machine-tool depends on plenty of factors, but it is possible to say about influence on the price of indexes of exactness, that they are in sedate dependence:

$$C = K \cdot (1/\delta)^{x},$$

where: C – cost,

K – coefficient of proportion, depending on the type of machine-tool, mass, type of CNC system, special requirements, terms of production, etc.,

δ – absolute error of treatment on this equipment,

x – degree index.

The degree index of **x** is always more unit and approximately proportional to the standard size of machine-tool. Thus the task of the required exactness achievement at saving the affordable cost is especially complicated for the heavy machine-tool equipment which has its own features. First of all it touches the features of construction: component beds, collapsible sending, collapsible constructions of corps of bulky knots, plenty of joints, etc.

Cutting modes and consequently cutting forces or resilient deformations, also substantially differ from the modes of cutting on easy and middle machine-tools. In addition, the largeness of bearings constructions, low heat conductivity and presence of a few sources of heat, create terms for the origin of the heterogeneous temperature field and proper distortions of geometry of sending and bearing elements. These distortions substantially change in time, and also at the change of work terms of machine-tool. For example, researches of thermal deformations of bed of heavy lathe with the diameter of treatment 1250 mm show in normal external environments, that there is almost a half of treatment total error on thermal deformations of bed.

In spite of the indicated complications, the considered regularity is characteristic only for the classic way of exactness achievement. This way consists in that for the receipt of the required exactness of treatment on a machine-tool it is necessary to promote exactness of knots making and assembling of machine-tool to the necessary level, thus it, as a rule, must be on the order of the higher required exactness of treatment. Similar requirements belong to the inflexibility of knots of machine-tool participating in shaping. It is necessary to search a compromise between exactness, productivity and price, while an ultimate goal is a harmonious improvement of these indexes.

The creation of the adaptive systems of automatic control of exactness is the most perspective way now. Principle of adaptiveness consists in the receipt of information about technological process parameters by means of aggregate of sensors, and subsequent application of this information for adequate interference with motion of technological process with the purpose of maintenance of values of product certain parameters within the limits of admittance. This direction has powerful theoretical support as a theory of automatic control and it applies to the questions of exactness possesses practically unlimited possibilities. It became possible with appearance of the CNC systems and by virtue of development and reduction of prices of facilities of the electronic computing engineering, automation and measuring. Today the adaptive control appears the most effective and economic way of exactness achievement. The question of rational choice of minimum necessary set of the guided parameters and diagnostic information generators is the unique substantial problem for this direction.

The increase of degree of the equipment automation, especially due to numerical control, resulted in strong reduction of auxiliary, preparatory and final times. Comparison of basic times of treatment on an ordinary heavy lathe and heavy lathe with CNC exposed, that basic time in percent correlation from the total expenses of time approximately twice as much, than for a heavy lathe with a hand management. Thus, skilled determination of the best values of technological parameters of treatment is required. The technological parameters of the treatment method are determined the set technological task and chosen technological facilities. Part of parameters of a heavy-lathe, clamping facilities and instrument set structurally (primary parameters), and part of parameters in the limited area can be chosen freely (adjusting parameters). The technological modes (cutting speed, serve and cutting depth) allow adapting the treatment method to the technological task. The optimum adaptive adjusting is based on the complete dynamic initial model of cutting process. Optimization is carried out during all of treatment process and guarantees the optimum conducting of cutting process. Permanent determination of instantaneous position of optimum working point in accordance with the instantaneous cutting process state is carried out permanent comparison of actual values of parameters characteristic sizes. Metal-cutting machine-tools for the heavy cutting, equipped the systems of optimum management on the base of machine-tools with CNC present the high degree of automation and optimization of treatment process presently. At development of the optimum adjusting system intercommunications are developed between statistical and continuous optimizations. The dynamic model of cutting process lies in basis of the optimum adjusting. The values of criteria for the optimum adaptive adjusting present the extreme values of criteria of optimumness of cutting process, proper the objective functions of statistical optimization. A kind and essence of timechangeable values in objective functions is set by the treated signals, characterizing the process of treatment.

