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3-D Fixture Layout Design System Based on Genetic Algorithm

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Abstract—**Designing a fixture layout is the primary task of fixture design, which consists of determining the different combinations of locators and clamping scheme. Designing a fixture is a lengthy process and the performance of a fixture is usually difficult to predict. Designing fixture to effectively restrain complex components has been recognised as a bottleneck in fixture design development. The aim of this research is to develop a genetic algorithm (GA) based methodology to support effective fixture layout optimization for 3-D component. Reduce the dependence on designers expertise to deliver the fixture layout design against his/her own particular design methodology. Efforts of the application are focused on optimisation of the positions of locators and clamps for complex geometry components, such as a turbine blade. Overall, results suggest the feasibly of using GA in fixturing layout optimization.**

Fixture Layout Design System;3D Fixture Layout Design;Fixture DesignApplication; Genetic Algorithm

I. INTRODUCTION

A fixture layout represents a set of locators and clamps positioned on the workpiece surface, in which the part is restrained throughout the machining operations. Designing a fixture layout is the primary task in fixture design. The two main aspects in fixture layout optimisation often refer to the task of optimising the locating and clamping positions as well as the clamping force.

At present design of a fixture layout resides highly on an individual designer, who relies significantly on his/her personal expertises and experiences to synthesize a suitable locator and clamping arrangement to restrain a given component. Designing a fixture is a time consuming process and yet, other possible alternatives have not been systematically explored. In some extreme cases, a designer may even fail to find an acceptable fixture arrangement or may need to settle upon sub-optimal fixture [1]. According to Yeung and Chen [2], being unable to effectively designing fixtures will lead to the following scenarios:

- Individual designer may deliver the fixture design against his/her own particular design methodology, which may not necessarily satisfy the customer's general requirement or limitation.
- Conventional fixturing design activity may only consider the component features without acknowledging the capacity of the machining process. This practice would inevitably undermine its optimal process condition.
- Extra costs are borne for both designer and fixture user due to increased iteration requirements, scrap, non-conformance, increased machining cost and delay in manufacturing process.

This study targets the specific issue of heavy dependence on designers expertise to deliver the fixture layout design against his/her own particular design methodology, and utilises Genetic Algorithm as the optimisation technique to optimise fixture layout design.

Genetic algorithm (GA) has been used as optimisation methods for a wide variety of real-life problems, as well as speeding up the search for a high quality solution. Due to its powerful searching ability and easy manoeuvrability, it has attracted many researchers to investigate its performance on the fixture layout optimisation issue. GA has increasingly been applied and proven to be a useful tool for solving optimisation problem in engineering as well as design problem [3]. The GA approach is particularly suited for problems where a well-defined mathematical relationship between the objective function and the design variables does not exist [4].

The aim of this study is to develop an application which facilitates the use of Genetic Algorithms (GA) as a tool for automated fixture layout design, and optimising the locations of locators and clamps for three- dimensional (3-D) components.

II. 3D FIXTURE LAYOUT OPTIMISATION USING GENETIC ALGORITHM

Genetic Algorithms (GA) is an adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and biological system of reproduction to produce offspring that can better survive in the current environment.

GA is very different from other search methods, including traditional optimisation techniques, in the following four major ways [3, 5- 7].

- GA uses coding to represent the design variables and parameters of the problem, rather than the actual parameters themselves.
- GA maintains a population of potential solutions. Hence multiple regions in the search space are evaluated for each iteration instead of processing a single point.
- GA uses only the fitness or objective function value to guide the search. No derivatives or gradients are necessary.
- GA uses probabilistic methods to find new solutions rather than using deterministic rules based on gradient information.

In GA, a population of potential solutions are coded in the form of strings often referred as chromosomes or individual. It evolves over successive number of generations using a set of genetic operators: selection, crossover and mutation. First, the initial population is generated randomly and based on the criteria defined in the fitness function (evaluation), each individual is assigned with a fitness value. Then the selection operator is applied to choose individual with relatively high/low fitness value to be part of the reproduction process. In the reproduction process, new individuals are created through crossover and mutation operators. Crossover operator is the operation used to partially exchange chromosomes information between individuals to create the next generation, hence exploring in the search space. Mutation operator is used to introduce diversity into the population to avoid premature convergence as well as to increase the search area in the search space. The fitness value of the new population is then evaluated and the process continues to repeat until the maximum number of generation is reached, or when the population is converged [8].

