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# A Study of the Progressive Working of an Electric Product Using a 3D Shape Recognition Method

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*This paper describes the development of the computer-aided design of an electric product using bending and piercing operations for progressive working. The system is based on knowledge-based rules. Knowledge for the system is formulated from plasticity theories, experimental results, and the empirical knowledge of field experts. The system has been written in AutoLISP in AutoCAD on a personal computer and is composed of four main modules, which are input and shape treatment, flat pattern layout, strip layout, and die layout modules. Based on knowledge-based rules, the system is designed considering several factors, such as bending radius, bending angle, effect of springback, material and thickness of a product, bending sequence, and the complexities of the blank geometry and punch profiles. It generates the 3D strip layout drawing for an electric product. The die layout module carries out die design for each process from the results of the strip layout module. Results obtained using the modules enable the designer and manufacturer of piercing and bending dies to be more efficient in this field.*

**Keywords:** Bending and piercing; Die layout; 3D strip layout; Flat pattern layout; Knowledge-based rules

## 1. Introduction

Experience and intuition have been used for strip layout for electric products using bending and piercing operations. In order to improve the solution of this problem, the automation of computer-aided process planning for a designed product by formularising the experience of skilled engineers has been undertaken [1–7]. Fogg and Jaimeson developed an improved PDDC [1]. Shibata and Kunitomo followed them by developing a CAD system which produces screen-output for blank- and die-layout [2]. Nakahara et al. introduced a system for a progressive die design [3]. Wang and Chang studied the determination of the bending sequence in progressive die design [4], and See Toh et al. developed a system for a feature-based flat pattern [5]. Choi et al. also developed an automated process planning and die design system for blanking or piercing of irregular shaped sheet metal products [6,7]. In this study, an algorithm recognising a 3D shape is developed. Using the algorithm and a flat pattern layout drawing generated in the flat pattern layout module, the system carries out piercing operations according to the shapes of punches in the outer region of a product, and bending operations selected according to factors which influence the process. Also, process sequences relating to burring, piercing, and bending operations are determined. The strip layout system is able to carry out bending and piercing operations for a 3D electric product optimally. Using the data for the strip layout, the die layout generates the parts of the die. Results obtained using the modules enable the designer and manufacturer of piercing and bending dies to improve the efficiency of the operation.

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## 2. Constitution of System

The system is composed of four modules: input and shape treatment; flat pattern layout; strip layout; and die layout modules. It is accomplished without processing interruption as each module holds rules and a database in common. It is easy to use, as the dialogues are user-friendly with appropriate prompting statements for the various data required. The configuration of the system can be seen in Fig. 1.

For an electric product having bending and piercing operations, a user inputs the shape of the product, the bending angle, and the bending radius required into the input and shape treatment module. Then the system carries out the recognition process for these data and transfers the results of the shape treatment into the flat pattern layout module. A flat pattern layout drawing considering bending allowances is generated in this module and the results are transferred into the strip layout module to carry out strip layout automatically. The results of the strip layout module are transferred to the die layout module to generate parts and an assembly drawing of the die set. The

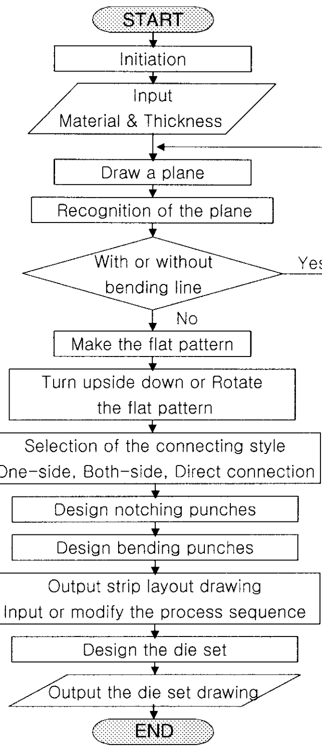



**Fig. 1.** Configuration of the system for progressive working.

functional description of the modules of the system is presented briefly as follows.

## 2.1 Input and Shape Treatment Module

The input and shape treatment module is divided into the input submodule and the shape treatment submodule. If a user inputs material type, thickness, width, heat treatment condition, and the shape of a product into an AutoCAD drawing by hand or outputs a drawing file on the screen, the input submodule automatically reads information about the mechanical properties of the material from the database. The shape treatment submodule converts the shape data into numerical data for recognising a 3D shape product. Figure 2 shows input of the material condition of a product.

### 2.1.1 *Theoretical Background*

Figure 3 shows the rotated coordinates of a point on the plane associated with the bending line.

The point, $p_6(x_6,y_6,z_6)$, is determined by rotating the point, $p_3(x_3,y_3,z_3)$, on the plane with reference to the bending line, which passes through the point, $p_1(x_1,y_1,z_1)$ and the point, $p_2(x_2,y_2,z_2)$.

The equation of a straight line, which passes through the point, $p_1(x_1,y_1,z_1)$ and the point, $p_2(x_2,y_2,z_2)$, is as follows:

$$\frac{x - x_1}{l} = \frac{y - y_1}{m} = \frac{z - z_1}{n} = k \tag{1}$$

where $l,m,n$ are unit vectors of a straight line and $k$ is a constant.

The equation of the plane, including the point, $p_3(x_3,y_3,z_3)$, perpendicular to the straight line is as follows:

$$l(x - x_3) + m(y - y_3) + n(z - z_3) = 0 \tag{2}$$

From Eqs (1) and (2), the intersection point, $p_4(x_4,y_4,z_4)$, is as follows:

