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The electrode inspection in integrated manufacturing system

***Abstract**. The article describes Robotic Transport System Flexible Manufacturing System, which is working in the Research Center IMIR in AGH University of Science and Technology. The system includes a EDM electrical discharge machine, System 3R's pallet clamping tools and material and CMM, i. e. a coordinate measuring machine. The results of measurement of dimensions and form deviations of the electrodes using CMM are used among other to calculate the machine offsets in order to correct the positioning of the tool relative to technological bases.*

***Streszczenie.** W artykule opisano Zrobotyzowany System Transportu Międzystanowiskowego Elastycznego Systemu Wytwarzania, który pracuje w Centrum Obsługi Badań Naukowych i Dydaktyki WIMIR w Akademii Górniczo-Hutniczej w Krakowie H. W skład systemu wchodzi eletrodrążarka, system mocowania paletowego firmy 3R narzędzia i materiału oraz współrzędnościowa maszyna pomiarowa. Wyniki pomiaru parametrów wymiarowo-kształtowych elektrod w cyklu pracy systemu, pozwalają m. in. na obliczenie offsetów elektrodrążarki i korektę pozycjonowanie narzędzia względem baz technologicznych. (**Kontrola elektrod w Zintegrowanym Systemie Wytwarzania**).*

Keywords: Coordinate technique, integrated manufacturing systems.
Słowa kluczowe: Technika współrzędnościowa, zintegrowane systemy wytwarzania.

Introduction

EDM (Electrical Discharge Machining) is a process of removing layers of material from the machined surface due to the phenomena of electrical discharges between the workpiece and the material of the working electrode which are immersed in the dielectric fluid. During the EDM process the forming is made by mapping the shape of the electrode in the workpiece material.

During the loss of workpiece material, the working surfaces of the electrode are subjected to simultaneous erosion. Other phenomena, such as the effect of thermal processes and dielectric impact are causing swelling and the formation of accretions, resulting in further deformations of the electrode shape and changes in dimensions. As a result of these interactions, the working surfaces change position relative to the machine axis and the axis of the handle, causing changes in the surface of the object mapped by the erosion. The result of progressive changes in the tool geometry and the wear is deprivation of ability to perform the machining within a specified accuracy range

Improvement in this area brings tool monitoring [1-2]. Monitoring can relate to many phenomena accompanying change in tool conditions.

The solution, which has been used in the planning and automation system WorkShopManager (WSM), working in the center IMIR AGH, is the electrode inspection by means of the coordinate measuring machine (CMM). The results of electrode measurements can be used to correct the zero points of EDM machines and to compensate thermal drift. In conjunction with robotic operations loading of objects it gives a full control of production.

Description of system WSM

System 3R International AB schema is shown on Figure 1 [3]. The system consists of EDM machine (Roboform 350 Sp) to manufacture the workpieces, 3R robot for loading workpieces and tools in and out of the machine and for using the identification cycles (Work Master robot) and CMM (DEA Global Performance). The CMM can be used for measuring the offsets of workpieces and tools before machining and for quality control measurements after machining. Software of CMM cooperates with the EDM Preset and Measure (EDM P&M) software. The interface of this software allows the formulation of commands and the event handling. The main functions are special macros, to control the calibration procedure, and transferring the parameters of the electrode. The central element of the system is a five shelves magazine M1-M5, with modular construction.

