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# An algorithm for automatic generation of assembly process of modular fixture parts

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***Abstract***: In metal mold production systems, rapid, high-quality, and low-cost production technologies are needed. In the systems, assembly tasks of fixtures to immobilize the mold are required. The mold must be firmly fixed by fixtures, in order to resist force generated by NC machine tools. In this paper, we discuss automatic generation of assembly process for modular fixture parts in the systems. The assembly drawing of the parts is obtained from STEP/AP203, which is a text file of CAD/CAF data. In the data, the shape and the configuration of all assembled fixtures are included. The shape of each fixture is constructed with planar, cylindrical, and conical surfaces. From the data, the number of surfaces contacting with the others is derived in each part. And valid contacts are judged with degree of importance. Tree of contacts among all fixtures are derived. In numerical examples, assembly process is automatically generated by our proposed method. It is shown that suitable assembly process is provided.

***Keywords***: Assembly process planning, modular fixture parts, CAD/CAF, STEP/AP203, assembly drawing.

## I. INTRODUCTION

In metal mold production systems, rapid, high-quality, and low-cost production technologies are needed. For this reason, integrated production systems have already been constructed, which include CAD, CAF (Computer Aided Fixturing), CAM, and NC machine tools, as shown in Fig. 1.

In the production systems, assembly tasks of fixtures to immobilize the mold are required. As shown in Fig. 2, the mold must be firmly fixed by fixtures, in order to resist force generated by NC machine tools. Characteristics of the metal mold productions are a diverse-types-and-small-quantity production, a variety of shape of fixtures, complex contact types among fixtures, and so on. From these reasons, recognition, adaptability, and dexterity of humans are required for the assembly tasks. Hence, at present, the assembly tasks are carried out by human beings with handwork, while they are checking the assembly drawing. In the tasks, however, human beings sometimes make mistakes such as inadmissible position and different assembly process of fixtures. As a result of them, we have serious problems leading to destruction of the metal mold and the machine tools. To overcome the problems, automatic assembly tasks must be realized without humans.

In Refs. [1]-[4], the authors explored elemental technologies for the assembly tasks. Refs. [1] and [2] analyzed grasp stability for the parts handling. Refs. [3] and [4] identified contact conditions between a grasped part and an external environment (the other parts). In this paper, we discuss automatic generation of assembly process planning for modular fixture parts.

In Refs. [5]-[8], fixture planning is treated. Babu et al [5] and Wu et al. [6] explored automatic fixture layout planning. Ames et al. [7] and Yi et al. [8] provided assembly planning for a given modular fixture

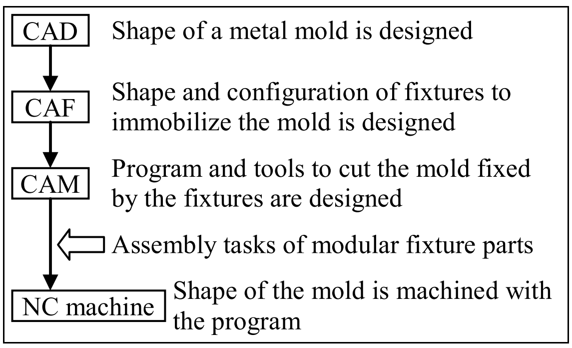



Fig. 1. Production process of a metal mold.

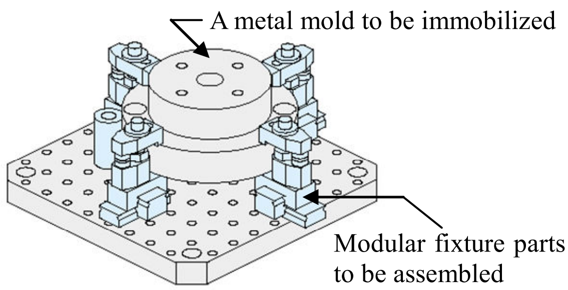



Fig. 2. Assembly drawing of a metal mold and modular fixture parts.

configuration. It is difficult to say to be used practicably. The similar problem of Refs. [7] and [8] is treated in this paper, to carry out the assembly tasks by robots with the technologies of Refs. [1]-[4].