The fixture layout optimisations procedures used in this research are based on using GA to search for locator configuration. Users of the fixture layout design application are required to define the GA parameters, loading of the workpiece information and define possible search space for locator point and clamping point, which is the region suitable for locator and clamp point to position on the workpiece surface.

The fixture layout optimisation consists of two main steps: locator position optimisation using GA, and systematic search for clamping optimisation. The algorithm would first generate the initial population and start the search based on the defined GA parameters. For every optimised locator layout, the imitation of the clamping position is undertaken; and the feasible clamping position and the most suitable clamping position are presented. The overall fixture configuration is recorded for further analysis.

The 3-D component is restrained by six locators and a single clamp. Two different 3-D components have been selected to test the applications of genetic algorithms. Case 1: A rectangular box with a truncated corner, and case 2: A turbine blade with locators and clampers on the aerofoil. For both cases the component is created from Pro-Engineer and then converted into the render (.slp) and 3-D vector graphics format based on the Initial Graphics Exchange Specification (.igs) file format. The .igs file is then loaded into ABAQUS to generate a surface mesh; the mesh points are extracted and saved in the form of a text file (.txt). The mesh text files are in the structure of X, Y, Z co-ordination listing the location of each candidate points. Users are able to select two different text files for mesh input, one for locator and one for clamp.

From the graphical user interface (GUI) in Matlab, users are allowed to select any render (.slp) file as input information source for the component. With the component and mesh information inputted into Matlab, users are required to enter the GA parameters into the GA toolbox before conducting a search for the optimum locator configuration. According to the locator configuration, the minimisation of the maximum clamping forces is calculated. If the clamping and locators position do not fulfil all requirements of the fixture design, users can modify the mesh size or area to refine GA search region until all the constraints are satisfied before finalising the design.

A. 3-D Fitness function

The fitness function is to maximise the determinant of the locator matrix which is known as the D-Optimality [9]. The locator matrix (L_M) consists of the locating scheme, given there are n number of locators, with locating normal vector being denoted by [a_i, b_i, c_i] and locating position being denoted by [x_i, y_i, z_i] for each locator, $i = 1,2,\ldots,n$ ($n = 6$), the locating matrix for 3-D model (L_M) is determined as below:

$$L_M = \begin{bmatrix} a_1 & b_1 & c & c_1y_1 - b_1z_1 & a_1z_1 - c_1x_1 & b_1x_1 - z_1y_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_i & b_i & c_i & c_iy_i - b_iz_i & a_iz_i - c_ix_i & b_ix_i - z_iy_i \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_n & b_n & c_n & c_ny_n - b_nz_n & a_nz_n - c_nx_n & b_nx_n - z_ny_n \end{bmatrix}$$

The fitness function returns an integer which is used to guide the GA to find an optimum solution.

In Matlab the Genetic algorithm toolbox minimises the fitness function. The GA Toolbox solves problems in the following form:

$$\underset{x}{\text{minimise}} \quad f(x)$$

When using GA toolbox to solve maximise f(x), the fitness function needs to be rearranged to minimise –f(x). The point at which the minimum of –f(x) occurs is the same as the point at which the maximum of f(x) occurs.

B. Srting representation

The string (artificial chromosomes) needs to be decoded so it corresponds to locator positions based on node number which is generated in ABAQUS as mesh points. Since there are six locator points for 3-D components, the length of artificial chromosomes consists of six parameters. L1, L2, L3, L4, L5 and L6 indicate fixture locator number 1, 2, 3, 4, 5 and 6. The encoded string for this research uses a real number between 0-1 to represent the locators' position in relation to the work piece frame for the initial population as shown in Fig. 1.

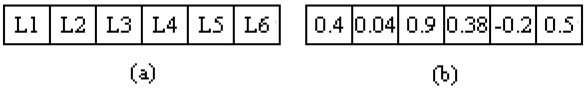

Figure 1. (a) Structure of the artificial chromosome (b) example of the artificial chromosome

C. Case Study 1

A 3-D rectangular box with a truncated corner (Fig. 2) is used as case study 1, since the component is a classical regular shape, a locator configuration can be accomplished with the 3-2-1 configuration strategy. Therefore this case is mainly used to test the algorithm to ensure it is suitable to determine appropriate locator arrangements. The genetic algorithm iterative process of begins by creating the initial generations of solution (population size, PSize = 80). This process will continue until a predefined maximum number of generations is reached (GenMax = 200), or until there is no appreciable improvement in the fitness function after 50 consequent iterations (GenStall), detail of the GA parameters are presented in Table I. These parameters are obtained based on initial estimating then adjusted after trial and error.