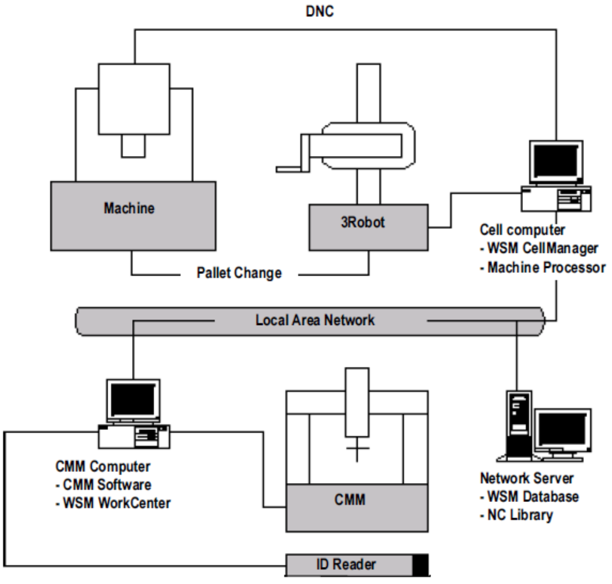


Fig.1. WorkShopManager system schema

It is possible to load into a cell on magazine rack the tools and the machine pallets with dimensions of 400x400 mm carrying the objects on them. In order to identify workpiece pallets and tool holders ID readers are used.


Fig.2. The loading cycle

The robot is able to identification the tasks and controls the cycle of work. The typical task of the robot is loading objects (on pallets) and the tools from the magazine to the machine or, conversely, downloading them.

Robot also supports the inspection by placing the palettes and tool holders on the CMM table chuck, and after measurements forwards them to the magazine or directly onto EDM machine (Fig. 2). The measuring program of CMM determines offset values, which are retrieved by WSM Work-Center. The NC programs, offset values and adjustments are sent to the computer and to the EDM machine.

The typical deviations of the hollowed surfaces

The accuracy of EDM machining is evaluated on the basis of deviations of actual geometrical characteristics of surfaces to their nominal geometry, which is described by the dimensions, the geometric tolerances, as well the parameters of micro-geometry surfaces (roughness, waviness). A measure of the ability of the electrode to machining a product in a specific accuracy is to keep the values of deviations within the certain ranges. In the presented study the last aspect of the quality of surface was omitted, because it was studied in many works and quite fully recognized, [4-6].

Dimensional deviations

Many factors cause disagreement of the product dimensions. The most important of them is the thermal expansion of the material from which the tool is made. The most popular material is a copper, which has high thermal conductivity. This can cause significant elongation of the electrode, in proportion to its length, so-called a thermal drift, especially during roughing machining.

Shaped by EDM dimensions of surface depends primarily on the dimensions of the electrode, but also on the dimensions of the channels delivering the dielectric fluid, gap width or the type and quality of the dielectric fluid, and other many factors associated with the process (eg. Voltage, current amplitude, etc.) [7]. These factors are influencing the tool wear, indirectly, also they have an influence on the dimensional accuracy of the product.

Size of dimensional deviations, calculated as the difference between the actual dimension and nominal value, can be associated with a linear ratio of the electrodes wear and the layer thickness of the workpiece, measured in parallel with the the direction of feed movement. Both parameters can be determined experimentally, but an irregular wear is expressed indirectly affecting the positioning accuracy and the tool path which is more difficult to estimate by the traditional method. In addition, the quality of face surfaces perpendicular to the feed travel differs significantly from the quality of the side surfaces or sharpened contour points, as there are differences between fuel wear or corner wear of electrode.

To check dimensional correctness of the hollowed product must first determine the value of dimensions in both planes, perpendicular and parallel to the feed movement, and – if possible – the radii of corners.

Form deviations

Form deviation arise mainly from differences in the distribution of wear on electrode surfaces, from the clamping system errors, from electrode guiding along the workpiece, as well as from the variability of the gap between workpiece and electrode. It increases the resulting dimension of its thickness.

The traditional measure of variation of electrode length is taken as a biggest difference thickness of the electrode surface, with uniform thickness of the removed material [8]. These differences express the form deviations of flat surfaces of the tool.

Deviation form of the machined surface of the workpiece is a difference between real (manufactured surface or contour) and the corresponding ideal nominal geometry.

According to the definition of the form tolerance in [8], it can be expressed by the greatest distance of the quasi–parallel boundaries of a zone, in which the entire surface of a real feature, its line element, its axis, or its center plane remains.

