

Study of Computer-Aided Design Process and Methods Based on Welding Fixture

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Abstract—Although various computer-aided fixture design (CAFD) systems have been developed to assist the designer during the various stages of fixture design, most of previous computer aided fixture design research has mainly concentrated on machining fixtures rather than welding fixtures. The development of complicated computer aided welding fixture design (CAWFD) system has received much less attention. Welding fixture can ensure welding dimension, improve assembly precision and efficiency. It can prevent the welding deformation. The function of welding fixture was introduced in this paper. The computer-aided welding fixture design workflow was developed. The design steps include the project creation, setup design, Orientation and position determination, fixture plan design, fixture configuration design, fixture design verification and fixture design output. The classification of welding fixture component has been demonstrated. Information tree and the database tables to save the unit information are designed. The unit information retrieval menu and interface based on UG, Visual C++ and database is realized.

Index Terms—Welding fixture, Computer-aided design, Database, UG, Visual C++

I. INTRODUCTION

A fixture is a device used in machining, inspection, assembly, welding, and other manufacturing operations to locate and hold a work piece firmly in position so that the required manufacturing processes can be carried out corresponding to design specifications. As a special kind of fixtures, welding fixtures are used widely in many manufacturing fields. In welding industry, a welding fixture is a fixture used to ensure welding dimension, improve assembly precision and efficiency and to prevent the welding deformation. Hundreds of kinds welding fixtures have been designed and built to meet with various requirements during welding for different geometric work-pieces. According to statistics, about 73% of variation problems from preproduction to the production phase were caused by fixture related problems [1]. To improve the situation, it is of great importance to develop a fixture scheme with less sensitivity to control variables and noise effects. Therefore, in-depth research on quality design of fixture planning for flexible sheet metal assembly is highly desired [2].

Welding fixture design should meet the following requirements:

1) Welding fixture should meet the requirements of precision of processes. Although welding processes do not need the high accuracy, welding accuracy cannot be ignored.

2) Welding fixture should achieve the requirement of processing productivity. Especially for mass production of fixture, it should be used to shorten the basic and auxiliary processing time.

3) The generalization and standardization of the fixture element should be improved appropriately. To choose standard components, especially the commercialization of standard components, will shorten the fixtures manufacturing period, lower the cost of fixture. All these requirements build up the complexity of designing a suitable fixture.

As a part of manufacturing tooling, fixture design and related activities make significant contributions to the production time and cost in daily production. To help fixture designer and fixture manufacturer, a computer aided design system become importantly necessary immediately. Manufacturers need an assistant to design or choose fixtures as soon as possible. Collection and representation of the knowledge from the designer's experience is crucial part in the development of computer-aided welding fixture design (CAWFD) systems. Computer aided welding fixture design (CAWFD) is a subsystem combining CAD and CAM. Software engineering and database technology assist designers to do welding fixture design and improve design efficiency [3-6].

II. PROCESS OF COMPUTER AIDED WELDING FIXTURE DESIGN SYSTEM

A. Computer-aided welding fixture design workflow and step

Various computer-aided fixture design (CAFD) systems have been developed through the years to assist the designer during the various stages of fixture design. A welding fixture is a fixture [7-10]. There are several main stages within the computer-aided welding fixture design workflow, such as that presented in Fig. 1.

