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# ASSEMBLY SETUP FOR MODULAR FIXTURE MACHINING PROCESS

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**Abstract:** In this paper a model of modular fixture setup relative to cutting forces is proposed, planned and assembled. Positioning is discussed and the best solution is offered. Tool movements influence the final quality of workpiece, and fixture influences tool movements. An example is presented as a possible solution. Modular elements make jigs and fixtures elements interchangeable and reusable, their design then becomes a task of selecting and assembling the proper elements together. Primary criterion used for grouping the manufacturing features to form setups is usually tool approach direction. For load/unload, for pin placements etc. Tool carries the main forces that later form the final shape of the work-piece.

***Keywords:*** *Fixture planning, modular, Tolerance minimization, jigs, assembly setup*

## 1 INTRODUCTION

Precision engineering and careful planning are of utmost importance in the manufacture of work holding solutions. Fixtures are used to uniquely locate, support and secure the workpiece in the correct orientation relative to the machine tool. Companies set up their own standards and conventions to increase designer's work efficiency, in other words, to eliminate the redundant design work by just picking up some standard components. The analysis [1] of the design parameters and specifications utilized in jigs and fixtures design using universal modular jigs and fixtures design system (UMJFS) is an often research topic. The features of fixtures include the type of the fixture (milling, drilling), the shape of the workpiece (rectangular, cylindrical), the size and weight of the workpiece (housing dimensions), and the workpiece material (steel, bronze, plastic etc). Different workpieces may have different sets of fixturing requirements resulting with different design strategies. Main locating principle is to restrict 9 degrees of freedom, and rotation. Machining fixture layout optimization is often analyzed with FEM and evolutionary techniques [2]. Fixture layout ensures quality and improves the productivity by ensuring ease of loading/unloading of the component and chip removal. In order to completely understand the clamping criteria and part constraints, time and effort need to be spent for imparting of knowledge into the design solution. Fixturing methodology that can be used is vice fixturing, modular fixtures, etc. Depending on the product variety and volume two systems are used: dedicated and modular fixtures. Dedicated fixtures are used for specific components, while modular can be disassembled at the conclusion of a job and reassembled with other components for another job. Modular fixturing systems as shown on the Fig. 1, they are flexible, and consist of a large number of standard fixturing elements like clamps, locators, V-blocs, base plates etc. Setup plans are generated based on feasible fixturing plans. The higher experience in the field of fixtures and jigs the better design. Many combinations of fixtures are result of advantages that are result of many elements that exist for tooling. Case of best current design depends on available elements and there are always trade-offs. Even the same designer does not design exactly the same fixture if required again a few months later.

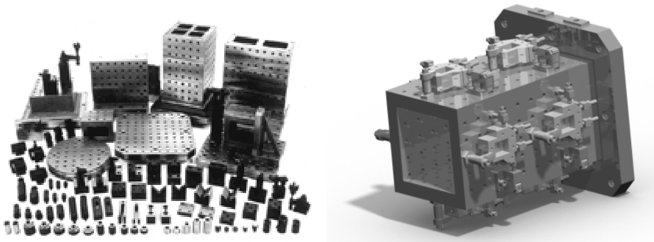

Fig. 1. Modular fixturing systems

## 2 COMENTS ON FIXTURE

Optimization of fixture must take in consideration the configuration of tool reach and part density, maximization of part retention, part to part clamp repeatability, part distortion, part vibration potential, optimum location from part datum's, ease and speed of part load/unload, operator safety & ergonomics, part load/unload error proofing, economic optimization.

### 2.1 Locators

The locators must ensure proper reference and repeatability of process, part after part.

