APPLICATION OF COMPUTER TOOLS IN THE DESIGN OF CLAMPING DEVICES

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Abstract: *To achieve ever-increasing productivity requirements in serial production, while ensuring product quality and machining process stability, special workpiece specific fixtures are required. Designing such a device can be a very complex and demanding process, requiring a high level of experience and insight from the designer. The purpose of this work is to show the potential possibilities of applying modern software tools to the fixture design process in order to provide reliable part positioning and clamping, while lowering the experience level required on the designer's part. The example analysed in the paper shows how applying modern software can enable detailed fixture evaluation and process optimisation in the early stages of fixture design, significantly reducing the risks associated with the classical design process and provide a deeper insight into the behaviour of the fixturing system.*

Key words: *Clamping device modelling, Computer-aided design process, Finite element analysis, Simulation, Clamping device optimization.*

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1. Introduction

One of the primary prerequisites for any successful machining operation is part positioning and clamping. Since machining operations rely on the workpiece having a fixed relative position to the machine origin, as well for the workpiece not to deform during the process, failing to secure either of those conditions will result in either large machining errors or a completely scraped part. Machine shops often use various types of clamping devices easily adaptable for a variety of workpieces, however, the flexibility comes at the cost of productivity. When performing machining operations as a part of a serial production process, a clamping device custom made with regards to the specific workpiece is required both to ensure the requirements for accuracy, repeatability, stability and productivity of the machining process.

A clamping device is a device used to position, hold, and support the workpiece during the machining process. It is an important element of a production process and required in most automated production processes, as well as inspection and assembly operations. The clamping device must correctly position the workpiece in the required orientation with respect to the cutting tool, measuring device, or another component. Clamping fixtures are usually designed for a specific machining operation and workpiece and are therefore custom manufactured. The use of fixtures allows the operator to easily position and clamp the workpiece, increases machining accuracy and uniformity of production quality, and enables partial or full automation of the process. (Gabor et al. 2005 , Kostal and Velisek, 2005) To clarify further descriptions, basic components that make up a fixture are briefly introduced (Fig. 1.):

- *Locators/Centerers*: Centring pieces position the workpiece on the clamping device. They are used to establish and maintain the position of the workpiece by limiting positioning degrees of freedom (DoF).
- *Clamping elements:* Clamping mechanism ensures the workpiece is tightly held to the fixture, through which stable positioning is achieved, despite external forces.
- *Backrests and supports:* A backrest is a fixed, while a support is an adjustable fixture element. Normally, supports are placed opposite the clamping point. If significant deformation is expected under the action of clamping and cutting forces, supports are placed and attached under that area. Several supports and backrests may be used in a single fixture.
- *Fixture body:* The body of the clamping device is the most important structural element. It maintains spatial relationships between the components of the clamping device in relation to the machine tool and the programmed origin.

The clamping device must ensure the stability of the workpiece during the machining process. This requires correct and repeatable positioning of the workpiece with regards to the clamping device, i.e., the coordinate system of the machine, as well as application of appropriate clamping forces.

Certain constraints must be observed (Keyvani, 2012, Rong et al., 2005; Zuperl et al., 2011):

- *position determination*,
- *movement restriction*,
- *deformation limitation*,
- *geometric constraint*.

In addition to the above-mentioned requirements that should be considered in the design, the clamping device should also be designed to allow for quick loading and unloading, consist of a minimal number of components, be accessible and portable, and have the lowest possible price.

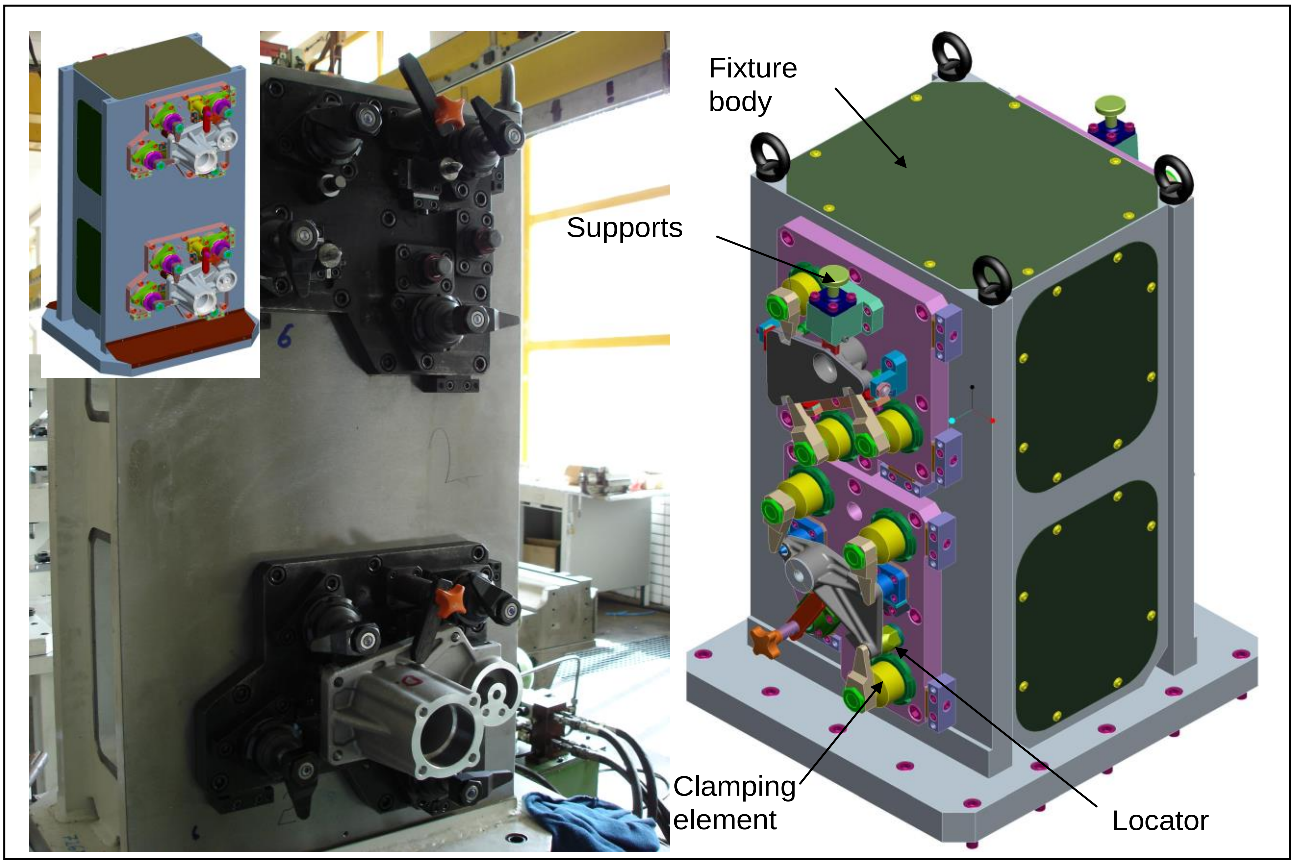

Fig. 1. Clamping device components [SAS-Strojogradnja]

