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An Automated CAD System for Progressive Working of Irregular Shaped Metal Products and Lead Frame for Semiconductors

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This paper describes the development of computer-aided design of irregular-shaped sheet metal products and 32LD PLCC lead frames and semiconductors, requiring very precise piercing operations for progressive working. The approach to the CAD system is based on knowledge-based rules. Knowledge for the CAD system is formulated from plasticity theories, experimental results, and the empirical knowledge of field experts. This system has been written in AutoLISP using AutoCAD on a personal computer and the I-DEAS drafting programming language on the I-DEAS master series drafting with an HP 9000/715(64) workstation. Transference of data between AutoCAD and I-DEAS master series drafting is accomplished using DXF and IGES methods. This system is composed of five main modules, which are input and shape treatment, production feasibility check, strip-layout, data-conversion, and die-layout modules. Based on knowledge-based rules, the system is designed by considering several factors, such as V-notches, dimple, pad chamfer, spank, cavity punch, camber, coined area, cross bow, material and thickness of product, complexities of blank geometry and punch profile, and availability of presses. As forming processes and the die design system using 2D geometry recognition are integrated with the technology of process planning, die design, and CAE analysis, the standardisation of die parts for lead frames requiring a high precision piercing process is possible. The die-layout drawing generated by the die-layout module is displayed in graphic form. Results obtained for each module provide help to the designer and the manufacturer of lead frames for semiconductors.

Keywords: Bending and piercing; Knowledged-base rules; Lead frame

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1. Introduction

The electronics industry has grown continuously owing to the investment in facilities to produce lead frames efficiently, and has become important. Lead frames, which are important metal products in the IC process and able to communicate as wire bonding with accuracies in micrometres are used in products from general computers to electronic products and toys and supports for semiconductor chips. In order to produce these products, standardisation of die design is necessary because of trends in miniaturisation, weight reduction, and time requirements in modern industry. Shear forming, by which parts with a desired shape are manufactured from sheet metal using a punch and a die, requires this kind of standardisation for the compatibility and accuracy of components. However, generally, only experience and intuitional decisions have been used for production feasibility checks, strip-layout, and die-layout for forming by blanking or piercing. In order to solve this problem, the automation of computer-aided process planning for the designed product by formularising the experience of skilled engineers has been undertaken [1–3]. In 1971, Shaffer developed progressive die design using a computer (PDDC) system [4] and Fogg and Jaimson followed him by developing an improved PDDC [5] by considering other factors which have an effect on die design. A weak point of this system is that it is semi-automated and the processing time is too long. Shibata and Kunimoto developed a CAD/CAM system [6] for which the aim is the screen-output of the blank-layout and the die-layout. Nakahara and the others introduced a system for a progressive die design [7]. Choi et al. developed a compact and practical CAD system for the blanking or piercing of irregular-shaped sheet metal products and stator and rotor parts [8,9].

In this study, a die layout module outputs the parts and the assembly of a die using the I-DEAS master series drafting software for a 32LD PLCC lead frame strip layout, and generates the drawing automatically using AutoCAD.

Automated strip-layout and die-layout of irregular shaped sheet metal products and lead frames should result in quantifi-

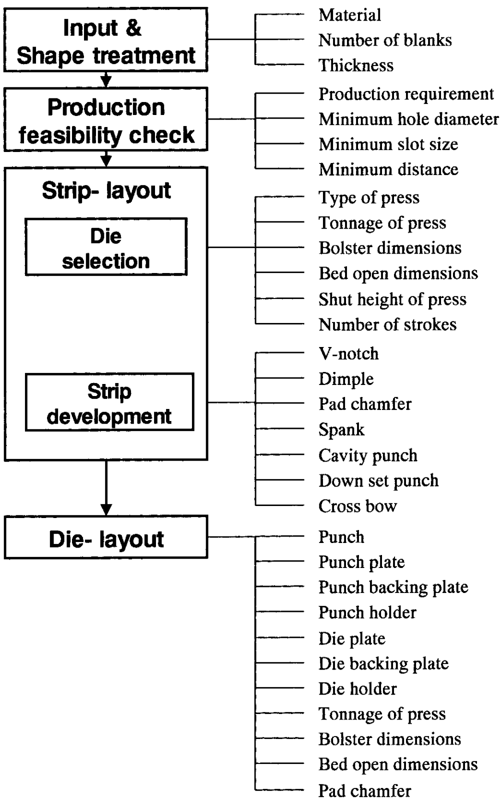

Fig. 1. Modular structure of the system.

able cost and time saving by improved standardisation, and can provide a permanent and confidential source of expertise. Furthermore, such a system can serve as a valuable consultant for experts and as a dependable training aid for beginners.

2. Structure of CAD system

The CAD system is composed of input and shape treatment, production feasibility check, strip-layout, data-conversion, and die-layout modules. It is accomplished in one operation and has the merit of being processed without interruption as each module holds the rule and database in common. It is easy to use, as dialogues are user-friendly with appropriate prompting statements for the various data required.

If a drawing of a lead frame product requiring very precise piercing operations is loaded in the developed system, the input module of the system automatically recognises the drawing of the product and prompts for input data for the product. Results produced in the shape treatment module are transferred to the production feasibility check module which checks the distances between the internal shapes, corner and fillet radii and the minimmum holes required for piercing. Data that is feasible in the production feasibility area are transferred to the strip-layout module for automatically carrying out strip-layout. Results from the strip-layout module are transferred to the die-layout module to generate parts and the assembly of the die set. The modular structure of the system can be seen in Fig. 1. The functional description of modules of the system is presented in detail as follows.

2.1 Input and Shape Treatment Module

The user inputs material type, thickness, width, heat treatment condition, and the shape of the product into an AutoCAD drawing by hand or as an output drawing file on the screen, and the shape treatment module automatically reads information about the mechanical properties of the material from the database and converts the shape data into numerical data and stores it. Numerical data, and internal and external shapes are used in each module of the system.