$$p_4(x_4,y_4,z_4) = (lk + x_1, mk + y_1, nk + z_1) \tag{3}$$

where,

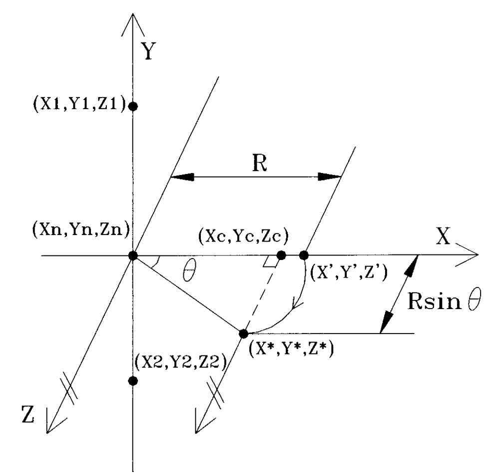



**Fig. 3.** Rotation of a point including the plane with reference to the bending line.

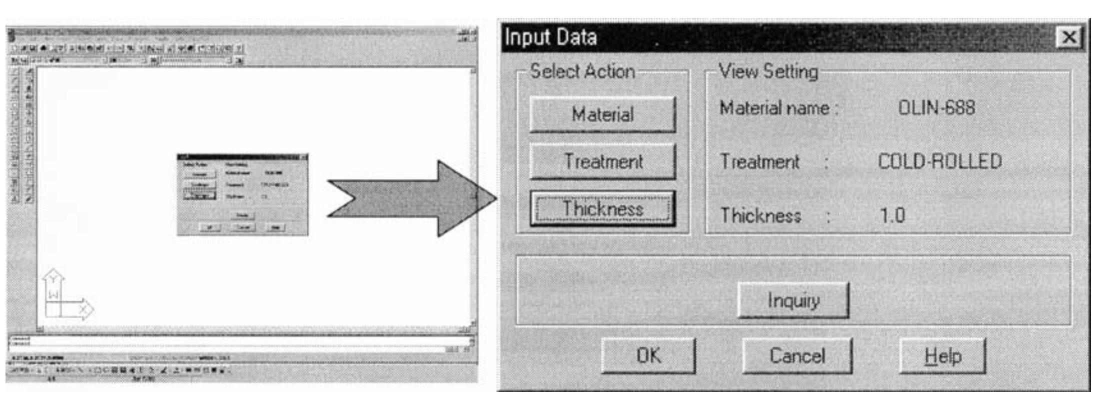



**Fig. 2.** Input of material condition of a product.

$$k = \frac{l(x_3 - x_1) + m(y_3 - y_1) + n(z_3 - z_1)}{l^2 + m^2 + n^2}$$

If $R$ is the radius of circle,

$$R = \sqrt{((x_3 - x_4)^2 + (y_3 - y_4)^2 + (z_3 - z_4)^2)} \tag{4}$$

$$\mathbf{d}_1 = \mathbf{d}_2 \times \mathbf{d}_3 \tag{5}$$

If the unit vector of $\mathbf{d}_1$ is $\mathbf{h}$,

$$\mathbf{h} = \frac{\mathbf{d}_1}{|d_1|} = (h_x, h_y, h_z) \tag{6}$$

The equation of a straight line, which passes through the point, $p_5(x_5,y_5,z_5)$ and the point, $p_6(x_6,y_6,z_6)$, is as follows:

$$\frac{x^* - x_5}{h_x} = \frac{y^* - y_5}{h_y} = \frac{z^* - z_5}{h_z} = t \tag{7}$$

From Eqs (6) and (7), the coordinates of the point, $p_6(x_6,y_6,z_6)$, rotated by θ with reference to the straight line, which passes through the point $p_1$ and the point $p_2$, are as follows:

$$\begin{aligned} x_6 &= t \times h_x + x_5 \\ y_6 &= t \times h_y + y_5 \\ z_6 &= t \times h_z + z_5 \end{aligned} \tag{8}$$

### 2.1.2 Shape List of Plane

Assembling the planes divided by the bending lines constitutes a product. Each plane is composed of an outer shape, an inner hole, and a slot. The entities of a product drawing organise the list by combining lines and arcs or only circles. Figure 4 shows the constitution of entities for recognising the inner shapes of a plane.

List representation constituted by lines and arcs
(0.0 ($S_p$ $E_p$) ($S_p$ $E_p$) … ($S_p$ $E_p$ $C_p$) ($S_p$ $E_p$ $C_p$) …)

List representation constituted by circles
(0.0 ($C_p$ $R$) ($C_p$ $R$) ($C_p$ $R$) …)

Where "$S_p$ $E_p$" is a line of the drawing entity, "$S_p$ $E_p$ $C_p$" represents arc, "$C_p$ $R$" circle, "$S_p(X_s$ $Y_s$ $Z_s)$" is the starting point, "$E_p(X_e$ $Y_e$ $Z_e)$" is the end-point, "$C_p(X_c$ $Y_c$ $Z_c)$" the centre-point, and "R" is the radius.

In order to recognise the shape from the drawing, the list of lines and arcs reorganise drawing entities as closed loops.

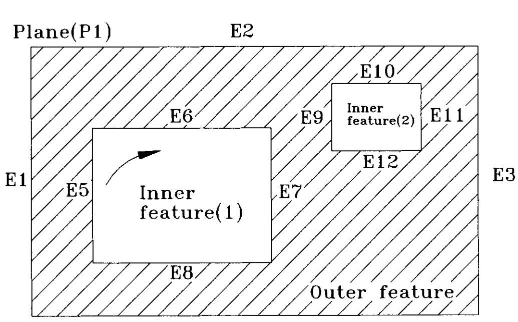



**Fig. 4.** Constitution of the list for recognising the shape of the plane.

(0.0 (($P_1$ $P_2$) ($P_2$ $P_3$ $P_c$1)($P_3$ $P_4$) …($P_{n-1}$ $P_n$ $P_{cn}$) ($P_n$ $P_1$))
(($q_1$ $q_2$)($q_2$ $q_3$)($q_3$ $q_4$ $q_{c1}$)…($q_{n-1}$ $q_n$ $q_{cn}$)($q_n$ $q_1$))

In "($P_{n-1}$ $P_n$ $P_{cn}$) ($P_n$ $P_1$)", "$P_n$" is the endpoint of "$P_{n-1}$ $P_n$ $P_{cn}$" and the starting point of "$P_n$ $P_1$", and "$P_{cn}$" is the centre-point of the arc.

In "$P_1(X_1$ $Y_1$ $Z_1)$", $X_1$ has the least $x$-coordinate in the closed loop of the "P" type. Based on the point "$P_1$", the closed loop of the "$P$" type has the entities in the clockwise direction.

Each of the internal and external shapes composed of closed loops has a list in one plane. By assembling these plane lists, shape lists for the product are organised as follows:

(("$P_1$" (external feature internal feature(1) internal feature(2) …internal feature ($n$))

(("$P_2$ (external feature internal feature(1) internal feature(2) …internal feature($n$))

---------------------------------------------------------------------------

(("$P_n$" (external feature internal feature(1) internal feature(2) …internal feature($n$))

### 2.1.3 Bending List of Product

Information of the bending angle and the line and relationship of the planes connected to one another should be defined for a product having bending and piercing operations. The information for a bending operation is composed of the entities of the bending line, the bending angle, the bending radius, and the movement of the bending line. The information of a plane is composed of a list of a fixed mother plane and a rotated children plane.