The correction – offsetting

Applying two or more electrodes of the same shape during machining process, working one after the other, limits the influence of factors which make worse the geometric accuracy. An effective approach is the form-dimensional compensation, used in advanced manufacturing systems. It is possible to correct the tool positioning with respect to workpiece or its trajectory using a numerical method.

In the machine class of Roboform 350 Sp the form-dimensional compensation requires entering in NC program line the parameters involving the changes in depth and width of the machined features.

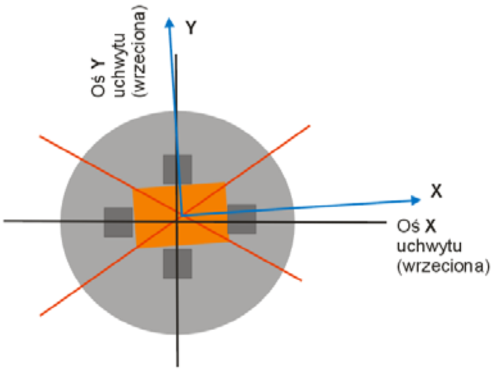


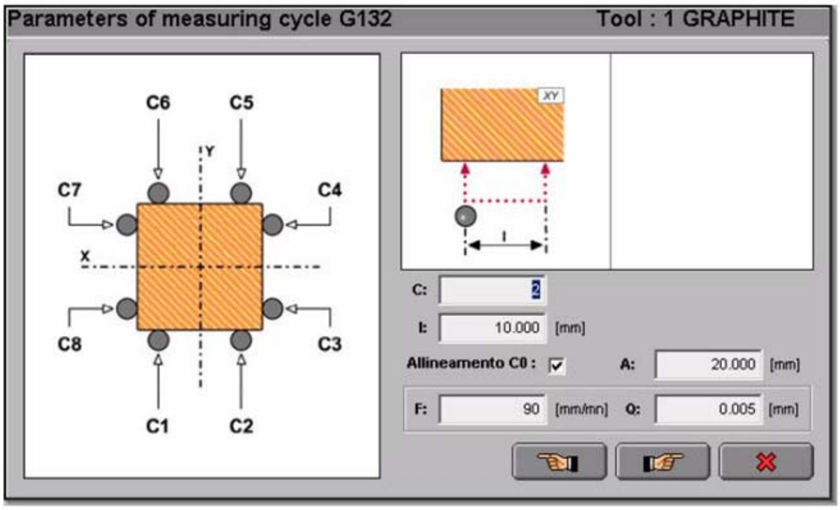
Fig.3. The parameters of the tool setting correction

The adjustments for tool setting and tool trajectory require entering the X, Y coordinates of center point of electrode position clamped in the machine chuck, as well the rotation C angle of their axes with respect to the EDM machine axes. The X, Y coordinates are referred to so called *zero point*, that correspond to the origin of the coordinate system associated with the spindle chuck (Fig. 3).

These parameters necessary to carry out of the correction can be determined by measurements directly on the workstation on which the machining process is executed.

For exemplary electrode, with the shape shown on Figure 4, the operator of the EDM machine can use the automatic measuring cycle *rib - pocket* (the G132 cycle: tool setting).

Automation and integration of measurements with manufacturing process implemented in WSM system allow you to perform the above operations using coordinate measuring machines. This allows you to release EDM machine from the measuring operations and from the need to reconfiguration (eg. installing the standard ball for the duration of the measurement). What's more, it allows to use the software of measuring device having much higher computational potential than the capabilities of the EDM machine.