System of deviations indemnification from the straightforwardness of sending beds

For heavy lathes dominant influence on exactness is rendered by the geometrical errors of the long-measuring sending longitudinal moving, resilient and thermal deformations of the technological system elements. Thus the last can considerably exceed the geometrical errors of sending. The system is the watching optical measuring system, forming the signal of correction for the drive of transversal serve of heavy lathe. The action of the system is based on measuring of the real position of support carriage in relation to an ideal measuring base which the ray of laser is utilized. The system consists of three basic knots: source of light, sensor of displacement of carriage and system of adjustment of light source (Fig. 1.). As the source of light the low-powered measuring helium-neon laser LGN– 207A is utilized. This device forms the bunch of monochromatic radiation (red area of visible spectrum) with very small divergence (no more than 10"). The laser is placed on a bed near the headstock between sending longitudinal moving under telescopic defense of sending. The adjustment device of the laser allows automatically to make the turn of the laser in vertical and horizontal planes, and also to displace the laser by hand on a horizontal line and vertical line for providing parallelness shining to the axes of centers of machine-tool. An additional optical sensor, set opposite the laser on the opposite end of bed, enters the adjustment system. Similarly as laser, a sensor can be displaced by hand on a vertical line and on a horizontal line. For normal work of the measuring system it is necessary to provide parallelness of laser ray to the axe of machine-tool centers by displacement of laser and additional sensor. An additional sensor consists of four photocells, located in a direct closeness to each other on directions of axes of coordinates (vertical and transversal).

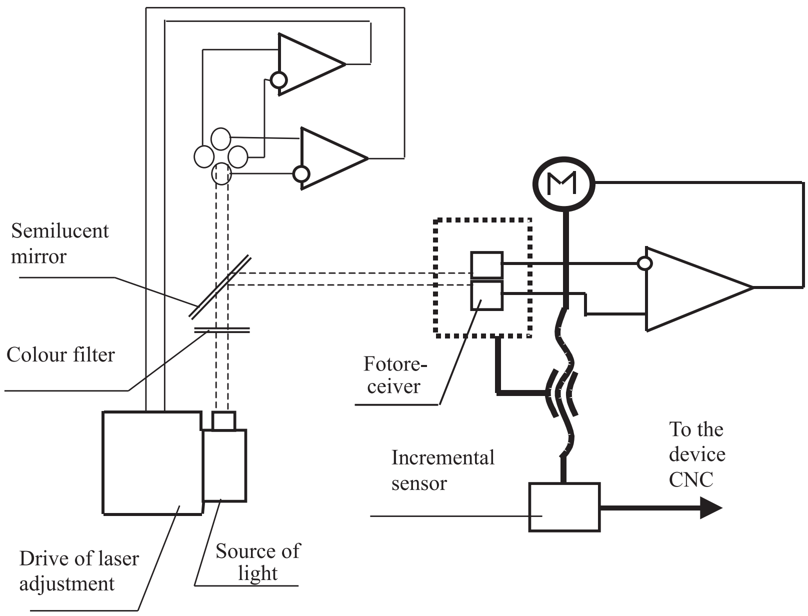

Fig. 1. System of deviations indemnification from the straightforwardness of sending beds

Rys. 1. Sposób rekompensowania odchyłek prostoliniowości łoża maszyny

The adjustment system of laser consists of two watching drives and works as follows. Normally the ray of laser gets exactly between four photocells. Thus luminosity of all photocells and accordingly their output tension are identical. Signals from opposite photocells are given on the contralateral entrances of differential strengtheners. Thus, if tensions on the entrances of differential strengthener are equal, his output tension is equal to the zero. In the case of distinction of entrance tensions output tension is proportional to the difference of entrance tensions and has the proper sign:

$$U_{OUT} = \left(U_1 - U_2\right) \times K,$$

where: U_{OUT} – output tension of strengthener,
U_1, U_2 – input tensions of strengthener,
K – amplification factor.

