Load Path Optimization for Hydroforming Process Using 3DEXPERIENCE Platform

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Abstract: *In tube hydroforming process, the load path which is the relation between axial feed and internal pressure plays a major role in deciding the quality of hydro formed components. This study demonstrates how to arrive at optimal load path curve to achieve maximum bulge height keeping thickness reduction within limit and ensuring that the component does not get tear off during the manufacturing process. The hydroforming process is simulated using explicit dynamic procedure in structural simulation application. The DOE process is defined using simulation process modeling, to identify optimum load path. 3DEXPERIENCE platform works as an effective integration and automation platform for such studies.*

Keywords: *Hydroforming, FLD, 3DEXPERIENCE platform*

1. Introduction

Tube hydroforming (THF) is widely used in manufacturing of tubular parts used in automotive industry. The advantages of THF compared to stamping are weight reduction, improved structural strength and stiffness, fewer secondary operations and lower manufacturing costs for large volumes. The success of a THF process is mainly depending on the load path which is defined as internal pressure versus time and axial feed versus time. A suitable load path must be established to avoid part failure due to wrinkling, tearing, buckling and bursting during manufacturing. Trial and error methods to arrive at appropriate load path are time consuming and expensive. Hence, it is important to establish a systematic simulation methodology for determining load path. In this study, explicit dynamic analysis is used to simulate the hydroforming process. FEA based Design of Experiments (DOE) is used to study the impact of process variables and identify the optimal load path. A template is developed in 3DEXPERIENCE platform with the combination of Physics Modeling and Simulation Process Modeling to obtain an optimal load path. The generic template is developed in such a way that it can provide optimal load path for incremental new die geometry.

2. Component Details

A tube of diameter 48 mm, length 555 mm and thickness of 1.5 mm with high strength steel (DP590) is considered for this study. Figure 1 shows the dimensions of the final component [3].

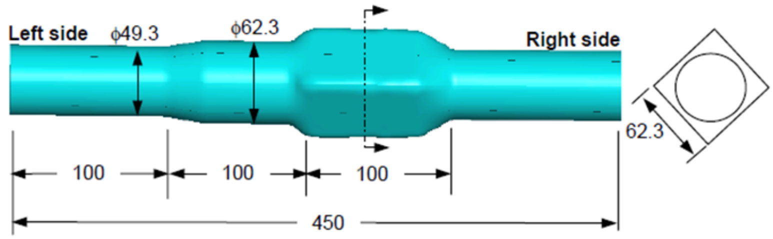

Figure 1. Tooling Geometry (All dimensions are in mm)

3. Modeling in Structural Dynamic Application

Quarter symmetry model is used for simulation. The die is considered as rigid body as shown in Figure 2. Tube is meshed using S4R elements with 12840 DOFs. Surface to surface finite sliding formulation is used for defining the contact.

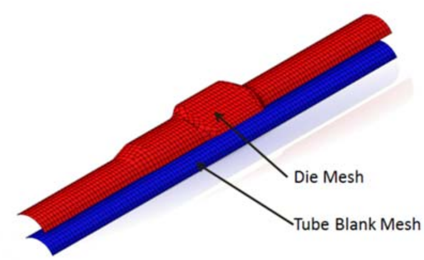

Figure 2. Meshes for Tube and Die

The detailed information about the material properties and FLD plot is provided below in Table 1. and figure 3.The material is modeled as an elastic-plastic material with isotropic elasticity, using the Hill anisotropic yield criterion for the plasticity.

Table 1. Material properties for DP590

n	K (MPa)	Yield Strength (MPa)	R_0	R_{45}	R_{90}	E (GPa)	μ
0.1795	1057.108	432	0.79	0.738	0.903	206	0.145

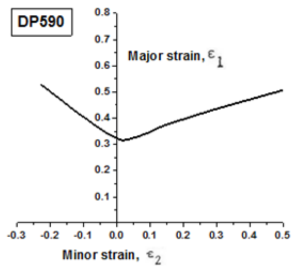

Figure 3. Forming limit diagram for DP590

The pressure load path is estimated by relating yield pressure of the material P_y and the calibration pressure P_c as given in Eqs. (1) and (2) respectively.

$$p_y = \sigma_y \frac{2t_o}{(D_o - t_o)} \tag{1}$$

$$P_c = \frac{2}{\sqrt{3}} \sigma_f \left[\ln \frac{r_b}{r_b - t_o} \right] \tag{2}$$

Where t_0 is the initial tube wall thickness, D_0 the tube diameter, r_b the smallest die corner radius, σ_f the flow stress of the material and σ_y the yield strength of the material. Axial feed for a specific part can be estimated by using volume constancy and assuming that the wall thickness of the formed part remains constant. Thus, the initial values for pressure and axial feed are shown in the Table 2. Time based axial feed and internal pressure is applied as load using amplitude curve as shown in Table 3 and Figure 4.