In this paper, the assembly drawing is obtained from STEP/AP203, which is a text file of CAD/CAF data. In the data, the shape and the configuration of all assembled fixtures are included. The shape of each fixture is constructed with planar, cylindrical, and conical surfaces. From the data, the number of surfaces contacting with the others is derived in each part. Then, tree of contacts among all fixtures are derived. To eliminate redundant contacts and closed loop contacts in the tree, valid contacts are judged with degree of importance. In numerical examples, assembly process is automatically generated by our proposed method. It is shown that suitable assembly process is provided.

## II. DATA EXTRACTION

### 1. STEP/AP203

A variety of CAD software is marketed for the mechanical design. The STEP form is an intermediate file of the text form used to exchange data among a variety of CAD systems. In the assembly drawing as shown in Figure 2, the shape and the configuration of the modular fixture parts are recorded.

Each part is constructed with a variety of geometry. In this paper, we discuss simple geometries such as planar, cylindrical, conical geometries. Local shape of the parts is extracted by the following methods.

### 2. Elements of planar geometry

The information of planar geometry is obtained from the commands such as Table 1. The detail of the geometry is extracted by searching the command number "#NUMBER". We obtain an outer unit normal vector $\boldsymbol{n}$, vertex points $\boldsymbol{v}_i$ ($i$=1,2,...,$n$), and edge vectors $\boldsymbol{e}_i$ ($i$=1,2,...,$n$).

### 3. Elements of cylindrical geometry

The information of cylindrical geometry is obtained from the commands such as Table 2. We obtain center points $\boldsymbol{c}_i$ ($i$=1,2) of both ends and radius $r$. The unit vector of the centerline is calculated by

$$\boldsymbol{l} = (\boldsymbol{c}_1 - \boldsymbol{c}_2)/\|\boldsymbol{c}_1 - \boldsymbol{c}_2\| . \quad (1)$$

### 4. Elements of conical geometry

The information of conical geometry is obtained from the commands such as Table 3. We obtain center point $\boldsymbol{c}_i$ ($i$=1,2) and radius $r_i$ ($i$=1,2) of both ends. The unit vector of the centerline is given by Eq. (1). The slope rate is calculated by

$$s = (r_1 - r_2)/\|\boldsymbol{c}_1 - \boldsymbol{c}_2\| . \quad (2)$$

## III. JUDGMENT OF CONTACTS AMONG THE PARTS

By using the elements extracted in Section II, it is judged whether each part is in contact with the other parts. And the number of contact surfaces of the part is derived. Then, a tree of contacts among all parts is produced.

### 1. Judgment of planar contact

Firstly, we choose one of the planar surfaces. It is denoted by $A$. The other planar surfaces are denoted by $Bj$, ($j$=1,2,...,$m$). In the following steps, we judge whether plane $A$ is in contact with the others.

**Step 1**: (Direction) The unit normal vectors of planes $A$ and $Bj$ are evaluated. Plane $A$ is parallel to plane $Bj$, if we have

$$\boldsymbol{n}_A^T \boldsymbol{n}_{Bj} = -1 . \quad (3)$$

**Step 2**: (Distance) The vertex points within planes $A$ and $Bj$ are evaluated. The two planes have zero distance from each other, if we have

$$\boldsymbol{n}_A^T (\boldsymbol{v}_{Bj} - \boldsymbol{v}_A) = 0 . \quad (4)$$

**Step 3**: (Common area) The two planes are in contact with each other, if plane $A$ has common area with plane $Bj$.

### 2. Judgment of cylindrical contact

In a similar way of III.1, we choose cylindrical surfaces $A$ and $Bj$, ($j$=1,2,...,$m$).

**Step 1**: (Radius) The radius of cylinders $A$ and $Bj$ are evaluated. We check

$$r_A = r_{Bj} . \quad (5)$$

**Step 2**: (Direction) The directions of cylinders $A$ and

Table 1. Commands of planar geometry

```
#2094=ADVANCED_FACE('NONE',(#13593,#13594),...
#13593=FACE_BOUND('NONE',#1792,.T.);
#13594=FACE_OUTER_BOUND('NONE',#25,.T.);
#13595=PLANE('NONE',#13596);
```

Table 2. Commands of cylindrical geometry

```
#7218=ADVANCED_FACE('NONE',(#17267),#17268,...
#17267=FACE_OUTER_BOUND('NONE',#6914,.T.);
#6914=EDGE_LOOP('NONE',(#6274,#5646,#4277,....
#17268=CYLINDRICAL_SURFACE('NONE',#17269,.....
```