2.2 Production Feasibility Check Module

The production feasibility check module is the module that checks the production feasibility of the product with the blank information and shows geometric regions which are difficult or impossible to form by piercing. When checking the production feasibility for blanking or piercing of a blank, this module compares holes to be pierced, and corner and fillet radii with criteria stored in the database. Therefore, this module shows feasible geometric regions.

2.3 Strip-Layout Module

The strip-layout module, automatically derives punch profiles for the external area of the product and carries out piercing. Also, this module decides the order of the processes for progressive working based on factors influencing the strip-layout of the lead frame, or semiconductor. The factors are as follows:

1. V-notch: prevention of bubbles and moisture.
2. Dimple: diffusion of heat through a flaw inside a die attached pad.
3. Pad chamfer: elimination of burr for a die pad.
4. Spank: compensation of internal and external lead after piercing.
5. Cavity punch: prevention of twist of lead.
6. Camber: curvature of the lead frame strip edge.
7. Cross bow: transverse bowing of lead frame.
8. Down set depth: intentional depression of the die attached pad.

2.4 Data-Conversion Module

The data-conversion module converts the shape data obtained in the strip-layout module using AutoCAD into recognisable shape data in the die-layout module using the I-DEAS master series drafting with a workstation, HP 9000/715(64). It converts the shape data of the strip-layout into numerical data for use in the die-layout module. The procedures to be converted are as follows:

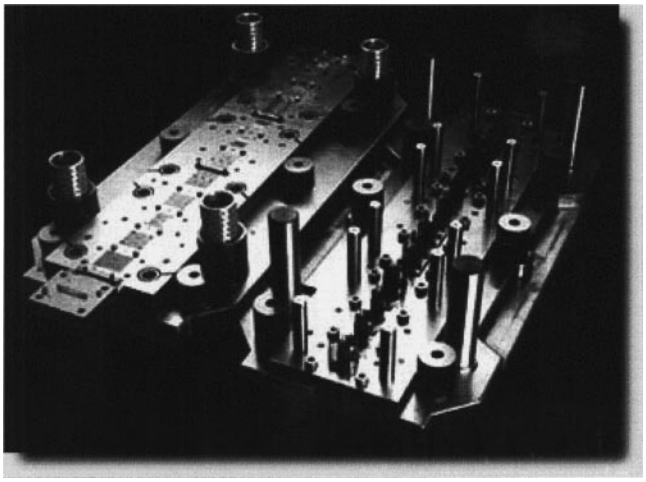

Fig. 2. Die set of lead frame for semiconductor.

Line representation

(Entity,[ViewNum],[LayerNum],[Color],[Weight],[Ltype],[Intell],{GroupName},[Xs],[Ys],[xf],pYf])

Arc representation

(Entity,[ViewNum],[LayerNum],[Color],[Weight],[Ltype],[Intell],{GroupName},[Xc],[Yc],[Rad],[Sa],[Ia])

Where, "Entity" is entity number, "[ViewNum]" view-number(1–63) of entity number, "[LayerNum]" number of layer, "[Color]" colour of display, "[Weight]" thiickness of line, "[Ltype]" type of line, "[Intell]" "yes" or "no" of intellig-net font, "[GroupName]" name of group, "[Xs]" x-coordinate of starting point, "[Ys]" y-coordinate of starting point, "[Xf]" x-coordinate of endpoint, "[Yf]" y-coordinate of endpoint, "[Xc]" x-coordinate of centre-point, "[Yc]" y-coordinate of centre-point, "[Rad]" radius of circle, "[Sa]" starting angle, and "[Ia]" is incremental angle.

In order to use these data in the die-layout module, the data-conversion module organises closed loops for the entities composed of lines and arcs. The representation, which is a 1D array, is as follows:

(Xs(1),Ys(1),Xf(1),Yf(1),Xc(1),yc(1),Rad(1),Sa(1),Ia(1))
(Xs(n),Ys(n),Xf(n),Yf(n),Xc(n),yc(n),Rad(n),Sa(n),Ia(n))

Where, "(n)" is the number of entities, the initial value is zero in the case of a line. The concept of a symbol is introduced to ease the generation of the parts of the die. The procedures are as follows:

Representation of die part

((Part_name$_1$ Sb_num$_1$ view_pt$_1$ layer$_1$ pt$_1$_x pt$_1$_y)
(Part_name$_n$ Sb_num$_n$ view_pt$_n$ layer$_n$ pt$_n$_x pt$_n$_y))

Where, "(Part_name$_n$)" is the name of the nth part, "(Sb_num$_n$)" number of symbol, "(view_pt$_n$)" number of view point, "(layer$_n$)" number of layer, "(pt$_n$_x)" x-coordinate of the part, and "(pt$_n$_y)" is the y-coordinate of the part.

2.5 Die-Layout Module

The die-layout module automatically designs the parts and assembly of the die to satisfy the rule design using the information on tool possition according to the processes obtained in the strip-layout module. The pattern of the die set of a lead frame is shown in Fig. 2.

3. Rule and Database of the System

An automated CAD system organises the rule and databases as process variables extracted from plasticity theories, relevant references and the empirical know-how of experts in blanking industries. Rules which organise empirical know-how and guide design, are based on decision trees of the form of "IF(conditions) THEN(actions)". According to the information on the condition of a part, the system calculates the action part and the results of the action part are the input to the next condition part.

3.1 Rule of Production Feasibility Check

Rule 1. The minimum distance between shapes of internal features and minimum distance between the edge of the strip and the edge of the product are decided from the database according to the thickness of material.

Rule 2. The minimum distancce between the shapes of internal features should be the criteria suggested from the database.

Rule 3. If the hole for piercing is a circle, the limit value depending on the properties, shape, and thickness of a product should be satisfied with the criteria obtained from the database.

Rule 4. If the material does not exist in the database, the diameter or slitting width should be greater than the thickness, 1t.

Rule 5. The corner or fillet of the radius should be greater than 0.5t.

Rule 6. When through blanking of an irregular shaped metal product is feasible for the shape of internal features, but infeasible for the external area, the production feasibility check module selects preferentially for the external infeasible area.

