Rebound Vibration of Two-Plates Bonded Model for an Internal Mirror of SLR Camera

Rebound Vibration of Two-Plates Bonded Model for an Internal Mirror of SLR Camera

You may also be interested in:

Rebound Vibration of Two-Plates Bonded Model for an Internal Mirror of SLR Camera

Hiroki MATSUMOTO[1], Miho KUMAGAI[1], Akitaka KIKUCHI[1]

[1] Muroran Institute of Technology, 27-1 Mizumoto-cho, Muroran-shi, Hokkaido, 050-8585, Japan

h_matsu@mmm.muroran-it.ac.jp

Abstract. In this study, the rebound vibration characteristics of the internal mirror of an SLR camera are investigated using experimental models. The mechanism of the mirror rebound phenomena is tested by using the two-rectangular-metal-plates model, which has two plates bonded by double-sided tape. The mirror (plates) model is supported by fixing its longitudinal edge on a horizontal rotatable shaft. The bonded-mirror-model swings down freely around a horizontal axis and hits a stopper. A laser displacement meter is used to measures the amount of rebound and the mirror model vibration behavior. The rebound angle varies by the stopper position and the bonded position of the double-sided tape. In the case of a small rebound angle, the mirror part of the plate (upper side plate) vibrates with large amplitude, and its movement is measured by a 3-dimentional high-speed camera.

1. Introduction

Single-Lens Reflex (SLR) cameras have a moving mirror system. When the shutter release button is pressed, the mirror swings up to the upper side of the camera, and the light coming through the lens proceeds straight to the shutter curtain. After the image pickup device is exposed, the mirror swings down and strikes the stopper. At this moment, the impact force is applied to the mirror and a rebound vibration occurs. While the mirror is vibrating, the autofocus mechanisms cannot work and a photographer is momentarily unable to shoot another photo. In order to shoot pictures continuously, a mirror rebound vibration suppressing mechanism is required. The actual internal mirror is bonded to a mirror on the body part by an adhesion or double-sided tapes.

High-performance SLR cameras have a rebound reducing mechanism, which leads to high production costs. Low-cost SLR cameras do not have a rebound reduction mechanism, and with this study, a new method for vibration suppression is sought after. In order to find such a method, first, the essential mechanisms of the rebound phenomena must be clarified. For this purpose, it is necessary to change the stopper position, mirror structure, and associated components.

The collision behavior of a bouncing object was presented in many previous articles [1]-[3]. Especially, previous studies on the collision behavior of a tennis racket [4]-[8] or a bat and a ball [9] have considered the eigenvalue and vibration modes to describe the rebound phenomena. Another point to consider is the mechanical energy of collision phenomena. From the previous study, it can be analogized that the mirror rebound phenomena is related to the vibration behavior of the mirror. However, in the study of the tennis rackets, the rebound object is the ball and the vibrating object is the racket, but in this study, the mirror vibrated and rebound by itself. Thus, an explanation of the

phenomena for the bouncing object was needed. Similar studies that summarize the behavior of the rigid body and elastic vibration of a plate that rebounds post-collision were not found.

In a previous study [10], [11], it was made clear that the rebound amount of a mirror model was determined by the mode of vibration. However, the mirror model used in this paper was a single-plate model. Actual internal mirrors consist of a body part and a mirror part. This study investigates the rebound characteristics of two-plates bonded mirror model. In order to clear the mechanisms of the rebound phenomena of the model, a 3-dimentional measuring system is used. The aim of this study is to explain the rebound mechanism of the two-plates bonded mirror model.

2. Experimental method

2.1. Mirror models
Figure 1 shows the mirror model used in this study. The mirror model shown in Figure 1 is a scaled-up model. M3 bolts with a jig fasten the mirror models onto the shaft. The mirror model rotates with the jigs and shaft. The stainless-steel-shaft diameter was 4 mm and was attached to the main body by ball bearings. In order to measure the vibration behavior of the mirror model in high precision, scaled-up mirror models were used. The characteristic of the rebound phenomenon was almost the same between the actual-size model and the scaled-up model [7].

