Focus on CADCAM

Robust engineering

New software will help sheet metal formers to achieve a robust, six-sigma production process – even during part and tooling design

Statistical Process Control (SPC) is familiar to sheet metal formers today. Typically applied during the production phase, SPC is a key factor for producing quality metal parts reliably and repeatedly.

However, what if SPC methods could be applied well in advance of production – yielding their benefits during the early planning and design phases? This is just one of three major innovations in a new software for sheet metal formers, called AutoForm-Sigma, which was developed by AutoForm over the past two years for the purpose of improving stamping process robustness.
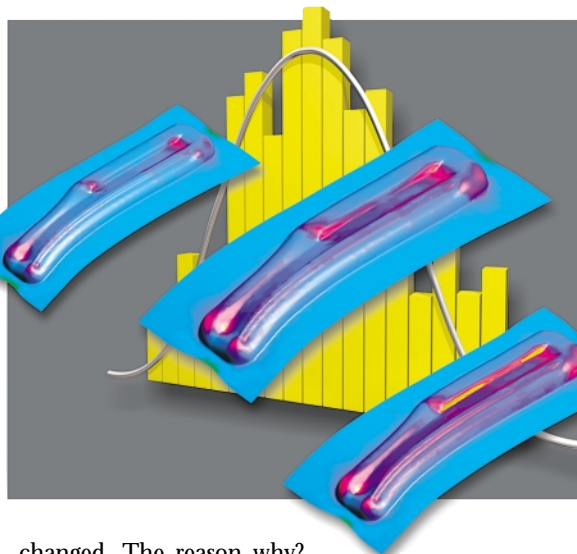
SPC + Simulation
The first innovation, says the manufacturer, is that the software combines statistical process control techniques with sheet metal forming simulation.

As a result, designers and engineers can improve forming process robustness and also determine process capability, even during the phases of product and tooling design, early in the development cycle. In other words, sheet metal formers can address and solve key manufacturing problems many months before going into production, with obvious benefits.

Noise and variability
A second innovation is that the software takes into account the noise and variability that are inherent in the factors that determine the forming process – in the coefficient of friction, in tool forces, in material characteristics, in tool wear etc. – thereby better reflecting manufacturing reality.

As many stamping engineers know, parts produced one day may all be acceptable, but another day's production can result in many rejects even though manufacturing conditions do not seem to have

changed. The reason why? Noise and variability in the forming process.

Current industry practice is that only a single simulation is normally carried out for a specific process set up. Therefore, it has not been possible to consider noise and variability in forming simulations. In contrast, AutoForm-Sigma carries out many simulations (even one hundred or more) which not only produces far more reliable results, but also gives a better understanding of the forming process and more realistic insights into it.

As a result, engineers can identify the most robust – and not necessarily the single best – product designs and stamping solutions from the hundreds of different alternatives that are possible. Similarly, they can identify those factors that influence most the quality of the stamped part and make necessary adjustments (e.g. to blankholder forces) to improve the forming process.

Statistics for designers and engineers
The third innovation concerns statistical algorithms, which have been adapted and integrated so

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they can be used directly by designers and stamping engineers, instead of requiring a separate statistical analysis department. In other words, AutoForm-Sigma increases the integration and productivity of design, engineering and production departments, by bringing statistical techniques also into the realm of design and engineering.

The software was developed by AutoForm Engineering, provider of software solutions for product feasibility, die face design, stamping tryout and optimisation. AutoForm-Sigma is now being tested in the stamping engineering departments of Audi, BMW and DaimlerChrysler, among others. The following illustrates the software's practical applications in engineering and manufacturing:
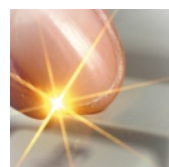
Robust engineering
During the initial phases of product development, for example during part design, tooling layout and process layout, engineers must make decisions to define the values of many design parameters such as:
• part radii
• binder surface geometry
• addendum geometry (e.g. punch and die radii)
• use and position of drawbeads
• blankholder force, etc.

