Analysis of a measurement system for characterisation of springback

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Abstract:
The following paper comprises different analysis methods for an isolated consideration of springback effects. It deals with the need of a more accurate springback calculation because of the increasing amount of automation in production.
The author suggests two experimental set ups, to take an isolated view on springback effects. Both testing methods deal with a bending process of sheet metal parts, which is the dominant factor for springback. The airbending test offers the possibility of open tools, that allow measurements from all directions. In contrast to this, the draw-bending test is only open to one direction, but it gives the possibility of applying different stress states.
Moreover optical and tactile methods for measurement of the parts geometry were presented and partly analysed. The analysis of the reachable accuracy of the optical methods showed a very high agreement of experiment and ideal geometry data. In addition with the high flexibility for measurements in loaded and unloaded conditions, this method is highly qualified for measurement of springback.
Finally three different analysis strategies for comparison of measured and calculated coordinates were shown, which offer, depending on position and quality of origin and reference coordinates, the possibility of high quality comparison of measured and calculated data.

1 Introduction

Since a few years the phenomenon of springback of thin walled sheet metal parts after forming is a well known problem of forming technology in general and special of the simulation of forming processes [1]. Although there were first estimations for springback of sheet metal in the 1950th and 1960th [2,3] and increasing research in fields of theoretical and practical approaches for the influence of material, material modelling and geometrical or technological parameters, the inquiry for a realistic estimation of springback effects is still an actual problem in forming technology [4,5,6].
This inquiry is supported by an increasing amount of automisation and an concomitant need for a high reproducibility of geometrical properties. Insufficient form- and dimensional accuracy is one of the major reasons for the need of removing bad quality parts from production lines [7].
The name "springback" is original founded in the geometrical difference of sheet metal parts after removing of the tools. But today the word springback is mostly used for all measured geometrical differences after the whole forming process between the ideal geometry and the produced part, even if the used presses do not close fully. An isolated consideration of springback phenomenon is rarely done.
Because of this, a springback compensation is today understood in common as a global compensation of all effects, that result in geometrical differences of a simulated and a real part and not a consideration of elastic or elastic-plastic springback itself.

2 Isolation of springback – experimental set up

To get to an analysis of springback itself, it is initially necessary to perform an experiment, where the influence of springback can be isolated. This could be for example a comparison between properties of a part in loaded and unloaded condition. One of the major properties in this case, can be the analysis of the parts geometry.
An isolated view on springback results, for example, from a contour measurement under loaded condition inside the experimental set up and after unloading. That's why there exists a need of finding an experimental set up, which makes a geometry measurement in loaded condition possible. Two usable forming processes that fulfil this need, where presented in the following:

Airbending: With this forming process a sheet metal part is initially clamped between a die and a punch. Afterwards, by moving the die, the part gets bended and finally springback occurs, when the die moves to it's initial position. The process is accessible as well from the upper, as from the lower side of the test specimen and gives the possibility of an online as well, as of a steady state geometry measurement. Touching surfaces are in this case the punch radius and the radii of the die.
To reduce process parameters in performing such experiments, the use of turnable die segments is suggested, to neglect the influence of friction, which is often difficult to describe.

Draw-bedning: In contrast to airbending, the draw-bending test works with an initially to 90 degree bended specimen, that will be positioned in the testing machine. By the use of a hydraulic system, defined forces can be applied on this part, which results in a controlled draw-bending of the specimen over a turning roll. Finally unloading of the specimen appears and springback takes place. The influence of friction can be controlled or minimized by a fixable turning roll (figure 1).

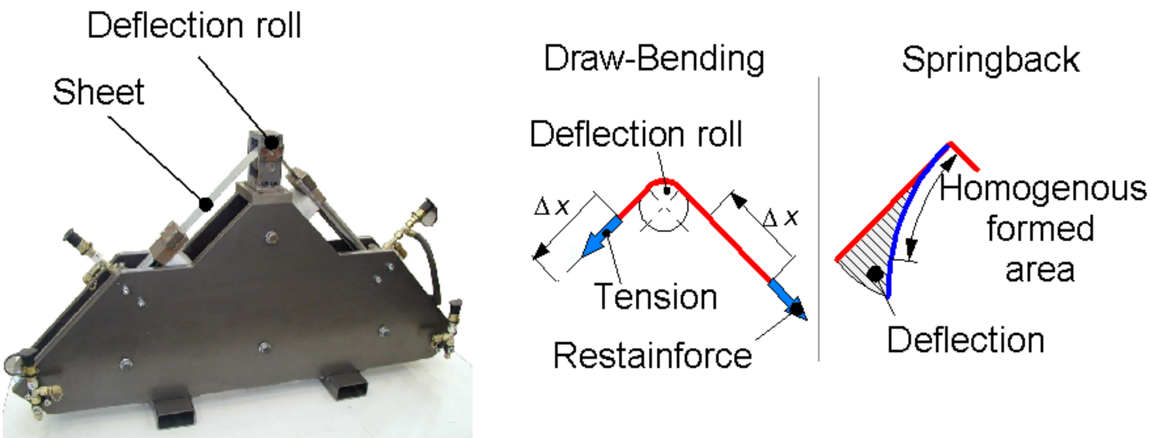


Figure 1: Experimental set up and draw-bending princip

The forming process can be subdivided into four states:

