Integrated Forming Simulation Using State Of The Art Methodologies

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Abstract. Forming simulation technologies continues to develop at a rapid pace, to address formability, tolerance control, and product performance issues in an increasing range of processes, and in ever more detail. Springback prediction and compensation continue to evolve, with new concepts for improving the accuracy of the springback prediction for example by the incorporation of geometric drawbeads, and further refinement in compensation techniques. The paper highlights how the integration of simulation and geometry plays an ever more important role, in improving accuracy and reducing time.

Other techniques which can help speed-up and improve simulation results for hydroforming, and tube bending are 'classical' and more recently 'in-process' optimization techniques. The paper will show the advantages on an industrial case, and the potential for the future.

The paper will discuss how the PAM-STAMP 2G™ and PAM-TUBE 2G™ integrated solutions are successfully implemented to deliver a positive business impact, by providing virtual product quality assessment, tolerance control, and springback compensation. The paper will also discuss how new forming processes such as hot forming, superplastic forming, and tube hydroforming, can be accurately modeled using the new modules.

Keywords: Simulation, Springback, Optimization.

INTRODUCTION

The rapid and continuous development in computer hardware & software technologies such as DMP parallel computing, sees manufacturing simulation playing an increasingly important role in vehicle development programs, helping to eliminate manufacturing risks, and to compress lead times on 'critical path' items such as large press tool manufacturing. This evolution has also resulted in the extended use of simulation, making it no longer the preserve of large companies such as OEM's and Tier suppliers, but also finding use in smaller suppliers, and in 'non automotive' applications where previously the hardware & software cost, coupled with training & end user resource would have been prohibitive.

STAMPING FORMABILITY CHECK TO VIRTUAL PANEL ASSESSMENT

The main advances in forming simulation have been the extension of the domain in which the results are considered truly predictive and reliable. Just a few years ago, most of the discussion was about the validity of forming simulation methods, the big discussion about implicit vs explicit solution schemes, and comparison or validation of results based on strains & thickness variations. In a relatively short space of time, we have moved on significantly. Largely the implicit vs explicit debate has gone away, with the realization that both methods have usefulness, and most software vendors are now utilizing both technologies today.

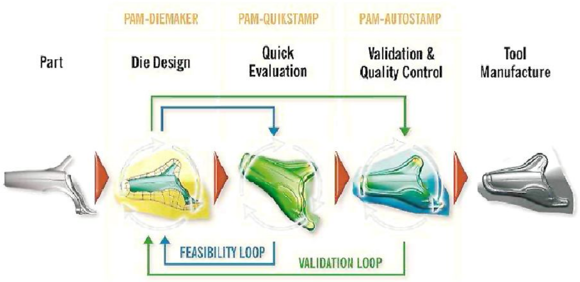
The last few years have seen a real focus and debate on the prediction of distortion due to

CP908, *NUMIFORM '07, Materials Processing and Design: Modeling, Simulation and Applications*
edited by J. M. A. César de Sá and A. D. Santos

springback, and the accuracy with which forming simulation software is able to achieve this.

The focus is increasingly on driving simulation methodologies to model the entire forming process chain, cutting costs and time from the overall development process. It is fairly commonplace today for companies to simulate the full 'die line up' including re-striking and flanging die operations.

The overall objective of all this work is to arrive at the point, where it is possible to easily perform a predictive virtual panel quality assessment, such an assessment would of course include tolerance control; in respect of springback, 'fit to gauge', trimline accuracy, and in the case of skin panels or visible panels, then also cosmetic surface quality.



PAM-STAMP 2G™ overview

Springback Prediction & Compensation

The topic of springback prediction and control or compensation is at the forefront in the field of stamping simulation software today. Compensation methods have been discussed at length for some time, but have only found use recently as springback prediction has come of age, and can be considered predictive, without this, even the best compensation methods would be futile.

The question of springback prediction remains complex, with a significant number of factors having influence.

Materials Evolution

In particular the advent of new material technologies, driven by the pursuit of weight saving & vehicle crash performance, has resulted in innovations such as 'Dual Phase', 'TRIP', 'TWIP', and 'Complex Phase' steels. This has rendered a lot of the 'old school' or experience based rules for spingback control worthless, meaning that there exists now an absolute need to rely on simulation where experience can no longer solve the problems. In order to keep pace, forming simulation softwares have had to respond with developments in material modeling to reliably capture the behaviors of these new material.

Until the advent of these advanced or ultra high strength steels, many companies did not really make use of springback prediction capabilities, preferring to solve the springback concerns during physical tryout, by process or die geometry adjustments, this however is simply not an option any longer, as the springback magnitudes witnessed from ultrahigh strength steels are very often greater than the thickness of the casting in the die face, this means that it becomes mandatory to *'engineer a solution'* to the springback control mechanism, rather than to *'solve the problem'* of springback under the press.