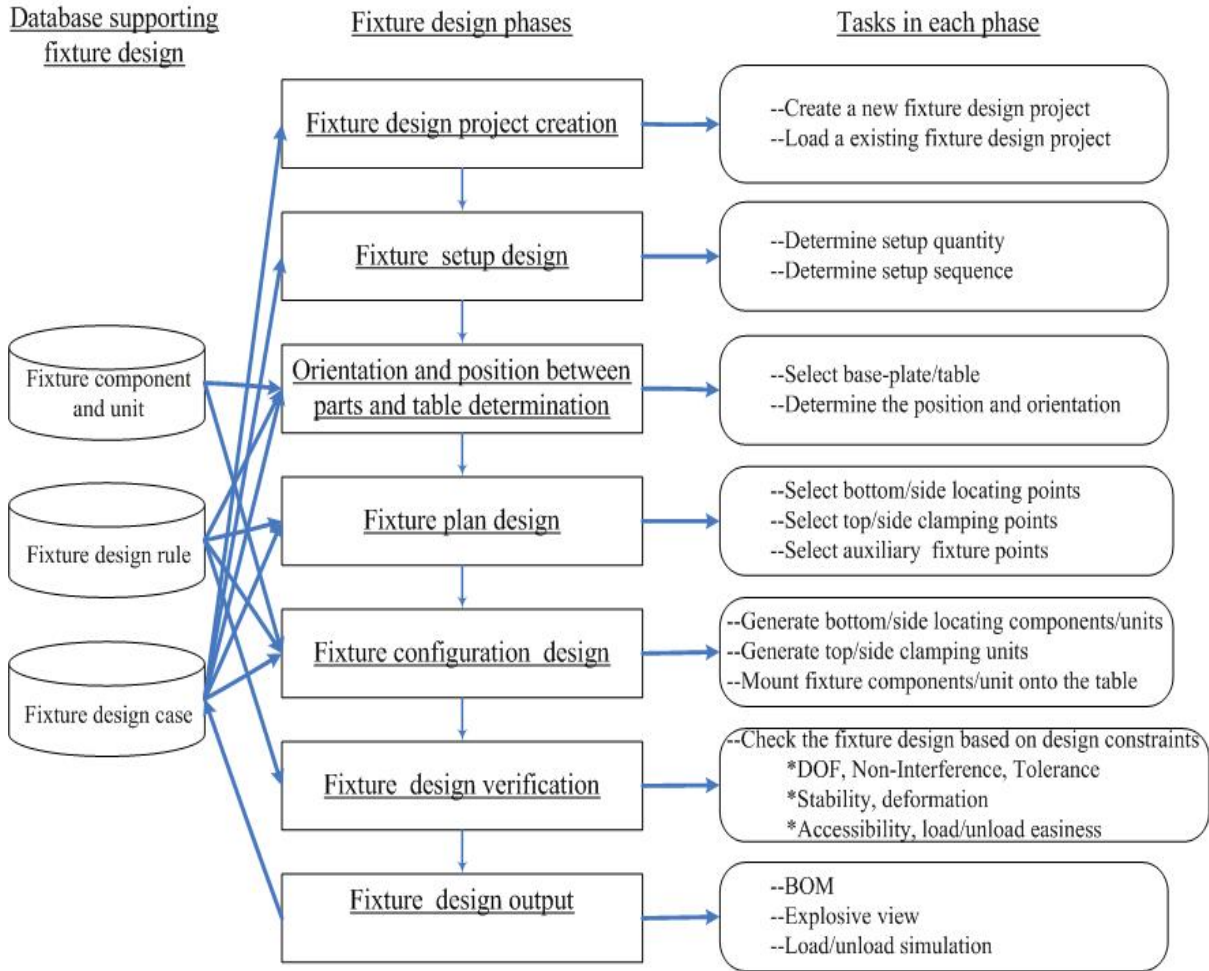


Figure 1 Computer-aided welding fixture design workflow

1) Project creation

A welding fixture design project is created from scratch. A saved fixture design project is reloaded, or searched from fixture design case base. A similar fixture design case is retrieved based on current user requirements including part CAD model and welding operation file. The retrieved fixture design is loaded.

2) Setup design

The setup quantity and sequence are determined in this phase.

3) Orientation and position determination

In this phase, parts to be welded in the setup will be loaded and assembled as a subassembly. Based on the overall dimension of subassembly, suitable welding table will be selected.

4) Fixture plan design

Based on well known 3-2-1 locating principle and other locating principles [3] stored in the design rule database, bottom locating points and side locating points should be selected to constrain six degree of freedom for each part. After locating point selection is done, associated top clamping points and side clamping points should be determined to keep the subassembly to contact

with the locating units and the stability should not be ruined. The rules on how to select the clamping points according to the existing locating points are also saved in the design rule database. For a complicated subassembly, the auxiliary locating points should be selected to keep the stability and avoid deformation.

