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Nebojša Arsić[1]
Nenad Kostić[2],*
Nenad Petrović[3]
Nenad Marjanović[4]

APPLICATION OF 3D SCANNING AND CAD DEVIATION ANALYSIS AS A BASIS FOR PRESS TOOL OPTIMISATION IN THE AUTOMOTIVE INDUSTRY

ABSTRACT: The aim of this paper is to analyse the geometrical deviations of a stamped part in relation to the nominal CAD model and to identify critical zones after the first trial of a press tool. The analysed sample is the left-hand stamped part obtained using a press tool intended for manufacturing left- and right-hand parts. After the first tool trial, the part was scanned using an EinScan-SE 3D scanner, resulting in an STL model of the manufactured part. The resulting model was processed by removing local noise and mesh irregularities generated during scanning, while preserving the basic geometry of the part. After alignment with the nominal CAD model, a comparative deviation analysis was performed. The results are presented as a deviation map, which enables the identification of zones with the most pronounced deviations. Special attention is given to the use of 3D scanning as a preliminary procedure in the early stage of tool adjustment, providing a faster overview of part geometry before final verification by more precise contact measurement methods. The identified critical zones indicate that the press tool elements involved in bending and final calibration should be inspected first, providing a basis for targeted corrections in subsequent trials.

KEYWORDS: 3D scanning, CAD model, press tool, stamped part, quality control

[1] *Nebojša Arsić, Faculty of Engineering, University of Kragujevac, Serbia, nebojsa.arsic@kg.ac.rs,*
https://orcid.org/0009-0009-2605-8108
[2] *Nenad Kostić, Faculty of Engineering, University of Kragujevac, Serbia, Corresponding author: nkostic@kg.ac.rs,*
https://orcid.org/0000-0002-0157-7501 *(*Corresponding author)*
[3] *Nenad Petrović, Faculty of Engineering, University of Kragujevac, Serbia, npetrovic@kg.ac.rs,*
https://orcid.org/0000-0002-7563-9883
[4] *Nenad Marjanović, Faculty of Engineering, University of Kragujevac, Serbia, nesam@kg.ac.rs,*
https://orcid.org/0000-0002-8441-4328

PRIMENA 3D SKENIRANJA I CAD ANALIZE ODSTUPANJA KAO OSNOVA ZA OPTIMIZACIJU PRESERSKOG ALATA U AUTOINDUSTRIJI

REZIME: Cilj rada je analiza geometrijskih odstupanja otpreska u odnosu na nominalni CAD model i identifikacija kritičnih zona nakon prve probe preserskog alata. Analizirani uzorak predstavlja levi otpresak dobijen na preserskom alatu namenjenom za izradu levog i desnog dela. Nakon prve probe alata, otpresak je skeniran pomoću 3D skenera EinScan-SE, čime je dobijen STL model izrađenog dela. Dobijeni model je obrađen uklanjanjem lokalnog šuma i nepravilnosti mreže nastalih tokom skeniranja, uz očuvanje osnovne geometrije dela. Nakon poravnanja sa nominalnim CAD modelom sprovedena je uporedna analiza odstupanja. Rezultati su prikazani pomoću mape odstupanja, koja omogućava identifikaciju zona sa najizraženijim odstupanjima. Posebna pažnja posvećena je primeni 3D skeniranja kao preliminarnog postupka u ranoj fazi podešavanja alata, čime se omogućava brži uvid u geometriju dela pre završne provere preciznijim kontaktnim mernim metodama. Identifikovane kritične zone ukazuju na to da najpre treba proveriti elemente preserskog alata koji učestvuju u savijanju i završnoj kalibraciji, što predstavlja osnovu za ciljane korekcije u narednim probama.

KLJUČNE REČI: 3D skeniranje, CAD model, preserski alat, otpresak, kontrola kvaliteta

INTRODUCTION

In the automotive industry, stamped sheet-metal parts must be manufactured within prescribed dimensional and geometrical tolerances because their geometry directly affects assembly, functionality and the quality of the final product. During the first trial of a press tool, deviations from the nominal CAD geometry may arise from tool geometry, forming conditions, material flow and springback (Wagoner, R. H. et al. 2013; Hartmann, C. et al. 2021). Early identification of such deviations is important because it enables critical regions of the part to be detected before subsequent tool trials and provides guidance for further inspection and correction of the press tool.

