# Early Detection of Rejects in Presses

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**Abstract.** Various production parameters such as inhomogeneous material properties or varying lubrication lead to deviations in manufacturing. Quality management must ensure that the required geometric dimensions and tolerances are maintained. In many cases, the inspection is carried out randomly, manually and at the end of the production chain, which prevents early detection of rejects and intervention. The problem complexifies due to the increasing demand for 100% testing of workpieces, e.g. for safety-relevant components in the automotive industry. This leads to additional effort regarding time, personnel and logistics. One solution to these problems is the inline measurement of the workpiece geometry. Due to rough environmental conditions in forming machines, the implementation presents particular challenges. In this publication, the disturbance variables occurring in presses are described and requirements are derived which result for the applied sensor technology. Based on this, a methodology for measuring small rotationally symmetrical workpieces is presented.

**Keywords:** Inline measurement · Reject detection · Quality management

## 1 Introduction

Due to a high output rate and efficient use of material, multi-stage presses (Fig. 1) are established in many industries for the production of small to medium-sized components with large batch sizes [4]. One aspect that offers potential for further development is the achievable manufacturing accuracy using multi-stage presses. The uncontrolled variation of workpiece dimensions has already been investigated and documented in various scientific papers [1, 5–9]. In general, the causes for the undesired variation of workpiece dimensions are the forming tool, the positioning of the workpieces in the tool, the lubrication, the raw material as well as the forming machine itself. In order to reduce weight and costs while increasing functionality and safety, the requirements on workpieces are getting higher and higher. A defective workpiece may have serious consequences and result in considerable economic damage to a company. Therefore, a demand for 100% good parts is no longer a rarity. Continuously dimensionally accurate, defect-free workpieces at the end of the production chain are the desired optimum required for profitable and competitive production [1, 10].

Even today, manual inspection of the workpieces at the end of the production chain is a common method to monitor the component quality. This requires a huge effort


M. Liewald et al. (Eds.): WGP 2022, LNPE, pp. 737–746, 2023.
https://doi.org/10.1007/978-3-031-18318-8_73

of logistics, personnel and time. The inspection costs are very high due to the high investment and operating costs of measuring equipment, the additional facilities required, and the need for specially trained personnel. In addition, component quality is often only checked after the entire batch has been produced. It is then no longer possible to intervene or change production parameters [3]. Thus, ensuring consistently high component quality at low production costs remains a major challenge for all manufacturing companies. Automated in-process monitoring of component dimensions is therefore intended to supplement or, in some cases, replace the manual inspection.

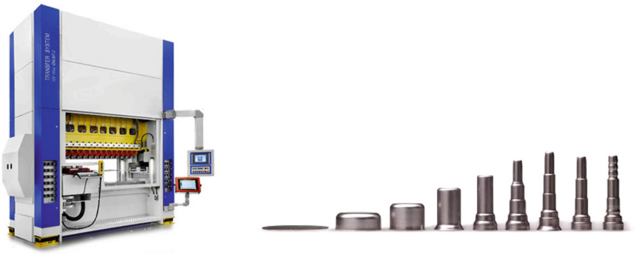

**Fig. 1.** Multi-stage press and exemplary stage sequence [11]

## 2 State of Research

*Quality management*

Although quality management has no direct impact on the value generation of a company, a wrong strategy can cause high costs and, hence, cut the profit. The time required for manual measurement of the workpieces after the production processs and, thus, the personnel costs are high. Once rejects have been detected, the machine must be stopped in order to identify and fix the cause. This procedure is also referred to as reactive maintenance. Another approach is the concept of preventive maintenance, in which active elements are replaced and readjusted after a certain time regardless of their condition. However, the potential to produce more quality parts with the existing components and the previous settings are lost [12]. In [13] a simulation method was presented in which the wear of all quality-relevant components in multi-stage presses is monitored in order to predict the quality loss of the final products and the system failure rate. From this, a decision can be made as to whether preventive maintenance is appropriate. A third variant is condition-based maintenance, in which intervention immediately takes place as soon as the production of rejects occurs. This approach requires that the workpieces and/or the active elements of the tools are monitored during the process.