5) Fixture configuration design

After the fixture points are selected, the coordinate values of each point will be calculated. The candidate fixture units will be retrieved by searching from fixture component or unit database and matching the type and values of fixture function attributes of fixture components or units with the type and coordinate values of the fixture point. The candidate fixture components and units will be listed according to the priority. Fixture designer can select any candidate from the list. The selected candidate fixture component or unit will be mounted on the table and kept contact with parts. The hole alignment between fixture component and unit and table will be realized.

6) Fixture design verification

The verification will be executed according to the following design constraints when the fixture configuration design is finished. All the six degree of

freedom of the part should be limited. When the fixture components or units are loaded, there should not exist interference between fixture components or units and parts, between any one fixture component or unit and another fixture component or unit. The overall dimension of assembly to be welding should be satisfied. The stability of assembly should be kept, which means the assembly can not move and rotate during the welding process. The deformation of assembly should be controlled in an accepted level. The welding points or seams should be assessable to welding gun after the fixture components or units are loaded. The parts, fixture components or units should be moved in or removed out without difficulty.

7)Fixture design Output

Bill of Materials(BOM) , explosive view , and load or unload view should be output. Bill of Materials is the term used to describe the raw materials, sub-assemblies, intermediate assemblies, sub-components, components, parts and the quantities of each needed to manufacture an end item . For CAWFD, the quantities of parts to be welded and different kinds of fixture components used are listed in the BOM. In explosive view, all the parts to be welded, welding tables, fixture components in the whole assembly will be exploded. And the relationship among them will be shown clearly. In load or unload view, the load or unload sequence of parts to be welded, welding table, fixture units will be simulated. The interference during load or unload will be detected.

B. Analysis and classification of welding fixture component

Welding fixture is composed by a group of components. Each component has its unique function. So we put function as our last principle of classification. We use the geometrical shape and number to carry on the preliminary classification. We classified welding fixtures into seven groups [11-12].



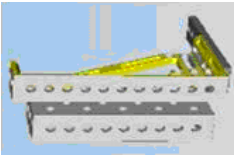
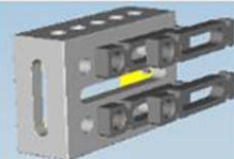
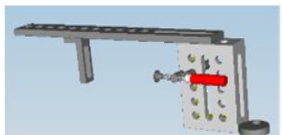
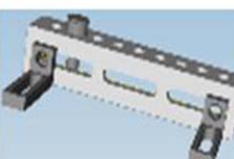

The name of seven classifications of units are: 1) one table leg with one angle frontally; 2) one table leg with one and angles frontally; 3) one table leg with one angle laterally; 4) one side clamping; 5) One and side clamping; 6) point locating; 7) others, which is shown as table 1.

The unit of 1) or 2) is mainly a bottom locator when it is put in vertical direction. Work piece is located on the cantilever of the angle. If work piece is located at the end of the cantilever of the angle, it is a side locator. In a horizontal direction, it is also a side locator when we use the cantilever to locate the side of a work piece. The unit of 2) can set relative position of different parts of the work piece.

The unit of 3) is a bottom locator when work piece is located on the cantilever of the angle or block, or side locator when work piece is located at the end of them. It leaves space to the work piece in front of the table leg. The second unit in 3) is mainly a bottom locator, and its support can locate a side of the work piece. The third unit in 3) is mainly a side locator.

The units in group 4) are much simple for they just clamp one side.

TABLE I.
CLASSIFICATION OF WELDING FIXTURE COMPONENT

group	figure
①	 table leg with 1 angle frontally
②	 table leg with 1+ angles frontally
③	 table leg with 1 angle laterally
④	 side clamping
⑤	 side clamping
⑥	 point locating
⑦	 others

The only one unit of group 5) locates the work piece at one side and clamps the opposite side. Though we have one unit here, more units will be found and classified into this group by the successors.

In the units of group 6), the stop can be put both in the vertical direction as a bottom point locator and in horizontal direction as a side point locator. The supports are in the horizontal direction and vertical direction, respectively.

In group 7), the units have more than one function in the same time. It can locate both bottom surface and side surface.

