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DESIGNING OF AN ADAPTIVE FIXTURE FOR THIN-WALLED PARTS

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Abstract—**Fixtures are the main elements in manufacturing processes, such as machining, grinding, welding, assembling etc. Pin fixtures are type of fixtures and they are gaining popularity since they can adopt part surface. This study aims to design and investigate the pin fixtures for thin-walled parts to be machined. In machining of thin-walled parts, main machining considerations are deflections which directly affect the dimensional tolerances and part qualities, and stresses considered as a main cause of deflection. Deflection results were obtained for three pin diameters, three pin configurations and three different forces at two points using ANSYS FEA software. The Von-Mises stresses were also analyzed for the same principle as used in the deflection analyses. Through determining the best pin fixture configuration and pin diameter, it is aimed to design an adaptive pin fixture for thin-wall machining and blade tip repair without excessive deflections. The results have shown that the array configuration can be used as the best adaptable fixture type for part-to-part geometry. Minimum deflections both for edge and midspan loading are obtained for array configuration using 2mm pin diameters.**

Keywords— **Adaptive fixture design, pin fixtures, free-form surfaces, thin-wall part**

I. Introduction

Fixture design is particularly important for complex and delicate geometries, such as thin-walled parts. The parts must be accurately located and clamped firmly in order to maintain tolerances. Fixture design especially for milling processes of thin-walled structures is a challenging process due to the high flexibility of the structure. The main difficult of this case is the high deflection and dimensional deformations during machining. At the same time, industry always aims at achieving tight tolerances while maintaining a high level of productivity. Pin-array fixture can be adaptive to accommodate small changes in workpiece geometry. According to the fixture's flexibility, fixtures also can be classified as dedicated fixtures and general purpose fixtures (e.g. reconfigurable and conformable fixtures, modular fixtures). Reconfigurable and conformable fixtures [1, 2, 3] can be configured to accept parts of varying shapes and sizes.

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Particularly, conformable pin-array fixture technology [4] is widely used in many fixture designs because some components contain internal variables that can be adjusted to meet the different features of workpieces. Pin-array fixtures are able to quickly accommodate for different shape and dimensions without extensive changes. Pin-fixture has advantages of adaptive locating for complex geometry, accurate positioning thanks to its adaptable components.

II. Literature Review

A. *Introduction*

Fixture design has been carried out manually and extensive heuristic knowledge from the designer is needed. The proper design, construction and operation of flexible workholding devices and fixtures are essential to the operation and efficiency of advanced manufacturing systems. An ideal fixture design maximizes locating accuracy and workpiece stability while minimizing displacements. Designing and fabricating fixtures can take up to 10-20% of the total cost of a manufacturing system. Fixture design work is also tedious and time-consuming.

B. *Fixture Design*

The fixture design process is generally divided into two sub activities, fixture layout design and fixture configuration design. Fixture layout design deals with determining the number of locators, supports, and clamps, and finding the optimal locations that the fixture elements should contact the workpiece in order to restrain the workpiece. Fixture configuration design deals with the design of the fixture elements and their 6 locations on a fixture body to realize the fixture layout design [1]. Zhuang et al. [2] explored the existence of modular fixture solutions for a given fixture configuration model and a workpiece, and presented a class of polygons which cannot be fixed by modular fixtures with dowel-pin system. It is important to analyze the locating correctness for the fixture design. When the locating correctness is valid, the designed fixture can be used to determine the position of the workpiece with respect to the cutting tool.

III. Adaptive/Flexible Fixture Design

The flexible fixture under consideration consists of passive (locators) and active elements (clamps) which can apply either prescribed forces or displacements. It is assumed that: (i) dry Coulomb friction is present at all contacts; (ii) all deformations are elastic and small; (iii) contacts behave according to the Hertzian theory of elastic contacts; (iv) the fixels act like cantilever beams; and (v) the arbitrary workpiece geometry can be modeled using bicubic Bezier patches connected to each other ensuring first- and

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second-order continuity. This type of parametric representation offers easy computation of point coordinates normal vectors, tangent vectors and principal curvatures at the point of fixture–workpiece contact [3].