Table 3. Commands of conical geometry

```
#1814=ADVANCED_FACE('NONE',(#13427),#13428,...
#13427=FACE_OUTER_BOUND('NONE',#1527,.T.);
#1527=EDGE_LOOP('NONE',(#884,#20855,#19480,...
#13428=CONICAL_SURFACE('NONE',#13429,.........
```

*Bj* are evaluated. The directions of the cylinders are parallel to each other, if we have

$$\left| \boldsymbol{l}_A^T \boldsymbol{l}_{Bj} \right| = 1 . \qquad (6)$$

**Step 3**: (Distance) The centerlines are located on the same line, if we have

$$\boldsymbol{l}_A \times (\boldsymbol{p}_{Bj} - \boldsymbol{p}_A) = 0 . \qquad (7)$$

**Step 4**: (Common region) We check whether the both ends of cylinder *A* has common area with cylinder *Bj*.

**3. Judgment of conical contact**

In a similar way of III.1, we choose conical surfaces *A* and *Bj*, ($j$=1,2,...,$m$).

**Step 1**: (Slope rate) The slope rates of cones *A* and *Bj* are evaluated. We check

$$s_A = s_{Bj} \qquad (8)$$

**Step 2**: (Direction) The directions of conical surfaces *A* and *Bj* are evaluated. The directions are parallel to each other, if we have Eq. (6).

**Step 3**: (Distance) The centerlines are located on the same line, if we have Eq. (7).

**Step 4**: (Common region) We check whether the both ends of conical surface *A* has common area with conical surface *Bj*.

## IV. GENERATION OF ASSEMBLY PROCESS

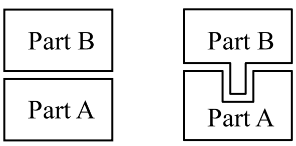
In the contact tree, generally, closed loop contact among more than three parts exits. For simplicity of the analysis, this paper considers the case of the loop with less than four parts.

**1. Screws**

Each screw is assembled at the last order from the contacted parts.

**2. Number of contact surfaces**

In order to enhance the connection of two parts, the next part to be assembled is selected with the evaluation of the largest number of contact surfaces from the remainder of the parts (Fig. 3).




(a) (b)

Fig. 3. Difference of the number of contact surfaces.

**3. Generation of Assembly Process**

We describe the assembly process with the following assumptions.

(A1) Screws and baseplates are listed in other files. The serial number of them is written in the files.

(A2) The serial number of each part is written in the STEP file of assembly drawing.

(A3) CAD data is not for machining (no chamfer).

From the contact information described above, we produce the assembly process by the following conditions:

(C1) A baseplate is picked up at first from the extracted parts.

(C2) The process is generated by the contact tree of the parts.

(C3) The part maximizing the number of contact surfaces is selected, if the previous part is in contact with two parts.

## V. NUMERICAL EXAMPLES

We generate assembly process from the assembly drawing shown in Fig. 4. The drawing is constructed with 41 parts listed in Table 4. These parts are classified into 11 types. The details of the parts are shown in Ref. [9]. These data are obtained from a STEP/AP203 file including more than 20000 command lines. The shape and the configuration of the fixtures are also obtained from the STEP file. Contacts among 41 fixtures are judged. Redundant contacts and closed loop contacts are eliminated in the contact tree. Finally, assembly process is automatically generated.

The generated assembly process is listed in Table 5. "Extracted number" means the extracted order from the STEP/AP203 file. "Extracted contact parts" mean a list of the parts contacting with each part, where the number is described in "Extracted number". "Assembly sequence" means the sequence of the assembly task. Several numbers are eliminated in the sequence, because three parts contact exist in the tree. In the assembly task, each part is selected in ascending order. It is shown that suitable assembly process is provided.

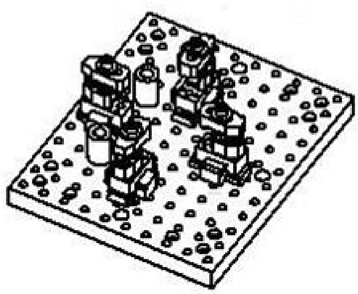


Fig. 4. Example of the assembly drawing.

