Properties of Flow near a Side-Wall of a Circular Cylinder
with Tangential Blowing

(Effects of Slot Shape at Cylinder-Side-Wall Juncture
and Angular Location of a Blowing Slot)*

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An experiment was carried out to understand effects of the slot shape at the cylinder-side-wall juncture and the angular location of a blowing slot on the spanwise distributions of various characteristic values near the side-wall of a circular cylinder with tangential blowing. The range of the side-wall effects and the characteristic values near the side-wall are much influenced by the slot shape and the location of the slot. When the slot shape like a knife edge, termed "Edge", is used, the range of the side-wall effects becomes narrower as the angular location of the blowing slot is farther downstream.

Key Words : Fluid Mechanics, Circular Cylinder, Tangential Blowing, Characteristic Values, Side-Wall Effect, Vortex

1. Introduction

The authors have carried out systematic investigations on a circular cylinder with tangential blowing, for example, the measurements of various characteristic values such as aerodynamic coefficients, the visualization of flow around the circular cylinder inside the test section and so on⁽¹⁾⁻⁽³⁾. According to these investigations, a strong vortex rolls up near the side-wall in the case of a circular cylinder even if the experiment is carried out on a two-dimensional model. Consequently, a two-dimensional approximation of the flow no longer holds in a wide area near the side-wall and the effect of induced velocity is not negligible even at the mid-span. This is an important problem for a circular cylinder with tangential blowing, because it is difficult to make an aspect ratio of the cylinder large enough.

The area of the side-wall effects is defined as the semi-span minus the spanwise distance from the mid-span to the point at which the two-dimensional approximation does not hold. Then, it is important to understand not only the spanwise distribution of induced angles of attack but also the range of the side-wall effects in order to carry out the experiment on a two-dimensional model. There are, however, only a few investigations on the circular cylinder

with tangential blowing⁽⁴⁾⁻⁽⁸⁾ and even a fewer investigations on the flow near the side-wall. This may have been caused by complexity of this problem and experimental difficulty due to numerous parameters involved.

From these viewpoints, the authors have already published a paper on the range of the side-wall effects and the spanwise distributions of induced angles of attack calculated theoretically⁽¹⁾. Moreover, a convenient method using the experimental values at the mid-span was proposed to determine the induced angle of attack at the mid-span. The two-dimensional characteristics of the cylinder were also given from the experimental values by making correction for the effect of the induced angle of attack thus obtained⁽³⁾. After that, the experiment was carried out with the slot shape of the cylinder-side-wall juncture (hereinafter referred to as "slot shape") and the angular location of the blowing slot as a parameter, since the investigation on the side-wall effects was still insufficient.

In this report, the effects of the slot shape and the slot location on various characteristic values near the side-wall are discussed on the basis of known facts in the previous reports.

2. Nomenclature

C_d : section drag coefficient
 C_l : section lift coefficient
 C_{ln} : lift coefficient normalized by C_l at the mid-span, C_{l0} ($= C_l/C_{l0}$)
 C_p : pressure coefficient
 C_{pb} : base pressure coefficient
 C_μ : momentum coefficient of the blowing jet ($= (\text{momentum of jet per unit span}) / \{ (1/2) \rho U_\infty^2 D \}$)
 D : diameter of the circular cylinder
 Re : Reynolds number ($= U_\infty D / \nu$)
 U_∞ : velocity of the uniform flow

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y_w : coordinate taken in the port direction from the starboard side-wall
 $\eta_w = y_w/D$ ($\eta_w = -4$ at the mid-span)
 θ_w : angle measured clockwise from the leading edge of the cylinder
 θ_j : angular location of the slot
 θ_u^j : angular position of the separation point on the upper surface of the cylinder
 ν : kinematic viscosity of air
 ρ : density of air
 Subscripts
 0 : value at the mid-span
 ED, ST, SQ : values for the slot shape of "Edge", "Streamline" and "Square", respectively

3. Experimental Apparatus and Method

3.1 Experimental apparatus

The experimental apparatus is the same as one illustrated in the references (1) and (3) except for a height of the slot.

