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A Design Method for Pin Holding Type Jig

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SYNOPSIS

Multi-item flexible manufacturing systems have been spread to correspond the short life-cycle and the diversification of products. Part handling plays an important role to operate multi-functional robot efficiently in these systems, and many jigs are widely used to hold a part. They should be exchanged at once according to changing products.

In this paper, we propose a pin jig which holds a part with two pins, and design method of the position, length and diameter of those pins for a cylindrical part. This jig has the following characteristics. As a surface of the jig is inclined to use gravity, the part can be fixed without any external forces. Therefore the structure of jig becomes simple, and loading and unloading of a part becomes easy for a robot hand.

1. INTRODUCTION

Automatic assembly machines and robots have been introduced to construct multi-item flexible manufacturing systems to correspond the short life-cycle and the diversification of products [1, 2]. Whenever their products will be changed, manufacturing line, robots, jigs, etc. should be slightly readjusted. In such a situation, a line and a robot can not be easily changed according to their high cost and difficulty of rearrangement. But even if in the lines have been introduced

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multi-functional robots, the jigs holding parts should be exchanged according to changing products. So the jig structure should be simple, the part should be held stably against external forces, and grasped easily by robot hands.

There are many types of jigs, for example, screw tightening type, pin hold type, spring hold type [3]. As the bolt or spring is used the external force to fix a part, there exists a possibility to deform the part. The accuracy to fix the part is proportional to the complexity of the jig, and more complex structure becomes more expensive. Therefore it is necessary that the jig can be made easily, and its structure is simple.

This paper proposes a method to design the pin hold type jig which can be used to fix the part by pins. In the design of this jig, it is assumed that the shape of the part is cylindrical because it is widely used, and a part is held by two pins. The two fingers of the robot hand act in a parallel way, and the grasping direction is perpendicular to the gravity along the surface of jig [4]. Under these conditions, the pin dimensions, such as, the position, length and diameter are calculated.

2. THE CHARACTERISTICS OF THE PIN JIG

The parts are brought up or down vertically by a robot hand, and slide down on the flat surface of jig palette which is inclined α degree. The part is held by two pins. The feature of this jig is shown in Fig. 1.

The pin jig is designed under the following conditions :

1) Parts can be fixed without any artificial external force. When a robot hand grasps or releases a part, a high accuracy of handling is not required.

2) The part is not tightly bound by the pins, and there is no gap between the pin and the part.

3) The statistical deviation of the size of the part does not affect the holding mechanism.

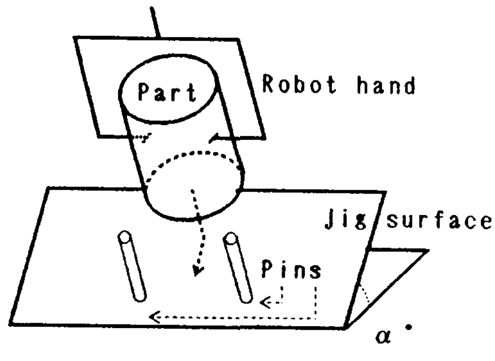

Fig. 1. The feature of pin jig.

3. DESIGN METHOD

3.1 Coordinate System

The coordinate system of this pin jig is shown in Fig. 2. It is assumed that the jig surface is the reference plane (X-Y plane), the center of gravity (G) on X-Y plane is the original coordinate (0,0,0), the perpendicular axis through original coordinate is Z-axis, the coordinate of center of gravity is G = $(0,0,Z_G)$, the grasping position of left finger is L1 = (X_{P1},Y_{P1},Z_{P1}), right one is L2 = (X_{P2},Y_{P2},Z_{P2}), the coordinate of one tip of the pin is S_{t1} = (X_{s1},Y_{s1},Z_{s1}), the other S_{t2} = (X_{s2},Y_{s2},Z_{s2}), and those of pins on X-Y plane are S_{b1} = $(X_{s1},Y_{s1},0)$, S_{b2} = $(X_{s2},Y_{s2},0)$.