2. General features of clamping devices

Clamping planning implies specifying the basic configuration of the work holding equipment based on the analysis of all available information about the material and geometry of the workpiece, the required machining operations, the equipment involved in the process and the operator. The specification of the input data, factory standards, ease of use, safety and economy should also be considered. In the initial concept development phase, it is first necessary to know the input variables.

They include (Kang et al., 2003, Part 1):

- type of clamping device,
- the number of workpieces per clamping device,
- the orientation of the workpiece in the clamping device,
- the positions of the base surfaces,
- clamping surfaces,
- supporting surfaces (if necessary),
- processes to be carried out (tool plans),
- geometrical tolerances, etc.

Based on the input data, the tasks involved in the clamping device design process include identifying clamping points, as well as positioning, support, and selection of appropriate clamping elements. The following requirements must be observed in this process (Keyvani, 2012; Kang et al., 2003, Part 2):

- *Positioning principles*: one of the main purposes of fixing the workpiece is positioning within the clamping device. Numerous factors are considered, such as reference planes, support surfaces, features that could affect the tool's machining movement or approach paths, etc.
- *Workpiece DoF restrictions*: Clamping devices should restrict certain workpiece DoF and ensure positioning and alignment repeatability with respect to the cutting tool. For prismatic products, the 3-2-1 limiting principle is used. The first three points on the primary surfaces must be spaced as far apart as possible for workpiece stability. For larger cast prismatic workpieces, the 4-2-1 positioning principle is often used.
- *Clamping principles*: In any machining process, machining forces are developed and transmitted to the workpiece upon which they are acting. The clamping process causes a locking action which ensures positional stability through frictional forces or shaping by applying external forces. A requirement for all clamping devices is to ensure an appropriate clamping force on the workpiece to prevent any workpiece movement or cause excessive damage.
- *Clamp types*: Clamping elements can be manual, pneumatic, hydraulic, electric, or a combination of the aforementioned principles.
- *External force influences on the clamping process*: Clamping elements are based on elastic deformations. They can be classified according to the deformation characteristics. There are two basic subdivisions:
    - clamping elements in which the elastic deformation increases with the clamping force (threaded spindles, levers, curves, etc.),
    - clamping elements in which the clamping forces assume constant values independent of the elastic deformation at the contact surfaces (hydraulic or pneumatic clamping cylinders).

2.1 Clamping device design process

The process of developing a clamping device involves a series of activities which consider the input data and clamping principles to achieve the goal of shaping a clamping device. It can be divided into four major development phases (Keyvani, 2012):

- *First phase*: in the first design phase the problem is defined, input parameters are determined, raw materials and the workpiece are analysed, the process is planned, available equipment is determined, operator safety and ease of use are considered. In this phase, all critical dimensions and the required types of machining operations are studied.
- *Second phase*: this phase considers workpiece clamping and defines workpiece positioning and alignment schemes. The clamping scheme refers to clamping points selection, the centring method, supporting elements, and the cutting tool approach analysis in accordance with the required machining operations. In this phase, different types of analyses are performed, such as positioning analysis, tolerance analysis, stability analysis, accessibility analysis, etc. After the analyses and the optimization of the system, a clamping plan is created, containing the following information:
    - clamping lever positions,
    - strut positions.
- *Third phase*: this phase includes selection and design of the mechanical structure for the clamping device body.
- *Fourth phase*: in this phase the chosen solution is verified. After conceptually defining the clamping device and completing the mechanical structure design, the optimization and verification processes follow. To measure the clamping device design quality, the geometric and kinetic models must be considered. The geometric model describes the relationship between the position of the workpiece and the position of the centring device, while the kinetic model considers the loads and deformations of the workpiece caused both by the clamping and machining forces.

In this article, an analysis of workpiece deformations caused by the cutting and clamping forces is performed on a specific workpiece example with the assumption that all supports are rigid.

3. Example of designing a mechanical clamping device

The design of clamping devices with the help of computers has been practiced for many years. Using interactive and semi-interactive design techniques, intensive work is being done to speed up the clamping device creation process by using commercial CAD systems and expert tools (Bi & Zhang, 2001; Vukelic et al., 2011; Vukelic, 2010). The approach is mainly focused on the fixture configuration, with little analysis of the interactions between the workpiece, fixture and cutting tool. The final goal is to include analysis at different levels at an early stage of the clamping device creation process, e.g., geometric, kinematic, force, deformation, etc., with the aim to automate part of the process (Leopold, 2008; Cecil, 2001; Kulankara et al., 2001). The finite element method (FEM) is best suited for analysing elastic deformations which occur in the workpiece-clamping device system under the influence of clamping and machining forces, which will be tested on a mechanical fixture in this article (Nirav et al., 2009; Qin et al., 2005; Yu, 2000; Zheng, 2005).

3.1 Geometrical workpiece analysis

The geometric workpiece analysis is one of the first analyses that must be performed. It includes dimensional tolerancing analysis, which greatly define the clamping and centring planes (Kang et al., 2003, Part 2). In this design phase, the clamping planes, centring surfaces and clamping areas are defined (Fig. 2.).