Table 2. Initial Pressure and Axial Feed values

Left side Axial Feed (mm)	Right side Axial Feed (mm)	Pressure (MPa)
30	50	120

Table 3. Initial Pressure and Axial Feed value wrt time

Pressure		Axial Feed	
Time (s)	Amplitude	Time (s)	Amplitude
0	0	0	0
0.0002	0.15	0.0002	0
0.001	0.75	0.001	0.5
0.003	0.75	0.0026	0.5
0.005	1.5	0.005	1

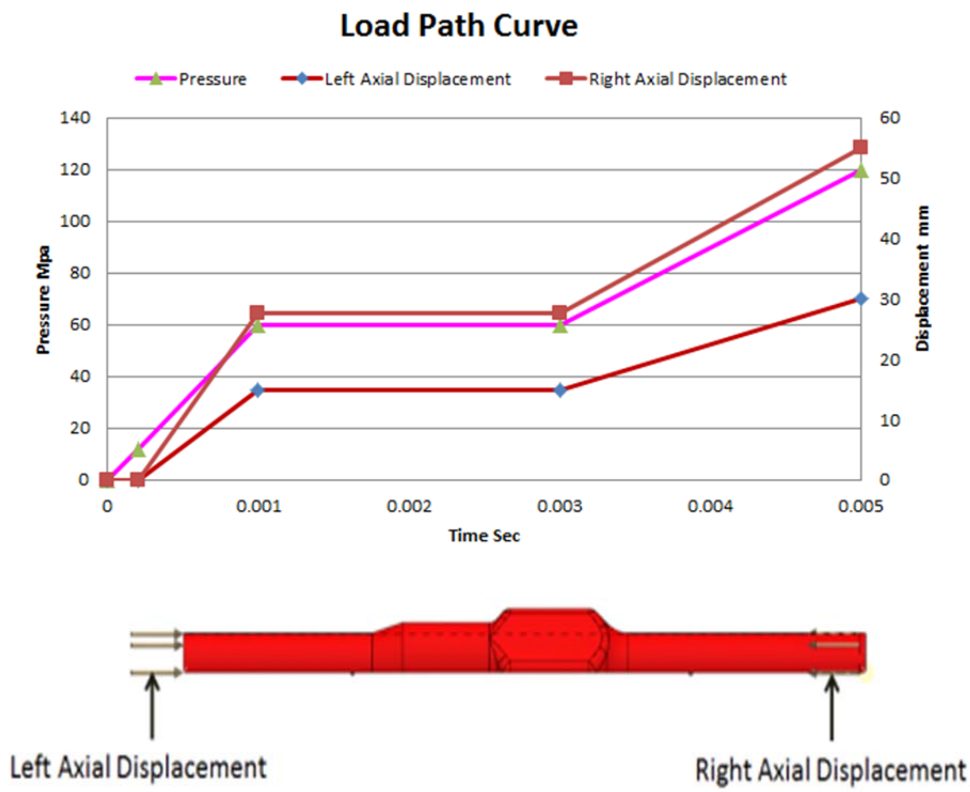

Figure 4. Load Curve for Initial Run

4. Workflow in Simulation Process Modeling

4.1.1 Design space exploration

Full factorial DOE technique is used to explore the design space. Pressure, Left end axial feed and right end axial feed are DOE variables. The response parameters are overall thickness reduction, bulge height and FLD values. The DOE workflow is shown in Figure 5.

Constraint:

- Thickness reduction (Min STH>1.2 mm) less than 20% reduction
- FLDCRT damage criteria (FLDCRT<1) to Minimum
- Bulge height >15 mm at reference node

Variables:

- Pressure (120 to 150 MPa)

- Left end axial feed (30 to 40 mm)
- Right end axial feed (50 to 60 mm)

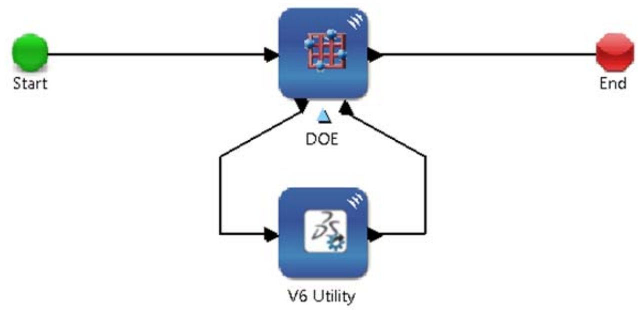

Figure 5. DOE Workflow

The V6 Utility adapter allows you to execute PLM batches, edit PLM batch arguments and set execution arguments. In addition, you can view and edit V6 parameters for the selected object.