Incorrect placement of part in a work holder and improper cutter position relative to the fixture causes the part to be machined incorrectly. In order to produce parts within tolerance limits the location relative to the tool and of the tool cutter must be consistent. The jigs and work holders are designed in order to maintain repeatability and to accommodate locating surfaces for the workpiece. Cast, forged, sheared, or sawed surfaces affect the accuracy of the location; the ideal locating point on a workpiece is a machined surface. All twelve degrees of freedom, six axial degrees of freedom and six radial degrees must be restricted in the central axes of the workpiece to ensure proper referencing of a workpiece. Locators restrict workpiece's movement with the necessary strength that maintains the position of workpiece during machining. Locators are designed to hold the workpiece against the cutting forces, while clamps act as a support to locators. Clamps are subjected to friction between the clamp and the workpiece and with sufficient force they could be moved. Locating can be done by plane, concentric and radial locating system. Plane-locating devices locate a part by its external surfaces. Concentric locators locate a workpiece from a central axis. Radial locators restrict the movement of a workpiece around a concentric locator. In many cases, locating is performed by a combination of the three locating methods. Locating from external surfaces, supports are the principal devices used for this location. The three major forms of supports are solid, adjustable, and equalizing. Solid supports are fixed-height locators. Adjustable supports are variable-height locators. Equalizing supports are a form of adjustable support used when a compensating support is required. Locating a workpiece from its external edges is the most-common locating method. The bottom, or primary, locating surface is positioned on three supports, based on the geometry principle that three points are needed to fully define a plane. Two adjacent edges, usually perpendicular to each other, are then used to complete the location. 3-2-1, or six-point, location method, this method uses six individual locators to reference and restrict the workpiece [3].

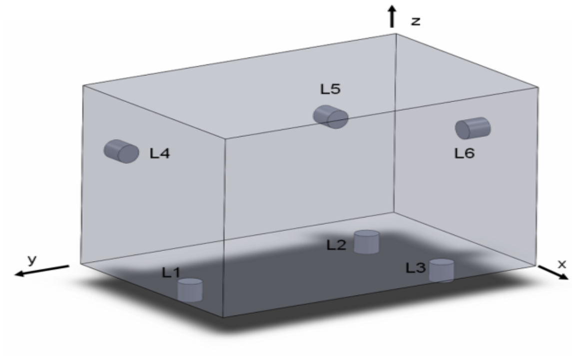


Fig. 2. Locating principle 3-2-1

Locating from internal surfaces from an internal diameter, individual holes or hole patterns represents a good form of location. Locating pins and locating plugs are used for locating of internal surfaces. Locating pins are used for smaller holes and locating plugs are used for larger holes. When positioning locators they should be spaced as far as possible from each other preferably on a machined side of the part. This compensates for irregularities in either the locators or the workpiece and offers maximum stability.

## 2.2 Clamps

Clamps as shown in Fig. 3 are used during the operational cycle. They hold the position of the workpiece in the jig or fixture. Clamping devices and their location on the work holder must be carefully selected. They hold the workpiece against the pins and they also hold against the movement. They are not designed to hold against the primary cutting forces. They are designed to hold under vibration, loading, and stress, vibrations can cause loosening of clamps. Clamps execute force on a workpiece and excessive force can cause unwanted deformation or stress. Unload/load speed is also important; clamping action should be fast and reliable. They have to be large enough to hold the workpiece against the locators and to resist any secondary forces generated in the operation. Position of clamps must not create interference with tool in process cycle.

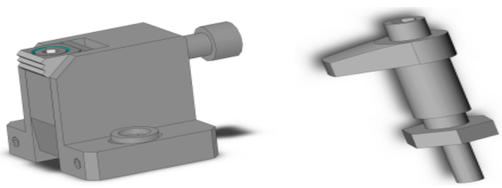

Fig. 3. Side clamp and hook clamp used in given example [4]

## 2.3 Fixture solution

Strategy approach to fixture design:

- Analysis of the workpiece drawing, problem.
- Identification of candidate elements (machined surfaces for locating, possible clamps positions, important regions of workpiece, tool path, possible tool interference points etc.).
- Support, location, clamping, base, guiding, fasteners and combination elements are taken in consideration.
- Methodology (modular, vice, v-block, point surface, angular structure, multi-workpiece clamping, 3-2-1 principle etc.).

- Identification of solutions (successful sequence of local solutions and creation of a consistent solution, selection of a pattern for modular fixtures (positioning of 2 or more workpieces)).
- Fixture design, simulation of stability, simulation of implementation procedure of fixture accuracy.
- Building of assembly.

Foundation of a strong and accurate fixture is material selection and for this purpose high-grade tool steels and engineering alloys are used. In order to resolve the optimum fixture placement a mesh was created and tool path calculated by the means of a genetic algorithm. The results of genetic algorithm vary, depending on the used parameters but a good approximation of optimal path is reached. The best solution [5] will be taken into account for the experimental evaluation and the influence and movement of forces are detectable. From the size of tool head the chip removal is calculated and resulting mesh is obtained. On this mesh the tool path is monitored and the optimal locating scheme is selected, as shown on Fig. 4. A stable clamping with minimal deflection is obtained. Overall size of fixture and of locating elements is determined by the workpiece size.

