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METHODOLOGY FOR SOME ORIENTATION AND CLAMPING DEVICES INTEGRATION ON CNC MACHINE TOOLS

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***Abstract**: The paper presents some general applications regarding the evaluation of the basic devices functions, them behaviour under the action of cutting forces and moments in order to integrate them into advanced production systems. For establishing the adaptation solution, the presented methodology proposed the connection of the classic methods of analysis from 35technical point of view with the modern ones, which involves the using of the IT, everything evaluated also from economic point of view. In this way, it is confirmed the idea that a solution that is technically accepts, under the conditions of the market economy, it cannot be take into account only if it fulfils the conditions of profitability and efficiency.*

Keywords: orientation and clamping device, CAD, FEM, sensors, methodology

EVOLUTION OF THE TECHNOLOGICAL SYSTEMS

Subsystems that are part of the technologic system are the machine tools, devices, cutting tools, tools manipulators, workpiece surfaces, workpieces manipulators, systems for chip exhaust, control systems and tools control systems. The economic medium, in a permanent change, determined the evolution of the technologic systems in flexible systems [13], flexibility becoming a dominant characteristic of the production systems. For determining a cutting process the cutting tool and the workpiece must be brought together in the working space of the machine tool, with orientation points rigorously defined. For creating the link between the tool and the machine tool assembly are mainly used chuck systems, when the clamping force F_f is created mechanically [4] or hydraulically [14]. Another way of fixing the tools is related to the using of modular systems [15], which have the advantage of a rapid procedure of changing by standardized connection elements**.**

CUTTING PROCESS-THE DEVICES PERFORMANCES EVALUATION FRAME

The requests of the international market are related to the existence of the high quality and adaptability products, at low production costs, that contribute to the permanent development of all machine tool components, cutting tools and clamping elements. In the last years the knowledge development of the cutting process has focused on the dynamics behaviour, on the processing accuracy, cutting forces and moments, tool wear for the basic technologic processes, fact that determined the improving of the machine tool performances by using cutting tools with superior technical performances and advanced applications for materials. The machine tool, as a component of the technologic system, is important to be capable to assure performances as: rigidity, processing process stability, high dynamic performances, precision. The interaction between the geometric shape of the workpiece, processing process, cutting edge of the cutting tool and the machine tool as a system must be modelled by simulation in a most appropriate way to the reality by using the virtual medium [1]. Global competition on the market has contribute to the increase of the manufacturers of automatic fabrication system attention regarding the improvement of the monitoring techniques and

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procedures on multifunctional machine tools for the products quality improvement, eliminating the control stages and increasing productivity [5]. The command system has a decisional role and also in assuring the hole command chain of the operational part of the machine tool. The commands are applied to the actuators and the information is send to the sensors [3]. The control equipment must be capable to receive, identify and process the information related to the environment, to save and process information working medium, to monitor them and send them back to the machine tool. The supervising capability of a monitoring system largely depends by the system ability to identify any error and to offer, in real time, the appropriate answer [2]. During the cutting processes the evaluation of the cutting forces F_c has a great importance for industrial applications but also for research. The estimation of the cutting forces F_c permits the tool wears supervising, the processing surfaces quality prediction, establishing the material workability properties, the cutting parameters optimization and studding the chip formation and vibrations

THE DEVICE, COMPONENT OF THE TECHNOLOGIC SYSTEM

In every technologic system the devices represents links with some or all of the components elements. These are a unit from technologic point of view, constructive and functional, which established and maintain the workpiece/tool orientation, with the possibility of realizing some of the machine tool or of the operator functions. The orientation and fixing devise must fulfil a series of conditions like simple construction, rigidity, a certain modularization level, adaptation al the flexible fabrication, maintaining the position of the workpiece and cutting tool during processing under the actions of the cutting forces F_c and moments and of the inertia forces and not to determine the vibration intensification during the cutting process. The orientation and clamping and entrainment devices for workpieces and tools must continuously adapt to the process parameters and cutting forces and moments increasing, ensure a safe clamping and adapt to the development of the processing materials and tools.

MECHATRONIC CLAMPING DEVICE, COMPONENT OF THE MODERN TECHNOLOGIC SYSTEMS

The mechatronic system is a technologic system which integrates, in a flexible configuration, mechanics, and electronics and command components with numerical systems, for an intelligent control, for obtaining of different functions.