3.2 Rule of Strip-Layout

Rule 1. Generally in the case of existing notches, they are pierced at the first step of the process.

Rule 2. If a V-notch, dimple, and pad chamfer exist, they are pierced at the first process.

Rule 3. When pilot pin holes, epoxy holes, and moulding holes exist, if possible they are pierced at the first process.

Rule 4. If pilot pin hole exists, the size of hole should be greater than 3 times the thickness of product.

Rule 5. If holes to be pierced are close to each other, or are not related to the function, holes are distributed over many processes.

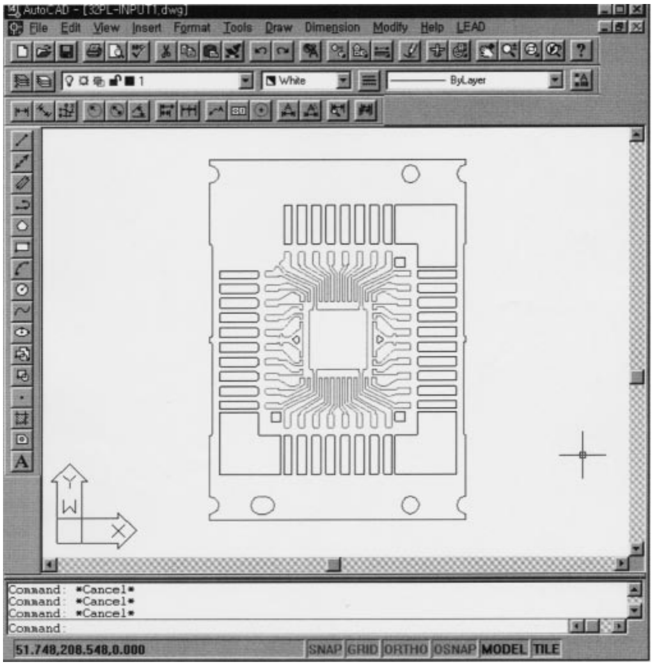

Fig. 3. 32LD PLCC lead frame.

Corner radius greater than criteria
Minimum corner radius : 0.5
Criteria : 0.1275

Fig. 4. Production feasibility check of a corner and a fillet radius for 32LD PLCC lead time with thickness 0.254 mm.

Min. Diameter of Circle Less Than. Criteria
Minimum Diameter : 1.25
Limits Diameter : 0.2032
Min. Rectangular Distance G.T. Criteria
Min. rectangular distance : 0.256
Limit distance : 0.1778

Fig. 5. Production feasibility check of holes for 32LD PLCC lead frame with thickness 0.254 mm.

Rule 6. As internal features which are related exist, the system being able to set punch equipment, they are pierced preferentially.

Rule 7. If a pilot pin hole, epoxy hole, moulding hole, V-notch, dimple, pad chamfer, internal lead cannot be pierced at the same time, the process order is as follows: dimple, V-notch, pad chamfer, pilot pin hole, epoxy hole, moulding hole and then internal lead.

Rule 8. So as not to use a punch of an intricate shape, the shape of the blank is divided automatically into simple shapes.

Rule 9. After calculating the perimeter for each blank, first of all, the strip-layout module decides the working order according to the size of the perimeter.

Rule 10. In each shape that is divided from the shape of the blank, the strip-layout module decides the size of the die blank which is capable of enduring normal pressure produced by the thrust force.

Rule 11. Each of the succeeding die blanks is first pierced on its specified pitch according to the working order, and shifts to the next pitch if it overlaps.

Rule 12. The ratio of thrust force to blanking force is obtained from the database.

Rule 13. The normal pressure exerted by the thrust force is decided as follows.

$$P_{\text{face}} = \frac{F_d}{L_{\text{shear}} \times t \times BLR}$$

Where

P_{face} = normal pressure (kg mm^{-2})
L_{shear} = summation or shear length (mm)
BLR = ratio of thickness of material to burnishing length
F_d = thrust force (kg)

Rule 14. Outer diameter endured normal pressure by thrust force is decided as follows

$$d_o = \frac{d_i}{\sqrt{\left(\frac{\sqrt{3}p_{\text{face}}}{m\sigma_y}\right)\sqrt{\left(2 - \left(\frac{\sqrt{3}p_{\text{face}}}{m\sigma_y}\right)^2 - 1\right)}}}$$

Where,

D_o = inner diameter of die blank (mm)
D_i = outer diameter of die blank (mm)
M = constant depending on yield criterion, $1 \leq m \leq 1.15$
σ_y = yield strength of die (mm)

Rule 15. Regrinding of die and punch is required after piercing from 600 000 to 700 000 strokes.

Rule 17. For a lead frame with over 16 pins, a spank process is required.

Rule 18. A punch with a cavity is divided and if possible, the cavity punch and cutting bar are operated together.

Rule 19. Note that in the case of working together, the process of the cutting bar precedes that of the cavity punch.

Rule 20. In order to compensate for the distance between the leads and crossbow, an equalising process is required.

Rule 21. Feed error is within $\frac{1}{100}$ mm and location error $\frac{5}{100}$ mm.

Rule 22. All dimensions of the lead frame are measured from the dambar.

3.3 Rule of Die-Layout

Rule 1. If the overall cutting dimensions of the blank are less than 300 mm, the complete blank profile is produced in one stage.

Rule 2. If any interrelated features exist within pilot holes, they are also processed in the first stage, provided that their punch mounting permits it.

Rule 3. If the minimum distance between the edge of the internal feature and the edge of the die block is less than twice the die block thickness, idle station is required for preventing die block, stripper plate and punch holder from being broken.

Rule 4. The die-layout module also designs the strip in such a way that it enables the component and its scrap to be ejected without interference.

Rule 5. The die-layout module decides the type of die to be designed to produce the given component by considering the complexity of the blank profile, production requirements, accuracy of the blank, and other related parameters.

