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On the Adsorptive Force in the Sucking Grasp as the Contact Surface was flat.

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SYNOPSIS

The sucking grasp, for example, the silicon or the rubber sucker has been used widely to handle the parts in various stages of the automated process.

But in order to use the sucking grasp more widely, it is necessary to develop the other type of sucking unit.

In this paper, we examined the distribution of the vacuum pressure in the contact surface and estimated the adsorptive force from the vacuum pressure, the area of the contact surface, the area or the number of sucking holes, and a gap or a roughness of surface under the contact condition that the flat surface of the sucking unit sucked up the flat surface of an object.

The vacuum pressure in the contact surface decreased exponentially, as the distance from the edge of the sucking hole became long. And the adsorptive force was estimated from the equation $Y=1.147 \cdot P \cdot S \cdot (S/M)^{-0.6}$ in the case of one sucking hole. It is necessary to consider the interaction between two sucking holes which were only separated by a very close distance to estimate the adsorptive force in case of many sucking holes.

The adsorptive force became weak, as the gap

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between contact surfaces was larger than 0.16 mm, or the roughness of the surface of object was larger than 150 μm.

1. Introduction

The mechamism of the sucking grasp has been used widely to handle the material because of the simple construction and the simple control, if an object has a adsorptive plane. [1,2]

As the contact between an object and the sucking area is a point or a open line, the adsorptive force becomes weak because of the low airtight condition. But as the contact is a closed line or a surface, the force becomes strong.

In this paper, as the contact surface was flat, it was examined how the adsorptive force was varied by the condition of the adsorptive plane of an object and of the sucking plane.

2. Factors influenced to the adsorptive force.

The following notation was used to show the factor of the sucking grasp. In this paper, it is assumed that an object has a plane to be sucked up and the sucking unit has a plane.

Fig.1 showed the sucking elements. The sucking plane could be exchanged by the experimental condition, that is, the area of the sucking plane, the area of the sucking hole, and the number of the sucking hole.

The object has a plane to be sucked up. This plane was denoted by the adsorptive plane in the latter.

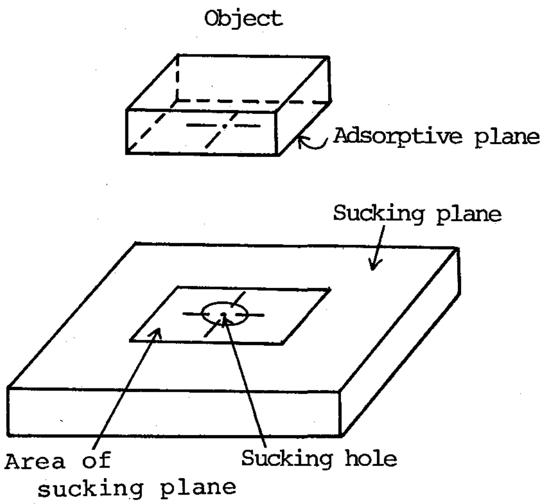


Fig.1, The elements composed of the sucking grasp

1) The area of the adsorptive plane :M.
2) The area of the sucking plane :SP.

It was assumed that the area of the sucking plane (SP) is greater than that of the adsorptive plane.

3) The area of the sucking hole: S.

The area to give the sucking force to an object. As the radius of a hole denotes r, the area (S) becomes as follows. $S=\pi r^2$.

4) The vacuum pressure: P.

The force to suck up the object.

5) The amount of flow: Q.

The flow volume under the sucking condition that the sucking plane sucked up the adsorptive plane.

6) The distribution of the vacuum pressure.

The distribution of the pressure in the contact surface under the sucking condition.

7) The number of the sucking hole: n.

8) The useful sucking area: Z.

The area to estimate the adsorptive force from the distribution of the vacuum pressure.

9) The gap: h.

The gap between the adsorptive plane and the sucking plane.

10) The roughness: W.

The roughness of the adsorptive plane of an object.

11) The relation among the factors.

As the adsorptive force = vacuum pressure x area x effect of gap or roughness, the relation between the adsorptive force and these three factors was made clear under the condition that the contact surface was flat.

3. Experimental Equipment

The equipment was composed of the vacuum pump, the control valve, the merecury manometer, the flow meter, and the sucking unit connected by the silicon hose each other.

The other part to measure the adsorptive force was composed of the hook went up and down, and the spring balance. The one side of the spring balance was fitted up the object and the other the hook.

