REVIEW ON COMPUTER AIDED FIXTRE DESIGN

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Abstract - *To meet the customers requirement to manufacturing the product within time & achieve the interchangeability of parts with the required accuracy the fixture plays significant role. Study of location, clamping & support system are necessary elements of the fixture. Traditionally the fixture design is based on the trial & error method. So fixture designing was time consuming process. Now currently the automation of fixture design is called as the computer aided fixture design which gives exact idea of virtual fixture & find out the deficiency in it. This CAFD is quick process. Due to globalization demand & variability in rapidly increases so to achieve the finished good suitable fixture design is required within short time. Many methodologies & approaches are given by researchers are shortly discussed.*

Key Words: Fixture design, Locations, clamping

1. INTRODUCTION

Fixtures are the significant tools used in the industries for achievement of interchangeable and duplicate parts. Fixture helps to raise the productivity of given respective component. Because of it eliminates the position of marking and measuring which acts against the value added activities. There are different types of fixtures. Mainly Machining fixture, Assembly fixtures And Inspection fixtures. Again the machining fixtures are classified into two main types one is dedicated fixture and other is modular fixture. Generally dedicated fixture uses where the nature of production is mass and there is no need to change the setup as the given component remains the same. The modular fixture uses where the nature of production and some similar type of variations in product in such cases the modular types of fixtures are used. The value of the fixture design & manufacturing is nearly 10-20% of the manufacturing process. In the globalization era the customers requirement and demand rapidly changes to meet the customers demand the product should be within it lead time with more accuracy. So it can be achieve by adoption of methodology of computer-aided fixture design.

Fig -1: Dedicated fixture [53]

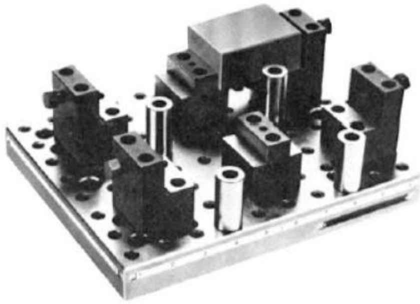

Fig -2: Modular fixture [53]

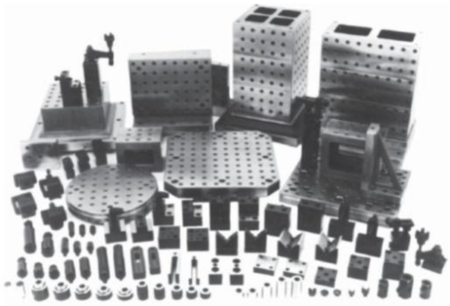

Fig -3: Modular fixturing elements (Carlane catalogue) [53]

2. Fixture Design

Mainly the computer aided fixture design is classified in 4 steps.

Setup planning shows that the component is oriented in a respective direction by taken into consideration of machining features on the component & when other group of machining feature is to be carry out then the position & orientation of the component is changed.

In Fixture planning desirable requirement & characteristic of respective fixture & fixturing layout are find out.

In unit design the various types of element is required for the fixture designing & has to be assemble the locating system, clamping system & supporting system. The conceptual unit design & detail unit design needs to be carry out.

Last stage is the fixture design verification against the desirable outputs of fixture i.e. check the desirable requirement of the fixture is fully satisfied or not.

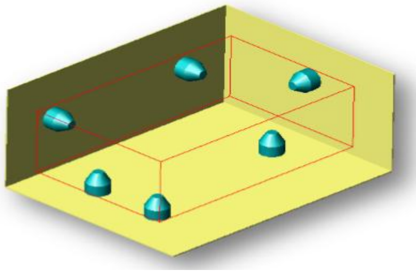

Fig -4: 3-2-1 principle of locations [4]

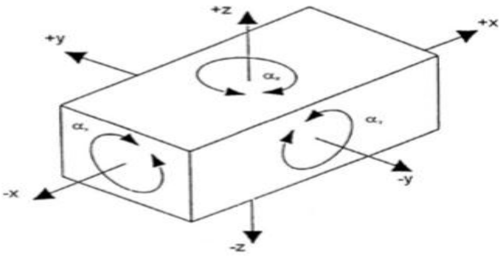

Fig -5: 3 The six degree of freedom [5]

