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Investigation of Effects (Welding Sequence, Fixturing, Welding Points) on Distortions after Spot Welding for Determining Individual and Cumulative Tolerances

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Abstract: The manufacturing and GPS (Geometrical Product Specifications and Verification) have to be thought and analysed together. Welding and Metal Forming are two of manufacturing methods, which are used to create sheet metal parts assembly groups. The dimensions do not stay steady and they change during these two manufacturing methods. Because firstly, after forming (for example bending) the springback and secondly, after welding (for example spot welding) the distortions exist. In this study, the distortions after spot welding are researched and their effects on tolerance chain and assembly tolerances are analysed. These distortions are determined with analysis software after designing some sheet metal part assembly examples. After that, these distortions are achieved with real measurement (scanning) after welding of the sheet parts. At the final step, the analysis and measurement results are compared.

Keywords: Statistical Tolerance Analysis Methods, Tolerance Stackup, Distortions, Spot Welding, Welding Sequence, Clamping

1. INTRODUCTION

Sheet metal industry is a very important and economical sector. Spot welding takes a big place by the assembly of sheet metal parts such as in the automobile or white goods sector. It is being observed that today the spot welding is made approximately fully by robots especially in the automobile industry. So, the design of welding parameters especially before automated welding process has to be determined carefully because they will play a role during the whole process inherently. In this context, the prior determination of sheet metal parts' tolerances and critical dimensions will provide an economical advantage because the rate of waste will decrease. Following that, the Statistical Tolerance Analysis Methods are very important in Measurement Technique. These methods are 'arithmetic', 'quadratic' and 'probabilistic' according to Renault notes (2009). Arithmetic method is known as Worst Case Analysis and quadratic method is known as Root-sum-square by Fischer (2004). There is another method called Monte Carlo but it is especially used for computer-based simulations (according to Fischer) and is not included in this study. With these methods, called 'Tolerance Stackup' or 'Tolerance Chain', cumulative tolerances can be reached by proceeding from individual tolerances. An assembly (cumulative) tolerance can be for example between two parts, which are not side-by-side, or in a place that can have a critical importance (for instance a midpoint of a hole). In this study, analysing how the distortions after welding affect on the individual and cumulative tolerances is aimed. Some of the factors, affecting on distortions also on the shape deviations, are clamping, welding sequence and the number of welding points. So, to determine these effects and their dimensions, at the beginning a sheet metal assembly group will be designed. This group will have simple formed individual parts, which will be combined with spot welding. This spot welding analysis will be made with the software 'Weld Planner'. After that, Statistical Tolerance Analysis Methods, mentioned above, will be used to progress from these individual tolerances to cumulative tolerances and compared. At the first step, the designed individual parts will have the same length in a dimension so that the computations can be implemented for 2-D. Also, some trigonometric calculations can be used, too because the parts will be designed according to that. The welding analysis will be made for several welding sequence combinations to progressing form singular to cumulative. In the final step, sheet group specimens will be manufactured and the deviations will be measured with various methods and these results will be compared with analysis results. This study will provide a preliminary impression and methodology for researching of some of the spot welding process effects on the Tolerance Chain. During these all steps, this study will depend on and create relationship with EN ISO 1101 Standards (2012), which introduce Geometrical product specifications (GPS) – Geometrical tolerancing – Tolerances of form, orientation, location and run-out, and with EN ISO 13920 Standards (1996) which introduce general tolerances for welded constructions.

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2. PREPARATION OF CALCULATION METHODS and ANALYSING

In this study some mathematical models will be prepared. The aim is to proceed from the simplest to the more complex. Firstly a beginning example will be detailed. So, the first model (Fig. 1) consists from 3 straight parts (lines) as if they have been assembled. Here it is accepted that not springback or distortion during montage have occurred and the end points (conjunction points) are subjected to a displacement (deformation) (for example: thermal expansion).

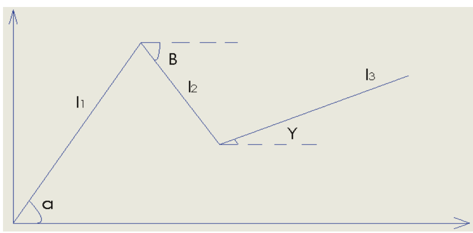

Fig. 1. The first mathematical model

For this example model the tolerance interval is given for arithmetic, quadratic and probabilistic calculation methods. While the left side of the matrix equations (1-4) shows the changing area, the right side illustrates the tolerance interval limits within it has to be stayed.

l_{10}, l_{20}, l_{30} : Nominal values;
l_{11}, l_{21}, l_{31} : Values after deformation
IT values represent the tolerance of each part.