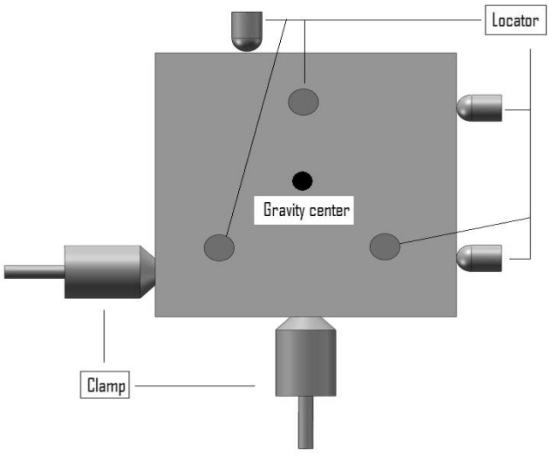


Fig. 4. Positioned clamps and locators for 3-2-1 locating principle

## 2.4 Modular system tools

Modular fixtures as shown in Fig. 5 are the most widely used flexible fixtures in industry because of their capability to reduce time and cost in fixture fabrication and storage. Floor space is at a premium in most shops. A single modular fixturing kit is organized and takes little space and can easily replace a vast number of fixtures (outdated, small batches etc.) saving valuable space and precious time. This are kits of tooling equipment that is used together in various combinations, for locating and clamping in machining operations, assembly and inspection operations. Most fixtures can be built from the information on tool data sheets and part drawings. When a fixture is needed modular components are gathered and setup drawing is planned. The important data are locating points, areas to be machined and the machine assigned to the job.

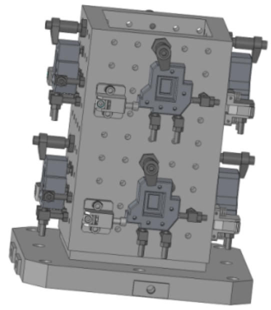

Fig. 5. Modular fixture, four sided tooling block, with four identical patterns

## 3 MACHINING TOOL

Milling, drilling, turning etc. are operations that can be preformed on a CNC machining canter. This requires cutter accessibility to all parts of the workpiece that needs machining operations. Three values are needed $\mathbf{a_i}$ (depth), **S** (speed = revolutions per minute r.p.m), **F** when deciding how to cut a material with a tool. The values of $\mathbf{V_c}$ and $\mathbf{F_z}$ are given from the tool manufacturer in various catalogues [6]. Optimum cutting speed depends on the material of the workpiece, cutter material (in example Aluminium 75-105 meters per min.) and the economic life of the cutter. These conditions have to be carefully set in order to calculate spindle speed ( r.p.m) and achieve optimal setup. Feed rate F is the speed at which the material is fed into the cutter, increasing S or z gives a higher feed rate. Therefore, machinists usually choose a tool with the highest number of teeth that can still cope with the load.

$$RPM = \frac{speed}{circumference} = \frac{V_c \cdot 100}{\pi \cdot D} = \frac{k \cdot speed}{D}, \quad (1)$$

- k is a constant, 320 for metric units.
- Speed ($V_c$) is the recommended cutting speed of the material (depending on k).
- Circumference ($\pi \cdot D$) of the workpiece measured in meters.

$$F = z \cdot S \cdot F_z, \quad (2)$$

- Fz –feed per tooth.
- Z – number of teeth.

Cutter life also depends on the quantity of parts being produced. For the purpose of decreasing the cutter vibration, as well as improving surface finish and dimensional control fixtures are used in milling. In fixture layout parameters to consider are the direction and magnitude of machining forces exerted during the operation. Usually the milling forces generated on a workpiece when properly clamped tend to push the workpiece down and toward the solid pin positions. The clamping action holds the workpiece against the solid pin and maintains the position of the part during the cut as shown on Fig. 6.
Fixtures and clamps have to keep low profile in order to prevent interference with ideal tool path. Jumping over the clamps has to be reduced or eliminated; also parallelism of surfaces has to be kept in mind.

