USE OF FINITE ELEMENT METHOD SIMULATION TO SHORTEN MEASUREMENT CYCLE OF SHEET-METAL PARTS WITH RESIDUAL STRESSES

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Abstract:

Sheet-metal parts produced by pressing, stamping or similar technology; usually have residual stresses, which tend to deform them. If these parts are intended to be assembled with other elements, it is necessary to perform measurements to check if constructive dimensions are within acceptable tolerance limits. Such measurements require at least four stages: positioning, clamping, measurement, unclamping. These stages are time-consuming and require manual work. This process is difficult to be automated, because every product needs its own clamping assembly.

Keywords: *sheet-metal, finite element method, indirect measurement, residual stress*

1. INTRODUCTION

The idea of this research is to find out the method to measure these products optically, and without clamping, as they are deformed elastically due to residual stresses. The measurement results of unclamped parts can be processed by computer to obtain usable results, which can give the answer if these products can be assembled, or if constructive parameters are within tolerance limits.

2. ELASTIC SPRINGBACK

Every plastic deformation is accompanied by elastic deformation. The consequence is change in dimensions of plastic deformed part after stress relief. Permanent deformation ε_t can be represented as the difference between plastic ε_{pl} and elastic deformation ε_{el}:

$$\varepsilon_t = \varepsilon_{pl} - \varepsilon_{el} \tag{2.1}$$

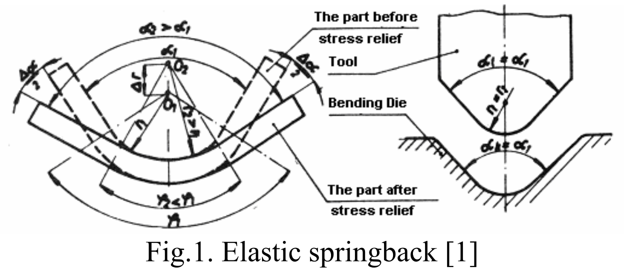

Fig.1. Elastic springback [1]

The key issue to be monitored during design phase of the part is to determine bending radius of the tool, in order to minimize stresses that cause elastic springback.

General input variables for elastic springback determination are material properties, tool geometry and friction condition. Stress and residual stress, that cause elastic springback effect, depend on a number of influence factors: deformation theory, incremental theory, repeating bending, cyclic material models and springback calculation methods [2].

A lot of research efforts are put into optimization of tools to minimize springback effect, but none gave the ideal tool that would completely eliminate elastic springback. It can be calculated, therefore predicted, and corrected by changing the tool geometry, but it cannot be avoided. This paper does not deal with elimination of elastic springback, but with checking the dimensions of plastic deformed sheet-metal parts **with** elastic springback. Such parts do not have dimensions within tolerance limits, but due to their thin walls, they can be elastically deformed to fit into these limits.

The idea for this research came from the project [3], which gave basic guidelines for application of finite element method in measurement of sheet-metal parts.

3. BENDING OF THIN PLATES

In order to perform this analysis, it is necessary to examine theoretical background of plate bending, i.e. to determine relationship between deformation and constructive dimensions that need to be measured.

The theory of thin plates bending is explained in [4]. The stress-strain relations depend mostly on boundary conditions. There are stress equations for various types of supports. All these equations are based on following assumptions:

- Neutral plane of the plate remains undeformed
- The points on the plate that were perpendicular to neutral plane remain perpendicular after bending
- Normal stresses perpendicular to the plate can be neglected.

There is no point to mention all cases of boundary conditions that are examined, but to give an example, here is the equation of elastic line of elementary segment of cylindrically bended plate :

$$\frac{Eh^3}{12(1-\nu^2)} \cdot \frac{d^2\omega}{dx^2} = -M \tag{3.1}$$

Where E is Young's modulus, h is plate thickness, ν is Poisson's coefficient, ω is vertical yield, x is the distance from the edge and M is the bending moment.

Since the shape of most real-life parts is not regular, but it is more often free-form, it is not possible to use equations such as (3.1) to determine the deformation. Numerical methods, such as finite element method are then used to perform necessary calculation.