Rule 6. The force for blanking or piercing in a progressive die is as follows.

$$P = L_{\text{shear}} \times t \times s$$

Where, P = force of blanking or piercing (kg_f/mm^2)

Rule 7. The thickness of die block verifies as the following expression.

$$H^2_{\text{dblock}} \geq \frac{2.5P}{\sigma_{\text{ai}}}\left(1 - \frac{D_{\text{bla}}}{1.5D_{\text{dblock}}}\right)$$

Where,

H_{dblock} = thickness of die block (mm)

σ_{ai} = allowable bending stress of die block (kg mm^{-2})

D_{bla} = diameter of the most outer shape of product (mm)

D_{dblock} = diameter of die block (mm)

Rule 8. The centre of pressure in a progressive die is calculated as follows.

$$x = \frac{\sigma E_j x_i}{\Sigma E_i}$$

$$y = \frac{\Sigma E_i y_i}{\Sigma E_i}$$

Where,

E_i = shear length of each entity (mm)

x_i = centroid of x-coordinates for each entity (mm)

y_i = centroid of y-coordinates for each entity (mm)

Rule 9. If the minimum distance between succeeding processes is greater than twice the thickness of the die block, partition of the die is required.

Rule 10. Punch length is smaller than the criteria suggested in the following expression.

$$1 \leq \sqrt{[(2\pi^2 EI/CP)]}$$

Where,

L = punch length (mm)

E = elastic modulus (kg mm^{-2})

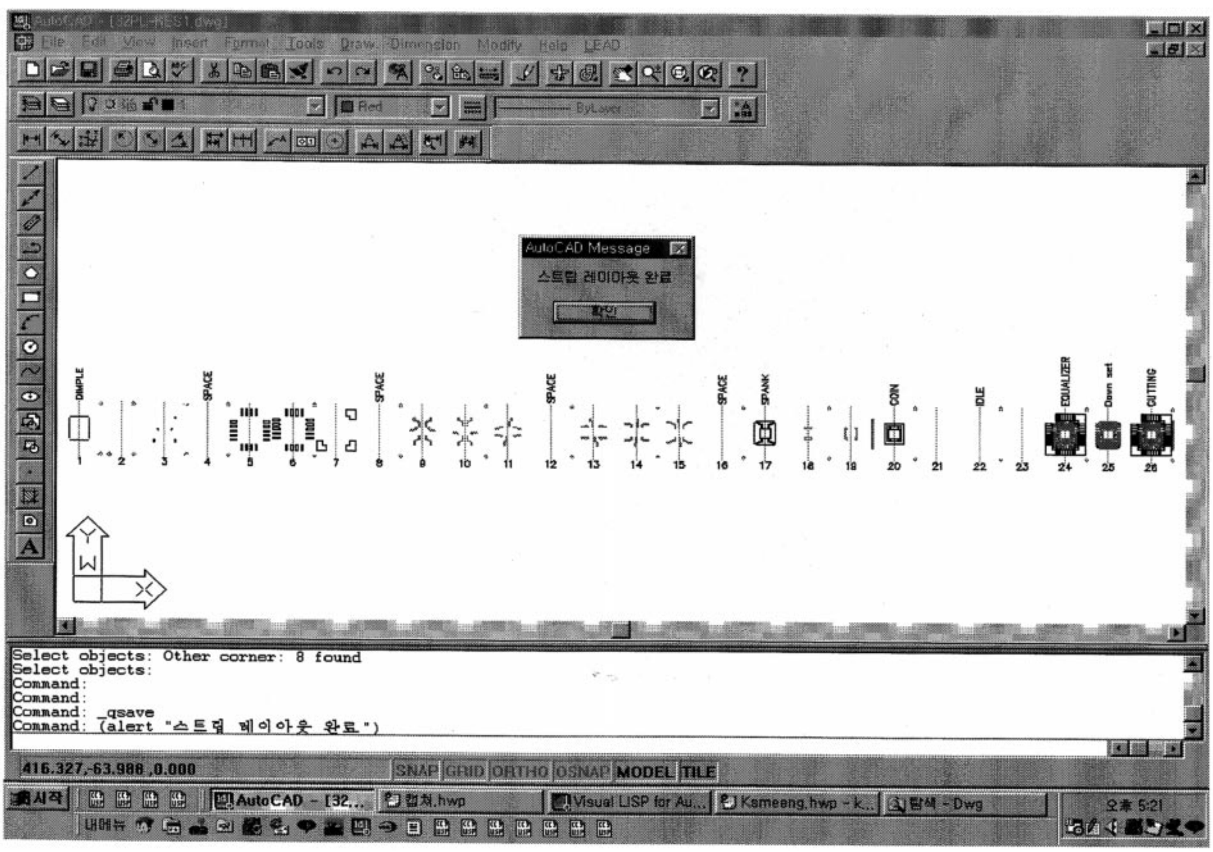

Fig. 6. An automatic strip-layout drawing for the 32LD PLCC lead frame semiconductor.

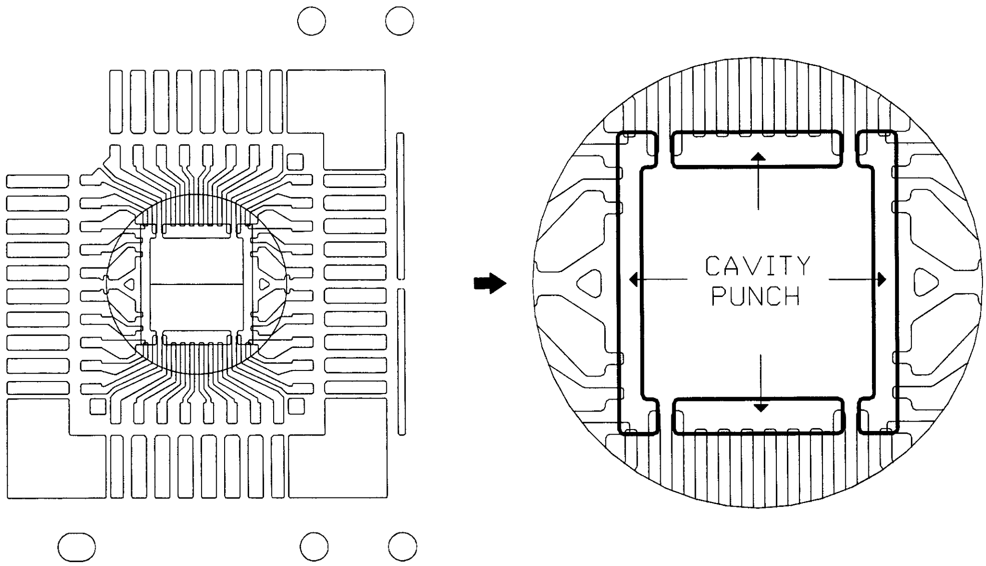

Fig. 7. Generation of the cavity punch of the 32LD PLCC lead frame in the shape treatment module.