The hook went up slowely and the indication of the spring balance was read at the instance coming off the object from the sucking plane. The measurement repeated seven times in one condition, and the mean value of the indications except for maximum and minimum values was calculated.

This value was the adsorptive force (gf). The maximum vacuum pressure (mmHg) and the maximum amount of flow of one vacuum pump were 62.8 mmHg and 64 l/min. And those of the other one were 600 mmHg and 140 l/min. The maximum flow of the flow meter used was 0.5, 4, 30, 60, and 200 l/min.

The object was made by the acrylic plate and has the different area of the adsorptive plane.(Fig.2)

The sucking unit was composed of the body and the sucking plane made by acrylic plate. The sucking plane was exchangable.(Fig.3,4)

As the sucking hole was one, it was located at the center of the sucking plane. And as the number of holes was greater than two, they were located symmetrically in the area of 2 x 3 cm^2 at the center of the sucking plane.

There was the adsorptive plate that was made the small holes (1mmϕ) located in the concentric circle round the center of the sucking hole.

This plate was used to measure the distribution of the vacuum pressure in the contact surface.

4. Experimental Condition

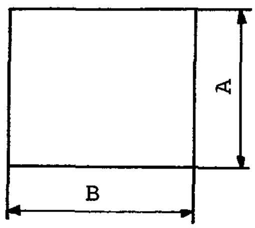
4.1 The loss of vacuum pressure.

The loss of vacuum pressure and the amount of flow were measured under the condition that the sucking plane (C11) sucked up the object (A7). The vacuum pressure was set as the following six levels (60, 200, 300, 400, 500, 600 mmHg).

4.2 The adsorptive force.

The adsorptive force was measured under the combination of the sucking plane (C6~C11) and the object (A1~A7).

Further the effect of the number of sucking hole to the adsorptive force was examined under the condition that the sucking plane (C12~C23) sucked



Adsorptive part NO.	A (mm)	B (mm)	Area of adsorptive plane (cm^2)
A1	20	30	6
A2	30	30	9
A3	30	40	12
A4	40	40	16
A5	40	50	20
A6	50	60	30
A7	60	70	42

Fig.2, The object

up the object (A1 and A3).

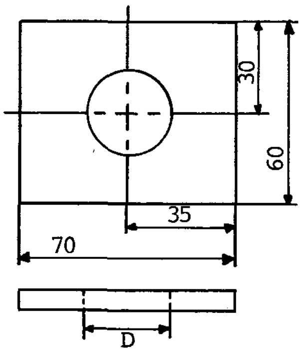
4.3 The distribution of the vacuum pressure in the contact surface

The distribution of the vacuum pressure was measured by the manometer connected to the small holes (1mmϕ) of the adsorptive plate which was sucked up by the sucking plane (C1~C5, and C7).

4.4 The gap or the Roughness.

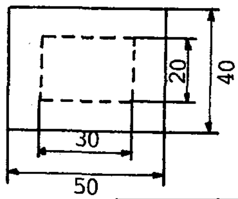
The gap between the adsorptive plane and the sucking plane was set as the following seven levels (0.063, 0.125, 0.161, 0.188, 0.250, 0.375, 0.5 mm) in Fig.5. And the amount of flow and the distribution of the vacuum pressure was measured under the condition that the sucking plane (C24~C26) sucked up the object (A5~A7).

The roughness of the adsorptive plane was varied by the abrasive paper having the different grain size (28, 57, 120, 150, 300 μm, JIS-



Sucking Plane NO.	D (mm)	Area of sucking hole (cm^2)
C 1	2.3	0.042
C 2	3.4	0.091
C 3	4.5	0.159
C 4	5.2	0.212
C 5	6.4	0.322
C 6	7.0	0.385
C 7	8.8	0.608
C 8	12.5	1.227
C 9	16.1	2.036
C 10	19.6	3.016
C 11	25.3	5.027

Fig.3, The sucking plane in the case of one sucking hole



Sucking Plane NO.	Number of sucking hole	Diameter of sucking hole (mm)
C12	1	9.0
C13	2	6.4
C14	3	5.2
C15	4	4.5
C16	5	4.0
C17	6	3.7

Sucking Plane NO.	Namber of sucking hole	Diameter of sucking hole (mm)
C18	7	3.4
C19	8	3.2
C20	9	3.0
C21	10	2.8
C22	12	2.6
C23	15	2.3

Fig.4, The sucking plane in the case of many sucking holes

R6001).[3]

The amount of flow, the vacuum pressure, and the adsorptive force were measured under the condition that the sucking plane (C9) sucked up the object (A5) which was adhered the abrasive paper on the adsorptive plane.