The principal characteristic of these type of systems is represented by the adaptation capacity, in a permanent way at the external conditions, the information supplying of different signals (mechanic, electronic, pneumatic, optic), by the automatization extension.

The characteristics, and also of the devices, are related to the multifunctionality, intelligence - which represent the ability to communicate with the medium and take decisions, flexibility – the possibility to be modify, without major difficulties, for different applications, because of the modular construction, the possibility to be command at the distance – which impose the knowledge and use of different interfaces of communication, permanent evolutions – because of the market dynamics and technologic possibilities of processing. These are composed [7], from a basic assembly in which mechanics, electrics and physical components are integrated to control the material, energy and information flux. The researches on the clamping devices for machine tools with reference for orientation and fixing systems have led to the development of active systems clamping with automatic positioning, orientation adaptation and error possibility correction.

THEORETIC APPLICATIONS REGARDING THE CLAMPING DEVICES PERFORMANCES EVALUATION AND THEM INTEGRATION IN ADVANCED PRODUCTION SYSTEMS.

From the analysis of the situation that exists on the international plane was identified the necessity of establishing a methodology for determining the performances of the clamping devices. The methodology will comprises the following steps: analysis of the workpiece, orientation surfaces, technologic processes and tools, production type, process parameters, knowledge and determination of elements loadings (cutting forces and moments, clamping forces), determination through modelling and simulation of the most stressed elements of the device structure, in the most unfavourable case.

As stages for the performances evaluation of an orientation and fixing device adaptable on a machine tool in an advanced production system, the most important are: the analysis of the constructive solution, determining of the clamping force F_f, developed by the device, modelling and simulation of the device behaviour under the action clamping and cutting forces. Analysis results led to the solution establishing for a sensor or transducer emplacement, which signal is compatible with the CN equipment of the machine tool [10].

Aspects that are taken into consideration when it is realised a clamping configuration are related to the processing type (milling, boring), the shape and the workpiece dimentions (rectangular, cilindrical) and its material (steel, aluminium, bronze), because the work-piece needs different design strategies for the orientation and clamping configurations, beeing necesary in most of the cases the canceling of six freedom degrees (rotations and translations).

The elaboration of the clamping configuration involves the establishment of the locators positions and the rigid fixing on the workpiece, taking into consideration it's shape and dimensions, the material and the processing requests.

A processing device, for fulfilling the functional role of orientation and fixing of the work-pieces for processing, must contain in them structure orientation elements, supplementary locating elements, clamping elements or subassemblies, adjustment and guiding elements for the tool, contact elements with the machine-tool.

For the prismatic workpieces a well-known method from the literature [6] and very often used is the principle 3-2-1. In this case the workpiece is being positioned using three perpendicular planes, the plane in which the workpiece is laid being the principal one. The secondary plane come in contact with two lateral locators, R_1 and R_2, and the tertiary plane is the one with only one locator R_3**.**

The orientation and clamping system must ensure a sufficient clamping force F_f, as during processing to maintain the position of the workpiece, under the action of forces and moments which tend to remove it from the equilibrum position, fact that have as principal consequence the obtaining of diferent dimensions or removing the workpiece from the device.

The application point, the direction and the sense of the clamping force F_f are established in a way to maintain the equilibrium of the workpiece on the locators and to avoid the deformation in the contact points. Clamping of the workpiece it can be realized by the application of the clamping force F_f on a surface that is parallel with the one of the locators pe R_1 şi R_2, figure 1, perpendicular on the surface of the locator R_3, parallel with one that the workpiece lays or at a specific angle with the surfaces for the locators R_1, R_2 and R_3, figure 2.

In figure 1 is represented a prismatic workpiece, orientated and fixed on the principle 3-2-1. The locator R_3 is opposite to the proccesing force, which is considered to be the cutting force F_c, and the locators R_1 and R_2 are positioned al distance l, respectively m related to AB, which marked the lateral surface of the workpiece. Locator R_3 is positioned at y_1, and F_c act al distance y_2. The clamping it is realized on the surface parallel with R_1 and R_2, at distance n.