("$B_1$" (information bending line) bending line, bending radius, information about bending line movement, referenced plane, rotated plane)
("$B_2$" (information bending line) bending line, bending radius, information about bending line movement, referenced plane, rotated plane)

---------------------------------------------------------------------------

("$B_n$" (information bending line) bending line, bending radius, information about bending movement, referenced plane, rotated plane)

Figure 5 shows the dialogue box for recognising the bending part of a product.

## 2.2 Flat Pattern Layout Module

The flat pattern layout module calculates the bending allowances taking account of the bending radius and bending angle extracted from the bending list from the shape treatment module, and the coefficient according to the material type, read from the database. Figure 6 shows the bending allowance between the mother plane and the children plane. The unfolding length of the flat pattern layout is calculated as follows:

$$L = a + b + x, \quad x = \frac{\theta}{360} 2\pi(r + \lambda t)$$

where λ is the coefficient obtained from the database according to $r/t$.

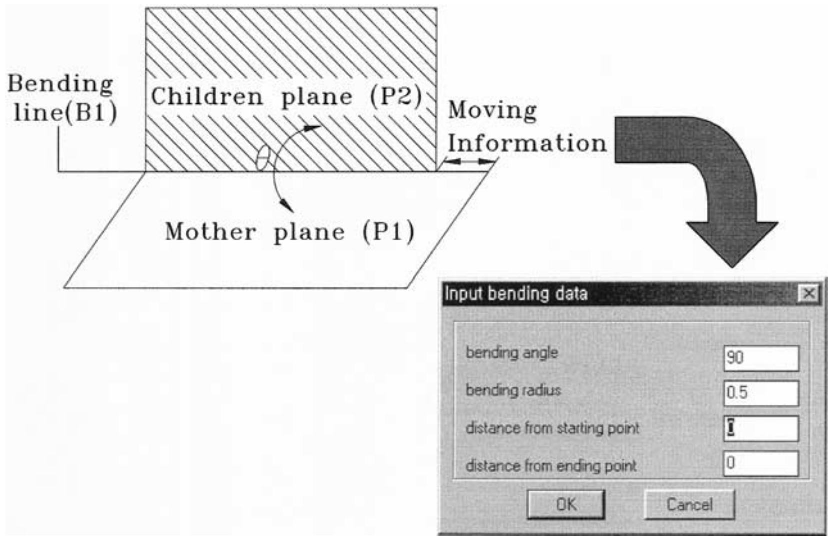



**Fig. 5.** Constitution of the list for recognising the bending part of a product.

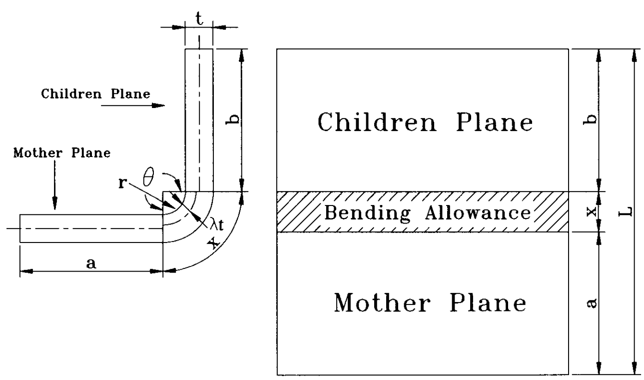



**Fig. 6.** Calculation of the bending allowance between the mother plane and children plane.

When the bending lines are unfolded one by one in the reverse order of folding the bending lines, the planes associated with bending lines automatically move by the bending allowances calculated.

### 2.3 Strip Layout Module

The strip layout module decides the order of the processes, which are capable of progressive working based on the factors influencing strip layout. Factors considered are as follows:

1. Minimum bending radius. The minimum bending radius is the least radius capable of folding without cracking or tearing at the bending line. Material, thickness, and heat treatment condition influence this.
2. High stress area and corner/fillet radius. The high stress usually occurs at the bending line and tears and cracks are propagated from this area.
3. Distance between bending line and internal feature. The minimum distance between holes and bending line is maintained to prevent distortion in the bending operation.
4. Distance between two internal features to be blanked or pierced.
5. Minimum hole to be pierced. After considering the rolling direction of a strip, the positional relations of the bending lines, and the connection method for a flat pattern layout drawing, this module decides the connection part and permits rotation and turning upside down, as shown in Fig. 7.

It also chooses the connection method through the dialogue box with the users. After checking the constraints on the bending operations, as shown in Fig. 8, it automatically generates a 3D strip layout drawing.

### 2.4 Die Layout Module

The die layout module carries out a die design for each process, obtained from the results of the strip layout. It then generates part drawings and an assembly drawing of the die set in graphic form. In this module, the type of die set and stripper plate are decided by considering the complexity of the blank shape, the number of parts to be produced in a year, the number of processes, the material of the blank, and the blank size. In order to compensate for the geometric shapes of the die and punch based on the blank shape of the strip layout for each process, values for these are decided automatically. Additionally, based on the value of the "strip layout area", the thickness of the die and stripper plate, the diameter of the guide post, the working length and the width of the die set are obtained from the database. This module also interacts with the standard parts database and extracts standard parts such as fasteners, springs, and dowel pins according to the design requirements.

