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Computer Aided Modular Fixture Planning and Design for Box-shaped Parts

PhD Thesis

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2015

Introduction

The topic of this research is Computer Aided Process Planning, more specifically Computer Aided Fixture Planning and Design. According to most general divisions of the technical sciences, the technical planning can be divided into constructional and technological planning. The final goal of the *constructional planning* is to define the shape and dimensions of an object or a product. The task of the *technological planning* is to determine the plan of the production process. The results of the production process planning directly influence the quality of the product and the costs of the production. Nowadays the machining tools and the equipment used during the production are almost completely automated, and as the flexible production systems are evolving there is an ever greater need for integrated planning systems, where the constructional and technological planning is in a close relation. The degree of the integration can be measured with the extent of the communication between the elements of the system, how great is the amount of the direct data exchange between the members of the system. The constructional planning, the technological planning and the production are happening almost simultaneously, thus the technological planning must be quick and complete. In order for these demands to be satisfied at modern engineering practice the process of the constructional and technological planning are performed with the help of computers. Two great areas must be mentioned here, computer aided constructional planning (CAD – *Computer Aided Design*) and computer aided technological planning (CAPP – *Computer Aided Process Planning*). The development of the CAD and CAPP systems has for long time happened independently. Because of that, with CAD systems those aspects were considered more significant, which make the constructional planning more simple and faster; while in the CAPP system the focus was on issues making the production process planning faster and more simple , making the processing of the data about the workpiece and the devices used during the production more efficient. As the CAD systems evolved, feature-based planning became available, yet it is possible that the same feature has a different meaning for the constructor and for the process engineer. For example, what a cooling or stiffening rib is for a constructor, it is the remaining material after milling for the process engineer.

Of course, there were many attempts trying to integrate the constructional and technological planning, and to automate the technological planning. The attempts to automate the technological planning were aimed at set up planning (determination of the required processes, selection of the machining tools, definition of the base surfaces, and – when it is enough to use only universal fixtures – the selection of the fixture, determination of the number and the order of the setups). Secondly, it was aimed on the automated decomposition of the setups into particular cuts (the content and the order of each cuts, tool selection, determination of the cutting parameters, and generation of the toolpaths). Thirdly, it was aimed the automation of the fixture planning and design (conceptual solution of the fixture, selection of the concrete fixture elements, interference check). Most of the attempts are focused only on a part of the problem, for example, the automated setup planning, or finding the conceptual solution of the fixture, or finding the optimal layout of the fixture elements, or determination of the required clamping force, etc. Given that often, when a decision should be made at one level, it would be good to know the results of the decisions that will be seen only at the next level, generally at the end of the planning one must go back and check if the decisions made later were in accordance with the assumptions made earlier. If there is any contradiction, the solution must be modified, and one must step back to a further level and check the feasibility of the solution. From this it follows that only such a system can be really efficient, where the communication between the different levels can flow without any problem. The systems that concentrate on the automated solving of one subtask of process planning assume that the final results of the problems to be solved at earlier stages are given. Of course, the input data could be determined with a system developed – to solve some of the earlier steps - by other researchers, but in that case the input data should be input manually. In case the input data are obtained from more different systems, further problems can occur, namely when the data structure at different researcher`s systems are different. In this case, before the data input begins, the structure of the data should be harmonized. Manual data input often takes a long time, and during the data intake there are many opportunities to make a mistake, such as false value input, or leaving out some data. Such mistakes can cause the proper solution not to be found. If one uses more independent systems to produce the input data, it may also happen that the same data must be input more than once (for example, the geometrical and topological data of the workpiece is needed for setup planning, but also for the decomposition of the setups into particular cuts, and also for fixture planning and design). All this (manual data input, harmonization of the data structure, inputting the same data more times) increases the time of the process planning, and by that, the production time of a product, as well.

An integrated system, that handles the problem of setup and fixture planning simultaneously, that can obtain all necessary information from the model of the workpiece (the final result of the constructional planning), that can decompose setups into particular cuts on the basis of the results of the setup planning, that can modify the model of the workpiece on the basis of the results of the fixture planning or the fixture design, can work much more efficiently than two or more independent programs that are developed to solve some subtasks of the process planning. Because of these, naturally, there were attempts to make a system whose input is the model of the workpiece and handles the problem of the setup and fixture planning concurrently, but these attempts either search for a too general solution, or are concentrating only on a narrow field. The attempts belonging to the first group cannot take into consideration that a different strategy ought to be followed at a full material part, and a different strategy at a similar sized thin-walled part. The attempts belonging to the second group result in such systems, which can be used only for some very similar parts.