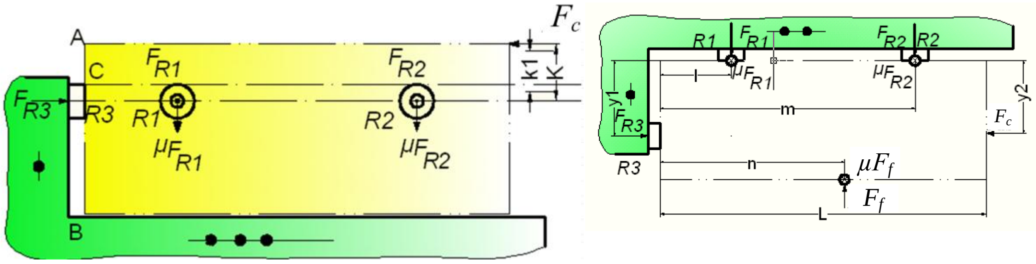

Figure 1. Upper and frontal view of the workpiece into the device [12]

For determining F_f first stage represents the establishing the forces and moments that acts on the workpiece surface. After establishing the application point, direction and sense of the clamping force F_f, is determined the reaction force from the locators R_1, R_2 and R_3, taking in consideration them position on the workpiece, the value and the application point of the clamping force F_f. It follows the determination of the necessary clamping force, as a function of cutting force F_c, the position of the clamping force and of the locator R_3.
When the cutting force and the reaction force from the locator R_3 acts at the same distance from the end of the workpiece, the reaction force from the locators R_1, R_2 and R_3 and the clamping force can be determined using the formula (1- 4).

$$F_{R3} = F_c \tag{1}$$

$$F_{R1} = \frac{m-n}{m-l} \cdot F_f \tag{2}$$

$$F_{R2} = \frac{n-l}{m-l} \cdot F_f \tag{3}$$

$$F_f = \frac{k}{2 \cdot \mu \cdot n} \cdot F_c \tag{4}$$

The values for the reaction forces from locators R_1 and R_2 for a prismatic workpiece with the dimensions 176x88x50, for different values of the parameters n, m and l can be represented in figure 2, taking into account that the clamping force and cutting force act at the same distance from the end of the workpiece, for F_f=823N and F_c=580N

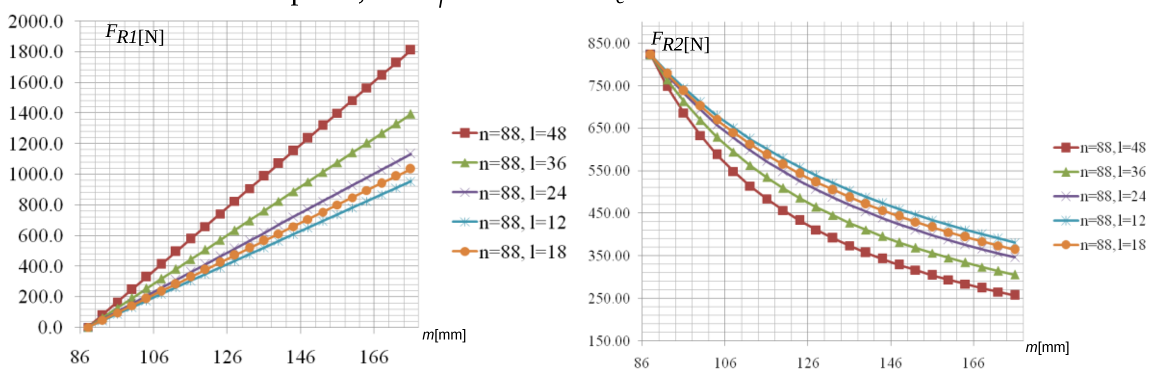

Figure 2. Variation of the reaction forces F_{R1} and F_{R2} from locators R_1 respectively R_2 [12]

A similar analisys it can be realised when the claping force F_f is applied at a certain angle with the laing plane of the three locators, as represented in figure 3. In this case, for the procesed workpiece, the locators R_1 and R_2 are positioned at length l, respectively m from AB. The locator R_3 is positioned at length y_1, and the cutting force F_c acts at distance y_2. The workpiece clamping is realized at α angle. For establishing the relations is used the methodology anterior presented, particularized for the analyzed situation.

