Potentials for the use of tool-integrated in-line data acquisition systems in press shops

S Maier¹, T Schmerbeck¹, A Liebig¹, T Kautz² and W Volk¹

¹ Institute of Metal Forming and Casting, Technical University of Munich, Walther-Meißner-Straße 4, Garching 85748, Germany
² BMW Group, Landshuter Straße 56, Dingolfing 84130, Germany

e-mail: simon.maier@utg.de

Abstract. Robust in-line data acquisition systems are required for the realization of process monitoring and control systems in press shops. A promising approach is the integration of sensors in the following press tools. There they can be easy integrated and maintained. It also achieves the necessary robustness for the rough press environment. Such concepts were already investigated for the measurement of the geometrical accuracy as well as for the material flow of inner part areas. They enable the monitoring of each produced part’s quality. An important success factor are practical approaches to the use of this new process information in press shops. This work presents various applications of these measuring concepts, based on real car body components of the BMW Group. For example, the procedure of retroactive error analysis is explained for a side frame. It also shows how this data acquisition can be used for the optimization of drawing tools in tool shops. With the skid-line, there is a continuous value that can be monitored from planning to serial production.

1. Introduction

One of the essential parts of the fourth industrial revolution is the "digital shadow" of production processes. This shadow means a comprehensive recording and analysis of digital information of the processes. In the metal forming industry, especially in the production of complex car body parts, there are no such measuring systems established. One reason for this is the rough production environment in press shops. A successful implementation of the fourth industrial revolution in press shops requires new, robust measurement concepts.

In academic fields, many different kinds of measuring systems for forming processes were developed. A promising approach is the measurement of the part’s flanges positions after forming process. They give an information about the outer material flow. If too much material comes out of the flange, there is an increased risk of the appearance of wrinkles on the finished car body part. Conversely, a lower flow can lead to cracks. So a process window between wrinkles and cracks could be derived by the flange position. A wide range of sensor concepts have been investigated. Mechanical, tactile sensors have proven to be wear-sensitive and are therefore less suitable for series production [1]. So optical laser triangulation sensors were the next step [2]. They are measuring with no contact, but are dirt-sensitive. By the use of eddy current sensors a concept could be developed, which fulfills both requirements [3].

Common to all developments is the fact that the material flow is measured from the outer areas. Bräunlich and Grießbach have already pointed out that this is problematic for complex car body parts
It should always be measured where the forming takes place. In addition, the flanges must be measured in the forming tools because they are often cutted off in the next production stage. In this work, a new approach for measuring internal material flows is shown by the detection of skid-lines.

2. System for optical skid-line detection

The skid-lines on car body parts are created during the first contact between the tool radii and the sheet metal. While forming the part this line moves with the inner material flow. Since they are defined by the tool radii itself, inaccuracies in the production and positioning of the sheet play no role for the skid-lines. In addition, it is also visible on the finished parts for many different structural components, so it can also be recorded in later production stages. In contrast to the first drawing tools, later production tools for cutting or forming usually offer more space for the integration of sensors.

The functionality of the optical skid-line detection was first discussed in [5]. Sensor cameras were integrated into a cutting tool of an inner door sheet. When the tool opens, they take a picture of selected part areas. Through image processing, the position of the skid-line is determined from the matrix information of the grey values for each produced part. It gives an indication of the internal material flow. In particular, statistical simulation methods have a great potential for determining the most sensible camera positions already in the planning of such systems. The location of skid-lines are a result of most forming simulations today. So an unproblematic comparison between simulation and reality could be done. In the overall context the skid-line is a measurement variable from the planning and simulation to the last produced component of a serial production. In addition, the relation between spring back and the position of skid-line for a real door panel was shown in [6]. The results illustrate the relevance of the skid-line as a quality information.

Two practical applications of the skid-line detection are described in this paper. The method of retroactive error analysis will be explained for a side frame. For a door panel the detected information from a tool optimization process is discussed.

3. Retroactive failure-analysis on a side frame

In the series production of the selected side frame various quality errors can occur, which are summarized in Figure 1. Cracks of type 1 arise in the flange radius of the B-pillar when there is too much material flow and the tangential stresses increase as a result. There are two other crack-critical positions. Wrinkles occur preferably at the lower frame of the C-pillar.

![Figure 1. Failure types on the side panel.](image-url)
The positions of two sensor cameras were based on the locations of these failures. They inspect the skid-lines on the frames of C- and B-pillars. The system configuration is shown in Figure 2. In the fifth tool, a cutting tool, the cameras and their lighting were fixed by profiles. The images taken in each stroke are also shown in Figure 2. The distance from the skid-line to part’s flange is measured for each part. The calibration between mm and pixel is defined by rigid tool elements in the pictures with known dimensions.