Table 4. List of modular fixture parts included in Fig. 4

| Name | Serial number | Quantity |
|---|---|---|
| Baseplate | BJ010-5060-16 | 1 |
| Slide unit 1 | FJ20-16063_01 | 4 |
| Slide unit 2 | FJ20-16063_02 | 4 |
| Slide unit 3 | FJ20-16063_03 | 4 |
| Quick nut | FJ42-16001 | 4 |
| System clamp 1 | FJ40-16055S_01 | 4 |
| System clamp 2 | FJ40-16055S_02 | 4 |
| System clamp 3 | FJ40-16055S_03 | 4 |
| Baseplate screw | CSB M16X40 | 8 |
| Locator | BJ400-16075 | 2 |
| Locator screw | BJ701-16055 | 2 |

Table 5. Generated assembly sequence.

| Extracted number | Serial number | Extracted contact parts | Assembly sequence |
|---|---|---|---|
| 1 | FJ40-16055S_03 | 5,9 | 43 |
| 2 | FJ20-16063_01 | 3,4,7,8,10 | 15 |
| 3 | FJ20-16063_02 | 2,4 | 24 |
| 4 | FJ20-16063_03 | 2,3,6,9 | 28 |
| 5 | FJ40-16055S_01 | 1 | 47 |
| 6 | FJ42-16001 | 4,9 | 35 |
| 7 | CSB M16X40 | 2,10 | 16 |
| 8 | CSB M16X40 | 2,10 | 17 |
| 9 | FJ40-16055S_02 | 1,4,6 | 39 |
| 10 | BJ010-5060-16 | 2,7,8,13,17,18 20,21,25,26,30 32,33,39,40,41 | 1 |
| 11 | FJ20-16063_02 | 12,18 | 18 |
| 12 | FJ20-16063_03 | 11,15,18,19 | 25 |
| 13 | CSB M16X40 | 10,18 | 3 |
| 14 | FJ40-16055S_03 | 15,16 | 40 |
| 15 | FJ40-16055S_02 | 12,14,19 | 36 |
| 16 | FJ40-16055S_01 | 14 | 44 |
| 17 | CSB M16X40 | 10,18 | 4 |
| 18 | FJ20-16063_01 | 10,11,12,13,17 | 2 |
| 19 | FJ42-16001 | 12,15 | 30 |
| 20 | BJ400-16075 | 10,21 | 5 |
| 21 | BJ701-16055 | 10,20 | 6 |
| 22 | FJ42-16001 | 28,29 | 31 |
| 23 | FJ40-16055S_01 | 24 | 45 |
| 24 | FJ40-16055S_03 | 23,28 | 41 |
| 25 | FJ20-16063_01 | 10,26,27,29,30 | 7 |
| 26 | CSB M16X40 | 10,25 | 8 |
| 27 | FJ20-16063_02 | 25,29 | 20 |
| 28 | FJ40-16055S_02 | 22,24,29 | 37 |
| 29 | FJ20-16063_03 | 22,25,27,28 | 26 |
| 30 | CSB M16X40 | 10,25 | 9 |
| 31 | FJ40-16055S_01 | 35 | 46 |
| 32 | FJ20-16063_01 | 10,33,36,37,39 | 10 |
| 33 | CSB M16X40 | 10,32 | 11 |
| 34 | FJ40-16055S_02 | 35,37,38 | 38 |
| 35 | FJ40-16055S_03 | 31,34 | 42 |
| 36 | FJ20-16063_02 | 32,37 | 22 |
| 37 | FJ20-16063_03 | 32,34,36,38 | 27 |
| 38 | FJ42-16001 | 34,37 | 33 |
| 39 | CSB M16X40 | 10,32 | 12 |
| 40 | BJ400-16075 | 10,41 | 13 |
| 41 | BJ701-16055 | 10,40 | 14 |

## VI. CONCLUSION

We have discussed an algorithm for automatic generation of assembly process of modular fixture parts. In this method, the geometry and the location of each part is extracted from STEP/AP203 file. The tree of contacts among all parts is derived. Then assembly process is automatically generated.

In this paper, we have discussed simple geometries such as planar, cylindrical, and conical surfaces. In the future work, we will discuss more complex geometries. And we aim to carry out the automatic assembly of the modular fixture parts by robots.

## VI. ACKNOWLEDGMENT

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