

Characteristics of a wind-actuated aerodynamic braking device for high-speed trains

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Abstract. To shorten the stopping distance of the high speed trains in case of emergency, we developed a small-sized aerodynamic braking unit without use of the friction between a rail and a wheel. The developed device could actuate a pair of two drag panels with a travelling wind. However, after the drag panel fully opened, vibrational movements of the drag panel characterized by its slight flutter were repeated. In this study, to stabilize the opened panel, matters pertaining to the angle of attack with respect to the drag panel and pertaining to the arrangement of the two panels were examined by a wind tunnel experiment using a scale model. As a result, to stabilize the opened panel and to keep the good performance of the braking device, it is found out that an angle of attack of 75 to 80 degrees is suitable provided that the interval of the two panels is narrow enough.

1. Introduction

There is a strong demand for improving the brake performance of high-speed trains in Japan [1] to shorten the stopping distance in case of emergency such as an earthquake. The emergency brake for the conventional train is ensured by a wheel disk brake system. However, its performance is affected by rail surface conditions (dry or wet condition) especially in a high-speed region because of its dependency on the adhesion force between a wheel and a rail. Therefore, an additional brake system which is unaffected by the adhesion force is required, and it should be lightweight and compact.

As a braking device satisfying to this objective, we developed a small-sized aerodynamic braking device for trains [2]. This device can get air drag force directly for braking by a panel set on the train roof. An aircraft is generally equipped with a similar device, but trains have never been equipped with it. One of the originality of the developed device is actuating a pair of two drag panels with a traveling wind (a head wind). In this study, we report matters pertaining to the drag and stability of the aerodynamic braking device which were examined in a wind tunnel experiment using a scale model.

2. Overview of the developed aerodynamic braking device

2.1. Prototype device

The author attempted to miniaturize the device in order for the device to be installed flexibly on the train roof, whereby many devices with small-sized drag panels were appropriately arranged throughout the train roof to obtain higher drag force.



Figure 1 shows the prototype of the aerodynamic braking device. Figure 1(a) shows the drag panel folding position and figure 1(b) shows the opening position (braking position). To raise the drag coefficient of the panel, the drag panel was a rectangular thin plate. The maximum design load by the drag was set to 3,000 N/unit on the assumption that the train runs at 400 km/h in a tunnel section.

A pair of drag panels rotating around a horizontal axis are connected by a pair of spur gears called a ‘torque balancer’ so as to make each of them rotate in the opposite directions. When the panels open slightly by a spring, the rotational force by the drag acts on the panels so as to open or close the panels; it depends on the train traveling direction and the panel opening direction, as shown in figure 2.

At this time, due to the difference between the drag coefficient of one panel and that of the other, the rotational force acting so as to open the panel becomes greater than that acting so as to close the panel. The difference of drag coefficient is caused by difference in attack angle. Therefore, the pair of drag panels can be actuated by the traveling wind without external power. Besides, the prototype has a mechanical panel locking mechanism actuated by a pneumatic cylinder so that the drag panel does not lift unintentionally by vibration or disturbance when the train running normally.

