Minimization of Forming Load of Gear Driver Forging Process with AFDEX and HyperStudy

Executive Summary

With a constant need for faster and more meaningful simulation results, the use of optimization tools at an early stage of design has become inevitable. In the case of metal forming, the synergy of the forming simulation software and an optimization tool would be a firm step in the right direction towards reducing the design lead time. In this paper, a workflow is presented that integrates the functionalities of a metal forming simulation software, AFDEX and a multidisciplinary optimization software, HyperStudy. Using this approach, the forming load of a gear driver used in an automotive transmission is minimized and two die design parameters are optimized. Further design sensitivity analysis and approximation models can be carried out using HyperStudy as an extension of the established framework.

Introduction

The design and verification of forming processes have long involved a time consuming process of trial and error. Any software or theoretical aid that facilitates an efficient design will be invaluable to a process designer. This is especially true in the automotive industry, where there is always a demand for shorter lead times [1] which in turn, has a significant impact on the firm's competitiveness. Figure 1 shows the manufacturing process of a gear drive used in a gearbox of an automobile. In this paper, the first two processes namely, blocker and finisher die based forming processes are examined in detail with an objective to reduce the forming load in the die of the finisher process.

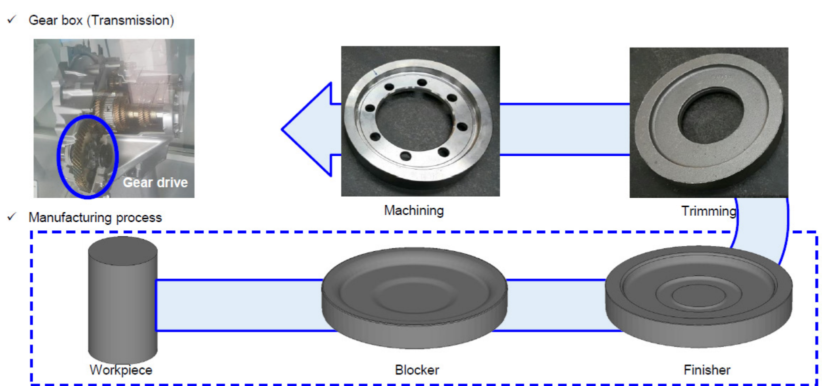

Figure 1: Manufacturing process of a gear drive in an automotive gearbox

AFDEX, an intelligent metal forming simulator developed by MFRC, is used to simulate a two-stage forging process. Based on the results of the initial design run, two die shape parameters in the process are optimized using Altair HyperStudy, the multi-disciplinary design exploration and optimization software.

Problem Definition and Solution

From Figure 2, it can be observed that a two-stage hot forging process is considered for this example and the aim is to reduce the forming load of the finisher process with two die shape parameters as design variables. The forming load is a very important factor that influences the die life and this adds more weight to the importance of this optimization problem and a proper solution methodology.

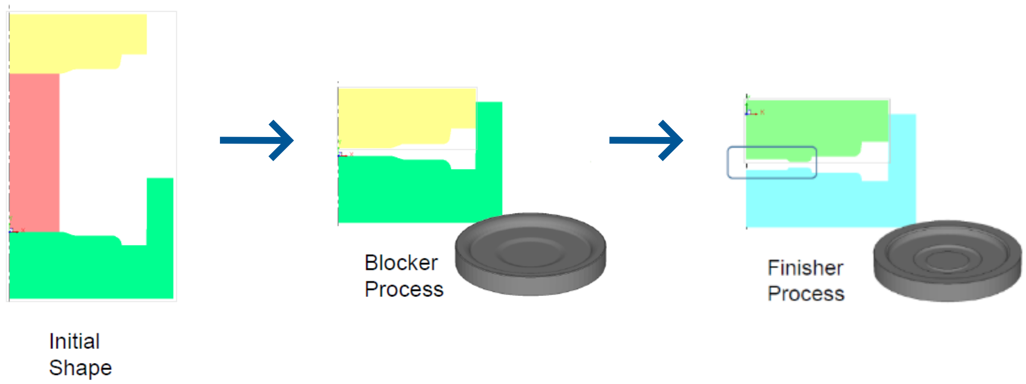

Figure 2: Process design

Once the material properties and the friction phenomenon have been defined, the simulation is executed in AFDEX. A user-friendly interface and an inbuilt intelligent re-meshing algorithm helps in obtaining the solution with minimum user intervention. The forming load versus the time is plotted in the left half of Figure 3. The results of this simulation will be used as the basis for further optimization.

