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# Computer-Assisted Tooling Pattern for Constructing Procedures

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***Abstract*—Tooling design for constructing procedures refers to direct tooling for constructing a part such as decides and dies for injecting influenced components and metal stampings, or for asserting developing procedures such as jigs and fixtures. This paper resumes some of the R&D activities in those areas over a period of 20 years in the Department of Mechanical Engineering. It is noted that changing use of computer tools has turned what is used to be known as a "black art" into a discipline covering both heuristic and scientific analyses.**

***Index Terms*—Computer-aided Tool Design, Plastic Injection Molds, Jigs and Fixtures.**

## I. INTRODUCTION

Constructing engineering establishes a significant branch of technology study as any direct betterment of existing manufacturing processes or an introduction of novel processes could importantly amend output efficiency, product quality and cut down design and interval. This would heighten the fight of a manufacturing company and maintain its leading edge over its competitors. Tooling design is as essential a topic as the constructing process itself. Without suitable tooling, manufacturing processes are often gimpy or rendered totally ineffective. The trade of a tooling designer, however, has been traditionally linked to long years of apprenticeship and skilled workmanship. There appears to be more heuristic know-how and cognition acquired through trial and error than deep scientific analysis and understanding. With the increasing use of computer tools and technology, this assumption has changed rapidly since the introduction of CAE tools in the early 1980s.

This paper covers several topics in tooling around design and the use of computing machine tools in accomplishing improve and faster design, and the use of computer simulation proficiencies in depicting the actual working consideration. One area is in the design of tooling for molds and dies, and another area is tooling around for affirming producing operations, i.e. jigs and fixedness's for orienting, locating and supporting parts in a machining centre. All these fields used to rely intemperately on skilled tool architects, and regrettably, there is a worldwide deficit of such people due to long years of developing the necessary skill and the disinclination of the more youthful generation to enter into this trade.

## II. FIXEDNESS'S IN AFFIRMING CONSTRUCTING PROCEDURES

### *A. Introduction*

Fastnesses are in general mechanical devices used in helping machining, assembly, inspection, and other constructing operations. The function of such twists is to demonstrate and ensure the desired position and orientation of work assembles in relation to one another and concurring to the design stipulations in a predictable and repeatable manner. With the coming of CNC engineering and the capacity of multi-axis automobiles to execute several procedures and reduce the number of set-ups, the fixedness intention task has been somewhat simplified in terms of the number of fixtures which would need to be designed. However, there is a need to address the faster response and shorter lead-time required in designing and constructing new fixtures. The rapid development and application of Flexible Manufacturing System (FMS) has added to the requirement for more flexible and cost-effective fixtures. Traditional fixedness's (dedicated fixtures) which have been expended for many years are not able to assemble the necessities of modern constructing due to the lack of flexibleness and low reunification. The substitute of committed fixtures by standard and compromising fixtures is high in automated constructing systems, due to much littler batch sizes and abbreviated time-to-market.

Standard fixedness's are built from standard fixturing components such as basis-plates, locaters, affirms and clinches. These components can be gathered together without the need of extra forming operations and are planned for reuse after dismantlement [1]. The main advantages of employing modular fixtures are their flexibleness and the diminution of time and cost commanded for the meant manufacturing operations. Automation in fixture design is largely based on the concept of modular fixtures, particularly the hole-based arrangements, due to the following features: (a) foreseeable and finite number of locating and confirming attitudes which allow heuristic or numerical search for the optimal positions, (b) ease in assemblage and dismantlement and the possible of automatized assembly using robotic devices, (c) proportional ease of employing design rules due to the finite number of component compounding.

In this paper, most of the described research actions are based on standard fixedness's.

***B. Computer-aided Fixture Research in the last two Decades***

Fixture research applying computer aids commenced in the late 70s and early 80s. In the initial years, interactive and semi-interactive fixture design proficiencies were built on top of commercial CAD systems and practiced system tools. These advances were primarily referred with fixture form and there was little psychoanalysis on the other expressions such as work piece-fixture-cutting tool fundamental interaction.

A comprehensive examination fixture explore plan should demand the psychoanalysis at different computationally levels, viz., geometric, kinematic, force and contortion analyses. The following sections will present brief overviews of the research activities in each of the above-mentioned areas, followed by the need to design an intelligent fixture which can be integrated with the machine tool.

**1) Geometric Analysis**

Geometric analysis is intimately linked with fixture designing and spatial concluding. It finds out the choice of the type and number of fixturing components, support and settling elements, the order of datum planes, etc. The analytic thinking also admits the checking of interference between work piece and fixturing components, as well as cutleries.

Most of the early fixture explore demanded geometric analysis and synthesis of fixture construction with comparatively little attention to kinematic and deformation analysis.

**2) Kinematic Analysis**

Kinematic analysis is used to find out whether a fixedness shape is able to right locate and furnish concluded constraint to a work piece.