- The material gets stressed elastically.
- Reaching the turning roll the forming zone plastifies because of the dominating bending process. Proceeding drawing around the turning roll, the material gets only moved translatoric.
- At the end of the turning roll, the material plastifies a second time because of the re-bending process, but this time to the opposite direction.
- Finally, because of strain hardening, the material gets elastically deformed – depending on the amount of force.

This test is only accessible from the upper specimen side, but it gives the possibility of super-positioning of different stress states.

3 Measurement of the geometry / measurement methods

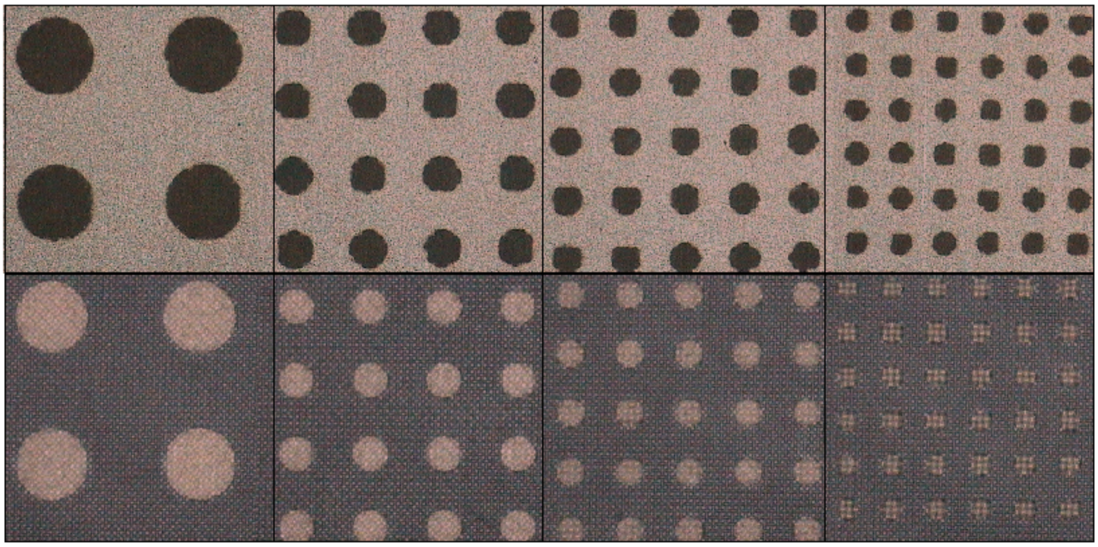
For measurement of the geometry of sheet metal specimen in loaded and unloaded condition, different methods can be used. In this paper the focus lays on optical and tactile measurement methods:
Tactile measurement of specimen: For tactile measurement of sheet metal parts generally a 3-dimensional coordinate measurement system is used. This machines offer the possibility of numerical controlled measurement, which simplifies the positioning of the part inside the measurement equipment drastically. Depending on the used tactile system (measuring or switching system), complete outlines or discrete points of the part can be measured.
The disadvantage of this system is that by the touching principal of the sensor which can lead to deformation of parts with low stiffness. Furthermore the identification of discrete points on the specimens surface according to their position on an ideal geometry is quite problematic.

Optical measurement: Optical measurement of a parts geometry can be achieved in different ways: On the one side an optical sensor in a 3-dimensional coordinate measurement system (instead of a touching one) can be used for non touching measurement. This can be done by the measurement of reflections from a laser light or LEDs by the use of a photodiode.
On the other hand the position of discrete measurement points on the specimens surface can be found out by the use of photogrametric analysis of pictures made from different directions.
In this case a grid is applied or projected on the specimen, which midpoints (in case of an elliptic grid) or crossing points (in case of a line grid) can be searched with algorithms based on methods of digital picture analysis. By the use of specially coded markers (usually circular codes) and marker-finding-algorithms or the knowledge of the cameras position, a positioning of the grind points of each picture relatively to the other pictures is possible. [8,9]. The measurement results in a cloud of points that can be scaled to real dimensions by the use of a predefined distance of two fix-points. The process results in the coordinates of defined material points, which can be used as a base for example, for the calculation of strains occurred in a forming process.
A major advantage of this method is the non-touching, 3d surface-area measurement. No discrete paths have to be driven like it has to be done with a normal coordinate measure-

ment system. Furthermore the measurement system needs only less space inside the testing tool and a positioning of the tools according to the measurement system is not necessary. This arguments and the high flexibility lead to a further analysis the optical measurement system in terms of accuracy to analyse their usability for springback measurement