C. Analysis of interference checking between welding fixture components

Interference checking between fixture components is one of the important performances of welding fixture design. Once the fixture configuration design is generated with computer aided welding fixture design, interference checking should be employed. A rapid interference checking algorithm is studied for detecting possible interference between fixture components. In order to simplify the algorithm of interference checking, the fixture components need to be modeled. After the simplifications, fixture component models are 2-D geometric elements with certain heights.

1) Intersection detection of two line segments.

In general, the intersection of two line segments can be determined by examining the line equations. When a line is defined by two points $[x_1, y_1]$ and $[x_2, y_2]$, as shown in Fig. 2, the coordinates of point on the line can be expressed as[13]

$$x_a = x_1 + T_a(x_2 - x_1) \tag{1}$$

$$y_a = y_1 + T_a(y_2 - y_1) \tag{2}$$

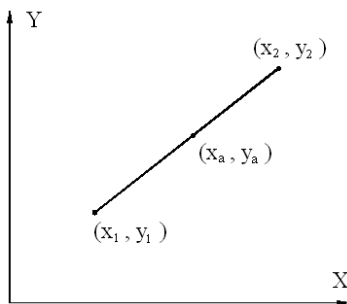


Figure 2 A line segment

where T_a is a coefficient with a value $0 \leq T_a \leq 1$.

When T_a is changed from 0 to 1, the point $[x_a, y_a]$ moves on the line segment from one end to the other. Thus, if $T_a < 0$ or $T_a > 1$, x_a and y_a will extend beyond the segment.

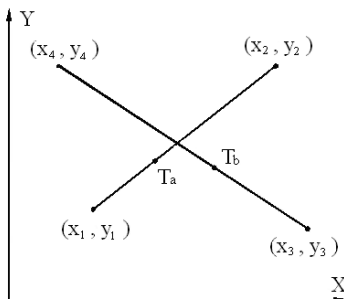


Figure 3 Intersection of two line segments

If the intersection occurs between two lines and the second line is defined by point $[x_3, y_3]$ and $[x_4, y_4]$, as shown in Fig. 3, the intersection point becomes

$$x_a = x_b \text{ and } y_a = y_b \tag{3}$$

then

$$x_1 + T_a(x_2 - x_1) = x_3 + T_b(x_4 - x_3) \tag{4}$$

$$y_1 + T_a(y_2 - y_1) = y_3 + T_b(y_4 - y_3) \tag{5}$$

Finally, the solution of these simultaneous equations is

$$T_a = \frac{-(x_3 - x_1)(y_4 - y_3) + (y_3 - y_1)(x_4 - x_3)}{-(x_2 - x_1)(y_4 - y_3) + (y_2 - y_1)(x_4 - x_3)} \tag{6}$$

$$T_b = \frac{-(x_2 - x_1)(y_3 - y_1) + (y_2 - y_1)(x_3 - x_1)}{-(x_2 - x_1)(y_4 - y_3) + (y_2 - y_1)(x_4 - x_3)} \tag{7}$$

If the denominator of the expression defining T_a and T_b is zero, the lines are parallel. Hence, they do not intersect. If a solution is found when $0 \leq T_a \leq 1$ and $0 \leq T_b \leq 1$, the segments intersect. Once T_a and T_b are obtained under the intersection condition, the intersection position can be figured out by solving x_a and y_a .

2) Intersection detection of a line segment and an arc.

An arbitrary points on an arc with radius R and center (x_c, y_c) can be defined as

$$x_a = x_c + R \cos \theta \tag{8}$$

$$y_a = y_c + R \sin \theta \tag{9}$$

where the angular range of the arc is (θ_1, θ_2) , as shown in Fig. 4. If an intersection of the arc occurs with a line segment, we have

$$x_1 + (x_2 - x_1)T_a = x_c + R \cos \theta \tag{10}$$

$$y_1 + (y_2 - y_1)T_a = y_c + R \sin \theta \tag{11}$$

Rearranging the terms to cancel θ ,

$$\cos \theta = \frac{(x_1 - x_c) + T_a(x_2 - x_1)}{R} \tag{12}$$

$$\sin \theta = \frac{(y_1 - y_c) + T_a(y_2 - y_1)}{R} \tag{13}$$

and $\sin^2 \theta + \cos^2 \theta = 1$. This equation can be rewritten as a quadratic function,