4. PROBLEM DESCRIPTION

Measurement process of sheet-metal parts consists of 6 steps [3]:

1. Removing the part off the tool
2. Positioning the part into measuring system
3. Constraning
4. Measurement
5. Unconstraining
6. Removing the part off the measuring system

To implement the automated measurement process, it is necessary to shorten the cycle, by avoiding steps 3 and 5. It is possible to measure unconstrained part, and then apply virtual constraining (using FEM). Comparison of CAD model of the tool and deformed FEM model of the measured part gives the answer whether the part can be used in assembly or not.

Some prerequisites must exist to enable virtual constraining. First of all, there should be a CAD model of the tool, which will be used as basis to set the boundary conditions. Then, deformation is presumed to be within elastic limits; no plastic deformation should occur. The unconstrained part (deformed due to springback stresses) is to be scanned by means of 3D scanner. The scanner gives the "cloud of points" as a result, which should be converted into 3D model by means of reverse engineering techniques. That model will be virtually deformed by means of FEM, and checked if deformation is within elastic limits and allowable dimensional tolerance limits.

5. 3D SCANNING

A number of techniques is available nowadays that enable 3D scanning of industrial parts. For this purpose, there is a need for techniques with high acquistion rate. 3D laser scanners such as ATOS™ or similar system have 500.000 points per second acquisition rate. Thus measurement can be performed in seconds. The process of constraining and unconstraining would last much longer.

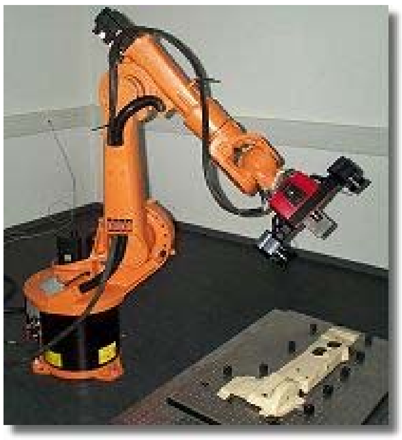

Fig.2. 3D Laser Scanner (www.gom.com)

6. REVERSE ENGINEERING

Reverse engineering of 3D models can be performed by widely awailable commercial software solutions, such as EDS Imageware, Metris Cadcompare, Raindrop Geomagic, ...

A lot of researches were performed recently in order to improve the process of feature recognition and conversion of "clouds of points" (results of 3D scanning) to CAD models. Most software packages have the possibility to perform error estimation and calculation of measurement uncertainty.

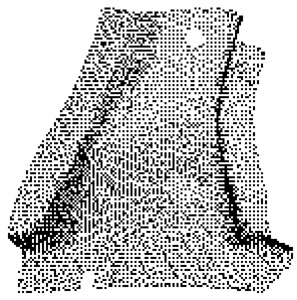

Fig.3. Cloud of points

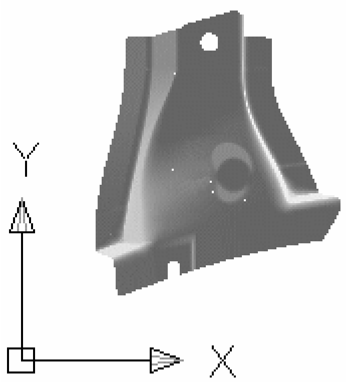

Fig. 4. CAD Model

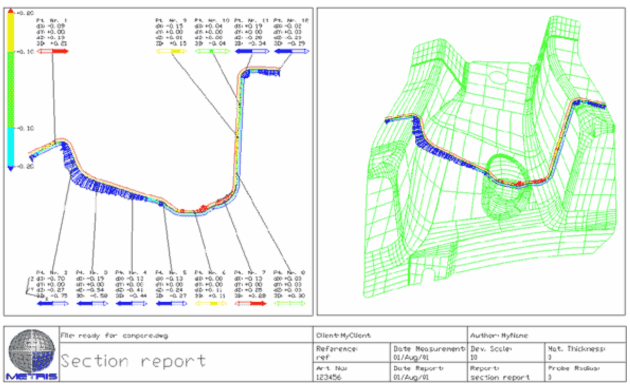

Fig. 5. Tolerance checking (www.metris.com)