My research is aimed at developing parts (modules) of such an integrated system that speeds up the setup and fixture planning of box-shaped parts (first of all gearbox housings) and makes it more efficient.

The scientific results of the research

My research is the continuation of the work done by Dr. Michael Stampfer. He made a setup planning module, which determines the number and the sequence of the needed setups after the manual input of the information about the workpiece, and gives a proposal on the conceptual solution of the needed fixtures. The manual data intake requires careful and time consuming preparations, the input takes a long time, besides that, there are numerous opportunities to make a mistake. By studying the data structure of the CAD models, and the information needed for the technological feature-based workpiece model, the expedient data structure of it I concluded that the geometrical information of the workpiece required for setup planning, operation planning and fixture planning can be obtained from the CAD model of the workpiece. What cannot be obtained from the single workpiece model are the allowances, and the surface displacements caused by the allowances. Both the workpiece model and the model of the bulk piece are needed so as to be able to automatically determine the allowances; or besides the workpiece model, the technology of the producing the bulk piece must be known and an allowance database is needed. Apart from the geometrical data, some technological data (the tolerance classes (IT) of the dimensions, the surface roughness (R_a), the shape and relationship tolerances, which hole is made in full material, which is precast) are also required for setup planning, for operation planning and for fixture planning and design. The geometrical model of the workpiece does not contain these data, thus either the user must prescribe them, or they could be determined automatically. For automated determination a huge amount of data (the data of the other parts of the product in which the actual part will be assembled, their mutual positions, the role of each parts) would be needed, and an artificial intelligence (a program) would be required that can recognize and classify the functional surfaces. Even if these data would be recognized automatically, the constructor and the process engineer must check the result. The third possibility to automatically obtain the data related to the manufacturing processes to be used and to the fixture to be used is to derive them from the 2D documentation. But if the model of the part and the 2D documentation are saved in neutral format the associativity of the surfaces is lost.

1. Thesis

I have developed a method which allows the input data required by the setup planning module – partially automatically, partially with the interaction of the user – to be generated from the CAD model of the workpiece. This way the careful preparation which often takes several hours, and the long-lasting and mistake-prone manual data intake are replaced with a considerably shorter (about ten minutes) activity.

***1.1** The method makes it possible to automatically obtain data required for the technological feature-based model of the workpiece from the 3D model of the workpiece saved in IGES (Initial Graphics Exchange Specifications) format, from the geometrical and topological information stored there.*

***1.2** The method allows the user to interactively supplement the mentioned input data with further technological data required for the technological feature-based model of the workpiece, while the actual feature and its characteristic data are visualized.*

***1.3** The set of the features that can be recognized on demand can be further widened. I have checked if the knowledge base of the setup-planning module is widened, then with my method the needed plus information can be obtained from the IGES model of the workpiece without significant modification of the program.*

Based on the above-stated, I have made a module, which on the IGES model of the workpiece automatically recognizes those features that are most common on gearbox housings, automatically extracts and restructures those characteristic data that are most important from the aspect of fixture planning and design. Those technological data that are not contained in the geometrical model of the workpiece can be given by the user (preferably by the process engineer) in an interactive manner. The module structures the data so that they are appropriate for setup planning, operation planning and fixture planning and design.

Publications connected to this thesis: [7], [9], [13], [15], [17] I have studied several modular fixture element sets and systematized the elements depending on their function and mateability to each other. I have examined the methods used for fixture planning and design and came to the conclusion that the existing fixture planning and design systems either search for too general solution, or can be used only for several very similar parts. The problem with too general solutions is that such systems do not take into consideration that different searching strategies should be followed at a full material part, and also different strategies ought to be followed at a thin-walled part; as if the same clamping method and clamping points are applied, the same cutting or clamping forces can cause considerably larger deformations at a thin-walled part compared to a full material part. The other problem with the systems that look for a too general solution is that in some cases, these do not compose the most appropriate fixture for the workpiece, since they can apply only the most commonly used methods, and the special solutions are left out of the consideration. However, there are cases, while supplementing a modular fixture (built from standard elements) with a non-standard element – machined in accordance with the workpiece demands - a certain amount of time can be saved thanks to the fact that a fixture which better fits the workpiece enables greater depth of the cut and/or feed rate. It is also possible that the use of a special (extra) locator element reduces the number of the required setups during machining, and at the same time the precision tolerances of the fixture are substantially reduced, when all relationship tolerance connected surfaces of the workpiece are machined in the same setup, thanks to the extra locator element.

