Introduction of Predetermined Airbag Tear Lines in Decorative Skins

Surface Technology. Predetermined airbag tear lines in decorative layers on automotive dashboards are normally introduced by laser cutting, cutting with a cold knife or hot-knife cutting. In a new process, a C-frame holds a knife and a roller ball. The integrated sensor technology permits high accuracy, reproducibility and safety.

Because of these requirements and the high commercial risk associated with failure of this safety-relevant component, very high requirements are now specified for residual wall thickness tolerance, which can only be met by very expensive machine technology. The main methods currently used to introduce predetermined airbag tear lines in decorative skins are laser cutting, cutting with a cold knife and hot-knife cutting.

Laser Cutting

In creating the line of weakness by a laser, the material is vaporized by laser energy and expelled by an additional gas. Since a groove produced in this way would have a strong tendency to show on the outside, there has been a move towards producing the tear line as a series of perforations with blind holes. For process monitoring and control, a sensor on the outside of the component detects the quantity of laser light shining through the residual wall. However, the level of sensitivity currently achievable in sensor technology only permits reliable detection of light quantity through a comparatively thin residual wall and, even then, the value obtained is highly material- and color-dependent. In addition, the residual material in the vicinity of the perforation is so thermally degraded that it can show through.

Fig. 1. Basic idea and main advantage of the newly developed scoring tool
other problem lies in the actual laser process itself, which can give rise to toxic vapors and deposits. These must be extracted and treated, which is a very time-consuming and costly process. Contaminants that persist on the component require expensive cleaning. On account of its high-maintenance technology, this method generates high costs compared with the methods described below – not just in terms of the initial purchasing investment but also during operation.

Cutting with a Knife

In cutting with a knife, a 6-axis industrial robot or NC machine moves a hard metal knife through the workpiece, while this is held in a vacuum fixture. Such systems are provided with a wealth of sensors for process monitoring. An inductively contour milled and solidly designed, while the workpiece is fixed in position by flat vacuum fields. In addition, the close contact of the workpiece is checked at various points by precision switches. A reproducible fixture position is achieved by dispensing with the usual rotary tables for parallel process component assembly.

Knife wear in these systems is normally determined by measuring the knife geometry. However, wear mainly affects the sharpness of the blade in the first instance. The way in which decreasing blade sharpness while knife length remains the same can have quite significant effects on the residual wall thickness achieved will be further explained later in this article. The systems on the market at present, however, have no facility for directly or indirectly determining blade cutting performance.

While the NC machines used have adequate path accuracy, the requirements for typical 6-axis articulated robots are at the limits of factory-specified dynamic path accuracy, so that only relatively expensive, highly accurate robot models can be used.

Despite the above-mentioned disadvantages, a large number of these knife machines are being used because of their low purchasing and operating costs, programming flexibility and capacity for gentle material processing with low mark-through.

Sensor-monitored Knife Cutting

In conventional knife cutting, the distance accuracy of the knife movement in relation to the fixed support or fixture depends mainly on the dynamic accuracy of the mechanical arms used. In the new approach introduced here, efforts have been made to define this distance mechanically. For this purpose, the component support plate had to be replaced by a precision mounted, freely rotatable ball. This ball is connected to the knife via a rigid C-frame. The decorative skin lies between the ball and knife, so that the distance between the knife tip and ball surface can be adjusted to define the residual wall thickness by a servo-controlled precision spindle drive with integrated stroke measurement. If the skin is now fixed in a fixture so that it is lightly pretensioned over the ball, the skin elasticity can compen-
sate for any tolerances in the movement path of the tool perpendicular to the skin surface. Provided it is possible to ensure that the skin is extended over the ball throughout the entire cutting operation, all the previous fault sources resulting from an inaccurate movement path, are completely eliminated.

To apply this basic idea (Fig. 1) in a tool suitable for the industry, the C-frame was rotatably mounted about the knife axis (Fig. 2) with precision bearings and coupled with a torque support to axis 5 of the robot. The robot can turn the knife in any required orientation with axis 6, while the C-frame maintains a fixed angle with the robot arm. So only one side of the component must be accessible to the C-frame, which permits a small C-frame opening width and simple fixture design.

Residual wall thickness was measured destructively using a high-precision digital microscope. Although this method of measurement complies with the current industrial standard, it is associated with a whole series of problems, which sometimes considerably influence the result. The method of sampling and determination of measuring point positions play an important role here. In addition, the skin grain is another disturbance factor. Since the height of the grain alone is 0.2 mm, there is no suitable reference plane.