The actual mirror has some parts in a mirror system, such as a sub mirror or support frame. The mirror models were made out of aluminum plates with a thickness of 1 mm. A 54x68mm rectangular plate was used for the model of the mirror part, and a 60x80mm plate with a 20x40 rectangular hole was used for the model of the body part. Both plates were bonded by a double-sided tape. The stopper position was determined by distance y_s from the model edge as shown, and y_s can vary from 0 mm to 40 mm by 4 mm increments. The rebound angle was measured at every stopper position of y_s. The stopper was a consisted of an aluminum column with a 5 mm diameter, and a 1 mm length of column contacts with the mirror model. Hardness of stopper is important to determine the mirror angle in a SLR camera. The mirror angle has to decide exactly in static position for good finder image and auto focus sensor working well. Because of above, the soft materials do not use for the stopper.
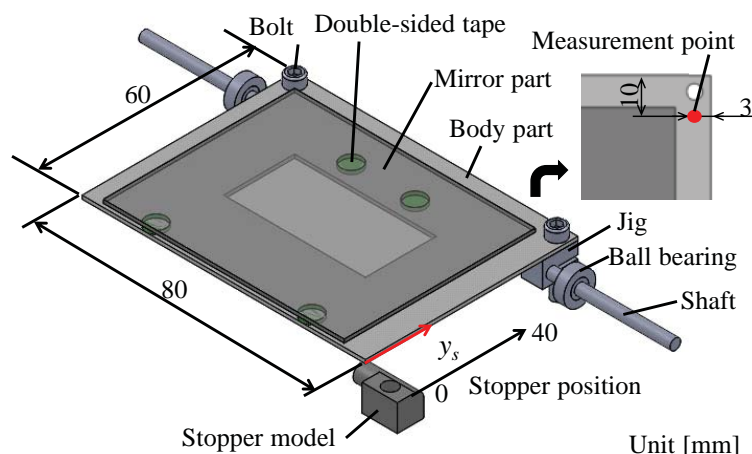
Figure 1. An internal mirror model of a SLR camera.

Two kinds of double-sided tapes were used. One was a polyethylene foam, the other was a fiber fabric. The thicknesses of the polyethylene tapes were 1.2 mm and 0.33 mm. The thickness of the fiber fabric tape was 0.17mm. These tapes were different from the actual bonded material of an internal mirror. In this study, in order to define the movement of the mirror part and the body part of the mirror

model, the parts were bonded softer than an actual mirror. Three kinds of bonded types were used, as shown in figures 2 to 4. Type A is the original position. This is a model of an actual internal mirror. The location of the tape is asymmetric in some cases of actual internal mirror. Type B is bonded by all sections of contact surface between the body parts. Type C is bonded by the edge of the mirror parts.
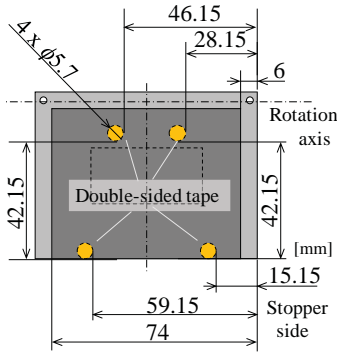

Figure 2. Type A (Original position)
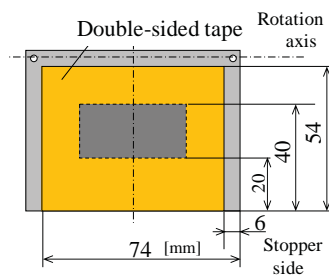
**Figure 3.** Type B (All section of the mirror part.)
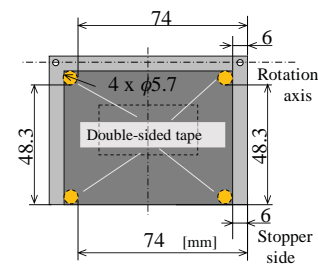
Figure 4. Type C (Edge of the mirror part.)