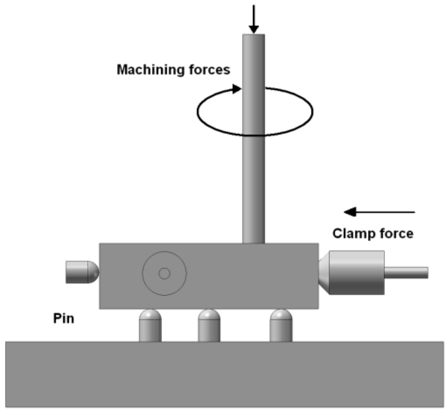


Fig. 6. Tool action and clamp action during the cut

To estimate cutting forces in fixture designs on the workpiece both magnitude and direction, a rough guess based on experience, or a calculation based on machining data is used. The chip problem in machining is solved by positioning the locators away from areas with a high concentration of chips. Another possibility is to relieve the locators in order to reduce the effect of chips on the location. Because of chips locators have to be easy to clean, self-cleaning, or protected from the chips.

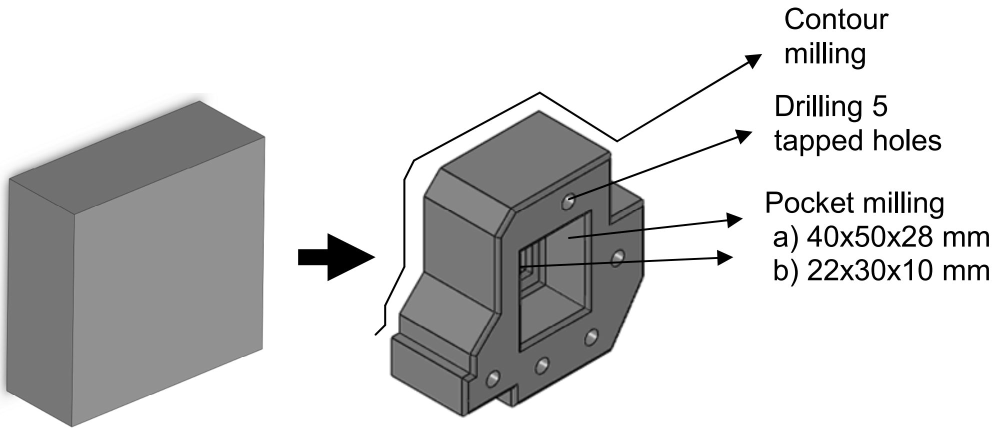


Fig. 7. Cutter accessibility

## 4 TOOLING FOR FLEXIBLE MANUFACTURING SYSTEM

The flexible manufacturing systems (FMS) use CNC machining centres or head-changers tied together by a material transport system controlled by a central computer. The loading and unloading of workpiece is done while the machines are working resulting in good machine utilization and complete flexibility. Dedicated type of duplicated fixture is used, but with interchangeable components (clamps and locators) that are designed in order to handle variations found in a family of parts. For low-volume production and the production of prototype parts for preproduction testing, CNC controlled machining centres (automatic tool changer, multi-position dial index tables, pallet shuttle systems, and automatic pallet changers (Fig. 7)) have proven to be most effective [7].

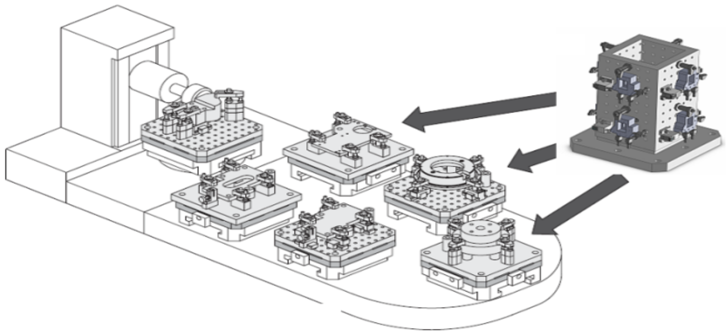

Fig. 8. Horizontal Machining Center (six pallets) [6]

When a setup is complete, an automated guided vehicle (AGV) removes the pallet holding the setup and delivers it to the input stand of the Horizontal machining Centre (HMC) scheduled to machine that particular part. Four main considerations in fixture design for CNC machines are: accessibility, accuracy, rigidity, easy changing of workpiece. Also it is important easy clamping, machining in a single machining cycle, quick and precise pallet mounting when changed from one pallet to another, elimination of the need for dedicated fixtures as much as possible.