2. Thesis

I have developed a planning method for automated fixture planning and design. This method is feasible for box-shaped parts (first of all, gearbox housings), and makes the fixture planning quicker and easier.

2.1 *The method (system of the rules), having the technological feature-based workpiece model, the conceptual solution of the fixture, and the data of the modular fixture elements models, makes possible the automatical building of the CAD model of an appropriate modular fixture.*

2.2 *The method offers a solution for cases when the elements found in the modular element set are not enough to solve the fixturing problem. In such cases the CAD model of the needed (extra) locator element is generated – and if required modificated - automatically.*

2.3 *It may happen that there is no need to generate a new (extra) locator element, but it is sufficient to modify an adapter plate. The adapter plates are semi-finished by the manufacturer, and the final shape of it is machined by the user. The developed method allowes automated modification of the adapter plates.*

On the basis of the above-described, I made a module that takes into consideration the recommended type of the supporting, locating and clamping of the workpiece. Apart from these, the module takes into consideration the proposed supporting, locating and clamping surfaces, the shape, the size and the location of these surface, the shape and dimensions of the workpiece, the dimensions and the function of the fixture elements, their joining (contact) surfaces, and with adjustable elements, the range of the adjustability. The module selects the appropriate elements, and makes the fixture in accordance with the technological requirements and fixturing principles. During the determination of the position of locator elements the interference between the fixture elements and between a fixture element and the workpiece are avoided. Thanks to the module, a work process that earlier took several hours is shortened to an activity of several minutes.

The publications related to this thesis are [2], [3], [10], [11], [14], [16], [18] The decisions that have to be made on the different levels of technological planning are in tight relationship with each other. For example, how many setups are needed to finish a workpiece depends on the type of the machine tools, the type of the fixtures and tools used. Which kind of fixture would be the best to use (a decision which should be made during the setup planning) depends on the shape and size of the workpiece (a decision made on the level of batch planning), and also depends on the selected machine tools (a decision made on the setup planning level). Which surfaces can be machined in the same setup depends on which surfaces the tool can approach, which, in turn, depends on where the different elements of the fixture are, and how large they are (a decision made at fixture design level), and also depends on what kind of tool and how large tool (a decision brought at setup planning level) is used for the machining. It follows from these that the only really efficient system is one where communication between the different levels is possible. This requires such an integrated system where the output of each module can be interpreted by the rest modules. Among the advantages of the integration one must mention that the output data of a module can be used directly as the input to the next module, so there is no need for manual input. In the cases when the same data serve as input for several modules (for example, there are data which are needed at setup planning, at operation planning and at fixture planning) those do not need to be typed in manually more than once. Thanks to this, the process planning becomes faster and the possibility of making errors is also reduced.