Figure 1 shows a cross section of the model cylinder. A hollow cylinder with an outer diameter of 100mm and a small cylinder with a diameter of 25mm form a blowing slot with a constant height across the whole span. The outer surface of the cylinder is chromium-plated and 335 static pressure holes are circumferentially distributed at ten spanwise sections. The height of the slot is 0.59mm in the case of varying the slot shape and is 0.58mm varying the slot location.

Fig.1 Cross section of the model cylinder.

Figure 2 shows a test section of the wind tunnel. The model cylinder is mounted at the center of the test section and passes through two partition-plates of 10mm in thickness inside the test section (hereinafter referred to as "side-wall") and the tunnel walls. The cylinder-side-wall junctures are denoted by the dotted circles in this figure.

Figure 3 shows three kinds of slot shapes used in this experiment. Figure 3(a) shows the slot shape termed "Edge"; the tip of a brass ring of 10mm in thickness is sharply shaped like a knife edge over a quarter of its circumference. This brass ring is fixed in the cylinder so that the edged portion of it can contact with the slot. In this case, a jet blown out from the slot flows along the cylinder sur-

Fig.2 Test section of the wind tunnel.

Fig.3 Slot shapes at the cylinder-side-wall juncture.

face of the both sides of the side-wall after being cut into two parts by the sharply shaped side-wall at the exit of the slot. Next, Figure 3(b) shows the slot shape termed "Streamline"; an epoxy-resin side-wall fairing of 10mm in thickness whose nose is streamlined is put into the inside of the slot at the cylinder-side-wall juncture. Then, the side-wall fits in the inside of the slot. A jet flows out from the slot after being divided into two parts by the streamlined nose of the side-wall inside the slot. Finally, Figure 3(c) shows the slot shape termed "Square"; the portion of the brass ring shaped like a knife edge shown in Fig.3(a) is filled up with oil clay so as to make a tip of the ring 10mm in thickness. A jet is suddenly divided into two parts by a square board of 10mm in thickness at the slot exit. In this report, these slot shapes are identified as "ED", "ST" and "SQ", respectively.

3.2 Experimental method

The experiments were carried out under the conditions of constant Re of 2.1×10^5 and constant aspect ratio of 8. In the case of varying the slot shape, θ_j was fixed at 90° and C_u was varied to three different values of $C_u = 0.1, 0.2$ and 0.3 for each slot shape shown in Fig. 3. On the other hand, in the case of varying θ_j , the slot shape of ED was used and θ_j was varied to five values of $\theta_j = 50^\circ, 70^\circ, 90^\circ, 110^\circ$ and 120° . Two experiments for each θ_j were carried out; one was a case of varying C_u arbitrarily and the other was a case of adjusting C_u so as to give the same value of C_{10} for each θ_j . Two desired values of C_{10} were taken as about 3.6 and 6.2.

The circumferential static pressure distributions were measured with a multitube

manometer for all cases mentioned above.

4. Experimental Results

4.1 The case of varying the slot shape

Figure 4(a) shows the spanwise distribution of upper separation points θ_u . θ_u increases over the whole span with an increase of C_μ . θ_u gradually increases with an approach to the side-wall and decreases rapidly after taking a maximum value. Since θ_u takes a minimum value at the side-wall ($\eta_w=0$), the separation of flow first occurs there. The effect of the slot shape on θ_u is hardly noticed at the mid-span but clearly noticed near the side-wall. In the cases of ED and

(a) Case of varying the slot shape

(b) Case of varying the slot location (arbitrary C_μ)

(c) Case of varying the slot location (constant C_{l0})

Fig. 4 Spanwise distributions of upper separation points.

ST, the variations of θ_u owing to C_μ are a little at the side-wall, that is, $\theta_{uED} \approx 120^\circ \sim 125^\circ$ and $\theta_{uST} \approx 115^\circ \sim 120^\circ$. However, in the case of SQ, θ_u varies in a range of $\theta_{uSQ} \approx 105^\circ \sim 120^\circ$ at the side-wall. The value of θ_u is also smaller than that of θ_{uED} for varying of C_μ from 0.1 to 0.3. This suggests that the flow near the side-wall is considerably affected by the value of C_μ in the case of SQ in comparison with the cases of ED and ST.

