XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

LOCAL WALL THICKNESS MEASUREMENT OF FORMED SHEET METAL USING FRINGE PROJECTION TECHNIQUE

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Abstract – An optical system based on fringe projection method has been developed for the measurement of the cross-section area of formed sheet metal, which is generally susceptible of being reduced, and sometimes leads to necking and tearing during forming process. A better understanding of the material and component behaviour is a challenge to experimental measuring methods. To realise such a method the part to be measured is digitised in different orientations by a fringe projection system. With the help of a newly developed inspection technique, the estimation of wall thickness in the critical zones of formed sheet metal part will be implemented by evaluating the measured data, taken in different orientations from the fringe projection system, and the result would be displayed for visualisation. This method allows fast, objective and non-destructive inspection of formed metal sheet and the detection of its defects. This measurement system can be integrated in automated operating procedure for 100% inspection and also enables the speeding up of mass production. This work presents an evaluation strategy and first measuring results.

Keywords: wall thickness, fringe projection

1. INTRODUCTION

Formed sheet metal parts like the pressed parts of a car body, shielded enclosure in electrical engineering and housing are fabricated using metal forming processes. There are lot of technical processes for forming sheet metal parts. Typical processes are for example bending, deep drawing and different stamping operations. To obtain the desired product by metal forming, a piece of material is plastically deformed between tools. By deep drawing, for example, during the forming stage the material is drawn out of the blankholder-die region, whereas the material is subjected to compressive and tensile stresses during forming. When a very high blankholder force is applied, the deep drawing process becomes a stretching process. In stretch forming the material is fixed under the blankholder, leading to thickness reduction in the remaining part of the blank in which the stresses are tensile in almost all directions. Stretch forming is used mainly to produce large shallow parts that must fulfil the working functions like operational stability, i.e. should have a defined wall thickness.

Driven by cost reduction the metal working industry requires objective and non-destructive inspection equipment for reliability increasing need. For this purpose, the fringe projection systems can be used. They have gained importance in response to industry demands for fast, production-integrated, exact 3D measurement.

2. DIGITALISATION OF OBJECT OF MEASUREMENT

The main part of coordinate measurement process is object surface digitalisation that results in object topology capture in form of point clouds. The modern optical measuring instruments provide fast, precise and operator independent measurements. The developments in optoelectronic, digital signal processing and microcomputer technology give new possibilities for the design and performance capabilities of optical measurement systems. In fringe projection system for 3D coordinate data acquisition are actively used high resolution and high-speed digital CCD (Charge Coupled Devices) cameras as recording device and Digital Micromirror Device™ (DMD™) or Liquid Crystal Display (LCD) in the projection device.

The fringe projection systems operating procedure is based on the principle of image triangulation [1]. The set-up for triangulation consists of the triangle formed by a distinct point on the object surface, a projector and a CCD camera (fig. 1). The light from the light source is projected by projector with a DMD™ device onto the measuring surface.

To detect the object height differences, the light patterns in form of fringes are sequent projected. From point of view of the camera, under the angle of 30°, the fringes look deformed. The degree of deformation depends on the surface curvature. This operating method is also called fringe projection. Object topography is evaluated by computer from the deformation of the recorded fringe pattern by the CCD camera.

To facilitate the fringe analysis and 3D coordinate evaluation, a combination of the gray-code and phase shift fringe projection method is used. By using the fringe projection technique there is the ambiguity between projected and acquired fringe line accordance. This ambiguity is solved using so-called gray-code fringe projection technique. Similar to binary code, for each light and dark line a “1” or “0” is assigned. For each point in measuring field a sequence of light and dark lines, extracted from the video-images, forms the full gray-code of the corresponding projected line. To extend the resolution of the fringe projection system the fringes with a cosine-modulated intensity are projected and sequent shifted to some period part. From a gray value for each image element a phase will be evaluated and small variations in object depth detected.