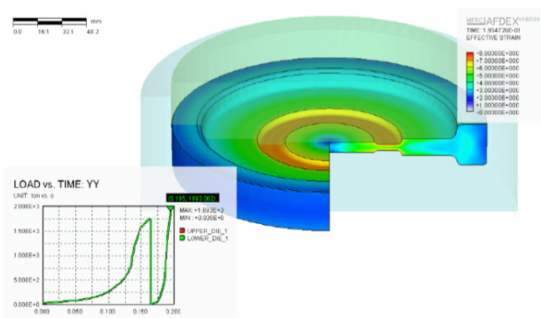

Figure 3: Simulation Results - AFDEX

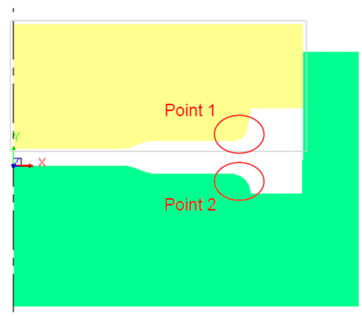

Figure 4: Design variables

The die radii at points 1 and 2 indicated in Figure 4 would be the design variables that need to be optimized.

The optimization problem at hand can be described as follows:

Design Variable: Radius of point 1 and 2 in the blocker process

Design Objective: Minimize the forming load of finisher process

Constraints: Forming load of blocker process < 1600 tons

Considering the simulation results from AFDEX as initial values, the optimization problem is defined in the Altair HyperStudy environment. The approach adopted for this problem is depicted in Figure 5.

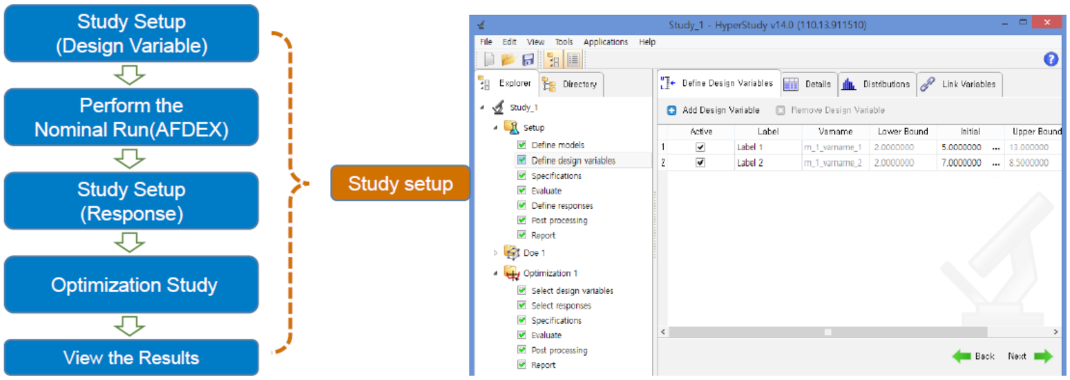

Figure 5: Solution Methodology

HyperStudy is a solver neutral multi-disciplinary design exploration, study and optimization software, and allows the realization of parameterization in various methods such as from an excel spreadsheet. It can be integrated with any simulation software that has ASCII input files through template files [2]. Template files (with extension '.tpl') are parameterized versions of the simulation input files (Figure 6) which usually depend on the solver which is used for carrying out the nominal run. The input files of AFDEX are SIF and SCF which correspond to Simulation Input File and Simulation Control File respectively. As the names suggest, SIF files contain information about workpiece and die geometry, the input process parameters like friction, die velocity etc. and SCF files consist of the factors that control the simulation and it is subject to change during execution.

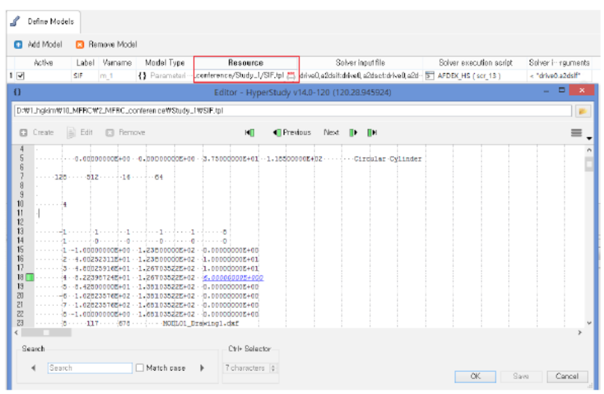

Figure 6: Template Editor – HyperStudy with input files from AFDEX

In the solver input deck, "parameter" statements are added which are linked to properties like thickness or radius. In this example, the die radii would be parameterized. Having defined the design variables (die radii), the simulation input files and the solver input arguments, the simulation is executed for a nominal run through the AFDEX's solver. Once the results are obtained, the next step is to define the responses. The forming load constraint on the blocker process die is defined as the first response. The objective function, i.e. the forming load on the finisher process die which needs to be minimized, is defined as the second response.