TABLE I. GENETIC ALGORITHM OPERATORS AND PARAMETERS SETTING FOR CASE STUDY 1

PSize	=	80
GenMax	=	200
GenStall	=	50
Selection Operator	=	Stochastic Uniform (SU)
Crossover Operator	=	Single point
Mutation Operator	=	Gaussian (3, 0.1)
Number of Node (Locator)	=	973
No. of Clamp	=	Single
Number of Node (Clamp)	=	973
Number of Run	=	100

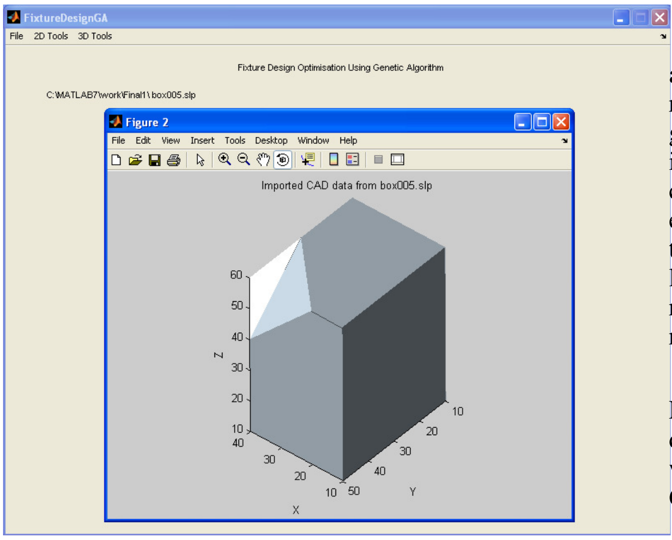

Figure 2. Component of the case study 1.

D. Case Study 2

A 3-D turbine blade (Fig. 3) is used as case study2 is restrained by 6 locators and 1 clamper on the aerofoil or on the inner side of the component in order to allow access to both roots of the blade for manufacture. The GA parameters are presented in the Table II. The best layout from all generations is taken as the optimal solution.

TABLE II. GENETIC ALGORITHM OPERATORS AND PARAMETERS SETTING FOR CASE STUDY 2

PSize	=	80
GenMax	=	200
GenStall	=	50
Selection Operator	=	Stochastic Uniform (SU)
Crossover Operator	=	Single point
Mutation Operator	=	Gaussian (3, 0.1)
Number of Node (Locator)	=	1161
No. of Clamp	=	Single
Number of Node (Clamp)	=	1161
Number of Run	=	100

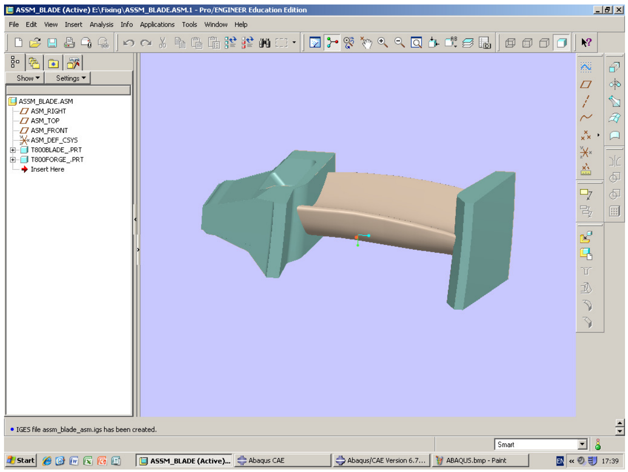

Figure 3. Screenshot from Pro-E of a turbine blade for case study 2.

III. SYSTEM DESIGN FOR 3D FIXTURE LAYOUT DESIGN SYSTEM

Firstly, it is important for the fixture layout design application to generate the final fixture layout in a reasonable amount of time with small number of generation. Secondly, a flexible development environment is desirable to allow easy implementation of new constraints. It is also important that results generated are easy to interpret and understand. This chapter describes the specific application developed and used for fixturing layout optimisation in this research. The input file format requirement, program functionality, and the way which results are interpreted are illustrated.