$$A t^2 + B t + C = 0 \tag{14}$$

where the constant A , B , and C are defined as

$$A = (x_2 - x_1)^2 + (y_2 - y_1)^2 \tag{15}$$

$$B = 2(x_1 - x_c)(x_2 - x_1) + 2(y_1 - y_c)(y_2 - y_1) \tag{16}$$

$$C = (x_1 - x_c)^2 + (y_1 - y_c)^2 - R^2 \tag{17}$$

and $\Delta = B^2 - 4AC$. If $\Delta < 0$, there is no intersection between the line and circle. If $\Delta = 0$, the line is tangent to the circle. Then, one solution is obtained from the equation.

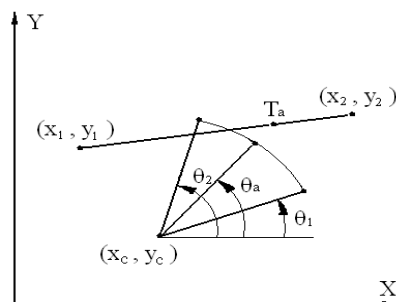


Figure 4 Intersection of line and arc

$$T_a = -\frac{B}{2A} \tag{18}$$

In this case, whether the intersection occurs can be determined in two general steps. First, the intersection point is checked laying on the line segment under the

condition $0 < T_a < 1$, which was discussed above. Otherwise, there is no intersection between the line segment and the arc. If $\theta_1 < \theta_a < \theta_2$, the intersection occurs. Otherwise, no intersection point exists on the line segment and arc.

If $\Delta > 0$, the line and the arc have two valid intersection points for which

$$T_a = -\frac{B \pm \sqrt{\Delta}}{2A} \quad (19)$$

Similarly, each of two points is checked by using the exactly same method discussed when $\Delta = 0$. If $0 \leq T_a \leq 1$, the intersection occurs and the intersection position can be identified.

III. DATABASE CONSTRUCTION OF CAWFD

A. Database composition

CAWFD can be divided as two sub-system: interface and framework sub-systems and DB sub-systems [14], which is shown in Fig. 5.

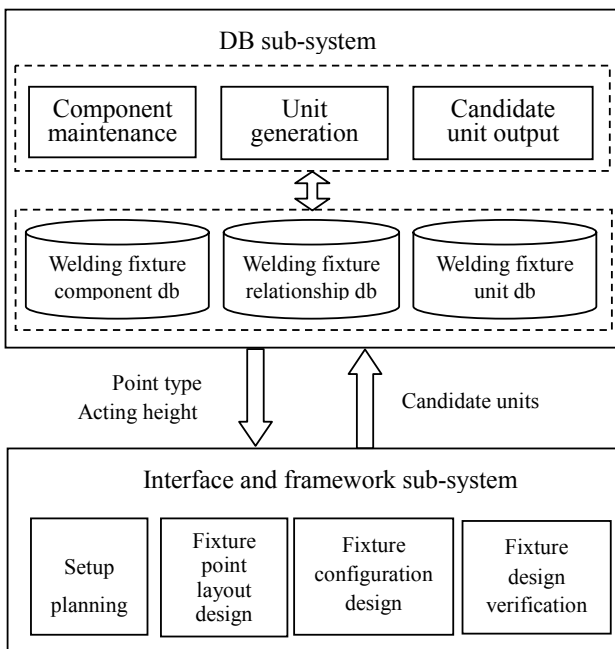


Figure 5 Database construction of CAWFD

Interface and framework sub-system includes four modules:

- 1) Setup planning where how many setups are needed to realize the whole assembly welding is determined;
- 2) Fixture point layout design where fixture points are selected;
- 3) Fixture configuration design where fixture unit are assembled and mounted on the fixture table;
- 4) Fixture design verification where the fixture design is checked.

DB sub-system includes three databases:

- 1) Welding fixture component db,
- 2) Welding fixture relationship db;
- 3) Welding fixture unit db.