5. Results.

5.1 The loss of vacuum pressure and the amount of flow.

The loss of vacuum pressure was about 1.9~5.2% (mean = 4.5%) for the given pressure, as the sucking plane and the adsorptive plane were made by the acrylic plate.

As the pressure in the sucking hole denotes P',

$P' = 0.955P$. --- (1)

Further as the amount of folw (Q) was linear to the pressure (P') under the sucking condition that the sucking unit sucked up the adsorptive plane.

$Q = 0.002P'$. --- (2)

5.2 The distribution of the vacuum pressure.

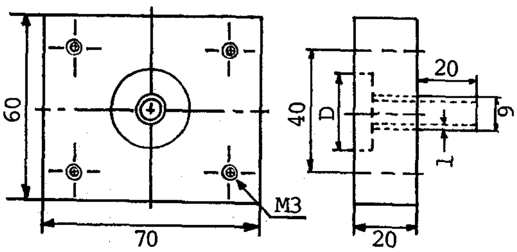
In the sucking hole, the distribution of the vacuum pressure was uniform and the equation (1) was established in the case of one sucking hole [4].

In the contact surface between the adsorptive plane and the sucking plane, the vacuum pressure dicreased exponentially as the measurement point went away from the edge of the sucking hole. (Fig.6,7)

As the distance from the edge of the sucking hole was put as X, the rate (P_R) of the vacuum pressure (P_S) for P' at X was shown as follows from the regression analysis.

$P_R = P_S/P' = EXP(-0.423X)$ ----(3)

where P' was the vacuum pressure at the sucking hole.



Sucking Plane NO.	D (mm)	Area of sucking hole (cm^2)
C 24	16.4	2.112
C 25	24.0	4.524
C 26	35.0	9.621

Fig.5, The sucking plane in the case of the gap

5.3 The adsorptive force in the case of one suckiing hole.

The adsorptive force was measured at 60,200,400, and 600 mmHg of the vacuum pressure (P). The adsorptive force (Y) was estimated as the following equation from the regression analysis.

$$Y = 1.147 \cdot P \cdot S \cdot (S/M)^{-0.6} \quad --- (4)$$

S: the area of the sucking hole (cm^2)

M: the area of the sucking plane (cm^2)

5.4 The adsorptive force in the case of many sucking holes.

The adsorptive force increased with the number of sucking hole and became stable at five or six sucking holes. (Fig.8)

As the total area of the sucking holes was equal inspite of the number of sucking holes in this experiment, it was considered that the interaction among the sucking holes influenced to the increment of adsorptive force. This phenomenon was explained from the useful sucking area defined as follow.

1) The definition of the useful sucking area.

As the surcomference of the sucking hole was airtight, the area of the sucking hole (S) was equal to the sucking area (M), that is, S=M.

Then the adsorptive force was obtained logically as follows.

$$Y = 1.36 \cdot P \cdot S \quad --- (5)$$

But as the surcomference of the sucking hole was not airtight, the sucking area which generates the adsorptive force is more wide than the area of

