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INTELLIGENT FIXTURE – BRIEF REVIEW

BY

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Abstract. Fixtures are components of the technological system that have the function of orientation-position and clamping of the workpiece during machining, inspection, assembly processes. In this paper a literature survey is presented for intelligent fixtures and significant work is presented. Intelligent fixture employs integrated sensor and actuator in fixture structure in order to overcome the shortcomings of vibrations, deformations of the workpiece during machining. A series of clarification are made in accordance with conventional fixture design methodology regarding clamping force determination.

Keywords: intelligent fixture; variable clamping forces.

1. Introduction

Fixtures are components of the technological system that have the function of orientation-position and clamping of the workpiece during machining, inspection, assembly processes. The main task of the fixtures is to define the orientation and position of the workpiece (location) in the workspace of a machine tool (usually) and maintain this location, by clamping, under the influence of the static and dynamic mechanical and thermal loads generated by the machining processes and guide this loads to the machine structure inside the

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force flux (Gherghel, 1981; Brăgaru *et al.*, 1982; Rong and Zhu, 1999; Rong *et. al.* 2005; Gherghel and Seghedin, 2002; Gherghel and Seghedin, 2006; Nee *et al.*, 2004; Seghedin, 2003; Möhring *et al*., 2016a).

General structure of technological fixtures consist of at least 35 group of components according to (Gherghel, 1981; Gherghel and Seghedin, 2002; Gherghel and Seghedin, 2006; Seghedin, 2003). The typical components found in fixtures can be *common* to all fixtures and *specific* to various types of fixtures.

The *common* components are: 1. elements, mechanisms, subassemblies for orientation and position of the workpiece (supports, locators); 2. clamping components used for tighten the workpiece during machining, has the role of converting and distributing the acting force, 3. self-centring components – that simultaneous centre and clamp the workpiece; 4. acting elements, drive components that are prime mover for the clamping mechanism, 5. internal connexion components, frame; 6. components for fixture locating in the technological system; 7. components for fixture clamping in the technological system; 8. assembly components.

A selection of *specific* components that can be found in fixture structure is presented: components for increasing the workpiece-fixture subsystem rigidity and stability such as supports, lifting, locking, indexation, tilting, balancing, mechanisms, element for transmitting information, verification, command and protection.

In conformity to the *design methodology 12 Steps* (S) it is necessary to determine the optimal orientation and positioning scheme and another main task is to determine the optimal clamping scheme and considering the fixturing definition from Technical Lexicon the fixture components have limited movement capabilities during setup and are fixed during work or machining (Lexiconul Tehnic, 1960).

The general structure of the technological fixture reflects the complexity and vastness of the tasks accomplish by fixtures, but also the complex issues of designing fixtures

Various design methodologies have been developed from genera "3-2-1" design methodologies to 12 Steps (S) (Gherghel, 1981) to SEFA-DISROM (Brăgaru *et al.*, 1982) to Computer Aided Fixture Design (Li *et al*., 1999; Ma *et al*., 1999; Rong *et al.*, 1999; Kumar *et al.*, 1999; Kumar *et al.*, 2000; Nee *et al.*, 2004; Rong *et al.*, 2005; Kaya, 2006; Mervyn *et al*., 2006; Rong *et al.*, 2010; Bi, 2010). From the identified literature, Computer Aided Fixture Design (CAFD) has the purpose of assisting design engineers in developing fixture solution. Various structures of CAFD system and various methodologies have been proposed for determining the optimal fixture plan layout. Among the proposed methodologies we mention: genetic algorithm, neuronal networks, case-based reasoning. However, little work has been directed to the investigation of fixture execution and behaviour at work. It must be said that the vast majority of work in this research field has been done by academic and not by industry (Li *et al*., 1999; Ma *et al*., 1999; Rong *et al*., 1999; Kumar *et al*., 1999; Kumar *et al*., 2000; Rong *et al*., 2005; Kaya, 2006; Mervyn *et al*., 2006; Rong *et al*., 2010; Bi, 2010, Wang *et al*., 2010; Maniar *et al*., 2013; Bakker *et al*., 2013).

In this paper the equal critic task of fixture execution is studied and the machining accuracy improvement methods offered by the intelligent fixtures.

2. Intelligent Fixtures

An intelligent fixture, according to Nee (Nee *et al*., 2004), has incorporated a fixturing planner that is used to generate viable fixture configurations and a corresponding "*live fixture*", that can correct fixture orientation and position of the workpiece by tool path compensation before machining.

