

OPTIMIZATION IN TUBE FORMING

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ABSTRACT

The need for fast design and delivery of concepts for hydroformed parts has become important to address tight vehicle development cycles. The use of finite element simulation for the hydroforming process has helped to address some of the issues but not for the full design validation phase. The need for a fast full solution tool that helps to address from product feasibility to various stages of bending, preforming and hydroforming tooling Design, process development and validation become critical. This introduced the integrated solutions, which helped save a lot of time in the process of computer aided design of the hydroforming processes.

With both FEM and the complete integrated software packages available on the market today, the next step is to look at the whole process to see where still time can be saved. One possibility here is the use of automated optimization methods. This paper will discuss different solutions for tube bending and hydroforming processes, looking at current situation and planned solutions for the future.

Keywords: Tube bending, Tube hydroforming, FEM, optimization.

1. INTRODUCTION

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. Of course lack of proper machine and controlling mechanisms play a big role here, but also the understanding of the hydroforming process is not easy. When the dies close, we don’t see anymore what is “going on in there” – and the understanding of why things happen, and what influences there are is not clear at all.

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 FEM for hydroforming simulations

Since the early ‘90ties, the FEM method has developed rapidly from being a tool for investigating processes to become a tool for validation and quality control. For the forming processes, this has mainly been driven by the sheet metal forming industry, but also for hydroforming

developments have been done, but normally after new developments had been tested in sheet forming first. During all this time, the FEM method has helped to gain understanding on the process, and has helped solving problems. But in the same time, some “bad habits” of FEM method were recognized which meant that the reliability of the simulations was not always good enough to base the decisions on it. – samples being the use of one-step-solvers for hydroforming, use of membrane elements and simplified contact algorithms. In the later years, we have seen a development towards increased accuracy, with more realistic modelling of reality. Especially the fact to be sure to model the real world, and not model something almost like real makes a big difference towards the improvement of the results. This allows the user to base the process definition on the simulation results and helps cutting time and costs.

Development of integrated solutions

Once FEM started to be used industrially, soon the users run into other problems than just FEM-related. The pre-processing 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 in [Hor], 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.

Another reason for why integrated solutions should be used is the time factor. Since the beginning of FEM simulation, the increase of computation power has reduced the time needed for FEM simulation drastically, whilst this effect for CAD systems has not been as significant because the time consuming part here is the manual labour. The use of integrated planning systems meant that it was possible to cut the time spent for CAD work significantly. Pam-Tube 2G is such an integrated solution for tube bending and hydroforming processes:

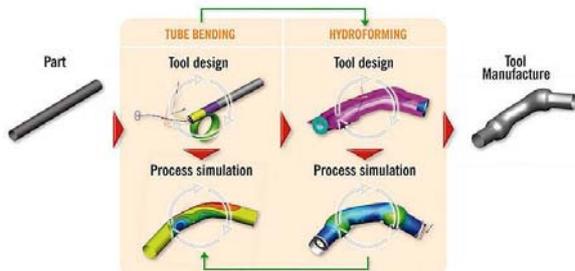


Figure 1: PAM-TUBE 2G™ overview.

2. 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 is to introduce automated optimization techniques.

The classical description of the optimization problem for process optimization:

$$\begin{aligned} \min z & (q_1, \dots, q_n, e_1, \dots, e_m) \\ \text{with } e_j &= f_j(q_1, \dots, q_n) \\ & (j=1, m) \\ \text{under } r_k &(q_1, \dots, q_n, e_1, \dots, e_m) \geq 0 \quad (k=1, l) \\ \text{whereas } z &= \text{objective function} \\ & q_i = \text{process parameter} \\ & r_k = \text{restriction} \end{aligned}$$

e_j = output result

f_j = calculation model

Here „ $e_j = f_j(q_1, \dots, q_n)$ “ represents part of the process model.

As you can see, 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

3. “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 optimized 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 for the automatic tube hydro-forming applications.

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.

4. 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, which acts like advanced, general non-linear optimizer. It’s highly advanced algorithms assure the minimization of number of solver calls needed whilst still finding the optimum by eliminating bad parameter combinations.

5. SAMPLE HYDROFORMING

After some internal testing on different parts, we got a real part from hde Solutions in Germany where we could test the optimization strategies:



Figure 2: Sample part, courtesy hde Solutions GmbH.

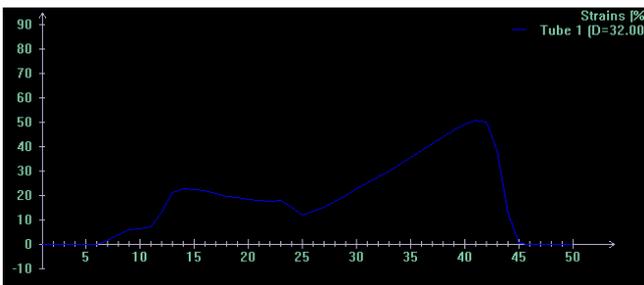


Figure 3: Max 2D-expansion : 50%.

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:

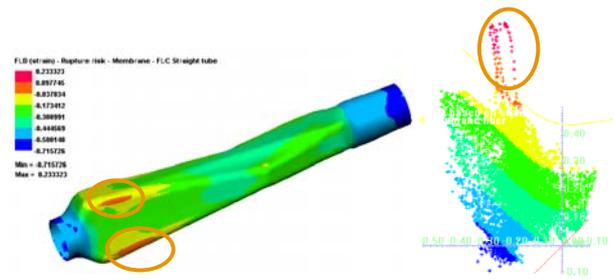


Figure 4: Rupture in indicated areas.