The interface and framework sub-system will output fixture point type and acting height to DB subsystem. DB subsystem will generate candidate units by searching

component information and relationship among components from component db and relationship db according to point type and acting height requirement satisfaction. Also db sub-system will output these candidate units to the interface and framework sub-system which will be mounted on the welding table.

B. Information tree

Fixture units in database can be divided as two classifications and be represented as corresponding information tree, one is unit with single function and another is unit with multiply function [15].

Unit with one single function (Fig. 6) can be classified as four sub-classifications: bottom locating unit, side locating unit, side clamping unit and top clamping unit. Vertical and horizontal acting height range and vertical/horizontal discrete vale are described in the information tree. Other information such as unit id, unit name, 3D model file path and image file path are also described in the tree.

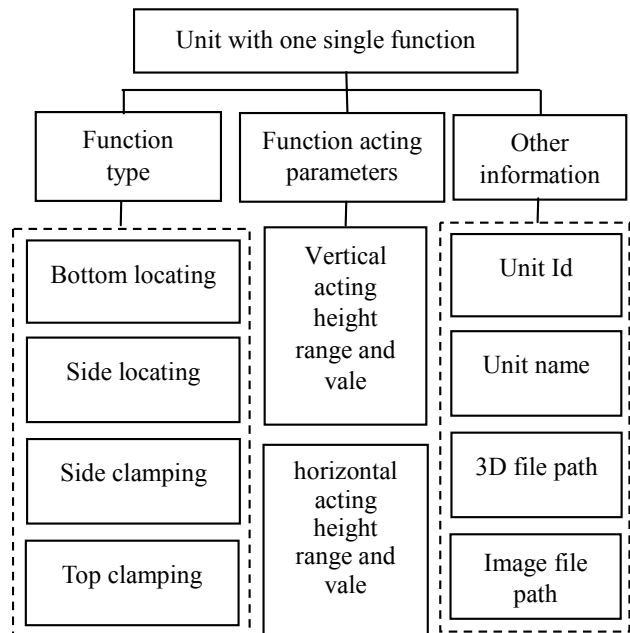


Figure 6 Information tree for unit with single function

Unit with multiply function (Fig. 7) can be classified as following sub-classifications: bottom locating & bottom locating unit, bottom locating & side locating unit, side locating & side locating unit, bottom locating & side clamping unit, bottom locating & top clamping unit, side locating & top clamping unit and side locating & side clamping unit. Vertical/horizontal acting height range and vertical/horizontal discrete vale are described in the information tree. Other information such as unit id, unit name, 3D model file path and image file path are also described in the tree.

C. Database table design

Based on the information tree, the database tables for database units can be designed as follows Fig. 8 [16-18].

The DDL (Data Definition Language) for these tables are described as below.