## 5 MODELLING

Toolmakers in the process of building a quality fixture present their intent by creating clear detailed drawings and with tight tolerances on each dimension. The task is to generate a fixture plan that provides proper machining, location, support, and clamping such that all the required features can be machined. Today work-holding solutions are designed in 3D CAD software. By the use of visualization tools engineers can monitor designs and provide input early-on in the design process.

Design of fixture begins with drawing of the workpiece, and the selection of relevant surfaces for current machining operation. At the outset there is no fixed knowledge about the structure of needed operations (steps) for the completion of the fixture setup. Before creating a fixture a setup of operations must be planned. The task of setup planning involves consideration of all manufacturing feature instances such that each can be machined in a single setup if possible [8]. Planning of sequences of the operations within each setup, as well as the sequence of setups is determined.

When methodology and the operation steps are selected the workpiece is positioned on the main fixture body and a pattern is selected (production of two or more parts on a fixture). In accordance to the pattern and features to be machined clamps and locators are selected and positioned. They can be taken from existing databases, online catalogues or drawn for the occasion. After successful assembly the fixture is analyzed and an assembly sequence is defined. For each components setup, the fixture plan needs to be determined, ensuring that the planned fixture configuration will provide a force closure on the workpiece during the machining. Also selection of tools must be considered in setup planning before the fixture plan is generated, for each step. In 3D environment detailed models of the fixture elements are available, and each step of the assembly can be verified for proper placement and feasibility. The procedure of planning proceeds by breaking the overall problem into local problems and integration of local solutions in a consistent solution. Lin and Chang [9] developed a methodology for automatic generation of assembly plans for threedimensional mechanical products. Matching and collision information is inferred from the assembly solid models (Fig. 9). Because of large number of mates interference detection was calculated and a clamp was detected to be wrongly placed. Wrongly placed elements can result with a wrong calculation of the NC code.

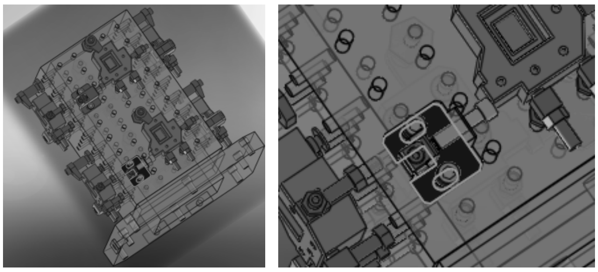

Fig. 9. Interference detection

Tolerance-critical machined parts often require careful engineering analysis when designing clamping and machining configurations. These computer-aided analysis tools are instrumental in optimizing the work holding design well before it is actually built. This makes for little or no adjustment in the fixture during part run-off, shortening the production time.

## 6 MODELLING RESULTS

Fixtures are parts or assemblies that help orient and hold the stock during a machining operation. Components of a fixture can be created and then saved in part or assembly mode. They can be also imported as such from different catalogues directly from suppliers. Once created, they are usually assembled or imported into the machining software for creation of operation steps, programming of NC code. For their successful use in a manufacturing process, fixture setups must be defined. To each fixture setup a name is given and its components are listed, this information is present when the setup is active. When an operation or a tool path is being set up, the fixture setup is defined and as such fixtures belong to operations.

In this example a part needs to be machined on a flexible machining system the horizontal boring and milling machine, with the use of pallets. Modular fixture needs to be designed with a CAD/CAM approach in assembly centre and then sent in production center.

Total number of components in complete assembly was 259, parts 217, unique parts documents 16, unique parts 16. The number of subassemblies is 6, and unique subassemblies 6 together with 204 mates.

Machining was to be preformed under the following conditions:

Fixture: Four-sided grid block, 480 x 300 mm Fig. 12., 8 hook clamp, 8 side clamp, 24 locator pins, 24 adjustable miniature stops.

Machine: Horizontal boring and milling machine; Fig. 9.