The proposed intelligent fixture incorporates three independent sub-function, elements: analysis and synthesis of fixture components generation, workholding execution (Nee *et al*., 2004).

First step refers to generation of fixture design for orientation and positioning the workpiece and clamps the workpiece according to the imposed machining requirements.

The second sub-function is the assembly of the "*live fixture*". The "live fixtures" refers to a *dynamic clamping actuator* able to apply time-varying clamping forces. The aim is to reduce workpiece displacement and distortion under clamping forces and machining forces. The fixture structure incorporates sensors and control components, actuators, capable of on-line control of the fixture actions. In this case the clamping force adjusted continuous depending on the machining force amplitude (Nee *et al*., 2004).

The third sub-function is the execution of the *adaptive workholding* operation by performing a probing procedure used by CMM (Coordinate Measurement Machine) or the CNC machine to determine the workpiece position after clamping and adapting accordingly, the tool path through NC code corrections (Nee *et al*., 2004).

According to Tol (2003) Intelligent Fixturing System (IFS) or Complete flexible automated fixturing are able to: real time adaptive clamping forces so as to minimize part deformation, adaptively to the disturbances and provide feedback information to IFS controller.

According to Bakker, the supplementary functions of an intelligent fixture above a specialized fixture, considering the Flexible Manufacturing systems requirements are (Bakker, 2010; Bakker *et al*., 2013):

– Low reconfiguration times;

– Improved location accuracy by sensors usage;

– Automatic adjustability for parts with poor, but still acceptable, tolerances;

– Ability of realigning and manipulation of the workpiece in the case of badly loaded workpieces;

– Reconfigurability of clamps and supports during the manufacturing process;

– Active control of clamping forces, to minimise the deformation in the part- fixture system due to the clamping forces.

Župerl proposed an intelligent fixture system for adjusting the clamping force and location adaptively to the magnitude of the machining, cutting force. In order to achieve minimal deformation of the workpiece the following operation must be performed: monitor the clamping force, monitor the machining force, adjust the clamping force to a present condition, and adjust the clamping force according to the change in the workpiece geometry. Thus the “intelligent“ functions of the fixture beside the base functions are: control of clamping forces/torques acting on workpiece, monitoring of clamping operations and elements of fixtures, readjustment of locators and change of clamping elements. But due to cost and limited access the proposed system only allows off-line optimisation of the location of the clamps and on-line optimisation of clamping force magnitude (Župerl *et al*., 2011a, b).

According to (Möhring *et al*., 2016a, b, c,; Möhring *et al*., 2017) an intelligent fixture uses integrated sensor and actuator in fixture structure in order to overcome the shortcomings of vibrations, deformations of the workpiece during machining. Fig. 1 presents an intelligent fixture realized by Möhring.

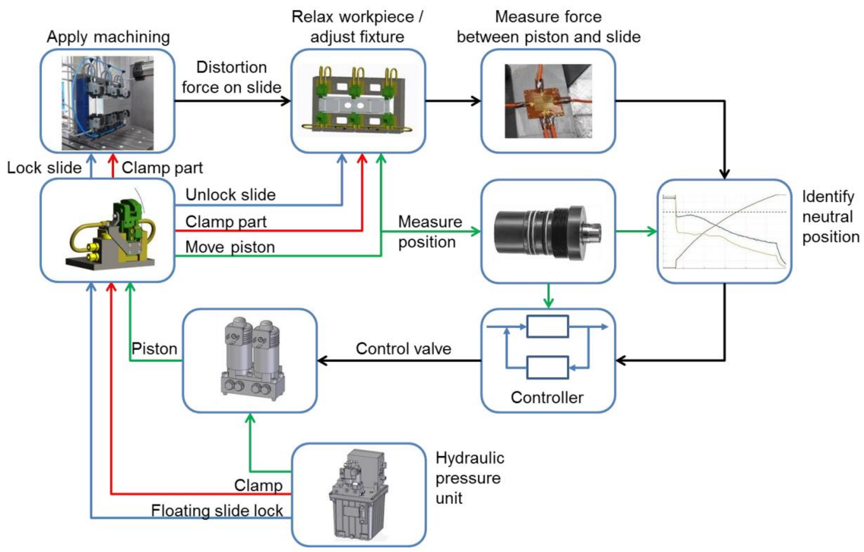

Fig. 1 – Command and control diagram for an intelligent fixture realized by Möhring (Möhring *et al*., 2016a, b).

