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Measurement of Geometry of Small Axisymmetric Sheet Metal Component after Forming

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Modelling sheet metal component properties and forming is an important topic in part design process. Cost effective component geometry optimization and tool design can be based on reliable models. To achieve trustworthy models it is important to get feedback from actual forming process of components with real geometry up to changes in sheet metal thickness. Therefore accurate geometry measurement of a component is a key issue to get reliable feedback. The focus of the study is on different methods to measure the shape of the formed small axisymmetric component, which has spline curves, diameters and also "hidden" areas that are necessary to detect with reliable accuracy and low labour intensity. Measurement with required accuracy may be challenging because of limitations connected with one measurement method. In present study different components are measured with selected methods and the results are compared to each other. Metallographic cross-section method is studied to get reliable results of sheet thickness and hidden areas geometry of the component assembly. Results show that some 3D scanning methods can provide accurate measurements and can be used as reasonable labour intensive method for the most of the measurements. However combined measurements are used to get all necessary data from the component. Metallographic cross section method is necessary especially for "hidden area" and double seam measurement for the component design process.

Keywords: metallographic cross section, axisymmetric sheet metal component, sheet metal component forming, double seam.

1. INTRODUCTION

Competitiveness of sheet metal forming industry relies on knowledgeable design of a product and a forming tool. Modeling can offer wide range of possibilities to design component with optimized geometry using advanced high strength steels.

Stamping and forming of a complex shape sheet metal components from high strength steel can be a complicated task where the result is influenced by many factors, which can be process based and component based.

Due to the complexity of a forming process there is always a difference in shape geometry between a modeled and a formed component. Formed component actual geometry is important in many studies. Incremental Sheet Metal Forming studies are focused on the process control in terms of geometrical accuracy [1, 2]. In [3 – 6] the finite element (FE) model results are compared to experimental results to assess the suitability of the model. The influence of the material and process parameters on the properties of products in incremental sheet metal forming is estimated in [4 – 5]. Development of the FE models and materials with higher strength requires more studies, which are related to the accuracy of the formed components in any kind of sheet metal forming [3 – 6]. Many studies rely on metallographic method to measure component geometry and thickness [7 – 9]. Metallographic method assures easy feedback for complex geometry with thickness reduction, but there are no notable studies discussing accuracy and springback issue of the method. Accuracy of the formed component will be more important because weight reduced optimized component geometry and thickness deviations can lead to the failure of the product [10]. Even minor changes in production (tool wear, coating of the tool, steel properties etc.) can lead to the changes in product properties. Therefore understanding the changes of component geometry influencing factors during different production steps is important. Current study focuses on progressively formed double seamed aerosol cans that have to withstand pressures up to 22 bar [11]. The reasons of aerosol can failures have been studied by several authors [12 – 14]. It is important to monitor a component and double seam geometry during production to prevent possible failures. But there is not widely discussed how to perform accurate geometry and seam measurements. Weight reduced optimised component requires even more accurate measurements using methods which give reliable results with reasonable effort.

There are many measurement devices and techniques available for measurement of a component of an aerosol can. These include devices for automatic destructive seam measurement and tightness check as well as CT scanners (Computer Tomography based on X-ray) for non-destructive component measurements. In a research on aerosol can design the CT scan technology is used to measure the thickness of a can wall [15]. Despite CT scan can deliver accurate results the method is very expensive and compute-intensive in term of post-processing and therefore is not widely used.

Current study focuses on the measurement methods with uncertainty that can be used to describe geometry of

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small axisymmetric sheet metal component. Uncertainty is important in further studies to detect real changes in formed component or double seamed container. Therefore the development of the FE model of component forming and optimized design process can be based on this work.

2. EXPERIMENTAL

In current research different measuring methods as well as contact and non-contact are used: Coordinate Measuring Machine (CMM), 3D optical scanner ATOS and metallographic cross sectioning method.