2.2. Experimental equipment

Figure 5 shows the experimental equipment. The stopper was located 45 deg below the rotation axis of the shaft. The mirror model freely swung down from the horizontal plane ($\theta = 45$ deg) and hit the stopper that was located at $\theta = 0$ deg. As shown in figure 1 and figure 5, the measurement point of the rebound angle was placed, and the laser displacement meter was used to measure the displacement of the mirror model. Then, an A/D converter and a computer were used to record the time series data. The sampling period was 100 μsec. The measured displacement was converted to the mirror model angle θ. Figure 6 shows an example of the experimental result. The maximum rebound displacement in the time series data is defined as θ_r that is the rebound angle of the mirror model. The measurements were repeated three times per set, and the average was taken as the rebound angle. The measurements were repeated 3 times per set and the average was taken as the rebound angle. The maximum data variability was 0.8 deg in 3 times measurement.
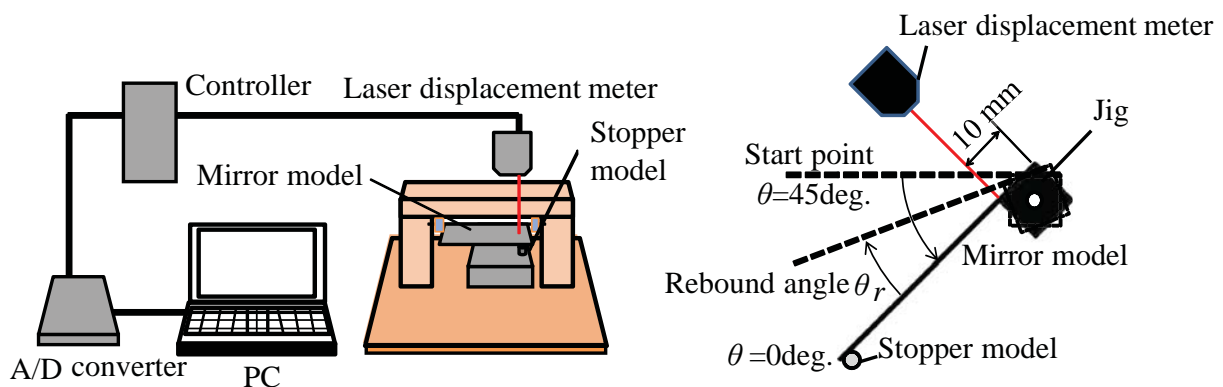

Figure 5. Experimental equipment to measure the rebound angle of the mirror model.
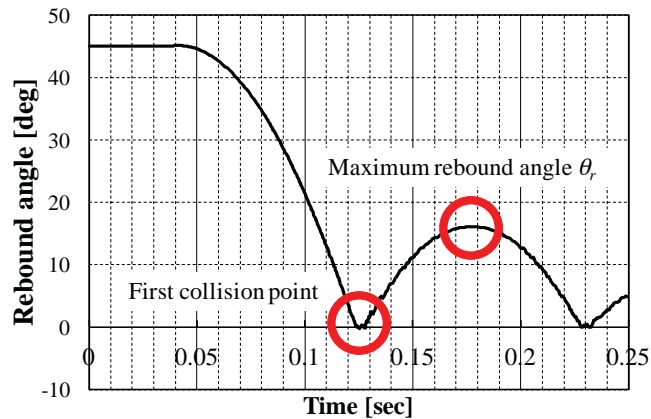
Figure 6. Example of the time series of a mirror rebound phenomenon, where the mirror model repeats the collision many times. The maximum rebound angle is determined at θ_r.