The evolution within material modeling has to cover not only new materials, but also new processes which are used to form these materials.

Cold forming material models have evolved to offer better Yield descriptions such as the Corus Vegter model, and also better hardening models, capturing Kinematic hardening effects such as the Yoshida model. Other advances have been the inclusion of damage and rupture models, though of course this has limited advantages for springback prediction.

Hot forming of Boron steels is becoming increasingly important, one of their major advantages being that they do not suffer with springback, though of course there are a number of other issues related to their forming which limit their use to a few crash critical components. Forming simulation has had to evolve to incorporate not only material models to handle this behavior, but also to describe accurately the heat transfer.

Other Hot forming processes such as superplastic forming are also successfully modeled using specific material models.

Integrated Compensation

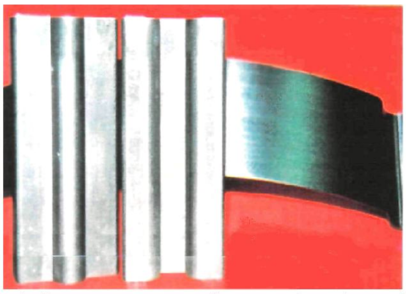
The last two years have seen all of the major stamping simulation software vendors releasing compensation functionality. The methodologies have evolved in partnership with Automotive OEM's and materials providers. Some significant early success has been seen, particularly in the smaller toolmakers, who have been the first to really embrace this technology and use it to their advantage, in many cases, being able to achieve correct component shape directly in the first tryout, after cutting dies to the predicted compensated shape.

Already in such a short space of time, the state of the art in die compensation is already capable of offering unique automatic, iterative compensation & simulation loops, which seek the minimization of deviation between the final part shape & the desired or target shape, the study being deemed to have converged once a given area (typically 95%) of the part is within the desired tolerance.

Geometry Integration

The subject of springback compensation has been one of the biggest drivers to highlight the need for closer integration of Geometric data into simulation. Until recently it has been sufficient to begin with CAD definition and to perform forming simulation based on that definition, springback compensation however requires the modification of the geometry and its subsequent incorporation into simulation in an iterative process.

The need for geometry integration is not completely limited to compensation. Drawbeads for example have typically been modeled using equivalent models, these models account for restraining and opening forces, and may also impart changes in plastic strain and thickness to the blank, but they are not perfect, and do not capture all the effects evident with real drawbeads. Notably the flow of material through a drawbead section will inevitably result in some residual curvature in the material.



Residual sheet curvature after passing through bead

This residual curvature, or curling effect will have an influence in the springback in reality, in many cases it can be neglected as often the material affected by this phenomenon is removed during part trimming, however in cases where material passing through a drawbead ends up in the component itself, the effect must be considered. In order to capture the effect, it is becoming common practice to incorporate physical drawbeads in stamping simulation for such cases.

PLM Integration

The natural evolution for this trend toward closer integration of simulation and geometry definition is to eventually embed full simulation systems into CAD, and whilst this is not yet complete, steps in this direction are already well under way. However there will probably be some intermediate steps, with the integration of geometric engine for automatic CAD modifications by the springback compensation schemes.

TUBE BENDING AND HYDROFORMING

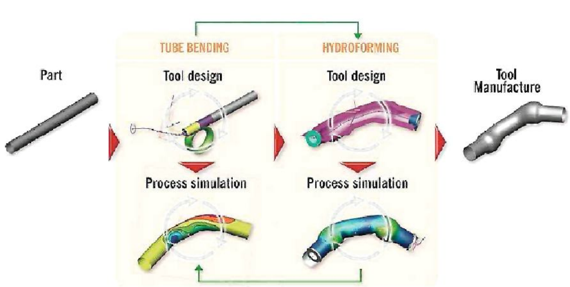
Understanding hydroforming

The first patent on hydroforming came in 1903 ("Apparatus for forming Serpentine Bodies"). The first high volume production in automotive industry came in the early '90ties (1990 Chrysler Minivan IP Beam, 1994 Ford Contour, Engine Cradle). It took a long time from the fundamentals of hydroforming were discovered until the methodology was introduced to high volume production.

Still today one can observe difficulties in managing problems that occur during setup of complex hydroforming processes. Using finite element method to simulate the processes can give a good help in understanding the process, and both avoid problems and solve problems that occur.