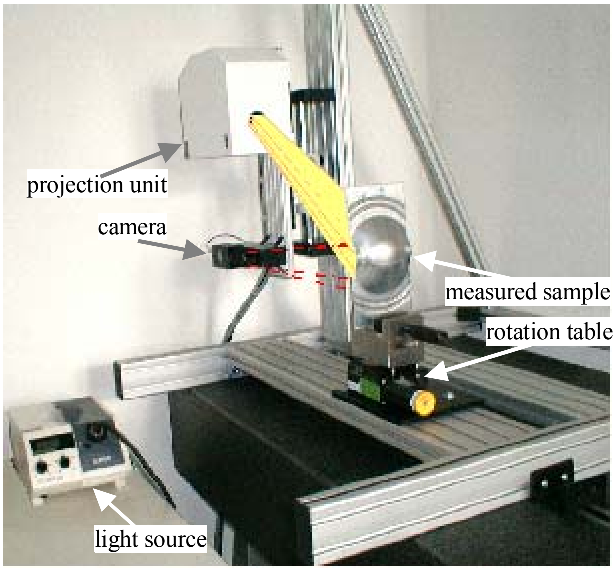

Fig. 1. Fringe projection system

The measuring range of the system is 90 mm × 70 mm lateral and 40 mm vertical. The lateral resolution is 75 µm and vertical resolution 40 µm.

3. EVALUATION APPROACH

The evaluation strategy will be shown using a simple formed sheet metal sample. To obtain the 3D object shape, it has to be measured using fringe projection system.

By optical measurements of strong reflecting metal parts outliers often occur because of non-uniform distribution of reflected light intensity i.e. existing areas with extremely high and extremely low light intensity. To obtain a diffuse and relative uniform reflection the object surface was coated with a thin chalk layer (about some micrometer) by the Met-L-Check® Developer D-70 spray from Helling GmbH.

After measuring one side, the formed metal part is rotated using a rotation table by 180° and the reverse side acquired (fig. 2).

Now, both 3D-data sets are in different coordinate systems. The next step is the coordinate transformation. For this purpose, the estimation of rotary table axis reference to coordinate system of fringe projection system is needed.

To transform the point clouds into a common coordinate system a rotation axis estimation is needed. To obtain the rotation axis, we apply approved method from coordinate metrology. The most verified one is the ISO recommended method for acceptance and reverification test for coordinate measuring machines with the axis of a rotary table using two spheres at different height levels [2] (fig. 3). According to the chosen approach, the spheres with diameter of 15,000 mm and shape tolerance 0,014 mm has been measured in 16 positions. To the evaluated sphere's centre coordinates, for each sphere level, a plane is fitted. To the projected onto the plane sphere centres, a circle is fitted. The rotation axis is evaluated as the conjunction vector of both circles centre points.