A. *Pin Fixturing*

Pin-array fixture can be adaptive to accommodate small changes in workpiece geometry. According to the fixture's flexibility, fixtures also can be classified as dedicated fixtures and general purpose fixtures (e.g. reconfigurable and conformable fixtures, modular fixtures). Reconfigurable and conformable fixtures [5,6,7] can be configured to accept parts of varying shapes and sizes. Particularly, conformable pin-array fixture technology [8] is widely used in many fixture designs because some components contain internal variables that can be adjusted to meet the different features of workpieces. Pin-array fixtures are able to quickly accommodate for 10 different shape and dimensions without extensive changes. Pin-fixture has advantages of adaptive locating for complex geometry, accurate positioning thanks to its adaptable components.

Cook et al. [9] extends pin-tool research through investigating a new method to accurately position high-fidelity pins in an array, with each pin uniquely positioned under computer control. The resultant tool is a reusable prototyping system for the rapid generation of three-dimension (3-D) profiles using CAD extracted data, with application potential in a variety of manufacturing processes

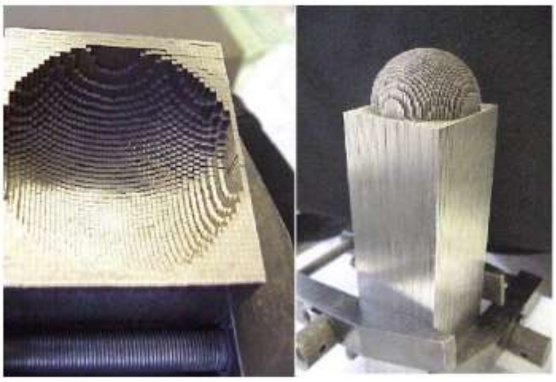


Figure 1 Both ends of a 50×50 demonstration array of 1.0 mm "headers" showing a three-dimension profile manually imparted from a hemispherical former [9].

Al-Habaibeh et al. [10] have made an attempt to an experimental design and evaluation of a pin-type universal clamping system. The clamping system is designed for holding complex-shaped aerospace components, such as turbine blades, during machining processes.

B. *Milling of Thin-Walled Parts*

Rai et al. [11] describes an overview of a comprehensive finite element method(FEM) based milling process plan verification model and associated tools via considering the effects of fixturing, operation sequence, tool path and cutting parameters which simulates the milling process in a transient 3D environments. And also it predicts the part thin wall deflections and elastic-plastic deformations during machining.

Liu et al. [12] presents a finite element model along with an accurate cutting forces model to optimize the positions of the locators in peripheral milling of a thin-walled workpiece. They use the finite element model which takes into account the thickness variations of the workpiece in peripheral milling. The locators on the secondary locating surface directly influence the surface errors in peripheral milling of thin-walled workpiece, so this study deals with the optimization of the positions of the locators on the secondary locating surface.

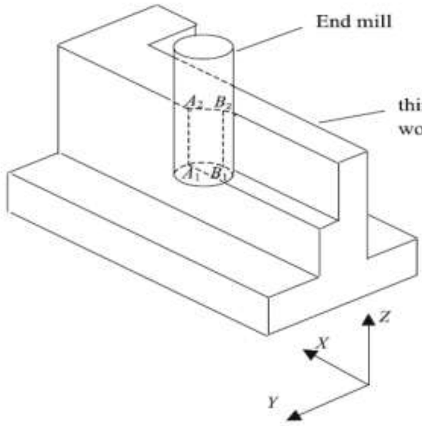


Figure 2 Peripheral down milling of a thin-walled workpiece [12]

Herranz et al. [13] presets a methodology that provides several steps that can be taken in order to minimize the bending and vibration effects; suggests optimal monitoring methods to detect process instability; and describes the best way to tune the cutting conditions and chip load, by means of simulation at different machining stages. In this way, the reliability of aeronautical production significantly increases. The global approach presented in this study has been applied to two test pieces and two real parts, which were milled without suffering either static or dynamic problems.