Development of integrated solutions

Once FEM started to be used industrially, soon the users run into other problems than just FEM-related. The model and the process setup is not at all easy for complex processes such as tube bending and hydroforming. More is needed than only a good solver in order to make the simulation as a tool popular to industrial users. As described Hora in [11], it was shown that "FEM-Simulation is only a brick in the complete planning chain", showing that combining a normal CAD with a FEM-solver is not a suitable solution in order to solve the complete planning process.



PAM-TUBE 2G^{TM} overview

Need for optimization

Keeping the objective of further cutting the time spent for the design of a part production, we need to look at the whole job. Until now, we have concentrated on the single task of making a design, and simulate it. In reality this is a loop, which even experienced designers need to complete numerous times from the reception of a part until the final design is ready.

For hydroforming parts, determining the pressure-feed-curve for complex parts that are on the limit of the formability has always been a time-costly process. Normally several simulation-loops are needed in order to find a pressure-feed-curve that makes the part feasible.

For complex bent tubes with small R/D-values and high strength steel used, determining the pressures and travel distances of the different tools is an equally time consuming task.

So looking at the whole job, there is clearly a potential for time savings using optimization to find the process parameters that make the part feasible to produce. The way to do this it to introduce automated optimization techniques.

The optimization problem is highly non-linear – which means that solving the problem mathematically is highly CPU-intensive. The objective to find the global optimum can therefore not be a realistic! Normally it is sufficient to know that the found solution is "good enough", and that the solution converges.

There are different methods to implement a solution for this problem with the objective to minimize the number of solver calls. In this presentation we will look at 2 different methodologies to optimize tube forming processes:

- An "automatic solver" approach
- A stochastic approach

"Automatic solver" approach

Looking at the pressure-feed-curve problem; this could be solved by using stochastic optimization – which will be mentioned in the next paragraph. But often there is no time for running dozens of simulations – the more elegant solution would be to have an "automatic" solver, which can monitor the process while calculating. A lot of work has been done on this field which has resulted in several papers – e.g. "Determination of Proper Loading Paths in Tube Hydroforming and Stamping using FEA Simulation" by Altan et al from Ohio State University.

So the idea is not new, but has not really found industrial use. So there is still some improvement to be done obviously. But maybe also the objective is not correct? Looking at this as an automatic solution– it is probably not realistic to be able to hit the optimum in only one run? But still – if we could make this automatic solution superior to any human made first try – we have increased the quality of that first run. So changing the objective slightly to not be "find the optimum in one simulation" to "find a very good solution in one simulation" it should be possible to develop such an "automatic solver".

Continuing to work in this direction, we are testing different possibilities using fluid cell calculation technology. The solver will automatically vary the volume feed rate and the displacement of the punches in order to minimize thinning and avoid wrinkles. All criterions used have "Global" formulations, this is necessary to increase the robustness of the option. One good solution is in general guaranteed at the end of simulation, no big risk of divergence or bad solution.

The quality of the optimised solution depends especially on the quality of the "global" wrinkle and thinning criterions formulations. A lot of investigations on this side have been done to find good and robust formulations.

At the moment we can only use this algorithm for hydroforming calculations, but the intention is to extend this for the future, to also work for bending calculations.

Stochastic approach

The above described methodology of an "automatic solver" will have limited area where it can work only the feed-pressure curve can be optimized. Using a more global approach, will allow the user to optimize also other parameters of the process, this being for instance for the bending process the pressure or the feed of the pressure die etc. or addendum surface for the hydroforming process.

Pam-Opt is such a program; an advanced, general non-linear optimizer. It's sophisticated algorithms assure the minimization of number of solver calls needed whilst still finding the optimimum by eliminating bad parameter combinations.

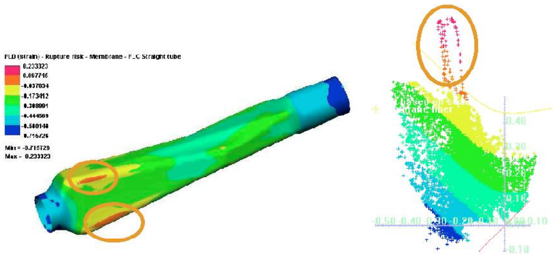
Sample hydroforming

Sample part, courtesy hde Solutions GmbH.

This part has a maximum expansion of 50%, combined with fairly sharp edges at the max expansion – which makes it not an easy task to find the optimal pressure-load curve.

Manual tryout

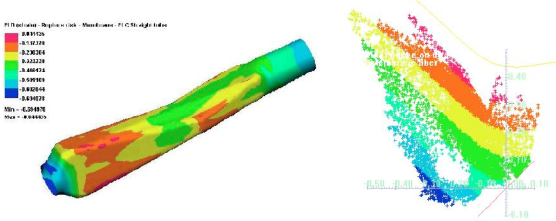
The manual tryout to find a feasible curve gave this result:



Rupture in indicated areas.