*In-process control of component dimensions*

The inline, machine-integrated measurement of forming parameters has been a topic of academic discussion for many years. Ever more accurate and robust sensor technologies are constantly offering new application possibilities. However, such systems are still rarely found in forming plants [2].

*The reasons for this include the following:*

- High demands on the measuring technology to be applied.
- Lack of guidelines and planning instructions for users.
- Financial investment without prior assessability of the actual benefit.

According to the current state of the art, only indirect systems are available for the automated, in-process control of sheet metal components manufactured using multi-stage presses. In these systems, for example, the forming force or noise emission are measured and irregularities or process errors are inferred [14–17]. However, the accurate and direct measurement of the component geometry of small components during ongoing production is not possible with these systems. Systems providing 100% in-process monitoring only exist for large automotive body components, which are produced with a low number of cycles [18, 19].

To provide direct measurement of small rotationally symmetrical components in multi-stage presses and multi-stage dies, the topic is subject of the already finished AiF project 19904N [20] and the still ongoing project 21554N at IFUM. The measurement is supposed to take place during the process in the last, free stage of the multi-stage die (Fig. 2). The disturbance variables in presses that are relevant for sensors, will be investigated. Based on this, the use of different sensor systems will be discussed.

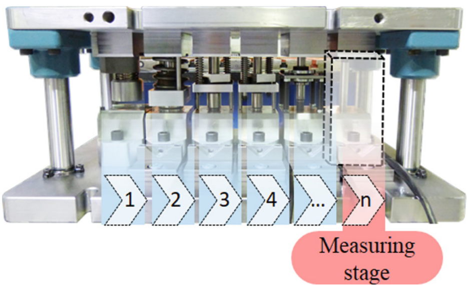


**Fig. 2.** Measuring system in the last stage of a multi-stage press or a multi-stage die

## 3 Measurement Conditions in Production Environments

The lack of available measuring systems for automated, in-process control of sheet metal components produced by multi-stage presses is mainly a result of the difficult environment conditions in the installation space of a press [20].

- thermal interactions and high temperatures,
- changing lubrication condition of the workpieces,

- shock and vibrations,
- short measuring time window due to high stroke rates,
- impurities,
- limited installation spaces for measuring systems.

As part of the AiF project 19904N, the effects of disturbance influences on the measurement of the workpiece geometry during production were investigated and requirements for sensor technology were derived. For this purpose, an industrially used multi-stage press was equipped with various sensors and the possibility of integrating a measuring system in the last, free-standing stage was investigated.

*Temperature*

Measurements with a thermal imaging camera showed that the maximum temperatures in the multi-stage press (~70 °C) were locally limited to the component and the temperature in the press room (~35 °C) and the die stages were lower (~45–50 °C). In addition, the temperatures of both component (~45 °C) and installation space (~35–45 °C) were lower as well in the last stage, where the measuring stage is to be integrated. This is because no forming takes place at this point and accordingly no additional thermal energy is released. Depending on the processed material, the stroke rate, the number of stages, the forming operations, the dimensions of the components and the installation situation, may vary.

However, the measurements show that even in cold forming processes the temperature conditions certainly play a role. Sensor systems that have to be used in close proximity to the workpiece as a result of a small measuring range can reach their limits or not be used at all, since adhesive layers between sensor components can soften, for example. The use of sensors with a greater distance between sensor and measured object (e.g. laser profile sensors) is less critical in this respect. Nevertheless, in all cases it must be kept in mind that the workpiece to be measured in a warm state still undergoes a reduction in volume as a result of the cooling process, which can certainly play a role depending on the accuracy requirements [20].