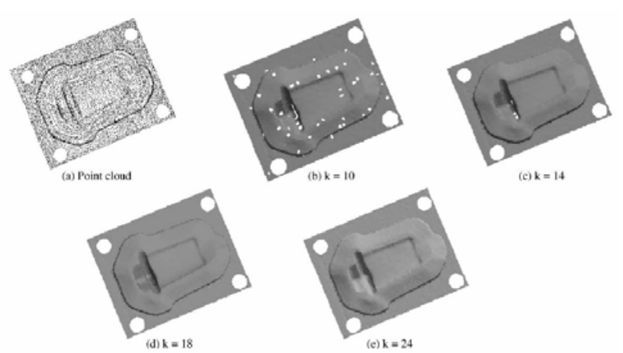

Fig. 6. Reverse engineering [6]

Some interesting researches include conversion of geometrical tolerances into vectorial tolerance representations [5], combinatorial manifold mesh reconstruction and optimization from unorganized points with arbitrary topology [6], or evaluation of circularity from coordinate and form data using computational geometric techniques [7]

7. FEM ANALYSIS

Conventional calculation of stresses and deformation can not be used in this problem, because of stress concentration; some equations are set up for ideal forms, but real parts are never deal, they have features such as holes, chamfers, fillets, which lead to stress concentration. Therefore, numerical analysis is the most appropriate for this purpose.

Major problem in FEM analysis of model obtained by 3D scanning and reverse engineering is to choose the most appropriate points that should be virtually constrained. This points should be marked with attention, and related to corresponding points on CAD model of the tool. The tool represents the ideal form (error free, with zero tolerances).

Another problem can be the time required for calculation (including both mesh generation and FEM model solution). The development of computer systems that occured recently shows that very soon, average workstation will be able to perform such analysis within seconds.

8. ERROR ESTIMATION OF INDIRECT MEASUREMENTS

There are two sources of experimental error: Systematic error arises from miscalibration of an instrument or incorrect experimental technique that results in an estimate of a quantity that is systematically biased in a particular direction away from the true value. Random error arises from the normal uncertainty inherent in any measurement and does not result in systematic bias.

Statistical analysis can treat random error only and cannot quantitate or correct for systematic error. For the sake of the present discussion we shall assume that systematic error is negligible.

The indirectly measured quantity to be obtained by calculation is z, and the directly measured or independently determined quantities used to calculate z are x, y, and ... . We make N measurements of x and M measurements of y.

If function that connects z and x,y,... is continuous and differentiable, then:

$$Z_{NM} = f(X_N, Y_M, ...) \qquad (8.1)$$

The estimated error of indirectly measured quantity is given as:

$$\sigma^2_{NM}(z) = \left(\frac{\partial z}{\partial x}\right)^2_{x=X_N, y=Y_M} \sigma^2_N(x) + \left(\frac{\partial z}{\partial y}\right)^2_{x=X_N, y=Y_M} \sigma^2_M(y) + \dots \quad (8.2)$$

To estimate the uncertainty of indirect measurement of dimensions of sheet-metal parts that are subject of this research, it is necessary to establish the functional relation of all directly measured quantities and the final dimension. Then, that function should be partially derived over all directly measured quantities and multiplied by sqare of uncertainty of directly measured quantities (8.2).

9. CONCLUSIONS

The finite element method can be used in dimension control of sheet-metal parts deformed due to residual stress (springback effect), in order to shorten the measurement cycle. Such an application must use reverse engineering techniques to transform the result of 3D scanning into CAD model. The CAD model of the tool is used to apply boundary conditions for FEM.

The criterions for analysis are tolerance limits and assumption that only elastic deformation occur, i.e. there is no plastic deformation in measured part.

To perform indirect measurement of sheet-metal parts without constraining during measurement process by means of FEM, it is important to estimate uncertainty of such measurements. That can be done only if there is known functional relationship between the directly measured quantities and the deformation that is to be measured indirectly.

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