Parameters of measuring cycle G132 Tool : 1 GRAPHITE

C: 2

l: 10.000 [mm]

Allineamento C0 : ☑

A: 20.000 [mm]

F: 90 [mm/mn]

Q: 0.005 [mm]

Fig.4. The automatic measuring cycle *rib* – *pocket* of the Roboform 350 Sp system

The measuring cycle is defined by the operations sequences, which are included in the macro of the EDM P&M software [9]. The macro has the form of the NC part program programmed in DMIS standard. The macros register the points probed on electrode surfaces, which are transferred to the EDM software. These data are then used in order to calculate the X, Y coordinates, the C angle, and additionally the form deviations of tool surfaces.

The chuck calibration

The head with electrode pulled from the EDM machine is clamped in quick-change pneumatic chuck, which is placed on the CMM table. The construction of this table chuck imitates the geometry of the chuck for directly mounting the tool into a EDM machine spindle.

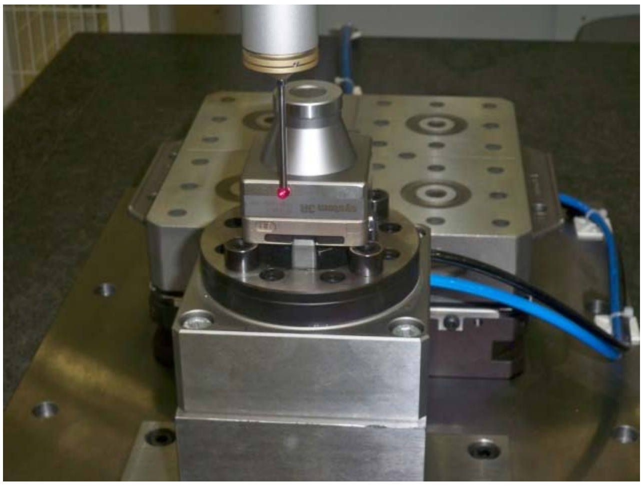


Fig.5. The calibration of the chuck placed on CMM table

The calculated parameters are referring to the coordinate system that is defined basing on the measurements of this base chuck.

The calculated coordinates of the center point of electrode should cover the origin of the coordinate system corresponding to the chuck axis, and thus theoretically it should correspond to the position of the EDM machine spindle. The observed differences are representing the displacement of the center point against the machine spindle axis and they are taken as the values of parameters correcting the tool setting.

The position of the origin point of the system can be subject in fact to the errors arising from the measurement of the chuck or to its actual deviations. To identify the errors of the chuck on CMM table before the electrode inspection the calibration using the reference part is performed, as Figure 5 shows.

The conception of research

A radical elimination of the deformations of the electrode geometry or changes on dimensions due to the high temperature is not possible, however monitoring the tools can significantly reduce these impacts. The surface quality achieved by EDM machining on a set of process parameters to a large extent will then depend on category of cutting machine as well its equipment. Researches on repeatibility of the tool mounting in chuck ware presented in [10] confirmed high stability of 3R clamping system.

According to the concept of prevention of defects in modern manufacturing systems, the information from the tool inspection is used directly for modification the manufacturing process. The inspection carried out periodically is not limited to the tool condition, but interferes with the process itself. As a result of inspections arises a diagnosis of tools that can be transferred to the machine's controller, taking an appropriate action (to correct or to compensate). It is not possible to determine universal rules fixing the frequency of inspection tools. The frequency depends on the requirements which are imposed on a particular process, for example the required accuracy of the product, the size of product series or production costs depending on time of manufacturing the product.

The increasing time intervals results in an increase of the deformations of the tool geometry and the deterioration of the quality of the product. Performing the electrode inspection is a decision that should be based on the recognition and consideration of these issues.

The first is selecting the numerical indices, which will allow to assess possible level of geometric accuracy for repetitively machined features, basing on their measurements eg. the hollowed cavities.

It is therefore necessary to test the relation between the accuracy of machined part and the varying parameters describing the geometry of the electrode. Acceptable form deviation of the working electrode surfaces should be entered into the program EDM P&M to judge whether the actual deviations allow further tool exploitation.