2.1 SETUP PLANNING

At first the machining features are studied then according to the similarity between machining features if it is grouped together it is easy to carry out machining process on that required features In a single setup without any changing setup. If machining groups are more than one is formed then every single time the position & orientation of component is to be changed. A set up planning is a position of a component to be rested. Setup planning is required to do for accommodate as possible as possible machining features in minimum setup planning so that minimum tool changing & reduces the time of loading & unloading of component. Set up planning for prismatic part is given below

Table -1: Setup planning

Feature	Operation	Tool approach direction	Group
Blind hole	Drilling	1	1
Face	Milling	4,5,6	2
Face	Milling	1,5,6	2

2.1.1. Setup sequencing

A group of second setup taken first because less number of machining features & then after machining of group second then first group is taken for machining . The setup planning provide guidance for the more space for the locating & clamping positions. Because the less number of machining features is always taken first due to sufficient space for clamping, locating & supporting.

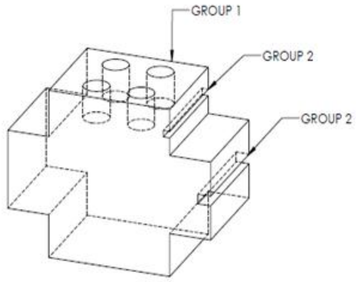

Fig -2: Prismatic Component for set up planning

2.1.2 Approaches for setup planning

Many authors had worked in the field of setup planning by giving various methodologies. Attila et. al. [1] The research methodology focused on the setup planning & fixture planning module (SUPFIX) in which the solution for the required fixture can achieve by past data available of the previous module. The module determines the possible same tolerance can machine in a single setup. Else it refuses then it determines that all machining features can machined in a single setup. Like this the module proceeds. Mohring et. al. [2] Aim is to check the influence of the fixture setup in milling process on the stability of the process. A reconfigurable fixture used for different setup & Finite element (FE) analysis approach used. Maniar et. al. [3] Machining component TEE body of an petroleum refinery its Setup planned such that all the machining features can combine in a single setup on a single machining centre by using rotating fixture. Premortem tool methodology used along with IV quadrant, VIII quadrant & VIII diamond quadrant computer aided mass balancing used. Huang et. al. [4] Setup planning is the orientation of component, datum selection & setup sequencing. Tolerance has vital role in precise manufacturing. Tolerance analysis applied in process planning to compensate time required for datum selection & setup. Graph theory applied as a mathematical tool. Ming et. al. [5] Hopfield Neural Network approach used it results in the efficient tolerance relationship between setup. Yuru et. al. [6] An Integrated methodology used for setup planning & fixture design such that it automatically determines the parameters likes tolerance relationship, forming machining groups, restrictions of degree of freedom. Fixture designing by using fuzzy evaluation & Hybrid RBR. Contini et. al. [7] Developed a optimized set up planning by using graph based approach. Results shown that minimum number of set up planning required for the specimen to perform its machining operation in most convenient way. Ong et. al. [8] To find out orientation & position of specimen in each machining operation setup planning gives the exact ideas. In their research work presents approaches used hybrid genetic algorithm (GA) & simulated annealing to enhance the results setup planning optimized by precedence relationship matrix (PRM). Zhang et. al. [9] In their research presents setup planning with various methodologies. Hybrid graph which shows relation between machining features & Datum. Tolerance information of geometric tolerance & Dimensional tolerance. Bansal et. al. [10] Research focus on the minimization of tolerance by integration of setup planning & fixture.

2.2. Fixture planning

In fixture planning the positions of locations , positions of clamping are find out. The locators are place only where the surface is machined and having more accuracy i.e. where the machined surface have lower tolerance. There must be a more gap between the locators so that the locators can accommodate the component completely. 3-2-1 principles are used for locations of prismatic components for higher rigidity. The possible type of fixturing layout are find out according to the component. Fixture planning is integrated of machining feature recognition & typical fixturing requirements. Following table represents typical fixturing requirement.