A Screenshot of the main program are presented in Fig. 4 and Fig. 5 show the flow chart for the fixture layout design system. The application is implemented in Matlab with the support of genetic algorithm toolbox and the Graphical User Interface (GUI).

a) Data preparation

In order to use the program, users need to prepare the input file. In general, three types of input file are needed:

First type of input file contains information about the workpiece model. 3-D workpiece model that needs to be inputted to the Fixture layout design system is generated by CAD model then convert the 3-D CAD model into SLP format.

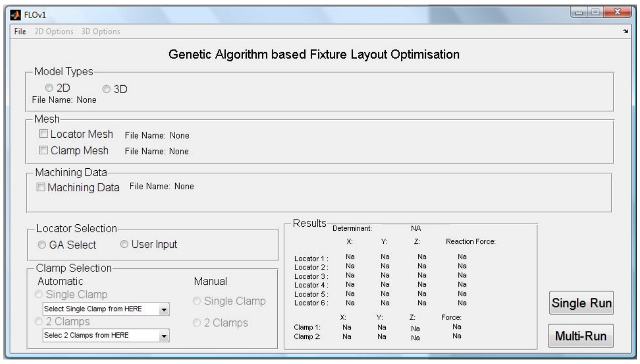

Figure 4. Screenshot of the main program interface program

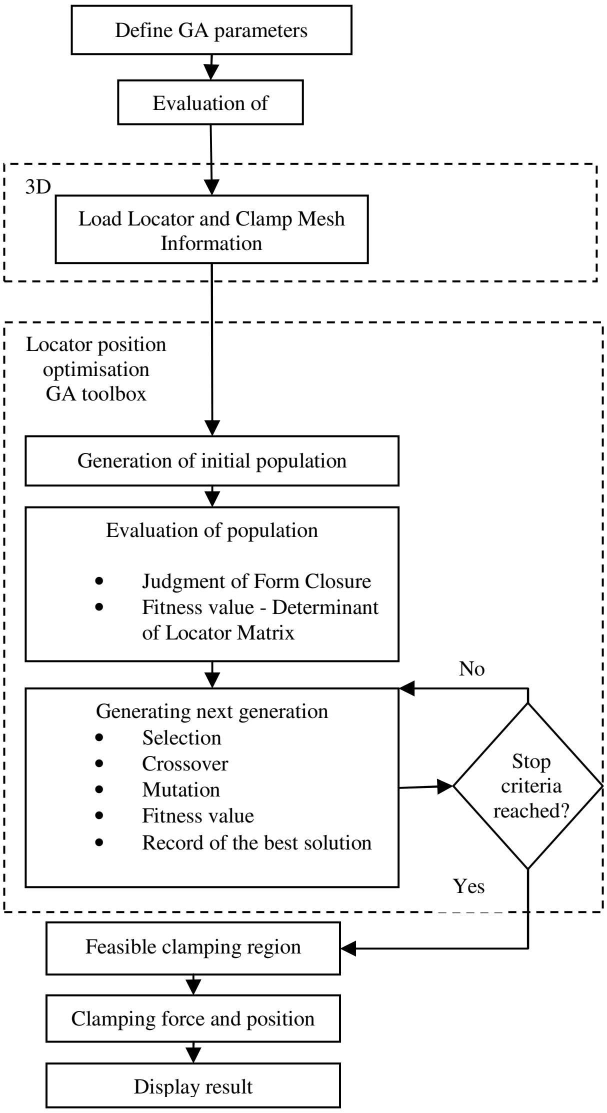

Figure 5. Flow Chart of the fixture layout design system based on Genetic Algorithm.

The second type contains information about possible locator and clamping positions. For 3-D model, users need to prepare a list of X, Y, and Z coordinates of possible locator and clamping position that lies on the workpiece surface. The coordinates of the model can be generated by ABAQUS as mesh nodes.

The third type contains machining data. For 3-D model, users need to prepare a list of X, Y, and Z coordinates that show the machining path (Fig.6).

