MEASUREMENT OF PRESSURE DISTRIBUTION OF THE AIRCUSHION BY THE AIR FLOATER WITH MOVING PLATE

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ABSTRACT
The floating system which can carry the material by non-contact has a problem that the transported materials vibrate and contact with the floating device. In this report, we observe concerning the change of the pressure distribution which occurs due to the movement of the material using the belt device that simulated the moving material and which has the static pressure tap. As a result, we show that the influence to the pressure distribution with the movement of the conveying material is larger than effect caused by simple shearing stress.

KEY WORDS
non-contact support, air floatation, moving belt, jet, flow pattern

INTRODUCTION
In the production process, non-contact support is requested from view points of the wound, cleanliness, and so on. The air cushion technology makes the material carried by using the air pressure to its surface, and can decrease power for carry because it is possible not only to transport by non-contact but also there is little friction. There is no machine drive part compared with the roller and it has the advantage such as being able to simplify the device.

The floating system is one of the air cushion technologies which can carry the material by non-contact, and is used in the manufacturing process where avoiding the defect on which the wound of which it causes contact to the surface of the product depends becomes a problem. The large-scale floater is used for the manufacturing process of the steel strip while finishing up the surface of the material. There is a problem that the carried material vibrates and it comes in contact between the material and air floaters, so enough space is kept for the warp of the vibration and the material so as not to come in contact, it is driven safely. Research is made in order to solve the problem of vibration and improvement of performance[1,2]. It is discussed by floating system based on the theory used by development of a hovercraft in many cases[3,4,5].

When the carried material which is thin and light, ex. for the surface treatment of paper, it seems that the distribution of the pressure of the air cushion influences the performance of the device very much. It is expected that the pressure distribution in the air cushion is changed by a viscous effect of the surface of the moving material. The floating system is applied to thin products such as metallic foils and the films in addition to the one with large system of a metallic strip. It is easy to receive the influence of the change of the pressure which generated by the change of the flow caused by the such a thin moving material. The influence by the vibration of pressure is harmful to transportation of a thin product with stability[1,2].

However, the flow in the air cushion is not examined in detail. The pressure distribution on the movement transportation material might be difficult the measurement and hardly known. Demand for the transportation of the product by the ratio contact along with the industrial growth has increased steadily.

The influence appears more strongly to the pressure distribution when the material like the steel strip and paper are carried at high speed.

In this report, we observe concerning the change of the pressure distribution in the air cushion which exists on the floating device which occurs due to the movement of the conveying material. But it is difficult to measure pressure on moving surface. Therefore, it is almost the case that an experiment is conducted on the stationary plate[6]. To obtain this pressure distribution, we made the belt device that simulated the moving transportation material and which has the static pressure tap on the surface. The static pressure at an arbitrary position was measured by moving this.

In this paper, the pressure distribution on the material being transported of the movement is measured. It reports on the influence given to the pressure distribution in the air cushion of the material to be transported.

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Fig.1 Experiment Setup
Floator Model
The floater model which is adopted here has the slit in line on the both ends of the device and is called as peripheral type. Cross section of floater model is shown in Fig. 2. Length and width of the floater surface are 190mm and 72mm individually. Two slit nozzles are on surface of the floater model in parallel and their width $t$ is 2mm and length $l$ is 174mm. They are installed vertically on the floater surface and distance of two nozzles $b$ is 70mm. Air jet sheet blows from these slit nozzles to the surface of the moving belt. The external wall which parallels to the slit has the angle of 60 degrees against the floater surface in order not to have an influence on pressure distribution.