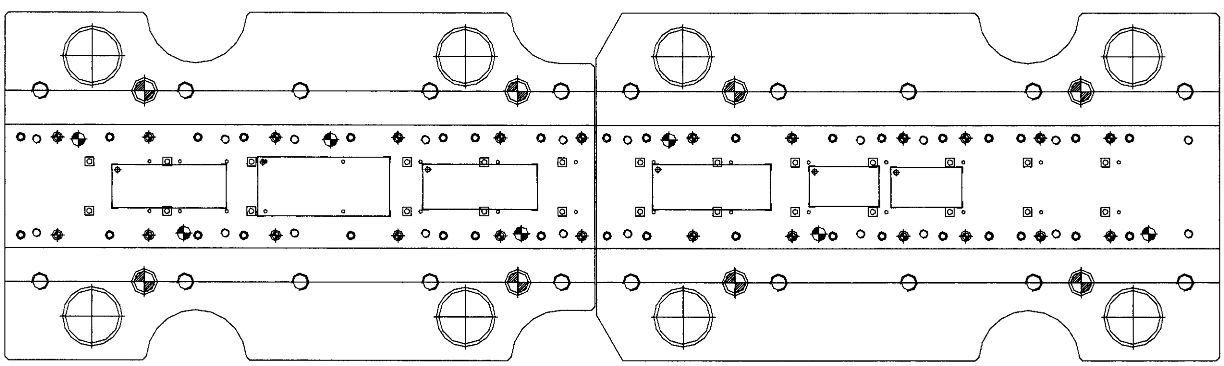

Fig. 8. A drawing of the die plane of the 32LD PLCC generated in the die-layout module.

I = second moment of area (kg mm^{-4})
CP = safety factor

Rule 11. Amount of preliminary compression of spring is from 3 mm to 6 mm.

Rule 12. On the press working, the amount of compression of spring is as follows.

$$I_{workcom} = t + I_{punch} + I_{stripper}$$

Where,

$I_{workcom}$ = compression length of spring on working of press (mm)
I_{punch} = amount of penetration of punch on closing of die (mm)
$I_{stripper}$ = amount of penetration of punch on opening of die (mm)

Rule 13. Total amount of compression of spring is as follows.

$$I_{workcom} = I_{punch} + I_{stripper}$$

Rule 14. Spring is calculated from the following expression.

$$F_{spring} = K_{spring} \times I_{totcom}$$

Where,

F_{spring} = spring force (kg)
K_{spring} = constant of spring
I_{totcom} = total compression length of spring (mm)

Rule 15. Clearance between die and punch is decided from the database considering the thickness of material and ultimate strength.

Rule 16. The stripping force is calculated by the following expression.

$$F_{strip} = P \times (1.1 \sim 1.2)C_{strip}$$

Where,

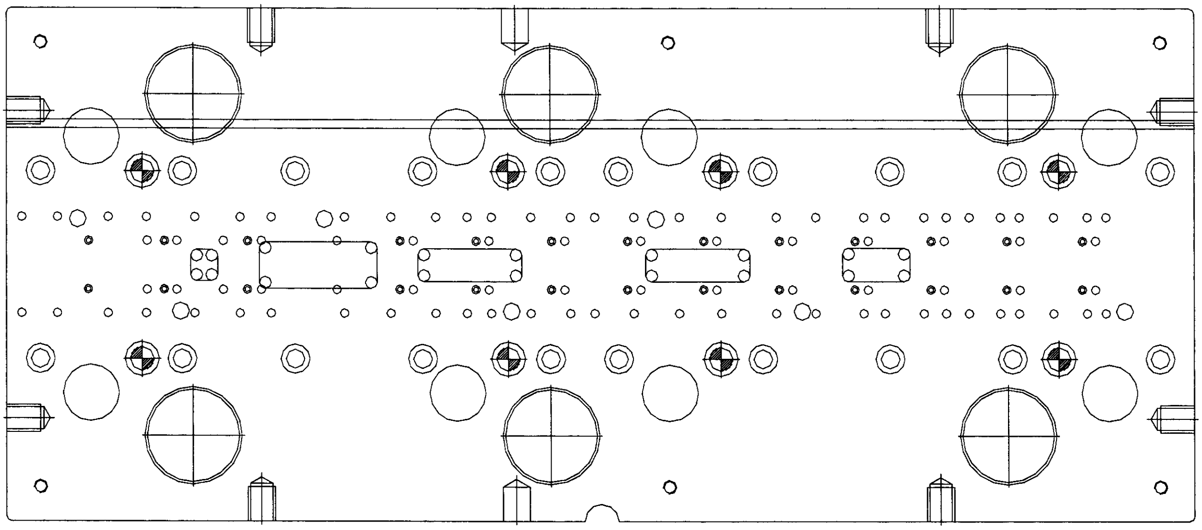

Fig. 9. A drawing of the die holder of the 32LD PLCC generated in the die-layout module.

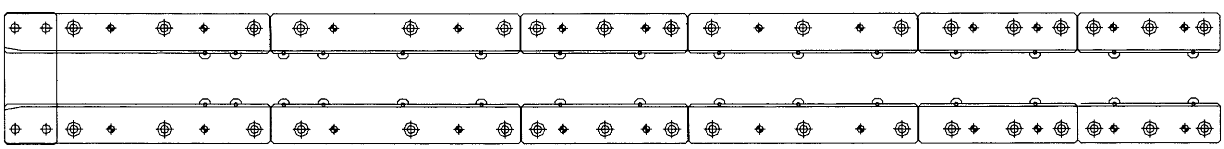

Fig. 10. A drawing of the guide plate of the 32LD PLCC generated in the die-layout module.