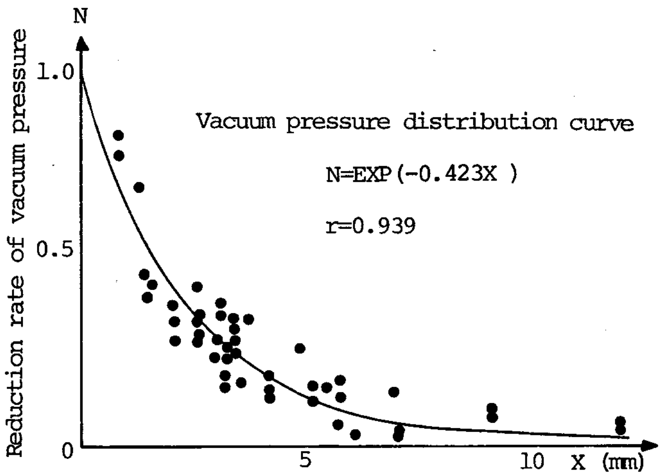


Fig.6, The distribution of the vacuum pressure under the contact condition

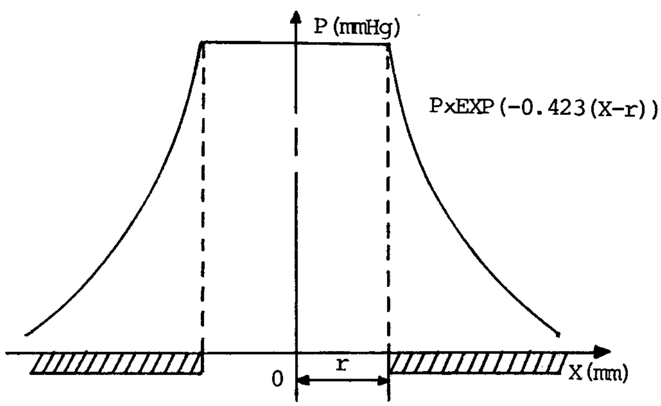


Fig.7, The distribution of the vacuum pressure in the case of one sucking hole sucking hole (S). From the equation (4), $Y=1.147 \cdot P \cdot S$, as S=M and the acrylic sucking plane was used. Then the fall of adsorptive force was $16\%=(1-1.147/1.36)\cdot 100$ for the logical one.

Therefore, the useful sucking area (Z) defined as follows on the sucking plane.

$$Z = \pi(D_Z+r)^2 \quad \text{---(6)}$$

where : $0.84 = EXP\{-0.423(D_Z)\}$ in equation (3)

2) The useful sucking area in the case of one sucking hole.

From the equation (6), the useful sucking area was as follows.

$$Z = \pi\{r+(\log 0.84)/(-0.423)\}^2 \quad \text{---(7)}$$

r:radius of the sucking hole

3) The useful sucking area in the case of many sucking holes.

The distribution of the vacuum pressure under two sucking holes adjacent to each other was shown in Fig.9 in a section cut by axial plane through the centers of two sucking holes. It was assumed that the adsorptive force was generated from the sum of two vacuum pressure distributed by the equation (3) in the contact surface.

As r_1 and r_2 were the radiuses, d was the distance between centers of two sucking holes, and X was the distance from the edge of one sucking hole, the rate of the vacuum pressure (R) was as follows from the equation (3).

$$R=EXP(-0.423X)+EXP\{-0.423(d-r_1-r_2-X)\} \quad \text{--(8)}$$

And as R put as 0.84,

$$X=\log\{(0.84\pm\sqrt{0.84^2-4K})/2K\}/0.423 \quad \text{---(9)}$$

$$K=EXP\{-0.423(d-r_1-r_2)\}$$

For each sucking hole

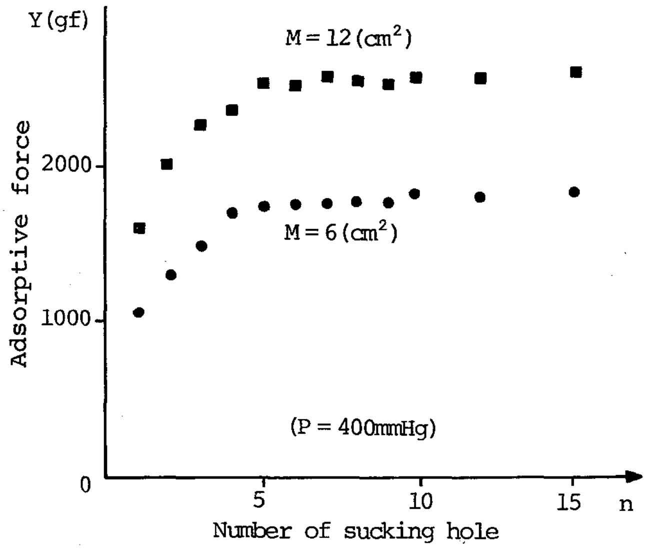


Fig.8, The relation between the adsorptive force and the number of sucking hole

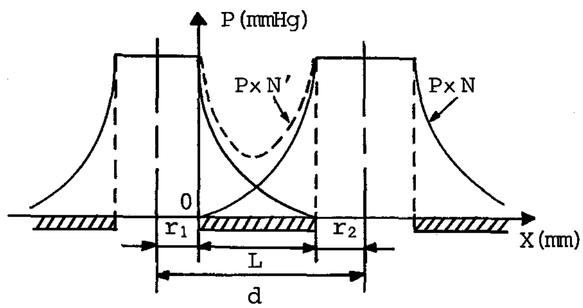


Fig.9, The distribution of the vacuum pressure in the case of two sucking holes

(SH_ℓ), $\ell=1,2,\cdots,K$, the useful sucking area (Z_ℓ) was calculated as follows.