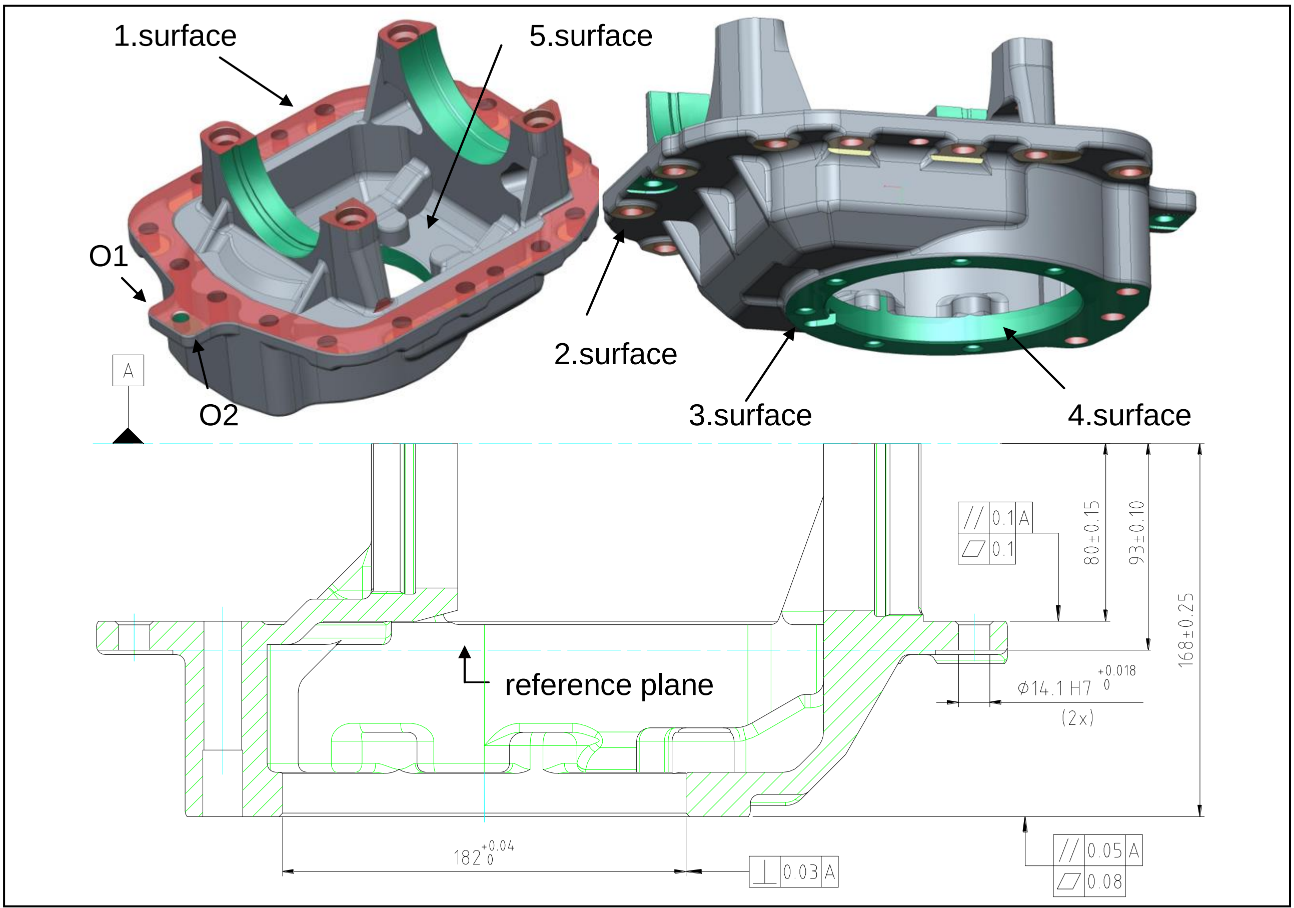

Fig. 1. Workpiece configuration and tolerance requirements

The choice of locations where workpiece rests and clamping forces are applied has a significant influence on clamping quality. In the example shown in Fig. 2., milling operations are performed on the front side of the flange (surface 1). This suggests that clamping points must be located inside the workpiece (surface 5). Based on the tolerance analysis, a reference plane was determined on which to place the solid supports (surface 2). It is immediately apparent that the magnitude and position of the clamping forces can significantly affect the elastic deformation of the workpiece, i.e., it can significantly affect the stability of the process and machining quality. Based on the tolerance analysis, it is clear that great attention must be paid to the choice of support and clamping points, since it is necessary to ensure that the flatness of the machined flange surface is less than 0.1 mm (step 1), i.e., it is ultimately necessary to ensure a repeatability within 0.05 mm (to meet statistical indicators cmk<1.3 and cpk<1). Centring is performed on the pre-machined surface of the central hole (surface 4), while workpiece alignment is performed using points O1 and O2.

3.2 Setting the position of the backrest; centring, alignment, and clamping

Selecting the basic components of the clamping device should ensure stability of the workpiece with minimal deformation and machining with minimal vibrations, to ensure longer life of the cutting tool. The arrangement of fixed supports, adjustable supports (if required), choice of clamping locations, type of centring and alignment, as well as clamping force magnitudes are chosen based on designer's experience and assumed machining forces, without deeper insight into the structure or the behaviour of the workpiece under load.

For the workpiece shown previously, an arrangement of fixed and adjustable supports (three fixed supports defining the plane) was assumed adequate to ensure the stability of the machining process (Fig. 3.). In this case, it was not possible to place fixed supports opposite the clamping point, and therefore adjustable supports were provided, i.e., supports that would be installed later when a certain clamping force had been reached. The clamping forces are meant to ensure stable workpiece positioning through friction and solid supports upon which the workpiece is placed.