5. Results and Discussion

5.1 Initial Results

Thickness reduction is measured using STH output variable and Limiting strains are measured in terms of Forming Limit Diagram failure criterion (FLDCRT) as shown in figure 6. Maximum bulge height is measured using U3 output variable in Figure 7.

First run results:

- Minimum section thickness: 1.25 mm (less than 20 %; satisfies the constrain)
- FLDCRT Max: 0.786 (Less than 1; satisfies the constrain)
- Maximum Bulge Height: 14.2mm (Less than 15 mm; violate the constrain)

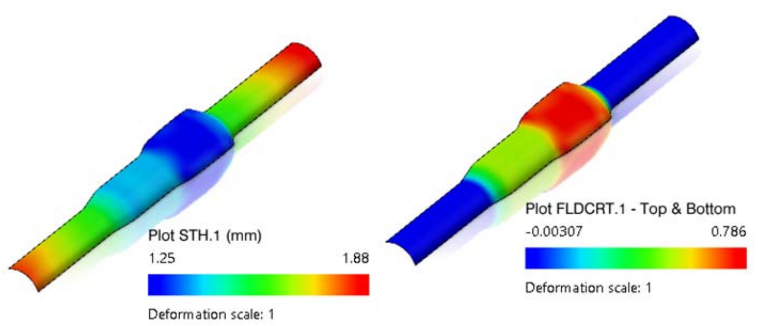

Figure 6. STH and FLDCRT Plot

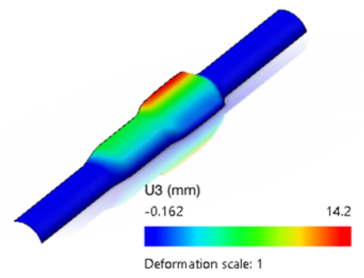

Figure 7. Maximum Bulge Height (U3) Plot

5.2 Simulation Process Modeling Results

5.2.1 DOE Results

Table 4 shows the variation of selected parameters and corresponding response which is obtained from the DOE technique; Table 5 shows the optimal results which satisfied objectives. And Table 6 shows the results summary for initial and optimal run. Figure 8 shows the optimal load path.

Table 4. DOE Results

Design #	Rank	Overall Score	Left_Axial_Feed	Pressure	Right_Axial_Feed	Buldge_Height	FLDCRT	MinSTH
1	0	0	-0.03	80000000	0.05	0.014252	0.785666	1.2465e-3
2	0	0	-0.03	80000000	0.055	0.014484	0.770045	1.2594e-3
3	0	0	-0.03	80000000	0.06	0.014675	0.750293	1.2758e-3
4	0	0	-0.03	1.0000e8	0.05	0.014982	0.879649	1.1764e-3
5	0	0	-0.03	1.0000e8	0.055	0.015104	0.859003	1.1911e-3
6	0	0	-0.03	1.0000e8	0.06	0.015241	0.841445	1.2020e-3
7	0	0	-0.03	1.1000e8	0.05	0.015176	0.930104	1.1483e-3
8	0	0	-0.03	1.1000e8	0.055	0.015273	0.900474	1.1668e-3
9	0	0	-0.03	1.1000e8	0.06	0.015357	0.879473	1.1792e-3
10	0	0	-0.035	80000000	0.05	0.014151	0.76848	1.2598e-3
11	0	0	-0.035	80000000	0.055	0.014271	0.748582	1.2758e-3
12	0	0	-0.035	80000000	0.06	0.014533	0.733289	1.2889e-3
13	0	0	-0.035	1.0000e8	0.05	0.015011	0.866837	1.1840e-3
14	0	0	-0.035	1.0000e8	0.055	0.015126	0.847827	1.1963e-3
15	0	0	-0.035	1.0000e8	0.06	0.015272	0.825649	1.2112e-3
16	0	0	-0.035	1.1000e8	0.05	0.015189	0.917956	1.1549e-3
17	0	0	-0.035	1.1000e8	0.055	0.015288	0.888492	1.1713e-3
18	0	0	-0.035	1.1000e8	0.06	0.015357	0.871336	1.1817e-3
19	0	0	-0.04	80000000	0.05	0.014117	0.747326	1.2776e-3
20	0	0	-0.04	80000000	0.055	0.014054	0.727857	1.2876e-3
21	0	0	-0.04	80000000	0.06	0.014613	0.723494	1.2939e-3
22	0	0	-0.04	1.0000e8	0.05	0.015019	0.847879	0.001196
24	0	0	-0.04	1.0000e8	0.06	0.015257	0.819809	1.2152e-3
25	0	0	-0.04	1.1000e8	0.05	0.015139	0.884265	1.1735e-3
26	0	0	-0.04	1.1000e8	0.055	0.015337	0.873242	1.1802e-3
27	0	0	-0.04	1.1000e8	0.06	0.015354	0.862592	1.1874e-3