Mohring designed and realized a series of fixtures for clamping large parts from the aeronautical field, where up to 90% of the material is removed. Thus, these parts are prone to distortion due to gravitational, clamping and machining forces.

Also, Möhring designed and realized a series of chuck that use piezo-actuators for correction of the workpiece position and dampening of vibrations.

2.1. Clarifications on Intelligent Fixtures Definition

From the presented definitions there are different opinions on the "intelligent fixture" and on the requirements or capabilities of this fixture (Szuba 2000; Rakowski 2002; Nee *et al.*, 2004; Mudriková *et al.*, 2009; Kerak *et al.*, 2011; Župerl *et al.*, 2011a, b; Kostalova *et al.*, 2012; Kostal *et al.*, 2012; Zhang *et al.*, 2016; Bhendarkar *et al.*, 2016; Möhring *et al.*, 2016a, b, c; Möhring *et al.*, 2017). Analysing the presented work and considering the functions of the fixture presented in the introduction and the corresponding components that materialize these functions a series of observations can be made:

1. the intelligent fixture can modify or optimize the optimal orientation and position scheme by moving the locators – used for orientation and position of the workpiece, or by moving the support that supplementary increase the stiffness and stability of the workpiece fixture assembly. In all cases locator and support are considered fixed (fixels). There are no consideration on the *auto-mobile/ self-regulating/ oscillating supports*, or on the *mobile support* – used for correct orientation and position of the workpiece or on *floating supports* – linear or angular.

Also, in the case of support displacement the limits of those movements are not presented (for instance if there are superior or inferior to the workpiece tolerances) or if the movements are linear (presumably) or angular.

2. the movement of the supports can be made on or offline. On line – continuously during machining and offline after the workpiece is clamped in the fixture. In the presented consideration in the introduction (Lexiconul Tehnic) during machining the supports and clamps used are fixed. In the presented considerations movement of the supports and clamps are allowed (Nee *et al.*, 2004).

3. the intelligent fixture can modify or optimize the optimal clamping scheme online, continuous during machining by moving the point of application and magnitude of the clamping force. However to complete define the clamping operation the following aspects must be clarified:

– which are the variable clamping forces: - preliminary clamping forces (used for assuring firm contact with the locators/ supports), main clamping force (used for maintain the optima orientation-positioning scheme during machining) or supplementary clamping forces (used for increased stiffness and stability); presumably the main clamping forces and supplementary clamping forces.

– when selecting the optimal clamping scheme the following criteria must be analysed:

• direction, point of application, number of main clamping forces;
• magnitude of main clamping forces;
• necessity of supplementary clamping forces;
• decomposition of the main clamping forces on several directions;
• contact pressure between workpiece and clamps.

The only variable element form the presented criteria is magnitude and direction of the main clamping forces.

From the presented consideration regarding functions of the intelligent fixtures there are different levels of automatisation of fixtures by integrations of various sensors and actuators that allows interventions during machining in accordance with command inputs from a PLC (Programmable Logical Controller) with various command loops.

To the notion of intelligent fixture a series of subordinate notions considering the level of automatisation involved:

– sensor based verification fixture/ sensor integrated fixture;
– sensory clamping system;
– dynamic clamping/ intelligent clamping;
– active fixture/ adaptive fixture.

Sensor-based fixture/ sensor integrated fixture design refers to fixtures where various sensor systems are utilised to ensure that the part is located correctly in the fixture (foolproofing - preventing incorrect loading), by alerting is proper contact is not made with the fixtures supports. It is the case of symmetric workpieces that are easy to place wrong in the fixture (Jonsson, 2008; Rong *et al.*, 2005; Bakker, 2010). In order to accomplish fixture foolprofing and part contact verification fixture components with sensor must be used (Nee *et al.*, 2004).

Sensory clamping system refers to usage of sensors for monitoring the clamping forces indirectly by monitoring the clamping mechanism behaviour in order to avoid complex measuring system. Denka realized an hydraulic clamps that uses strain gauges to determine hydraulic pressure inside the piston chamber and indirectly the clamping force (Denka *et al.*, 2016a, b). In this case, there is a simplification of the force measuring equipment as presented earlier compared to previous cases *eg.* pressure sensor or Kistler force sensors (Župerl, 2011), thus forming the basis for further process monitoring.