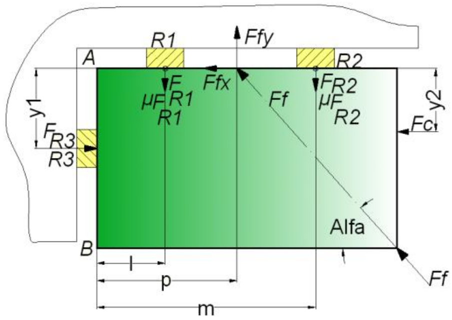

Figure 3. Workpiece into the device – upper view

It is determined:

$$F_{st} = F_{as} \cdot \frac{[-k + \mu \cdot (y_1 - y_2)]}{\cos(\alpha) \cdot (k - k_1 - n - \mu \cdot y1) - \mu \cdot \sin(\alpha) \cdot p} \tag{5}$$

$$F_{R2} = F_{st} \cdot \frac{\sin(\alpha) \cdot (p - l) + \cos(\alpha) \cdot y_1}{m - l} + F_{as} \cdot \frac{y_1 - y_2}{m - l} \tag{6}$$

$$F_{R1} = F_{st} \cdot \frac{\sin(\alpha) \cdot (m - p) - \cos(\alpha) \cdot y_1}{m - l} - F_{as} \cdot \frac{y_1 - y_2}{m - l} \tag{7}$$

For the particular case of a prismatic workpiece 176x86x50, for y_1=y_2, F_c=580N, F_f =1189, the clamping angle is 45°, the variation of the reaction forces in the locators R_1 and R_2 are presented in figure 4.

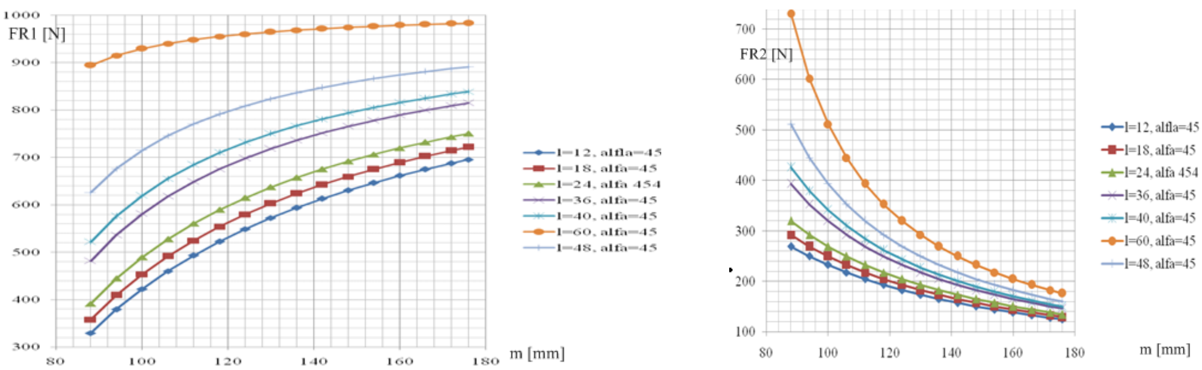

Figure 4. Variation of the reaction forces F_{R1} and F_{R2} from locator R_1 respectively R_2 [11]

NUMERIC RESEARCHES ON MODELS REALIZED BY MODELING AND SIMULATION

Performances analysis using FEM has as purpose the static behaviour determination for the analyzed system, to determine on one hand the frequencies and vibration modes and on the other the most stressed element in the device structure, on which is recommended to be

located a displacement sensor for transforming the device in a mechatronic one for its integration in advanced production systems.
A stage in the numeric researches is represented by the functional–constructive analysis for a modular clamping device, with screw clamping mechanism and adjustable locators. For this device were first analyzed the reaction forces on the three locators of the device, taking into consideration the position of the cutting force and of the clamping point. The workpiece (1) is positioned using three perpendicular planes, the laying plane of the workpiece being the one of the modular motherboard (2), with T channels, as in figure 5.

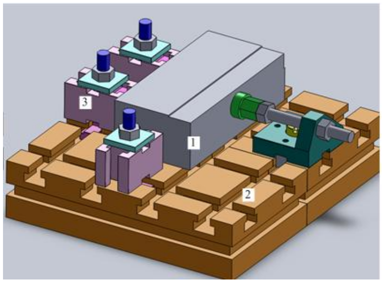

Figure 5. Modular fixing device [10]