Because of these difficulties, which have already been identified, the current practice for verifying capability characteristics is therefore often to record the values for the approximate distance of the knife from the counter surface. In the conventional systems described, these values are generally just within the required tolerance of ±0.05 mm. With the new system, however, the values are only composed of the inaccuracy of the actuator and bending of the C-frame and are therefore nearly ten times lower than previously. It can be seen, therefore, that a very significant advance has been made in terms of system accuracy, and especially system reliability, as compared with the present state of the art.

The position of the blade relative to the ball counter surface can be automatically re-referenced after each knife change. For this purpose, the actuator travels to just in front of the expected blade tip and switches there to a slow advance rate. During the further movement, the forces acting on the ball are recorded with the highest possible sensitivity and monitored. When there is contact between the knife and ball, this is indicated by a signal from the sensor and

Residual wall thicknesses were achieved versus cutting path for TPO.

To monitor the skin contact with the ball, a high-precision force sensor is mounted between the ball and actuating spindle, which continuously determines the axial load on the ball. If a preset value is understepped, the component is identified during the machining cycle as being “faulty” and is suitably labeled or destroyed. The moving sensor makes it possible to monitor the skin contact at any position of the cut.

A possible reason for a change in the knife-ball distance could be the elasticity of the C-frame. Bending of the C-frame would be directly manifested as a fault in residual wall thickness. To quantify this fault source, the load-deflection curve of the C-frame was experimentally determined. In the relevant force range up to 5 N bending was only about 0.01 mm and was therefore ten times lower than the required system accuracy. Since the cutting forces during the cutting process only vary within a small range, the actual influence of bending is in reality far less than quoted above.

The achievable tolerances with the system described were experimentally determined on various materials, while varying important process parameters such as feed rate, principal prestress, tool wear and the preset knife-ball distance.

Figure 3 shows by way of example the curve for residual wall thickness plotted against the cutting path for an ungrained skin produced from polyolefin elastomer (TPO). The residual wall thickness varies here within a range of only 0.22 to 0.26 mm, which is around 50 % of the maximum tolerance specified today.

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Residual Wall Thickness

![Fig. 3. Residual wall thicknesses achieved versus cutting path for TPO](image)

Reproducibility

![Fig. 4. Force and position values in referencing the blade tip](image)
Figure 4 shows the reproducibility of the zero position determined in this way for 50 repeated referencing operations. The value is less than 5 μm. The second curve shows the recorded maximum forces during the referencing operation, which are well below 0.4 N. An additional microscopic study of the knife tip and the ball surface confirmed that these small forces had not caused any mechanical damage to the knife or ball, even after 50 repeated referencing operations. Through the combination of a shading sensor to monitor fracture with the precise blade measuring method described here, it is possible to reduce the load on the blade imposed by the measuring process to a safe, tolerable minimum and still achieve a significant increase in accuracy with simplified measuring systems as compared with the systems previously used.

As already mentioned, the skin contact force against the ball is continuously monitored and recorded to determine whether a threshold value is understepped. These recorded forces in conjunction with the known load-deflection curve of the system also provide information about the magnitude of C-frame bending. In addition, the preset constant actuator position is logged and tested. In these numerous experimental studies, it was also found that the residual wall thickness did not exactly correspond with the precisely adjusted and monitored knife-ball surface distance. This effect can be attributed to the elastic behavior of the material under the knife. As Fig. 5 shows, the skin under the knife is elastically compressed by the cutting forces to an extent that depends on the particular material characteristics. After cutting, the material relaxes again and the actual residual wall thickness is higher than the preset value. To obtain the required residual wall thickness, the knife-counter surface distance must be reduced by trial and error until the desired result is achieved. This is what happens in current practice. The effect described above is increasingly pronounced as the blade becomes blunter, which leads to a gradual creeping change in the residual wall thickness. In the new system, such knife wear is monitored through the deviation of the recorded cutting forces from a tolerance range.

So for the first time a system has been developed that takes account of this important disturbance factor and integrates it into process monitoring.

**Conclusion**

The new system described for introducing predetermined airbag tear lines operates on a simple, reliable principle, which makes it possible to dispense with special costly sensor technology with its inherent problems and instead to use integrated sensors and actuators for different tasks. With this new approach, higher accuracy was achieved than with current robot-assisted systems and at the same time the quality of process monitoring was considerably improved because cutting forces could be taken into account for the first time. These advances also enable the design of the cutting machine as a whole and the fixtures to be greatly simplified, so that finally it has been possible to develop the most cost-effective airbag tear line solution in this high accuracy class.

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Fig. 5. Elastic behavior of the skin under the knife