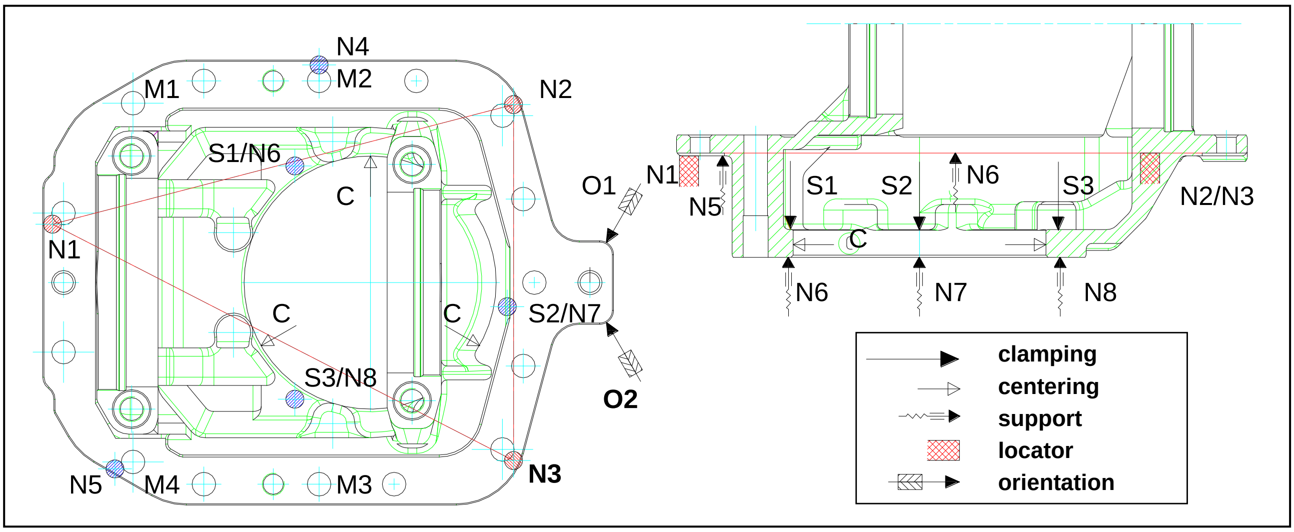

Fig. 3. Arrangement of backrests, supports and clamping points on the workpiece

Fig. 3. shows the proposed arrangement of three fixed backrests marked N1-N3, the positions of the clamping points are marked S1-S3, and the positions of the adjustable backrest supports are marked N4-N8.

Centring is performed on the previously machined surface (Plate 4, Fig. 2.), and the locations are marked with the letter C in Fig. 3. Workpiece alignment was performed using features marked O1 and O2, and the positions for workpiece deformation measurement are marked as M1-M4.

3.3 Machining process and cutting force analysis

Based on the proposed clamping and support positions, a clamping and machining force analysis was performed. Machining forces that affect the quality and flatness of the surface can occur when milling or drilling holes. Fig. 4. shows the machining operations and cutting tools used to perform them. Cutting forces and required machining power were estimated for the selected machining regimes. Milling forces directly affect the flatness of the flange surface (surface 1 in Fig. 2.), while drilling forces have no direct effect on flatness. Therefore, in further considerations, milling forces are used as machining forces for calculating deformations and clamping forces.

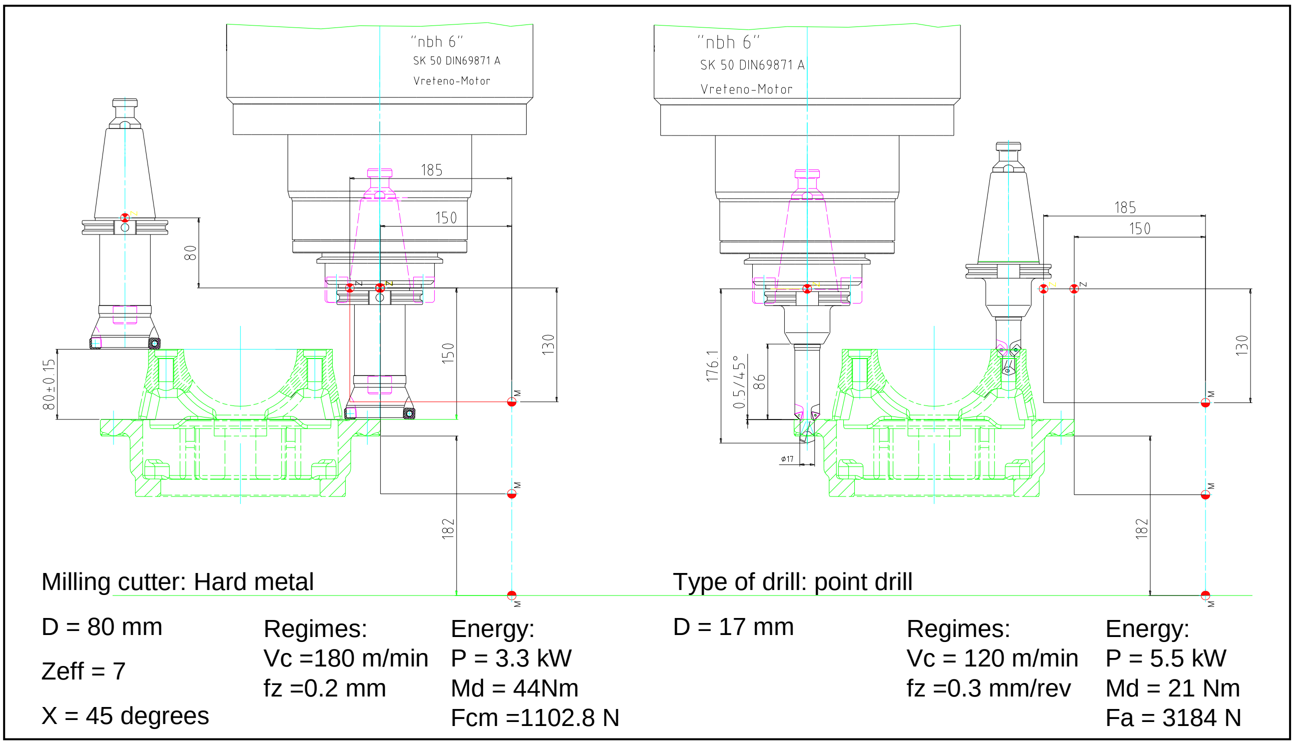

Fig. 4. Analysis of the cutting tool, tool accessibility, and cutting forces

In this example, it is clear that the clamping forces must ensure the workpiece positioning primarily through frictional forces. The frictional forces are estimated as a function of environmental conditions. Due to uncertainty in estimating the input variables, it is necessary to apply a safety factor to the calculated values, i.e., to apply a significantly higher clamping force than required. However, applying large forces has a significant effect on workpiece deformation. When using the classical design method, determining the required clamping force magnitudes and how they affect the deformations of the workpiece is left to the designer's judgment and experience, without a deeper insight into the clamping process itself.