The secondary plane come in contact with two lateral locators, R_1 and R_2, (3), and the tertiary is the one that contains a single support (4). The element, which assures the clamping of the workpiece, it can be used in different positions on its surface. The orientation and clamping device is realized in a modular structure, with interchangeable and reusable components. With the help of the orientation configuration are cancelled 6 freedom degrees. On the device can be generated some adjustments imposed by the cutting parameters, the shape and the dimensions of the workpiece, its positioning on the machine table, adaptation from dimensional point of view, because of the multidimensional modular elements. In addition, by attaching sensors and command systems it can be realized the force control, them adaptation to the optimal values and the inclusion of the device in a technological system tool-workpiece machine tool-manipulation system autonomous.
Performances evaluation of the mechanical structure of a modular clamping device supposed the determination of the deformation and equivalent stress (von-Misses) when the clamping force is 1000N. As a result was established that the maximum deformation is 1.86 μm, figure 6, respectively the maximum specific deformation is $3.4e^{-5}$, figure 7. Analyzing the results it can be said that the deformation is in the admissible limits and in not affected the processing precision.

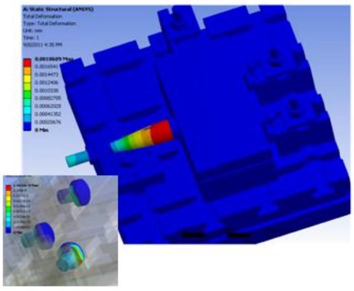
Figure 6. Total static deformation

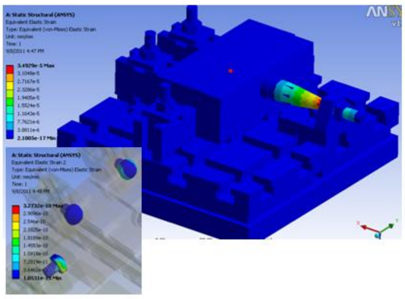
Figure 7. Total equivalent stress

Another important step in evaluating the performance of the device by numerical researches is the modal analysis, which is commonly used to determine the dynamic characteristics of structure analysis, namely frequencies and own vibrations modes. Were determined the first 6 frequencies. From the analysis of obtained data by simulation, for the screw, it is found that the first vibration mode is the simplest, and corresponds to the static deformation and has no inflections points. The second vibration mode is also a bending mode but in another plan. The third mode of vibration corresponds to the twisting of the front end. In mode 4 is a first inflection point. As the mode of vibration increases its frequency, vibration mode of deformation complicates the contribution of total deformation mode decreases. Structure does not vibrate after the first or the second mode, but after a linear combination of all modes of vibration. The first vibrations modes have the most important contributions.

EXPERIMENTAL RESEARCHES REGARDING DEVICES PERFORMATIONS EVALUATION AND INTEGRATION IN ADVANCED PRODUCTIONS SYSTEMS

Researches related to the jaw chuck clamping systems monitoring were done in static and dynamic regime. For dynamics the clamping device of the workpiece is a jaw chuck [15], was evaluated at turning and threading, on a Linear Gildemeister CTX420 Lathe. The cutting forces F_c were measured with a Kistler dynamometer 9121 [16], which were mounted in contact with the tool. In this way was realized a mechatronic clamping device for the tool. Were measured the components of the cutting forces F_x, F_y and F_z, for every technologic process which was applied.
The proposed methodology [9] for monitoring in real time of the whole process starts with the cutting force F_c measurement on the three principal directions and how to use them to determine the necessary clamping force F_f. The data needed for determining the necessary clamping force for the safeness of fixturing are: the workpiece dimensions and material, the forces measured during the cutting processing, the inertia force which acts on the workpiece and the device constructive date.
The final result is represented by the determination of the optimal clamping force F_f. For improving the safeness of processing is necessary to compare the results obtain by calculation, with the real clamping force measured during processing. As a solution the authors propose the implementation of a similar montage with the one represented in figure 8.
On the clamping device jaws are mounted transducers which register the value of the clamping force F_f with the help of a data acquisition system. With the help of a comparing program are read on a hand the value for the necessary clamping force and on the other the value of the real clamping force assured by the fixing device. When the value of the assured clamping force is smaller than the necessary clamping for is recommended the modification of the processing parameters.