In simple terms, a response surface is an algebraic or numeric expression which describes the response of a model as a function of the input parameters. They act as a proxy for the model and enable quicker estimation of the model response without actually simulating the entire analysis. The Global Response Surface Method (GRSM), a response surface based algorithm is used for optimization. In this method, designs are generated for each iteration and all the generated designs can be solved in parallel. A maximum number of 100 evaluations with 4 initial sample points are defined and the optimization is executed.

Convergence was observed in the 13th iteration with the die parameters optimized and a minimized forming load for the finisher die.

	Label 1	Label 2	Forming Load	Iteration	StepIndex	StepMajor	Condition	Best StepMajor
1	12.500000	8.5000000	1808.9204	1	2	1	Feasible	
2	11.500000	8.5000000	1678.6073	2	5	2	Feasible	
3	10.500000	8.5000000	1667.8693	3	7	3	Feasible	
4	10.500000	8.5000000	1667.8693	4	7	3	Feasible	
5	10.000000	8.5000000	1643.3833	5	11	5	Feasible	
6	10.000000	8.5000000	1643.3833	6	11	5	Feasible	
7	10.000000	8.5000000	1643.3833	7	11	5	Feasible	
8	10.000000	8.5000000	1643.3833	8	11	5	Feasible	
9	10.000000	8.5000000	1643.3833	9	11	5	Feasible	
10	11.500000	7.5000000	1617.9295	10	21	10	Feasible	
11	11.500000	7.5000000	1617.9295	11	21	10	Feasible	
12	11.500000	7.5000000	1617.9295	12	21	10	Feasible	
13	11.000000	7.5000000	1589.3216	13	27	13	Acceptable	49
14	11.000000	7.5000000	1589.3216	14	27	13	Acceptable	49
15	11.000000	7.5000000	1589.3216	15	27	13	Acceptable	49
16	11.000000	7.5000000	1589.3216	16	27	13	Acceptable	49
17	11.000000	7.5000000	1589.3216	17	27	13	Acceptable	49
18	11.000000	7.5000000	1589.3216	18	27	13	Acceptable	49
19	11.000000	7.5000000	1589.3216	19	27	13	Acceptable	49
20	11.000000	7.5000000	1589.3216	20	27	13	Acceptable	49

Figure 7: Iterations – HyperStudy

The forming load in the finisher process die has been reduced by 22% (Figure 8) which is a crucial factor for die life.

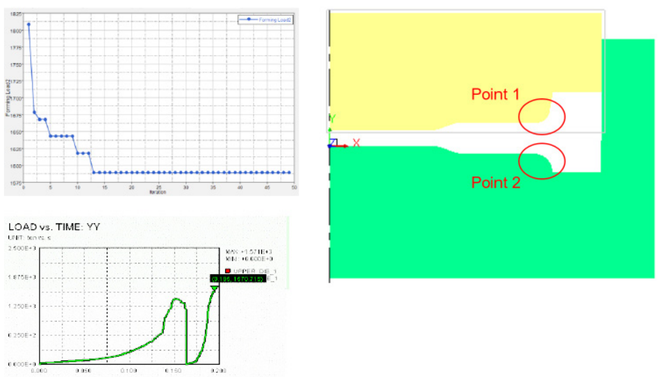

Figure 8: Minimized forming load after optimization

Conclusion

A significant 22% reduction in the forming load of the finisher process of a gear driver used in an automotive transmission system has been achieved through the integrated use of AFDEX and HyperStudy. The approach described in this paper can be very useful to the process design engineer in arriving at the best design in the least amount of time. Further sensitivity analysis and approximation models can be applied through the multitude of optimization options available in HyperStudy. With a detailed parameter study, the optimization period can be further reduced enabling even faster results.

References

[1] Mattiason, K., “On Finite Element Simulation of Sheet Metal Forming processes in Industry”, European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS (2000).

[2] “HyperStudy Introduction – DOE, Fit, Optimization and Stochastic”, Altair HyperWorks.

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