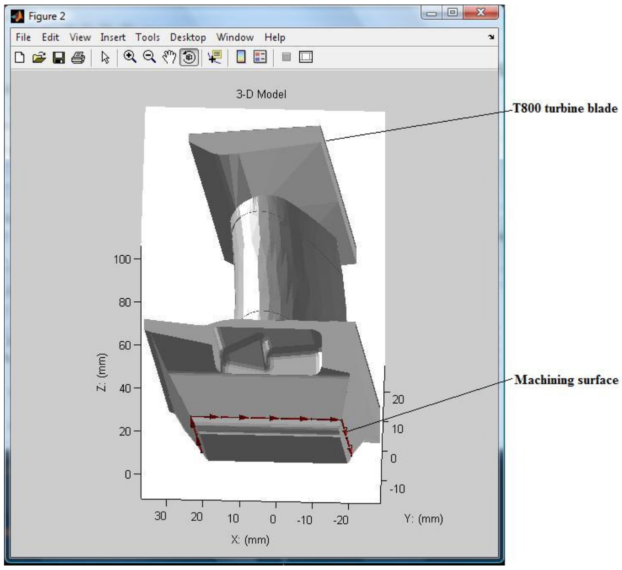

Figure 6. Machining path at the root of the tubine blade

b) Selection of locator positions

After the input files are prepared, they are then inputted into the program. Users can choose whether they want to select locator positions by GA optimisation or manually. To increase the interaction between user and the program, users can choose in what extent they want to choose locator positions by GA optimisation (GA select) or by the user himself (User input). For example, for 3-D model consisting of 6 locator positions, users can choose one locator position manually then use GA to optimise the other automatically; the users can also use GA to optimise all of the six locator positions or use GA to optimise one location position and chose the other five manually.

c) Selection of clamping position

After the locator positions are selected, users can go ahead to choose the strategies for selecting clamping position. There are various strategies available for choosing clamping position: the strategies for single clamping point include minimising clamping force, minimising sum of reaction force, minimising highest reaction force, and minimising the SD of reaction force; while the strategies for double clamping points include minimising sum of clamping force, minimising highest clamping force, minimising SD of clamping force, minimising sum of reaction force, minimising highest reaction force, and minimising the SD of reaction force.

d) Executing the search

After the strategies used to calculate the locator and clamping positions are chosen, users can execute the search. Users can choose between single run and multi-run when executing the search. For multi-run, users can specific the number of runs they wish to perform.

e) Presentation of results

For both single and multi-run, results will be presented in the form of table and diagram. However, the way in which results from single and multi-run are displayed differ slightly. In the table, the determinant value of locator matrix (fitness value), X, Y and Z coordinates of locator and clamping positions, clamping force, and locator reaction force are displayed.

IV. RESULT

Result for case study 1: Since the component is a regular shape, there are more than one set of locator configurations that can fulfill all constrains. 100 different configurations have been reviewed; hence there is no repeat of the same configuration. However some of the locator positions are more popular than the others, the similar trend is also true for the clamping positions. 107 different locators were selected by the GA and 7 different best clamping positions. The summary of the results is shown in Table III and only the top 10 most repetitive locators are shown in this table. The configuration with the highest determinate are showed in Fig. 7.

TABLE III. SUMMARY OF THE RESULT FOR CASE STUDY 1

Locator	x	y	z	Frequency
P1	15.025	10	57.7106	29
P2	15.0218	10	12.2894	24
P3	34.9749	10	57.7106	22
P4	23.5	12.5981	10	21
P5	10	47.0569	56.117	20
P6	10	12.5471	14.4118	18
P7	10	47.4465	14.4007	18
P8	32.5028	10	12.5965	16
P9	10	14.6154	57.3353	16
P10	10	44.8711	57.6515	16
Clamping	**x**	**y**	**z**	**Frequency**
C1	37.7778	47.7778	44.4444	31
C2	31.1111	47.7778	51.1111	28
C3	35.5556	45.5556	48.8889	19
C4	37.7778	41.1111	51.1111	15
C5	37.7778	45.5556	46.6667	3
C6	33.3333	47.7778	48.8889	2
C7	35.5556	43.3333	51.1111	2

Result for case study 2: The computational time required to conduct 100 multi-run is estimated to be 3 hours, which less than 2 minutes per run. On average there is no significant improvement on the quality of results after 180 generations. As expected the consistency of freeform workpiece is not as good as regular workpiece that is test case 1. After the initial 100 trials were conducted. However, 40% of the solutions do not have feasible clamping position. This might be explained by the fact that fixturing layout optimisation is a multi-objective problem; therefore merely optimising the locator layout based on locator accuracy would result in unsatisfactory outcome in finding a feasible clamping position. This problem has already been reported in the literature that for the optimal or suboptimal locators, few or no clamping locations exist for form-closure. This can be a common problem of optimum fixture design schemes that focus on the locators alone [10]. One possible way to overcome this problem is to use GA to search for 7 locator points simultaneously, then choose one of the locator points obtained and convert it into clamping point. By doing so, a clamping point can be guaranteed.

