http://doi.org/10.24867/JPE-2018-01-049

Journal of Production Engineering

Vol.21 No.1

JPE (2018) Vol.21 (1) Original Scientific Paper
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COMPUTER-AIDED DESIGN AND OPTIMIZATION OF FIXTURES FOR PLASTIC PARTS MACHINING

Received: 02 February 2018 / Accepted: 28 April 2018

Abstract: *Reviewed and verified in this paper is a system which integrates functions of fixture design and optimization. The system was developed for machining of plastic parts. Due to specific characteristics of plastic parts, the system allows optimization of location of fixture elements for clamping and locating, using minimum deformation of plastic parts as the goal function. The paper present the basic steps of the methodology applied, reviews specific segments of the system, and illustrates its applicability on a study case featuring operations of drilling and milling of ABS parts.*
Key words: *plastic parts, fixture, genetic algorithms, knowledge base*

Računarom podržano projektovanje i optimizacija pribora za obradu plastičnih delova. *U radu je prikazan i verifikovan sistem koji integriše funkcije projektovanja i optimizacije konstrukcije pribora. Sistem je razvijen za potrebe mašinske obrade plastičnih delova. Zbog specifičnih karakteristika plastičnih delova, sistem obezbeđuje optimizaciju pozicije elemenata pribora za stezanje i pozicioniranje, koristeći minimalnu deformacija plastičnih delova, kao funkciju cilja. U radu su prezentovani osnovni koraci primenjene metodologije, razmatrani su specifični segmenti sistema i prikazana je primena sistema na karakterističnim studijama slučaja u operacijama bušenja i glodanja delova od ABS-a.*
Ključne reči: *plastični delovi, pribor, genetski algoritmi, baza znanja*

1. INTRODUCTION

The last couple of decades have seen an intensive research in the domain of plastic materials. Until recently, manufacturing industry relied mostly on steel, grey iron, non-ferrous metals, etc. However, today there is an ever-growing application of plastic materials in new products (PVC, PET, ABS, PP, etc.). Until recently, it was not always possible to manufacture products from plastic due to a number of structural, technological, and exploitation characteristics which have to be met. However, in cases when hardness, strength, and stiffness of a product are not of vital importance, plastic is always a good choice due to its numerous advantages. In comparison with metals, the most important advantages of plastic materials are: machinability and formability, lower costs, low specific mass, excellent dielectric features, resistance to corrosion, acids, and aggressive chemicals, good thermal insulation, etc. [1]. Plastic parts are manufactured by various methods: extrusion, injection, blowing, pressing, rotational casting, etc. [2]. Furthermore, numerous plastic parts require additional machining, such as turning [3], drilling [4], milling [5], grinding [6], etc. Adequate equipment is required in order to perform the machining and inspection of dimensions, geometric features (straightness, flatness, circularity, cylindricity, etc.), and surface quality characteristics (roughness, waviness, etc.). The most vital equipment for manufacture of plastic parts includes machine tools, cutting tools, and.

The main objective of fixture is to establish and secure the desired position and orientation of the part during machining, inspection, etc. [7, 8]. A fixture consists of fixture elements. These fixture elements can be made from various materials, however, expensive steels have been most often in use. There are a growing number of applications of plastic materials for fixture elements to be used in machining and inspection of plastic parts. The use of plastic materials significantly reduces total costs of manufacture. Due to small forces, and absence of vibrations, fixtures used in inspection processes are almost entirely manufactured from plastic materials. Unlike the fixtures for metal parts, the fixtures used for plastic parts are exposed to much more complex influences. To compensate for lower strength and hardness of plastic, of primary importance is optimization of forces. These forces cause the bending and contact deformations of plastic parts [9].

Fixture design takes a significant part of the total time (cost) necessary for production preparation. The costs associated with the design and manufacture of fixtures are sizeable, accounting for some 10-20% of the total cost of a manufacturing system [10]. To shorten that time means also to decrease the adjoining costs. This can be done, among other things, by applying new methods in fixture design. These new methods are based on computer-aided fixture design [11]. The so far research in the area of computer-aided fixture design has included various approaches. Two investigation fields were prominent: optimization of fixture design, and development of fixture design systems [12].