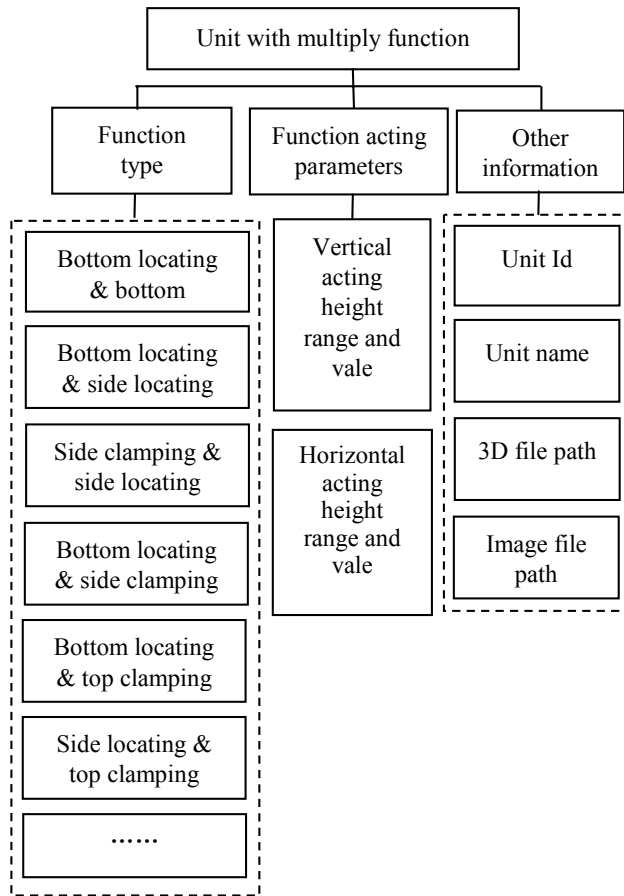


Figure 7 Information tree for unit with multiply function

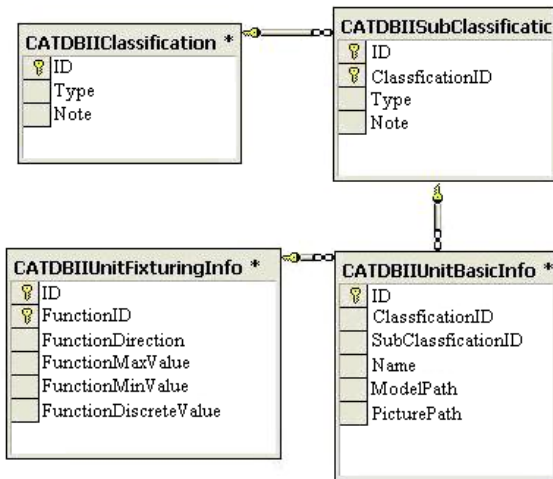


Figure 8 Database tables

```
CREATE TABLE CATDBIIClassification(
ID CHAR (10),
Type VARCHAR (50),
Note VARCHAR(100),
PRIMARY KEY (ID),
);
CREATE TABLE CATDBIISubClassification(
ID CHAR (10),
ClassificaitonID CHAR (10),
Type VARCHAR (50),
```

```
Note VARCHAR(100),
PRIMARY KEY (ID),
FOREIGN KEY (ClassificaitonID) REFERENCES
CATDBIIClassification (ID),
);
CREATE TABLE CATDBIIUnitBasicInfo(
ID CHAR (10),
ClassificaitonID CHAR (10),
SubClassificaitonID CHAR (10),
Name VARCHAR (50),
ModelPath VARCHAR (50),
PicturePath VARCHAR (50),
PRIMARY KEY (ID),
FOREIGN KEY (ClassificaitonID) REFERENCES
CATDBIIClassification (ID),
FOREIGN KEY (SubClassificaitonID) REFERENCES
CATDBIISubClassification (ID),
);
CREATE TABLE CATDBIIUnitBasicInfo(
ID CHAR (10),
FunctionID CHAR (10),
FunctionDirection Integer,
FunctionMaxValue Integer,
FunctionMinValue Integer,
FunctionDiscreteValue Integer,
PRIMARY KEY (ID, FunctionID ),
FOREIGN KEY (ID) REFERENCES
CATDBIIUnitBasicInfo (ID),
);
```

IV. MENU AND INTERFACE DEVELOPMENT

A. Construction of integration environment based on UG, Visual C++ and database

1) Integration between UG and Visual C++

The menu and interface are developed based on and seamlessly integrated with UG 5.0, via UG/OPEN/API, using Visual C++ language

2) Integration between Visual C++ and database

ODBC (Open Database Connectivity), a standard interface for connecting from visual C++ to relational databases, it allows individual providers to implement and extend the standard with their own ODBC drivers. Here are procedures in Visual C++ coding for connecting to a database.

- Include Header Files
- Open a Connection to a Database
- Choose an ODBC Driver
- Query the Database
- Creating an ODBC Statement Object
- Executing a Query and Returning an ODBCResultSet Object
 - Extracting Data from an ODBCResultSet
 - Closing the ODBCResultSet and ODBCStatement
- Importance of closing the connection

B. Realization of menu and interface

A unit tree management menu (Figure 9) is embedded in UG CAD software platform, when designer selects the

menu, the interface (Fig. 10) for unit is popped up [19-23].