Dynamic clamping system refers to a fixture structure that incorporates sensors in the locators/ support and actuator rod and control components, actuators in the form of a electromechanical system primarily consists of a DC servomotor and a linear actuator, capable of on-line control of the fixture actions, presented in Fig. 2. In this case the clamping force adjusted continuous depending on the machining force amplitude (Nee *et al.*, 2004).

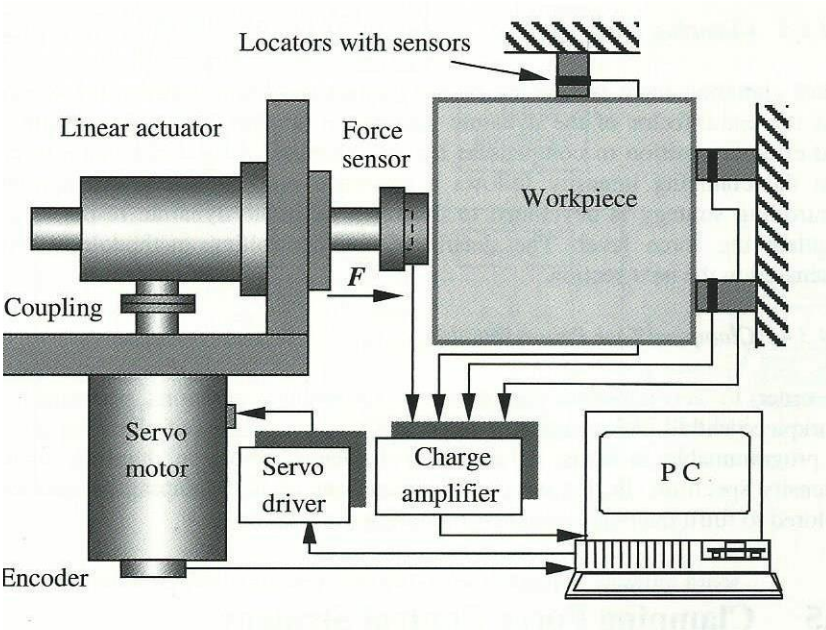

Fig. 2 – Dynamic clamping actuator (Nee *et al.*, 2004).

Adaptive fixtures includes fixturing systems with elements that can apply variable clamping forces, responding to external machining conditions. These fixtures usually deploy clamping elements that incorporate actuation and sensing capabilities, rendering them able to operate in a closed-loop manner. Contrary to NC fixtures, adaptive fixtures are most often not reconfigurable (Bakker, 2010). According (Papastathis, 2011) active fixture/ adaptive fixture have the capacity of clamping force variation and, also clamping position variation.

3. Conclusions

Intelligent fixture as presented cover a large aria of fixture operation optimization thus resulting varies level of capability. The main goal of intelligent fixture or common denominator is controlling the clamping force by various means (mainly hydraulic, pneumatic actuation), in order to overcome one negative aspect of conventional fixture as the excessively large clamping force for the whole operation. Still there is a lack of clarity about which components of the tightening forces are controlled: point of application, number of clamping forces, succession, force type – main supplementary, direction and orientation, etc.

From the presented work several modalities of expressing the basically the same thing for example: - active fixture/ adaptive fixture. Also there is no agreement on the correct definition and delimitation of intelligent fixtures. Confusions are frequent by focusing on fixture components and allocating features to the entire fixture.

From analysis of structure of technological fixtures components found in intelligent fixture are common with conventional fixture. Most of the presented work is conducted by academic researcher and not by the production sector. In this case the sensors used are designed for research use and not for mainstream machining production.

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DISPOZITIVE INTELIGENTE – RECENZIE SUCCINTĂ

(Rezumat)

Dispozitivele sunt componente ale sistemului tehnologic cu rol în orientarea-poziționarea și strangerea semifabricatelor la operații de prelucrare, control și asamblare. În acestă lucrare se prezintă un studiu al literaturii din domeniu privind dispozitivele inteligente și se prezintă realizările reprezentative. Dispozitivele inteligente folosesc senzori și actuatori din structura dispozitivului pentru a depăși dezavantajele generate de vibrațiile, deformațiile pieselor în timpul prelucrării. O serie de clarificări sunt realizate în acord cu metodologiile de proiectare ale dispozitivelor convenționale privind determinarea schemelor optime de strângere și proiectarea mecanismelor de strângere.