Output tensions of strengtheners act on the drives of the small moving of laser adjustment mechanism. As a result at deviation of laser ray from parallelness to the axe of centers because of temperature deformations or other revolting factors, shining spot on an additional sensor displaced, changing luminosity of photocells, that results in including of the proper engine of adjustment mechanism, which turns the laser until luminosity of all photocells will not become identical. The sensor of carriage displacement is also executed as a watching drive. The sensor consists of the optical system, including a colour filter, semilucent mirror and carriage with two photocells, mechanical system including an engine of direct current and device transmission screw-nut, moving a carriage with photocells, and counting system consisting of optical incremental (fotoimpact) sensor with the proper controller. This sensor is set on the same shaft with the engine of watching drive.

The sensor of carriage displacement works as follows. Signals from photocells, as well as in the laser adjustment system are given on the contralateral entrances of differential strengthener, and tension of strengthener drives to the action the engine of direct current which displaces a carriage with photocells. Thus, the carriage with photocells "watches" after position of laser ray. Incremental sensor counts the number of discrete directly, which photocells were displaced on, and as the carriage drive with photocells is fastened on the support carriage, it is a number of discrete will correspond displacement of carriage of support from some initial position which is set during initializing of the system and determined position of eventual switches. The counted number of discrete will be transformed with the sensor controller in more comfortable form of presentation, for example in a parallel binary code which is utilized in the CNC system as a signal of transversal coordinate correction.

Application of the adaptive systems at treatment of geometrically-complex wares on heavy machine-tools

It is especially needed to pay a regard to process of geometrically-complex treatment on heavy machine-tools. Characteristic representatives are the rental fellings with the difficult contour of surface, parts of heavy machine-tools, wheeled pair of mobile composition and other. Researches, conducted by a firm "Sandvik Coromant" (Sweden), showed that general charges at grinding of type of the surface rolling of one wheeled pair, with the inefficient depths of cutting (i.e. exceeding the height of the taken off layer of metal and deleted defect - slide-block), made about 70 dollars of the USA on every superfluous millimeter of the taken off metal. The ineffective tooling of the wheeled pair results in the considerable exceeding minimum of necessary stock on treatment cutting, to the promoted wear of machine-tool equipment and growth of expense of cutting instrument. Especially sharply this problem stands in the automated systems of treatment of the wheeled pair, at the lathe-copying chart of treatment.

Providing high performance to making details of difficult type is attended edge cutting treatment with large difficulties. Traditional methods of decision of this task, such as an increase of inflexibility, application of new instrument, to the present tense already uses up itself. By principal reason of increase of expenses on machining process there are breakages of instrument at grinding of the wheeled pair. Therefore basic directions for diminishing of cost of repairs and increase the term of exploitation of the wheeled pair it are been: removal of optimum stock at grinding and diminishing of probability of breakage of instrument.

Treatment of the wheeled pair is conducted at terms, changeability of most parameters of cutting process, variable stock, conditioned both the wear of surface of rolling and comb of wheel and terms of providing of the required geometry after treatment; are different mechanical properties of material on a surface rolling, conditioned difficult thermo-power influence of wheel and rail. All of this corrects to the heavy conditions of work of cutting instrument. Treatment of the wheeled steel has the features: at first, material has enough high hardness 250-300 NV; secondly, steel is viscid. Another feature of repair of the wheeled pair is that the wheeled pair of different producers come on treatment, therefore properties of material can hesitate in considerable limits, plus to it they can be exposed to consolidating or sheeting can be inflicted. An on the average cutting plate (without coverage) maintains grinding of 2-3 wheeled pair (30-45 mines) on condition that treatment of surfaces will be made with small defects. On a picture 3 the wear of instrument is illustrated at treatment of one wheeled pair in a flow 15 min. Treatment on copying wheel-turning lathes is made cup and tangential plates. Character of wear and breakage of plates is different, it is determines the features of treatment. Also the wear of plates depends on the inflicted coverage.