If a better estimate of system behaviour is desired in the early design phase, process optimization must be performed using one of the software methods. For complex workpieces, it is impossible to qualitatively evaluate the behaviour of the system without using a 3D workpiece CAD model and the finite element method.

3.4 Structural version of the clamping device

This paper describes and analyses the mechanical clamping device shown in Fig. 5. Several lever mechanisms were used in the design of the clamping device to provide adjustable clamping at three points around the circumference of the lower flange (points S1-S3). The design considered the accessibility of the tool to the work surfaces and the ease of access to the clamp. Tightening is performed by means of a trapezoidal thread and a nut with the help of a torque wrench, ensuring controlled and uniform tightening by the operator. In this way, the stability and reproducibility of the clamping process was achieved, i.e., the control of the workpiece deformations due to the clamping forces was ensured.

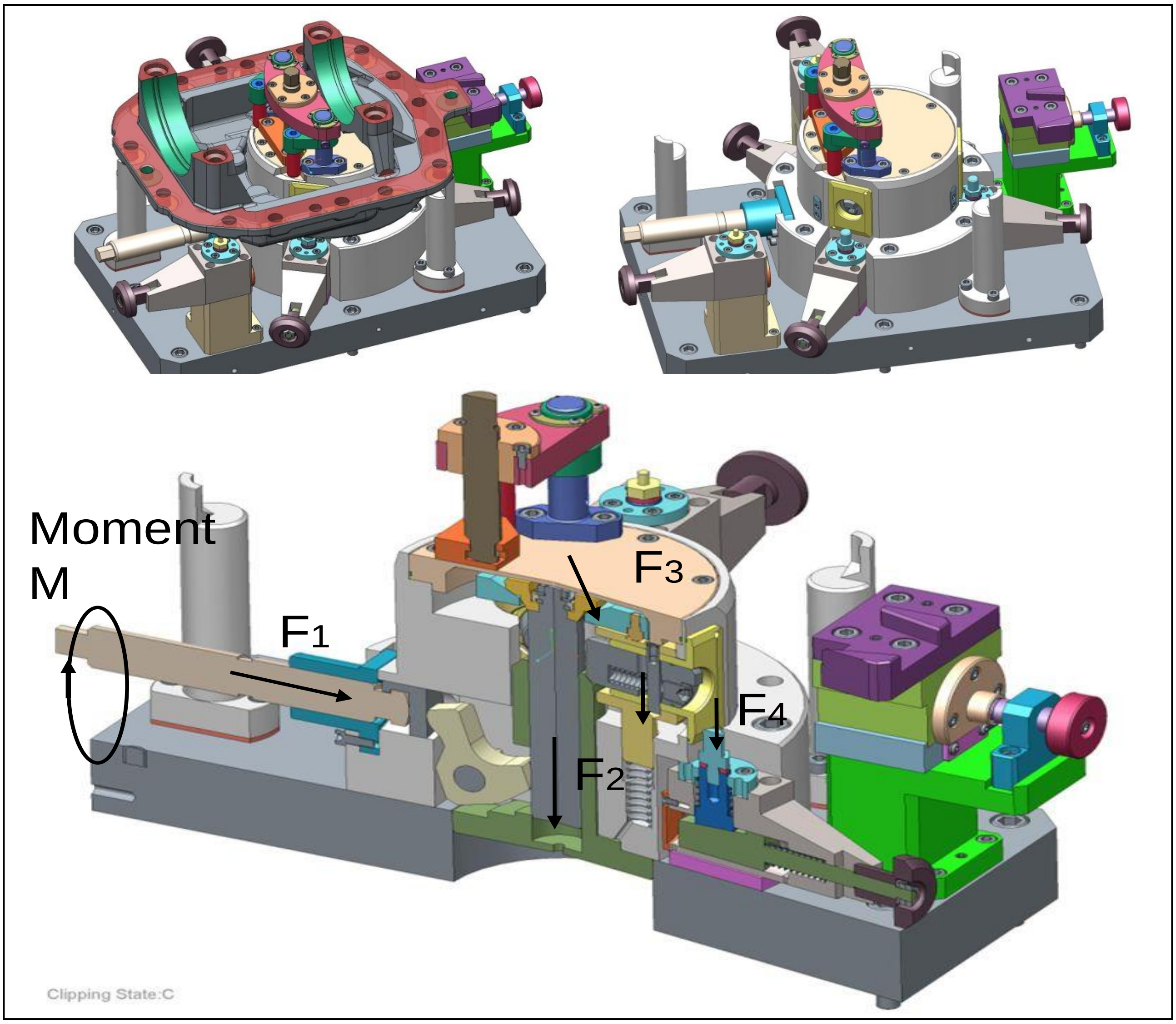

Fig. 5. Mechanical clamping device and its section

4. Experiment planning

The purpose of this paper is to determine and evaluate the utility of using computer analysis as a tool for predicting deformations and optimizing the position of the backrest in the initial clamping device design stages. Using the example in the previous chapter, the procedure for creating a basic clamping device concept was described. After that, FEM analysis was performed to assess workpiece deformations under different conditions during the clamping process.

In this sense, the FEM analysis was performed and compared with actual measurements performed on the designed object. The experimental part refers to the real workpiece deformation measurements with machining and clamping forces being applied in different conditions. The FEM analysis was performed using the Pro/Mechanica software package. Various input variables were tested and their influence on workpiece deformation was observed. Magnitudes of clamping and loading forces were changed and deformations were measured with three different combinations of support and prop placements on the workpiece. Tab. 1. shows the conditions under which the experiments were performed.

- C1 - fixed backrests (N1, N2, N3), (surface 2, Fig. 2.),
- C2 - fixed backrests and adjustable backrests (supports) under the clamping point (N1, N2, N3/N6, N7, N8), (surface 2 and 3, Fig. 2.),
- C3 - fixed rests, adjustable rests (supports) below the clamping point and additional adjustable rests (supports) around the flange (N1, N2, N3/N6, N7, N8/N4, N5), (surface 2 and 3, Fig. 2.).