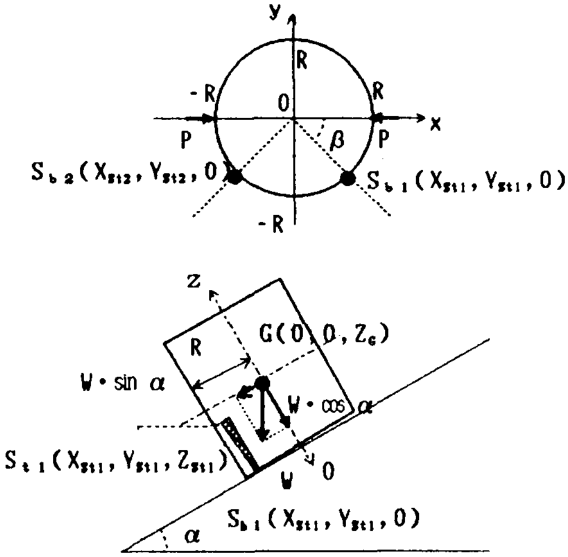

Fig. 2. Coordinate system

The weight of a part is W grams (g), the grasping force of hands is P (g), the diameter of the cylindrical object is 2R (mm), the friction coefficient on X-Y plane is μ, and the angle between horizontal plane and X-Y plane is α (degrees).

3.2 The Location of the Pin.

Because of the symmetry of the part on X-Y plane, the analysis is shown about only one pin (S_{t1}).

The X-Y plane is inclined α degrees, and the downward force (P_1) along the X-Y plane is given by the equation (1) [5].

$$P_1 = W \cdot (\sin\alpha - \mu \cdot \cos\alpha) \tag{1}$$

The resultant ($\bar{P}$) is calculated from the downward force (P_1) and the grasping force (P). γ is denotes the grasping angle between P and X-axis.

$$\bar{P} = \sqrt{(P \cdot \cos\gamma)^2 + (P_1 + P \cdot \sin\gamma)^2} \tag{2}$$

Let θ be the angle between $\bar{P}$ and X-axis. θ is obtained from P, P_1 and γ as follows.

$$\theta = \tan^{-1}\{(P_1 + P \cdot \sin\gamma) / (P \cdot \cos\gamma)\} \qquad (3)$$

Let β be the angle between the X-axis and the line passed from the pin (S_{b1}) to the center of gravity (G) of the part. P_2 is put as the tangential force at S_{b1}, P_3 the force along the external normal line at the pin (S_{b1}), and μ_1 the friction coefficient between a part and a pin.

The moment of rotation around the pin is considered. Let a downward moment of rotation along X-Y plane be M_d, and a clockwise moment be M_r. The distances from the pin to the load points are ℓ_1, and ℓ_2.

M_d and M_r are calculated from P, P_1, and R as follows.

$$M_d = \ell_1 \cdot P_1 = R \cdot \cos\beta \cdot P_1 \qquad (4)$$
$$M_r = \ell_2 \cdot P = R \cdot \sin(\beta - \gamma) \cdot P \qquad (5)$$

If the condition ($M_r > M_d$) is satisfied, the part is rotated clockwise around the pin. Then the pin location is calculated under $M_r \leqq M_d$. The relation of β and γ is shown as follows.

$$P \cdot R \cdot \sin(\beta - \gamma) \leqq P_1 \cdot R \cdot \cos\beta \qquad (6)$$
$$\sin(\beta - \gamma) \leqq (P_1 / P) \cdot \cos\beta$$
$$\beta - \gamma \leqq \sin^{-1}\{(P_1 / P) \cdot \cos\beta\}$$

β is satisfied the equation as follows (7).

$$\gamma \geqq \beta - \sin^{-1}\{(P_1 / P) \cdot \cos\beta\} \qquad (\beta > 0) \qquad (7)$$

There is other relation between θ and β from the balance of force at the pin. The direction of tangential force of $\bar{P}$ is changed downward or upward according to $\theta > \beta$ or $\theta < \beta$. So the balance of force is considered under two cases.