3D optical measurement was done with 3D optical scanner GOM ATOS II 400 (Advanced Topometric Sensor), which measures the surface of the object. The ATOS system is based on the principle of triangulation and uses fringe patterns of different size to measure object surface. ATOS II 400 measuring speed is 1.4 million points in 7 seconds [16, 17]. Sphere spacing error of ATOS system is 0.026 mm according to German 3D scanner standard VDI 2634. The measuring volume of 350 x 275 x 275 mm was used. The object was scanned and transformed to the coordinate system and cut by *xy* – plane to get the cross cut profile which then was measured in ATOS system. The STL model of a component is presented in Fig. 1.

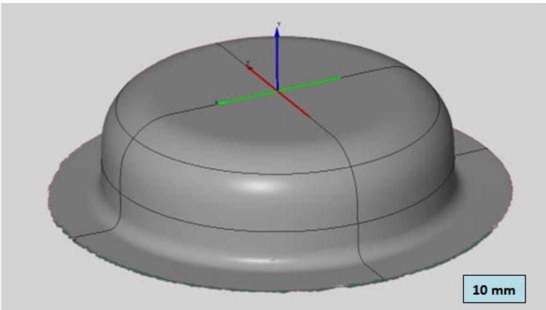


Fig. 1. Component scanned with ATOS II 400

CMM measurement was done with the machine TESA Microhite 3D, which has measurement accuracy of 0.007 mm [18]. The primitive geometry of a component was defined by taking measurements at many locations, for example for the diameter the measurements were taken at 4 and 8 points.

Metallographic cross-section measurement was developed to measure the "hidden areas" of a component. This method is especially important for measuring the geometry of double seam. A component was cast into epoxy resin EC152 using special mold to position the component at the center. Then the component was cut through using a circular saw and polished for the scanning procedure. One half of a polished part was scanned with the 2D scanner (3200 ppi) using precise scale bars from GOM ARGUS (optical strain measurement) system [17]. Then the image was imported into CAD (Computer Aided Design) program were necessary dimensions were taken. Overview of cross cut component is presented in Fig. 2. In addition thickness measurements were taken under the microscope ZEISS AXIOVERT 25 (Fig. 3) to compare the results.

Fig. 2. Cross cut component

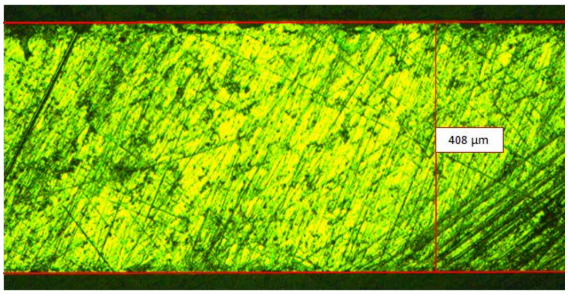


Fig. 3. Measurement of thickness under microscope (200x)

For the seam measurement industrial method was used. A seam saw CMC-Kuhnke MK-2000 with two parallel blades was used to make a cross cut in the double seam of a product which was examined. The seam section between two cutting lines was bent into the can and cutting line was cleaned of cutting chips using compressed air. Bending the seam section was necessary to make it possible to position the seam microscope’s CMC-Kuhnke VSI-5000A head near the cross-section. After a quick manual sample adjustment clear seam image was visible on computer screen which was connected to the seam microscope. Seam dimensions were measured in seam inspection software CMC-Kuhnke SVW60A.

3. RESULTS AND DISCUSSION

3.1. Geometrical aspects of small component

Punching and forming of a small component from high strength sheet metal is a complicated task where the result is influenced by many factors. Thus there is always a difference in geometry between a designed and a formed component. Influencing factors can be process dependent and component dependent. Process dependent factors are the speed of the forming process, lubrication, cooling conditions, the tool geometry etc. Component dependent factors are mainly associated with material properties of a component, coatings like tin, lacquer, paint which in turn are affecting the tribological conditions. Hereby geometrical dimensions can vary if some of these factors changes. Component shape and required dimensions have to be monitored during the set up and production phase in fast and simple way. Product quality assurance measurements in production comprises two categories. First category is for the start of production where there is a need for fast and accurate enough measurement method to assure critical dimensions. The second is for verifying whether critical dimensions are in accordance with the standard requirements. In the last category the accuracy requirement for the measurement is higher, similar for modeling the forming process where all small changes with the part has to be detected.