On a production the unique method allowing to avoid breakage of instrument, at treatment of the wheeled pair on a copying wheel-turning lathe there is diminishing of serve of *S* and cutting speeds V, that in same queue negatively to tell on the productivity of treatment. It is therefore necessary in the automatic mode to identify the locations of defect, his type and to optimize the parameters of treatment. For these aims it is expedient to apply the adaptive system. And as a process of treatment is carried by unstationary character, means it is necessary to utilize at once a few informative signals from the area of treatment, the informativeness of signal rises here. The signal of acoustic emission was taken for one of informing parameters as he possesses high noise immunity, especially in area of frequencies of signals of cutting area, exceeding frequencies from noises of workings knots of machine-tool, that provides the receipt of reliable information about the wear of instrument, change of properties of material, quality of the treated surface. However it should be noted that the degree of correlation can between the parameters of AE and probed description of cutting, changes in wide limits, therefore the adaptive system takes into account the change of cutting force, because these parameters are reliably associate. It ensues from aforesaid, that for adaptive control a cutting process the signals of change of cutting force can informing signals serve from time $F(t)$, and from the corner of turn of milling cutter $F(\varphi)$, and also criterion of estimation of signal of AE. Criterion of physical optimization of the cutting mode determined as:

$$W_M = \frac{A^2 \dot{N}_\Sigma}{P_z V_{cut}},$$

where: $A^2 N_\Sigma$ – power of acoustic radiation,

A – amplitude of signal of AE,

$\dot{\mathbf{N}}_\Sigma$ – is activity of signal of AE,

$P_z V_{cut}$ – cutting power,

V_{cut} – cutting speed.

$$W_I = \frac{A \dot{N}_\Sigma}{V_{cut}}.$$

It ensues from expression, that in obedience to a criterion W_I, a minimum of intensity of wear will have places at high speeds of cutting, not causing a sharp increase W_I. However by the lack of application of size parameters of AE, for control of wear of instrument there is a high sensitiveness to changing of instrument (that enough often takes a place in the real terms), I.e. to the change of acoustic resistance of wave highway “area of cutting-sensor”. Because sensor set at some distance from the area of cutting (on support of machine-tool in protected from chip place). Therefore it is necessary to utilize the dimensionless size W_K (statistical factor of current status of instrument) of the peak distributing of signals of AE. Although it reduces exactness of measuring, however allows taking into account static character of cutting process in the conditions of contact a «plate is a chisel block-support:

$$W_K = \frac{N_{MW}}{N_{GEN}},$$

where: N_{MW} – a number of impulses in the narrow range of amplitudes (peak window),

N_{GEN} – a general number of the registered impulses of the peak distributing of signals of AE, here

$$N_{MW} = \sum_{i=j}^{i+k} N(A_i), \quad N_{GEN} = \sum_{i=j}^{n} N(A_i),$$

where: i = 1, 2, 3, … , i, … , j + k, …, n; $N(A_i)$ it is a number of impulses in a single window.

Apparently by an analysis only of variations of W, it is not always possible to identify reason of this change, and, consequently, to accept an adequate decision in the automatic loop of treatment. Therefore criterion of W at adaptive control a cutting process, it is possible to utilize only in a complex with other parameters of AE and traditional thermopower descriptions of cutting process (Fig. 2.). At the construction of the adaptive systems control for complex cutting process control it is necessary to utilize one of informing signals, as a primary informing sign (for example, signal of AE) of stability of cutting process control, and on leaving of him from possible limits it is necessary to include the special system of recognition of the fixed noted anomalous rejections of signal. In connection with that the resilient moving and size wear of instrument are principal reasons of diminishing of exactness of treatment, breakage of instrument can result in an emergency situation and cause waste of detail, consequently, complex approach is needed. Most perspective at the construction of the adaptive systems for complex cutting process control as informing parameters to measure efforts of cutting and description of signal of AE. In future it is necessary experimentally to set correlation dependences of size of wear with informing descriptions of signal of AE and get the practically realized informing of dependence of AE = f(h).