The indices, which inform you about gradual deformation of EDM tools are wear indices. Assuming a regular wear of the electrode, absolute value of wear depends on the thickness of the removed layer of material. It is well characterized by a linear wear rate of electrode, used in practice in order to determine whether the wear degree is acceptable.

As a result of irregular wear of working electrode increases irregularity of the eroding the surface of the workpiece. In this case the deterioration of the surface is expressed not only by changing the dimension of hollowed feature dependent on linear wear of the electrode, but also by the appearance of irregularities for which the suitable measure is the form deviation.

In order to recognize these issues a series of investigations has been conducted. Was assumed that will be examined the relation between the deviations of electrode geometry, caused by the erosion and others factors occurring in practical machining circumstances, and the same kind of deviations of the machined feature.

The deviations of the geometrical features of flat square cavity (*pocke*t) were considered. The possibility of using indices that characterizing the condition of the electrode to evaluate the ability of obtaining specified surface accuracy was examined.

Design of experiments

The specimen. It was assumed that they would be made the square cavities in the solid material. The hollowed shape reflects the geometry of the electrodes. The features were to be repeatedly positioned on the three rectangular specimens, visible on Figure 6, for which the specified accuracy was the same. The cavity position on a specimen and the axis of the cavity was defined in relation to a workpiece coordinate system. After preparation of the specimens the EDM machining process was developed. For each cavity the surface to remove was 18mm x 14mm x 10mm. The specimen material used in this study was stainless steel hardened up to 56 HRC.

The electrodes. Three electrodes were used in conducted experiments. Figure 6 shows the type of electrodes. They were made from electrolytic copper (M1E). This material allows to get the accurate surfaces, and at the same time is subject to an accelerated wear because of low melting point. Before EDM machining the faces and sides of electrodes has been milled and finished.

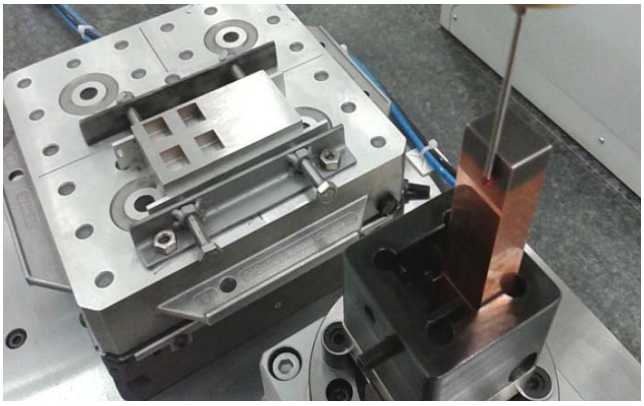


Fig.6. The electrode and the four hollowed cavities

The highest roughness of the electrode surfaces measured by TOPO L250 IZTW was found not more than Ra = 0.5 μm, Rz = 4.2 μm. The dimensional parameters and geometrical deviations were measured. In order simplifying further analysis the measurement results were saved in files.

The EDM machine. The experiments were performed on Roboform 350 Sp supplied by Charmilles Technologie.

The identical EDM process parameters were used in a single machining cycle, i.e. adequate for previously stated value of Ra roughness parameter. No wear compensations of electrode nor adjustments were used. The experimental setup presents Table 1.

Table 1. Experimental setup

	Cycle 1	Cycle 2	Cycle 3
Machine	Agie Charmilles EDM machine ROBOFORM 350 Sp		
Material	NC6		
Eroda	M1E		
Adjustment Ra [μm]	4	5.6	6.3
Cutting depth [mm]	10	10	10
Peak currents [A]	9	13	15
Voltage	25.5	25.5	25.5

The machining. The same experiment was repeated with all three electrodes. Each electrode performed machining the eight cavities on each specimen, successively positioning one after the other.

The measurement station. The CMM Global Performance was used with measuring range (in mm) 500x700x500, and accuracy MPE_E=from 1.5+L/333 μm. It is model developed for industrial use and for work in the production floor, equipped with PC Dmis software.