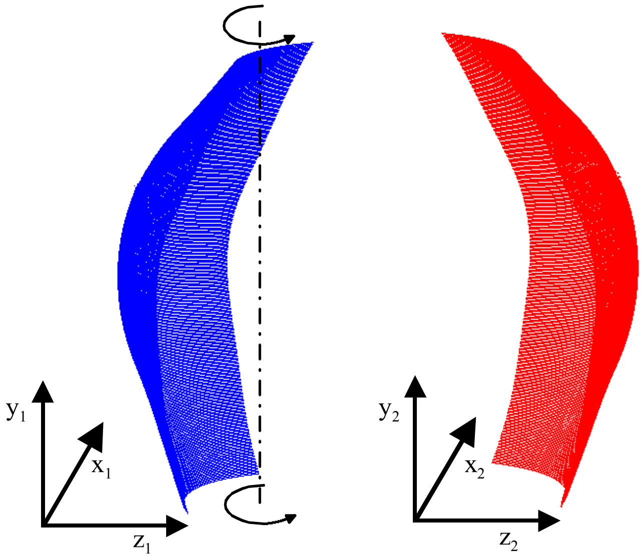

Fig. 2. Measurement of the front and back side

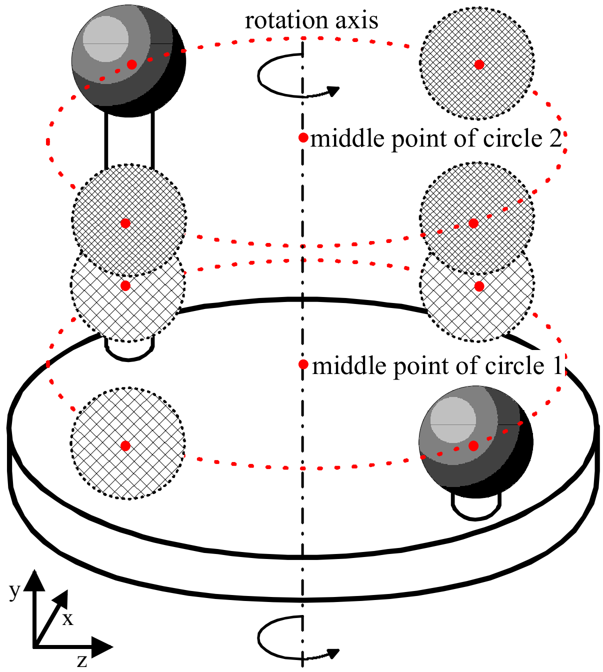

Fig. 3. Rotation axis estimation

The common coordinate system origin is defined in the middle point of the circle 1 and the y-axis is defined along the rotation axis. The measured point clouds are transferred into the new common coordinate system by adding a translation matrix (T_x, T_y, T_z) and multiplying it with the rotation matrices according to the following equation, where (x', y', z') should be substituted with measured point coordinates:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \left[\underbrace{\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} + \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix}}_{\text{translation}} \right] \times \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha_x & \sin\alpha_x \\ 0 & -\sin\alpha_x & \cos\alpha_x \end{pmatrix}}_{\text{rotation around x-axis}} \times \underbrace{\begin{pmatrix} \cos\alpha_y & 0 & -\sin\alpha_y \\ 0 & 1 & 0 \\ \sin\alpha_y & 0 & \cos\alpha_y \end{pmatrix}}_{\text{rotation around y-axis}} \times \underbrace{\begin{pmatrix} \cos\alpha_z & \sin\alpha_z & 0 \\ -\sin\alpha_z & \cos\alpha_z & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{rotation around z-axis}}, \quad (1)$$

here (x', y', z') and (x, y, z) - original and transformed coordinates respectively, α_x, α_y, and α_z - angles to x-, y- and z-axis.

Finally, one point cloud is rotated in opposite to the mechanical rotation direction around the estimated rotation axis at the taken from rotary table control unit angle.

After the coordinate transformation the point clouds from the both part sides are in the same coordinate system (fig 4).

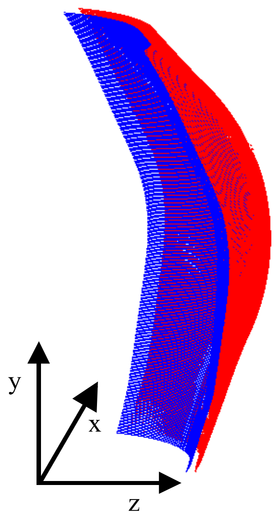

Fig. 4. Registration

It is now possible to begin with wall thickness evaluation. Simplest way - to find the nearest neighbour on the one side for each point on the opposite side and estimate the distance between points. Simplified 2D example of this kind of evaluation is shown in the fig. 5. It is easy to see that this approach is not the optimal one and a distance from point to interpolated line (plane in 3D case) is shorter than actual distance. In addition, an effective method for the nearest neighbour search is needed. Therefore, the next step should be surface modelling.

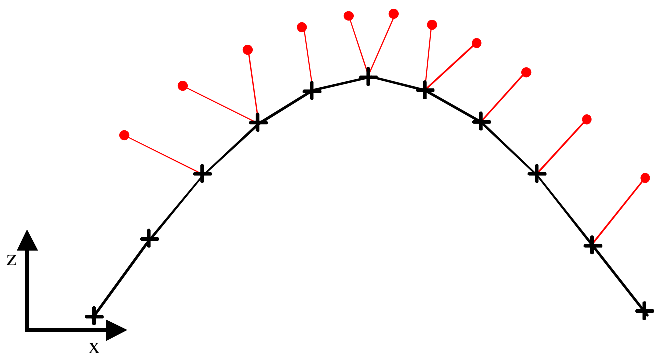

Fig. 5. Evaluation of point-to-point distances

For a surface description of measured point clouds a topology (neighbourhood) information is also needed. A simple and effective way is using the Delaunay triangulation method [3]. Delaunay triangulation is a 3-connected graph that defines a symmetrical and isotropic neighbourhood relationship between the points. It takes into account the discrete nature of the problem, uses a global data structure that will allow the extraction of a minimal representation of the shape, and can be computed efficiently. An example of triangulated point cloud is shown in the fig. 6.

