Abstract

In a passenger air bag used in an instrument panel on middle and compact class cars, the door is formed on the back side surface by costly laser machining for high precision. This report introduces a completely new approach that utilizes a more versatile milling method.

1. Introduction

As auto manufacturers are accelerating the shift to overseas production, the parts suppliers also need to deal with global production deployment. Instruments panels that are being produced are no exception to this trend.

Meanwhile, the air bag door for the passenger seat is conventionally designed to be separate from the instrument panel, which leads to a disfigurement problem due to the parting line around the door. In recent years, more door design cases have appeared to be integrated with instrument panels to make the doors invisible, and thereby to improve the styling (Fig. 1). These integrated doors are formed by a machining process (herein after “tear processing”) on the back surfaces of the instrument panels, which enables cleavage when needed in case of collision. Since the processing typically requires high cost dedicated laser-based equipment, it was considered to be a concern particularly for overseas production deployment. We then tackled technological development on utilization of less expensive milling process to alleviate above-mentioned issue and yet to maintain the door opening performance.

2. Aim of development

Conventionally, the integrated door is formed by the tear processing where the lines shaped like the Chinese character ‘日’ are laser-cut on the back surface of the instrument panel to help the air bag cleave the panel along these lines of the two doors (Fig. 2).

For the development of the new milling method, we set a target of achieving a comparable door opening performance with that of conventional laser machining.

We also aimed at using less expensive tear processing machines that could replace conventional ones, which will eventually enable less investments, easier localization and faster global production deployment.

3. Outline of the development

3.1. Functions of air bags

Automotive air bags function to mitigate the impact on the occupant’s head or chest during frontal crash. Most air bags are designed as SRS (Supplemental Restraint System), which supplements the function of seat belts to reduce the impact when used in combination with them.

Typically, air bags are designed and manufactured to inflate when the vehicle crashes head-on into a solid structure, such as a concrete wall, at the speed of 20 to 30 km/h or above, or collides with another vehicle.

Fig. 1 Air bag door on the Nissan Leaf instrument panel

Fig. 2 Tear area
3.2. Structure of air bag system

The structure of air bag system is shown in Fig. 3. When a vehicle collides, the folded air bag starts to inflate and pushes up in the center of the instrument panel door as shown in (B) in Fig. 4, breaks the weak tear area (C) and breaks out of the hard instrument panel (D).

3.3. Difference in processing methods

With conventional tear manufacturing process, a laser beam is used to create openings intermittently like perforations (Fig. 5), and to heat and sublimate the hard instrument panel to form tear lines.

On the other hand, milling process uses cutting tools to form tear lines whose depth is constant (Fig. 6), causing formation of chips and burrs.

3.4. Key to achieving performance of tear area

The key role of the tear area is to help air bags break out of the instrument panel properly. To achieve this function, it is ideal that this sequential opening mechanism works as shown in Fig. 7: the tear center is broken; the tear sides are broken; and then the instrument panel doors rotate around the tear hinges. For this mode, it is important to find an appropriate balance in breakage strength between each tear area.

4. Equivalence design for performance assurance

4.1. Concept for tear area design

As described above, function of the tear area is to control the load and sequence of the breakage process. Generally, the thinner the tear area is, the more easily cleavage occurs. Then, using a test bench with laser-cut tear area, we investigated how the breakage strength can be controlled by the size and shape in conventional product cases to find out certain equivalent method for the new products.
In addition, when the tear area is too thin, the markings are visible from outside, thus it needs to achieve both strength and appearance requirements in the process of optimization of the size and the shape. Considering these conditions, we conducted the studies below.

4.2. Equivalence study for tear area cleavage

Before equivalence study with the lase-cut tear area, we investigated the mechanism of opening process in terms of breakage mode. Through the observation of deformation mode of actual doors with a high-speed camera, we discovered that there was little deformation around the integrated doors but that the center area is swollen up when pushed by the airbag. We then made an initial assumption that the tear area was broken due to a bending mode by referring to a dynamic model of a beam with both ends fixed shown in Fig. 8.

Under this assumption that the bending mode promotes breakage, mechanically equivalent design can be achieved by adjusting the section modulus of the milling tear lines (yellow parts in Fig. 9) to the same as that of the laser-cut tear lines although the section shape of the lines is different between the two methods. Furthermore, we attempted to verify the relationship between breakage load and section modulus on experimental prototypes that were built using the section modulus as a parameter.

Since it is difficult to measure load level at cleavage in actual vehicles, we simulated it on a bench test with an airbag device that punched an instrument panel door from the back at high speed as shown in Fig. 10.