## 3. Rule and Database of the System

The system organises the rule and the databases as process variables derived from plasticity theories, relevant references

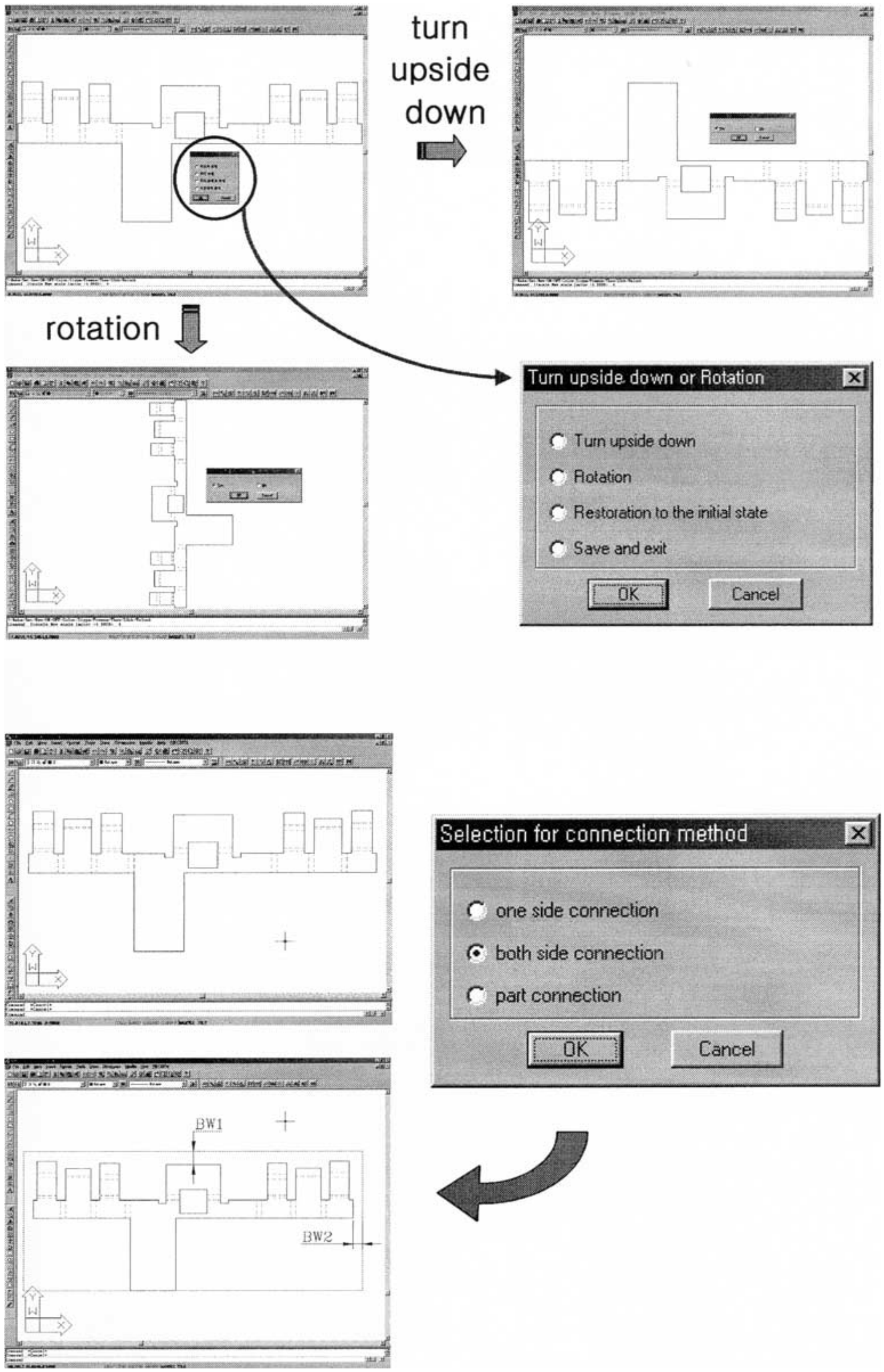
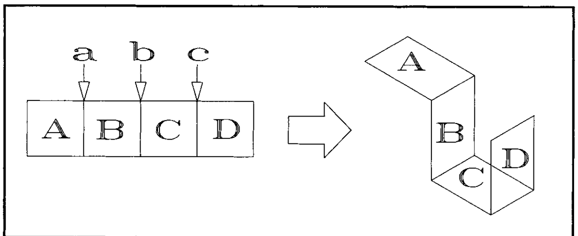



**Fig. 7.** The rotation and connection method of a flat pattern layout drawing for progressive working.




| Mother plane | Bending sequence | Plane sequence | Possible or impossible |
|---|---|---|---|
| A | a ⇒ b ⇒ c | BCD | Impossible |
| | a ⇒ c ⇒ b | BDC | Possible |
| | b ⇒ a ⇒ c | CBD | Impossible |
| | b ⇒ c ⇒ a | CDB | Impossible |
| | c ⇒ a ⇒ b | DBC | Impossible |
| | c ⇒ b ⇒ a | DCB | Impossible |

**Fig. 8.** Constraints on the bending operation for progressive working.

and the empirical know-how of experts in the blanking or piercing and bending 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 condition part, the system calculates the action part and the results of the action part are the input of the next condition part.

### 3.1 Rules of Flat Pattern Layout

*Rule 1*. The flat pattern layout of a bending product is divided into two parts, which are a straight part and bending part, but only bending parts are calculated.

*Rule 2*. The unfolding length of the flat pattern layout is calculated as follows:

$$L = \sum A_i + x, \quad x = \frac{\theta}{360} 2\pi(r + \lambda t)$$

where, $A_i$ = length of straight part (mm)
$X$ = length of bending part (mm)
$\theta$ = bending angle (degree)
$t$ = thickness of material (mm)
$\lambda$ = coefficient obtained from the database according to $r/t$.

*Rule 3*. The smaller $r/t$ is, the more the neutral axis of the bending moves inside and if $r/t$ is over 5, the neutral axis is half the thickness of the product.

*Rule 4*. If $r/t$ is less than 0.2, the length of the bending part in V-bending is as follows:

$$x = 0.5t$$

*Rule 5*. If $r/t$ is less than 0.2, the length of bending part in U-bending is as follows:

$$x = (0.45 \sim 0.5)t$$

*Rule 6*. The bending line is located in the middle of the bending arc from the neutral axis.

### 3.2 Rules of Strip Layout

*Rule 1*. Bending operations in the feeding direction are carried out simultaneously, if tool interference does not occur.

*Rule 2*. Bending operations perpendicular to the feed direction are carried out by progressive working after carrying out the bending operation in the feed direction, as shown in Fig. 9.

*Rule 3*. A piercing operation is preceded by a blanking operation in the outer region.

*Rule 4*. If setting the punch is possible, internal features associated with one another are selected preferentially.

*Rule 5*. Shapes to be pierced are arrayed on the die blank sequentially from the leftmost pitch, following the working order.

*Rule 6*. Each succeeding die blank is first placed on its specified pitch according to the working order, and shifted to the next pitch if it overlaps.

*Rule 7*. Margin width between shapes of a product and between the edge of the strip and the shape of the product are decided from the database according to the thickness of product.