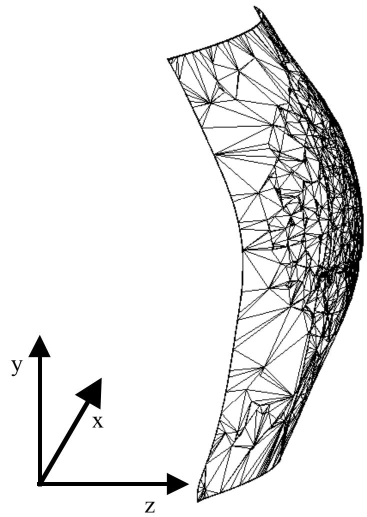

Fig. 6. Surface modelling

The evaluation of the wall thickness is a complex task and lot of problems are to be considered. The most characteristic problem is the noncommutativity i.e. an evaluation of the wall thickness from front to back side give other results and vice versa. In addition, the evaluated results are dependent on the applied pre-processing and mathematical surface modelling method. These problems are the focal point of our actual research work.

In the first approach, a wall thickness has been estimated using the linear interpolated triangle surfaces. In the fig. 7, the simplified 2D example of this method is shown. Thickness as closest distance between front and back sample surfaces in two directions is estimated. For each point of first surface the closest distance as perpendicular to the triangle plane at the opposite surface that include the nearest point is found.

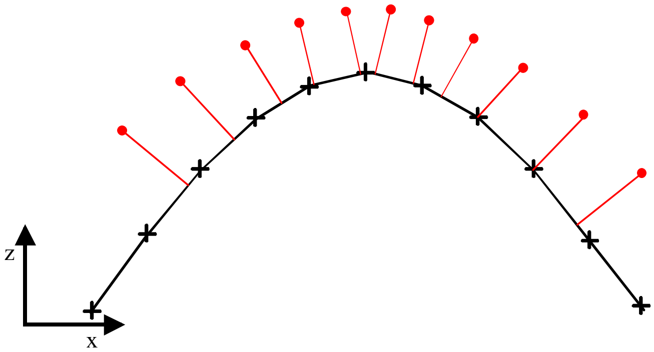

Fig. 7. Evaluation of point-to-plane distances

This method of areal distances evaluation make a wall thickness representation over the measured surface possible. For example, a colour-coded error picture in the fig. 8 is shown. It gives a facility easy localise the areas of the smallest wall thickness and helps to find reference of the wall thickness corresponding to the measured surface zone.

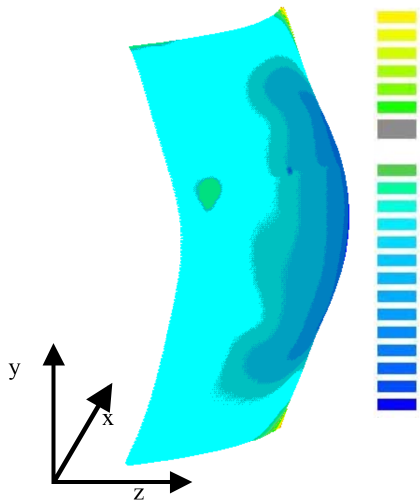

Fig. 8. Colour-coded thickness distribution

4. CONCLUSIONS

The described technical basis approach of wall thickness measurement systems promise to be a solution for the actual problems of sheet metal forming. The current work will fulfil the task of elaborating the basics for a fast, non-destructive, user independent technique able to be integrated in automated operating procedure. It is performed within the scope of the research project at the Chair Quality Management and Manufacturing Metrology at the University Erlangen-Nuremberg.

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