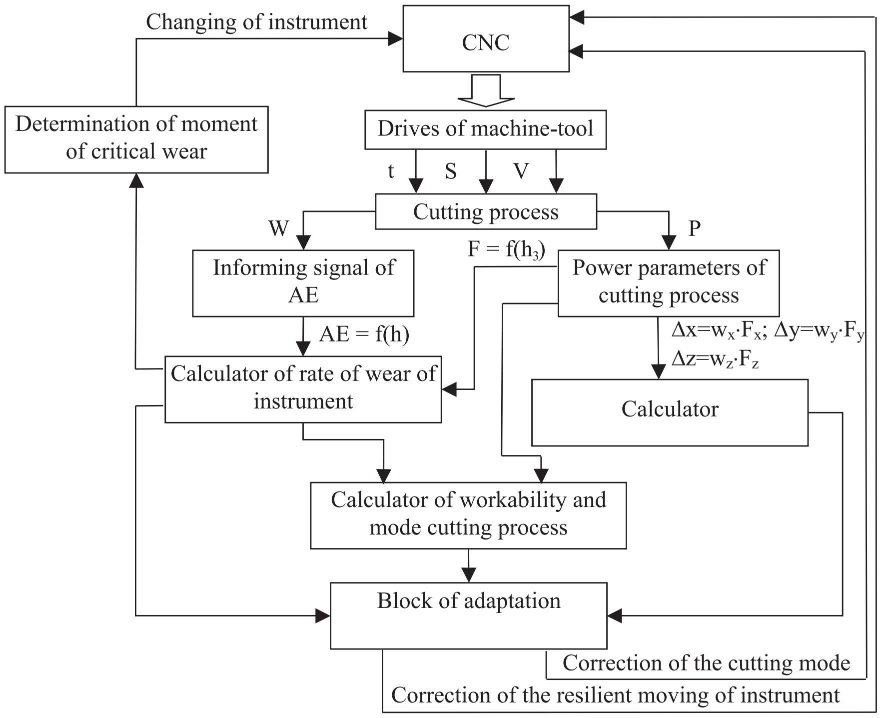

Fig. 2. Flow diagram of adaptive control the system for complex process of cutting
Rys. 2. Algorytm systemu sterowania adaptacyjnego kompleksowego procesu skrawania

Conclusions

The systems of adaptive control of heavy machine-tools must be created as the integrated complex, which includes a heavy machine-tool, systems of instruments, system of adaptive control with the complete sets of measuring and diagnostic facilities, mathematical models of functioning of the technological system. The algorithms of work of the optimum system of adaptive control must be formed with including of criteria: prime price of treatment, productivity, exactness, quality and reliability of the system, etc. The structure of the adaptive technological system must have a high degree of circumference feed-backs: on relative positions and trajectories of shaping motions of the system elements; to their bodily condition and revolting factors. Quality of adaptive control process can be appraised by the theory of quality metering as quality of the difficult hierarchical system, which lets in number to estimate efficiency of different charts variants, define ponderable factors and informing channels of diagnosing. Adaptive control cutting processes must be built on the base of the multilevel system of making a decision with the elements of artificial intelligence.

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MOŻLIWOŚCI STEROWANIA ADAPTACYJNEGO W SYSTEMACH TECHNOLOGICZNYCH NA PRZYKŁADZIE OPRZYRZĄDOWANIA WIELKOGABARYTOWEGO

Opracowano sposób sterowania adaptacyjnego systemu technologicznego jako zintegrowany kompleks, który zawiera wielkogabarytowe oprzyrządowanie, system narzędziowy, system sterowania CNC z kompletnym centrum pomiarowym i diagnostycznym oraz matematyczne modele funkcjonowania systemu z wykorzystaniem sztucznej inteligencji. Opracowano algorytm funkcjonowania optymalnego sposobu sterowania adaptacyjnego przy uwzględnieniu takich kryteriów, jak: koszty obróbki, wydajność, dokładność wymiarowa, jakość oraz niezawodność systemu.

Słowa kluczowe: system kontroli adaptacyjnej, dokładność wymiarowa, narzędzia wielkogabarytowe, sensor

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