Pressure Distribution Measurement Equipment
We must measure the pressure distribution regarding the transported materials which are moved in this experiment. The surface of the pressure measurement should move for that. We used moving belt and the pressure measurement plate to achieve this state as shown in Fig. 3. The surface of the material which is conveyed is simulated with two belts. The gap of these belts is 3mm. The belt is installed by common four rollers, one among those is driven by the AC motor, and these belts turn at the same speed. The running speed of a belt was performed in the range to about 4.2m/s by this experiment. Pressure tap plate is under these belts. This plate has the convex section of the same width 3mm as the slit of two belts and has closed the underside of the belts entirely. The height is made being the same as the thickness of the belt, in order to match the surface of the belt. And, paralleling to the slit of the belt (x axis direction), the stepping motor makes this plate move. This belt and the plate are moved by another stepping motor along the longitudinal nozzle of Floater. Therefore, this device is used, it becomes possible to measure the pressure distribution of the surface of moving materials which are moved in detail. As understood from this explanation, with this experiment the moving material has rigid surface. In regard to the direction of length of the floater, only the half area was measured in experiment, because it is symmetrical. The pressure tap plate scans for the range of 100mm x 100mm by 2mm, and pressure was measured. The plate is larger than floater model so that it covered the whole surface area of the floater model at all locations of the plate.

EXPERIMENT SETUP
Experiment setup is shown in Fig. 1. The air is supplied by the blower, and the flowing ratio is measured by the differential pressure of orifice. The rotational speed of the blower is being controlled by the inverter. The flow enters the surge tank to rectify it. The flow passes honeycomb and diffuser and it enters the floater model. In this experiment, the floater model is set over the moving belts which simulate moving material. So the floater model is set upside down as shown in Fig. 1. With experiment, we adjusted the supply pressure inside floater $p_i$ with the blower. When the flow which is obtained from the orifice is divided in the nozzle area it can calculate velocity of nozzle jet. The distance $h$ of the floater and the moving belt, with the lifter which is under the stand where the moving belt is installed.

EXPERIMENTS RESULTS
The belt running device was stopped in the beginning and the distribution of pressure was measured. $C_p$ was made dimensionless by pressure $p_i$ in pressure floater that measured pressure $p$ on the surface of the transportation material at the same time. The Floater model used in this experiment, the atmosphere is opened at the short edge (longitudinal). Therefore, it is thought that the flow in the air cushion becomes very complex. The typical pressure measurement results at rest are shown in Fig. 4. Dimensionless length $X$ and $Y$ are determined by dividing distance $b$ between floater slits and floater nozzle slit length $l$ respectively. The origin of $X$ is
center of the section of the direction of the floater width, and the origin of Y axis is center of the slit nozzle. Dimensionless height $h/l = 1.0, 2.0,$ and $3.0$ are shown. The air pressure on the plate is nearly uniform in wide region at center of floater between two slits surrounded by two jets. And the air pressure is decrease along the Y axis then it drops suddenly near the edge of the floater. High peak pressures appear under the slit nozzles, and the value of these pressure peak is almost $C_p = 0.9$. The pressure drop is observed along these peaks. When the air gap between a floater and the pressure plate is large, these pressure drops are remarkable. This is thought influence of the strong vortex which was made inside the air cushion by the flow from the nozzle jet. When the air gap between a floater and the pressure plate becomes large, the flow of the jet increases, the pressure drop becomes large. The air pressure of the area which is uniform also decreases as the air gap is large. These experimental results being symmetrical are thought the rational result.

The main test variable is the velocity of moving belt. The pressure profile for the gap between the pressure tap plate and a floater model fixed as $h/l = 1.0$ are shown in
Fig. 7. Visualization of the flow on the stable plate \((h/t = 4.0, v_j = 26.6 \text{ m/s}, V' = 0 \text{ m/s})\)

Fig. 5. This figure shows the pressure profiles in the cross section \(Y = 0\), and has shown excerpting the profile regarding the value of typical speed \(V'\). You can verify that distribution of pressure when standing still becomes the object even here. As the speed of the moving belt becomes large, distribution of pressure of the air cushion area stops being flat, it is recognized that it keeps inclining gradually. It can look at the modification of the area of pressure drop. With increase of speed, the pressure drop becomes large on upward of the belt-running direction. Conversely, it reduces the value of pressure drop in the downward area. As for these phenomena, strong shear stress due to the belt running is considered to have produced the effect in the flow.