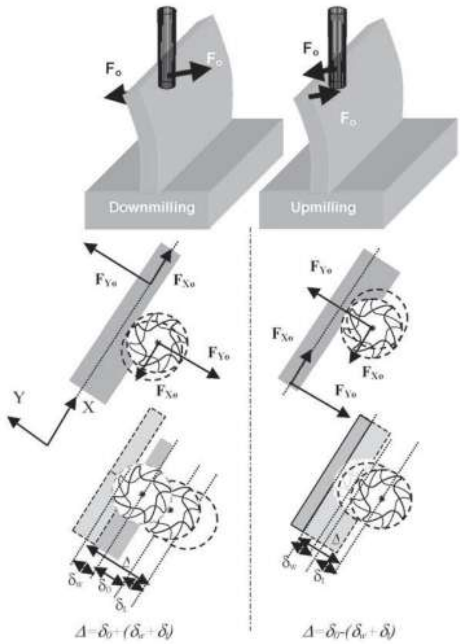


Figure 3 Forces in downmilling and upmilling. Schematic view (top); force at each side of the part/tool interface (center); and displacement induced by force (bottom) [13].

IV. Finite Element Modelling Of Adaptive Pin Fixture

In pin fixturing the pins are able to give the orientation of the workpiece with respect to the reference datum surfaces. Pins can be adjusted for accommodating the part surfaces in order to obtain accurate and correct workpiece positioning. Another important function of pins is to prevent from dynamic effects which are produced during machining operation. In this thesis, finite element analyses (FEA) approach was chosen in order to predict deflections and stresses produced normal cutting force. Workbench in ANSYS, FEA software was used for that purpose. FEA tools that evaluate the performance of the pin fixture-part model helped to determine the best pin configuration for minimum deflection and stresses.

A. *Workpiece and Pin Materials*

Because of their excellent high specific strength (strength-to-weight ratio), titanium and its alloys are used extensively in aerospace applications. Machining operations such as milling, drilling, reaming tapping and grinding are used in aerospace industry. End milling titanium Ti–6Al–4V has wide applications in aerospace, biomedical, and chemical industries. The surface of titanium is easily damaged during machining operation due to their poor machinability. Titanium alloys are extremely difficult to machine materials. The machinability of titanium and its alloys is generally considered as poor owing to several individual properties of the material. Because of these reasons Ti–6Al–4V (Grade 5) alloy was chosen as a workpiece material in ANSYS modellings, deflection analyses, and stress analyses. Table 1 gives the chemical compositions of Ti–6Al–4V alloy and Table 2 gives mechanical properties (taken from ANSYS library) used in the ANSYS models.

Table 1 Chemical composition of titanium alloys

Workpiece Matetial	Chemical Composition (wt.%)						
Ti-6Al-4V	V	Al	N	O	H	C	Fe
	4	6	0.05	0.2	0.0125	0.1	0.3

Table 2 Mechanical properties of workpiece material

Workpiece Material	Ti-6Al-4V
Tensile Strength (MPa)	930
Yield Strength (MPa)	850
Modulus of Elasticity (GPa)	114
Hardness (HB)	340
Ductility(%)	10
Density(kg/m^3)	4620
Possion Ratio	0,36

Pins are part of fixture; therefore they are produced from structural steels in general. In this work, since the pins are applying a point force on the workpiece surface, they must be softer than the workpiece materials. Thus pin material was chosen as structural steels in the models. Mechanical properties of structural steel are given in Table 3.

Table 3 Mechanical properties of pin material

Workpiece Material	Structural Steel
Tensile Strength (MPa)	250
Yield Strength (MPa)	460
Modulus of Elasticiy (GPa)	200
Density(kg/m^3)	7850
Possion Ratio	0,3

The .SLDASM.file produced in Solidworks CAD models is converted to IGES (initial graphics exchange specifications) format. Static Structural Analysis module in Workbench in ANSYS to perform a static analysis for part deflection. At this phase, analysis information such as contacts, material properties, boundary conditions, and the calculated machining load are the inputs to calculate the deflection.

B. *Plate and Pins Geometry*

Plates to be considered as workpieces and pins are designed and modelled in SolidWorks® CAD software and then the CAD data were exported to ANSYS19 Workbench®. Plates are in 50x50x1 mm dimensions as shown in Figure 4 (a). Pins were designed and modelled with rounded tip (spherical tip) and cylindrical body, as shown in Figure 4 (b). Diameters of spheres of the pins are varying as 2, 3, and 5mm. These diameters are the common diameters used in pin fixtures and those pins can easily be manufactured.