Table -2: Featuring desire requirements of fixture

SR.NO.	GENERIC REQUIREMENTS	DETAILS OF GENERIC REQUIREMENTS.
1	Physical	Robust design fixture should be manufactured.
		Size & shape of given component should be easily placed in fixture.
		Fixture should provide stability to the given component.
		Fixture should be designed by considering minimum material required so as to avoid excess weight to it.
		Loading & unloading of the component should be easy & quick.
		Sharp corners should be avoided.
2	Constraining	Fixtures should prevent all its degree of freedom.
3	Collision prevention	Avoid unnecessary contact with the component.
		Cutting tool path is in the exact way of machining features only.
4	Tolerance	Tolerance of fixture should be capable to satisfy component tolerance.
5	Cost	Cost should be low.

2.2.1 Approach for fixture planning & optimization

Attila et. al. [11] Fixture configuration module (FIXCO) used to generate current fixture planning for a specimen. Past module database utilized. Output of CAD model given into to CAM model results in tool path visualization which gives prior idea that collision prevention. Kaya [12] To prevent the deformation of specimen the positions of location & clamping optimized for better results in terms of fitness value by using Genetic Algorithm (GA) & FE approach. Vasundara et. al. [13] Due to machining forces & clamping forces error occurred because of deformation of workpiece. To minimize the deformation the location & clamping points changed for the optimization purpose. Methodology used as FEA, ANN & RSM. Song et. al. [14] All degree of freedom of specimen under –constraint determined automatically. Results in proper locating positions. In their research the rank of locating matrix utilized to achieve constraint status geometrically & then algorithm developed to support information for unconstraint motion of workpiece in under-constraint motion. Stamfer et. al.[15] Consequences of workpiece – Fixture interaction considered dynamically. Genetic Algorithm (GA) used along with finite element analysis. Results shown that optimized model shows less deformation of workpiece. Hangrove et. al. [16] Research focus on Generic IDEF model which integrated used in Fixture planning & fixture design. IDEF model determine information required between process planning & fixture design. Cecil et. al. [17] Research work consist of functional aspect of location strategy & clamping strategy discussed. Krishnakumar et. al. [18] Fixture layouts directly impacts the machining accuracy of a specimen. Different positions of clamping & locating gives varying deformation of specimen. In their research work the Genetic Algorithm (GA) used to optimized the fixturing layout by changing the positions of locating & clampings. Shreyes et. al. [19] A discrete elastic contact model used to check interface between fixture – workpiece. Locating errors reduced to enhance the locating accuracy. In their research two fixturing layout compared.

Masoumi et. al. [20] Research work focus on optimization of fixture layout in a multi-station sheet assembly. liaison graph and Breadth-First Search algorithm approaches used. Menessa et. al. [21] Objective function decided to minimize the deformation of a workpiece finite element methodology utilized to determine the deformation. And for optimization Broyden-feltcher Goldfarb-shanno optimization utilized for best position for fixturing support elements. Gonzalo et. al. [22] Research work find out the causes of static deformation in clamping & by evaluation of reaction forces method adopted to reduce geometrical distortion using concept of intelligent fixture. Andrea et. al. [23] Geometricl error occurred when workpiece surface gets deviated by workpiece-fixture contact or due to machining forces. Deviation results into error. Determined the main source of error. A mathematical Part – Position algorithm used. Lu et. al. [24] 3-2-1 Principle scheme of location utilized & three point locations optimized by using Genetic Algorithm (GA) & using FEA & Neural Network deformation predictaed. Wan et. al. [25] To optimized the Natural frequency of fixture-workpiece novel non-linear programming problem based frequency sensitivity build. Siva kumar et. al. [26] Genetic Algorithm used along FEA (APDL) to achieve minimum error during machining operation of drilling.

2.3. Unit design

Already the fixturing layout is drawn into the CAD softwares. The locating system, clamping system & supporting system are firstly conceptual designed then its needs to be detailed design by considering various possible types of failures (failure due to shearing, bending, crushing, tensile & torsional) & check in the design whether the fixturing component is safe or not. If fixturing component is safe then proceed towards the last step of fixture design i.e. verification or else redesign the dimensions of respective fixturing unit design.