i) $\theta > \beta$

In this case, the direction of $\bar{P}$ is downward along X-Y plane as shown in Fig. 3. P_2 is obtained from the following equation.

$$P_2 = \bar{P} \sin(\theta - \beta) - \bar{P} \cdot \mu_1 \cdot \cos(\theta - \beta) \qquad (8)$$

If $P_2 \leqq 0$, the part can be supported by the pin. Therefore the area satisfying the inequality $P_2 \leqq 0$ is shown as follows.

$$\bar{P} \cdot \sin(\theta - \beta) - \bar{P} \cdot \mu_1 \cdot \cos(\theta - \beta) \leqq 0$$
$$\sin(\theta - \beta) \leqq \mu_1 \cdot \cos(\theta - \beta)$$
$$\tan(\theta - \beta) \leqq \mu_1$$
$$\theta - \beta \leqq \tan^{-1}\mu_1$$

$$\beta \geqq \theta - \tan^{-1}\mu_1 \qquad (9)$$

ii) $\theta < \beta$

In this case, the direction of $\bar{P}$ is upward along X-Y plane. P_2 is obtained from the following equation.

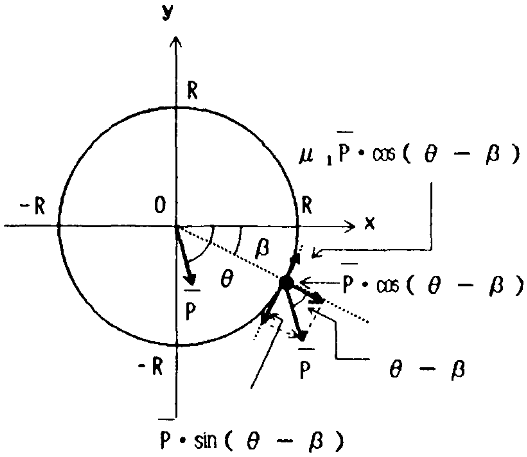

Fig. 3. The relation between pin position and $\bar{P}$ in case of $\theta > \beta$

$$P_2 = \bar{P}\sin(\beta - \theta) - \bar{P}\cdot\mu_1\cdot\cos(\beta - \theta) \qquad (10)$$

If $P_2 > 0$, the part will be slid upward by tangential component of force ($\bar{P}$). Therefore the area satisfying the inequality ($P_2 \leqq 0$) is shown as follows.

$$\bar{P} \cdot \sin(\beta - \theta) - \bar{P} \cdot \mu_1 \cdot \cos(\beta - \theta) \leqq 0$$
$$\sin(\beta - \theta) \leqq \mu_1 \cdot \cos(\beta - \theta)$$
$$\tan(\beta - \theta) \leqq \mu_1$$
$$\beta - \theta \leqq \tan^{-1}\mu_1$$

$$\beta \leqq \theta + \tan^{-1}\mu_1 \qquad (11)$$

From the inequality (9) and (11), β is satisfied the following inequality as shown in Fig. 4.

$$\theta - \tan^{-1}\mu_1 \leqq \beta \leqq \theta + \tan^{-1}\mu_1$$
$$0 < \beta < 90° \;,\quad 0 < \theta < 90° \qquad (12)$$

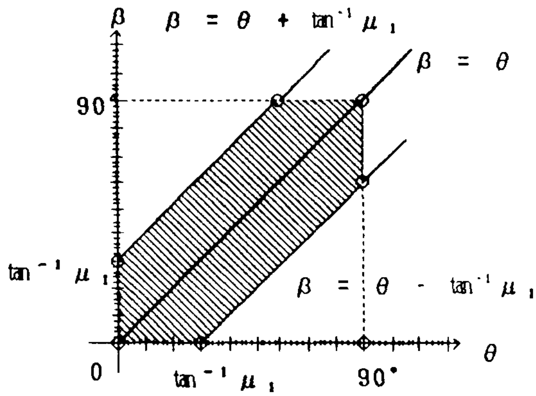

Fig. 4. The relation between β and θ.