Figure 5(a) shows the spanwise distribution of the base pressure coefficients C_{pb} . Here, C_{pb} is defined as a mean value of C_p 's at the upper and lower separation points; in the case of $C_\mu = 0.1$, it is de-

(a) Case of varying the slot shape

(b) Case of varying the slot location (arbitrary C_μ)

(c) Case of varying the slot location (constant C_{l0})

Fig. 5 Spanwise distributions of base pressure coefficients.

defined as a mean value of C_p in the separated region. C_{pb} gradually decreases with an approach to the side-wall and increases rapidly after taking a minimum value near the side-wall. As C_μ increases, so does C_{pb} . On the contrary, C_{pb} near the side-wall and the minimum value of it decreases. The effect of the slot shape on C_{pb} is observed near the side-wall; C_{pb} near the side-wall decreases in the order of ED, ST, SQ.

Figure 6(a) shows the spanwise distribution of the drag coefficients C_d . C_d increases with an approach to the side-wall and decreases after taking a maximum value. As C_μ increases, C_d at the mid-span and the maximum value of it increases and C_d at the side-wall decreases. The effect of the slot shape on C_d is noticed near the side-wall; C_d increases near the side-wall in the order of ED, ST, SQ.

(a) Case of varying the slot shape

(b) Case of varying the slot location (arbitrary C_μ)

(c) Case of varying the slot location (constant C_{10})

Fig.6 Spanwise distributions of drag coefficients.

As mentioned above, when the slot shape is varied, the effect of the slot shape on various characteristic values is hardly noticed at the mid-span but clearly noticed near the side-wall. A point of extremum also appears in the spanwise distribution of each characteristic value. The spanwise position of the point of extremum hardly varies with the value of C_μ in ED and ST but varies considerably in SQ (Figs. 4(a) to 6(a)). The spanwise distances from the side-wall to the points of the extremum for each characteristic value η_w are shown in Table 1. It is found from this table that the positions of extremum move farther from the side-wall in the order of ED, ST, SQ.

Figure 7(a) shows the spanwise distribution of C_{ln} ($=C_l/C_{l0}$). The distribution of C_{ln} is given as a single curve for ED and ST, independently of C_μ within the scope of experimental errors. Then it is found that the spanwise distributions of C_l for various C_μ are approximately similar each other except for SQ. The rate of decrease of C_{ln} near the side-wall increases in the order of ED, ST, SQ. In this figure, the

Table 1 Spanwise positions of the extremum of various characteristic values η_w (case of varying the slot shape).

	ED	ST	SQ		
			$C_\mu=0.1$	$C_\mu=0.2$	$C_\mu=0.3$
θ_w	-0.65	-0.80	-0.85	-1.05	-0.95
C_{pb}	-0.28	-0.30	-0.44	-0.60	-0.36
C_d	-0.60	-0.65	-0.80	-0.78	-0.68
Vortex	-0.40	-0.50	-0.66	-0.68	-0.50

(a) Case of varying the slot shape

(b) Case of varying the slot location

Fig.7 Spanwise distributions of lift coefficients C_{ln} normalized by C_l at the mid-span.

results for the case of ED are drawn by two dotted curves for reference.

Figure 8 shows the static pressure distributions on the cylinder surface for the case of $C_{\mu} = 0.3$. This figure is developed surface of the cylinder to give a clearer image of the separated region near the side-wall. The pressure in the separated region near the side-wall becomes lower in the order of ED, ST, SQ and this corresponds to the behaviours of C_{pb} and C_d . There is also a particularly low pressure part in the separated region of $\theta \approx 180^\circ$. According to the observation of the limiting streamlines on the cylinder surface, the spanwise position of this low pressure part is in accord with that of a vortex which shed directly from the cylinder surface and is swallowed up into the center of trailing vortex.⁽²⁾ The spanwise positions of the vortex center for each slot shape are also shown in Table 1. The position of vortex lies in between those of the extremum of C_{pb} and C_d . It hardly changes in the spanwise direction but a little circumferentially with the value of C_{μ} in ED and ST (not shown here).