The forming process of a component encompasses many steps whereby the final component is produced. In these steps the component shape changes from simple to complicate. In Fig. 4 a simple shape is presented and in Fig. 5 a part of more complex shape is presented. Nevertheless both simple and complex geometries can be defined by basic geometrical elements and their measurements.

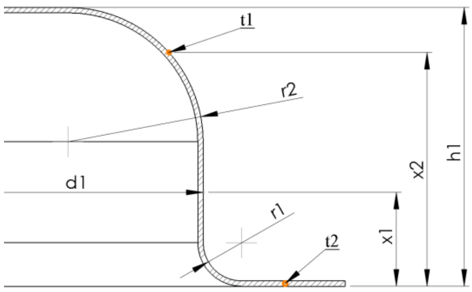


Fig. 4. A simple axisymmetric component with measures

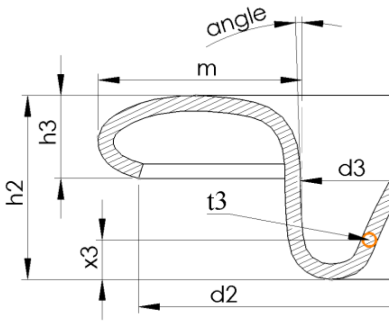


Fig. 5. A part of complex axisymmetric component with measures

In order to study advantages of different measuring methods specific component dimensions were chosen. These dimensions have to be measured in order to check the shape and evaluate the quality of the component. For axisymmetric component common measurements can be roughly grouped into 5 main categories: diameters, radiuses (inner and outer radius), heights, angles, thicknesses. Each type of measurement is important to measure in order to describe exact contour of a component. In Fig. 4 and Fig. 5 are shown main component measurements which need to be measured in order to do the quality analysis and to survey the shape. For example diameters *d*1 and *d*2 are necessary to evaluate how much a component expands after the cross section cut. Radiuses are mainly important to determine the buckling condition of a component and are of importance mainly in final shape of the component. Heights *h*2 and *h*3 and width *m* presented in Fig. 5 are specific from other dimensions as they are determining the shape of the seam. Thickness measures are for discovering the unsafe areas where the necking can occur.

Measurement of simple axisymmetric component can be partially quite simple. For example for diameter and edge thickness measurements a simple caliper can be used. For height measurement special height caliper or indicator can be used. Those kinds of measurements are quite simple to take. For radiuses (both outer and inner) it is more complicated to get the values because formed components are having variable radiuses and it needs special approach to do the measurement. For angles it is quite the same as for radiuses. The difficulty of thickness measurement depends on the location. At some locations it is quite simple to determine the thickness but for other locations for example at the radiuses it is complicated. Therefore optical scanning and shape measurement would be of interest. Also CMM method is chosen for evaluation.

The focus in current work is set to the small component with certain sizes. Therefore current study applies to the components with diameter values between 50 mm to 120 mm and height values of 10 mm to 80 mm.

In conclusion there is a need to observe the component shape and relevant dimensions to assure product quality in production startup and to check the shape accordance with the standards as well as the results of modeling process. Dimensions of a component are divided into 5 main groups on the basis of measuring methods, geometrical aspects, importance in different stages and the level of measuring difficulty.

3.2. Comparison and evaluation of methods

The measurement process of a geometrical object needs using specific measurement instruments. For example a diameter measurement one needs a simple caliper to take the measures, or for more accurate measurement results a CMM method can be used.

Since there are no universal measurement method which can be used to obtain all necessary measures there is a need for a combined methods which cover all necessary measurements with reduced measurement time.