"Automatic solver"

Running the same case with the automatic solver, the result after only 1 single solver call is:



No rupture estimated.

Stochastic approach

There are 3 design curve parameters:

- Left tool displacement / time curve
- Right tool displacement / time curve
- Pressure / time curve

There are 2 constraint functions

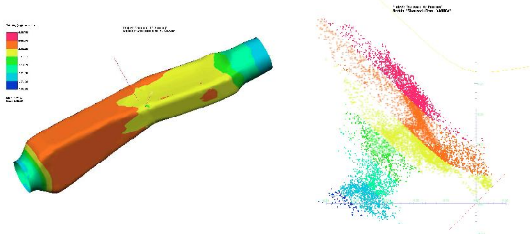
- tube-die-distance < 0.7 (no wrinkles)
- FLDmembrane-2% (no damage)

The objective function :

- Minimization of the Thinning

After 14 iterations, all the constraints were respected, and the thinning has been reduced from 0.45 to 0.21.

However – already after 2 iterations and 14 solver calls, a result was found which respected the constraints and gave a thinning of 0.27.



FLD diagram from the stochastic approach.

Comparison

The solution found by Pam-Opt has a lower thinning than the automatic solver found, and therefore seems to be the better solution. Still the automatic solver found a solution without failure within 1 solver run! Pam-Opt needed 14 solver calls to find a better solution.

Sample bending

Sample bending, courtesy Mewag Maschinenfabrik AG

There are 3 design parameters :

- Pressure-die-movement
- Piston-Force
- Pressure-Die-Force

There are 6 constraint functions

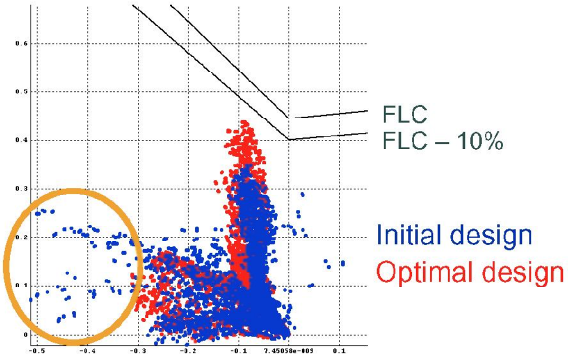
- bend-die-distance < 0.7
- clamp-die-distance < 0.7
- wiper-die-distance < 0.7
- FLDlower-10%
- FLDupper-10%
- Thinning < 0.3

The objective function :

- Minimization of the FLD

The main problem in this sample is strong wrinkling tendency on the inner side of the tube:

So how to catch these wrinkles in the optimization loops? We used the distance between the tube and the tools. Assuming that if the distance is > 0.7 mm, then a wrinkle must have occurred.



The wrinkling problem area is circled – as you can see, the optimal design eliminated that problem area. Still the FLD-10% was respected.

After 35 solver calls and 8 iterations, all the constraints were respected, and the wrinkling had been eliminated.

However – already after 2 iterations and 13 solver calls, a result was found which respected the constraints and with no wrinkles.

Summary

It seems the automatic solver can fulfil the objective of delivering "a very good solution" within 1 solver run, this makes it usable for feasibility studies and as a starting point for further optimization with Pam-Opt.

Using the robust PAM-OPT optimizer, it is possible to optimize both tube bending, and hydroforming process without making any tuning of the optimization process.

These 2 Different methodologies are available to help the engineer optimize the tube forming processes.

CONCLUSION

In this paper, the authors have set out to illustrate some key areas where the application of sound methodologies delivers state of the art predictive simulations in metal forming, offering an insight into the trends and directions currently visible.

The use of metal forming simulation has evolved dramatically over the past decade, and customer requirements continue to push the boundaries of what is possible, driving the software from tryout validation, through die design, virtual component quality assessments, process optimization, and towards virtual production, and this pace of evolution shows no signs of slowing down.

ACKNOWLEDGMENTS

The Authors wish to thank all contributors to this work, and in particular our customer partnerships, notably Mostafa El-Mouatassim of Renault (France) and Burlat Matthieu of Arcelor (France) for the work on springback compensation, Mark Schmidt of ATLAS Tool inc (MI. USA) for die compensation work, Thorsten Junge from hde Solutions for the hydroforming part

We also extend out gratitude to all of the members of the PAM-STAMP development teams in Paris, Lyon, & Aix-en-Provence (France), and Bangalore (India), and to our partners INPRO in Berlin (Germany), DELTA-CAD in Compiegne (France), iCapp in Zurich (Switzerland), data and Pierre Guyon (ESI-Group) for the Pam-Opt simulations.

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