Workpiece: rectangle aluminium (Hardness 50-100, 0.25 hp/($in^3$/min), specific energy U= 0.7 N-m/$mm^3$, at a chip thickness of 0.01 in)

Weight: Mass = 912.23 grams

Dimensions: 105 x 43 x 110 mm

Machining data: Operation number

Steps: rough machining, end milling, pocket machining, drilling, finishing. (From this step the length of the material blank are deduced and added to the modeling information for fixture construction).

Spindle speed 5-2,500 rpm

Cutter (Coromill Plura [6] as shown in table 1 and Fig. 9)

Tolerances: $D_c$ : h10, $d_{mm}$: h6

Cutting depth: $a_{max}$= 28 mm

| | | | Dimensions, mm | | | | | | | | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $D_c$ mm | **Ordering code** | Front type, $z_n$ | $dm_m$ | $l_2$ | $l_3$ | Helix $l_{sh}$ mm 2) | $D_4$ | $ch_1$ | $\alpha_o$ | Max $a_p$ 1) | H10F - |
| | **Cylindrical shank** | | | | | | | | | | |
| 8 | R216.32-08025-AK28A | 2 | 8 | 80 | | 56.00 | | | 14° | 28.0 | ☆ |

Table 1, selected milling tool [6]

In the Fig. 10 a representation of a Horizontal Boring/Milling Machine is shown, fixture is to be placed on a pallet as shown, also the selected tool for machining is shown..

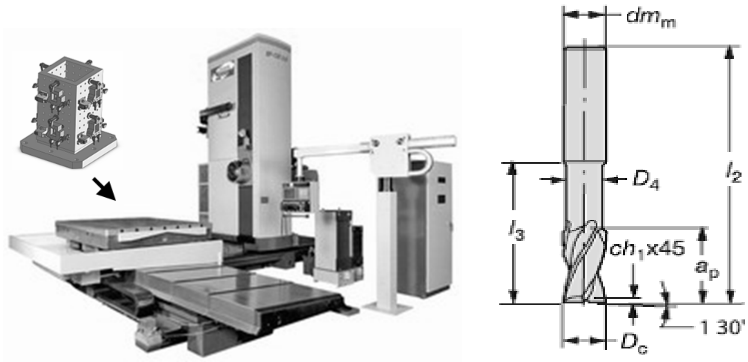


Fig. 10. Horizontal Boring/Milling Machine [10], and selected Coromill tool [6]

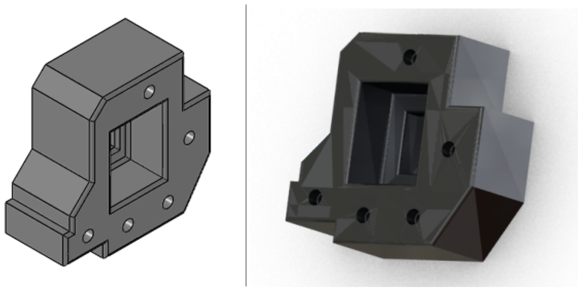

Fig. 11. Workpiece used in example, contains operations of milling, drilling

On the Fig. 11 and Fig. 12 workpiece is shown together with surfaces that are to be machined and those that are free during machining. These surfaces have been previously machined and are not scheduled for machining operation in current step.

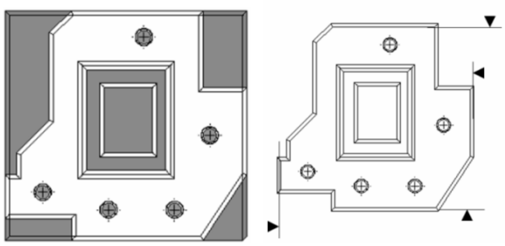

Fig. 12. Workpiece material to be removed, workpiece surfaces that are not machined are selected for positioning

In Fig. 13 a selection for positioning is shown. The positions L1, L2 and L3 are on the bottom of the workpiece and they are placed on equal distances. Locators L4 and L5 are placed next to each other, their distance should be greater. The space allotted for their placement is small and in case of errors alternative such as a single but bigger locator should be used.