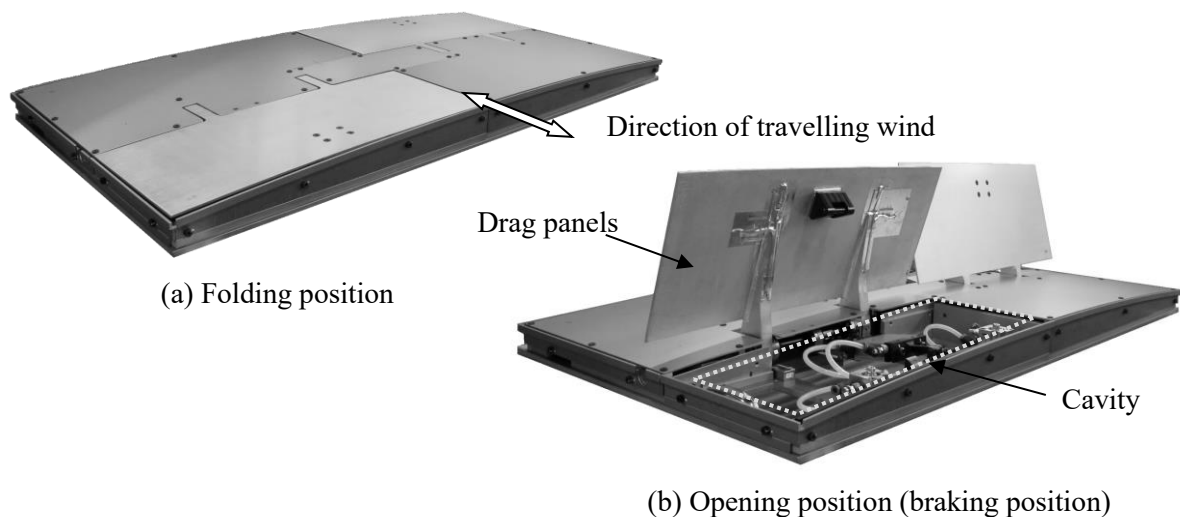


Figure 1. Prototype of aerodynamic braking device.

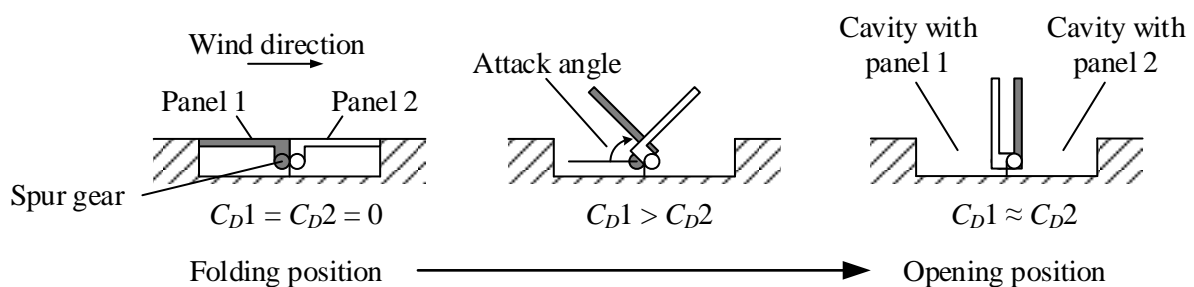


Figure 2. Motion of two-panels.

2.2. Stability of the prototype device

The prototype of the aerodynamic braking device was tested in large-scale wind tunnel facilities at a flow speed of 400 km/h (111 m/s). Drag panels immediately opened and produced the drag force, after

an operation command was outputted to the device. The process time of the motion from the folding position to the opening position required for getting drag force by the wind was only 0.4 seconds. This rapid motion is a great advantage for emergency braking.

However, after the drag panel fully opened, vibrational movements of the drag panel characterized by its slight flutter were repeated. We considered that this motion was caused by the instability of the rotational force by the drag acting on the pair of the two panels. The stability of the opened panel is as follows:

- Stable: $C_{D1} > C_{D2}$ and $C_{T1} > C_{T2}$
- Unstable: $C_{T1} \leq C_{T2}$

Torque coefficient C_T is obtained by formula $C_T = 2T/hA\rho U^2$, where T represents rotational force of the panel; h is the panel height; and A is the front projection area of the panel.

The magnitude of the drag force and that of the torque vary with the following factors:

- i) attack angle with respect to a panel,
- ii) arrangement of two panels,
- iii) location of a cavity for folding a panel.

Here, the cavity that is a box-formed space of around 50 mm in depth for folding a panel is located at the upstream or the downstream side of the panel. According to scale model experiments and numerical analysis with respect to a cavity [3], the drag force of a panel with a cavity at the upstream side was approximately 15% larger than that of a panel with a cavity at the downstream side because of differences in stagnation pressure. For the mechanical reason, the cavity of the panel 1 is always located at the front of the panel, and the cavity of the panel 2 is always located at the back of the panel (cf. figure 2). In this case, the relation of the drag force of the two panels are stable in $C_{D1} > C_{D2}$.

Therefore, to stabilize the opened panel, i) the attack angle with respect to the panels and ii) the arrangement of the two panels were examined by a wind tunnel experiment using a scale model.