Figure 6 shows the pressure profiles when velocity of the nozzle jet \(v_j = 18.3 \text{ m/s}\) and \(h/t = 1.0\). When you compare with figure 6, the area whose pressure is flat is a little wide, and the pressure drop which is on the both ends is smaller. On upward of belt running direction, when belt speed is large even, the value of air pressure almost is no change. But on downstream side of floater, pressure rises in the same way as \(v_j = 10.4 \text{ m/s}\), also the pressure drop becomes small.

Like above, as for air pressure distribution of the floater with respect to the boundary which is moved so far there was many a thing which assumes that pressure distribution is even, but, it was found that pressure of downstream side becomes high depending upon the influence of the material which is conveyed. In addition, the pressure change not only the even pressure part of the air cushion, it is found that influence is exerted to also the region where it is thought as the pressure drop by the jet adjacent vortex.

Then, to examine what influence the flow in the air cushion received by moving material, flow visualization was done. The oil flow method was adopted in visualization. The oil flow method was adopted in making to visible. Because making to visible by the flow on the movement boundary was difficult, the flow between two nozzles on the surface of floater was made visible. For referring the circumstances of the flow inside the air cushion, in when standing still also visualization of the surface of the hard conveying material went making use of another plate. Fig. 7 shows the flows when the gap between the pressure tap plate and a floater \((h/t = 4.0, \text{speed of jet } v_j = 26.6 \text{ m/s})\). \(H/t\) is set more greatly than the experiment when pressure is measured on this visualization. Weak two lines are observed. This corresponds directly under the slit nozzle and is the stagnation of the jet stream. It is found that the strong flow has gushed from these lines facing toward both sides. The flow seems to have the separation at the inside of air cushion.

In Fig.8(a) which is visualization when the moving belt is at rest, you see, the symmetrical satisfactory result is obtained in general. According to the spread of the jet stream you can see the flow which is thought immediately inside the nozzle. As the floater it goes to the edge, the floater it deflects the flow in length direction. The floater of this flow the exfoliation line is observed to centerline side. Furthermore there is the flow which faces to the slit inside that, existence of the vortex by the jet is presumed. Furthermore this flow you can see the muscle which
Fig. 9. Friction coefficient for jet Reynolds number

shows the symmetrical flow even on central site, but, with
this photograph it is not clear. The center of these lines
 corresponds to the position of the separation point in Fig. 7.

When the belt traveled, circumstances of the flow of the
floaters surface change as shown in Fig. 8 (b). There is
no symmetry already and new dense line has appeared on
downstream side of the center line. In these dual black
areas, the flow has diverged from the white central area.
We could verify the flow of slit side clearly in stationary
state, but, the twin vortexes occurred with influence of
traveling of the belt, it is thought that the speed increased.
On the one hand, in the region of upward, it is observed
that the black area which is paralleled to the slit nozzle
was clear and a little became large. Trace of the weak
flow in the downstream has gone out. These photographs
suggest that not only the primary vortex which occurs due
to the jet stream from the slit nozzle, the secondary vortex
which it occurs with that vortex exist. Furthermore, it
shows also the fact that those vortexes have received
influence with moving of the belt.

APPROXIMATE CONSIDERATION

Here, the friction with the viscosity which occurs due to
the movement of the material and change of the pressure
will be compared. But, pressure distribution form is
complicated, so it is difficult to define the change of
pressure. Then, by calculating the rough inclination of this
pressure profile, the direct effect due to friction is
examined.