Combination	Fixed supports			Support points					Clamping points		
points	N1	N2	N3	N4	N5	N6	N7	N8	S1	S2	S3
C1	X	X	X						X	X	X
C2	X	X	X			X	X	X	X	X	X
C3	X	X	X	X	X	X	X	X	X	X	X

Tab. 1. Combinations of fixed supports and additional supports

Fig. 6. Equipment used in the experiment

Load force simulation was realized through a hydraulic press equipped with manometers, enabling controlled simulation of the external processing force. A controlled clamping force was assured by using a torque wrench, and deformations were measured through precise measurement tools placed at measurement points M1 to M4 (Fig. 6.).

After simulating clamping forces and loads, and measuring their effects on workpiece deformations, the workpiece was machined under real conditions on a Heller-nbh 6 machining centre. After machining, dimensions of the finished products were measured on a coordinate measuring machine and statistically evaluated.

4.1 Results

4.1.1 Simulation results

As described earlier, two series of measurements were performed in this work. The first referred to the change in clamping force magnitudes and their effect on workpiece deformations with regard to different combinations of rests and supports (Tab. 2.). The second series of measurements refers to the effect machining forces had on the workpiece deformation at a constant clamping force with different combinations of rests and supports. The results can be seen in the Tab. 3.

Deformation [mm]	Clamping force [N]	Measurement points in FEM analysis			
Combination of supports		M1	M2	M3	M4
C1	6000	0.007389	0.014151	0.034973	0.036534
	7000	0.008623	0.016508	0.040794	0.042626
	8000	0.009855	0.018866	0.046622	0.048715
	10000	0.012319	0.023583	0.058277	0.060894
C2	6000	0.000701	0.001048	0.001135	0.000977
	7000	0.000818	0.001222	0.001324	0.001139
	8000	0.000935	0.001397	0.001513	0.001302
	10000	0.001169	0.001746	0.001891	0.001628
C3	6000	0.000601	0.000502	0.000960	0.000341
	7000	0.000701	0.000585	0.001120	0.000398
	8000	0.000801	0.000669	0.001280	0.000455
	10000	0.001002	0.000836	0.001600	0.000568

Tab. 2. Deformation of the workpiece due to clamping forces for different combinations of backrests and supports

To present FEM analysis results, graphical representations in various forms are usually used. Fig. 7. shows just some of the workpiece deformation FEM analysis results for various clamping and loading conditions. In the upper left corner of the figure, results of simulating workpiece deformations due to the action of only the clamping force of 10000N are shown. The remaining three pictures show simulation results for workpiece deformations using the same clamping force value of 10000N and machining force of 5000N acting in different characteristic points.