*Rule 8*. Minimum distances between the shapes of internal features should be greater than the criteria suggested by the database.

*Rule 9*. If the hole for piercing is circular or rectangular, the limit value, depending on the properties, shape, and the thickness of a product, should satisfy the criteria obtained from the database.

*Rule 10*. If the material does not exist in the database, the diameter or slitting width should be greater than the thickness, $1t$.

*Rule 11*. The corner or fillet of the radius should be greater than $0.5t$.

*Rule 12*. The minimum distance between the bending line and an internal feature should satisfy the following expression.

$$r < g + 2t$$

where, $g$ = minimum distance between bending line and internal feature (mm)
$r$ = bending radius (mm)

*Rule 13*. Normal pressure exerted by the thrust force is determined as follows.

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

where, $P_{\text{face}}$ = normal pressure (kg mm$^{-2}$)

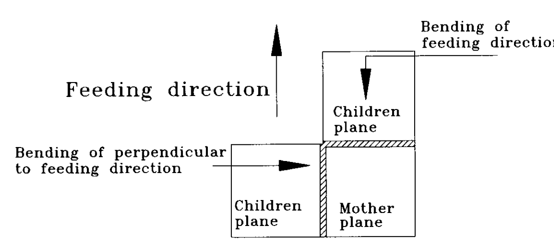



**Fig. 9.** Bending of the perpendicular to the feeding direction and bending of the feeding direction.

$L_{\text{shear}}$ = summation of shear length (mm)
BLR = ratio of thickness of material to burnishing length

$F_d$ = thrust force (kg)

*Rule 14*. Outer diameter subject to normal pressure by the thrust force is decided as follows:

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

where, $m$ = constant depending on yield criterion
$\sigma_y$ = yield strength of die blank
$d_i$ = inner diameter of die blank

*Rule 15*. Burnishing a part of the cutting section is carried out on the outside for preventing cracks caused by the bending operation.

*Rule 16*. The working force for V-free bending is decided as follows:

$$P_1 = C_1 \times \frac{B \times t^2 \times \sigma_b}{L}$$

where, $P_1$ = force for V-bending (kg)
$C_1$ = coefficient of correction for V-bending
$B$ = length of bending line (mm)
$\sigma_b$ = tensile strength of material (kg mm$^{-2}$)
$L$ = unfolding length of flat pattern-layout

### 3.2 Rules of Die Layout

*Rule 1*. The amount of springback is calculated as follows:

$$K = \frac{\alpha - \Delta\alpha}{\alpha} = \frac{r_p + t/2}{r_t + t/2}$$

where, $K$ = coefficient of springback
$\alpha - \Delta\alpha$ = bending angle after operation (rad)
$\Delta\alpha$ = angle of springback (rad)
$r_p$ = punch radius (mm)
$r_t$ = inner bending radius after operation (mm)

*Rule 2*. Stripping force is calculated as follows:

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

where $C_{strip}$ is 0.025 ~ 0.2.

*Rule 3*. The number of fasteners is calculated as follows:

$$F_{strip} = 30 \times d_f^2 \times n_f$$

where, $d_f$ = diameter of fastener (mm)
$n_f$ = number of fastener

*Rule 4*. The number of springs is calculated as follows:

$$l_{workcom} = t + l_{punch} + 1_{stripper}$$

where, $l_{workcom}$ = compression length of spring (mm)
$l_{punch}$ = penetration length of punch (mm)
$l_{totcom}$ = $l_{prcom} + l_{workcom}$
where, $l_{totcom}$ = total compression length of spring (mm)
$l_{prcom}$ = preliminary compression length of spring (mm)

$$l_{spring} = \frac{l_{totcom}}{C_{br}}$$

where, $l_{spring}$ = free length of spring (mm)
$C_{br}$ = deflection ratio of spring (mm)

$F_{spring}$ = $\text{K}_{spring} \times l_{totcom}$

where, $K_{spring}$ = stiffness of spring (kg mm$^{-2}$)
$F_{spring}$ = spring force (kg)

$F_{strip}$ = $\text{F}_{spring} \times n_s$

where $n_s$ = number of springs

*Rule 5*. The thickness of the die block satisfies the following expression:

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

where, $H_{dblock}$ = thickness of die block (mm)
$\sigma_{ai}$ = allowable bending stress of die block (kg mm$^{-2}$)
$D_{bla}$ = diameter of the outermost shape of the product (mm)
$D_{dblock}$ = diameter of die block (mm)

*Rule 6*. If any interrelated features exist within pilot holes, they are also processed in the first stage, provided that their punch mounting permits it.

*Rule 7*. 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, an idle station is required for preventing the die block, stripper plate, and punch holder from being broken.

*Rule 8*. If the minimum distance between succeeding processes is greater than twice the thickness of the die block, partition of the die is required.

## 4. Application and Results of the System

When an electric product requiring bending and piercing operations for progressive working is processed by the system, the study considers the results carried out in each module. An electric product used as sample is shown in Fig. 10.

### 4.1 Application to the Input and Shape Treatment

After the user inputs the items demanded, i.e. the type of material, the heat treatment condition, and the thickness of the electric product shown in Fig. 11(*a*), the shape data for each plane are input. A system capable of inputting planes in the *X-Y* coordinates is formulated for the user's convenience. After the shape data of one plane is recognised, this module chooses

**Table 1.** List for shape of parts and bending line.

1. *Shape list of plane*
((″P1″ ((((0.0 0.0 0.0) (1.13276e-015 18.5 0.0)) ((1.13276e-015 18.5 0.0) (1.13276e-015 23.2 0.0))
((1.42054e-015 23.2 0.0) (7.3 23.2 0.0)) ((7.3 23.2 0.0)) ((7.3 22.2 0.0) (7.3 22.2 0.0)) ((9.3 22.2 0.0) (9.3 22.2 0.0))
(9.3 23.2 0.0)) ((9.3 23.2 0.0) (12.8 23.2 0.0)) ((12.8 23.2 0.0) (12.8 19.7 0.0)) ((12.8 19.7 0.0)) ((19.8 19.7 0.0) (19.8 19.7 0.0))
(19.8 23.2 0.0)) ((19.8 23.2 0.0) (23.3 23.2 0.0)) ((23.3 23.2 0.0) (23.3 22.2 0.0)) ((23.3 22.2 0.0)
(25.3 22.2 0.0)) ((25.3 22.2 0.0) (25.3 23.2 0.0)) ((25.3 23.2 0.0) (32.6 23.2 0.0)) ((32.6 23.2 0.0) (32.6 18.5 0.0))
((32.6 18.5 0.0) (11.8 18.5 0.0)) ((11.8 18.5 0.0) (11.8 0.0 0.0)) ((11.8 0.0 0.0) (0.0 0.0 0.0)))))