The values given to these design parameters are frequently based on company specifications or past experience, and they have a direct impact on subsequent stamping process performance. Typically, the values are difficult to change later on in the development process and they will even predominate over the entire process life-time. To help engineers define the best values for these parameters, AutoForm-Sigma provides several analysis tools for 'Robust Engineering'.

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Robust Engineering refers to the design of the sheet metal part, tooling and stamping process so they result in the most efficient and stable manufacturing process while simultaneously meeting the engineer's desired quality targets for the part. In other words, it makes the forming process transparent, showing which design parameters (inputs) influence part quality (output) and by how much.

For robust engineering analysis, the engineer first defines a 'process window' for the design parameters in terms of their minimum and maximum values. AutoForm-Sigma then carries out multiple simulations while automatically varying the values of the design parameters and it analyses the results with statistical algorithms.

Influence analysis

Engineers need to know which design parameters to adjust, in order to improve product and process performance so as to meet desired quality targets. Therefore, it is important to identify which input parameters are dominant – those which influence most the stamped part.

In the example of the automotive reinforcement in Figure 2, AutoForm-Sigma shows that at each location within the part, a different parameter is the dominant influence on thickness strain (a measure of change in thickness). At the two ends of the part, the x-dimension or length of the blank (green) has the greatest influence. Drawbeads 1 (dark green) and 2 (purple) are the dominant parameters affecting the critical area circled in black, where excessive thinning occurs.

Therefore, one can conclude that excessive thinning is primarily due to the values of the drawbeads 1 and 2 restraining forces and not due to the other factors. With this type of feedback, engineers can focus on the appropriate design parameters to adjust to make their stamping process more robust.

Sensitivity analysis

Sensitivity refers to the degree that an input parameter must be
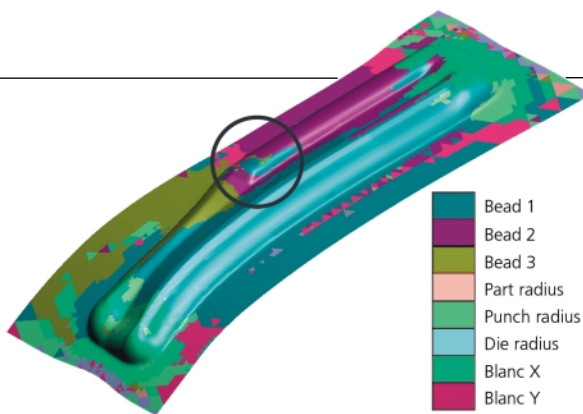

Figure 2. Maximum influence plot showing the influence of different parameters on thickness strain, for this automotive reinforcement part.

adjusted to achieve a desired quality target. For example, a 10% increase in drawbead restraining force results in 25% more thinning, which can cause part failure.

Figure 4 shows the scatter plot of thickness strain corresponding to the critical area shown in Figure 3. The x-axis represents the drawbead restraining force and the y-axis the
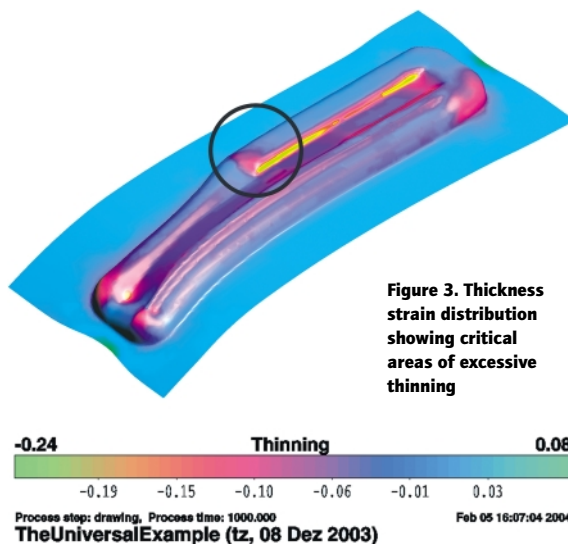

Figure 3. Thickness strain distribution showing critical areas of excessive thinning

resulting thickness strain. The red circles correspond to the multiple simulations carried out by AutoForm-Sigma. The black line indicates the dependency of thickness strain on drawbead restraining force.