Old work on fixture design mechanization extends comparatively little considerateness in allowing for a comprehensive fixture-element information and efficient assemblage schemes for the generation and grammatical construction of modular fixtures. The forum of modular fixtures is to configure the fixture components such as locators, clamps and affirms (in most cases, accessory elements are needed to generate fixture towers to fulfill the fixturing functions) on the base-plate according to a fixturing principle (e.g. 3-2-1 principle). The decision of the locating, affirming and enforcing details for the gathering of modular fixtures is a key issue in fixture design automation.

**3) Force Analysis**

In a forming fixture, unlike forces are received, viz., inertial, gravitative, forming and imposing forces. While the first three families of drives are ordinarily more foreseeable, fastening force can be rather immanent in terms of magnitude, point of applications programme as well as sequence of application program.

It has been widely consented that a exhaustive analysis of all the draws demanded in a fixture is a formidable task since it is an undetermined trouble with a multitude of fixturing components. When detritions are taken into account, the trouble becomes even more complicated because both the order of magnitude and the guidance of the static clash effects are unknown.

**4) Deformation Analysis**

Due to the complexity of force interaction, work piece deformation can be attributed to a combination of factors. Firstly, a work piece would deform under high cutting and clamping forces. Secondly, a work piece could also deform if the support and locating elements are not rigid enough to resist the above-mentioned forces. In the present analysis, it is assumed that work piece deformation is largely due to the first cause mentioned above.

The most commonly used method in analyzing work piece deformation and fixturing forces is the finite-element method.

***C. Work-holding Analysis***

A beneficial fixture invention is vital to the character of the completed work piece in terms of multidimensional accuracy, form exactness and come out finish. One of the necessity considerations in planning a good executable fixture is the contemporaries of fastening shape that includes the clamp placement, clamping sequence, and clamping intensities. Placing the clamps in wrong attitudes may trouble the equipoise of the work piece on the locators, resulting in the lost position of the part. Similarly, using an unequal fastening strength may give rise to movement and/or lift-off of the work piece throughout the producing process. On the other hand, an application program of unreasonable imposing forces would result in overweening deflection and high contact contortion of the work piece. In short, a poor inflicting layout could cause the final truth of the work piece to be out of the determined tolerances and bring about unnecessary rejects.

A less addressed explore area is the execution of a fixedness during forming in terms of its dynamic reaction and contortion. The issue is to insure producing truth through the proper control of work applying procedure during machining. Hence, a best approaching to the fixturing trouble is to incorporate optimal fixture intention with optimal fixturing execution in a unified process.

A levelheaded fixturing system [2] has been constructed. This system furnishes sensational resubmit and on-line fixturing assure scheme to execute an optimum work applying operation. Being an significant part of the "live" fixture, a novel dynamic imposing actuator capable of providing time-varying clamping saturations has been carried out. Comparative experimentations are carried out to look into the consequences of the dynamic fixturing nature of the system on work piece quality. Evaluated geometrical errors are equated with and without using the dynamic clamping forces.

**1) An Intelligent Fixturing System**

An intelligent fixturing organization comprising three mutualism sub-occasions has been constructed. The sub-occasions are: analytic thinking and synthesis, fixture computer hardware generation and work holding execution (Figure 1). Each sub-function conduces to the final quality of the completed work piece and should be treated with evenly attention. A distinguishing effectuation of work holding procedure starts with an analytical fixturing designing process which would generate a fixedness design that can accurate locate and hold the work piece with respect to the machine tool, and a set of optimized fixturing arguments.

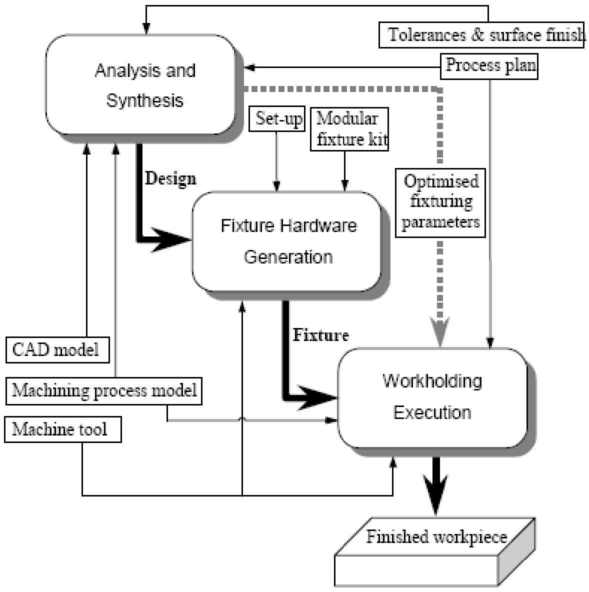


Fig.1 Model of an intelligent fixture system

The following sub-function is the computer hardware assemblage of the fixture employing standard fixture kit as well as feeling and assures devices, fastening driver, electronics and interfacing electronic equipment, and a PC. This fixedness, weaponed with sensors and actuators, is adequate to of on-line control of fixturing actions, as fought to a ceremonious "dummy" fastness with hard-wired imposing devices.