3. Drag and stability of the two panels

3.1. Experimental setup

Figure 3 shows an experimental set up of the wind tunnel. The experiments were carried out in small-scale wind tunnel facilities of Railway Technical Research Institute. The test section has a cross section

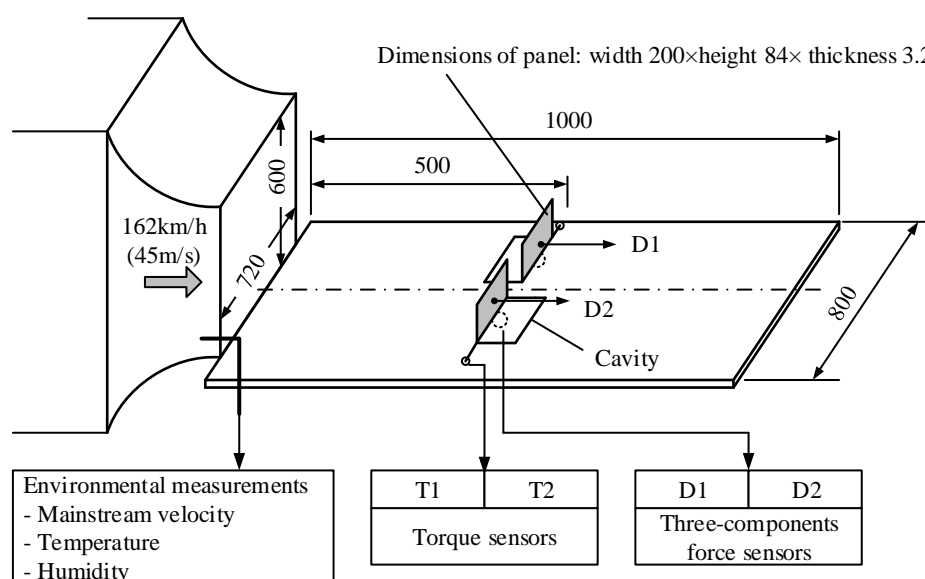


Figure 3. Sketch of an experimental setup.

of 0.6 m in height and 0.72 m in width, and is 1 m in length, and the maximum test velocity is 162 km/h (45 m/s). The model scale is 1/2.5. The Reynolds number based on the width of the drag panel is $Re = 6.0 \times 10^5$. Dynamic similarity with the full-scale prototype is not completely ensured, because the Reynolds number of the full-scale prototype is about 6 times as large as the scale model experiment. Hence, the purpose of the scale model experiments is to study the basic effect of matters pertaining to the arrangement of the two panels and pertaining to the attack angles with respect to the panel.

To measure the drag force, each panel mounted on three-component force sensor (*NISSHO-ELECTRIC-WORKS*, LMC-3891, full scale ± 100 N) with a gap around the fixed parts. In addition, to measure the rotational force of the panel, each axle of the panel is equipped with a torque sensor (specialized sensor consisting of strain gauges). The scale model experiments are examined with static angle (nonrotation); consequently, the measured rotational force is unaffected by a kinetic friction of the spur gear. Furthermore, the torque sensor is calibrated to cancel the rotational force of the panel weight.

3.2. Arrangement of the two panels

Figure 4 shows a schematic of the arrangement of the two panels. One of the streamwise intervals between the two panels $S1$ is 27 mm based on the prototype length, and the others of the intervals are 10 mm and 6 mm based on the practical dimensions of the rotating axis and the pair of spur gears. All interval conditions are $S1 > 0$; namely the panel 1 is always located in the downstream of the panel 2.

The spanwise interval between the two panels $S2$ is unlimited except that $S2 < 0$. However, it is desirable to make it short as much as possible in order to reduce the device size. Hence, one of the intervals between the two panels $S2$ is 20 mm based on the prototype length, and the others of the intervals are 10 mm and 1 mm based on the practical dimensions.

Figure 5 shows drag force and torque on each panel vertically opened; here, the plus sign of the torque coefficient is defined as the direction in which it should act to lift each panel. In the case of the streamwise interval $S1 = 27$ mm, the relation of the drag force of the two panels are unstable in $C_{D1} < C_{D2}$, and the torque coefficient C_T at the ‘torque balancer’ is negative. At this time, the main stream acts on the panel 2 first located in the upstream, and then a separated flow acts on the panel 1 located in the downstream. In addition, a jet between the panels flows over the cavity at the back of the panel. In the case of the streamwise interval $S1 = 6$ mm that is the arrangement of the two panels approximately in parallel, the relation of the drag force of the two panels changes to a stable condition in $C_{D1} > C_{D2}$ because C_{D1} with the upstream cavity is larger than C_{D2} with the downstream cavity in Ref. [3]. However, the torque coefficient C_T is still negative. It could be attributed to the lift force caused by a secondary flow around the panels.