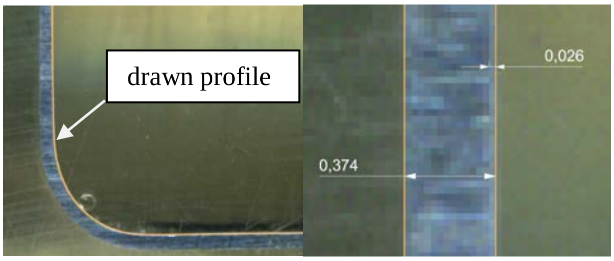
In this work the component was measured with 3 different measurement methods at predefined locations to conduct comparison analysis. For simplicity only one measurement of each type is taken and presented in current work. The results are presented in Table 1. 3D surface scanning with ATOS II 400 scanner was chosen to get the overall 3D model of the component from which measurements can be taken. As far as for measurement simplicity, time and accuracy it is a good choice. Since it is optical non-contact method it can capture only open geometry which can be seen. Therefore this is a good way to get diameter, height, radius, angle and thickness values all over the component perimeter. The accuracy of the results is dependent on the surface condition which have to be good enough in terms of reflectivity and color. Scanning time for the component including post-processing is approximately 10 – 15 minutes. Measurement uncertainty for the scanner is given 0.026 mm.

CMM method has the higher accuracy compared to the 3D scanning but since it is contact based method it can take longer time to have all the measurements done (app. 45 minutes for a component). Measurement uncertainty for the CMM measurement is given 0.0035 mm [18]. For a single measure and overall measurement verification it is reasonable method to use, nevertheless some measures like radiuses depend on the measurement locations and therefore may vary significantly.

Tabel 1. Data from measurements (according to Fig. 4 and Fig. 5)

Measurements, mm						
ID	Meas. type	Measurement location	CMM	ATOS 3D scanner	Metallographic cross section	
					Meas. in CAD	Microscope (200x)
*d*1	diameter	at height 6.500	56.840 ± 0.004	56.864 ± 0,045	57.040 ± 0.028	-
*r*1	radius	3 point radius	2.859 ± 0.059	2.830 ± 0,051	2.840 ± 0.028	-
*h*1	height	at center	18.693 ± 0.016	18.710 ± 0,028	18.740 ± 0.028	-
*t*2	thickness	at diam. *d*=68	0.407 ± 0.016	0.453 ± 0,033	0.400 ± 0.028	0.408 ± 0.002
*t*4	thickness	at the top	-	0.423 ± 0,027	0.395 ± 0.028	0.371 ± 0.002

Finally a metallographic measurement method was developed as it gives full overview of the cross section profile. The primary advantage of cross cut method is an ability to measure the geometry of "hidden areas". Metallographic measurement method takes much more time to complete than other methods (all together 10 hours) and is quite labour-intensive method. In terms of accuracy it can be seen that there is some uncertainty especially on the diameter values due to internal stresses of a component revealed by mechanical deformation with circular saw. In current study the increase in diameter is as high as 1 %. Therefore it can be concluded that the destructive measurement method has influence on the results of measurement which have to be taken into account. The other source of uncertainty is the process of taking measurements on 2D scanned images. In case of low resolution image there is a risk of taking the measurement some pixel away from the real border line thus causing higher measurement uncertainty. In Fig. 6 b a closer look of the profile is depicted.



a b

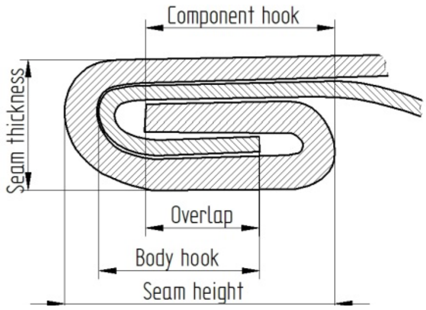
Fig. 6. Measurement taken on the metallographic image: a – drawn profile; b – zoomed image with pixel measures

The size of the pixel length is 0.026 mm. In order to reduce the uncertainty images with higher resolution have to be used. For current method estimated measuring uncertainty is 0.028 mm which is sufficient for the component measurement. As an alternative to the 2D scanner an optical microscope with high magnification rate can be used (Table 1) and this way more accurate measurements can be taken. Disadvantage is that the measurement area is small and options for taking measurements are limited compared to CAD system. Thus it can be useful only for the thickness measurement.