As angle (β) is obtained from the above relations, the coordinate (X_{a1}, Y_{a1}) of pin is calculated as follows.

$$X_{s1} = -R \cdot \cos\beta$$
$$Y_{s1} = -R \cdot \sin\beta \qquad (13)$$

The coordinate (X_{s2}, Y_{s2}) of the other pin which is shown symmetry with respect to Y-axis, is determined from the equations (14).

$$X_{s2} = R \cdot \cos\beta$$
$$Y_{s2} = -R \cdot \sin\beta \qquad (14)$$

3.3 The Length of Pin

The length of pin is calculated on the basis of balance of moment at the pin tip (S_{t1}).

The moment of force which presses down the X-Y plane in a clockwise direction is shown by R, W and α as follows.

$$R \cdot W \cdot \cos\alpha \qquad (15)$$

And the moment of force in a counterclockwise direction at the tip of the pin is calculated as follows.

$$\bar{P} \cdot (Z_G - Z_{s1}) \qquad (16)$$

If the moment of (15) is larger than that of (16), the part rotated at the tip of the pin and falls down. Then the relation of these moment are satisfied the following.

$$\bar{P} \cdot K \cdot (Z_G - Z_{s1}) \leqq R \cdot W \cdot \cos\alpha \qquad (17)$$

In this relation, K is the safety coefficient. And Z-coordinate (Z_{s1}) of the pin should be satisfied the following equation.

$$Z_{s1} \geqq Z_G - R \cdot W \cdot \cos\alpha \;/\; (K \cdot \bar{P}) \qquad (18)$$

Z_{s1} is determined as the value of left side of the inequality (18). And it is assumed that Z_{s2} is equal to Z_{s1}.

3.4 The Diameter of Pin.

The pin should be proofed the strength against $\bar{P}$. The diameter of the pin is calculated from the following equations.

The load on the pin (Q_{s1}) is shown by β and $\bar{P}$.

$$Q_{s1} = \bar{P} \cdot \cos(\beta - \theta) \tag{19}$$

The maximum bending moment (M_{s1}) at S_{t1} is given as follows.

$$M_{s1} = Q_{s1} \cdot Z_{s1} \tag{20}$$

The diameter of the pin (d_{s1}) is calculated from the equation (21) [6].

$$d_{s1} = \sqrt[3]{32 \cdot M_{s1} / (\sigma \cdot \pi)} \tag{21}$$

where σ is approval stress.

4. APPLICATION

We designed the pin holding jig for the parts of the electric motor to assemble in the automated flexible assembly line. This motor was composed of five parts of cylindrical shape : upper cover, stator, lower cover, rotor and bearing. The specification of this motor was shown in Table 1.

The center of gravity of the part were calculated with its cross section using image processing device which was developed to measure three dimensional shape.

Position, length and diameter of the pin for parts of a motor were calculated under the condition that σ was 3.0 kg/mm^2, μ and μ_1 were 0.36, and α was 30 degree.

Table 1. The specification of the motor parts.

	Diameter(mm)	Height (mm)	Weight (g)
Upper cover	100.0	20.0	133.0
Stator	100.0	71.5	1491.2
Rotor	53.0	112.0	649.0
Lower cover	44.0	3.6	24.7
Bearing	26.0	8.0	18.7

In these parts, the pin jig was designed for upper cover. The coordinate of center of gravity (G) of this part was (0, 0, 14.5), its weight (W) was 133 (g), its diameter (2R) was 100 (mm) and its height was 20 (mm).

And grasping points (L1, L2) of the robot finger were given as follows.

$$L1 = (-50.0\ ,\ 0\ ,\ 10.0)$$
$$L2 = (\ 50.0\ ,\ 0\ ,\ 10.0)$$

The holding force (P) of hands was put as 200g, and the direction of holding force was parallel to the X-axis (θ = 0).

(1) The location (X_{s1}, Y_{s1}), (X_{s2}, Y_{s2}) of the pin.