4.2 The case of varying the slot location

Figures 4(b) and (c) show the spanwise distributions of θ_u . In Figs. 4 to 6, (b) indicates the case of varying C_{μ} arbitrarily for each θ_j and (c) adjusting C_{μ} so as to give the same value of C_{l0} for each θ_j . According to Fig. 4(b), when θ_j is fixed and C_{μ} increases, θ_u increases over the whole span. The spanwise position of the maximum point scarcely moves with a change of C_{μ} but moves toward the side-wall as θ_j increases. In general, the larger the angle θ_j , the larger is the angle θ_u . In case of the same value of C_{l0} (Fig. 4(c)), although the values of C_{l0} are nearly constant irrespective of the values of θ_j , the spanwise distributions of C_l are considerably different among θ_j 's near the side-wall. Namely, in spite of small C_{μ} , the larger the angle θ_j , the larger is the maximum value of θ_u . Moreover, as θ_j increases, the spanwise position of the maximum point moves toward the

side-wall.

Figures 5(b) and (c) show the spanwise distributions of C_{pb} . In Fig. 5(b), C_{pb0} increases with an increase of C_{μ} for all θ_j 's. For $\theta_j \leq 70^\circ$, the minimum point is not clearly noticed near the side-wall even when C_{μ} is relatively large and C_{pb} decreases slightly toward the side-wall. There is no significant difference owing to C_{μ} among the spanwise distributions of C_{pb} . For $\theta_j = 90^\circ$, if C_{μ} is large enough, the minimum point of C_{pb} is clearly noticed. As C_{μ} increases, C_{pb} 's near the side-wall and at the minimum point decrease. For $\theta_j \geq 110^\circ$, the minimum point of C_{pb} appears near the side-wall even when C_{μ} is considerably small. When C_{μ} increases beyond the value of about 0.1, the minimum value abruptly drops. The spanwise position of the minimum point is nearly independent of C_{μ} and is dependent on θ_j alone; it moves toward the side-wall with an increase of θ_j . In the case of the same value of C_{l0} (Fig. 5(c)), the value of C_{pb0} are nearly independent of θ_j for both cases of $C_{l0} \approx 3.6$ and 6.2. For $C_{l0} \approx 3.6$, the distribution of C_{pb} is relatively flat and C_{pb} gradually decreases a little near the side-wall. The value of C_{pb} in the case of $\theta_j \geq 110^\circ$ is a little greater than that of $\theta_j \leq 90^\circ$ near the side-wall. For $C_{l0} \approx 6.2$, however, C_{pb} rapidly decreases and the minimum point is noticed near the side-wall. In particular, C_{pb} decreases remarkably in the case of $\theta_j \geq 90^\circ$ compared with that for $\theta_j = 70^\circ$.

Figures 6(b) and (c) show the spanwise distributions of C_d . According to Fig. 6(b), C_{d0} increases slightly with an increase of C_{μ} and the maximum values are noticed in the spanwise distributions near the side-wall for all cases of θ_j . They increase according to C_{μ} . For $\theta_j \geq 90^\circ$, the distribution becomes sharper near the maximum point. This tendency becomes stronger when C_{μ} increases beyond the value of about 0.1. Moreover, the spanwise position of the maximum point is independent of C_{μ} and moves toward the side-wall with an increase of θ_j . In Fig. 6(c), for $C_{l0} \approx 3.6$, the

Fig. 8 Static pressure distributions near the side-wall (case of varying the slot shape, $C_{\mu} = 0.30$).

spanwise distribution of C_d is relatively smooth for each θ_j . For $\theta_j \geq 110^\circ$, the distribution near the side-wall becomes sharper slightly than that for $\theta_j \leq 70^\circ$. The distribution for $\theta_j = 90^\circ$ lies in between those of $\theta_j \geq 110^\circ$ and $\theta_j \leq 70^\circ$. This tendency is more emphasized in the case of $C_{10} \approx 6.2$. For $C_{10} \approx 6.2$, the distribution curve near the peak becomes particularly steep in the case of $\theta_j \geq 110^\circ$. For $\theta_j = 90^\circ$, C_d becomes larger over a wide range of the span. The spanwise position of the maximum point of C_d moves toward the side-wall with an increase of θ_j for all cases of C_{10} . Moreover, the value of C_d is smaller than that of C_{d0} very near the side-wall, although C_{d0} does not depend on θ_j . The spanwise distance from the side-wall to the point of the extremum for each characteristic value η_w is given in Table 2, where θ_j is varied for the case of ED.