Dimensional inspection of stamped parts can be performed using conventional measuring instruments and coordinate measuring machines (CMMs), while optical 3D scanning offers the possibility of rapidly acquiring a large amount of geometrical information over the accessible surface of a part. Rękas, A. et al. 2021 applied a 3D optical measurement system to the inspection of large stamped automotive components by comparing measured geometry with nominal CAD models. Varda, K. et al. 2022 compared the application of coordinate measuring machines and 3D scanners for the control of dimensions, shape and position. Paunoiu, V. et al. 2022 demonstrated the use of 3D scanning in the inspection of automotive body parts, while Morovič, L. et al. 2019 showed that deviation maps can be used to visualise differences between scanned and nominal geometries. Kuş, A. 2009 also reported the application of optical 3D scanning in automotive inspection, including the comparison of manufactured sheet-metal parts with CAD models.

An important advantage of optical 3D scanning is the high density of acquired geometrical data, which enables the spatial distribution of deviations to be observed rather than evaluating only a limited number of discrete measuring points. Brajlih, T. et al. 2011 highlighted this advantage in the inspection of geometrically complex components, while also noting that optical scanning does not replace high-precision coordinate measurement when strict dimensional verification is required. The reliability of optical scanning also depends on factors such as surface visibility, optical properties and measurement coverage. Koutecký, T. et al. 2016 demonstrated the importance of these factors when planning the scanning of sheet-metal parts. Therefore, 3D scanning is particularly suitable as a rapid preliminary inspection method during the early stage of press tool adjustment, while critical dimensions and geometrical characteristics close to tolerance limits can subsequently be verified using more precise measurement methods.

The usefulness of deviation analysis is not limited to identifying whether a manufactured part differs from the nominal geometry. When the spatial distribution of deviations is considered together with the sequence of forming operations, the observed critical zones can also indicate which regions of the press tool should be inspected first. Springback is one of the important phenomena influencing the final geometry of formed sheet-metal parts, as discussed by Wagoner, R. H. et al. 2013 and Hartmann, C. et al. 2021. Tool-geometry correction and compensation procedures have therefore been investigated as a means of reducing deviations after forming. Mole, N. et al. 2014 presented a method for optimisation of forming-tool geometry considering springback and sheet thinning, while Siswanto, W. A. et al. 2014 proposed an alternative approach to springback compensation through modification of tool geometry. In this context, the combination of 3D scanning and CAD-based deviation analysis can support an iterative procedure consisting of part inspection, identification of critical zones, targeted tool correction and a subsequent tool trial.

The aim of this paper is to examine the application of 3D scanning and CAD deviation analysis for the rapid identification of critical zones on a stamped part after the first trial of a press tool. The method is not intended to replace final high-precision inspection using a coordinate measuring machine, but to provide a fast and accessible preliminary assessment of the manufactured geometry. The contribution of the paper lies in using the spatial distribution of deviations between the scanned STL model and the nominal CAD model to identify critical regions of the stamped part and to relate these regions to the corresponding bending and final calibration operations, thereby providing guidance for targeted inspection and correction of the press tool.

MATERIALS AND METHODS

The analysed sample was a left-hand stamped part produced during the first trial of a press tool intended for manufacturing both left- and right-hand components. The part was manufactured from EN 10130–DC01 cold-rolled steel sheet with a nominal thickness of 1.5 mm. The nominal geometry of the component was defined by the corresponding CAD model, while the manufactured part was digitised by 3D scanning and represented by an STL model.

Figure 1 shows the position of the analysed component within the press tool strip layout and the sequence of manufacturing operations. Particular attention was paid to the bending and final calibration operations because these stages determine the final geometry of the side walls, bend regions and transition surfaces that are subsequently considered in the deviation analysis.

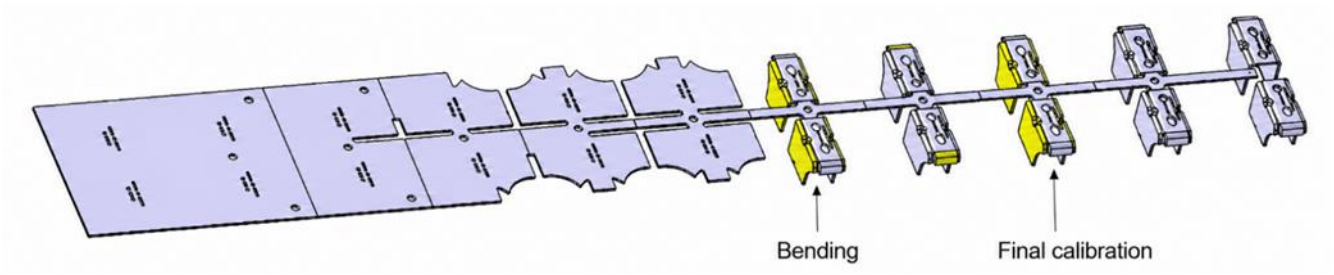


Figure 1 Press tool strip layout with the bending and final calibration operations highlighted