“Automatic solver”

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

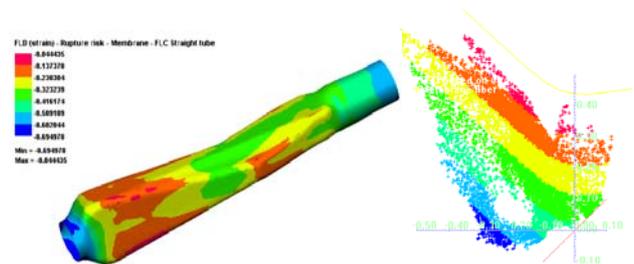


Figure 5: No rupture estimated.

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

There are 3 design curve parameters managed by 10 design parameters:

- Left Right tool displacement curves :
 - 3 design parameters per curves
 - making the displacement curves strictly growing.
 - The end of the curves are flat.
- Pressure curve
 - 4 design parameters

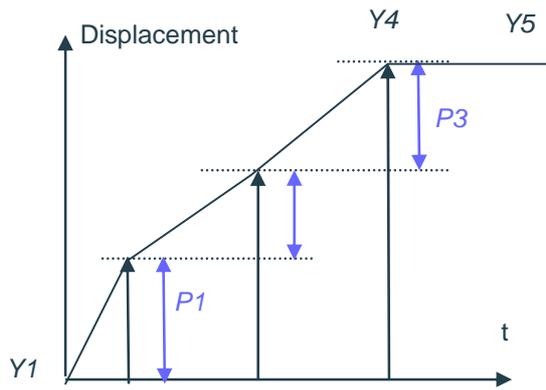


Figure 6: Design curve parameters.

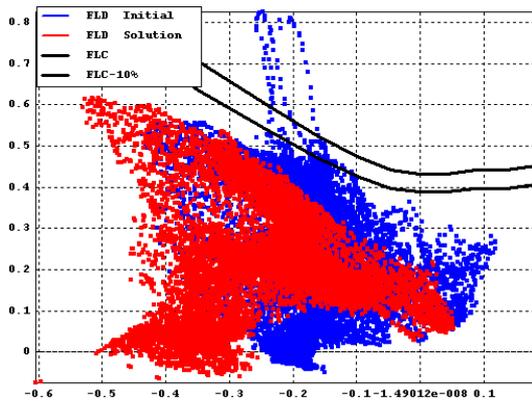


Figure 7: Comparison initial and final FLD – no rupture after optimization run.

After 76 solver calls and 14 iterations (for 10 design parameters), 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.

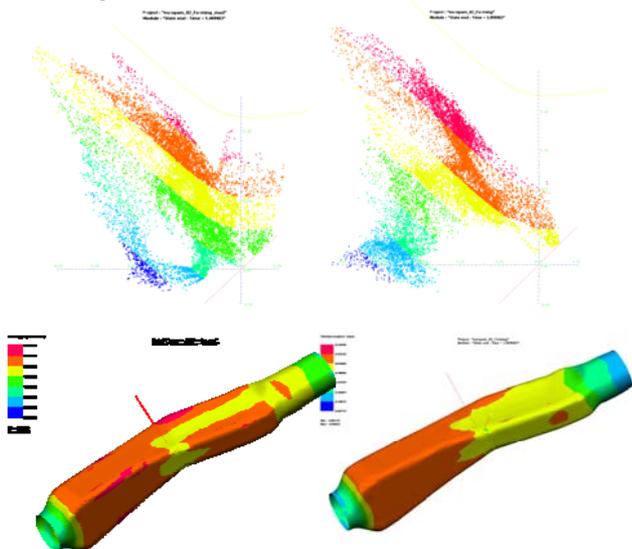


Figure 8: Comparison of the automatic solver (left) and the stochastic approach (right).

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.

6. SAMPLE BENDING

Then we took a look at the tube bending simulation. We got a sample from Mewag:



Figure 9: Sample bending, courtesy Mewag Maschinenfabrik AG.

For the bending case, we don't have an automatic solver approach ready yet, but still we wanted to investigate the possibilities of using stochastic optimization. For the bending process, there are a lot of parameters to take into account, as there are many tools with different shapes, movements, frictions and forces etc.

For this sample, we decided to concentrate on only 3 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:



Figure 10: Strong wrinkling trend on the inner side with manual try-parameters.

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.

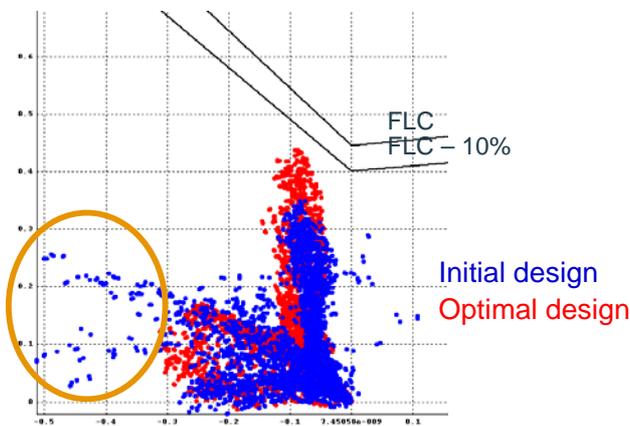


Figure 11: FLD of the initial and the optimal design.

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.



Figure 12: Result after optimization – no wrinkles.

7. CONCLUSION

- 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 an hydroforming process without making any tuning of the optimization process.
- PAM-OPT delivers a robust and quite fast optimization method for bending processes.
- 2 Different methodologies are available to help the engineer optimize the tube forming processes
 - a fast and good solution
 - a slower but more accurate solution

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