2.3. Measurement of vibration behavior of the mirror model

In order to measure the behavior of the mirror model, a 3-dimensional measuring system was used. Figure 7 shows the measuring system. Two high-speed cameras took movies from different directions. The mirror motion was analyzed by DIPP-Motion 3D. DIPP-Motion 3D is a motion analysis software that is able to analyze from two high-speed movies. DIPP-Motion 3D gives displacements of markers in the mirror model's moving picture in 3-dimensional space. Figure 8 shows the markers on the mirror model. Point P1 to P10 were analyzed by DIPP-Motion 3D. In the analysis, the Y-direction indicates the vertical direction of the mirror surface. Namely, the displacement of the Y-direction indicates the out-of-plane motion of the mirror model around $\theta=0$. The flame rate of the high-speed movie was 8,000 fps. Figure.9 shows an example of the motion analysis result. It shows that the collision between the bonded mirror model and stopper model occurs at about 0.006 sec.
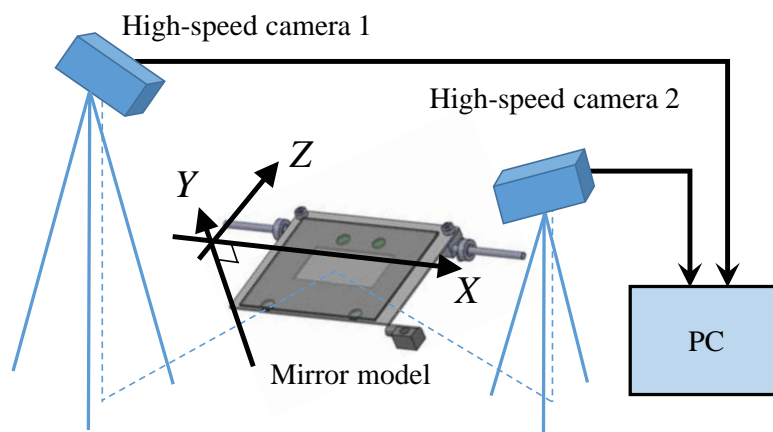
Figure 7. 3D motion measuring system which used two high speed cameras.
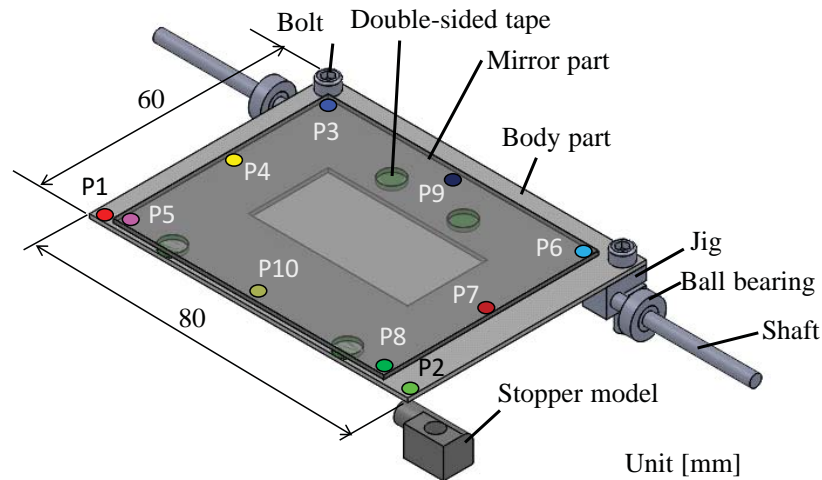
Figure 8. Markers for motion analysis of the mirror model. Point P1 to P10 are analyzed by motion capture software (DIPP-Motion 3D).
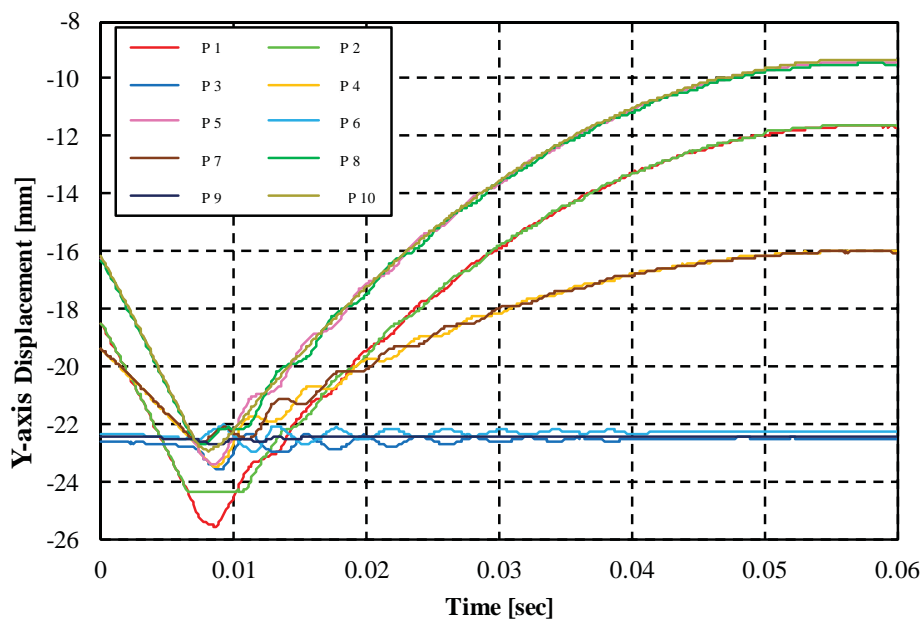
Figure 9. Example of 3D-motion analysis by DIPP-Motion 3D. Bonded mirror model is 1.2 mm tape Type A. The stopper position is 4 mm.