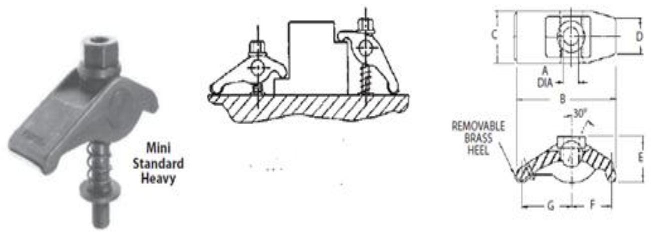

Fig -6 Unit design & detailed design of forged adjustable clamp

2.3.1 Approaches in Unit design

Mathew et. al. [27] Automated fixture design has significant role that interrelate between the CAD & CAM. The Cased based reasoning (CBR) approach used it refers past information available & applied to current present fixture design problems. Boonsuk et. al. [28] Research work focused on the automation of fixture design for a rapid machining process. Sacrificial fixturing in a rapid prototyping process & Support design methods shown. Price et. al. [29] Research focus on the approach of Case Based Reasoning (CBR) applied to the Welding fixture design. Its helps to decide the fixturing layout for current problem by using previous entire information available in database. Hurtado et. al. [30] Research focus on the Algorithm model which determines the suitable force of clamping & suitable numbers of positions & sizes of dowel pins to optimized. Stiffness based on tolerance limit specifications. Hunter et. al. [31]Research work focused on the Knowledge models standard process of fixture design discussed. Standard knowledge templates used to store the common entities like locators & clamps. Kumar et. al. [32] An automated fixture design technique utilized. Finding out the fixturing point by formulated as heuristic rules. Detailed selection of clamping point discussed. Mervyn et. al. [33] Evolutionary search algorithm to generate the modular fixture. Results into optimized fixturing layout. Raghu et. al. [34] Sequence of clamping affect the geometrical deformation of workpiece & leads to the error. Force based clamping sequence model used along with workpiece - fixture compliance model. Wang et. al. [35] Case Based Reasoning methodology used in their research work for welding fixture by using tools of computer aided. Researcher developed multi level CBR referencing past data. Tohidi et. al. [36] Varying different component needs to be developed different fixture so more time & cost required to compensate this problem the mathematical planning model developed for optimized locations of jiggins-pins for an modular fixture. This model solved by GAMS by using BARCON software.

2.4. Verification

Last step of fixture design which verify whether all the requirement of setup planning, fixture planning & unit design are satisfied or not. Verification ensures the fixture design is as per the standard. Stability of working component, restricted motion of degree of freedom, Tool path , loading & unloading of component, Machining force on component all the typical requirement of good fixture is verified.

2.4.1 Approaches used in fixture design for usability & affordability requirements

Factors considered for the usability & affordability is that low cost , low weight , don't damage to the workpiece, ease way of chip removal. Boyle et. al. [37] Performance of fixture is determined with respect to the usability & affordability requirements (Loading- unloading time, processing time, cycle time & cost). Ong et. al. [38] More analytical methodologies used to verify the performance of the designed fixture. Brost et. al. [39] Developed algorithm for modular fixture that can rebuilt the setup in a minimum time. The designed fixture verified by the genuine fixturing requirements.

2.4.2 Approaches used in fixture design for collision detection

Most significant aspect in a fixture design. Tool path should touch only the specific location where the machining operation required. It prevents damage to the workpiece & fixture & also save the tool breaking. Hu et. al. [40] Research focused on the fast checking interface collision detection in between the cutting tool & the workpiece. Swept volume methodology used for collision detection which is more convenient for verification in collision detection. Kumar et. al. [41] By the use of Computer aided fixture design (CAFD) methodology generated for the Automated fixture design (AFD) that find out fixturing locating & clamping points along with considering the tool collision free by interface detection sub module of workpiece & tool in a fixturing layout. Gaoliang [42] In their work for modular fixture design a 3D manipulation approach used result shows the collision detection free interaction between the component & machining tool in a modular fixture. Kow et. al. [43] collision free an integrated approach use in the modular fixture.

2.4.3 Approaches used in fixture design for constraining

Significant factor to be considered in fixture design. It restrict the free motions of workpiece during the machining operations. Ensures the stability of workpiece. Vishnupriyan et. al. [51] 3-2-1 principles of location used for the component stability. Deng et. al. [51] Sufficient amount of clamping force determined for the achieve stability of fixture dynamically. Qin et. al. [52] Exact location of locators are determined by concept of venn diagram & generated a methodology for restrict the degree of freedom.