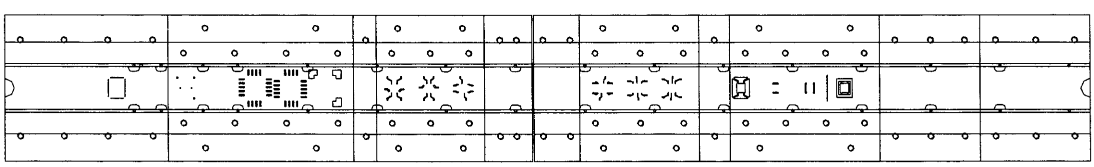

Fig. 11. A drawing of the stripper plate of the 32LD PLCC generated in the die-layout module.

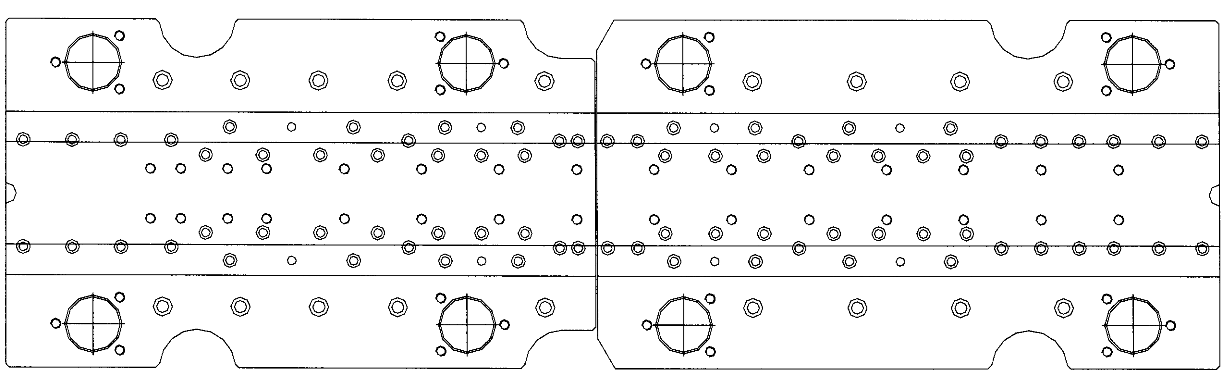

Fig. 12. A drawing of the stripper holder of the 32LD PLCC generated in the die-layout module.

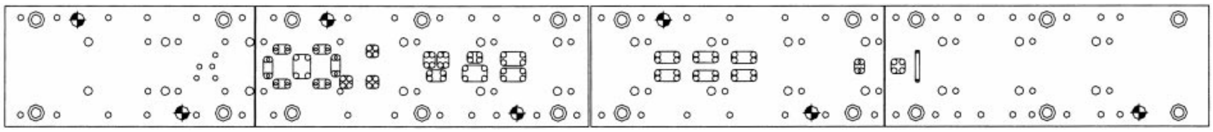

Fig. 13. A drawing of the die backing plate of the 32LD PLCC generated in the die-layout module.

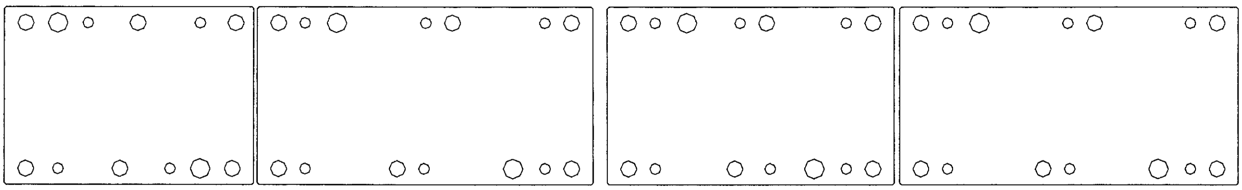

Fig. 14. A drawing of the punch backing plate of the 32LD PLCC generated in the die-layout module.

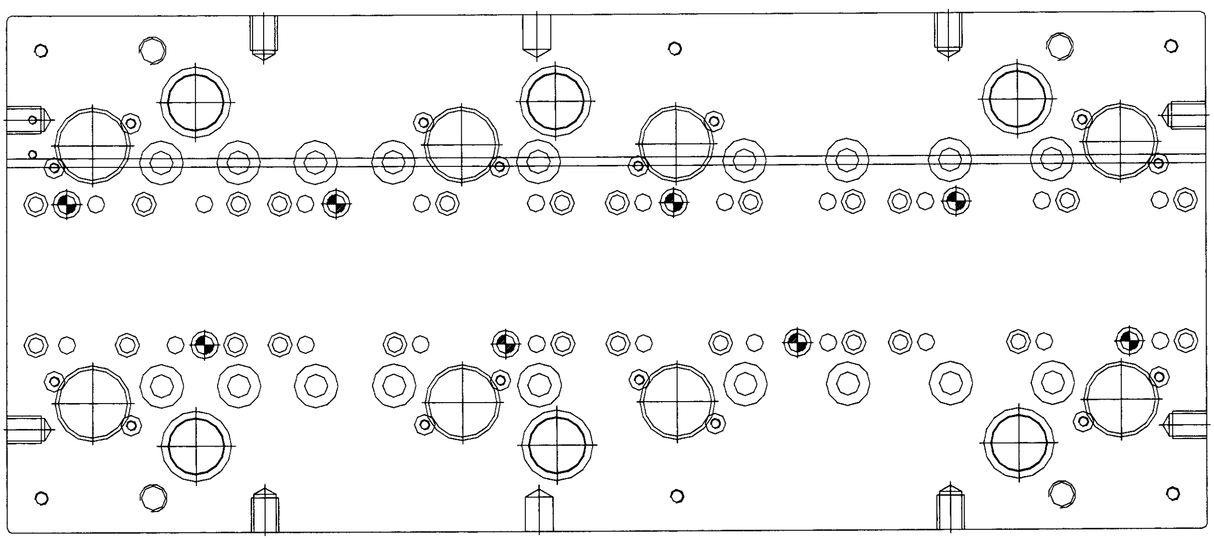

Fig. 15. A drawing of the punch holder of the 32LD PLCC generated in the die-layout module.