From Figure 4, one can see the following important results:

Figure 4. Scatter plot of thickness strain and drawbead restraining force
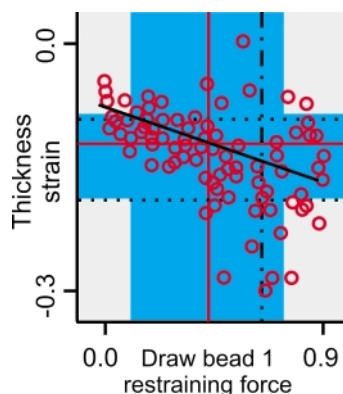
- If the drawbead restraining force increases, the thickness strain becomes more negative.
- For low values of the drawbead restraining force, there is a good correlation with thickness strain, whereas at high values the correlation is poor (the cloud of points is widely scattered)

Therefore, one can conclude that the drawbead restraining force should remain below 0.4 since, otherwise, the thickness strain is too large and very unpredictable.

Robust manufacturing

In the reality of the production environment, there is a lot of variability in the form of inherent, unavoidable noise in the parameters which affect the forming process. This variability can be categorised into two types:

- Noise in the forming process parameters – for example, variations of drawbead restraining forces and fillet radii due to tool wear, variation of blankholder pressure due to press tolerances, variations in lubrication and blank position, etc.
- Noise in the material properties – for example, yield strength, tensile strength and r-values, which can vary between batches and between suppliers

Robust Manufacturing considers the effects of such noise on the forming process and determines the process capability. As a result, engineers can determine the 'robust process window' containing the best forming conditions, taking into account the noise variables.

Example: noise in material properties

According to standard specifications, HSLA340 steel has a yield strength value $Rp0,2$ between 340 and 420 MPa. The Auto/Steel Partnership Program (1) carried out a program to measure the variation of HSLA430 mechanical properties over the entire lifetime of a vehicle programme and obtained the following results:

- The $Rp0,2$ mean value was 360 Mpa
- The $Rp0,2$ standard deviation

was 17 Mpa – i.e. for 68% of the material samples, the Rp0,2 value was between 343 and 377 Mpa

- The Rp0,2 minimum value was 312 Mpa – i.e. outside standard specifications – and the maximum value was 385 Mpa

These results highlight the need for robust manufacturing in terms of performance analysis and process capability to consider the effects of noise on the forming process.

Performance analysis

With AutoForm-Sigma, the engineer can carry out a 'performance analysis' of the stamping process. He first defines the variation of each of several noise variables in terms of their mean value and standard deviation. Based on this, AutoForm-Sigma runs a set of forming simulations and statistical algorithms then evaluates the entire cluster of simulations to achieve the desired quality targets. (Whereas the design parameters are analysed for robust engineering, it is the noise variables that are analysed for robust manufacturing.)

Figure 5 shows the frequency distribution (normal) for the noise variable Rp0,2 yield stress, which is an input for AutoForm-Sigma.

Figure 6 shows a graphical representation of the output of AutoForm-Sigma, with the robust process window corresponding to the input design parameters and noise variables.

Process capability

With the performance analysis results, the engineer can deter-
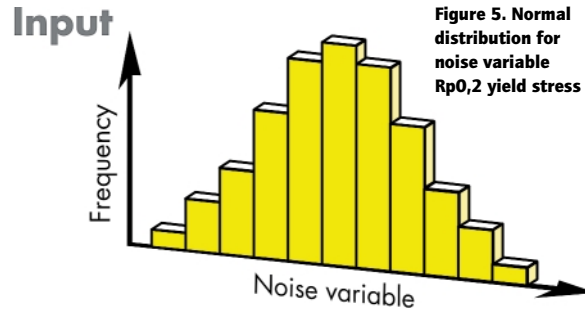