The final sub-function is the performance of the adaptative employment applying operation. It is critical to assure orthogonality and correspondence of the part within the fixedness after imposing actuation. Hence a probing process is executed to detect the literal position and predilection of the work piece within the fixture and correspondingly the tool path is compensated through NC code handling concording to the evaluated work piece translation. The fixture should denigrate work piece deformation during forming. This is accomplished through both furnishing reserve affirms and employing dynamical clamping forces. Confirms should be used to continue compromising characteristics on the work piece whenever possible to avoid large deflection or permanent wave damage to the part. Dynamical imposing forces are employed just adequate to confirm the impact of the cutting force load.

**2) Fixture Design Consideration**

During the fixedness design stage, a series of analyzes are executed in order to give an optimum design. As depicted in Figure 2, the complete process comprises of such modules as kinematic chasteness analysis, total constraint analysis, imposing intensity psycho psychoanalysis and FEM analysis.

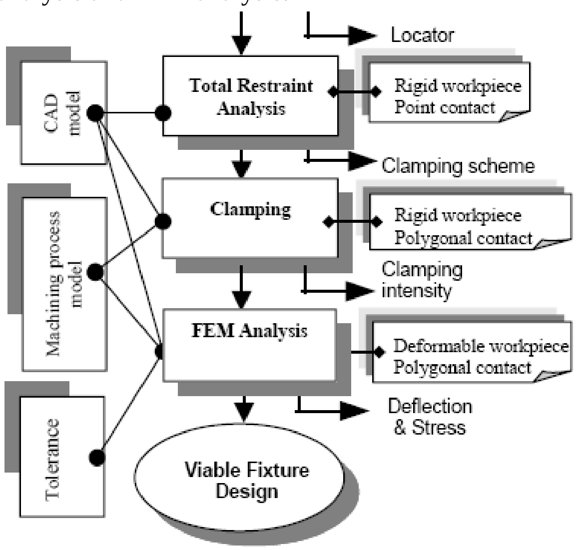


Fig.2 Analysis and synthesis procedures

The incorporated design curriculum and its purposes are summed up as follows:

(a) Kinematic chasteness psychoanalysis

Presuming rigid body and point contact, kinematic constraint analysis is to influence a settling scheme that is enough to furnish unambiguously exact place for the part. It can be carried out either by an expert system based on heuristic program cognition and the go through of tool designers, or by an analytic module relying on twist and sprain vectors from the Screw Theory. Once the locating points and placements are determined, the type of locators and their geometry can be designed according to the availability of modular fixtures and the type of the machine tool. In this study, the settling layout is determined by heuristic program rules such as the 3-2-1 principle to assure proper settling stipulation.

(b) Total Constraint Psychoanalysis

Based on computational pure mathematics theory and geometrical reasoning proficiency, this module is to mechanically generate a fastening scheme and fastening succession that is enough to totally restraint the part. This module would also furnish resubmit pertaining whether the kinematic constraint by the locating layout is enough. At this time, the clamps are still assumed to make point contact with a rigid work piece. Once the contact geometry of the clamps is designed, the resultant contact would be either point, linear or polygonal depending on the work piece geometry.

(c) Fastening Intensity Psychoanalysis

Contemporaries of clamping intensity are founded on the presumptuousness of rigid body and polygonally contacts. Quasi-static counterbalance considerations are employed in deliberation so that the encroachment of cutting down force dynamics is well explained. Treating forces are gained from proven tool force model [3]. Both lower limit and upper limit clamping intensities are generated using non-linear computer programming proficiencies.

(d) FEM Psychoanalysis

Work piece deracination and deformation is due to a count of physical developments such as work piece snap, fixture flexure, and contortion/lift-off at the work piece-fixture component reach regions. It is can be quite a severe throughout the forming of thin-walled characteristics on otherwise structural rigid work pieces. Presuming flexible work piece and polygonally contact, FEM psychoanalysis is executed to predict work piece divagation and/or lift-off that would innovate form error into the completed work piece in the practice of lost flatness or cylinder press.

**3) Function of an Intelligent Fixture**

The core components of an well-informed fixing system should furnish active responses to the work applying procedure and adjust work piece displacement reaction and hold deformation as far as possible to ensure the defined accuracy. As exemplified in Figure 3, its two essential occasions are tool path recompense and dynamical clamping actuation.