3. Thesis

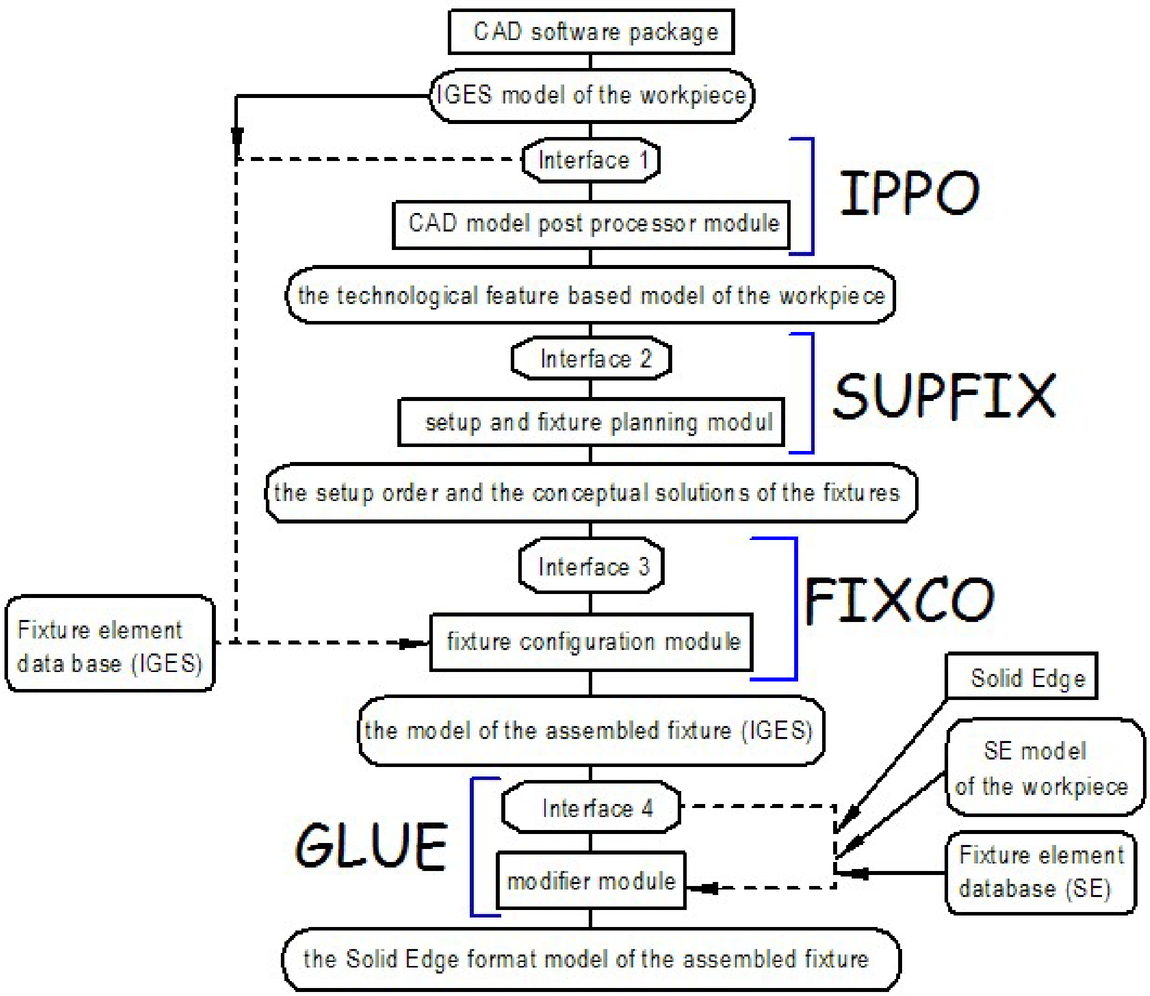
*I have created a uniform modular system of the constructional planning, the setup planning and the fixture design (**Figure 1.**). I have successfully integrated the earlier developed setup-planning module into the system. I have extended the capability of the setup and fixture planning module with the ability to search for a through hole on multilevel workpieces. I have defined the places and the tasks of the interfaces.*

Firstly, it was necessary to work out an interface, which can interpret the data stored in the IGES format workpiece model (a textual ASCII code file), with their help it can regenerate the entities of the workpiece, and can automatically extract from them the data needed for feature recognition (INTERFACE 1). Secondly, the CAD model post processor module creates the technological feature-based workpiece model, and stores the data - in a format understandable for the setup planning module – in an ASCII code text file (INTERFACE 2). Thirdly, it was important to ensure that the output data of the setup-planning module (also an ASCII code text file) can be interpreted by the fixture design module, from those data the fixture design module can automatically obtain the information necessary for fixture design (INTERFACE 3). Further, it had to be assured, that the fixture design module can automatically obtain those geometrical data, which are vital from the aspect of fixture configuration, from the models of the fixture elements. During the development of the modules I have ensured that the output data of each module can be interpreted by not only the next level (module), but by all other modules, too, this way the output data of the CAD post processor module can be interpreted by not only the setup planning module, but also by the operation planning module. The above-mentioned interfaces were made in the Visual Prolog 6.3 programming environment. Finally, the communication interface between the output data of the fixture design module (the type, the number, the location and the orientation of the fixture elements, information about that if an element must be modified, if yes the data needed for modification) and the Solid Edge modeler software package had to be made (INTERFACE 4). This interface was made in Visal Basic 6 programming language.