2.4.4. Approaches used in fixture design for tolerance requirement

Tolerance gives the accuracy in manufacturing. The selection of tolerance based on different approach discussed by various researchers. Boyle et. al. [44] Tolerance provided on location system such that it should be within the accepetable range of part design tolerance by considering the consequences during the deformation of under the applied machining force. Wang et. al. [45] The error due to locating compensated by providing high tolerance at locating system. But in the optimized layout need not provide unnecessary high precise tolerance to the locators. Bansal et. al. [46] Integrated system developed by considering tolerance minimization. Chaudhary et. al. [47] Their research focused on the effect of tolerance on the geometric error. Huang et. al. [48] Research focus on the formation of setup planning by using graph theoretical methodology considering the tolerance analysis. The methodology is mathematical in nature & easy to modified & computerized. Rong et. al. [49] Research shown that locating tolerance directly impact the daum location & machining features to be carry out. Vishnupriyan et. al. [50] Due to machining process the accuracy of component get influence. The desirable tolerance should be given for a locator such that it should accommodate the component tolerance. Genetic Algorithm used for the better fixturing layout.

3. CONCLUSION

It is the most essential need to Integrate the various methodologies & approaches used in the computer aided fixture design in a CAD software for a cohesive fixture achieve. Effectively reduction in time & cost required for the fixture design can be achieved by adoption of these methodologies.

4. FUTURE SCOPE

Essential need to integrate the various methodologies and approaches used in the computer aided fixture design in a CAD software additional with the help of intelligent fixture system to achieve more cohesive fixture design.

ACKNOWLEDGEMENT

I would like to thank with deep sense of gratitude the valuable guidance, encouragement and suggestions given by My project guide Assistant Professor V. D. Kamble for their valuable guidance and encouraging to me for this review paper and all the project work. I would also like to thank my PG Class Co-ordinator Professor S. S. Karidkar. And thank to all who helped me directly and indirectly for the completion of this review paper my parents and my friends.

REFERENCES

1]Retfalvi Attila, Michael Stampfer, SzeghImre, "Fixture and Setup Planning and Fixture Configuration System" Forty sixth CIRP Conference on Manufacturing Configuration System. Procedia CIRP, 2013, 7, 228-233.

2]Hans-christian Mohrring, Petra Wiederkehr, Intelligent fixture for high performance machining, 7th HPC 2016 CIRP conference on high performance cutting, Procedia CIRP 46 (2016) 383- 390.

3]Nirav P. Maniar, Dr. D. P. Vakharia "Design & development of rotary fixture for CNC with computer aided mass balancing method as pre-mortem tool" Procedia Technology 14 (2014) 397 – 404.

4]S.H.Huang , H.C. Zhang, W.J.B. Oldham, Tolerance analysis for setup planning: A graph theoretical approach. International Journal of Production Research, 1997, Vol. 35, No. 4, 1107- 1124.

5]X.G.Ming, K.L. Mak, Intelligent setup planning in manufacturing by neural networks based approach, Journal of Intelligent Manufacturing. (2000) 11, 311-331.

6]Zhang Yuru, Peng Gaoliang, Development of an integrated system for setup planning and fixture design in CAPP. Proceedings of the 2005 IEEE/ASME. International Conference on Advanced Intelliget Mechatronics, Monterey, California, USA, 24-28 July, 2015.

7]P.Contini, T. Tolio, Computer-aided set-up planning for machining centres configuration. International Journal of Production Research. 1 september 2004, Vol. 42, No. 17, 3473-3491.

8] S. K. Ong, J. Ding, A.Y.C. Nee hybrid ga and sa dynamic set-up planning optimization. International Journal of Production Research. 2002, Vol. 40, No.18 ,4697- 4719.

9] Hong Chao Zhang, Enhao Lin, A hybrid-graph approach for automated setup planning in CAPP. Robotics and Computer-Integrated Manufacturing.15 (1999) 89-100.

10]S. Bansal, S. Nagarjan, N. Venkata Reddy, An integrated fixture planning system for minimum tolerances. International Journal of Advance Manufacturing Technology. (2008) 38:501-513.

11] Retfalvi Attila, Michael Stampfer, SzeghImre, “Fixture and Setup Planning and Fixture Configuration System” Forty sixth CIRP Conference on Manufacturing Configuration System. Procedia CIRP, 2013, 7, 228-233.