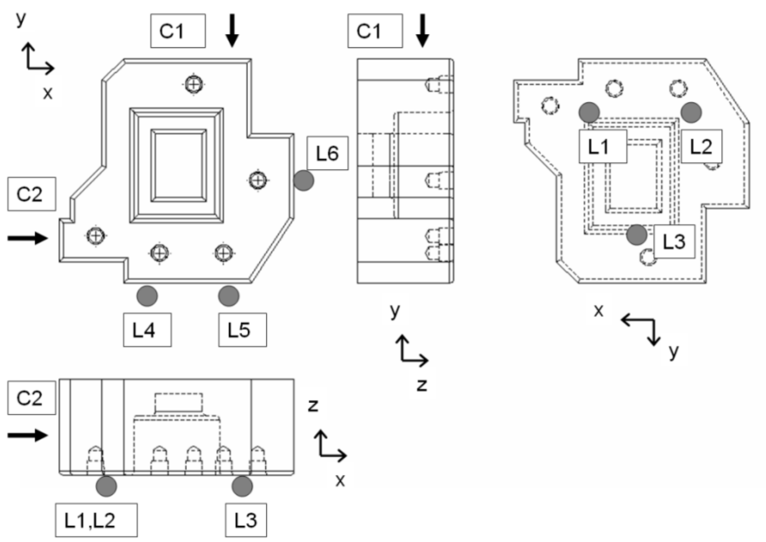


Fig. 13. Selection of ideal positions for locating and clamping

Clamp C2 is a side clamp placed on the remaining free surface, its task is to contain lateral forces of the machining tool, and easy placement of the workpiece. The possible interference with the machining process should be removed by placing an adequate pin in the clamp head. Clamps C1 is a hook clamp its main task is to prevent movement in z axis, its placement could interfere with machining process. A solution is shown in Fig. 14 by clamping at an angle of 24 º relative to the vertical axis of the clamp. Four-sided Tooling Block is used in the example. They are designed for use on horizontal machining centres and provide four identical surfaces for attaching workpieces or other components. They are usually mounted on a rotary table or 4$^{th}$ axis they can be indexed 90˚ and have four work setups to the cutting tool in rapid succession.

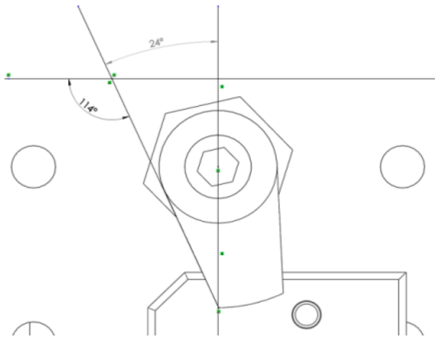


Fig. 14. Selection of ideal hook clamp position turn 24˚ from normal position

In Fig. 15 an optimal positioning setup has been selected based upon the workpiece drawing. Locating principle 3-2-1 has been used with addition of two clamps. One side clamp was selected and one hook clamp.