The tool measurements. The electrodes were measured after machining of each cavity using CMM. The following geometrical deviations were examined: straightness and flatness of the face and side surfaces, dimensional deviations as width and length deviations at cross-section, as well the coordinates of the center point. The measurement results were saved in files.

The workpiece measurements. After completion of the machining task the specimens were also measured by means of CMM. We calculated, as in the case of the electrode following parameters describing the cavity geometry: straightness and flatness of bottom surfaces and sides, cross-sectional (perpendicular to the feed motion) dimensional deviations, as well the coordinates of the central point were calculated. As above, the results were saved in files.

The results

Measurement results from each electrode measuring cycle were compared with results obtained from measuring the corresponding feature, that were machined before. It was observed that the most affected by variation of the shape and dimensions of electrodes were such characteristics as the depth of the cavities and the flatness of the bottom surface cavity. This confirms the nature of the phenomena accompanying hole machining for which the area influencing the material are electrode faces more than side surfaces [11]. These characteristics were analyzed further.

It has been found for each set of process parameters that deviations of cavity depths were almost proportional to the linear loss of electrode.

The relationship between the dimensional deviations of the electrode and the differences in the width of cavities with respect to the specified cycle was not so apparent. For example, for first specimen and for stated Ra=4 μm, the loss of the electrodes after machining the third cavity had a value of 0.012 mm (measured in a cross section of 2 mm from the electrode face), and the corresponding displacement of the fourth cavity (2 mm from the upper surface of the specimen) was just 0.015 mm.

Deviation of flatness to the bottom of the cavity changed noticeably with changes flatness deviation on the electrode face. Flatness measurements were performed in the scanning mode, using Leitz measuring head, which allowed for a good representation of the surface. In the third machining cycle (third specimen, Ra = 6.3 μm) flatness deviation of electrode after the first cavity was 0.030 mm, and after the eighth cavity it increased to a value of 0.177 mm. The deviations for the specimen changed in the range of 0.051mm (following the first cavity) to 0.154 mm (eighth hole). Similar dependencies could be observed for measurements of specimens obtained under the conditions of use of specified sets of process parameters.

Neural networks

A tool for overall assessment and monitoring of relationships between parameters characterizing the state of the tool, parameters of machining process, and the geometric characteristics of semi-finished products are artificial neural networks, which takes into account the new information collections [12].

The intention of creating the artificial neural network was prediction the change of the surface quality after the entering the information about the status of electrode (measurement results).

The Matlab program with the tool box nftool (Neural Network Fitting Tool) was used for modelling the neural network and calculations. The one-way two-layered neural network, with one hidden layer of 10 neurons and one output layer was modelled by nftool. The neurons in the hidden layer was activated by a sigmoid function, in the output layer by the linear function.

The neural network has two inputs: the parameter Ra of EDM machine and electrode wear and one output representing the dimensional deviation of workpiece. Learning of neural network was carried out using the Lavenberga-Marquardt feedback-propagation algorithm. The learning process was based on data obtained in the experiment.

After the learning process, dimensional deviation of workpiece map was generated by the artificial neural network. The exemplary surface was shown on Figure 7. The relationship between Ra parameter and electrode wear indicate that the smallest dimensional deviation of workpiece occurs when the small value of the Ra parameter is selected. We can observe the biggest dimensional deviation of workpiece when we have a low value of electrode wear and the big value of Ra parameter is selected.