The value of force (P_1) was calculated from the equation (1).

$$P_1 = W(\sin\alpha - \mu \cdot \cos\alpha) = 133.0 * (\sin 30° - 0.36 \cdot \cos 30°) = 25.03\ (g)$$

The value of angle (θ) and resultant ($\bar{P}$) were calculated from the equation (2) and (3).

$$\bar{P} = \sqrt{(P\cdot\cos\theta)^2 + (P_1 + P\cdot\sin\theta)^2}$$
$$= \sqrt{(200 \cdot \cos 0)^2 + (25.03 + 200\cdot\sin 0)^2} = 201.56(g)$$
$$\theta = \tan^{-1}(P_1 / P) = \tan^{-1}(25.03 / 200) = 7.13°$$

The area of β was determined from inequality (6) and (7).

$$200 \cdot 50 \cdot \sin(\beta - 0) \leqq 25.03 \cdot 50 \cdot \cos\beta$$
$$\tan\beta \leqq 0.125$$
$$0 < \beta \leqq 7.13° \qquad (22)$$

μ_1 and θ were substituted in the inequality (12), the area of β was obtained as follows.

$$\theta - \tan^{-1}(\mu_1) \leqq \beta \leqq \theta + \tan^{-1}(\mu_1)$$
$$7.13 - \tan^{-1}(0.36) \leqq \beta \leqq 7.13 + \tan^{-1}(0.36)$$
$$-12.67 \leqq \beta \leqq 26.92° \qquad (23)$$

β was determined as the maximum value which satisfied (22) and (23) simultaneously. Therefore β was put as 7.13°.

The coordinate of the pin S_{b1} is determined from the equation (13), (14).

$$\begin{cases} X_{s1} = -R\cdot\cos\beta = -50 \cdot \cos 7.13° = -49.61\ (mm) \\ Y_{s1} = -R\cdot\sin\beta = -50 \cdot \sin 7.13° = -6.21\ (mm) \end{cases}$$

$$\begin{cases} X_{s2} = R \cdot \cos\beta = 50 \cdot \cos 7.13° = 49.61 \ (\mathrm{mm}) \\ Y_{s2} = -R \cdot \sin\beta = -50 \cdot \sin 7.13° = -6.21 \ (\mathrm{mm}) \end{cases}$$

(2) The length (Z_{s1}) of the Pin.

The length of the pin was determined under the condition of K = 2 from the equation (18).

$$\begin{aligned} Z_{s1} &\geqq Z_G - R \cdot W \cdot \cos\alpha \ / \ (K \cdot \bar{P}) \\ &\geqq 14.5 - 50 \cdot 133.0 \cdot \cos 30° \ / \ (2 \cdot 201.56) \\ &\geqq 0.21 \end{aligned} \tag{24}$$

The length of the pin was determined as the minimum value which satisfied the equation (24). Therefore Z_{s1} was put as 0.21 (mm).

(3) The diameter (d_{s1}) of the pin

The diameter of the pin was satisfied the equations (19) ~ (21).

$$\begin{aligned} Q_{s1} &= \bar{P} \cdot \cos(\beta - \theta) \\ &= 201.56 \cdot \cos 0 = 201.56 \\ M_{s1} &= Q_{s1} \cdot Z_{s1} \\ &= 201.56 \cdot 0.21 = 42.33 \\ d_{s1} &= \sqrt[3]{32 \cdot M_{s1} \ / \ (\sigma \cdot \pi)} \\ &= \sqrt[3]{32 \cdot 42.33 \ / (3000.0 \cdot \pi)} \\ &= 0.53 \ (\mathrm{mm}) \end{aligned}$$

The pin position of the upper cover is shown in Fig. 5.

The results of the other parts, such as, rotor, lower cover, bearing and stator were shown in Table 2.