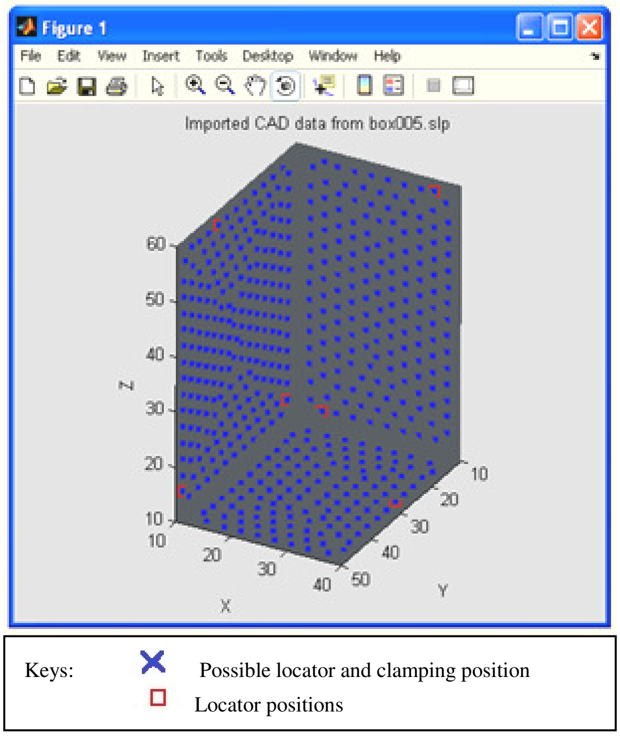

Figure 7. The best locator configuration for case study 1

Even by using finer mesh seed to search for clamper position, the chance of finding feasible clamping region does not significantly increase. However, by using smaller mesh size, it is possible to deduce more accurate solution. As before, some of the locator positions are more popular then other and similar situation is observed in clamping positions. 76 different locator positions and 8 different best clamping positions are selected by the GA. Only the top 20 most repetitive locators are shown in the Table IV and the best locator layout is showed in Fig. 7. Results from this research suggest the fitness function applied is capable to yield feasible solution for freeform components. At present, this research only solves the locator configuration for 3-D freeform component with single clamp, the same evaluation methods can be extended to take multi-clamping points into consideration to reduce clamping forces.

TABLE IV. SUMMARY OF RESULT FOR CASE STUDY 2

Locators	x	y	z	Frequency
LP01	8.4527	-4.959	22.7273	62
LP02	-10.65	-7.3332	57.9822	41
LP03	3.1731	-2.7451	27.5417	37
LP04	5.3768	2.8485	59.0531	36
LP05	-10.898	-2.6915	31.0878	31

LP06	9.5804	9.0546	25.9556	30
LP07	5.4077	2.7579	57.2564	24
LP08	-10.5448	-7.3822	56.6377	22
LP09	9.0366	9.7271	25.9137	21
LP10	3.4346	3.3636	59.9143	21
LP11	6.8634	8.4256	61.3213	21
LP12	6.9671	6.6747	61.2688	20
LP13	-10.3719	-7.3286	53.8297	19
LP14	-10.4308	-1.4474	30.6741	15
LP15	6.3532	7.6083	60.6257	15
LP16	-10.4891	-6.9132	52.37	11
LP17	5.6447	3.6336	61.1873	11
LP18	-10.6947	-1.9189	32.2467	10
LP19	-9.625	-1.1783	30.5722	9
LP20	5.7986	3.263	53.4737	9
Clampers	**x**	**y**	**z**	**Frequency**
CP01	3.2829	-2.5606	29.5676	37
CP02	2.5381	-3.1147	46.678	37
CP03	-3.6659	-2.1074	47.939	7
CP04	2.6637	-3.0126	43.7647	6
CP05	-4.2919	-2.2512	46.7049	6
CP06	2.7808	-2.9259	41.0415	5
CP07	-0.522	-0.641	54.1939	1
CP08	-2.7362	-1.6291	46.5974	1