An example of the test results is shown in Fig. 11. According to the assumption, we predicted that the relationship between the section modulus and breakage load should be proportional, i.e., the breakage load is zero if the section modulus is zero, and the breakage load becomes larger if the modulus is larger. However, we found that there is no correlation between the section modulus and breakage strength on the central, side or hinge tear sections, and accordingly this approach of equivalence design turned out to be unsuccessful with the simplified beam model with both ends fixed.

In the bending mode of the simple beam, tensile stress is generated on the top surface while compressive stress occurs on the back surface. From the above observation, we determined that this stress formation pattern needed to be further examined. Since the tear lines are located on the back surface of the breakage area, it is estimated the stress level there by CAE method (Fig. 12). As a result, the stress pattern appeared to change with respect to the thickness ratio of the tear area to the periphery, namely from compression to tensile stress on the back surface as the tear area became thinner (Fig. 13). We discovered that the breakage mode of the beam could be mainly associated with tension, instead of bending, because of the presence of the tear area.

Therefore, we conducted another experiment focusing
on section area as a factor dependent on tensile and shear strength, under the assumption that equivalence design would be achieved by equalizing the section area.

![Graph showing relation between breaking force and section modulus.](image)

Fig. 11 Relation between breaking force and section modulus

![Stress distribution at back side by CAE.](image)

Fig. 12 Stress distribution at back side by CAE

As a result, the correlation graph in Fig. 14 showed a proportional line between the section area and breakage load. This verified that the strength of the tear area is mainly dependent on the section area.

![Graph showing relation between breaking force and section area.](image)

Fig. 14 Relation between breaking force and section area

From the above results, we now identified an alternative characteristic to design the target performance. Using prototypes in which the study results were reflected, we conducted an airbag deployment test on a vehicle. As a result, we confirmed that the target was met and that a comparable performance with the conventional processing can be obtained.

5. Production engineering and equipment specifications for quality assurance

5.1. Outline of processing machine and critical quality

The tear processing machine has been developed based on an orthogonal tri-axial robot with the aim of lower equipment costs. Fig. 15 shows the appearance of the processing machine. The robot is equipped with a high-speed spindle to rotate the end mill for tear processing. A scrap collecting unit is installed around the end mill which scatters chips and burrs being formed during the processing and collects them via a duct.

![Machining machine of milling method.](image)

Fig. 15 Machining machine of milling method

To protect occupants by the deployment of air bags, it is essential to ensure that instrument panels are cleaved properly. The following points are required in manufacturing:

① Precisely controlling the residual thickness of tear processing areas
② Preventing chips and burrs from being scattered during airbag deployment

5.2. Assuring the residual thickness of tear processing areas

Fig. 16 shows a cross section of a tear area. After every machining cycle, the residual thickness \( t_1 \) is measured to ensure that cleavage occurs at the determined point. Since the residual thickness is affected by the accuracy of the processing machine’s repetitive movement, the jig and workpiece setting, in order to ensure precise machining, measures have been taken such as increased machine stiffness and lift prevention for workpieces by vacuum suction.

As shown in Fig. 17, the residual thickness \( t_1 \) is controlled within the specified range, which proves that a sufficient process capability is achieved.

5.3. Removing chips and burrs during processing

With laser machining, which heats and sublimates the processing area, no burrs are generated on the surface. On the other hand, milling forms chips and burrs on the processing surface as it employs mechanical cutting. Since there is a risk that these scraps are scattered during airbag deployment, formation of them needs to be avoided during processing and the removal should be ensured. We tackled this key issue with the approach described below.

① Developing an end mill dedicated to the processing section
② Optimizing machining conditions to suppresses chips and burrs on the bottom and side surface
③ Developing a scrap collecting unit

If the machining conditions are not optimal, burrs are generated on the bottom and side surface of the tear lines as shown in Fig. 18. The optimization of machining conditions and the scrap collecting unit are explained below.

Fig. 18 Surface after machining

Fig. 19 Machining condition

The optimal machining conditions were derived by looking into burrs at each area, the rotation speed of the end mill, and the feeding speed. Fig. 19 shows the range of the optimal machining conditions. Machining within this range can minimize burrs on the inner side of the surface.

Furthermore, a new device has been developed which can scatter chips and burrs formed during the processing and collect them to ensure that the scraps are removed.

Fig. 20 shows a concept drawing of the scrap collecting unit. A rotatable air nozzle in the machining direction is arranged to blow out chips and burrs. The scattered scraps are discharged outside via the duct. The angle of the air nozzle and the positioning with respect to the machining directions are optimally controlled as they are key points to improve the collecting efficiency.
Through the development of the manufacturing process described above, we have achieved quality assurance for airbag deployment and cost reduction in processing equipment for the milling method application.

6. Closing remarks

This invention has been employed in Nissan’s Leaf (produced in China) released in 2014. Further application is expected to be expanded to other globally produced models.

Lastly, we would like to thank all concerned for their cooperation in the development.

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