12] Necmettin Kaya Machining fixture locating and clamping position optimization using genetic algorithms” Computers in Industry 57 (2006) 112–120.

13] M. Vasundara, K.P. Padmanaban, M. Sabareeswaran, M. RajGanesh, “Machning fixture layout design for milling operation using FEM, ANN and RSM” Mathematical and Numerical methods in simulation and modeling, Procedia Engineering 38 (2012) 1693 – 1703 2012, 38, 1693-1703.

14] H. Song , Y. Rong “Locating completeness evaluation and revision in fixture plan”, Robotics and Computer-Integrated Manufacturing 21 (2005) 368-378.

15]Stamfer Analysis and optimization of fixture under dynamic machining condition with chip removal effect

16]S. Keith Hangrove, A system approach to fixture planning & design. International Journal of Advanced Manufacturing Technology. (1995) 10: 169-182

17] Joe Cecil, Richard Mayer and Umesh Hari, An integrated methodology for fixture design. Journal of Intelligent Manufacturing (1996)7, 95-106.

18]Kulankara Krishnakumar, Shreyas N. Melkote, Machining fixture layout optimization using the genetic algorithm, International Journal of Machine Tools and Manufacturing 40 (2000), 579-598.

19]Bo Li, Shreyes, N. Melkote Improved workpiece location accuracy through fixture layout optimization. International Journal of Machine Tools and Manufacturing 39 (1999) 871-883.

20]Abolfazal Masoumi , Vahid Jandaghi Shahi ,Fixture layout optimization in multi-station sheet metal assembly considering assembly sequence and datum scheme. The International Journal of Advance Manufacturing Technology.

21]R. J. Menassa, W.R. Devries. Optimization Methods Applied to Selecting Support Positions in Fixture Design.Department of Mechanical Engineering, Aeronautical Engineering and Mechanics, Rensselaer Polytechnic Institute, NY 12180-3590.

22]Oscar Gonzalo,Jose Mari Seara, Enrique Guruceta, Alberto Izpizua , Mikel Esparta, Iker Zamakona , Nicolas Uterga , Axier Aranburu , Johannes Thoelen.A method to minimize the workpiece deformation using a concept of intelligent fixture.Robotics and computer –integrated manufacturing.48 (2017) 209-218.

23]Corrado Andreaa, Polini Wilmaa, Moroni Giovannib, Robust design of a fixture configuration in the presence of form deviations.Procedia CIRP 43 (2016) 35 -40.

24]Cong Lu and Hong –Wang Zhao 2015, Fixture layout optimization for deformable sheetmetal workpiece. International Journal of Advanced Manufacturing Technology.

25] Xiao-Jin Wan, Yan Zhang, novel approach to fixture layout optimization on maximizing dynamic machinability. International Journal of Machine tools and Manufacturing 70 (2013) 32-44.

26]Siva kumar & Paulraj “Geometrical error control of workpiece during drilling through optimisation of fixture parameter using a genetic algorithm”, International Journal of Production Research, Vol.50No. 12,15June 2012,3450-3469.

27] Shekhar Tanji, Saiesh Raiker and Arun Tom Mathe, Computer aided fixture design - A case based approach.IOP Conference Series : Materials Science and Manufacturing and Engineering 263 (2017) 062058.

28] Wutthigrai Boonsuk and Matthew C. Frank, Automated fixture design for a rapid machining process.Department of Industrial and Manufacturing System Engineering, Lowa State University , USA. Rapid Prototyping Journal 15/2 (2009) 111- 125.

29] Shaun price “ A study of case based reasoning applied to welding computer aided fixture design”,Worcester Polytechnic Institute ,May 2009.

30] Jose F. Hurtado, Shreyes N. Melkote, A model for synthesis of the fixturing configuration in pin-array type flexible machining fixtures. International Journal of Machine Tools and Manufacturing 42 (2007) 877-849.

31] R. Hunter, A. Vizan, J. Perez Knowledge model as an integral way to reuse the knowledge for fixture design process" Journal of Materials Processing Technology 164–165 (2005) 1510–1518.

32] A. Senthil kumar, J.Y.H. Fuh, T.S. Kow, An automated design and assembly of interference-free modular fixture setup. Computer-Aided Design 32 (2000) 583-596.