3. Experimental results

3.1. Measurement of rebound angle

Figure 10 shows the result of the rebound angle measurement for the bonded-mirror-models. The bonded type was Type A. The kind of double-sided tape was changed. 0.17mm-thckness fiber fabric tape is often used commercial product. The horizontal axis is stopper position y_s and the vertical axis is the rebound angle θ_r (the maximum angle of the rebound motion). The rebound angles became larger

as the stopper position rises on the whole. The yellow line indicates the result of the mirror model without a mirror part. Namely, this mirror model is only the body part. The rebound angle amount varied from about 26 to 34 deg. The blue line indicates the result of a bonded-mirror-model with a 0.17 mm-thickness fiber fabric double-sided tape. These two curves were almost the same. It shows that the thin fiber fabric double-sided tape had only a marginal effect on the rebound behavior. In the case of the 0.17 mm double-sided tape, the mirror part is integrally bonded with the body part. From this result, it was supposed that this model vibrated like a unity plate. The adhesive strength of 0.17mm double-sided tape was enough to become unified the mirror part and body part. The green line indicates the result of a bonded-mirror-model with a 0.33 mm-thickness polyethylene foam double-sided tape. The mirror part is easy to move independently than the case of 0.17mm tape. In the case of the lower stopper position, the rebound angle was smaller than the single body-part case and the 0.17 mm-thickness case. The red line indicates the result of a bonded mirror model with a 1.2 mm-thickness polyethylene foam double-sided tape. In this case, the rebound angle was small against the stopper position. The thickness of tapes had suppression effect on the rebound angle.