*Lubrication*

Lubrication can be challenging in two ways: One is dripping oil or aerosol can get into the interior of sensor systems and cause damage or cause dirtying of relevant parts such as lenses. For another, oiling of the workpiece can lead to measurement errors, which especially affects the use of optical sensor systems. In the latter, two superimposed effects occur. First, the laser beam is refracted when it enters the oil layer so that it hits a different point on the surface of the workpiece than intended (Fig. 3a). Second, the incoming light is reflected by the oil layer, which leads to blurring or scattering of the measured values (Fig. 3b). The resulting error increases with the entrance angle of the laser relative to the surface normal and the oil layer thickness. Common oiling quantities are in the range of 1–5 g/m$^2$, which, depending on the component surface and assuming homogeneous distribution, results in layer thicknesses in the range of one to several tens of micrometers. Depending on the entrance angle, this leads to measurement errors of the same order. This must be taken into account in particular if the desired manufacturing and measurement accuracy is in this range. An inhomogeneous distribution of the oil layer thickness makes this aspect even more challenging.

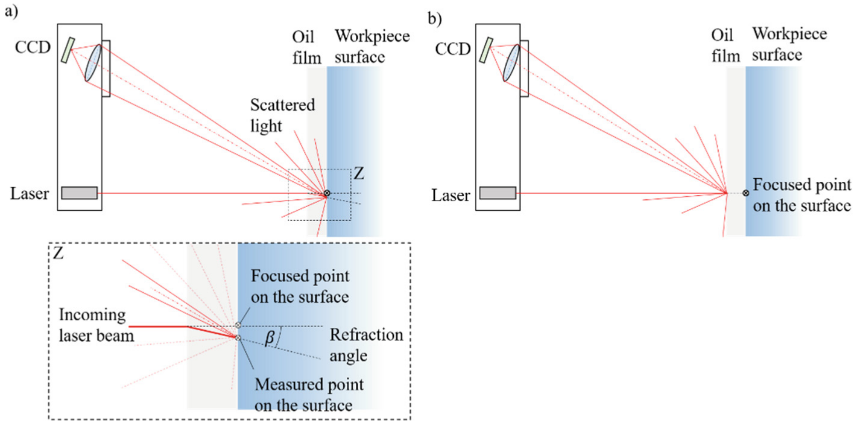


**Fig. 3.** Measurement error due to oiled surfaces

These effects can be prevented to a certain extent by the following approaches:

- Orientation of the sensor so that the entrance angle with respect to the surface normal is as small as possible,
- Off-center exposure of the measured object to reduce the light reflected by the oil layer,
- Removal of the oil layer in the measuring area by applying compressed air.

*Vibration*

The shocks and vibrations that occur in presses can result in a particular challenge for the applied measurement technology. They can lead to damages in the sensor and loosen adhesive surfaces or screw connections. As a result, measurement values become faulty and a readjustment of the setup is necessary. Further, measurement errors can occur because of the vibrations. The occurrence of errors even increases when the target and sensor are subject to different vibrational movements.

Hence, when using measurement technology in vibrating systems, particular attention must be paid to

- shielding the measuring system from vibrations by means of damping elements,
- designing the measuring system in such a way that the measured object and the sensor vibrate in the same manner, and
- designing the measuring system so that the natural frequency is higher than that of the press.

In order to quantify the requirements on the measurement technology in the case of the investigated multi-stage press, measurements were carried out with acceleration sensors at various positions (ram, transfer bars, machine block, bottom die, press frame, transport level). The measurements showed that vibrations of more than 100g occurred at the slide and the lower dies. On the machine block and press frame, however, significantly lower values occurred. The permanently occurring vibrations were in the range up to a maximum of 10 g [20]. Again, it should be noted that the results are highly dependent on the machine, the process, the die, and other aspects.