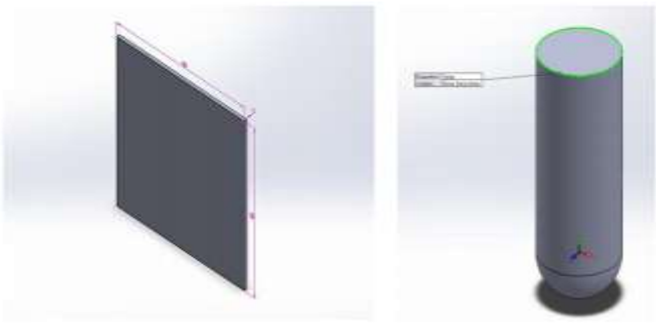
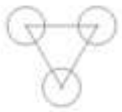


Figure 4 Solid models of plate geometry (a), and pin (b)

In this wok, three pin diameters (2, 3 and 5 mm) were used. Pins are normally assembled in fixtures. Depending upon the form of the workpiece surface pins are positioned via closing the fixture jaws. Pins are scattered to a fixture jaw surface area with 30×30 mm dimension and with minimum 1mm gap distances.

Table 4 Pin patterns according to configuration types

Configuration Type	Pin Patterns
Array	
Triangle	
Honeycomb	

C. *Condition Assignments*

The locators were modeled as displacement constraints that prevent workpiece translation in the normal direction. The clamping force was modeled as point force. The workpiece is considered as 2D by assuming the workpiece is subjected to plane stress. Static analysis is used to find out the deflection of the workpiece under machining. Pins were modeled as displacement constraints withstand to workpiece translation in the normal direction as shown in Figure

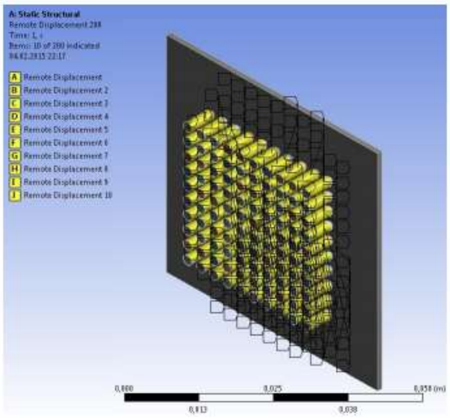


Figure 5 Remote Displacements of Pins

During fixture design process, the fixturing points should firstly be determined. It is required that to identify the faces of the workpiece to be machined, locating and supporting faces. In deciding the best possible supporting, locating, clamping faces, workpiece geometry and operation face are important. The supporter position is selected so as to make sure that the workpiece will not move during machining. In this study, the upper part of the workpiece is to be machined and therefore the bottom side of thin-walled workpiece has been chosen as support part in fixturing as shown in Figure 6.

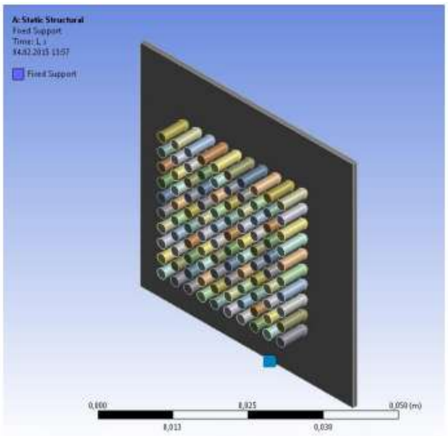


Figure 6 Supporting of Thin-Walled Workpiece

The cutting force reaches its maximum value during the initial cut, minimum in the middle of the side, and then increased gradually when the tool passed the middle. The maximum value of thin-walled part deflection occurs on the upper edge of the part. To determine the deformation of the workpiece, the –z direction force of material removal effect was considered between critical range (150-250N). Then the deformation of the workpiece was determined by Static Structural using Workbench in ANSYS Mechanical software. In our models, the normal force in –z direction was acting on the tip edge and midspan of the plate as shown in Figure 7 and 8.