Accuracy of optical measurement

Usual grids for optical measurement deal with circles with a diameter of 1,0 mm to 2,0 mm distance. That's gives a sufficient result quality and quantity for parts with a surface of 100000 mm². For a measurement of the geometry of bended parts, which only have a small, local forming zone, this grid is too rough to get sufficient results.
Because of this, the chair of forming technology of the university of Dortmund tested the usability of much smaller grid sizes in a range of 0.6 mm to 2.0 mm point distance. For applying the grids a electrochemical method has been used, to print the points by the help of a negative template (which can be produced by screen printing) and a electrolyte on the sheet metal part. Depending on the fineness texture and the used wire thickness the accuracy of the grid can be adjusted. The negative and the resulting point grids are shown in figure 2.



Point distance: 2.0 mm	**Point distance: 1.0 mm**	**Point distance: 0.8 mm**	**Point distance: 0.6 mm**
Point diameter: 1.0 mm	**Point diameter: 0.5 mm**	**Point diameter: 0.4 mm**	**Point diameter: 0.3 mm**

Figure 2: Different grid sizes for optical analysis of geometry and strain distriubution

It can be seen, that the resolution of the 2,0 mm and the 1,0 mm points results in a sufficient grid quality by the use of a width of the mesh of 45 µm and a wire diameter of 34 µm (120-34). With an increase in the number of points per area, the following three effects begin to worsen the quality:

- the accuracy of the points in terms of roundness decreases,
- the effect of moiré by a superposition of the wires grid and of the point grid decreases,
- the photographed area has to be chosen smaller because of the constant resolution.

Strain analysis of the major engineering strain of the non deformed grid is shown in figure 3.

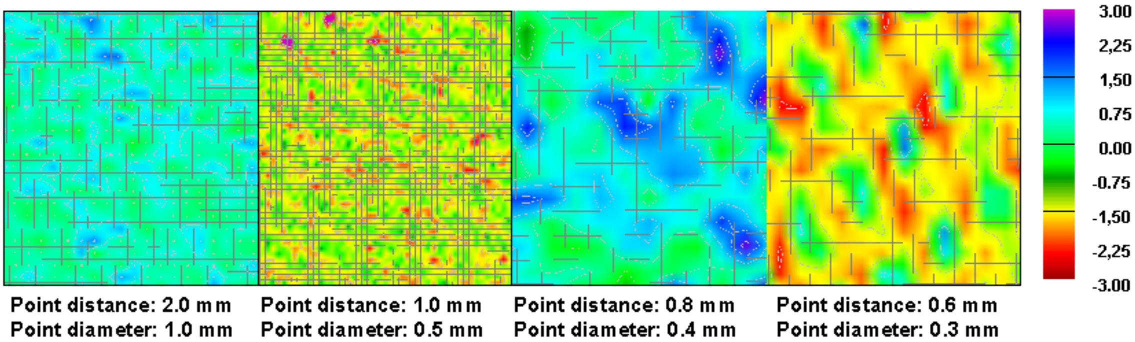


Figure 3: Analysis of major engineering strains of undeformed grids.

The measurements make clear, that independent from the grid size, mistakes in the grids or the analysis method occur. This mistakes vary in an area of +/- 1 percent, on an average. Around this average value, they differ in a range of +/- 2 percent per grid. By the knowledge of the point distance and the strain formula an absolute mistake of +/- 2 percent of the points distance has to be considered.
Summarising it can be said that, with increasing point size and distance, not only there is a quantitative improvement of the result, but also a qualitative improvement is possible. But with decreasing grid size, the quality of the grid points decrease, the effect of moiré occurs and problems in focusing appear.
It can be shown that optical measurement delivers sufficient accuracy for geometry measurement of springback. Because of further advantages such as high flexibility and non touching measurement, this method is proved to be a good measurement system for geometries in loaded and unloaded condition. Furthermore the possibility of analysing gridpoints, offers a method to compare translations of discrete material points with finite element nodes and of measured and calculated strain values.