Here, change of the pressure with friction, is estimated
as follows from pressure distribution. The air cushion area
is divided into three equal amounts, mean value of the
respective pressure is calculated concerning the part the
both ends. The pressure difference which causes the
difference $\Delta p$ of this value with friction it defines. When
the frictional force due to the surface of moving belt is
designated as $D_f$, it can expressed as

$$D_f = \frac{1}{2} C_f \rho S u^2$$  \hspace{1cm} (1).

Here, $C_f$ is coefficient of friction, $S$ is the area of the belt
under floater, $V$ is belt speed, $\rho$ is air density. Therefore it
can express coefficient of friction $C_f$ as follows.

$$C_f = \frac{D_f}{\frac{1}{2} \rho u^2 l} = \frac{h \Delta p}{\frac{1}{2} \rho V^2 l}$$  \hspace{1cm} (2).

It compares with the coefficient of friction of the
laminar flow and the turbulence which were requested this
and, making use of the velocity distribution system of
boundary layer.

$$C_f = 1.328 \text{ Re}^{-1/2} \quad \text{ laminar}$$
$$C_f = 0.072 \text{ Re}^{-1/5} \quad \text{ turbulent}$$  \hspace{1cm} (3).

Here, $\text{Re}=V l / v$, $v=1.459 \times 10^{-5}$ m/s, $\rho=1.22$ kg/m$^2$, $l=60 \times 10^{-4}$ m, $h=2 \times 10^{-4}$ m.

These results are shown in Fig. 9. The experimental
result designated the Reynolds number of the jet Re as
parameter. The result of relatively large jet Reynolds
number Re is visible as lined up on the almost same line.
And Inclination of the data line is approximate to the
laminar flow. But, order differs clearly. This result
suggests that the change in pressure not take place only
because of shearing stress though the calculate method is
rough.

CONCLUSIONS

The measurement result of detailed pressure distribution
on the moving material which was not done so far was
shown. As a result, it made that the pressure distribution
inside the air cushion with the influence of the moving
material receives influence clear. The measurement result
of detailed pressure distribution on the moving material
which was not done so far was shown. As a result, it
makes clear that the pressure distribution inside the air
cushion has influence of the moving material. That time,
the air cushion in not only the relatively even pressure
region but in the region in nozzle adjacent pressure drop
has influence too. Concerning the mechanism where these
pressures change, with the measurement result of pressure
distribution and the result of the visualization experiment
due to oil flow method comparing, the flow inside the air
cushion was considered. It was able to be presumed that
the flow changed in the air cushion by the moving belt,
and the appearance of the vortexes generated with the jet
flow had changed. Moreover, it seems that the flow in the
air cushion cannot be understood from consideration of
the shearing stress alone because the pressure change of
Floater actual than the change in the frictional pressure is
larger. It will be necessary to examine the interference of
the movement boundary and the jet flow in the future.
**NOMENCLATURE**

- \( b \) = distance of slot nozzles, m
- \( C_f \) = friction coefficient, \( D_f = C_f \rho l^2 S u^2 \)
- \( C_p \) = pressure coefficient, \( p/p_i \)
- \( D_f \) = friction force, N
- \( h \) = flotation height, m
- \( l \) = length of slot nozzle, m
- \( p \) = pressure of air cushion (gage pressure), Pa
- \( p_i \) = total pressure of jet (gage pressure), Pa
- \( p_r \) = supply pressure inside floater (gage pressure), Pa
- \( \Delta p \) = change of pressure, Pa
- \( Re = \) Reynolds number for nozzle jet, \( Re = tv/v \)
- \( Re_p = \) Reynolds number for moving plate, \( Re_p = lV/v \)
- \( S = \) area, \( m^2 \)
- \( t = \) width of slit nozzle, m
- \( V = \) speed of belt, m/s
- \( v_j = \) speed of jet, m/s
- \( x = \) distance from center of floater (lateral), m
- \( X = \) Non dimensional \( x (X = x/b) \)
- \( y = \) distance from center of floater (longitudinal), m
- \( Y = \) Non dimensional \( y (Y = y/l) \)

**REFERENCES**