33]Mervyn, a. senthil kumar and a. y. c. nee, Automated synthesis of modular fixture designs using an evolutionary search algorithm. International Journal of Production Reserch, Vol. 43, No.23 , 1December 2005, 5047-5070.

34] Anand Raghu, Shreyes N. Melkote, Analysis of the effects of fixture clamping sequence on part location errors. International Journal of Machine Tools and Manufacture 44 (2004) 373- 382.

35] Hui Wang, Yiming (Kevin) Rong, Case based reasoning method for computer aided welding fixture design. Computer-Aided Design 40 (2008) 1121- 1132.

36] Hossain Tohidi, Tarek Algeddawy Planning of modular fixture in a robotic assembly system 48th CIRP Conference on Manufacturing System –CIRP CMS 2015.

37] Latin M. Boyle, Kevin Rong and David C. Brown, CAFixD: A Case-Based Reasoning Fixture Design Method. Framework and Indexing Mechanisms. Proceddings of DTC 04. ASME 2004 Design Engineering Technical Conference and Computer and Information in Engineering Conference September 28-October 2, 2004, Salt Lake city, Utah USA.

38] S. K. Ong, J. Ding, A.Y.C. Nee hybrid ga and sa dynamic set-up planning optimization. International Journal of Production Research. 2002, Vol. 40, No.18 ,4697- 4719

39]Randy C. Brost A Complete Algorithm for Designing PlanarFixtures Using Modular Components. IEEE Transactions on Robotics And Automation, Vol. 12, No. 1, Feburary 1996.

40] W. Hu and Y. Rong A Fast Interference Checking Algorithm for Automated Fixture Design Verification. International Journal Advanced Manufacturing Technology (2000) 16:571-581.

41] A. Senthil kumar, J.Y.H. Fuh, T.S. Kow, An automated design and assembly of interference-free modular fixture setup. Computer-Aided Design 32 (2000) 583-596.

42] Peng Gaoliang, Wang Gongdongb, Liu Wenjiana, Yu Haiquan A desktop virtual reality-based interactive modular fixture configuration design system. Computer-Aided Design 42 (2010) 432-444.

43]T. S. Kow, A. S. Kumar and J. Y. H. Fuh, An Integrated Approach to Collision-Free Computer-Aided Modular Fixture Design. International Journal Advanced Manufacturing Technology, (2000) 16:233-242.

44] Lain Boyle CAFixD – a case-based reasoning method for fixture design. Worcester Polytechnic Institute. May 2006.

45] Michael Yu Wang, Tolerance analysis for fixture layout design. Assembly Automation Volume 22, Number 2, 2002, PP 153-162. @ MEB UP Limited, ISSN 0144- 5154.

[46] S. Bansal & S. Nagarajan & N. Venkata Reddy, An integrated fixture planning system for minimum tolerances. International Journal Advanced Manufacturing Technology. (2008) 38: 501-513.

[47] S.A. Chaudhary, E. C. De Meter, Tolerance analysis of machining fixture locators. Journal of Manufacturing Science and Engineering, May 1999, Vol. 121-273.

[48] Samual Huang, Hong- Chao, Zhang, Tolernce analysis of setup planning for rotationl parts. Journal of Manufacturing System. Vol. 15 / No. 5 , 1996.

[49] Y. Rong , W. Hu , Y. Kang , Y. Zhang & David W. Yen, Locating error analysis and tolerance assignment for computer-aided fixture design. International Journal of Production Research, 2001, Vol. 39, No. 15, 3529- 3545.

[50] S. Vishnupriyan, M. C. Majumder, K. P. Ramachandran, Optimization of machining fixture layout for tolerance requirements under the influence of locating errors.International Journal of Engineering Science and Technology, Vol.2, No.1 , 2010, PP 15-162.

[51]Haiyan Deng, Shreyes N. Melkote Determination of minimum clamping forces for dynamically stable fixturing. International Journal of Machine Tools and Manufacture 46 (2006) 847- 857.

[52] G.H. Qin, W.H. Zhang, M. Wan, S.P. Sun, A novel approach to fixture design based on locating correctness. International Journal Manufacturing Research, Vol.20 August 200.

[53] Jigs & fixture handbook by Carlane catalogue manufacturing.