Figure 7(b) shows the spanwise distribution of C_{ln} . This includes the results of not only the cases adjusting C_μ in order to give equal C_{10} but also of arbitrary C_μ . If C_{10} is large enough, the distribution of C_{ln} is determined by θ_j alone within the scope of experimental errors. Hence, the spanwise distributions of C_l for various C_μ are similar each other except for the case of $\theta_j \geq 110^\circ$ and $C_{10} \approx 3.6$.

Figure 9 shows the static pressure distributions on the cylinder surface for $\theta_j = 70^\circ, 90^\circ$ and 120° at $C_{10} \approx 6.2$. As θ_j increases, the vortex moves toward the side-wall and the pressure gradient near the vortex becomes steeper. Hence, the two-dimensional region becomes wider in the left side of the vortex with its rightward movement.

5. Discussion

5.1 The range of the side-wall effects

The spanwise range of the side-wall effects was defined as the range near the side-wall where the flow around the cylinder could not be approximated as quasi-two-dimensional. Then, it is expected that the

Table 2 Spanwise positions of the extremum of various characteristic values (case of varying the slot location).

θ_j°	50	70	90	110	120
θ_w	-0.98	-0.92	-0.65	-0.50	-0.48
C_{pb}	-0.52	-0.46	-0.28	-0.22	-0.18
C_d	-0.88	-0.80	-0.60	-0.38	-0.34
Vortex	-0.61	-0.52	-0.40	-0.25	-0.22

Table 3 Ranges of the side-wall effects.

$\theta_j = 90^\circ$		E D	
	η_w		η_w
E D	-1.30	$\theta_j = 50^\circ$	-1.86
S T	-1.40	70	-1.45
S Q	$C_\mu = 0.1$	90	-1.30
	0.2	110	-1.24
	0.3	120	-1.20

range of the side-wall effects is closely related to the spanwise position of the rolled-up shed vortex near the side-wall, that is, this range will become narrower with the movement of the vortex toward the side-wall. The spanwise positions of the vortex η_{wv} are already shown in Tables 1 and 2. According to the tables, when the slot shape is varied, the vortex moves toward the side-wall in the order of SQ, ST, ED. On the other hand, the vortex moves toward the side-wall with an increase of θ_j . Then, the range of the side-wall effects must become narrower according to the order mentioned above. Since the method of determining this range was already described in reference (1) in detail, it is briefly mentioned here. The range of the experimental scatter of C_{pb} corresponding to the experimental value of the angular width of the separated region θ_{sb} at a value of η_w is obtained by making use of the experimental relation between C_{pb} and θ_{sb} at the mid-span. If the experimental value of C_{pb} at the same η_w falls within this range of scatter of C_{pb} , the flow at that value of η_w is

Fig. 9 Static pressure distributions near the side-wall (case of varying the slot location, $C_{10} \approx 6.2$).

determined as "two-dimensional". The range of the side-wall effects is determined as the semi-span minus the spanwise distance of the two-dimensional region. The range obtained by this method is given in Table 3. As mentioned above, this range is also altered according to the variation of the spanwise position of the vortex. The range becomes narrower in the order of SQ, ST, ED and so does it with an increase of θ_j . Then, the slot whose shape is ED ought to be located as far downstream as possible in order to make the two-dimensional range as wide as possible.

5.2 The relations between the slot location, the slot shape and the range of the side-wall effects

As mentioned in the preceding section, the range of the side-wall effects is determined by the slot shape and θ_j ; it is closely related to the spanwise position of the vortex η_{wv} .

Figure 10 shows the relation between η_{wv} and θ_j obtained from Tables 1 and 2. In ED, η_{wv} is nearly proportional to θ_j . Since this relation is independent of C_μ , η_{wv} should be determined by θ_j alone.