The geometrical requirements relevant to the analysed component were taken from the technical drawing. Figure 2 presents a simplified extract showing the A–B–C reference arrangement, datum targets A1–A3, selected areas E–I and the related profile-tolerance indication. The original title block and all company, customer, product and document identifiers were omitted. The remaining dimensions are shown only to clarify the positions of the selected features and were not evaluated separately in this study.

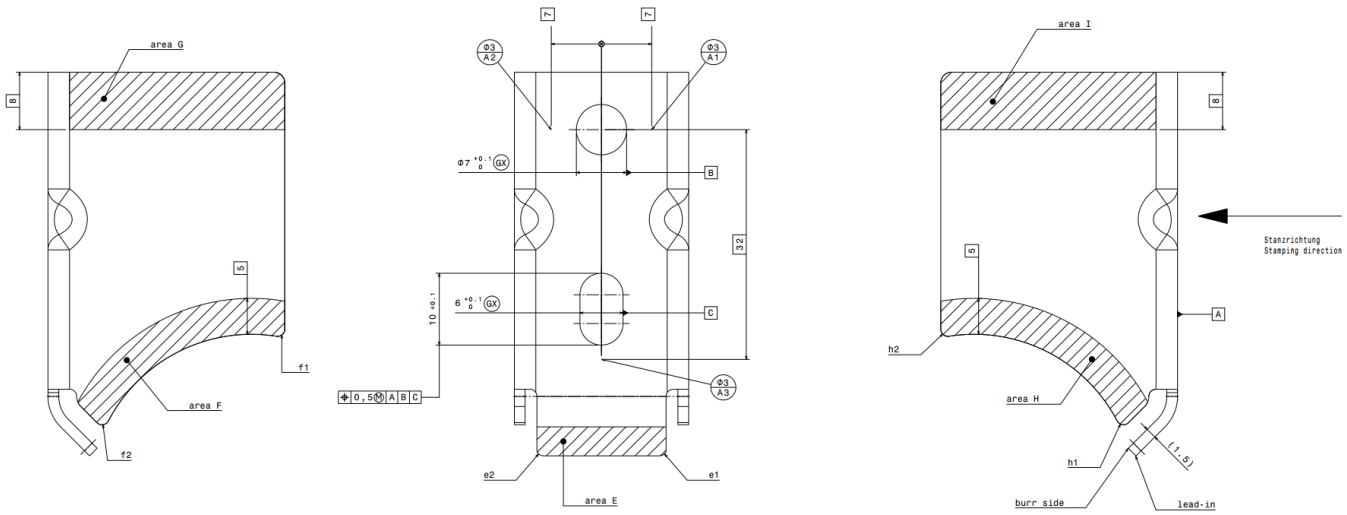


Figure 2 Simplified technical drawing of the analysed stamped part

The technical drawing specifies a surface profile tolerance zone with a total width of 2 mm relative to datum system A–B–C for the general formed surfaces and 0.5 mm for the designated areas E–I. These values were used as reference criteria for interpreting the global deviation map. Since the individual tolerance regions were not evaluated separately, the analysis was used to identify areas requiring further inspection rather than to establish formal conformity of the complete part.

3D Scanning and STL Model Preparation

The stamped part was digitised using a SHINING 3D EinScan-SE desktop structured-light 3D scanner together with a rotary table. Data acquisition and initial processing were performed using EXScan S v3.1.2.0. Before data acquisition, the scanner was calibrated using the procedure provided by the manufacturer, followed by white-balance adjustment.

Scanning was performed in Fixed Scan mode using the rotary table. No matte coating or reference markers were used. The numerical exposure settings and other fine acquisition parameters were not retained in the working record and are therefore reported as a limitation of reproducibility.