⋮

(″P18″ ((((−23.927 30.2435 −4.36074e-015) (−23.927 33.0715 −3.47256e-015)) ((−23.927 33.0715 −3.47256e-015)
(−18.927 33.0715 −8.08028e-016)) ((−18.927 33.0715 −8.08028e-016) (−18.927 30.2435 −3.47256e-015))
((−18.927 30.2435 −3.47256e-015) (−23.927 30.2435 −4.36074e-015))))))

2. *Bending list*
((″B1″ (((23.3 23.2 0.0) (19.8 23.2 0.0)) ((12.8 23.2 0.0) (9.3 23.2 0.0))) −90.0 0.5 0.0 0.0 ″P1″ ″P2″)
(″B2″ (((32.6 23.2 0.0) (32.6 18.5 0.0))) 90.0 0.5 0.0 0.0 ″P1″ ″P3″)

⋮

(″B16″ (((−6.5 23.7 6.5) (−6.5 23.7 1.5))) 45.0 0.5 0.0 0.0 ″P16″ ″P17″)
(″B17″ (((−3.26145 26.9385 6.5) (−3.26145 26.9385 1.5))) −90.0 0.5 0.0 0.0 ″P17″ ″P18″))

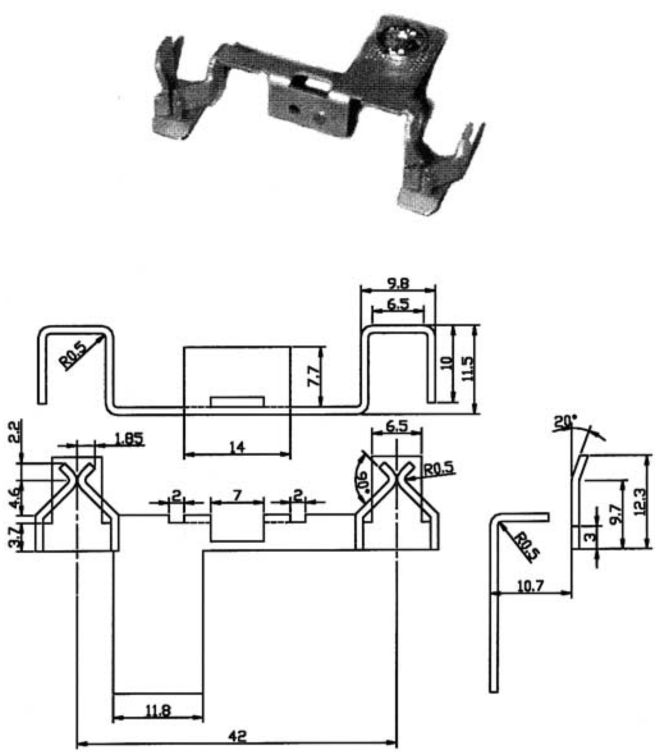



**Fig. 10.** A sample electric product.

the bending line as shown in Fig. 11(*b*). The user inputs the bending angle, the bending radius, and the information about the starting point of the bending line. After inputting these, only the bending line is redrawn in order to input another plane. The second plane is input as shown in Fig. 11(*c*) and this module automatically recognises it and outputs the shape. The results produced by these procedures are shown in Fig. 11(*d*). The shapes and the bending list of the electric product, automatically recognised, are shown in Table 1.

### 4.2 Application to the Flat Pattern Layout

Using the shapes and the bending list automatically recognised in the input and shape treatment module, the flat pattern layout drawing is output in this module. The bending allowances are calculated from the bending radius and the bending angle extracted from the bending list and the coefficient obtained from the database according to the product material. After the system automatically searches for the planes associated with the bending lines and rotates the nodes on the plane, the planes associated with the bending lines automatically move by the calculated bending allowances. Repeating these procedures, the flat pattern layout drawing is output as shown in Fig. 12.

The hatched parts represent the amount of bending allowances.

### 4.3 Application to the Strip Layout

When the flat pattern layout drawing, as shown in Fig. 12, is applied to the strip layout module, the results carried out in this module are shown in Fig. 13.

It carries out notching and piercing preferentially in the outer region before bending operations, according to strip layout rule 4. The shapes of the notching punches are designed from the outer shape through dialogue, which is user-friendly with appropriate prompting statements for the various data required. The piercing and bending forces of each stage are shown in Table 2 after calculating them according to the relevant rule.

In Fig. 13(*a*), the side cutting process, which cuts off both ends of the strip, is carried out in order to reduce feeding error and standardise the shape of the strip. This module carries out the notching and piercing operations in the outer region preferentially before performing the bending operations shown in Fig. 13(*c*). At the same time, the piercing process is carried out in the middle of the part. The notching for the bending operations in Fig. 13(*f*) and also the bending of both ends of