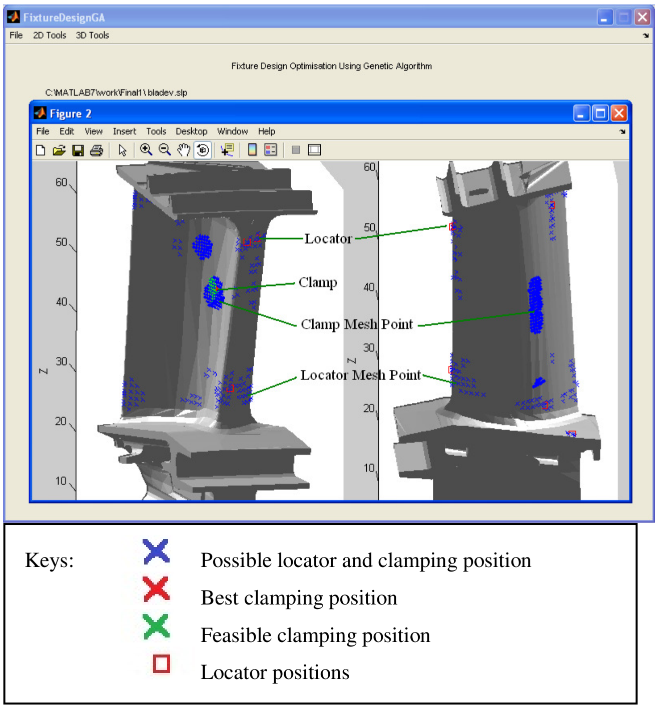

Figure 8. The best locator configuration for case study 2

V. SUMMARY

Fixture layout design development in industry today is still highly dependant on human expertise. Fixture designers have not yet fully utilised the available modelling and simulation tools to predict fixture behaviour. These result in discrepancy between the expected and final behaviour of fixture after fabrication and consequently, high lead time and cost due to the iteration in the whole design process. These issues are particularly apparent in complex 3-D freeform components. This research proposed the use of GA to optimise fixture layout for complex freeform component, which provides the basic framework to support a systematic methodology for reducing the iteration of fixturing design, thus increasing the efficiency of the fixture development process. The research fulfill the objectives:

- To develop an interactive application using genetic algorithm as a tool to support fixture layout design for 3-dimensional complex freeform components.
- Using realistic representative component with complex geometry as case study, to validate that the developed application is adequate to justify its uses in fixture layout design.

Findings of this research would benefit the industries and the automated fixture design communities. It serves as a useful technique for researchers to providing them with indispensable tools for rapid fixturing layout development. Furthermore, it allows novice designers to use the fixture layout design application to formulate an optimised fixture layout and the performance of the new fixturing layout designs can be easily and quickly evaluated.

REFERENCES

[1] R. Wagner, G. Castanotto and K. Goldberg, "FixtureNet: Interactive computer-aided design via World Wide Web," Int J. Human-Computer, vol. 46, pp. 773-788, 1997

[2] K. Y. Yeung and X. Chen, "Web-based Approach for Fixture Design", Proceeding of the 12th Chinese Automation & Computing Society Conference in the UK, pp. 171-175, 2006.

[3] N. Kaya, "Machining fixture locating and clamping position optimization using genetic algorithms", Computer in industry, vol 57, pp. 112-120, 2006

[4] K. Krishnakumar and S. N. Melkot, "Machining fixture layout optimization using the genetic algorithm", International Journal of Machine Tools and Manufacture, vol 40, pp. 579-598, 2000.

[5] G. Renner and A. Ekart, "Genetic algorithms in computer aided design", Computer-Aided Design, vol 35, pp. 709-726, 2003.

[6] X. G. Ming and K. L. Mak, "Intelligent approaches to tolerance allocation and manufacturing operations selection in process planning", Journal of Materials Processing Technology, vol 117, pp. 75-83, 2001.

[7] A. Senthil-kumar, V. Subramaniam and K. C. Seow, "Conceptual Design of Fixture using Genetic Algorithm", vol 15, pp. 79-84, 1999.

[8] D. E. Goldberg, "Genetic Algorithms in Search, Optimisation and machine learning", Addison-Wesley Publishing Company Inc, Reading, Massachusetts. 1989.

[9] Y. Wang, "A Methodology of Fixture Evaluation, Analysis and Optimisation", Ph.D. Thesis, University of Nottingham, 2000.

[10] M. Y. Wang, "An Optimum Design for 3-D Fixture Synthesis in a Point Set Domain," IEEE Transactions on Robotics and Automation, vol 16- 6, pp. 839-846, 2000