F_{strip} = stripping force (kg)
C_{strip} = coefficient of stripping

Rule 17. The number of fasteners is calculated by the following expression.

$$F_{\text{strip}} = 300 \times d_f^2 \times n_f$$

Where,

d_f = diameter of fastener (mm)
n_f = number of fastener (mm)

Rule 18. Positions of the knock pins and springs are arranged around the punch contour at equal pitch.

Rule 19. Screws and dowels are located around the perimeeter of the die block in a straight line at equal pitch.

Rule 20. If any error at an equal pitch occurs, it is adjusted at the central position.

Rule 21. From the database, its die-layout module seleccts other standard parts in accordance with the dimensions of parts calculated in earlier stages.

Rule 22. In order to produce N holes whose diameter is d_i and centre-point is (x_i, y_i), the minimum effective size of plate, $(A_{\text{eff}})_{\min} \times (B_{\text{eff}})_{\min}$, is as follows.

$$X_{\min} = \text{MIN}[(x_i - 1.5d_i), \quad i = 1, N]$$
$$Y_{\min} = \text{MIN}[(y_i - 1.5d_i), \quad i = 1, N]$$
$$X_{\max} = \text{MAX}[(x_i + 1.5d_i), \quad i = 1, N]$$
$$Y_{\max} = \text{MAX}[y_i + 1.5d_i), \quad i = 1, N]$$
$$(A_{\text{eff}})_{\min} = X_{\max} - X_{\min}$$
$$(B_{\text{eff}})_{\min} = Y_{\max} - Y_{\min}$$

Where,

$(A_{\text{eff}})_{\min}$ = minimum effective length of plate (mm)
$(B_{\text{eff}})_{\min}$ = minimum effective width of plate (mm)

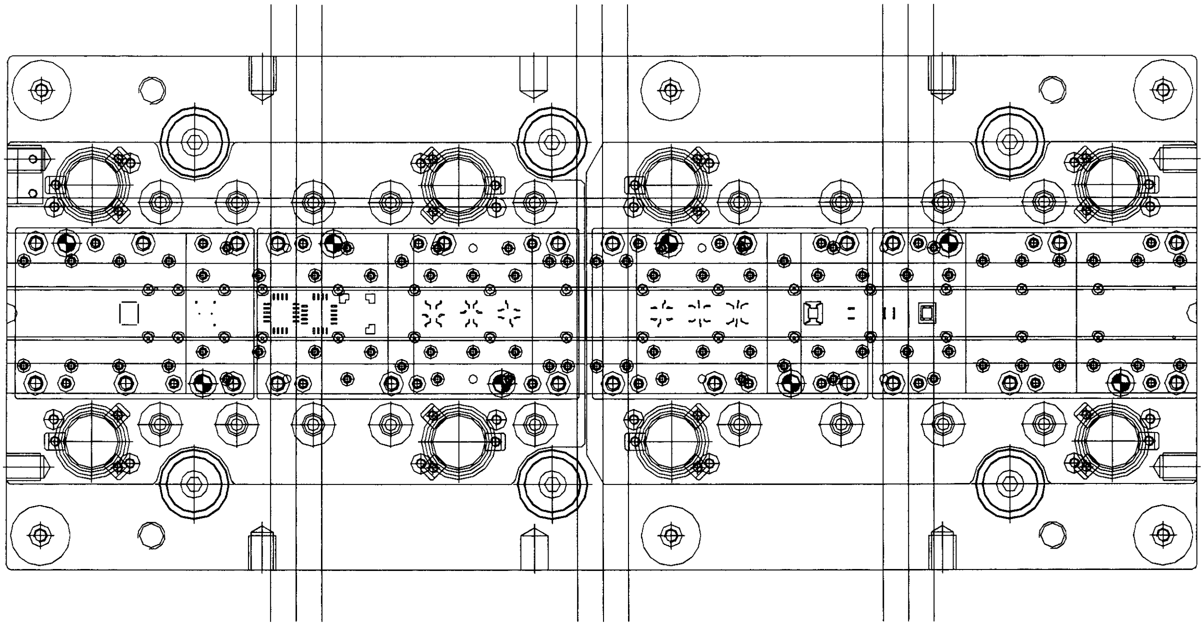

Fig. 16. A drawing of the upper die (punch parts) of the 32LD PLCC generated in the die-layout module.