Table 5. Optimal DOE Results

Design #	Rank	Overall Score	Left_Axial_Feed	Pressure	Right_Axial_Feed	Buldge_Height	FLDCRT	MinSTH
15	7	93.521	-0.035	1.0000e8	0.06	0.015272	0.825649	1.2112e-3
24	8	92.374	-0.04	1.0000e8	0.06	0.015257	0.819809	1.2152e-3
6	9	91.181	-0.03	1.0000e8	0.06	0.015241	0.841445	1.2020e-3
3	18	48.149	-0.03	80000000	0.06	0.014675	0.750293	1.2758e-3
21	19	43.439	-0.04	80000000	0.06	0.014613	0.723494	1.2939e-3
12	20	37.385	-0.035	80000000	0.06	0.014533	0.733289	1.2889e-3
2	21	33.709	-0.03	80000000	0.055	0.014484	0.770045	1.2594e-3
11	22	17.476	-0.035	80000000	0.055	0.014271	0.748582	1.2758e-3
1	23	16.078	-0.03	80000000	0.05	0.014252	0.785666	1.2465e-3
10	24	8.3834	-0.035	80000000	0.05	0.014151	0.76848	1.2598e-3
19	25	5.7779	-0.04	80000000	0.05	0.014117	0.747326	1.2776e-3
20	26	1	-0.04	80000000	0.055	0.014054	0.727857	1.2876e-3

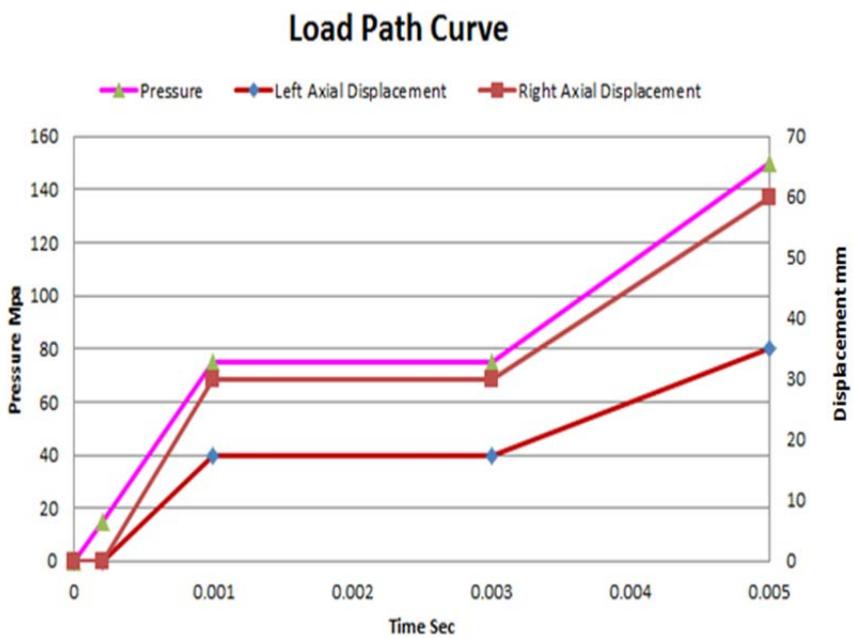

Figure 8. Load Curve for Optimal Run

Table 6. Optimal Results Summary

Range	Left Displacement (mm)	Right Displacement (mm)	Pressure (MPa)	FLDCRT Max	Bulge Height (mm)	STH Min (mm)
Initial Run	-30	50	120	0.786	14.2	1.25
Final	-35	60	150	0.826	15.3	1.21

5.2.2 Final Results

Figure 9 shows the STH and FLDCRT plot; Figure 10 shows the Bulge height plot for optimal load path.