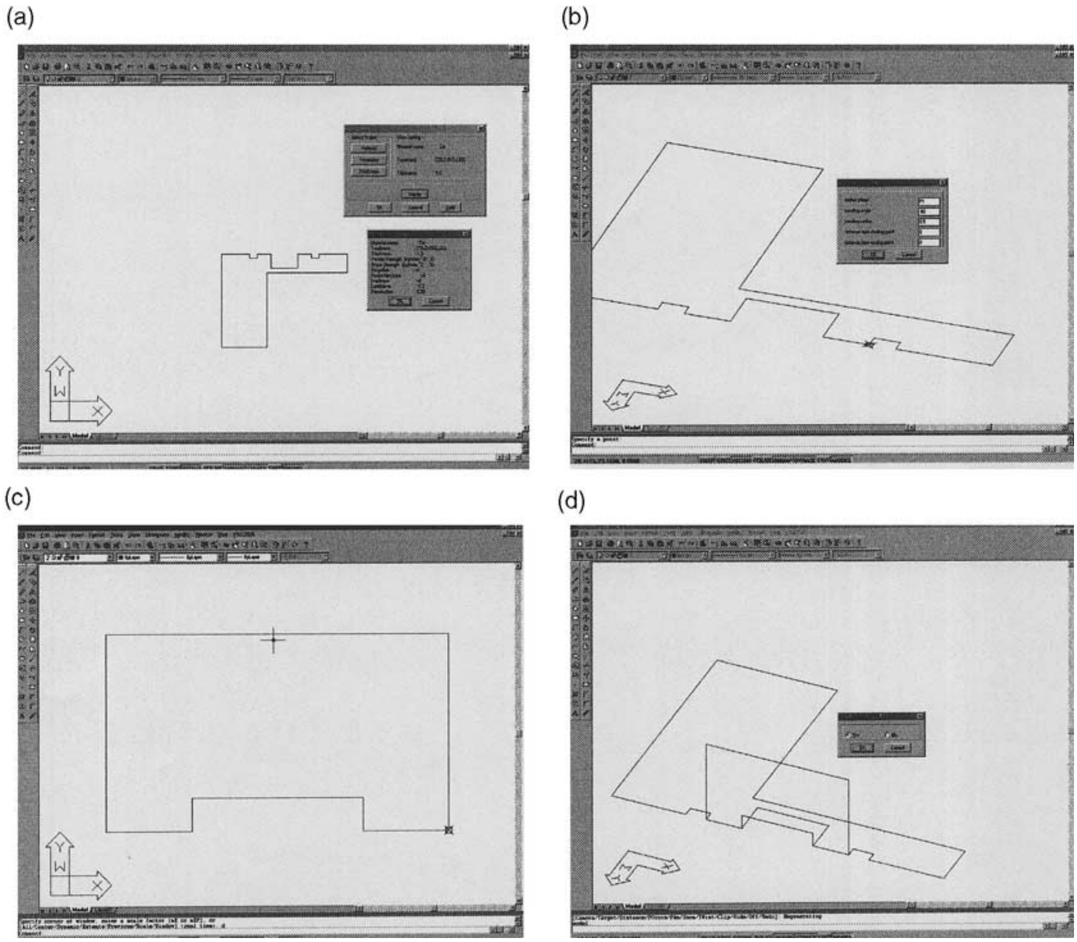



**Fig. 11.** Inputting shape data of each plane.

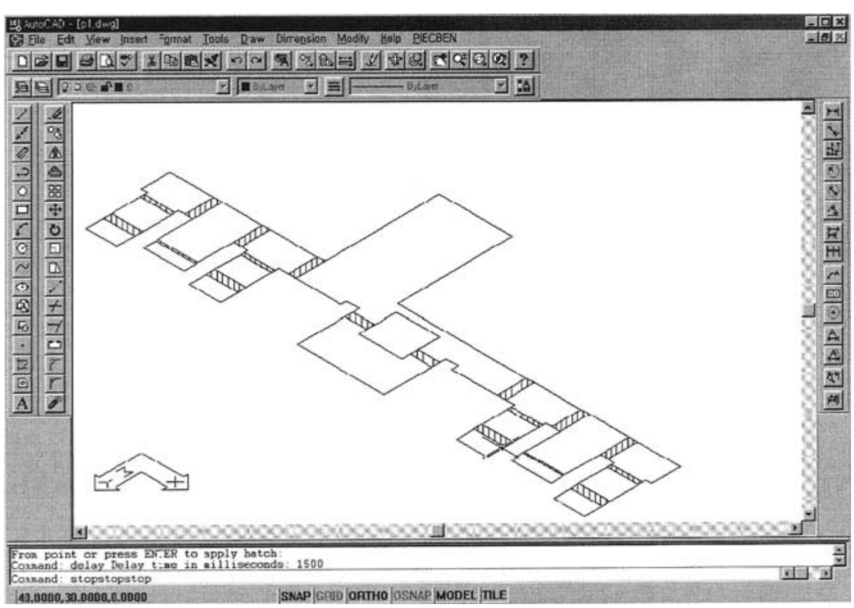



**Fig. 12.** Results in the flat pattern layout module.

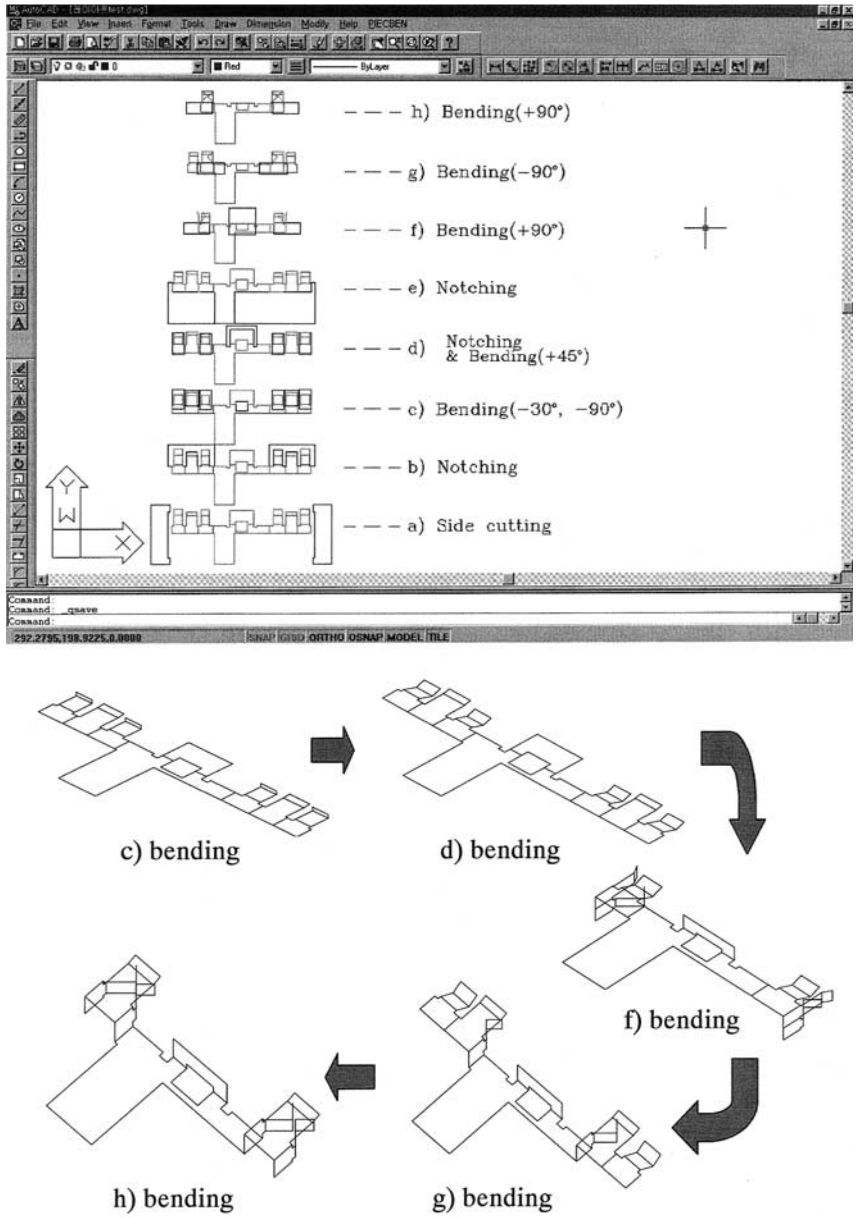



**Fig. 13.** The strip layout drawings generated in the strip layout module.

**Table 2.** The results of force and shear length calculated in each stage.

| Stage | Shear length (mm) | Blanking force (kg) | Bending force (kg) | Total force (kg) |
|---|---|---|---|---|
| 1 | 190.286 | 5708.58 | 0 | 5708.58 |
| 2 | 268.311 | 8049.33 | 0 | 8049.33 |
| 3 | 0 | 0 | 963.63 | 963.63 |
| 4 | 80.036 | 2401.08 | 208.58 | 2609.66 |
| 5 | 206.508 | 6195.24 | 0 | 6195.24 |
| 6 | 0 | 0 | 156.432 | 156.432 |
| 7 | 0 | 0 | 83.43 | 83.43 |
| 8 | 0 | 0 | 83.43 | 83.43 |
| Total | 745.141 | 22354.23 | 1495.502 | 23849.732 |

the strip are carried out as shown in Fig. 13(*d*). The bending in Fig. 13(*f*) is carried out through the notching process in Fig. 13(*e*). Two types of bending (the bending to the feeding direction occurrs in the middle part, and the bending perpendicular to the feeding direction occurs in both ends of the strip) are carried out and are shown in Fig. 13(*f*). There are six bending operations perpendicular to the feeding direction, three at each side. Among the bending operations perpendicular to the feeding direction, the bending in the middle part is preferentially carried out to prevent interference, as shown in Fig. 8. According to the design rule, the bending operations are carried out and are shown in Fig. 13(*g*, *h*). Finally it generates the 3D strip layout drawing, as shown in Fig. 13.

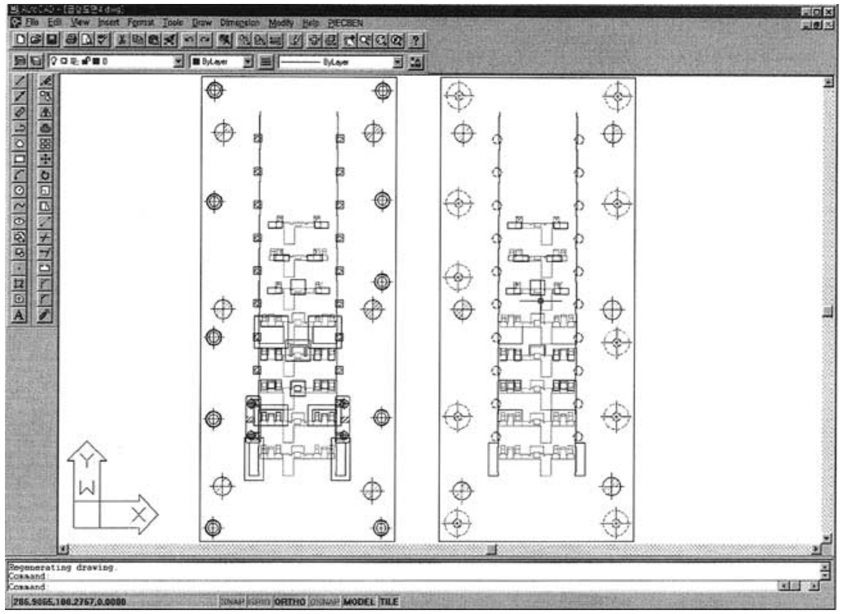


**Fig. 14.** The die layout drawing generated in the die layout module.

### 4.4 Application to the Die Layout Module

Based on the value of the "strip layout area", after obtaining the length and width of the die block, the dimensions of the die block are standardised to the nearest dimensions of a die block saved in the database. Based on the dimensions of a standardised die block, the thickness of the die block, the minimum distance from the side of the die block to the dowel pin and fastener and the diameter of the dowel pin and fastener are obtained from the