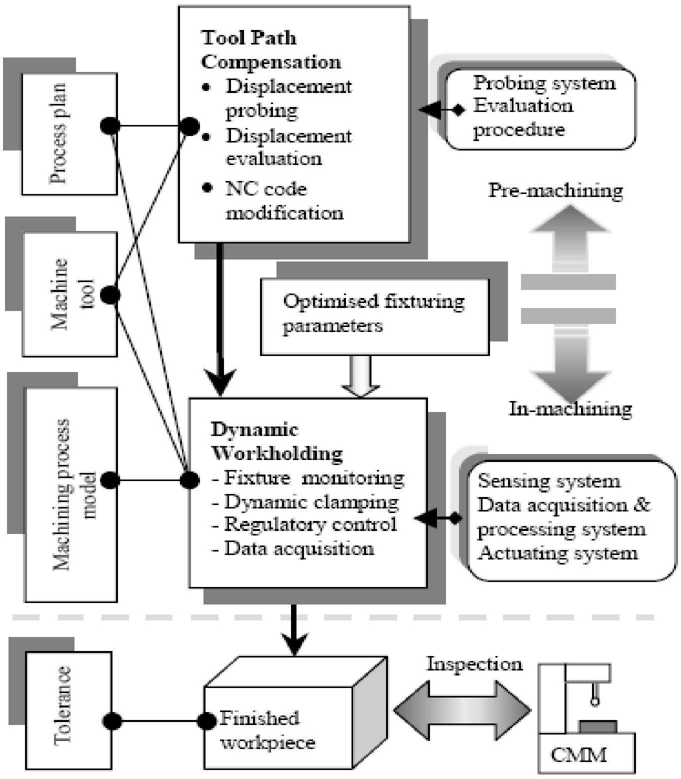


Fig.3 Functions of an intelligent fixture

As all the close drives would induce the work piece to be fired within fixedness, it is best to do tool path recompense both before and during the forming process. A form of proficiencies such as inductive displacement reaction sensing can be applied to perform on-line measuring of the work piece displacement reaction. However, it would command an open-computer architecture NC controller for this intention. At this stage, tool path recompense is only used to adjust the displacement reaction caused by clamping actuation before producing. During producing, the well-informed fixture would perform functions such as supervising, dynamic clamping, regulatory control, and data skill to ensure successful execution of machining operation and understate work piece deviation.

Its schematic drawing constellation is demonstrated in Figure 4.

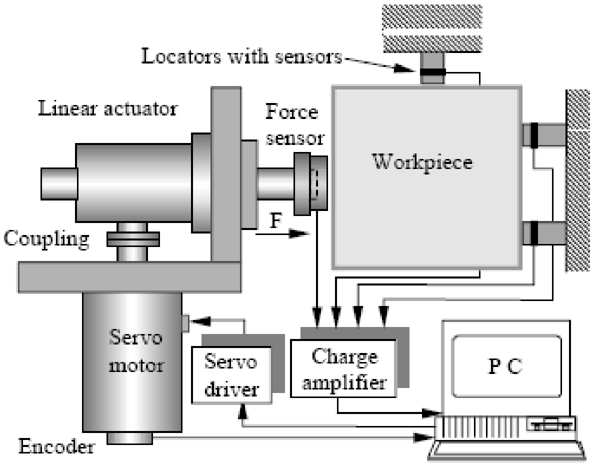


Fig. 4 Healthy fixedness with dynamic clamping

The characteristic lineaments of the healthy fixture include the following:

(a) Automated supervising

Automated monitoring concerns to the acknowledgment of the characteristic substitutes of a work piece-fixture system demonstrated on the rating of system touches. It mainly constitutes of three tasks: sensing, signal marching and monitoring decision-making. Reserve sensor signal sources include reaction forces on the fixturing elements, imposing forces, work piece deflection, chatter and vibration. At this time, only reaction forces are used to monitor the stability of the work piece-fixture system and as input to the decision-making scheme for the self-shape of the fixture system to provide the highest work piece accuracy. The hardware demanded for doing this task includes force sensors and data acquisition board.

(b) Employing dynamic fastening forces

Employing dynamic fastening forces concerns to the action of adjusting the fastening intensities consorting to the optimized fixturing parameters fathered at the fixture designing level as well as the perceived data of work holding stability. The performance demands the co-ordination of the imposing action with the forming operation. Electromechanical or hydraulics mechanisms may be applied to apply the real-time optimum forces to the part. In this study, an electromechanical device imposing mechanism was formulated.

(c) Regulative control of work applying stability

While machine-controlled supervising crosses the performance of work applying process and discovers the differences from normal consideration, regulatory control enforces preventive/corrective action with respect to imposing intensities in reaction to sudden undesirable replaces in the work agreeing considerations due to external commotions.

(d) Data acquirement

Data acquirement denotes to the aggregation and showing of the fixture marching data and linked data establishment, specifying, polishing, and disciplinal measures. After forming, a work applying history could be developed from the gathered data, and substantial work holding consequences (e.g., “lift-off”, “sliding”, “vibration”, “chatter”, etc) and the time of their occurrence can be differentiated through the rating of the sensed information. Consequently, chastisements to the fixturing process and the fixture design stipulation can be made as requirement so as to fine-tune the work holding procedures in later performances.