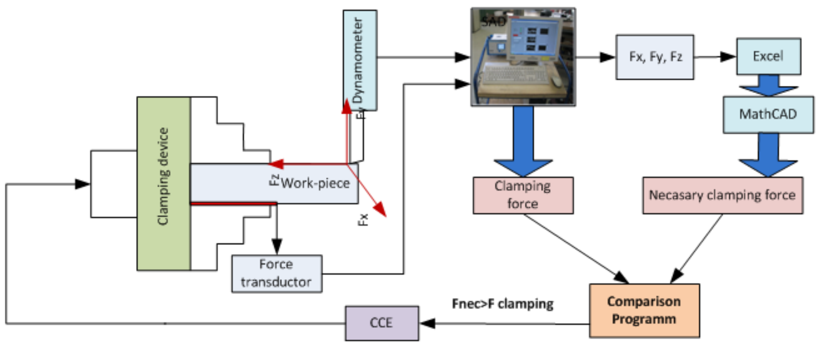

Figure 8. Monitoring and command methodology for a jaw clamping device in dynamic regime [9]

For statics was realized the evaluation of an orientation and clamping device of the workpiece with rotation surface, for boring, enlarging and milling, an o Hermle Center. For data acquisition was realized an experimental montage using a Kistler Dynamometer 9272 [16],

which with the fixing device for the workpiece forms a mechatronic orientation and fixing device. The workpiece clamping device realized by Röhm [17] is a jaw chuck. The proposed methodology [8] for monitoring the jaw clamping device, figure 9, contribute to the integration of these devices in advanced production systems, taking in consideration two important aspects: spatial and functional integration.
It appears the necessity of establishing links with all of the system equipments, and the need, in addition to the classic device, the data acquisition and processing, command and control systems. All of these equipments create the necessary conditions of designing a monitoring system for the process. The monitoring methodology for a jaw orientation and fixing devices contribute to them integration in an advanced production system and to the respecting of the actual trend of improving the devices intelligence by creating a monitoring procedure and establishing a communication protocol.

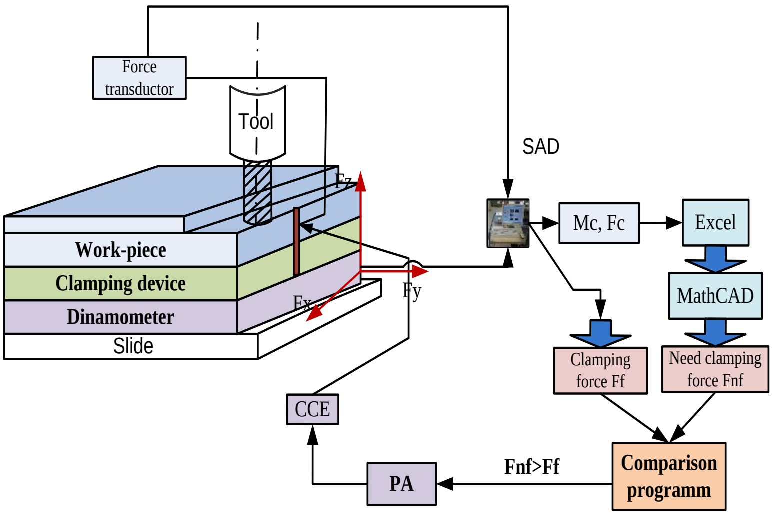

Figure 9. Monitoring and command methodology for a jaw clamping device in static regime [8]

The cutting forces measuring for determining the necessary clamping force for fixturing the prismatic workpieces when it is used the 3-2-1 locating principle were done on a CNC processing centre with 3 axes. Machine tool axis has the same directions with the one of the dynamometer. For measuring the cutting forces and moments was used the experimental montage in figure 10, having as principals components the workpiece (1), fixed on the machine tool table (3), with the help of the Kistler dynamometer 9257B (2), the signal amplifier Multichannel Tip 5070A (4), the data acquisition board PCIM-DAS1602/16, mounted in a PC (5), with Windows XP and a special program for data processing DynoWare Type 2825A.
For the prismatic workpiece from OLC 45, with the dimensions 86×176×56 mm, for processing was used a frontal milling tool with the diameter D_c=80 mm, with z=6 (Cod R365-Q27-S15M080) and a milling tool with diameter D_c=18 mm and z=3 (cod R216.13-18030-BS18P). On the upper surface of the workpiece were done various milling operations for the realization of the surfaces S1-S4, for which were registered the cutting forces and moments. During S_1-S_4 processing were registered the experimental data related to the cutting forces, on the three principal directions, Table 1.