$SH_{\ell i}$, $i=1,2,\ldots,K_\ell$

denotes the sucking hole located around SH_ℓ in Fig.10-(a).

For $SH_{\ell i}$, the distance ($X_{\ell i}$) from the edge of SH_ℓ was calculated by the equation (9). $d_{\ell i}$ is the distance between the centers $SH_{\ell i}$ and SH_ℓ.

Let Θ_i (rad) be the angle between the line connecting the centers of $SH_{\ell i-1}$ and SH_ℓ, and that of $SH_{\ell i}$ and SH_ℓ.

a) $(d_{\ell i}-r_{\ell i}-r_\ell) > 4.1$ for $i=1,2,\cdots,K_1$

In this case, $SH_{\ell i}$ was far from SH_ℓ in Fig.10-(a).

$$Z_{1\ell}=\sum_{i=1}^{K_1}(X_{\ell i}+r_\ell)^2\cdot(\Theta_i+\Theta_{i+1})/4 \qquad ----(10)$$

where 4.1 mm = 2x2.05 was calculated from the equattion (3) put as P=0.84/2

b) $d_{\ell i}-r_{\ell i}-r_\ell < 4.1$ for $\ell=1,2,\cdots,K_2$

In this case, as $SH_{\ell i}$ and SH_ℓ close enough to each other, the sucking areaes of $SH_{\ell i}$ and SH_ℓ were overlaped.

The useful sucking area was calculated from the approximation with the area of trapezium having the vertices of two centers of $SH_{\ell i}$ and SH_ℓ, and the two cross points of circles that the radiuses were r_i+2.05 of $SH_{\ell i}$ and r_ℓ+2.05 of SH_ℓ in Fig.10-(b). $Z_{2\ell i}$ was calculated from the Heron's formula, as $d_{\ell i}$, r_i+2.05, r_ℓ +2.05 were given.

$$Z_{2\ell}=\sum_{i=1}^{K_2} Z_{2\ell i}$$

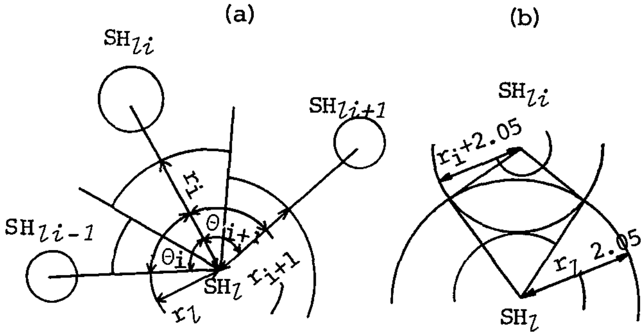


Fig.10, The distribution of the vacuum pressure in the case of many sucking holes

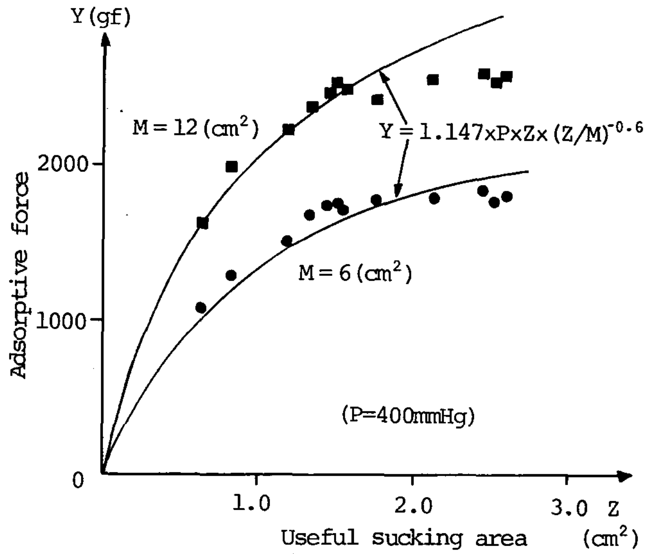


Fig.11, The relation between the adsorptive force and the useful sucking area

Then the useful sucking area was as follows.

$$Z = \sum_{\ell=1}^{K} (Z_{1\ell}+Z_{2\ell})$$

The adsorptive force was estimated from the equation (4) by substitution Z for S as follows.

$$Y=1.147\cdot P\cdot Z\cdot (Z/M)^{-0.6} \quad --- \quad (11)$$

The validity of equation (11) was examined from the correlation coefficient between the estimated value by the equation (11) and the observed value under the conditions of M=6 and 12 cm^2.