The setup and fixture planning module, developed by Dr. Michael Stampfer, did not examine the mutual position of the different holes, instead, it asked the user if there was a feasible through hole on the workpiece, when it seemed to be possible to clamp the workpiece over a through

hole. Conversely, I have established a system of the aspects to be checked at multilevel parts (those hollow parts which have one or more inner walls parallel with the side walls) to see if every condition for clamping the workpiece over a through hole is fulfilled, and I have also developed a method that allows this verification to be performed automatically.
As a final result of the planning the Solid Edge model of the assembled fixture(s) is made, it can be opened with a CAM module, and before the toolpath generation, the fixture elements are marked as Check Bodies (bodies that must not be machined, and must not collide with the toolholder elements). This way the CAM module will avoid the machining of these elements and the collision with these elements during the toolpath generation. A possible direction of further development of the system is to ensure total integration with a CAM module, i.e. to make the system automatically the data required for setup and fixture planning and the output data of the setup and fixture planning interpretable for a CAM module. This way, due to the elimination of the repeated intake of the same data, a significant amount of planning time can be saved.

Publications related to this thesis: [1], [5], [6], [8], [9], [10], [11], [12], [14], [15], [16], [17], [18]



*(**SE** = Solid Edge)*

Figure 1. Integrated setup and fixture planning and design system

I have studied several modular element sets of the most well-known modular fixture elements set manufacturers, and came to the conclusion that for locating the workpiece over an inner hole, these sets offer only some bolts and pins. Some of them must be finished by the user. When locating a workpiece with the help of bolts or pins it must be taken into consideration that the dimensions on the bulk vary within a zone. This zone is defined by the production tolerances of the bulk. At locating a workpiece over an inner cylindrical surface the pins or bolts must be arranged in a way so that the bulk with the smallest (still acceptable) diameter can be put on the fixture. The consequence of this is that when a bulk with the largest (still acceptable) diameter is put on the fixture, the center point of the hole – and of course, the whole workpiece along with it – deviates compared to the ideal position. The extent of this displacement depends on the production tolerance of the hole on the bulk, of the production tolerances of the pins and bolts, and of the locations of the pins or bolts. At three pin locating the smallest one is the deviation of the center point if the pins are arranged at 120° to each other. On the base plates, found in modular element sets, the gridholes are on a defined distance to each other (usually at every 50 or 25 mm). The task of these holes is for fixture elements to be joined to the base plate. Because of the discrete layout of the gridholes it is rare when on a locating diameter every pin can be directly put in a gridhole that is at 120° to the neighbouring pins. Thus we either deviate from the 120° arrangement, which increases the center point deviation, and leads to prescribing greater allowances on some surfaces of the workpiece; or we implement adjustable locator elements. If adjustable locator elements are used, the exact position and orientation of these elements must be defined in a way so that not only the locating pins are set at the right place, but the stable clamping of the adjustable elements is also possible. Due to the discrete gridhole layout it may be time-consuming to find the appropriate orientation for the adjustable elements, and the greater the number of the elements built in the fixture is, the smaller the final stiffness of the fixture.

Technical result

The elements of a modular fixture element set offer few possibilities for locating a workpiece over an inner cylindrical surface, and because of this, I proposed three relatively simple fixture elements, which allows quick part change over.

I have deduced a formula for calculating the possible maximal locating error at three-pin locating. Applying this formula to different cases, I recognized that sometimes the locating error imposes great surplus allowance on the bulk part. On the one hand, the proposed elements enable smaller allowances on the bulk part, due to gapless centering of the part. On the other hand, these elements ensure easier fixture planning, since, from the aspect of the joining surfaces, it is much easier to put one element at the appropriate place than to put three elements at the appropriate place, and simultaneously be the center they define also at the appropriate place. With the use of the proposed elements, the stiffness of the resulting fixture is larger than what can be achieved with the use of adjustable elements.

Publication related to the technical result: [4]

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