*Measuring Time*

The processes on multi-stage presses and multi-stage dies are designed for high performance and are carried out with the highest possible number of strokes. The time window available for measurement is therefore accordingly short. Its definition depends on various factors, such as object visibility, object position, and disturbance variables. To determine the available time, the transfer movement, the ram movement, the gripper activity and the occurrence of vibrations and shocks in particular must be considered in detail. On the one hand, it must be ensured that the measured object is not in the grip of the transfer system and that the grippers do not cover the measured object after setting down or before picking up. On the other hand, the measurement time window must be chosen so that the vibrations are as low as possible in order to reduce or avoid the measurement errors caused by this. The aspects mentioned above must be considered for every production case, as well as shock and vibration.

*Installation space*

One of the great benefits of multi-stage presses and dies is the efficient use of space. The stages are therefore kept as compact as possible, which makes the integration of measuring systems more difficult. Particularly in the case of small components, the available installation space is another limiting factor in the integration of sensors in press systems. The characteristics of the transfer movement are also an important factor. Depending on the measuring range of the sensors, they must be positioned more or less close to the workpiece. To avoid collisions, it is therefore necessary to match the positioning and mounting of the sensor to the conditions of the transfer system.

## 4 Suitable Sensor Systems and Their Limitations

Depending on the measuring task, application point, temperature of the workpieces and materials used, there are different types of sensors best suited for the task. Sensors that have a high measuring rate and high accuracy while being robust against vibrations and shock are laser-optical systems and eddy current sensors. The latter are the least susceptible to disturbances. However, compared to laser-optical systems, the sensors are often more expensive and only allow point measurement. In addition, the sensor heads are large compared to the dimensions of the available measuring spot. Thus, they can only be inserted into narrow openings such as inner diameters of rotationally symmetrical components to a limited extent. Another challenge is that these sensors must be mounted very close to the workpieces due to the small measuring range. Especially in complex systems such as multi-stage presses or multi-stage dies, difficult installation conditions arise because of the transfer of parts between the stages. On the other hand, laser-optical systems are more susceptible to disturbances, especially when reflective surfaces are to be measured in oily environments. The use of laser profile sensors, however, offers the possibility of measuring workpieces in their entirety with just a few sensor units. For workpieces with particularly narrow inner diameters, the measuring range of a laser profile sensor may not be sufficient, or the angle of incidence may be too wide. In this case, a compact sensor could be moved into the interior of the workpiece. However, this requires a measurement offset by 90° relative to the longitudinal axis. Such models can be found among the confocal chromatic sensors.

**Table 1.** Suitable sensor systems

| |  [21]Laser profile sensor [21] |  [21]Confocal displacement sensor |  [21]Eddy current sensor [21] |
|---|---|---|---|
| *Measurement* | | | |
| Type | Profile | Point | Point |
| Range | ++ | – | – |
| Rate | + | 0 | ++ |
| Accuracy | + | ++ | ++ |
| Special feature | / | 90° version | / |
| *Disturbance resistance* | | | |
| Vibration/shock | + | + | ++ |
| Temperature | + | + | ++ |
| Material surface/lubrication | – | 0 | ++ |
| *Mounting space/integration* | | | |
| Size | – | ++ | + |
| Distance sensor-target | ++ | – | – |
| Costs | + | – | – |

## 5 Measuring Device in Multistage Forming Tools

In AiF project 21554N, a measuring stage is currently under development that enables an integration into the final stage of a multi-stage die. Here, the use of two laser profile sensors will be tested, which are used to measure the entire workpiece geometry of a flange housing (Fig. 4). The measurement methodology involves rotating the workpiece once. During rotation, angle-dependent contour profiles are measured. In order to relate the two sensors to each other locally, a reference object is placed under the workpiece. This object is manufactured with high precision and the position of key features and contour elements in relation to each other is known very precisely. Since the sensors measure certain parts of the reference object, the measured contour profiles of the workpiece can also be assigned to a specific location.