### *D. Dynamic Work applying*

The set-up comprises of several steps. First the fixedness is identified on the automobile table and the machine axes; cutter and fixture coordinate system are adjusted. A dial indicator could be accompanied the automobile spindle so that the blinker could run across the data point surface on the fixture to adjust the axes. Here it is accepted that the settling datum has already been exactly aligned with respect to the fixture datum surface. The position of the cutting tool relative to the fixedness reference frame is then demonstrated using an edge finder. Afterwards the NC code is modified so that the reference proportions in the part and curriculum reference frames are adjusted.

The host computing device transfers the optimized fixturing parameters for a part to be formed. The clamp comptroller then remembers the dynamical fastening intensity example from the host. After that, the work piece is bombed into the fixedness. Six dial indices are directed over and brought into reach with the part and their interpretations are zeroed. Now the host flags the controller to actuate the clamps until individual force set-points are achieved. After the work piece is fastened, the part deracination is checked through the rating of the taken measurements. Tool path recompense is then executed and the translated NC code is afterward transferred to the machine controller. At this time the cutter path is adjusted with the existent work piece location rather than the axes of the machine. The imposing comptroller is at the same time adapting the clamping intensity with respect to the position of the cutter. Simultaneously, the acquisition system gathers and saves all the force assesses on the locaters and clamps. These activities are continuously carried out till the culmination of the forming procedure.

***E. Observational Examine of a thin-walled Work piece***

The main trouble affiliated with producing of thin-walled parts is elastic contortion, which can be due to numerous factors such as cutting down and imposing forces, work piece rigidity, cutting temperature and inner stresses. The defection of the employment piece would result in dimensional and form errors. It is potential to cut down the elastic distortion through holding the part with an optimized fixture and employing minimal fastening forces.

In order to inquire the impact of the dynamical fastening strategy on the work piece quality and forming process, a bagging procedure is executed on a box-shaped thin-walled work piece to equate the completed accuracy under fixed and dynamical imposing schemes. As shown in Figure 5, the work piece has an overall sizing of 80(H) x 130(W) x 220(L) mm with a cubic cavity. The wall oppressiveness of the part is cut down from 5 mm to 3 mm through finish bagging by a 20 mm flat-end mill. The depth of cavity is 35mm so that the air pocket walls are milled at 5mm increases until the bottom of the air pocket is achieved. Therefore, the axial and radial deepnesses of cut are 5mm and 2mm respectively.

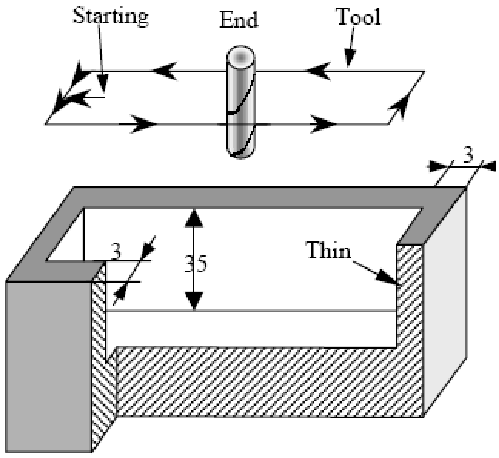


Fig.5 Pocket milling operation on a thin-walled part

The spindle accelerate was set at 500 rev/min and the feed rate at 100 mm/min. Two superposable parts are formed with the same cutting arguments complying the same machining procedure, but under fixed and dynamic clamping schemes respectively. All the end milling operations are conducted in downward cutting (climb cut) due to various reasons such as service life of tool, machining accuracy, and vibration. The part is located by six flat tipped locating pins according to the 3-2-1 principle and held by two dynamic clamps from the sides.

It should be mentioned that the magnitude and direction of the cutting force vary drastic in a bagging procedure. As the cutter accomplishes a corner of cavity, the employment width increases dramatic from 2mm to 16mm in this case, ensuing in sharply higher cutting forces with increment of outcome force from 264.2N to 482.8N. Once the cutter passes the corner, the cutting forces return to the normal, but exchanges its direction. The change of the cutting forces is taken into considerateness in the generation of dynamic claming force spectrum.

***F. Work piece accuracy comparability***

In producing procedures on flexible work pieces, both cutter and employment piece bending would cause errors of the produced surface. Work piece deflections could be induced by both cutting and clamping forces. While the cutting forces produce deflections both on the cutter and on the work piece such as the case of pocketing with thin walls, clamping forces only bring about contortion on the part. For climb milling, the cutter invariably avoids away from the work piece so the final proportion of the part is always larger than hoped. The opposite is true for the clamping action as they commonly constrict the part. In this examine, it is presumed that the surface mistakes brought on by the cutting forces are the same for both fixed and dynamic imposing cases as the cutting parameters and conditions are superposable. The attention is hence focused on the surface faults caused by the clamping force induced deflections.