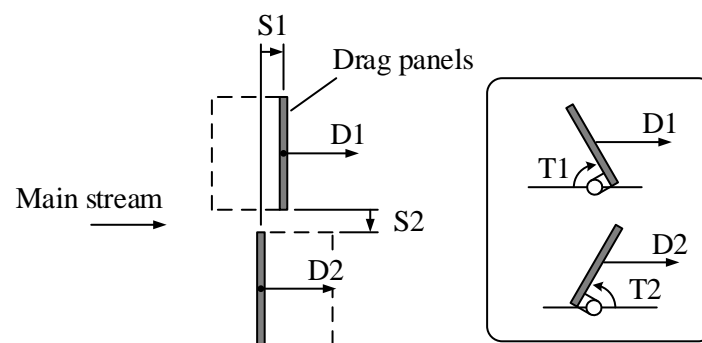


Figure 4. Schematic of arrangement of the two panels. The streamwise intervals $S1$ are 27 mm, 10 mm and 6 mm. The spanwise intervals $S2$ are 20 mm, 10 mm and 1 mm.

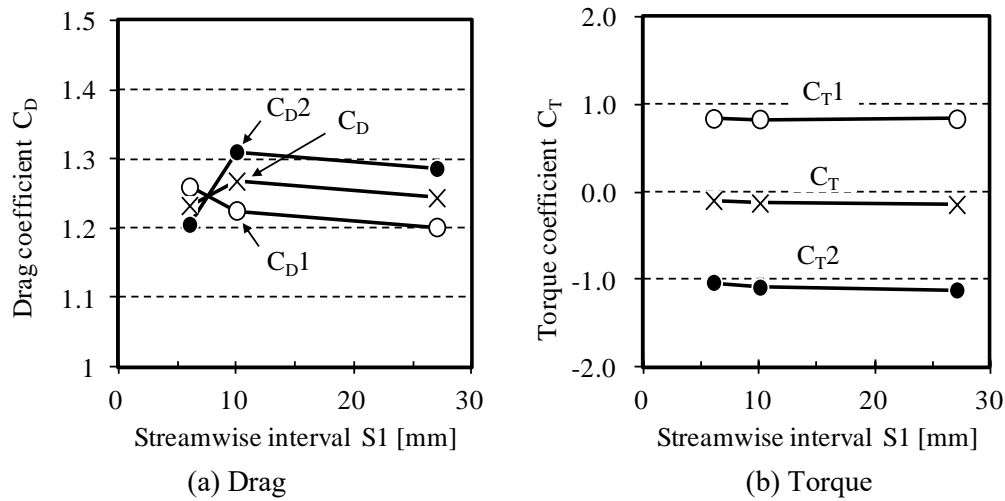


Figure 5. Relationship of the streamwise intervals $S1$ on each panel vertically opened; spanwise interval $S2$ is 20 mm.

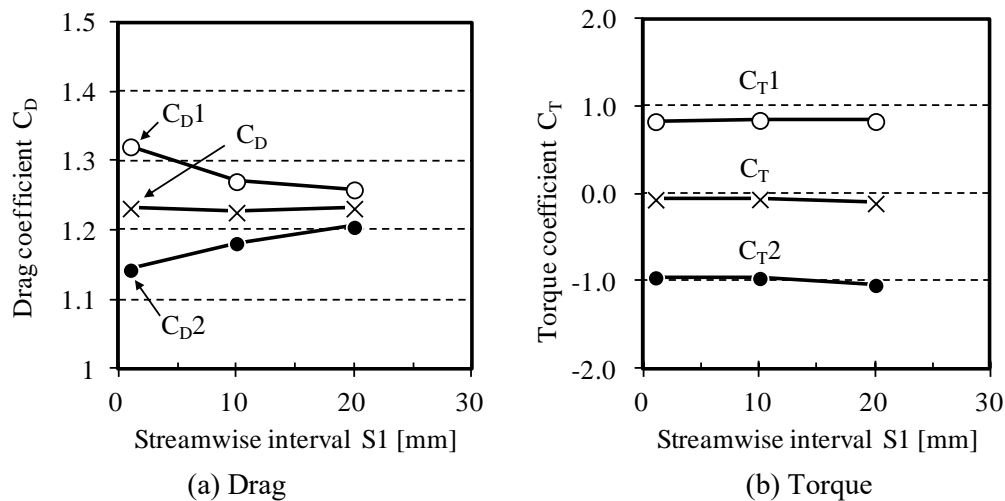


Figure 6. Relationship of spanwise intervals $S2$ on each panel vertically opened; streamwise interval $S1$ is 6 mm.