To optimize position of locating and clamping elements, finite element method (FEM) analysis has been most often used [13-16]. However, the basic drawback to such approach is the lack of global optimum solutions, as well as the fact that the goal functions used do not depend on variable design parameters, i.e. positions of locating and clamping elements. Hence these approaches improve solution to some extent, without reaching the global optimum. Besides, the solutions thus generated are highly sensitive to the quality of initial solution which represents input to the process of optimization. On the other hand, there have been some investigations which utilized genetic algorithms (GA) for optimization of fixture design solution [17-21]. In such cases the problem was rather simplified, disregarding the dynamic nature of forces and machining torques. Furthermore, output results were not sufficient to render concept solutions with all the necessary fixture elements.

In the domain of development and application of systems for automated fixture design numerous results have been published [22-24]. Other fixture related work include fuzzy based fixture design [25], reuse based fixture design [26], component based fixture design [27], functional based fixture design [28], virtual reality based fixture design [29], knowledge based fixture design [30], ontology based fixture design [31], neural network fixture design [32], etc. None of them, however, met all the requirements. One of the general traits of such systems is the ability to automatically generate partial fixture solutions for simple prismatic parts, with locating and clamping fixture elements in focus. Although this is not the only approach possible, all of the previous investigations were based on the 3-2-1 locating method, fully arresting the part, while disregarding the fact that this substantially increases fixture cost due to proliferation of fixture elements. The influence of locating error has also been disregarded, despite its significant impact on the total error, i.e. machining accuracy.

The basic goal of this research is development of an integral system for automated design and optimization of fixtures for plastic parts. The idea is to integrate both stages of fixture design, as opposed to previously published results. Optimization module should, on the one side, allow definition of optimal positions of elements for locating and clamping, with the primary goal of achieving required part accuracy and surface quality. On the other side, the system should generate collision-free design solution. Design module should allow selection of particular fixture elements based on mechanical, physical, and geometrical characteristics of plastic parts, on the one side, and forces and torques, on the other.

2. SYSTEM FUNCTIONING

The system consists of the following four parts: input data module, fixture planning module, design fixture module, and output data module.

2.1 Input data

The first module within the system is the input data module. Factors which influence fixture design can be adequately unified by appropriately defining the input information. Input information can be broken down into two basic categories:

- machining features (machining type, machine tool, type of machine tool, cutting conditions, number of simultaneously machined parts, number of tools, characteristics of the tool, number of machined surfaces, etc.),
- part features (plastic material characteristic, shape of part, geometric characteristics, tolerance, number of reduced degrees of freedom, locating principle, locating scheme, characteristic dimensions of locating surfaces, shape and quality of locating surfaces, clamping scheme, number of directions of clamping force, type of clamp actuation, clamping force intensity in particular directions, etc.).

Input information are used to feed all other (subsequent) system modules. Shown in Fig. 1 is a segment of input masks for definition of input data.

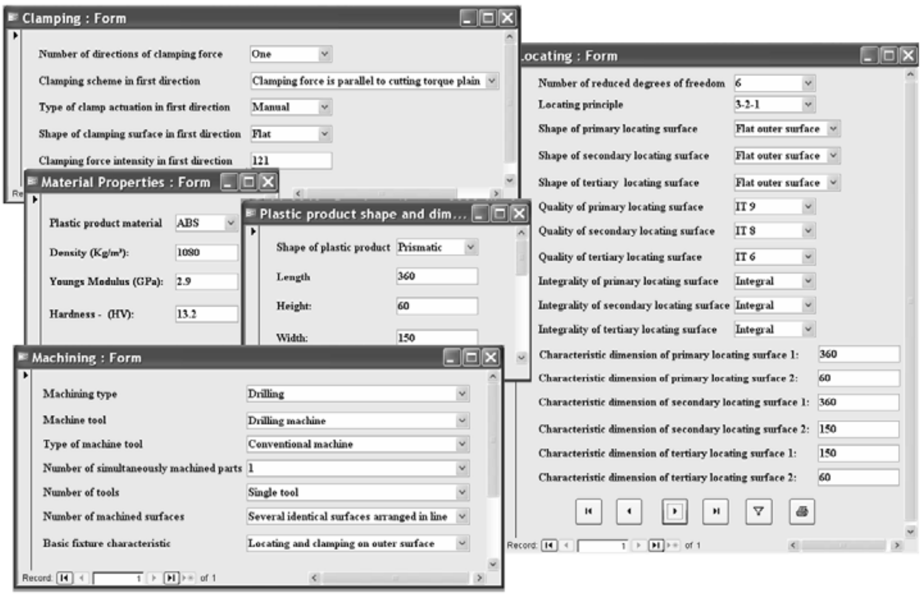


Fig. 1. Segment of input masks which facilitate definition of input data

2.2 Fixture planning

Basic function of the fixture planning module is to determine surfaces and points for part location and clamping. In this way, basic fixture framework is defined since locating and clamping elements are the crucial fixture components. Those elements directly affect accuracy, efficiency, costs, selection of others fixture elements, etc.