The profiles of the completed thin walls were evaluated using a CMM for finding out the surface errors. For each experiment, the formed surface is visited several times so as to provide statistical sound measurements. Cross-sections of the thin-walled part under fixed and dynamical clamping schemes are shown in Figures 6 and 7. The fixed imposing scheme has to maintain larger clamping forces throughout the producing pass; more material is thus took out around the area opposite to the clamping points as the clamping forces cause inward distortion. In the figure, a dip in the middle can be observed; this is caused by the applied clamping force. It is clear that the ascendant element of the surface accuracy is from the clamping induced bending.

It is possible to predict the magnitudes of the errors of the produced profiles using FEM calculations. Work piece deformation analysis can be executed in discrete time instants for the machining procedure using the FEM model. They are useful for demonstrating the basic cognition of the features of the errors developed with different clamping positions. An FEM simulation of the work piece under the fixed fastening strategy is shown in Figure 8.

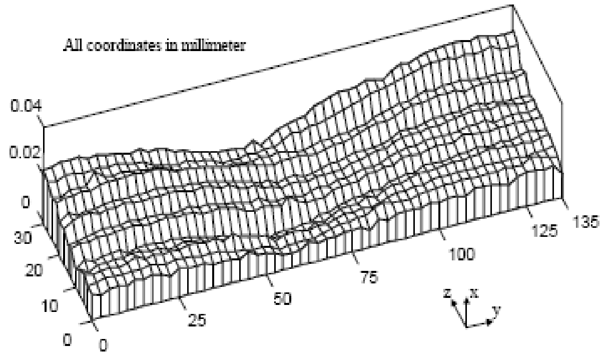


Fig.6 Measured profile under fixed clamping scheme

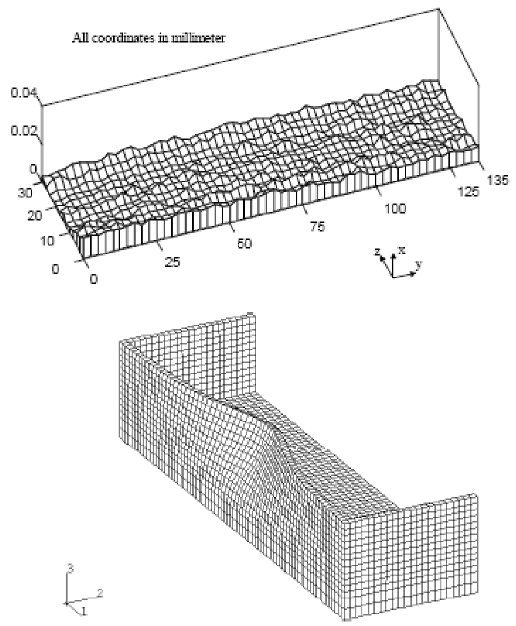


Fig. 7 Measured profiles under dynamic clamping scheme

The dynamic and compromising clamping scheme of an intelligent fixture has demonstrated to be more superior to a fixed fastening scheme of traditional fixtures in terms of the capacity to reduce work piece contortion. This prototype intelligent boasting system would finally lead to new contemporaries of work holding devices that can regulate themselves founded on receptive feedback.

## III. PLASTIC INJECTION MOLD INVENTION AND ANALYSIS

### *A. Introduction*

Molding-constructing used to be largely experience-based and trusts intemperately on competent craftsmen, typically conditioned under a position scheme, and have developed their expertness through years of practice. The supply of conditioned work force, however, is rapidly decreasing as the younger generation is reluctant to go through the long training periods of time and would prefer other types of jobs. This situation was halted to some extent with the introduction of CAD/CAM engineering in the late 70s. The mold-making scene has for the most part been translated from the tacit knowledge developed by the individuals to knowledge-based intelligent computer systems. Compared to the application of computer tools in the other constructing areas, however, mold design has been comparatively slow in progress. Until only quite recently, commercial software systems have started out to appear and are assumed in the tool-making and influencing industry.

According to CIMdata [4] in a recent analyze of the mold-making industry disclosed that mold design explicates some 20% of the total work effort in mold shops and CAM computer programming accounts for about 8%. More or less half of the 20% design work is linked with core and cavity design, with the remaining activities linked with mold base design/selection and the preparation of a design model for manufacturing. From this analysis, it can be seen that mold design is a major function in the mold shops. This high concentration of design activities has led to many software systems focusing their effort on providing solutions to the mold design aspects. These software systems are able to assist the mold designer in the various aspects of design such as automated parting line and surface determination, core and cavity design, runner and gate selection, analysis of temperature distribution and flow of plastic material in the mold, and the effective interfacing with different mold bases. A typical injection mold generated from the IMOLD system is shown in Figure 9.