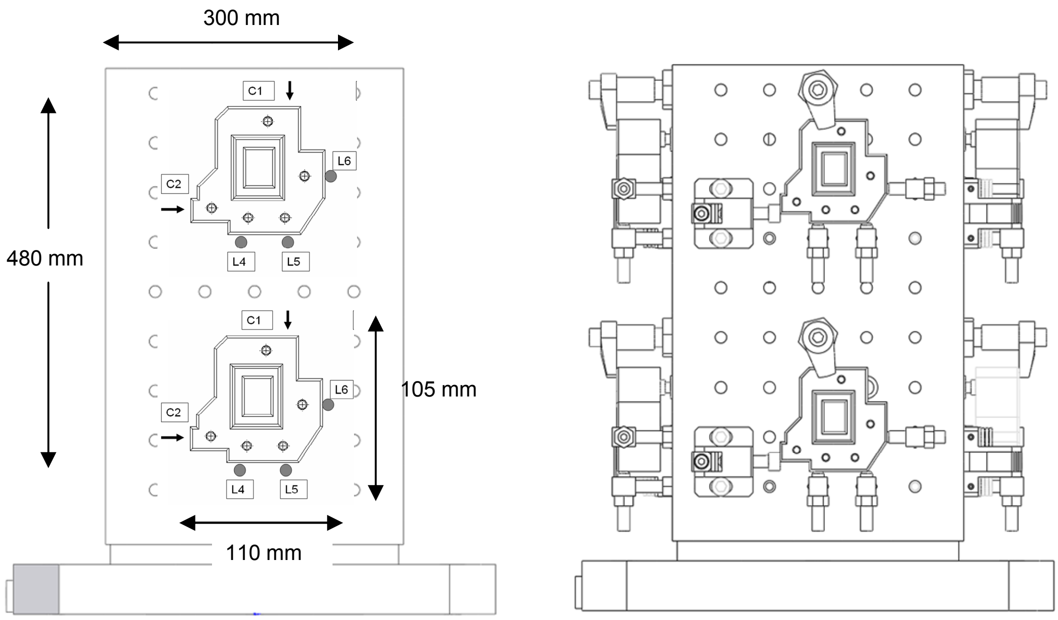


Fig. 15. Plan of a setup pattern, and the final completed setup

In Fig. 16 the final solution of CAD/CAM fixture design is shown. The fixture facilitates a machining cycle for 8 workpieces, saving in this way time and production costs.

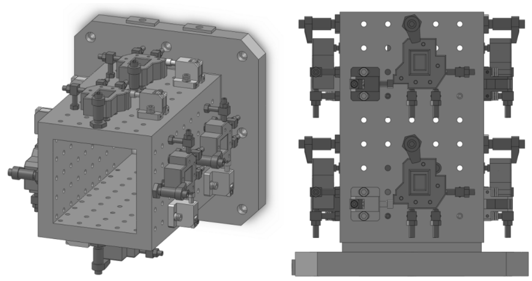

Fig. 16. CAD/CAM approach for modular fixture design

## 7 CONCLUSION

High-performance, accurate and long lasting components represent a crucial ingredient of a well-functioning, reliable fixture. Often offers from firms with elements could be found, but there ware no data about the process itself. This may prove the importance, complexity and purposefulness secrecy of presented process. A 3D model has been created and a solution for fixture placements was selected. Use of a 3D CAD system allows the engineer freedom of experimentation with several design alterations before arriving to optimal solution. A crucial element in work holder design is that locators, not clamps must hold the workpiece against the cutting forces. In this paper a method for positioning the locators relative to the forces has been proposed. Design of fixtures is a complex and intuitive process that usually involves several phases of planning. By creating a modular fixture costs have been saved and production cycle improved. With proposed procedure a flexible solution has been created and the computer system design 3D and setup plan are exploited to the fullest. The next step is machining simulation and its optimization.

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## References:

[1] Kakish, J; Zhang, P. I. & Zeid, I (2000). *Towards the design and development of a knowledge-based universal modular jigs and fixtures system, Journal of Intelligent Manufacturing (2000) 11, 381-401,* 0956-5515, Kluwer Academic Publishers.

[2] Prabhaharan, G.; Padmanaban K. P. & Krishnakumar R. (2006). *Machining fixture layout optimization using FEM and evolutionary techniques, Int. J. Adv. Manuf Technol* (2007) 32: 1090–1103, DOI 10.1007/s00170-006-0441-6, Springer-Verlag London Limited

[3] William E. Boyes, Ramon Bakerjian (1989). *Handbook of Jig and Fixture Design*, Society of Manufacturing Engineers - Technology & Engineering,

[4] Catalogue of fixturing components and fixtures (2008), (http://www.imao.biz/12.12.2008)

[5] Kršulja, Marko; Barišić, Branimir; Sladić, Saša. Optimization of Deformation for Milling Operation Using 3-2-1 Clamping Method // Proceedings of the 12th International DAAAM Workshop CA Systems and Technologies/Piatrová : UŽ-Faculty of Mechanical Engineering, 2007. 97-104

[6] Catalog Sandvik Coromant (2009), (http://www.sandvik.com)

[7] David Spitler, Jeff Lantrip, John G. Nee, David A. Smith (2003). *Fundamentals of Tool Design*, Society of Manufacturing Engineers, Technology & Engineering,

[8] Joneja, A. & Chan, T-C. (1999). *Setup and fixture planning in automated process planning Systems, SpringerLink – Academic journals,* IIE Transactions (1999) 31, 653-665.

[9] Lin, A. C. and Chang, T. C. (1993). An integrated approach to automated assembly planning for threedimensional mechanical products, Int. J. Prod. Res., 31(5), 1201, 1993.

[10] B2Bmanufactures 2008, (www.B2Bmanufactures.com, 12.12.2008)