Figure 11 shows the relation between $(C_{l0}-C_{lw})$ and $(C_{pb0}-C_{pbv})^{1/2}$, where C_{pbv} is the minimum value in the spanwise distribution of C_{pb} and is to be regarded as an approximate value of C_{pb} at the vortex core on the cylinder surface. C_{lw} is also the value of C_l at the side-wall ($\eta_w=0$). $(C_{pb0}-C_{pbv})^{1/2}$ is proportional to $(C_{l0}-C_{lw})$ in ED. Now, since $(C_{l0}-C_{lw})$ is proportional to the total amount of the trailing vortex shed from the cylinder between the mid-span and the side-wall (hereinafter referred to as "strength of the trailing vortex"), $(C_{pb0}-C_{pbv})^{1/2}$ ought to be proportional to the strength of the trailing vortex. On the other hand, $(C_{pb0}-C_{pbv})^{1/2}$ is approximately proportional to the strength of vortex core (vortex tube), because it indicates a square root of pressure difference between the vortex core and the separated region distant enough from the vortex core. Therefore, if only θ_j increases under constant $(C_{l0}-C_{lw})$, the vortex core should move toward the side-

wall keeping its strength constant since η_{wv} is determined by θ_j alone independently of C_μ (Fig. 10). Now, even though C_μ increases under the fixed θ_j , both the value of η_{wv} and the range of the side-wall effects do not vary as described earlier, but the value of $(C_{l0}-C_{lw})$ increases (Fig. 7(b)). Since $(C_{pb0}-C_{pbv})^{1/2}$ increases in proportion to $(C_{l0}-C_{lw})$, the vortex core hardly changes in size but increases in strength in this case.

It is concluded from these discussions that the size of the vortex core hardly changes but the spanwise position and the strength of it are affected by θ_j and $(C_{l0}-C_{lw})$, respectively. Thus it is suggested that only when θ_j is varied under the constant C_{l0} , the larger decrease of the minimum value C_{pbv} of C_{pb} for $\theta_j \geq 90^\circ$ than that in the case of $\theta_j = 70^\circ$ (Fig. 5(c)) results from the increase in strength of the vortex core due to the increase of $(C_{l0}-C_{lw})$.

On the other hand, when the slot shape is varied under the fixed angle $\theta_j (=90^\circ)$, the strength of the vortex core is proportional to that of the trailing vortex in ST. Then, the same discussion also holds in this case. However, even if the value of $(C_{l0}-C_{lw})$ is equal to that for ED, the strength of the vortex core becomes stronger (Fig. 11) and the position of the vortex moves farther from the side-wall (Fig. 10) than in ED. Since in SQ, the position of the vortex core is varied by C_μ even if θ_j is fixed, the same discussion does not hold. The strength of the vortex core, however, becomes greater and its position moves farther from the side-wall than in ST, even though the strength of the trailing vortex is equal to that in ST.

6. Conclusions

Experiments were carried out on the spanwise distributions of various characteristic values of a circular cylinder with

Fig. 10 Relation between spanwise position of the vortex and the slot location.

Fig. 11 Relation between the pressure of vortex core on the cylinder surface and the strength of the trailing vortex.

tangential blowing for various locations of the slot, jet intensities and slot shapes. The conclusions from all of these are as follows:

(1) The range of the side-wall effects is determined for each location of the slot and each slot shape as shown in Table 3.

(2) The range of the side-wall effects becomes narrower in the order of SQ, ST, ED. In the case of ED, the larger the angle θ_j , the narrower becomes this range. Also, this range is independent of C_μ except for the case of SQ when C_μ is large enough.

(3) If θ_j is fixed, the spanwise distribution of C_l is similar except for the case of SQ but is not similar for the case where C_μ is small and $\theta_j \geq 110^\circ$.

(4) The strength of the vortex core is proportional to that of the trailing vortex. In the case of ED, the spanwise position of the vortex core is determined by θ_j only.

References

- (1) Yoshino, F., et al., Bulletin of the JSME, Vol.24, No.192 (1981-6), p.926.
- (2) Waka, R., et al., Proceedings of the Second International Symposium on Flow Visualization, Bochum, (1980-9), p.367.
- (3) Waka, R., et al., Bulletin of the JSME, Vol.26, No.215 (1983-5), p.755.
- (4) Dunham, J., J. Fluid Mech., Vol.33, part 3 (1968-9), p.495.
- (5) Sato, M. and Matsuoka, K., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.36, No.289 (1970-9), p.1493.
- (6) Furuya, Y. and Yoshino, F., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.41, No.341 (1975-1), p.170.
- (7) Ueda, S. and Tanaka, H., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.41, No.350 (1975-10), p.2853.
- (8) Furuya, Y. and Yoshino, F., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.42, No.358 (1976-6), p.1830.