 

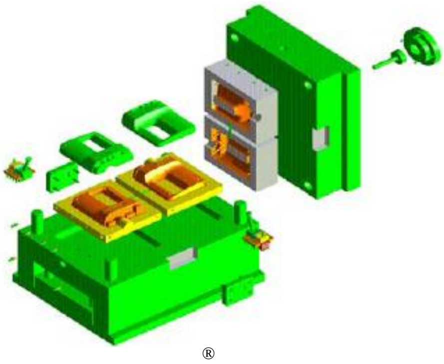

Fig. 9. An injection mold generated from the IMOLD® system (Courtesy of Manusoft Technologies Pte. Ltd.)

### *B. Computer-aided Design of Plastic Injection Molds*

CAD, CAE and CAM tools have been developed in the last two decades to assist mold designers in mold design configuration, analysis and machining. More specifically, they can be divided into the following categories.

1) More plastic part designs are presented to the mold shops in electronic formats and this is expected to increase from the present 53% to 90% in the next two years [4]. Mold designers would need to use compatible CAD software to retrieve the part design information, edit the design and make necessary alterations to prepare a final design model that meets all the manufacturing specifications.

2) Computer-aided engineering (CAE) software such as temperature and flow analysis programs is used to simulate the plastic injection process to check for possible defects in the molded parts, and for the suitable design of runners and gates. Such feedbacks will be used for modification of the molded part and/or the mold so optimum cooling and material flow can be achieved.

3) CAM software for the direct generation of NC tool-paths and programs for machining complex 3D surfaces based on the number of axes and configuration of an NC machine is available from several vendors. With the advent of high speed machining technology and the rapid adoption by the mold-makers, a new breed of CAM software has now been designed to cater for the high machining speeds and feed rates.

4) Although high speed machining of hardened die blocks has reduced the amount of EDM work, it is still necessary for EDM to handle the finer details of a mold. CAD/CAM software is able to extract features from cavities and design electrodes for EDM machining of complex 3D surfaces.

5) Many mold-shops would still prefer to document their designs and assembly details with 2-D drawings. CAD software for the automatic generation of 2-D drawings with full dimensional and annotation capabilities from a final 3-D design is available.

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### *C. Research on Plastic Injection Mold Design and Analysis*

#### 1) Undercut features, parting direction and parting line determination

The recognition and extraction of undercut features and parting line determination are the first steps in injection mold design. Many researchers have attempted to provide solutions to these problems.

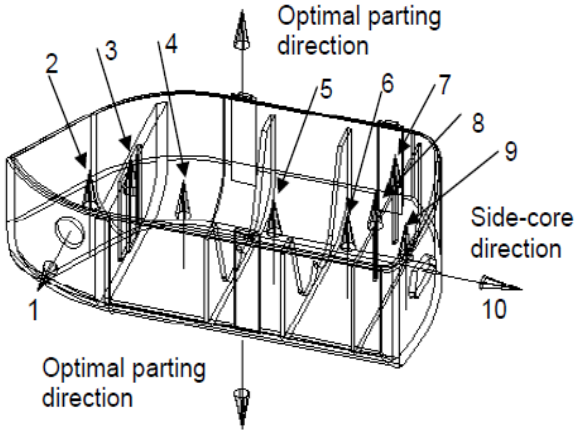


Figure 10. A sample part to illustrate the identi-fication of the optimal parting direction [5]

Figure 10 illustrates a sample part where the optimal parting direction has been identified. Automatic determination of parting lines and surfaces were reported by Nee et al [6] using a novel molding surface classification scheme and generation of edge-loops in different surface groups. Li et al [7] presented a novel approach for 3-D parting line search using all the surfaces in an initial solid model and divided them into union parting surfaces and multiple parting surfaces.

 

The multiple parting surfaces are then decomposed into several union parting surfaces using the discrete model method before parting line search, creating the new edges as potential parting lines. Parting line search is completed based on the pure union parting surface model.

**2) EDM electrode design**

In plastic injection mold manufacturing, NC milling and EDM have been the main processes traditionally until the advent of high speed machining. However, the two processes are still complementary as EDM is able to produce finer features and the required type of surface finish. Currently, the design of EDM electrodes is time-consuming and is done interactively using a CAD system. Over 100 sets of electrodes may be needed to manufacture the mold of a relatively simple hand phone cover. For more complex parts, it may run into several hundreds. Electrode design and manufacturing is a bottleneck in the entire mold manufacturing process [8]. Unfortunately, until today, there are very few software systems which are able to meet the needs of the mold-maker. Figure 11 shows a set of electrodes for the mold of a handphone cover.