Among the most important factors which influence selection of optimal location and clamping points are: plastic part characteristics, friction coefficient and machining forces.

Plastic part characteristics have a key role in the design of a fixture design system. Information regarding the part can be broken down into three groups: geometry (shape, size, dimensions, tolerances), topology (features, surfaces), and structural and physical characteristics of plastic parts (density, Young modulus, hardness, etc.). Friction coefficient defines boundary condition for contact points, in this case between locating elements and part and also between clamping elements and the part. Friction coefficient depends on the contact conditions. Five different types of machining forces acting within the part-fixture can be summarized as follows: gravitational force, cutting force, clamping forces, reaction forces on locating and frictional force (between clamping elements and part; between locating elements and part).

During the machining process, two types of deformations occur: deformation of part contact points and part bending. Deformation of part contact points appears in the contact area between the part and fixture elements. Those points on the part are in contact with the locating and clamping elements. The second type of deformations (part bending) occurs due to all forces which affect part during machining, as well as due to the type and position of the locating and clamping elements. This deformation is of utmost importance when considering fixture design. The problem of finding maximum deformation and its distribution has special importance in the given process conditions.

When defining the exact positions of locating and clamping elements, the goal function is to minimize forces which act upon part during machining, and thus minimize part deformations, while at the same time denying the part any movement (after it has been located and clamped).

Design optimization methodology is shown in Fig. 2. Based on input data (part orientation during machining operation on a particular machine tool, part surfaces, dimensions and tolerances) candidate locating surfaces are generated so as to minimize or completely eliminate the machining error. Upon selecting the locating surfaces, the system selects the clamping surfaces. Clamping surfaces are located opposite the locating surfaces. Once the locating and clamping surfaces are defined, the system defines the points (exact positions) at which the locating and clamping elements are interfacing part.

Positions of locating and clamping elements are defined in two steps:

- definition of initial position of locating and clamping elements,
- generation of optimal position for locating and clamping elements.

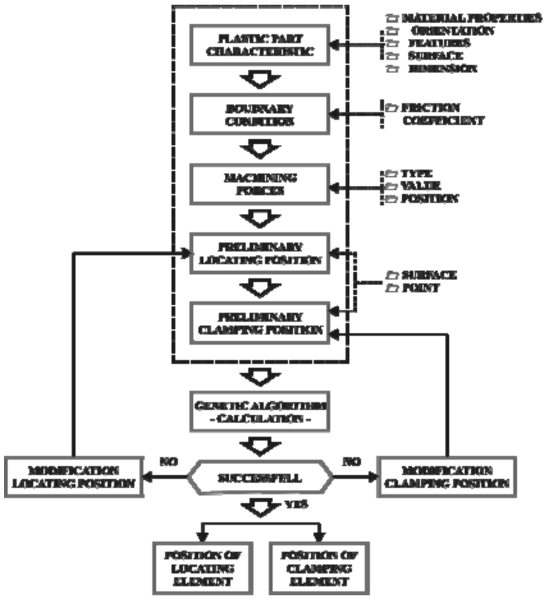


Fig. 2. The structure of the fixture planning module

Initial position of elements for locating is determined as the center of a particular two-dimensional surface which is used for locating. In order to optimize positions of locating elements, the base surface is discretized into a finite number of elementary surfaces, i.e. locating mesh is generated which defines all possible positions of locating elements. The exact position of locating elements is possible to achieve only in the next design stage when all the forces acting upon part during machining are taken into account.

Initial position of elements for clamping is determined as the position placed on the surface opposite (parallel) to the surface of locating elements.

Optimization of positions of clamping and locating elements is performed with genetic algorithm (GA). GA initialization requires initial population. Here, initial population represents the initial position of locating and clamping elements.