In order to perform the measurement reliably, the component has to be centered, fixed and rotated in the measuring stage. A pneumatically actuated centric gripper was selected for centering and fixing on the inner side of the workpiece (Fig. 5). This allows a fast reaction time and a high force transmission while minimizing the covering of the workpiece. In addition, the three gripper fingers are mechanically coupled to each other via the wedge-hook principle, which allows very precise centering of the component. However, this gripper requires a compressed air supply for operation. The rotary unit therefore requires the possibility of a compressed air feed-through. A servo-electrically operated rotary unit with a hollow shaft is thus used in the measuring stage.

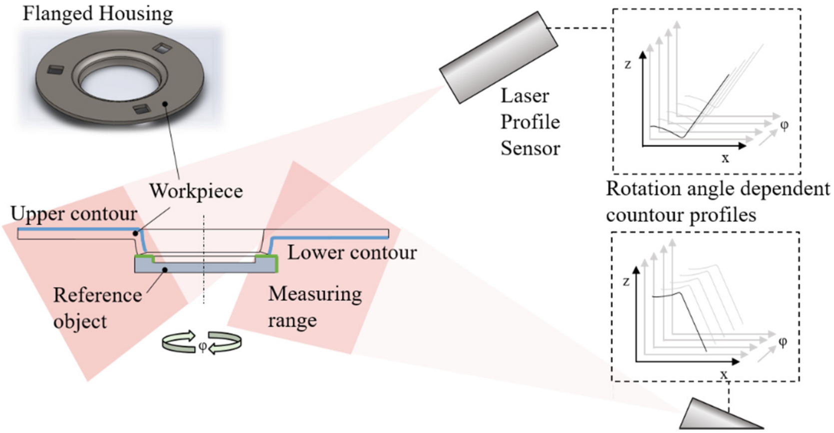


**Fig. 4.** Measurement of workpiece geometry with two laser profile sensors

In order to precisely measure the angle of rotation, the rotary unit has an integrated encoder. Despite the extremely compact design, the dynamics of the motor are sufficient to completely rotate both the gripper and the workpiece in 200 ms. The measuring stage is currently being implemented within a test setup and will subsequently be subjected to a measurement capability analysis. For this purpose, the measuring stage is also tested under different lubrication and temperature conditions of the component in a vibration test rig available at IFUM.

## 6 Summary

Today, there exist no systems for direct, in-process measurement of component geometry in press systems, which is mainly due to the challenging environmental conditions in press systems. However, advances in sensor technology are constantly opening up new

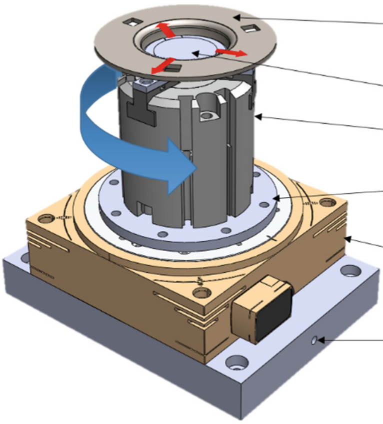


**Fig. 5.** Model of the measuring stage

possibilities for implementing appropriate systems. In various completed and ongoing projects, the IFUM is working on the direct measurement of components in multi-stage presses and multi-stage dies. In this context, the disturbance variables occurring in presses have been measured and analyzed, and requirements for sensors that could potentially be used have been derived. On the basis of the knowledge gained, a measuring system is currently under construction which will be used in the final stage of a test die to measure the entire geometry of small rotationally symmetrical workpieces during the process.

**Acknowledgement.** The IGF project "In-process reject detection by means of comprehensive measurement of the workpiece geometry in multi-stage presses" (funding number 21554 N) of the research association EFB e.V. was funded by the German Federal Ministry of Economics and Climate Protection via the German Federation of Industrial Research Associations (AiF) within the framework of the program for the promotion of joint industrial research (IGF) on the basis of a resolution of the German Bundestag.