Figure 11 shows the result of the effect of the bonded type on the rebound angle. In the case of Type B and Type C, the rebound angle was almost the same. The rebound angle of Type A was the smallest of the three kinds of bonding type. When the stopper position y_s is 4 mm, the rebound angle of Type A has the smallest amount of 15.5 deg. In the case of 1.2 mm polyethylene double-sided tape, it has shown that the bonded type has large effects on the rebound angle. The Type A was the best bonding form of the three kinds of bonding type. Because, if the maximum rebound angle becomes small, the mirror rebound vibration will stop in a short time. However, when the stopper position becomes large, the rebound angle of Type A becomes as large as other models.
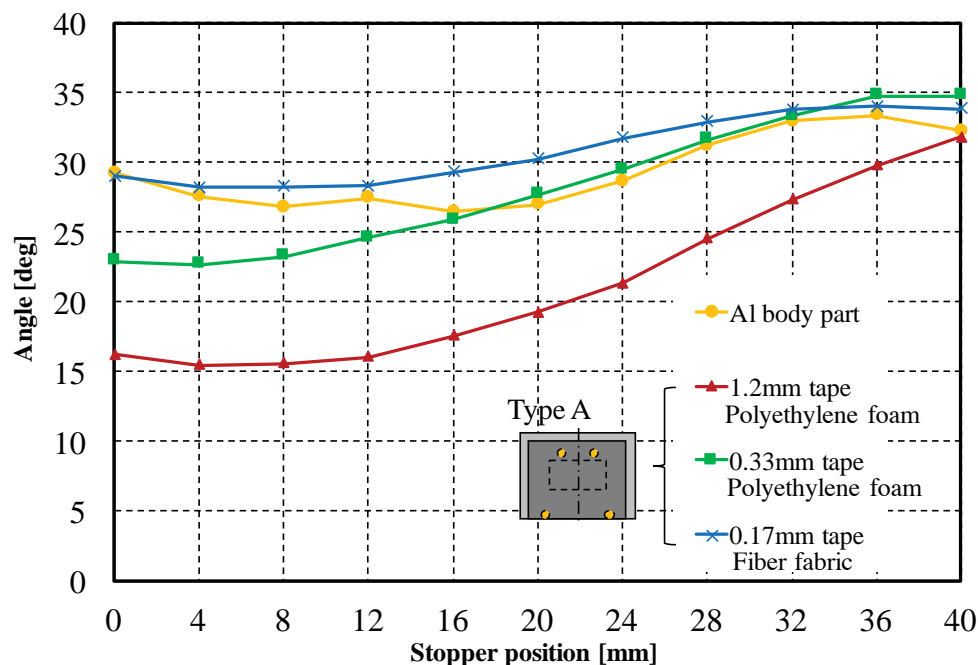
Figure 10. Effects of different kinds of bonded tape on the rebound angle of the bonded mirror model. The rebound angle varies by stopper position and kind of tape.
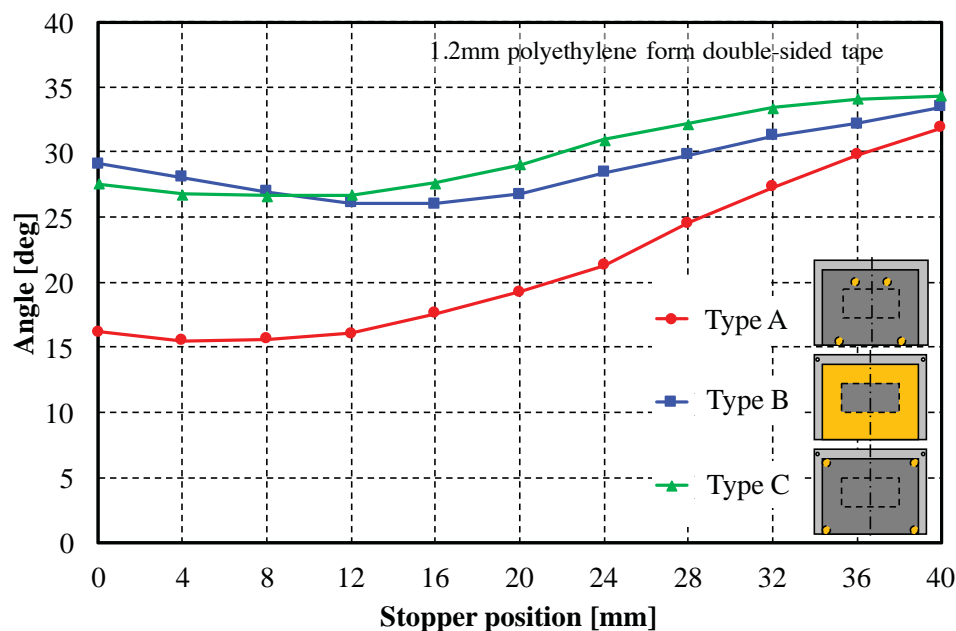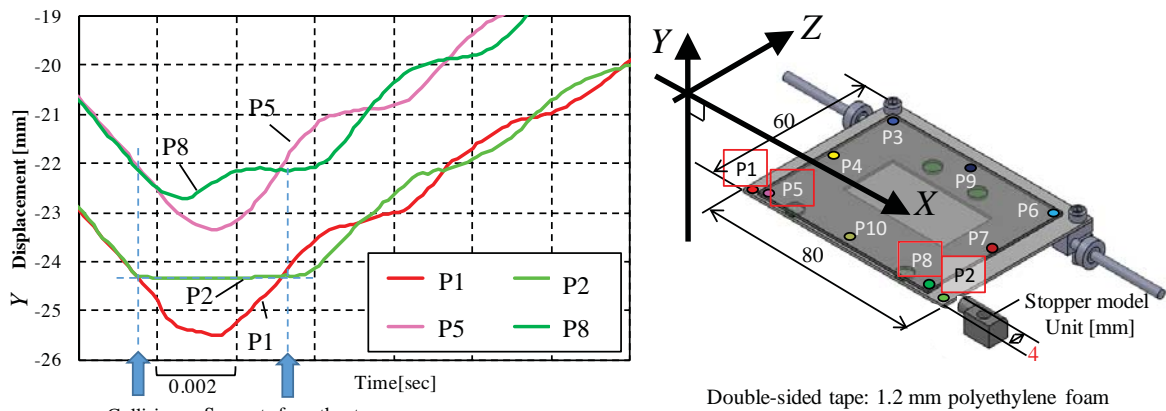
Figure 11. Effects of bonded type on the rebound angle of the bonded mirror model. The kind of tape is polyethylene foam with a 1.2mm thickness.