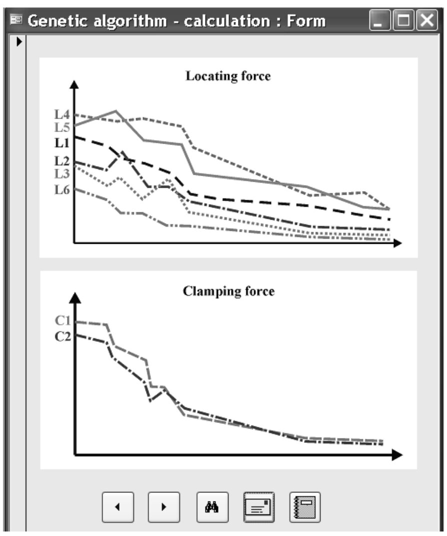
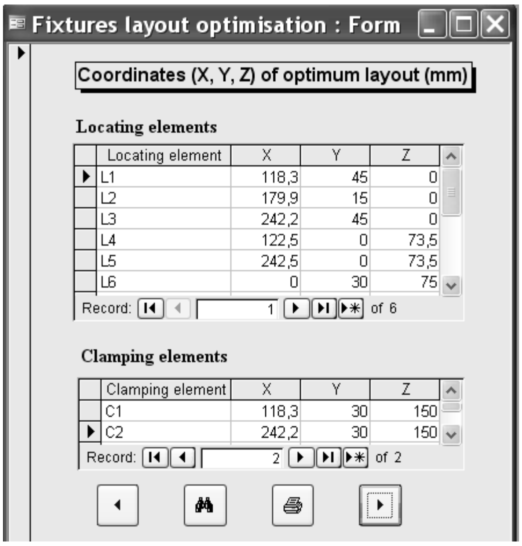


Fig. 3. The convergence of GA

In this case, the three unknowns are locations and intensities of the clamping forces, as well as the locations and intensities of the locating forces (support reactions). These forces should be kept at minimum so as to allow minimum part deformation. Combinations of various variants of these components, make up the solution space. GA is used to search this space in order to find optimal arrangement and intensity of forces. Each possible solution is represented as a chromosome (concatenated array) of stated components, whereas each particular component is called gene.

The module for fixture planning selects chromosomes which are to be reproduced based on their deviations from the optimal solution. Novel fixture solutions, which have lower deviations from the ideal solution, are generated by genetic operations like crossover and mutation. These operations are cycled through several generations, until positions and intensities of forces (clamping forces and support reactions) with minimum deviations are obtained. The output from this module consist of optimal positions of elements for location and clamping (Fig. 4).


Fixtures layout optimisation : Form

Coordinates (X, Y, Z) of optimum layout (mm)

Locating elements

Locating element	X	Y	Z
L1	118,3	45	0
L2	179,9	15	0
L3	242,2	45	0
L4	122,5	0	73,5
L5	242,5	0	73,5
L6	0	30	75

Record: 1 of 6

Clamping elements

Clamping element	X	Y	Z
C1	118,3	30	150
C2	242,2	30	150

Record: 2 of 2

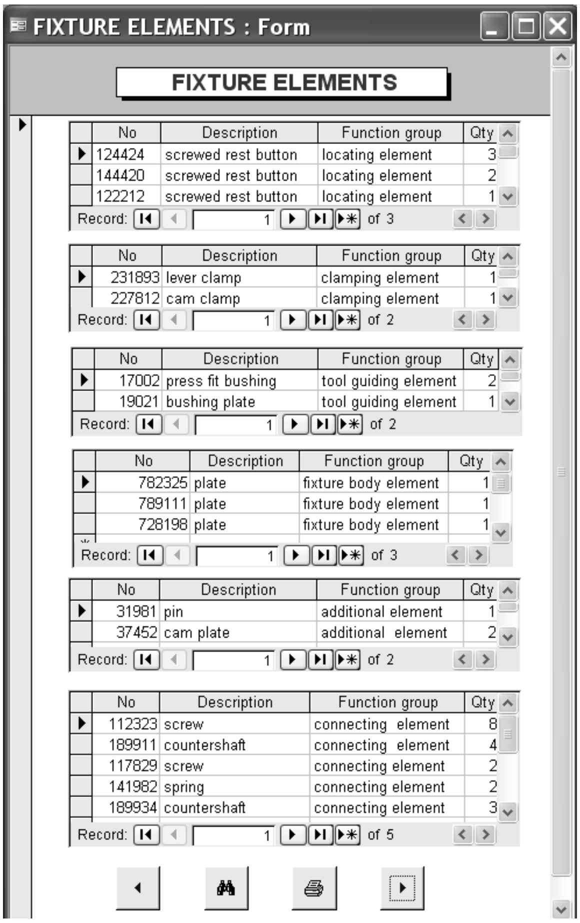
Fig. 4. Optimal positions of elements for locating and clamping

2.3 Fixture design

Within this module selection of all required fixture elements was made within particular functional groups. Each functional group of fixture elements has some specific features in terms of logical selection. For the developing purpose, the fixture elements system was divided into several functional groups: locating elements, clamping elements, fixture body elements, tool-guiding elements, aligning elements, connecting elements, and additional elements.