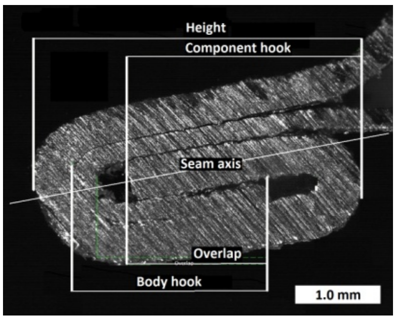
In conclusion, 3 different measurement methods were used and compared to measure the dimensions of the component: 3D optical scanner, CMM and metallographic cross section measurement method. 3D optical scanning is fast measurement method thus giving 3D model of the component in a short time. Since the method is optical, it is valid only for some measurements with sufficient accuracy. CMM method is more time-consuming and cannot be used to take all the necessary measurements since it is contact based. Metallographic cross section method gives the overall shape of the profile including “hidden areas” but is most time consuming. Accuracy of the method mainly depends on the resolution at which the measurements are taken on scanned image and also stress relief during opening the closed axisymmetric part which may result with springback of opened component.

3.3. Double seam measurements

Five double-seam dimensions are measured: height, thickness, overlap, body hook, component hook (Fig. 7 a)



a



b

Fig. 7. Seam dimensions: a – seam drawing; b – seam microscope image

Double-seam dimensions are a part among other factors that determine the quality of the seam and the product. These affect leak resistance of steel package, also compatibility with other parts like plastic caps or paper etiquettes which are added in the latter phases of production cycle. Therefore it is important to verify that seam measurements carried through during production are trustworthy.

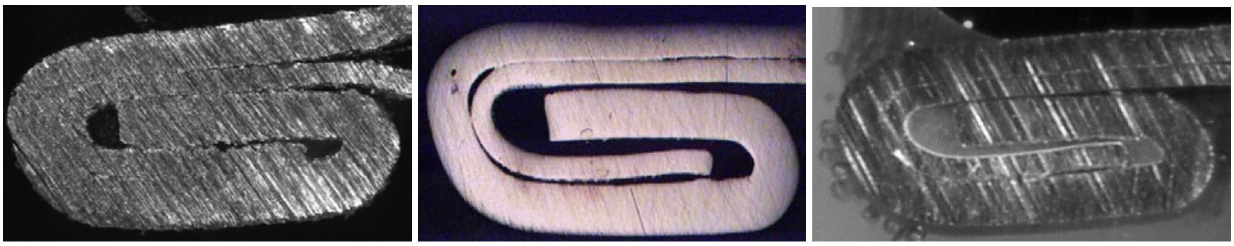
It is rather easy to quickly check seam thickness and height with a seam micrometer caliper. But to measure the inside dimensions of a double seam or a pressure tested (deformed) seam it is necessary to make a cross-section of the seam observed. Two cross-section preparation and three measuring methods were performed to find out what are the differences and advantages of each. The seam microscope method is widely used in industry due to its simplicity.

The whole process starting from cutting and ending with seam inspection takes about 2 minutes to complete. The image received with this method (Fig. 8 a) is very informative about seam overall shape. Seam dimensions are given with 0.01 mm accuracy nevertheless it does not give high accuracy information about seam dimensions due to specimen positioning method in the seam saw. By hand positioned seam cutting line may deviate from actual centre line ± 1 mm. The seam microscope software does not allow correcting the angle of a sample and all measurements are made parallel to horizontal or vertical axis of aerosol can instead of seam axis (Fig. 7 b and Fig. 8 b). All other methods are based on using seam axis. Also it is not possible to inspect seams which have come through destructive testing of pressure resistance as deformed specimens does not fit in saw nor in microscope.