3.2. Measurement of motion of mirror model

Figure 12 and 13 show the result of the motion analysis of the boded mirror model. In the analysis, DIPP-Motion 3D can analyze 10 points on the mirror model at same time. Figure 12 and 13 show only the characteristic points from the results. Point P1 and point P2 were markers on the body part of mirror model. Point P5 and point P8 were markers on the mirror part of mirror model. The horizontal axis indicates the time scale in an increment of 0.002 sec. The vertical axis of the graph indicates the displacement of the marker point in the Y-axis direction. The sampling period was 1.25×10^{-4} sec. This sampling point was determined by the frame rate of the high speed camera.

Figure 12 shows the result of the stopper position of y_s =4 mm. In this case, the rebound angle became the smallest value in all mirror models. At the collision time, point P1 moved in the negative direction, but point P2 did not move. This result shows that the body part deforms elastically because of collision with the stopper model. The pink line indicates the movement of point P5 that is on the mirror part. The P5 moved similarly to the movement of P1. The difference of the Y-axis displacement between P1 and P5 equals the sum of the thickness of the mirror part and the double-sided tape. The dark green line indicates point P8's movement. The P8 vibrated with the different period of other points. At the separation time, P1 and P5 were moving in the positive direction but P8 was moving in the negative direction. P2 remained stationary at this time. This movement of point P8 provided a reaction force to the body part through the double-sided tape. The direction of the reaction force was negative on the Y-axis. At the same moment, another reaction force was acting from the stopper. This reaction force was positive on the Y-axis. Therefore, the resultant force was reduced. The resultant force determined the rebound angle. The reason for reducing the rebound angle is that the reaction force from the mirror part acts on the negative direction. This reducing mechanism was similar to a dynamic damper.

Figure 12. Time series of the *Y* axis direction displacement of the bonded-mirror model at the collision time. Stopper position is 4 mm, which is the smallest rebound angle case. The kind of tape is polyethylene foam with a 1.2 mm thickness.

Figure 13 shows that the time series of the *Y* axis direction displacement of the bonded-mirror model. The stopper position was y_s =40mm. In this stopper position, the rebound angle became the largest value in this model. All curves were similar to each other. Point P2 and P8 had almost the same movement. In the same manner as these two points, the movements of point P1 and P5 were similar to each other. From this result, it was supposed that the reaction force from the stopper and the reaction force from the mirror part acted in the same direction. Therefore, the rebound angle became large.

In the case of the larger rebound angle, the mirror part did not rotate around the Z-axis. Conversely, when the rotating motion of the mirror part occurred around the Z-axis, the reaction force from the mirror part reduced the resultant force acting on the mirror model.
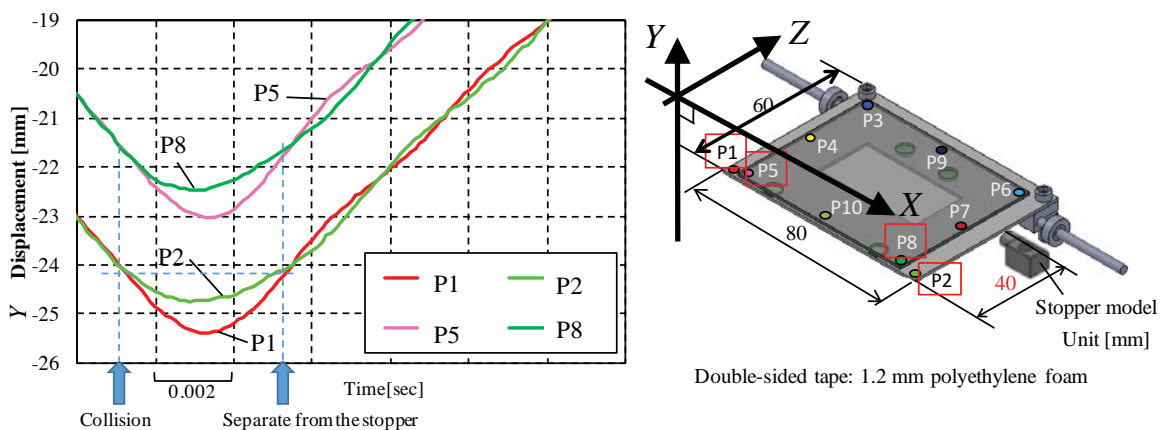
Figure 13. Time series of the *Y* axis direction displacement of the bonded mirror model at the collision time. Stopper position is 40 mm, which is the largest rebound angle case. The kind of tape is polyethylene foam with a 1.2 mm thickness.