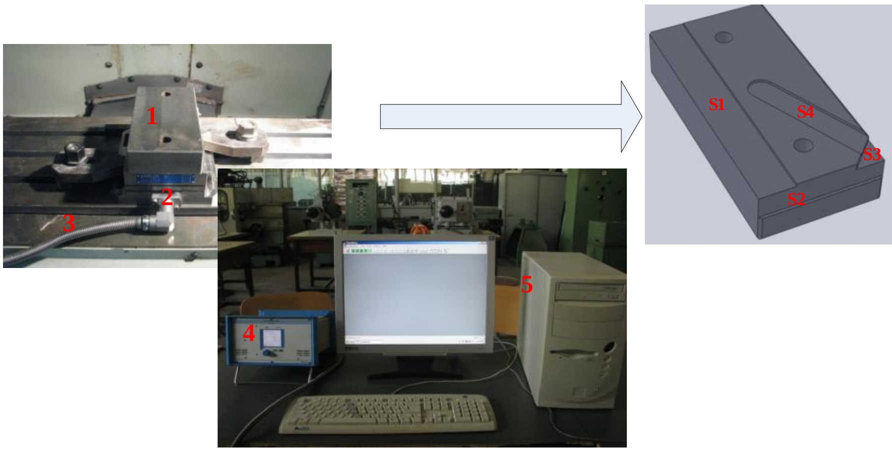

Figure 10. Experimental setup [10]

By data processing with DynoWare 2825 A, were obtained the variations diagrams and also the minimum, medium and maximum force value. The measured cutting forces F_c are useful in the algorithm used for determining the clamping force F_f and the locators optimal position for prismatic workpieces, when for orientation and clamping is used a 3-2-1 modular device.

Table 1. Cutting forces and parameters [10]

	Cutting conditions							F_x[N]			F_y[N]			F_z[N]		
	D_c [mm]	z nr. dinti	a_e [mm]	a_p [mm]	f_z [mm]	v_f [mm /min]	n_c [rot/ mm]	min	med	max	min	med	max	min	med	max
S1	80	6	25	1.5	0.06	43	716	-277	-8	312	-167	146	485	-279	32	465
S2	80	6	25	0.5	0.06	43	716	-176	-2	173	-34	23	196	-62	49	302
S3	18	3	2	18	0.03	90	3000	-37	88	273	-334	-124	38	-155	-27	45
S4	18	3	18	5	0.03	90	3000	-254	-30	47	-322	-85	24	-113	-25	56
S5	18	3	18	3	0.03	90	3000	-65	118	319	-367	-184	43	-98	-44	13

The accomplishment of an orientation and clamping configuration represent a complex action that involves the establishment of different design variances through which it is desired the cancelation, in most of the cases of 6 freedom degrees (rotation and translations). It will be taken into consideration the following aspects: processing type (milling, boring, etc.), the workpiece form and dimensions, the workpiece material and also the machine tool type and used cutting tools. The orientation and fixing layout assume the establishment of the locators and rigid fixing of the workpiece, taking into consideration its forms and dimensions, material and processing requests.

Performances analysis of the devices in order to be integrated in advanced production systems involves the getting over the stages of the methodology proposed in figure 11. Taking into account all the facts involved through FEM is established the optimal configuration for clamping. An acceptable solution from technical point of view, in the conditions of the market economy cannot be taken into account if it does not fulfil the conditions of profitability and efficiency.