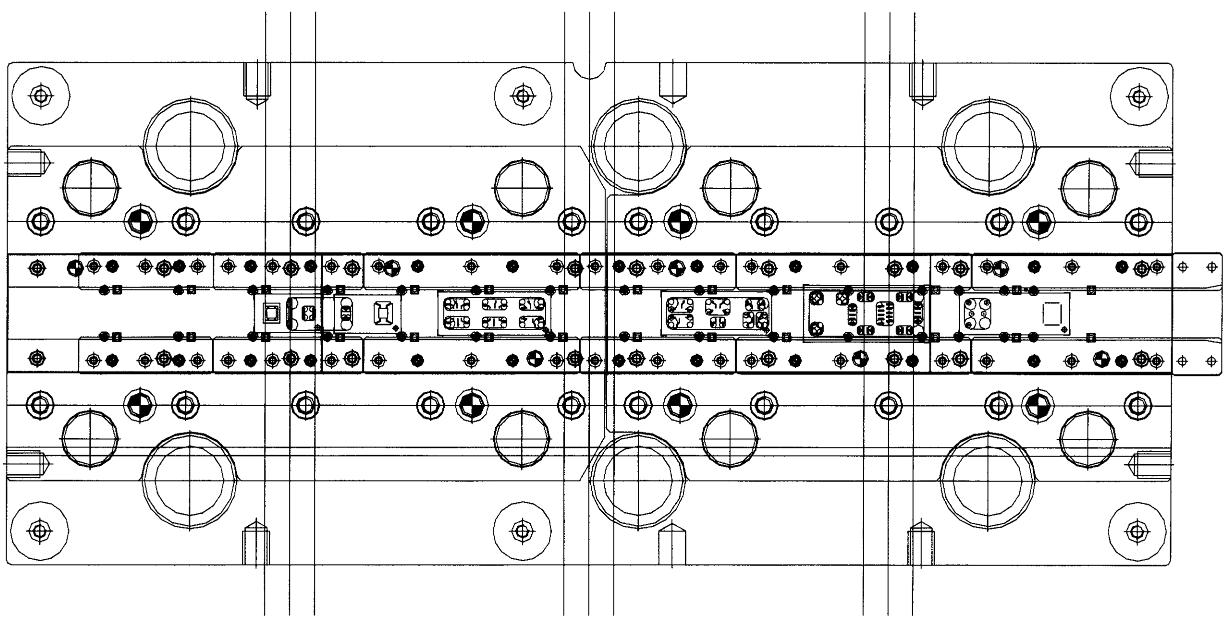

Fig. 17. A drawing of the lower die (die parts) of the 32LD PLCC generated in the die-layout module.

4. Application and Results of the System

When a lead frame for a semiconductor requiring a very precise piercing operation for progressive working is designed on the automated CAD system, the results obtained in each module are given in the following sections.

4.1 Application to Input and Shape Treatment Module

When a user inputs items demanded for the lead frame product as shown in Fig. 3, the shape treatment module, being the recognised drawing of input shape, converts the numerical list into a list of closed loops to design each module. These lists are used to run the program in each module using the rule and database in common.

4.2 Application to Production Feasibility Check Module

When the internal lead of the lead frame, 32LD PLCC, is applied to the production feasibility check module, the results of checking the corner radius of the product, the holes to be pierced, and the distance between the shapes of internal features are shown in Figs 4 and 5. From these results, this system knows that the minimum distance between the shapes of internal features and the holes to be pierced are within the feasible area. This module, therefore, prevents errors which would occur in the actual workshop.

4.3 Application to Strip-Layout Module

When the 32LD PLCC lead frame product is applied to the strip-layout module, the results which are output by this module are shown in Fig. 6 [10]. The strip-layout module, by checking the interference of the outer diameter of the die blank and the thrust force, can carry out an automated strip-layout to prevent the die from being broken. In the case of punches working on the external part of the product, the pilot pin hole, epoxy hole, external lead, moulding hole, and cutting bar, and shape of the product is the same as that of the punch, but in the case of complicated punches, the die pad, and internal lead, and punch profiles are divided automatically. When piercing internal leads, this module carries out progressive working considering the minimum distance so as not to interfere according to the size of the shear length. Plastic deformation occurring at the end part of the internal lead is required for designing the cavity punch to prevent such a deformation. This module extracts the list of cavity punches from the numerical data of the lead frame and designs the cavity punches automatically. It shows the shapes of the cavity punches automatically generated in Fig. 7 [10].

4.4 Application to Die-Layout Module

The data-conversion module converts the shape data of the strip-layout drawing for the lead frame into recognisable shape data in order to use the I-DEAS master series drafting program. When the lead frame, 32LD PLCC, is applied to the die-layout module, the parts and assembly of the die set are generated and can be seen in Figs 8–17. The module reads standard parts from the database according to data obtained from the strip-layout module, and for non-standard parts not stored in the database, and carries out the design. Therefore it generates the die-layout drawing. Calculating the outer diameter under normal pressure of the die, and the clearance of geometric shape between die and punch, the centre of pressure for the balance of forces, the number and arrangement of screws, and the number and arrangement of dowel pins, and the size of the die block is decided by the following procedures. It calculates the "area of die-layout" based on the length and width of the strip-layout drawing. After calculating these data of the die plate, the dimensions of the die set are standardised to those of the die set stored in the database. Also, based on the dimensions of the standardised die set, the thickness of the die plate and stripper plate, the minimum distances from the edge of die plate to the dowel pin and to the bolt, are obtained from the database. The diameters of the dowel pin and the fastener, and the diameters of the sub-guide and the main-guide posts are obtained from the database. It checks success or failure by buckling of a punch. In the internal lead of the lead frame, the dimensions to be pierced are the same as those of the punch and the dimensions to be blanked, as those of the die. After all the die blanks are arrayed, moments are calculated from the position and centre of gravity of each shape in order to determine the balance force point. Matching this point to the centre of the die set produces a balanced pressing pressure and reduces the wear of the die and punch. By quantifying the techniques and experience in this workshop, this module can generate the best die-layout drawing preventing plastic deformation and defects.

5. Conclusion

The study developed an automated CAD system for process planning and die design for lead frame products, for semiconductors, with very precise piercing operations.

The automated CAD system has the following features.

1. Input and shape treatment modules, by recognising the shape of the product input, convert a numerical random list of shape data into a numerical list of closed loops to use easily in each module.
2. The production feasibility check module can check production feasibility for a lead frame product requiring very precise piercing operations.
3. Taking account of the outer diameter of the die blank under normal pressure for each shape of product, in the production feasibility check module, the shapes of the punch profiles were divided automatically for the external area.
4. The strip-layout also checks the idle station between succeeding processes to prevent the die from being broken and generates the strip-layout drawing automatically.
5. The die-layout module can carry out automated die-layout and generate parts and assembly drawings of the die set in graphic form.

This system quantifies techniques and experience needed in designing die sets and standardises design rules for formulating procedures for design. It has the advantage that it can be used by a novice who may not have any knowledge of tool design. By realising an automated CAD system on AutoCAD for process planning and on I-DEAS for complicated die design, the system, linked with other CAM software, can automatically generate NC data so a CAD/CAM system for lead frame for semiconductors requiring very precise piercing operations may soon be developed.

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