4 Analysis strategies

By the use of equal positioned finite element nodes with material points, it is possible to make a direct comparison of coordinate differences of calculated and measured data. In cases of differences in the data's origin a transformation of the geometric points has to be done. This process can happen in three ways:

<u>Choice of an equal origin:</u>
The choice of an equal origin of measured and calculated geometric data, leads to a direct comparability of the points and nodes coordinates. No further transformations are necessary, the differences between experiment and simulation result from the differences of the coordinates of each direction.
This method is the most simple comparison method for the user. But it makes use of a very accurate experimental set up, to come to same origin positions. To make sure, that there are no differences in positioning some reference points, which undergo no translations have to be chosen and compared.

If the origin is positioned right and the measured coordinates of the reference points fit to the ones from the finite element method, this method results in a high accuracy by simple handling.
But if origins aren't equal or the coordinates of the reference points differ, for example in case of an offset, a transformation of at least one dataset is necessary.

Translation by reference coordinates: If the datasets have no equal origin system or the reference coordinates differ a transformation of the point coordinates is needed. The easiest case (different origin position) can be handled with a transformation of the origins to equal coordinates.
Mentioning that, with equal origins, a translatoric or rotatoric difference still can exist, a further transformation has to be done. In this case, based on the knowledge of the reference points coordinates, a new origin can be chosen and by translation and rotation to equal reference points coordinates the coordinates can be imaged.
This strategy needs little more work and knowledge from the user to perform the necessary transformations in case of differences in origins.
But if there are differences in origins and no clear reference coordinates on the part and the simulation model, this strategy is also not useful.

Best-fit-transformation by the method of least coordinate differences:
If the suggested strategies still result in differences of origins and reference coordinates of measured and ideal data, a best fit of the coordinates can be done by using the method of transforming to least coordinate differences.
This strategy deals with an optimisation algorithm that analyses the difference of the respective coordinates. By defined transformation and following calculation of the new differences a comparison of the differences can be done. Making use of mathematical algorithms – for example downhill-simplex - a straight search for the minimum of differences can be done. To adjust this method, a weighting of selected points can improve result quality.
This strategy is the most complex one of the here mentioned ones. The user needs as well knowledge about the configuration differences, transformation of coordinates and optimisation algorithms. By the choice of an useful initial configuration and well chosen weighting good results can be reached. A final plausibility check is absolutely affordable, to check the work of the optimisation algorithm.

5 Summary:

This article deals with different analysis strategies for the measurement of geometrical and dimensional differences of sheet metal parts. Facing springback caused differences, two experimental set-ups were suggested, that allow an isolated analysis of the springback phenomenon. The airbending test is qualified because of the open tools, that allow measurements from all directions. Using turnable die elements, friction can be neglected in this test.
The draw-bending test is only open to one direction, but it gives the possibility of applying different stress states.
For measurement of the parts geometry optical and tactile methods were shown. An analysis of the reachable accuracy of the optical methods showed the high quality standard of this systems. In addition with the high flexibility for measurements in loaded and unloaded conditions, this method is highly qualified for measurement of springback.

Finally different analysis strategies for comparison of measured and calculated coordinates were shown. Depending on position and quality of origin and reference coordinates, this strategies give the possibility of high quality comparison of measured and calculated data.

Literatur

[1] Heidl, W.; Eichhorn, A.: Rückfederung beim Tief- und Streckziehen von Feinblechen. Blech Rohre Profile. 4/1999. page 90-93

[2] Boer, de, R.; Bruhns, O.: Zur Berechnung der Eigenspannungen bei einem durch endliche Biegung verformten inkompressiblen Plattenstreifen. Acta Mechanica, 8/ 1969. page 146-159

[3] Schwark, H.F.: Rückfederung an bildsam gebogenen Blechen, Dr.-Ing. Dissertation, Technische Universität Hannover,1952

[4] Brosius, A.; Kleiner, M.; Rohleder, M.; Roll, K.: Investigation of springback in sheet metal forming using two different testing methods

[5] Brosius, A.; Kleiner, M.: Abschlußbericht Bauteilauswertung s-Rail. UniversitätDortmund 1999

[6] Inpro: Rückfederung, Entwicklungen zur industriell anwendbaren Vorhersage der Rückfederung. Berlin. 13./14. March. 2003

[7] Rohleder, M.: Simulation rückfederungsbedingter Formänderungen im Produktentstehungszyklus von Blechformteilen. Dr.-Ing. Dissertation. Universität Dortmund. 2001

[8] Wiora.: Optische 3D Messtechnik: Präzise Gestaltvermessung mit einem erweiterten Streifenprojektionsverfahren. Dr.-Ing. Dissertation. Universität Heidelberg. 2001

[9] Behring D.; Thesing J.; Becker, H.; Zobel, R.: Optical coordinate measuring techniques for the determination and visualization of the 3D displacement in drash investigations. SAE-SP. 1773. page 225-231. Warrendale. Society of Automotive Engineers. 2003