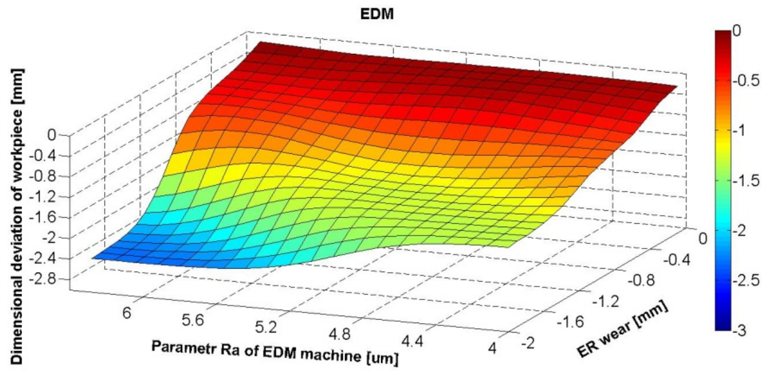


Fig.7. Estimated values of the dimensional deviation of the cavity depth

SPC elements in the assessment of resulting accuracy

The acceptable level of tool deformation occurring with a specific process parameters depends on the surface accuracy being intended. In general, for any roughness stated in EDM process the resulting accuracy can be different. The accuracy is determined by the tolerance for given geometric characteristic of the feature.

Assessing the capability of the tool to obtain the assumed quality of the surface two previously considered parameters can be employed as the indices for this purpose, i.e. the dimensional deviation measured parallel to the feed with respect to original length (linear loss of electrode) and flatness deviation on electrode face.

The ratio of the parameter value to the corresponding product tolerance interval will be informed about the effectiveness of the process, i.e. the degree of achievement of the planned results. Limits of acceptability should be stated before. If the indicator gains an established value it may indicate the need to take corrective action (preventive activities).

The developed neural network allows to obtain the anticipated values of selected characteristics, describing the quality of the product. On this basis is possible to elaborate a decision about tool inspection, the result of which is the determination of values of process correction.

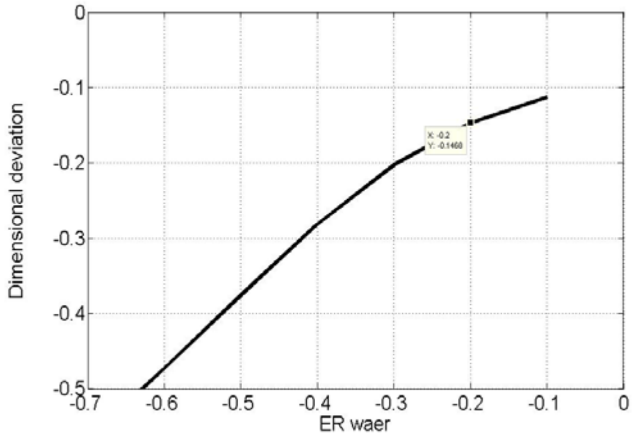


Fig.8. The determination of the anticipated deviation of cavity depth for selected Ra = 4 μm

The Figure 8 shows how to anticipate the dimensional deviation of the bottom surface of cavity taking into account the linear loss of electrode, determined with respect to original length. For example, if from electrode measurement the linear loss is 0.2 mm, the anticipated dimensional deviation of machined cavity will be 0.1458 mm.

For process parameters and specified level of surface quality will be existed a limit number of cavities, after which the electrode must be replaced or regenerated, regardless of the correction of machine.

Conclusions

The analysis of the results of the experiments has been performed. The experiments were aimed to determining the influence of the linear wear and surface irregularities of the electrode on the geometrical characteristics of the product. The dependencies between the form-dimensional deviations of the electrode geometry and the deviations of machined surface were analyzed. Based on the selected measures shall be drawn diagnosis of tools that can be transferred to the system taking appropriate action.

In order to propose a convenient method for determining the time interval between successive cycles of tool measurements the neural network has been developed, basing on the empirical data. The obtained results allow for planning further researches to improve the diagnosis of electrode and increase knowledge of the properties of this unconventional technique of forming the product, as EDM machining.

Finally, it should be taken into account that monitoring of the tools condition can bring significant benefits in terms of achieving better quality of products, automate processes, and reduce human involvement in the process on the way of elaborating a decision.

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