Figure 2. Sensor cameras for optical detection of skid-line on the side frame.

Figure 3 shows the results for a production of 1600 side frames. Wrinkles were complained for the first 1000 parts. A retroactive error analysis revealed that the position of skid-line and thus the material flow in the C-pillar is too high. Process corrections were done for the following parts. They corrected the position of the skid-line. So no more wrinkles were complained on this parts. In addition, the real-time measurement of the skid-line shows which corrections have an effect on the quality problem of wrinkling. While the additional oiling in inner areas have a great importance, there is no measurable influence of oiling on the outside. The in-line measurement and error analysis thus enables the derivation of recommendations.

Figure 3. Relation between skid-line distances at c-pillar on wrinkles.
The Real-time visualization of measuring results is illustrated in Figure 4. It also shows results of measurements of the skid-line in the area of the B-pillar. Type 1 cracks could be identified whenever the skid-line ran too far what leads to higher tangential flange stresses in that area. In addition, a check measurement can be carried out through control of rigid tool edges or their positions in the image.

**Figure 4.** Relation between skid-line distances at b-pillar on cracks of type 1.

4. **Cross-departmental use of skid-line Information - tool optimazation process**

In the current optimization process of forming tools, the aim is to create tools that produce failure-free car body parts. Apart from geometrical requirements, there are no tangible, measurable goals for this process. Such a measurable quantity could be the skid-line position. It should be specified by simulations and then controlled in the real process at selected points by cameras. This allows a direct comparison between simulation and reality. In addition, the influence of the production press can be estimated if the same material is processed with same settings on different machines. Initial experiences with the use of the skid-line detection in the tool optimization process were collected for a door panel. The system configuration is shown in Figure 5. The skid-line was monitored in the door’s lock and hinge area, whereby only the lock area is discussed below.

**Figure 5.** Optical system for skid-line detection on an inner door panel.

Figure 6 describes the procedure for comparing simulation and reality results. On the left picture the position of the skid-line from the reference simulation is shown. The right picture illustrates the real area with its skid-line. The part’s upper edge (punch-area) serves as a datum-line. The skid-line distance
is measured from this datum-line to the skid-line. A calibration mark is located on the stamp, in order to be able to precisely align the camera with the area in the simulation.

![Simulation vs reality comparison](image)

**Figure 6.** Comparison between simulated and real skid-line position.

Figure 7 shows the measuring results on the door’s lock area for a tool optimization unit on production press. A total of 200 parts were produced. At the beginning, cracks (a) occurred at the lock-area of the door panel with a starting force of 360 kN/cylinder. Due to the definition of the skid-line distance, a higher distance means a greater thinning of material. So the cracked parts, which showed high distances, were overstretched. The position of the skid-line can be significantly influenced by variations of the blank holder force. There flows too much material for 270 kN/cylinder (six-point die cushion). Due to wrinkles, which block the material flow in draw beads, there are cracks in the area of door’s sill. A process window can be derived from these measurements. Between 44 and 47 mm, wrinkle- and crack-free parts can be produced without having to use additional oiling. There are no cracks in the lock and sill area. With the additional oiling of 0.5 g/m² this systematic changes. It is no longer possible to make any statements to the quality of sill-area from the measurements on the lock area.

A comparison between simulation and real measurements, based on results of basic simulations, is problematic. It can be seen that the predicted skid-line position of the simulation with pressure-dependent friction value lies in the process window. However, due to the large scatterings in serial production, it is not recommended to compare single simulation results. Process windows could be derived by statistical forming simulations and should be compared to real process windows (see Annen [7]). Thus, the real tool could be optimized in tool-shops to the target process window from the planning stage.
**Figure 7.** Measuring results of the skid-line distance at lock area while a tool optimization process on production press.

### 5. Conclusion

With the optical inspection of skid-lines, there is a promising measuring concept for the monitoring of forming processes of complex car body parts. Two exemplary applications were presented in this work. Due to the retroactive error analysis on a side frame, it could be shown that the skid-line is directly related to the part’s quality. On the other hand, the potential for tool optimization was tested. Real process windows can be recorded reliably and with high perception. The direct comparison of such measurements with statistical simulation results will contribute to the development of simulation accuracy as well as the tool optimization process. In the future, such systems must be taken into account when planning new forming tools. So their costs can be minimized.

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