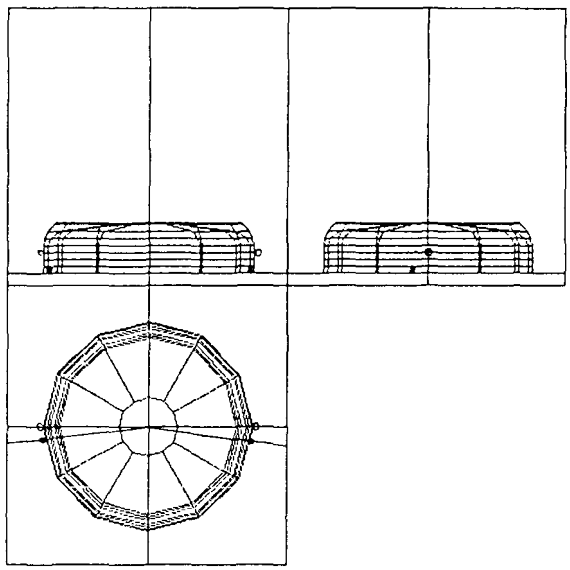

Fig. 5. The pin position of the upper cover.
o : holding position
· : pin position

Table 2. The results of the motor parts.

	Upper cover	Stator	Rotor	Lower cover	Bearing
Center of gravity G (mm) (0,0,Z_G)	(0,0,14.5)	(0,0,34.1)	(0,0,42.9)	(0,0,1.1)	(0,0,3.9)
Weight of part W(g)	133.0	1491.2	649.0	24.70	18.70
Work point of hand (mm) L1 (X_1,Y_1,Z_1)	(-50.0,0,14.5)	(-50.0,0,45.0)	(-26.5,0,42.9)	(-22,0,0,0.8)	(-13.0,0,3.9)
L2 (X_2,Y_2,Z_2)	(50.0,0,14.5)	(50.0,0,45.0)	(26.5,0,42.9)	(22.0,0.0,0.8)	(13.0,0,3.9)
Holding force P (g)	200.0	2240.0	970.0	37.0	28.0
Position of pin (mm) Left S1 (X_1,Y_1,Z_1)	(-49.61,-6.21,0.21)	(-49.61,-6.21,35.28)	(-36.30,-3.29,35.28)	* (-21,83,-2.73,0.01)	(-12.90,-1.61,0.17)
Right S2 (X_2,Y_2,Z_2)	(49.61,-6.21,0.21)	(49.61,-6.21,35.28)	(36.30,-3.29,35.28)	(21,83,-2.73,0.01)	(12.90,-1.61,0.17)
Diameter of pin (mm) Left d_1	0.53	6.17	4.89	* 0.11	0.25
Right d_2	0.53	6.17	4.89	0.11	0.25

Notes : *K=16

The rotor was consisted of the magnetic core (width 45 mm, and diameter 53 mm ϕ) and the rotation axis of 9 mm ϕ. The core was inserted at 20 mm from the end of rotation axis. As the coordinate of the center of gravity was (0,0,42.9), the part could not stand alone stably. However, this part was able to fix stable with two pins by the proposed method as shown in Fig. 6.

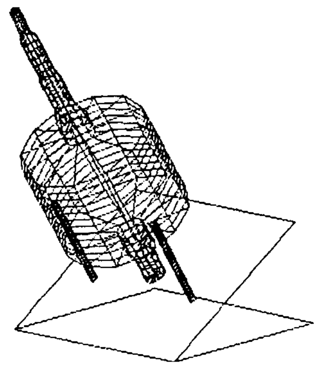

Fig. 6. The three dimensional shape of the rotor.

5. CONCLUSIONS

In this paper, we proposed the design method of a pin jig to hold a part for a flexible assembly line.

The characteristic of the proposed method is as follows.

1) As a part slid on inclined surface of jig by the gravity, the part can be fixed without any artificial external forces, and the structure become simple. Furthermore the robot hand does not require high accuracy to grasp a part.

2) A part on the jig is held by two pins. And the pin position is determined on the basis of the friction coefficient between a part and jig surface, the grasping position and force of the robot hand, and weight of the part. The length of the pin is calculated according to the balance of the moment of rotation which is taken

into consideration of the safety coefficient at the pin, and its diameter is calculated taking in account the moment of rotation at the pin tip.

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