Table 1. C_D and C_T on experimental conditions.

Spanwise interval $S2$		Streamwise interval $S1$		
		27 mm	10 mm	6 mm
20 mm	C_D	1.24	1.27	1.23
	C_T	-0.15	-0.13	-0.10
10 mm	C_D			1.23
	C_T			-0.06
1 mm	C_D	0.98	0.98	1.23
	C_T	-0.13	-0.06	-0.06

Furthermore, the narrow spanwise interval of $S2$ tends to stabilize the relation of the drag force of the two panels, according to figure 6 under $S1 = 6$ mm conditions. It is found that both narrower $S1$ and

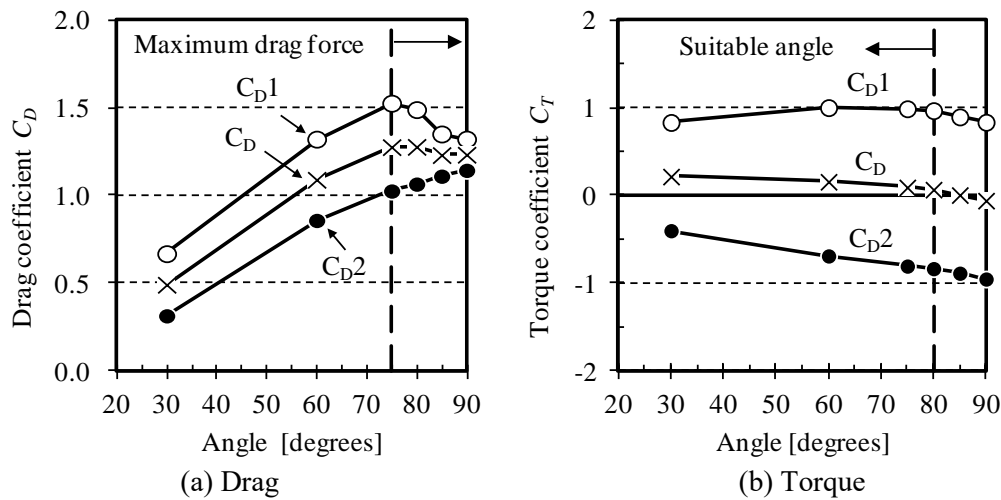


Figure 7. Relationship of the attack angles; streamwise interval S1 is 6 mm, and spanwise interval S2 is 1 mm.

narrower S2 would tend to stabilize the opened panels. Nevertheless, it was impossible to improve the C_T condition by changing the arrangement of the two panels.

3.3. Attack angle with respect to the panel

In this section, to stabilize the opened panel, the attack angle with respect to the fully opened panel is reduced from 90 degrees.

Figure 7 shows the drag and torque according to the attack angle with respect to a panel, provided that the streamwise interval and the spanwise interval are $S1 = 6$ mm, $S2 = 1$ mm. It is pointed out that the C_T is in a positive state when the attack angle is 80 degrees or less. On the other hand, the drag coefficient C_D falls off when the attack angle is less than 75 degrees, and the performance of the aerodynamic braking device goes down.

Therefore, to stabilize the opened panel and to keep the good performance of the braking device, it is found out that an attack angle of 75 to 80 degrees is suitable on this arrangement of the two panels.

4. Conclusion

A wind-actuated aerodynamic braking device consisted of a pair of two drag panels. However, after the drag panel fully opened, vibrational movements of the drag panel characterized by its slight flutter were repeated.

In this study, to stabilize the opened panel, matters pertaining to the angle of attack with respect to the drag panel and pertaining to the arrangement of the two panels were examined by a wind tunnel experiment using a scale model. As a result, to stabilize the opened panel and to keep the good performance of the braking device, it is found out that an angle of attack of 75 to 80 degrees is suitable provided that the interval of the two panels is narrow enough.

References

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