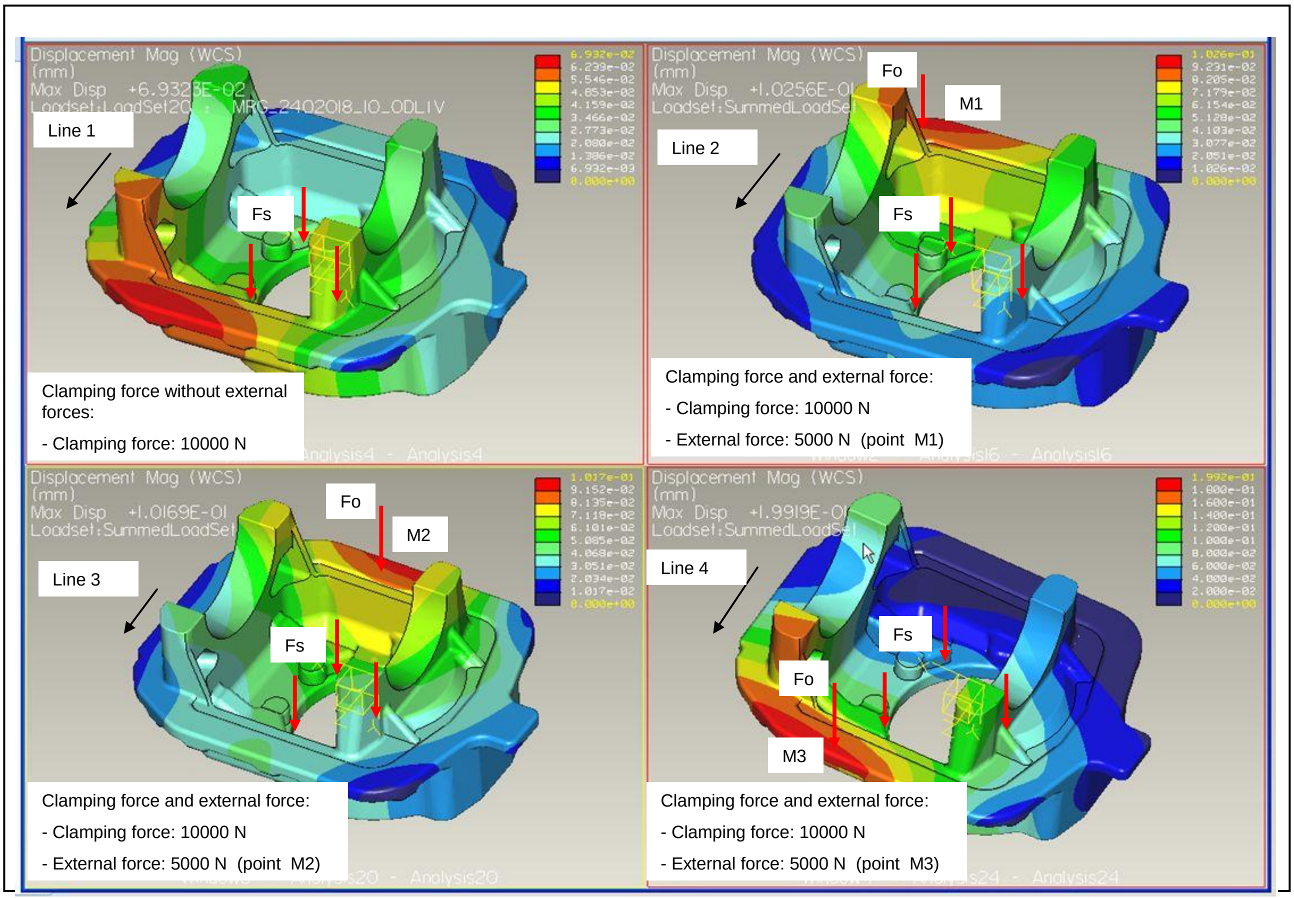

Fig. 7. Deformation analysis with the help of FEM analysis

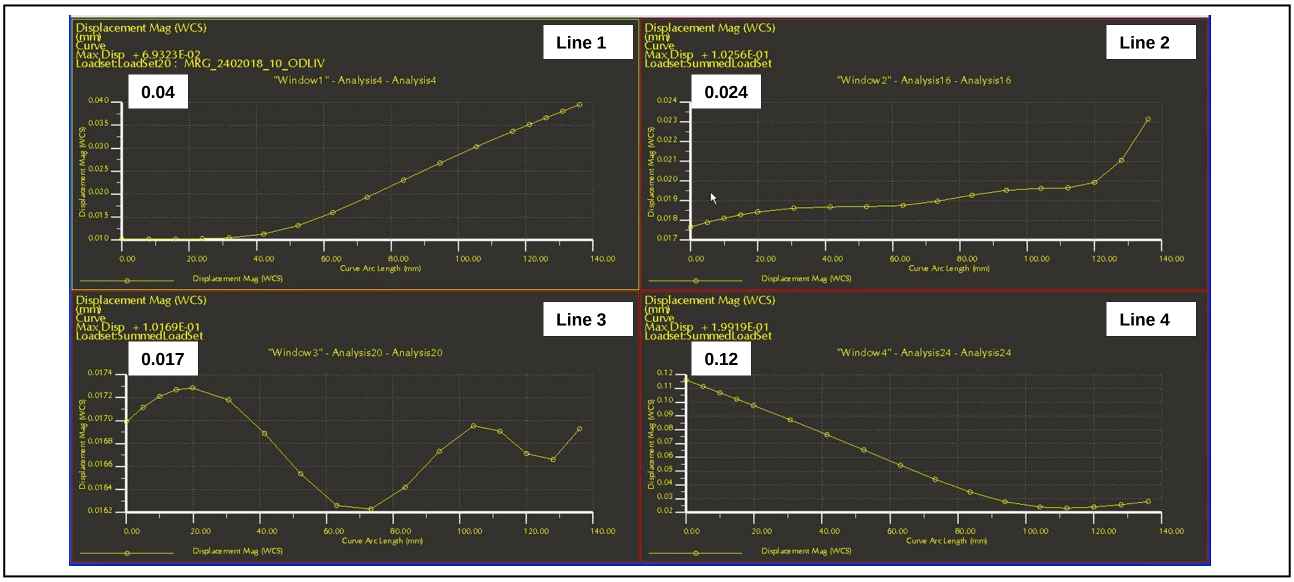

Fig. 8. Analysis of deformations by individual lines

The FEM analysis software package contains various forms of simulation result representation. One of them is the system behaviour representation, which shows the flow of deformation along a given line using diagrams. The line on the left edge of the workpiece flange is taken as an example (Fig. 8.).

Using this tool, it is possible to estimate the locations with the largest deformations and predict the placement of fixed or adjustable supports as required. As it can be seen from the diagram, workpiece deformations depend on the location and magnitude of the clamping and machining forces acting upon the workpiece. These diagrams can be useful for reducing workpiece deformation by optimizing fixed and variable backrest positions.

They can also be used to provide deeper insight into the behaviour of the clamping and machining processes and evaluate their influence on the quality of final products. The first set of simulations, related to the position of the support and the clamping force magnitude, was followed by a second set of analyses. This second set analysed the influence external loads and machining forces have on workpiece deformations at a constant clamping force of 10000 N, while using different combinations of supports and backrests. 58 tests were carried out at different points and under different clamping conditions to determine workpiece deformations with external forces acting upon it. Some of the FEM analysis results are shown in Tab. 3.

Deformation [mm]	Clamping points	Processing force [N]	Measurement points in FEM analysis			
Combination of supports			M1	M2	M3	M4
C1	M1	3000	0.060423	0.054619	0.041733	0.033718
		4000	0.077018	0.064839	0.036171	0.025345
		5000	0.094968	0.075094	0.030794	0.018313
	M2	3000	0.041564	0.067668	0.047741	0.041056
		4000	0.051800	0.082374	0.044327	0.034659
		5000	0.061991	0.097839	0.040654	0.028055
	M3	3000	0.015181	0.013215	0.123958	0.128904
		4000	0.020226	0.010109	0.145812	0.151496
		5000	0.025746	0.007420	0.167664	0.174090
C2	M1	3000	0.023577	0.007761	0.001073	0.006013
		4000	0.032308	0.009972	0.001347	0.008435
		5000	0.041995	0.012136	0.001766	0.010845
	M2	3000	0.006382	0.018687	0.001439	0.001541
		4000	0.008318	0.025101	0.001339	0.002326
		5000	0.010134	0.033110	0.001240	0.003139
	M3	3000	0.001387	0.001285	0.017783	0.007060
		4000	0.001901	0.001192	0.023873	0.008925
		5000	0.002524	0.001091	0.030638	0.010993
C3	M1	3000	0.019246	0.002391	0.001411	0.001524
		4000	0.026508	0.003031	0.001377	0.001932
		5000	0.000870	0.000785	0.002342	0.008418
	M2	3000	0.000880	0.000800	0.002977	0.018325
		4000	0.001775	0.005571	0.001518	0.000576
		5000	0.002393	0.012111	0.001524	0.000606
	M3	3000	0.000859	0.000761	0.016555	0.001874
		4000	0.000834	0.000763	0.022301	0.002341
		5000	0.000814	0.000763	0.028638	0.002849

Tab. 3. Deformations of the workpiece due to the action of external forces

4.1.2 Measurement results

Using the described equipment, experimental measurements were performed, and the results were compared with the results of FEM analyses. The measurement and FEM analyses results are shown in Tab. 4. and 5., respectively. The influence clamping forces have on the workpiece deformation is given in Tab. 4., and in Tab. 5. the results of machining force influence measurement and simulation for a constant clamping force of 10000 N are given.