Arithmetic Method:

$$\begin{vmatrix} \cos\alpha & \cos\beta & \cos\gamma \\ \sin\alpha & \sin\beta & \sin\gamma \end{vmatrix} \begin{vmatrix} l_{11}-l_{10} \\ l_{21}-l_{20} \\ l_{31}-l_{30} \end{vmatrix} \leq \begin{vmatrix} IT_1\cos\alpha + IT_2\cos\beta + IT_3\cos\gamma \\ IT_1\sin\alpha + IT_2\sin\beta + IT_3\sin\gamma \end{vmatrix} \quad (1)$$

Quadratic Method:

$$\begin{vmatrix} \cos\alpha & \cos\beta & \cos\gamma \\ \sin\alpha & \sin\beta & \sin\gamma \end{vmatrix} \begin{vmatrix} l_{11}-l_{10} \\ l_{21}-l_{20} \\ l_{31}-l_{30} \end{vmatrix} \leq \begin{vmatrix} \sqrt{IT_1^2\cos^2\alpha + IT_2^2\cos^2\beta + IT_3^2\cos^2\gamma} \\ \sqrt{IT_1^2\sin^2\alpha + IT_2^2\sin^2\beta + IT_3^2\sin^2\gamma} \end{vmatrix} \quad (2)$$

The secondly dealed model shows the assembly of three parts, which have been bent with different bending angles and have different lengths, in 2 dimensions. Their length in one dimension is the same. The Fig. 2 shows the beginning position (with the index A) and the position after occurring of distortions for welded construction (with the index B). They show the coordinates of the endpoints of singular parts for both positions. Here also the coordinate calculation that has been made for other parts could be made for the third part, too. However, trigonometric calculations and (formulas) have been used because of the appropriate geometry of this part. Proceeding from here, not only dimension but also angular tolerances can be considered, included and put in the calculations.

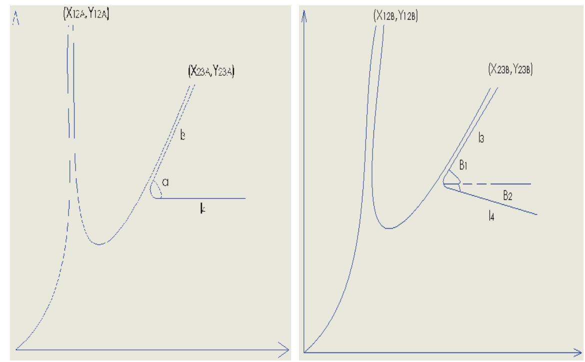

Fig. 2. Mathematical model (beginning position and position after distortion)

Arithmetic Method:

$$\begin{vmatrix} (X_{12B}-X_{12A})+(X_{23B}-X_{23A})+\left|(l_4\cos\beta_2 - l_3\cos\beta_1)-(l_4-l_3\cos\alpha)\right| \\ (Y_{12B}-Y_{12A})+(Y_{23B}-Y_{23A})+\left|(l_4\sin\beta_2 + l_3\sin\beta_1)-(l_3\sin\alpha)\right| \end{vmatrix} \leq \begin{vmatrix} IT_{1X}+IT_{2X}+(IT_{4X}-IT_3\cos\alpha) \\ IT_{1Y}+IT_{2Y}+(IT_{4Y}-IT_3\sin\alpha) \end{vmatrix} \quad (3)$$

Quadratic Method:

$$\begin{vmatrix} (X_{12B}-X_{12A})+(X_{23B}-X_{23A})+\left|(l_4\cos\beta_2 - l_3\cos\beta_1)-(l_4-l_3\cos\alpha)\right| \\ (Y_{12B}-Y_{12A})+(Y_{23B}-Y_{23A})+\left|(l_4\sin\beta_2 + l_3\sin\beta_1)-(l_3\sin\alpha)\right| \end{vmatrix} \leq \begin{vmatrix} \sqrt{IT_{1X}^2+IT_{2X}^2+(IT_{4X}-IT_3\cos\alpha)^2} \\ \sqrt{IT_{1Y}^2+IT_{2Y}^2+(IT_{4Y}-IT_3\sin\alpha)^2} \end{vmatrix} \quad (4)$$

Besides, some tolerancing problems, solutions and examples are introduced by some studies. In one study, Thimm et al. (2006) investigated the parallelism tolerance and angular error analysis. There are other studies, belonging to Dahlström et al. (2007) and Shaoyun et al. (2006), too which showed tolerance analysis by changing process parameters and compared with actual and real results.

The simulation software programs for welding are being developed newly. Before that, some works including FEA based on electric and thermal formulas have been generated for Aluminium Resistance Spot Welding Process by Sun et al. (2000). There is another FEA study of Nied (1983) dividing the workpiece and electrode contact region into small quadrilaterals. Also, spot welding has been analysed, for other aims, too, for example to study nugget formation by modelling the process for the software ANSYS by Thakur et al. (2010). The resistance spot welding has been modelled