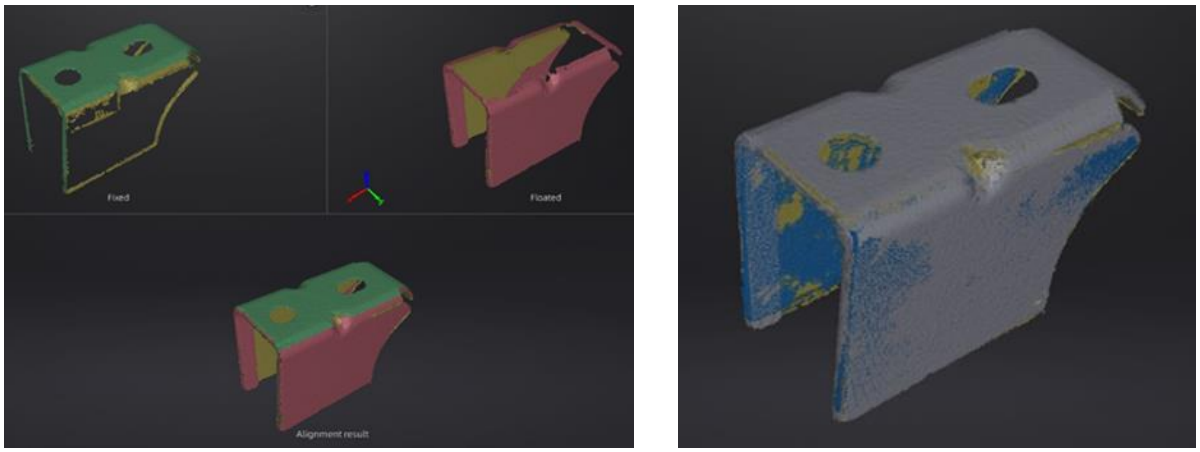
The EinScan-SE has a declared single-scan accuracy of ≤ 0.1 mm and a point distance of 0.17–0.20 mm (SHINING 3D n.d.). These values represent the specifications of an individual scan and should not be interpreted as the measurement uncertainty of the complete procedure, which also includes acquisition from different part orientations, scan alignment, mesh generation and subsequent CAD comparison.

The final dataset was acquired from four different orientations of the stamped part. Eight angular views were acquired in each orientation using the rotary table, resulting in a total of 32 accepted scans. The use of different orientations enabled surfaces that could not be completely captured from a single position to be scanned.



Figure 3 Experimental setup for 3D scanning of the stamped part using the EinScan-SE scanner and rotary table

The acquired scans were organised into scan groups and subsequently aligned in EXScan S. Corresponding points were selected on overlapping scanned regions, after which the aligned groups were merged to obtain a more complete digital representation of the stamped part. Figure 4 illustrates the alignment of the scan groups and the resulting merged scan data.



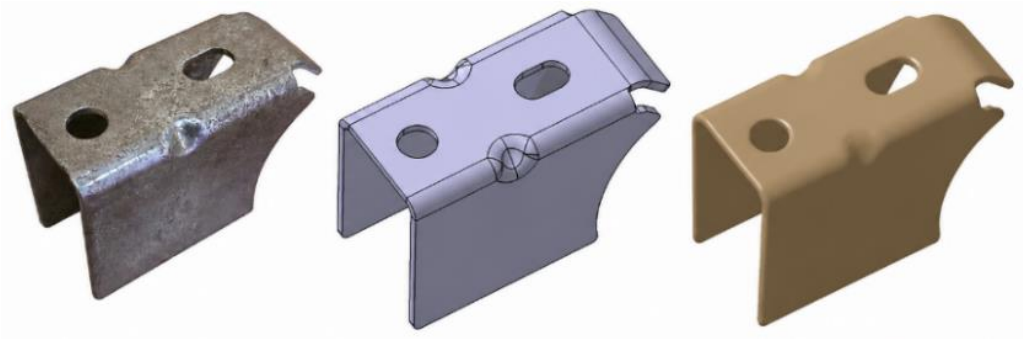
a) b)

Figure 4 Data processing in EXScan S: a) initial alignment of two scan groups using three manually selected pairs of corresponding points; b) merged dataset of 32 accepted scans

After the scan groups had been merged, a polygonal mesh was generated. Limited optical access resulted in incomplete data in some internal regions of the part. Gaps and local mesh irregularities in these regions were repaired during post-processing, while the measured external geometry was preserved. The repaired regions remained in the final STL model and therefore represent reconstructed rather than directly measured geometry. This limitation was taken into account when interpreting the deviation map. The processed model was exported in STL format for subsequent CAD-based deviation analysis.