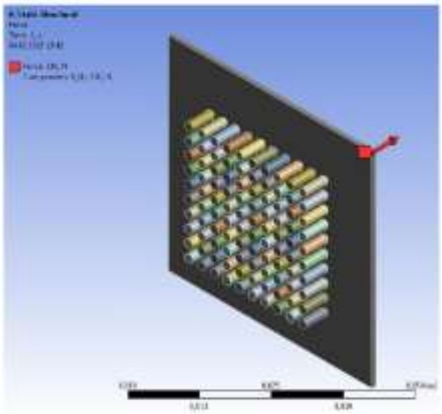


Figure 7 Edge Force acting on Workpiece for Ø2 mm Array Configuration

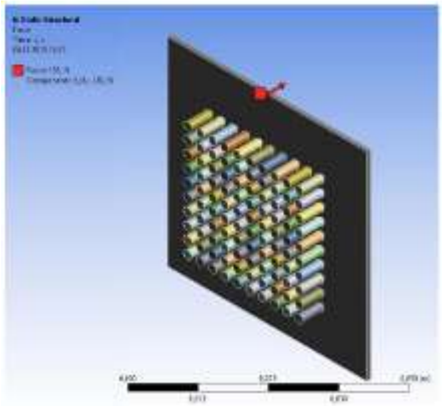


Figure 8 Midspan Force acting on Workpiece for Ø2 mm Array Configuration

V. Results and Discussions

This section covers the deflection and stress analyses results of the selected workpiece geometry and material for different pin configurations (array, triangle and honeycomb) and pin diameters. Main causes of the deflection and stress results are also discussed in each section. Pins in the fixture jaw area varied with diameter of pins. Ø2mm pins have higher numbers than Ø3mm and Ø5mm pin numbers. The variation of the pin numbers vs pin diameter for array, triangle and honeycomb configurations.

Deflection is a geometrical deformation caused by an applied force. Depending upon the direction and magnitude of the applied force, amount of deflection and its direction in the local coordinates may change. This type of deformation of a part is mainly dependent on load, length of the part, elastic modulus and moment of inertia. In this work, rather than calculating the deflections caused by the cutting force on the pin fixture models using standard deflection formula, ANSYS directional deformation models were preferred. The reason is that the pin fixtures contain high number of pins assembled to two fixture jaws should be considered with the workpiece geometry as well as other fixture elements. Thus, ANSYS directional deformation method is the most proper method for such complicated analyses. In fact, there are two types of deformation in fixturing: (a) Bending of workpiece caused by cutting forces; (b) Deformation of contact regions caused by clamping forces.

Edge deflection results based on pin diameter are given according to the cutting forces for the pin diameters and for the different pin configurations as shown in Figure 4.2. It is obvious that when the cuttings force increases deflection increases. For 2mm pin diameter, honeycomb and triangle pin configurations are varying between 60-120µm. Both configurations have almost the same results. However array configuration has less edge deflections results. The reason of that pins in array configuration has more contact point on the workpiece surface and therefore pin array configuration may show better support against the cutting forces. Edge deflection results for 3mm and 5mm pin diameters were obtained almost same amount varying between 60-120 µm. Thus 2mm pins in array configurations give less edge deflections compared to other pin diameters.

Stress is the main cause of deflection and therefore stress analyses must also be done in order to see their variations. In this work, Von-Mises stresses were analyzed for different cutting forces, pin configurations and diameters. Von Mises stress is widely used to check whether the design will withstand to a given load conditions. Von Mises stresses comprise the principal stresses in 3-dimensions as well as shear stresses. Therefore it is the best stress analyses criteria.

VI. Conclusions

This work aims to investigate the deflection and stress analyses for different pin fixture arrangements. In pin fixturing rather than the other fixture elements (supporting and positioning elements) pins, pin diameters and pin configurations in the fixture jaw area are of primary importance. Therefore only the pin diameters (2, 3 and 5mm) and three different pin configurations (array, triangle and honeycomb) were considered in this study. Three different cutting forces (150, 200 and 250N) are affected to the edge and midspan of the workpieces in the –z directions. Deflections were analyzed using Workbench in ANSYS FEA software by considering as directional deformation in the same direction of the cutting force. Deflection results were obtained for three pin diameters, three pin configurations and three different forces at two points. In addition to deflections, also the Von-Mises stresses were analyzed for the same principle as used in the deflection analyses. Number of pins in the developed pin fixture models is the highest in array configuration, less in honeycomb configuration and the least is in the triangle configuration. Minimum deflections both for edge and midspan loading are obtained in array configuration using 2mm pin diameters. Minimum edge stresses were obtained using 5mm pin diameters for all pin configurations. Pin array configurations have found that the best adaptable fixture type for part-to-part geometry. The results also showed that triangle and honeycomb configurations may be preferable rather than the array configurations when manufacturability, fixturing time and cost are primary considerations.

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