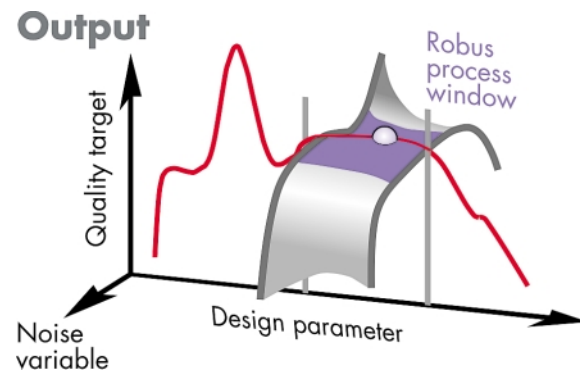Figure 5. Normal distribution for noise variable Rp0,2 yield stress

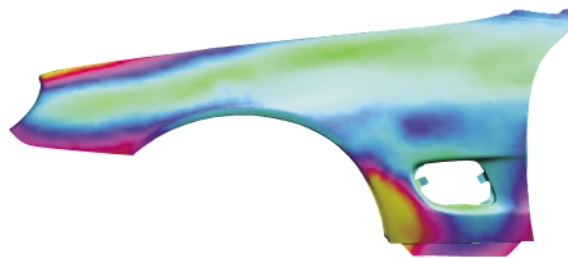Figure 6. Performance analysis shows process robustness

Figure 7. Unconstrained springback: variation of normal displacement on front fender (Courtesy of DaimlerChrysler)
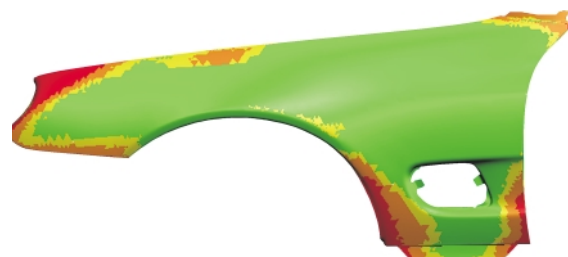

Figure 8. Process capability Cpk, with respect to defined tolerance limits for acceptable springback

mine the 'process capability, Cpk' of the forming process: the ratio and relative position of the variation of these results to the tolerance limits (the quality target). The Cpk value of the process indicates its stability and reliability.

Example: front fender

In the production of a front fender, a critical factor to consider is the variation of springback due to variations in noise variables.

Using AutoForm-Sigma, 98 forming simulations were run and the following noise variables were analysed: material properties (Rp0,2, Rm, r0°, r45°, r90°), sheet thickness and the coefficient of friction.

Figure 7 shows the resulting variation of normal displacement of unconstrained springback (for the 98 simulations). The colour plot reveals excessive variation of springback at the lower left corner of the fender (yellow), which is caused by a combination of the noise variables. So, the engineer needs to verify whether this springback variation is acceptable or not. Therefore he must check process capability.

As shown in Figure 8, AutoForm-Sigma plots process capability corresponding to the upper and lower tolerance limits, on the part. Now by simply looking at the part, the engineer can see where and to what extent the current forming process will result in part rejects.

For this fender, the quality department has defined tolerance limits for springback of –4mm and +4mm. The large green area in Figure 8 indicates a reliable process with respect to springback tolerance. However, the red areas near the wheel housing and the headlight indicate unacceptable process reliability with a part reject rate of about 5%.

Therefore, by analysing process performance and process capability, one can improve and validate the stamping process and reduce or eliminate part rejects.

Over the next few months, additional feedback will be gathered from industry regarding practical applications of AutoForm-Sigma – how the software helps companies to improve the robustness of their sheet metal forming operations early in the development cycle, and to achieve six-sigma reliability in production. **ISMR**

Reference:
1. Auto/Steel Partnership, *Material Uniformity of High Strength Sheet Steels* – Vol.2, November 1998.

BENEFITS OF ROBUST DESIGNS

- Noise and variability do not hurt output quality
- Higher quality of stamped parts
- Fewer rejects, re-work and warranty claims
- Fewer inspections of tooling and of produced parts
- More stable production process
- Improved process productivity and efficiency
- Increased engineering department expertise
- Shorter product development cycles
- Faster tooling tryouts and faster process set-up
- Defining tolerance limits for quality control