As the correlation coefficient was 0.949 in Fig.11, the adsorptive force can be estimated from the equation (11) using the useful sucking area.

5.5 The effect of the gap and the roughness.

5.5.1 the amount of flow under the various gaps.

The amount of flow was shown in Fig.12 under various gaps.

The maximum of amount of flow was 119 l/min, as the adsorptive plane was not used.

The amount of flow (Q) was estimated from the following equation, as the radius (r') of sucking hole, the gap (h), and the velocity of flow (v) at r' were given.

$$Q = 2\pi hvr'$$

If r' and v were constant, relation between amount of flow (Q) and the gap (h) became linear. In Fig.12, the linearity was aplicable to the region of gap from 0 to 0.17 mm.

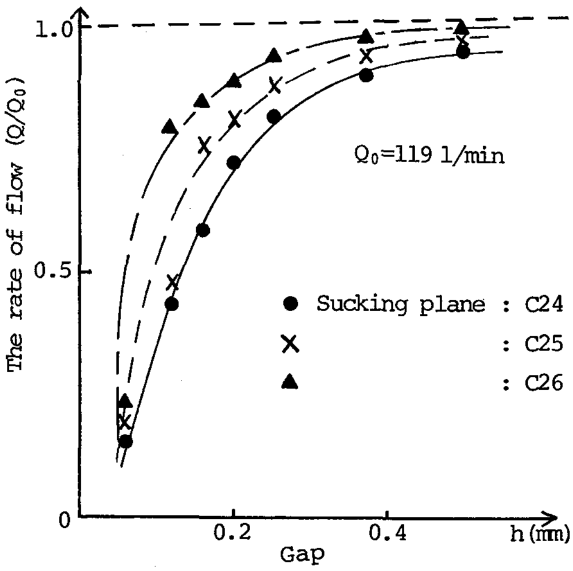


Fig.12, The amount of flow under various gaps

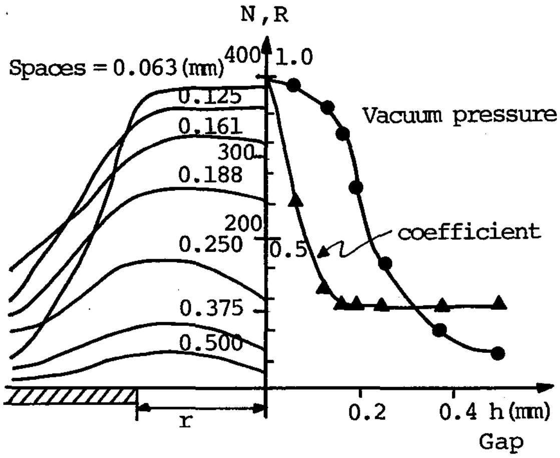


Fig.13, The distribution of the adsorptive force under various gaps

The gap was larger than 0.17 mm, the amount of flow converged to 119 l/min.

5.5.2 The distribution of the vacuum pressure.

The distribution of the vacuum pressure was measured under various gaps and shown by the equation of P=400•EXP(-ax). The vacuum pressure was set as 400 mmHg.

The rate of the vacuum pressure (P/400) at the sucking hole and a'=a/0.423 were shown in Fig.13.

The vacuum pressure at the sucking hole decreased gradually, as the gap was smaller than 0.161 mm.

But the distribution in the contact surface became flat, as the gap was larger than 0.125 mm.

Therefore as the gap was larger than 0.161 mm, the adsorptive force became low rapidly.

5.6 The amount of flow and the distribution of the vacuum pressure under various roughnesses.

The relation between the amount of flow and the vacuum pressure was shown in Fig.14 under the roughness of 28 to 300 μm.