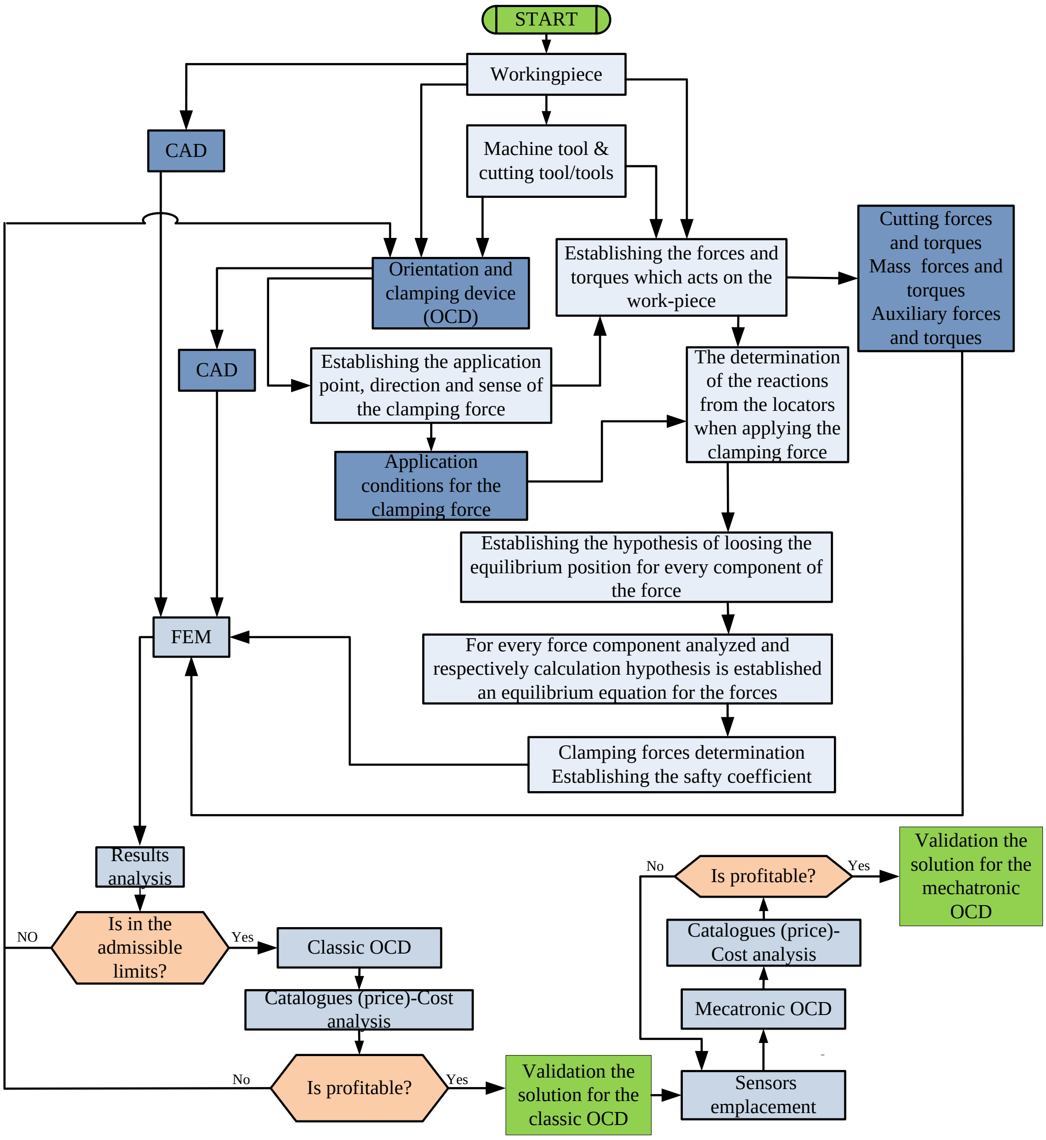

Figure 11. Methodology for performances evaluation of an orientation and clamping device

CONCLUSIONS

As it's specified in standards the workpiece processing on machine tools is done with respecting the conditions of dimensional accuracy, form, quality and productivity. The assurance of these conditions is related to the technologic system performance in which the orientation and clamping system will be integrated, actuating equipments, command and control. It is impossible to integrate an orientation and clamping device without an evaluating stage for it, when is important to detect its week point and to improve its performances. The article principal conclusions are:

- Theoretical and experimental researches converge to the importance of the orientation and clamping devices performances evaluation for them integration in advanced production systems.
- Clamping procedure design must be completed as to assure the repeatability possibility, all the freedom degrees cancelling and the possibility to ensure a permanent contact with the locators and the fixing arm.
- The criteria on which base it is realized the clamping devices performances evaluation are: basic technologic process, the clamping device constructive-functional characteristics, actuating type, automatization and modularization degree, machine tool type on which the

device is adapted.

- The clamping devices performances analysis assumes going through a methodology which comprises the following stages: the workpiece and the locating surfaces analysis, of the technologic processes and of the tools, of the production type, process parameters, knowledge and determination of the loading elements (cutting forces and moments, clamping forces), determining by modelling and simulation of the most stressed elements from the devices structure, in the most unfavourable case.
- The analysis results leads to the emplacement solution for a sensor or a transductor, as a principal element of the mechatronic device. The signal from the sensor is measured and processed as to be compatible with the numeric command equipment of the machine tool.
- Clamping device integration in advanced production systems involves taking in consideration two aspects spatial integration, which means establishing the link between the mechanical and the electrical part, and respectively functional integration, the link with the command and control system.

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