CAD Deviation Analysis

Figure 5 shows the analysed stamped part and the corresponding nominal CAD and processed STL models.



a) b) c)

Figure 5 Analysed stamped part and corresponding digital models: a) manufactured stamped part; b) nominal CAD model; c) processed STL model

Before the deviation analysis, the processed STL model was manually aligned with the nominal CAD model in CATIA V5 using the component features corresponding to the A–B–C reference arrangement shown in Figure 2. The Deviation Analysis function was then applied to determine the magnitude and spatial distribution of the surface deviations. The alignment supported a comparative CAD–STL assessment and was not used for formal verification of datum-related positional tolerances. The final analysis included 27,856 evaluated surface points.

Particular attention was paid to the side walls, bend regions and transition surfaces. The locations of pronounced deviations were subsequently considered together with the sequence of bending and final calibration operations in order to identify regions of the press tool that should receive priority during further inspection and adjustment. In this way, the deviation analysis was used as a preliminary engineering procedure for locating critical regions and providing guidance for subsequent tool corrections.

RESULTS AND DISCUSSION

The results are presented by means of the deviation map shown in Figure 6. The map provides an overview of the magnitude and spatial distribution of deviations over the analysed surface of the stamped part.

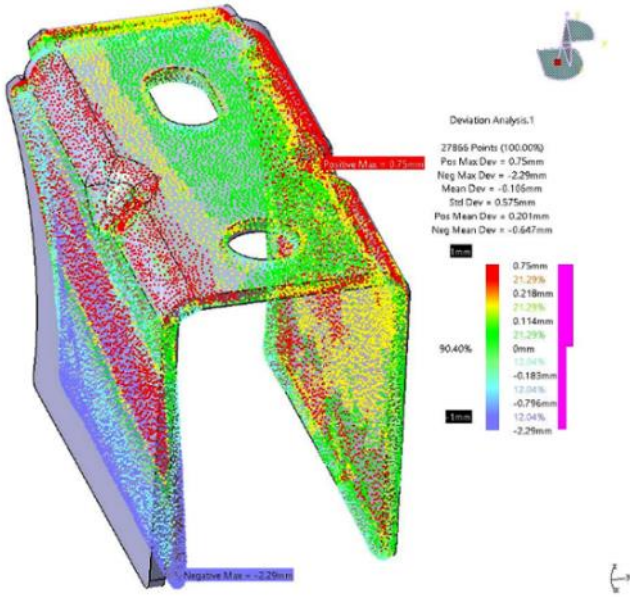


Figure 6 Deviation map between the nominal CAD model and the processed STL model of the stamped part

The maximum positive deviation was +0.75 mm, while the minimum deviation was −2.29 mm. The minimum value occurred near the lower mesh boundary and was therefore interpreted with caution because boundary and reconstruction effects may have contributed to it. The deviations were not uniformly distributed over the part, and the most pronounced zones occurred mainly on the side walls, in bend regions and on transition surfaces. The value of 90.40% shown in the CATIA legend denotes the proportion of evaluated mesh points within the displayed interval of ±1 mm and not the conformity percentage of the complete part.

The deviation pattern suggests additional closing of one side of the part relative to the nominal geometry. Since this region is influenced by the final calibration operation, priority should be given to inspection of the corresponding calibration element and its driving mechanism. The observed deviations may also be influenced by springback and local contact conditions during forming, as discussed by Hartmann, C. et al. 2021. Therefore, the deviation map is used to identify the most critical regions and to guide subsequent tool inspection and correction, rather than to establish the exact physical cause of the deviation.

The deviation map provides a rapid preliminary assessment of the manufactured geometry, but it does not represent a formal verification of all geometrical tolerances specified in the technical drawing. Characteristics close to their tolerance limits should therefore be verified using a calibrated measurement method with suitable measurement uncertainty.

CONCLUSIONS

This paper presents the application of 3D scanning and CAD deviation analysis for the preliminary geometrical assessment of a stamped part after the first trial of a press tool. Comparison of the processed STL model with the nominal CAD geometry enabled the identification of critical regions, with the most pronounced deviations occurring mainly on the side walls, bend regions and transition surfaces.

The observed deviation pattern suggests that the press tool elements involved in bending and final calibration should be inspected first. The proposed procedure can therefore support targeted tool corrections during subsequent trials. However, the deviation map does not replace characteristic-specific geometrical inspection of the complete part. Features with narrow tolerance requirements and results close to tolerance limits should be verified using a calibrated measurement method with suitable measurement uncertainty.

Future work should include repeated measurements after tool correction in order to evaluate whether the implemented modifications reduce the observed deviations.

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