- Thickness reduction is less than 20 % (Minimum section thickness: 1.21 mm)
- FLDCRT is within limit. (**FLDCRT Max: 0.82**)
- Bulge height displacement which is greater than 15 mm (**Bulge Height: 15.3 mm)**

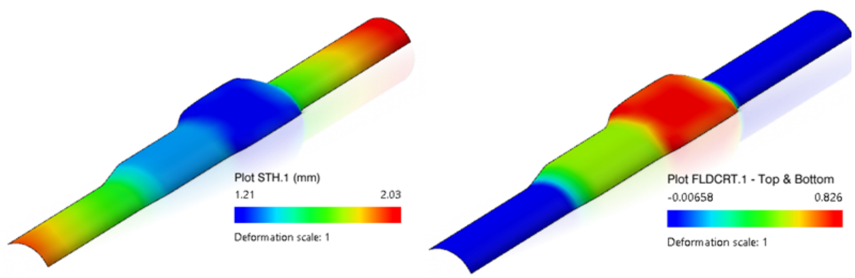

Figure 9. STH and FLDCRT Plot

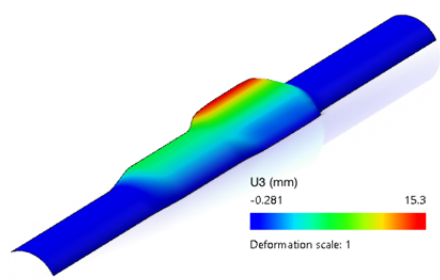

Figure 10. Maximum Bulge Height (U3) Plot

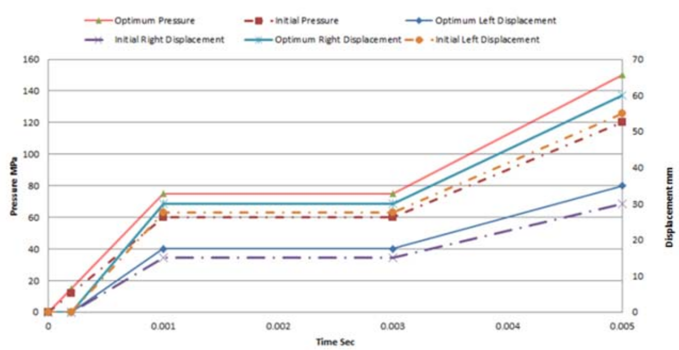

Figure 11. Linear Load Curve Compared with Initial and Optimal Results

5.2.3 Simulation Process Template

Workflow for THF load path optimization is defined in the Simulation process modeling as shown in figure 12. This workflow can be referred as template which will be used to predict the optimal load path for the incremental component modification as well as completely new component. In the current study die will be replaced with the new die as shown in Figure 13. And the complete workflow will be executed to obtain the optimal load path for replaced component. The template will also be used to provide optimal load path for incremental modifications over this replaced component.

Figure 12. Simulation Process Template

Figure 13. Die Geometry Replaced With New Die Geometry

Table 7. Optimal Results Summary for new Die Geometry

Range	Left Displacement (mm)	Right Displacement (mm)	Pressure (MPa)	FLDCRT Max	Bulge Height (mm)	STH Min (mm)
Initial Run	-35	55	110	0.8759	10.3	1.17
Final	-35	45	80	0.8190	10.3	1.2085

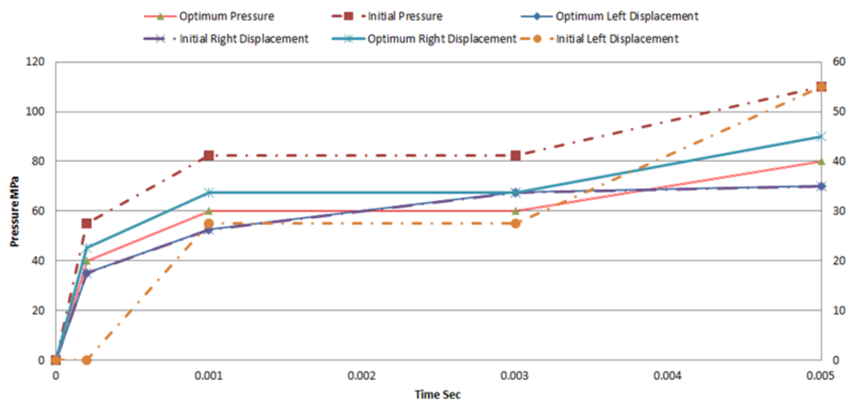

Figure 14. Linear Load Curve Compared with Initial and Optimal Results for New Die Geometry

6. Conclusion

This study demonstrates that 3DEXPERIENCE platform is a powerful tool in order to obtain optimal load path for tube hydroforming application. In comparison with the traditional trial and error method 3DEXPERIENCE platform is cost effective tool. Developed Simulation process template allows to capture the best practices that are encapsulated in a well-designed simulation process. As a result, this template will be used to predict the optimal load path for the incremental new die geometry.

7. References

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