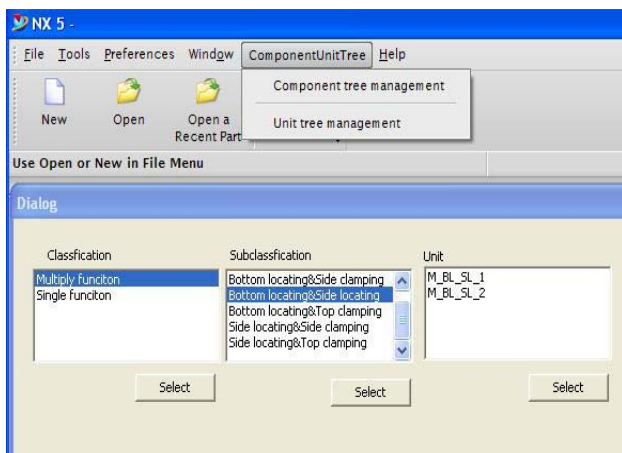


Figure 9 A unit tree management menu

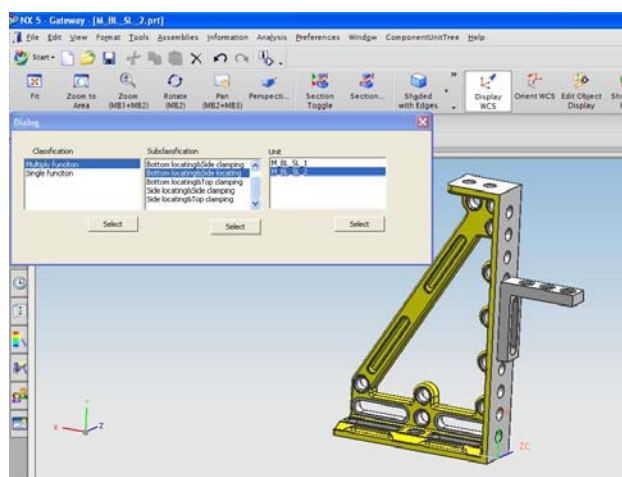


Figure 10 A unit tree management interface

The two options single function and multiply function was listed in the ‘classification’ box. Designer can select either one and click ‘Select’ button. The sub-classifications for this classification will appear in the ‘Sub-classification’ box. And designer can also select any of sub-classifications and click ‘Select’ button. Then the units belonging to this sub-classification will be shown in the ‘unit’ box. Designer can select one unit from the unit box. The selected unit will be loaded in the UG and designer can review the unit by rotating and zooming the unit.

C. Application of CAWFD system

In order to meet the demand of rapid reconfiguration of the welding fixture for different work-pieces, appropriate amount of components are designed. The CAWFD system was applied to design a welding fixture. Fig. 11 is an example of the welding fixture [24].

V. CONCLUSION

Welding fixtures have a direct impact upon welding quality, productivity and cost. Currently, most of reported research has been mainly focused on machining fixture,

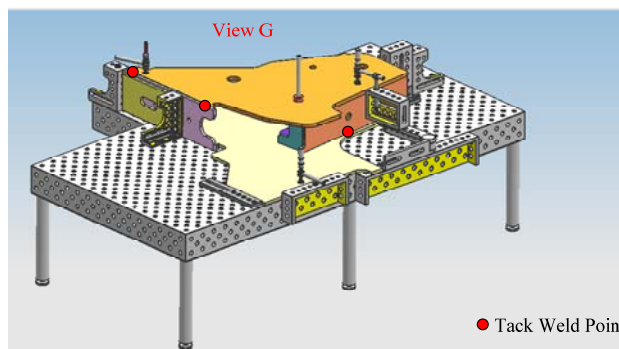


Figure 11 An example of the welding fixture.

and the applications of computer aided fixture design (CAFD) technology are still very limited in the welding sector. One key reason is the lack of an effective method that can utilize massive welding-related production data, existing fixture solutions and fixture design experience that is available in a lot of manufacturing companies. Firstly, this paper gives the functions of welding fixture. Secondly, computer-aided welding fixture design workflow and steps are described. And analysis and classification of welding fixture component are completed. Then, the database construction of CAWFD system is provided. Fixture units in database are divided as two classifications and are represented as corresponding information tree. And the database tables to save the unit information are designed. Finally, the unit information retrieval menu and interface based on UG Open/API, Visual C++ and database are realized.

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