## References

1. Endelt, B., Nielsen, K.B.; Danckert, J.: Adaptive shimming control for the ultimate deep drawing process. In: Proceedings of the IDDRG 2008 International Conference, pp. 569–580, Olofström, Sweden (2008)
2. Maier, S.J.: Inline-Qualitätsprüfung im Presswerk durch intelligente Nachfolgewerkzeuge. Dissertation Technische Universität München. Schriftenreihe Umformtechnik und Gießereiwesen, TUM.University Press, Munich, Germany (2018)
3. Gevatter, H.-J., Grünhaupt, U.: Handbuch der Mess- und Automatisierungstechnik in der Produktion, Springer-Verlag, Heidelberg, Germany (2006)
4. Herlan, T.: Optimaler Energieeinsatz bei der Fertigung durch Massivumformung. Dissertation Universität Stuttgart, Springer-Verlag, Berlin Heidelberg New York London Paris Tokyo, 1989
5. Behrens, B.-A., Javadi, M.: Exakte und kostengünstige Qualitätskontrolle an Pressen in der Blechverarbeitungsindustrie. UTFScience **2**, 1–5 (2009)

6. Doege, E., Strasser, D.: Instabilitäten bei Pressen für den Karosseriebau. Idee — Vision — Innovation. Verlag Meisenbach, Bamberg, Germany (2001)
7. Doege, E., Derenthal, M.J., Großmann, K., Jungnickel, G.: Analyse der Werkzeug- und Maschinenerwärmung während der Anlaufphase von Anlagen der Blechverarbeitung. In: Research Report on EFB Project 208 (AIF 12721BG), Europäische Forschungsgesellschaft für Blechverarbeitung, Hannover, Germany (2003)
8. Malikov, V., Ossenbrink, R., Viehweger, B., Michailov, V.: Experimental study of the change of stiffness properties during deep drawing of structured sheet metal. J. Mater. Process. Technol. **213**(11), 1811–1817 (2013)
9. Weck, M., Brecher, C.: Werkzeugmaschinen 5, Messtechnische Untersuchung und Beurteilung, dynamische Stabilität. 7 edn. Springer Verlag, Berlin, Heidelberg, New York (2006)
10. N.N.: Sensing the quality. Sheet Metal Industries, July 2001, pp. 4–5 (2001)
11. Hubert Stüken GmbH & Co. KG
12. Reichel, J., Müller, G., Mandelartz, J.: Betriebliche Instandhaltung. Springer, Berlin Heidelberg, Germany (2009)
13. Lu, B., Zhou, X.: Quality and reliability oriented maintenance for multistage manufacturing systems subject to condition monitoring. J. Manuf. Syst. **52**(A), 76–85 (2019)
14. Doege, E., Behrens, B.-A.: Handbuch Umformtechnik: Grundlagen, Technologien, Maschinen, 2nd edn. Springer-Verlag, Berlin (2010)
15. MARPOSS Monitoring Solutions GmbH Homepage. https://brankamp.com. Last accessed 27 Apr 2022
16. TRsystems GmbH Homepage. https://www.unidor.info. Last accessed 27 Apr 2022
17. Yun, J.W.: Stoffflussregelung beim Tiefziehen mittels eines optischen Sensors und eines Fuzzy — Reglers. Dissertation, University of Hannover, Hannover, Germany (2005)
18. GOM — Gesellschaft für Optische Messtechnik mbH Homepage. https://www.gom.com/de. Last accessed 27 Apr 2022
19. Carl Zeiss Optotechnik GmbH Homepage. https://optotechnik.zeiss.com. Last accessed 27 Apr 2022
20. Behrens, B.-A., Krimm, R., Höber, A.: Prozessbegleitende Bauteilvermessung in Stufenpressen. In: Research report on EFB project 541, Europäische Forschungsgesellschaft für Blechverarbeitung e.V., Hannover, Germany (2020)
21. Micro Epsilon Messtechnik GmbH & Co. KG Homepage. https://www.micro-epsilon.de/. Last accessed 27 Apr 2022