The specimen was cast into resin to prepare more accurate cross cut of a seam than it is possible with seam saw. The resin has high hardness and good grinding properties, slow curing time (8 hours) to prevent stress accumulation inside a specimen and relatively low price compared to special sampling resins. The whole process starting from casting and ending with seam inspection takes about 10 – 11 hours to complete. Two inspection methods were compared: metallographic microscope with 25x objective and 2D photo scanner with resolution 4800 dpi. Metallographic microscope gives very sharp image (Fig. 8 b) of casted specimen compared to the scanned image. Advantages of 2D scanning (Fig. 8 c) and measuring in CAD are possibility to analyse much bigger sample area (210 x 297 mm) at once and to make a 2D CAD model of measured specimen.

As metallographic cross sectioning and industrial seam sawing are both destructive methods, two specimens were needed for measurements. Seam micrometer calliper and digital calliper was used to link the results of two cross sectioning methods.

Comparison of metallographic microscope and CAD image gave about 2 % difference in results which can be explained by differences between scanner and microscope image capturing method and sharpness of image which influences measuring accuracy. So the choice criterion is more in availability of methods rather than in accuracy differences of those. Comparison of industrial seam microscope measurements and CAD measurements of seam microscope image gave differences as seam microscope does not take into account the angle of a seam. The seam microscope image quality is good enough for industrial purpose but dimensions should be verified with some image processing or CAD system. Also the positioning of sample inside the seam saw seems to have some influence on results as seam micrometer and calliper results are more different from industrial methods than from metallographic cross sectioning method. The results can be seen in Table 2.



a b c

Fig. 8. Seam microscope image (a), metallographic microscope image (b), scanned image (c)

Table 2. Data from measurements (according to Fig. 7)

ID	Specimen 1			Specimen 2		
	Industrial methods	Metallographic cross section		Industrial methods		
	Seam micrometre, caliper (mm)	Microscope 25x casted sample (mm)	CAD casted sample (mm)	Seam micrometre, caliper (mm)	Seam microscope image (mm)	CAD seam microscope image (mm)
Thickness	1.76 ± 0.02	1.792 ± 0.002	1.83 ± 0.03	1.78 ± 0.02	1.97 ± 0.01	1.87 ± 0.03
Height	3.35 ± 0.02	3.280 ± 0.002	3.33 ± 0.03	3.33 ± 0.02	3.36 ± 0.01	3.29 ± 0.03
Body hook	-	2.133 ± 0.002	2.18 ± 0.03	-	2.26 ± 0.01	2.20 ± 0.03
Component hook	-	2.211 ± 0.002	2.25 ± 0.03	-	2.34 ± 0.01	2.30 ± 0.03
Overlap	-	1.459 ± 0.002	1.50 ± 0.03	-	1.63 ± 0.01	1.60 ± 0.03

Based on the results it can be concluded that a seam microscope can be successfully used for fast seam inspection if seam dimensions are verified in an image processing or CAD software and with a seam microscope and a calliper. Metallographic cross-sectioning and scanning are useful for modelling and product developing process where more information about the seam is needed.

4. CONCLUSION

In production of axisymmetric sheet metal component there is a need to control the shape and relevant dimensions to assure product quality in production start-up and to control the shape accordance to the standards as well as to the results of modelling process. In current study a few components were chosen to measure with different measuring methods. Most important dimensions of a component and seam are chosen and divided into 5 main groups on the basis of measurement method, importance and the level of measuring difficulty.

In the measuring process mainly 3 different measurement methods were used to measure the dimensions of the component and the seam: 3D optical scanner, CMM and metallographic cross section measurement method which were developed. As a result 3D optical scanning is fast thus giving 3D model of the component with sufficient accuracy. Since the method is optical it is valid only for taking some measurements. CMM method is the most accurate and consequently appropriate for quality inspection purposes. Method is more time-consuming and cannot be used to take all the measurements since it is contact based. Metallographic cross section method gives the overall shape of the profile including hidden areas but is the most time consuming. Accuracy of the method mainly depends on the resolution at which the measurements are taken on scanned image.

From the results of seam measurements it can be concluded that a seam microscope can be successfully used for fast seam inspection if seam dimensions are verified in an image processing or CAD software and with a seam microscope and a calliper. Metallographic cross-sectioning and 2D scanning methods are useful for modelling and product developing process, where more information about the seam is needed.

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