database. According to the size of the die block, the number of guide pins arranged in the upper and lower dies is six. Using the working force calculated in the strip layout and the die layout rules 2 and 3, the number of fasteners is 10. The fasteners are checked for interference with the guide pins and arrayed on the same pitch. In case of interference, they are arrayed at non-interfering positions. According to the stripping force calculated, there are 10 springs according to die layout rule 4 in the upper die. They are also arrayed at positions shown in Fig. 14, after checking for interference with the fasteners and guide pins. The lift pins are arrayed on the same pitch in non-interfering positions.

The dimensions of the parts which are to be pierced are the same as those of the punch, and the dimensions of the parts which are to be blanked are the same as those of the die. Results obtained using the modules enable the designer and manufacturer of piercing and bending dies to be more efficient.

## 5. Conclusion

The study developed an automated process planning and die design system capable of generating a 3D strip layout drawing for an electric product involving bending and piercing operations for progressive working operations.

It has the following features:

1. A 3D progressive strip layout drawing is generated in graphic form for an electric product involving bending and piercing operations.
2. A list of internal and external shapes and bending line are automatically recognised and a flat pattern layout drawing is generated in the flat pattern layout module.
3. Using the results of the strip layout module, the die layout module generates part drawings and an assembly drawing of the die set in graphic form.

This system quantifies techniques and experience needed in designing strip layout and standardises design rules for formulating design procedures. By developing an automated process planning and die design system on AutoCAD, the system, linked with other CAM software, can generate NC data automatically which is suitable for working operations, so a CAD/CAM system for electric product requiring piercing and bending operations may soon be developed.

*Acknowledgements*

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