The selection of each element of fixture was made based on previously defined rules (heuristic criteria of selection from the fixture elements data base).

If all the required elements exist in the data base, the design sub-system outputs fixture elements which are subsequently used in fixture synthesis. If the required fixture element is missing, then the missing element must be either designed and manufactured or purchased.


FIXTURE ELEMENTS : Form

FIXTURE ELEMENTS

No	Description	Function group	Qty
124424	screwed rest button	locating element	3
144420	screwed rest button	locating element	2
122212	screwed rest button	locating element	1

Record: 1 of 3

No	Description	Function group	Qty
231893	lever clamp	clamping element	1
227812	cam clamp	clamping element	1

Record: 1 of 2

No	Description	Function group	Qty
17002	press fit bushing	tool guiding element	2
19021	bushing plate	tool guiding element	1

Record: 1 of 2

No	Description	Function group	Qty
782325	plate	fixture body element	1
789111	plate	fixture body element	1
728198	plate	fixture body element	1

Record: 1 of 3

No	Description	Function group	Qty
31981	pin	additional element	1
37452	cam plate	additional element	2

Record: 1 of 2

No	Description	Function group	Qty
112323	screw	connecting element	8
189911	countershaft	connecting element	4
117829	screw	connecting element	2
141982	spring	connecting element	2
189934	countershaft	connecting element	3

Record: 1 of 5

Fig. 5. Output from the fixture design module - fixture elements

2.4 Output data

Output data module represents the last segment of the system. This module performs assembly of fixture based on elements generated within the fixture design module. Upon generating fixture solution which satisfies the set criteria, generated in the next step is the required engineering documentation which, in fact, is the output information from the system. Finally, the generated fixture solution is stored within the data base and made available for future use in fixture design.

3. RESULTS

To verify the system, comprehensive tests of every module were performed in real industrial environment. Part material used in all machining operations was ABS.

Shown in Table 1 are the results of experimental testing. The experiments were conducted for drilling and milling operations, with various cutting tools and on different machine tools. Shown for each machining operation are fixture design solution, and a corresponding plastic part. Upon completion of the design stage, fixtures were assembled and machining operations were completed.

As shown in Table 1, the fixture design time is minimized, amounting to just 214 minutes in the worst case.

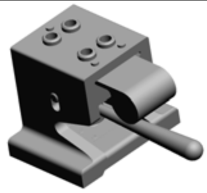
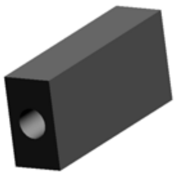
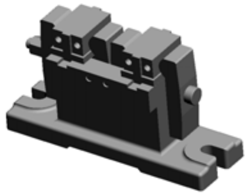
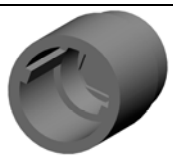
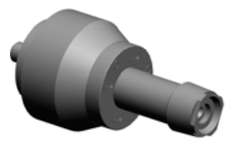
Plastic part	Operation / Cutting tool / Machine tool	Fixture	Design time
	• Drilling • Twist drill • Horizontal drilling machine Union BFB 125/5		149 min.
	• Drilling • Twist drill • Radial drilling machine Otto muller 21023		214 min.
	• Milling • Slab mill • Horizontal milling machine UH-3		127 min.
	• Milling • End mill • Universal milling machine Schaublin 53		121 min.

Table 1. Results of system verification

4. CONCLUSION

The system for integral design encompasses methods and techniques for design and optimization of fixtures for plastic parts. The system allows fixture design based on minimum location error and machined surface accuracy. It also provides means for optimization of fixture design based on arrangement of elements for locating and clamping, machining forces and torques, dimensional and geometric tolerances. The modular structure of the system requires complete theoretical framework for fixture design. Cornerstones of this framework are the criteria for selection of fixture elements, and the corresponding design-related decision-making logic used in design. The tests confirmed the system's practical applicability.

At this developmental stage the system is applicable for locating and clamping of plastic parts, while, given certain modifications, it could also be used for parts from other materials.

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