4. Conclusion

The results of experiments for investigation about the characteristics of rebound vibration of the two-plates bonded mirror model are as follows.

- Thin fiber fabric double-sided tape had small effects on the rebound angle. The rebound angle has been almost the same as the single plate model.
- The polyethylene foam double-sided tape has been effective to reduce the rebound angle. The effective condition was that the bonding form was Type A and stopper position was 4 mm in this study. Type A was the structure that rotates around the *Z*-axis easier than other models. When the rotating motion of the mirror part occurs around the *Z*-axis, the reaction force from the mirror part to the body part reduces the resultant force acting on the mirror model.
- The vibration reducing mechanism has been supposed to as the mechanism of a dynamic damper.

The simulation of a simple lumped parameter model is a future work of this research. The result of it will reveal more about the mechanisms of reducing rebound angle of two-plates bonded mirror model. The location of the tape will be optimized by the simulation.

References
[1]   Cross R 1999 The bounce of a ball *American Journal of Physics* Vol.67(3) pp 222-227
[2]   Barnes G 1958 Study of collisions Part I. A survey of the periodical literature *American Journal of Physics* 26 pp5-8
[3]   Flansberg L 1979 Dynamic solutions for liner elastic collisions *American Journal of Physics* 47 pp911-914
[4]   Kawazoe Y 1992 CAE of Tennis Rackets with Impact Phenomena (Prediction of Racket Response and a View of Restitution in Racket-Ball Impact) (in Japanese) *Transactions of the Japan Society of Mechanical Engineers Series C* Vol.58 No.552 pp 143-150
[5]   Kawazoe Y 1993 Analysis of Coefficient of Restitution during a Nonlinear Impact between a Ball and Strings Considering Vibration Modes of Racket Frame (in Japanese) *Transactions of the Japan Society of Mechanical Engineers Series C* Vol.59 No.562 pp 76-83
[6]   Kawazoe Y, Tomosue R 1998 Prediction of a Sweet Area on a Racket Face in a Tennis Impact (Restitution Coefficient, Rebound Power Coefficient and Ball Post-Impact Velocity) (in Japanese) *Transactions of the Japan Society of Mechanical Engineers Series C* Vol.64 No.623 pp 72-78
[7]   Kawazoe Y 2006 Effect of Racket Frame In-Plane Hoop Vibrations on the Coefficient of Restitution and Energy Losses in Tennis Rackets (in Japanese), *JSME Symposium on Sports Engineering: Symposium on Human Dynamics 2006* No.06-35 pp 130-135
[8]   Yamaguchi T, Yamamoto T, Tsunoda M, Iwatsubo T 1995 A Study for Optimum Design of Tennis Racket (in Japanese), *Transactions of the Japan Society of Mechanical Engineers Series C* Vol.61 No.588 pp. 197-202
[9]   Hata H, Utsuno H, Matsuhisa H 2004 Modal analysis of a metal baseball bat considering the restitution of ball (in Japanese) *JSME Symposium on Sports Engineering: Symposium on Human Dynamics 2004* No.04-26 pp 89-94
[10]   Matsumoto H, Hirashima M 2013 Vibration Behavior and Rebound Angle on the Collision of Mirror Models inside a SLR Camera, *Journal of System Design and Dynamics Japan Society of Mechanical Engineer*s Vol.7 No.4 pp393-404
[11]   Matsumoto H, Hirashima M 2015 Suppration Method for Rebound Amount of the Internal Mirror Model of an SLR Camera, *Mechanical Engineering Journal* Vol.3 No.3 Paper No. 14-00553