The amount of flow was linear to the vacuum pressure under the roughness of 28 to 120 μm. But the amount of flow was equal to 119 l/min under the roughness of 300 μm, as the vacuum pressure was larger than 400 mmHg. Fig.15 showed

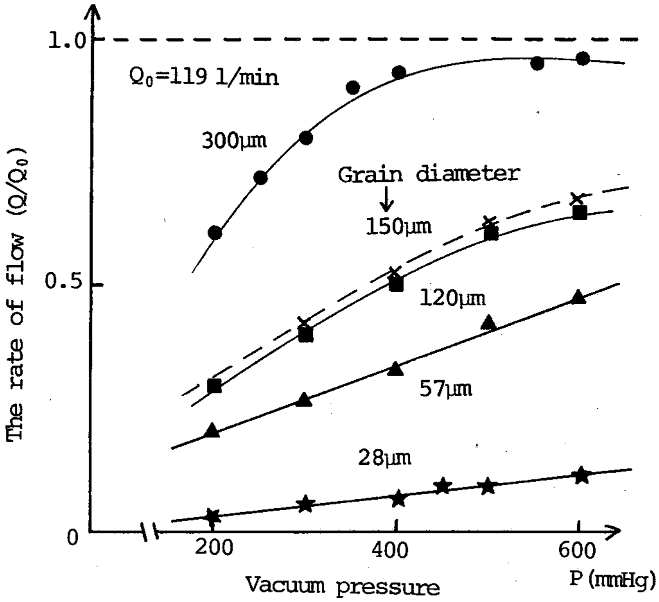


Fig.14, The amount of flow under various roughnesses

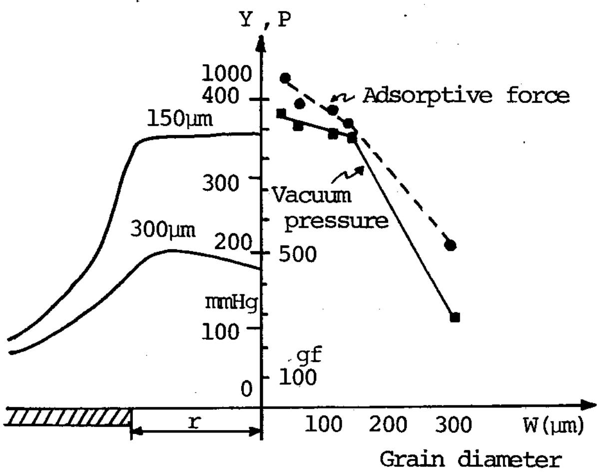


Fig.15, The distribution of the adsorptive force under various roughnesses the distribution of the vacuum pressure in the contact surface, as P was set as 400 mmHg, and the roughness was 150 and 300 μm .

The vacuum pressure of 300 μm was about half of that of 150 μm at the sucking hole.

The vacuum pressure and the adsorptive force decreased a little, as the roughness was smaller than 150 μm.

Therefore the adsorptive force was stable, as the roughness of the adsorptive plane was smaller than 150 μm.

6. Conclusion

It is very important to ensure the stable adsorptive force in the sucking grasp. Therefore it was examined how the factors influenced to the adsorptive force, as the sucking unit sucked up the object under the condition that the flat surface of sucking unit sucked up the flat surface of an object. Then the following resullts were obtained.

1) In the contact surface between the adsorptive plane and the sucking plane, the vacuum pressure (P') at the distance (X) from the edge of the sucking hole was shown as the following equation in the case of one sucking hole. Where P was the vacuum pressure at the sucking hole.

$$P' = P \cdot EXP(-0.423X)$$

2) The adsorptive force (Y) was estimated from the following equation in the case of one sucking hole, as the area of sucking hole was S cm^2 and the area of sucking plane was M cm^2

$$Y=1.147 \cdot P \cdot S \cdot (S/M)^{-0.6}$$

3) In the case of many sucking holes, the distribution of the vacuum pressure was overlapped in the area between two sucking holes which were only separated by a very close distance. The adsorptive force was estimated with the aid of the concept of the useful sucking area which was shown the interaction between two sucking holes.

4) As the gap between the adsorptive plane and the sucking plane was larger than 0.16 mm, the adsorptive force reduceed exteremely under 400 mmHg (vacuum pressure). As the roughness of the adsorptive plane was larger than 300 μm, the adsorptive force became weak, and the sucking condition became unstable.

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