Deformation [mm]	MEASUREMENT POINTS								
Combination	M1			M3			M4		
Support	Measured	Calculated	[%]	Measured	Calculated	[%]	Measured	Calculated	[%]
C1	0.035	0.012319	284	0.070	0.058277	120	0.060	0.060894	99
C2	0.030	0.001169	2567	0.055	0.001891	2908	0.040	0.001628	2457
C3	0.020	0.001002	1997	0.050	0.001600	3125	0.020	0.000568	3520

Tab. 4. Results of simulation and actual measurement without load

Deformation [mm]		MEASUREMENT POINTS								
		M1			M2			M3		
Combination	Clamping force [N]	Measured	Calculated	[%]	Measured	Calculated	[%]	Measured	Calculated	[%]
C1	2000	0.040	0.043155	-7	0.050	0.052893	-5	0.080	0.102087	-22
	3000	0.060	0.060423	-1	0.060	0.067668	-11	0.095	0.123958	-23
	4000	0.085	0.077018	10	0.085	0.082374	3	0.125	0.145812	-14
	5000	0.110	0.094968	16	0.105	0.097839	7	0.135	0.167664	-19
C2	2000	0.040	0.017714	126	0.040	0.012713	215	0.035	0.012460	181
	3000	0.060	0.023577	154	0.055	0.018687	194	0.050	0.017783	181
	4000	0.080	0.032308	148	0.075	0.025101	199	0.070	0.023873	193
	5000	0.100	0.041995	138	0.095	0.033110	187	0.080	0.030638	161
C3	2000	0.035	0.012889	172	0.020	0.003543	464	0.030	0.011505	161
	3000	0.055	0.019246	186	0.030	0.008001	275	0.040	0.016555	142
	4000	0.075	0.026508	183	0.040	0.005571	618	0.050	0.022301	124
	5000	0.090	0.008700	934	0.045	0.012111	272	0.060	0.028638	110

Tab. 5. Simulation and actual measurement results

5. Result analysis

Based on the FEM analyses results and measurements performed, it is shown that the FEM results correctly represent the actual situation when loaded by external forces in conditions where clamps are engaged without supports (within 20%). When placing the movable supports below the clamping point, the simulation values change significantly and do not correspond to the actual measured values. Gaps in the elements, part tolerances and the compliance of the workpiece clamping arrangement, which are not considered in the FEM analysis, significantly affect the behaviour of the clamping elements and lead to unpredictable failures. The moving backrests were assumed to be rigid, which was not true in this case. Subsequent measurements showed that the flexibility of the adjustable backrests was 0.02-0.03 mm, depending on the load.

Thus, the flexibility of the elements, which is not considered in the model, significantly affects the quality of the evaluation of the system behaviour and the results are not meaningful. In this case, the FEM analysis for the initial evaluation of the system behaviour corresponds exactly to the actual situation and can be used for a quick evaluation of the proposed fixture variant. It can be concluded that FEM analysis can provide good results in assessing the quality of the support and clamping point arrangement, as well as predicting deformations due to machining forces.

However, initial assumptions must be considered and tested because the actual results may differ significantly from the simulated ones. After the experiments and simulations, a dozen workpieces were machined on the machining centre. After statistical analysis, measurements results show that the obtained workpiece accuracy value in terms of surface flatness is on average 0.027 mm, which is within the required limits. It should be considered that the machining errors are also influenced by the repeatability of the machine on which the machining was performed (Heller nbh 6).

6. Conclusion

Proper fixture design plays a key role in the final quality of the workpiece in terms of dimensional accuracy, shape accuracy and surface quality. An ideally designed fixture not only ensures machining repeatability and high productivity, but also provides solutions that reduce workpiece deformation due to clamping and machining forces. The article provides a brief introduction to the general principles of fixture design, which have not changed significantly despite rapid advances in machine tools and production technologies. Poor clamping can ultimately lead to lower workpiece accuracy or scrap.

The quality of fixture design still depends mainly on the experience of the designer, who is required to consider clamping locations, sequence, and intensity. Since fixture design is still largely based on the experience of the designer, improvements, and deeper insights into the behaviour of the workpiece during clamping and the machining process can be achieved by using modern software tools. In this work, an analysis of deformations caused by clamping and machining forces was performed. It was found that the use of 3D models with the help of FEM analysis can provide a good basis for further improvements in fixture design and a deeper insight into the analysis of the workpiece behaviour during clamping and throughout the machining process.

The analysis has shown that the simulation models provide good approximation of real-life behaviour, but one has to be careful when making assumptions which are used to model the simulation setup. From the research carried out, it appears that FEM analysis can be used to predict workpiece deformations caused by the machining forces, thus serving to optimize the position and number of supports. This is particularly evident in complex thin-walled products made of light metals.

When the supports are placed below the clamping point, FEM analysis does not provide correct clamping force values due to the flexibility of the fixture elements. Due to the simplified model, in the case where the clamping forces are applied to the workpiece wall, they have no influence on the global deformation of the workpiece and are almost negligible, which is not the case in reality. In real conditions, due to the individual fixture part tolerances, as well as their unevenness and compliance, disturbances and deformations occur which cannot be predicted. In this case, the simulation model should be additionally upgraded to reduce the influence of tolerances and clearances present in the real-life system.

Based on the results obtained through this work, it is shown that the application of 3D models and FEM analysis together with the classical approach to fixture design, while applying analysis iterations, certainly gives a deeper insight into the fixturing process without requiring previous empirical experience on the designer's part. However, an important finding of the experiment is the requirement for more precise definition of the FEM simulation model when applying more complex backing/clamping solutions. If the model is setup properly the analysis results can be very close to the real-life situation and extremely useful. However, one or two wrong assumptions entered into the model can lead to significantly varying results and therefore should be treated with special care.

One option is to limit the use of FEM analyses to simply examining the behaviour of the workpiece for clamping with fixed three-point backrests under the clamps. This can provide useful insight even to experienced designers to aid in planning of the workpiece clamping and could be extremely useful information for less experienced engineers. However, this still leaves a lot of room for further research to examine both the way backrests are implemented into the fixture, as well as what is the best way to model them to reduce their influence on the model results. Future research is required to ascertain how this issue is best solved, whether by adjusting the backing method or by introducing additional model element definitions into the FEM analysis model.

7. References

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