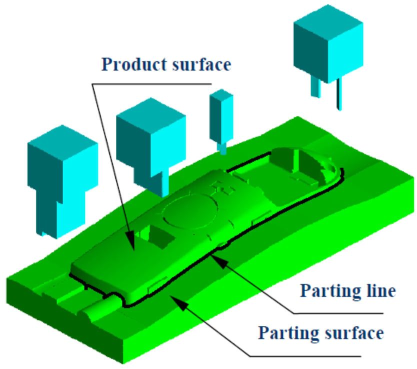

Fig. 11 Electrode design for a handphone cover [8]

**3) Mold cooling analysis**

Injection mold cooling design is a critical consideration as efficient and uniform cooling effect could improve both the productivity and part quality. As the mold cooling process is highly complex, a rigorous cooling analysis is essential to accurately predict the required cooling time and simulate the cooling process of a given design. In the last two decades, many research studies applied the 2-D Boundary Element Method (BEM) based techniques on the simulations and optimizations to reduce cost and computation time [9-13]. Most of the commercially available CAE software, either in 2-D or 2½-D, utilizes the BEM- or FEM-based shell elements and the Hele-Shaw approximation. For a 2½-D software, the mesh used in the analysis comprises shells with reference surfaces located at the mid-plane of the component, which is generally not a simple matter to derive from a solid model. Another technique, the so called Dual Domain Finite Element Method (DD/FEM), uses a surface mesh on the exterior of the part for flow analysis [14]. Sun et al. [15] studied a mold with a hot runner system using a 3-D, transient, FEM cooling analysis.

Simulation results in Figure 12 indicated that for a mouse cover, the temperature distributions of core and cavity with 'U'-shape milled grooves are more uniform. Besides, the 'U'-shape milled grooves is able to remove heat more efficiently; the temperatures of the molds are lower than the ones with straight cooling channels. As a result, the molding cycle time with the 'U'-shape milled grooves can be shorter, hence a shorter molding time per loading, leading to a higher production rate and increased efficiency.

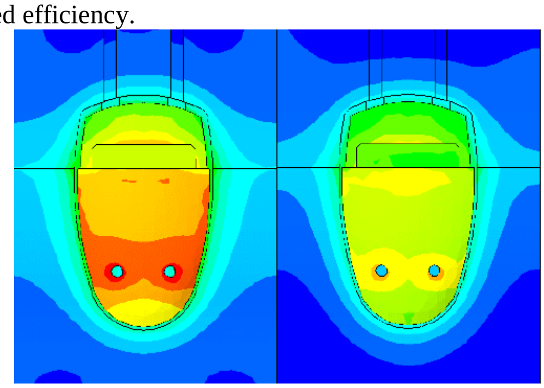
Fig. 12 Temperature distribution of a straight drilled and a 'U'-shape milled groove mold of a mouse cover [15]

**4) Tool path regeneration techniques**

To reduce the time required for regenerating tool paths, a novel tool path regeneration approach that can make use of the generated cutter location (CL) points for die and mold design modification has been reported [16] With this approach, the affected CL points which cannot be reused are identified and removed first, new CL points are then calculated and added to replace the removed ones, and those unaffected CL points are maintained in the new CL data. Hence, only the affected tool path points need to be re-calculated, the new tool paths for the modified work-piece can be regenerated efficiently. An algorhm of tool path modification has been developed and tested with several industrial parts. Figure 13 illustrates the tool paths of the work-piece before and after modification.

 

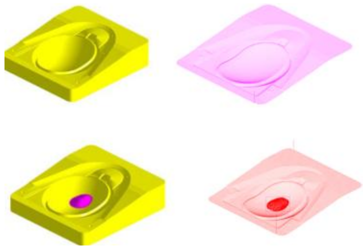

Fig. 13 Tool paths of workpiece before and after modification [16]

## IV. CONCLUSION

This paper summaries some of the developments in computer-aided fixture and plastic injection mould research in the last one and half decades at the National University of Singapore.

Although fixture design and planning has traditionally been regarded as a science as much as an art, it is now possible to successfully design and plan fixtures using computer applications. Optimal clamping force control remains an essential issue to be addressed. With the development of intelligent fixtures incorporating dynamic clamping force control, workpiece accuracy can be controlled on-line and this will further enhance the smooth operation of automated manufacturing systems.

Similarly, mold design and machining has taken a great step ahead as advanced software algorithms, machining and computer technologies are now available to the mold makers. A trade that was used to be craft-based has now become totally revolutionized and largely IT-based. Customers can now expect to see faster delivery times as well as better quality products. An increasing trend is the use of Internet technologies and this is expected to play a much bigger role in the next few years, in terms of distributed design as well as e-business activities.

Tooling design for manufacturing processes has been transformed from the "black art" into a science-based and IT savvy discipline. The notable increasing trend is towards the greater use of computer tools and Internet technology. It is foreseeable that tooling design activities will now be drawn from various geographical locations and there will be reduced reliance on the diminishing expertise in tool design.

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