Optimization of an ANSYS CFD Model Using HEEDS MDO

ANFLUX, Inc. and Red Cedar Technology

Introduction

The design of a reliable and efficient torque converter presents many engineering challenges and requires an advanced understanding of fluid dynamics. From a mechanical design standpoint, the main challenges are choosing the design geometry, for the pump and turbine blades, that works effectively for a variety of operating conditions. Commonly used design processes for creating pump and turbine blade geometries involve the iterative use of computational fluid dynamics (CFD) CAE tools with the hopes of meeting a predetermined set of design criteria.

A popular tool used for CFD analysis is the ANSYS CFD package. ANSYS tools allow an engineer to create design geometry, apply the presumed loading conditions, analyze the response of the design, and view and evaluate the results generated from the analysis. Rather than manually iterating design changes until all design requirements are met, an engineer can work more effectively by automating the design process and allowing an optimization algorithm to create a final design that meets the particular requirements.

HEEDS MDO is an optimization software package that can interface with a variety of analysis tools, including ANSYS CFD. HEEDS MDO relies on its proprietary SHERPA algorithm to efficiently and effectively optimize any number of responses from the design being analyzed. By interfacing the HEEDS MDO software with the ANSYS CFD analysis tools, an optimal torque converter design can be found.

The Torque Converter Pump Design

A torque converter's primary function is to create a coupling between a drive motor and some driven load. The torque converter assembly consists of three sets of blades or impellers, two of which are connected to the drive motor and the driven load, and a fluid that passes between them. Figure 1 illustrates a common torque converter assembly. The pump is fixed to the drive motor. When rotated by the drive motor the pump blades generate a rotational motion of the fluid within the assembly. This fluid then applies a load to the turbine

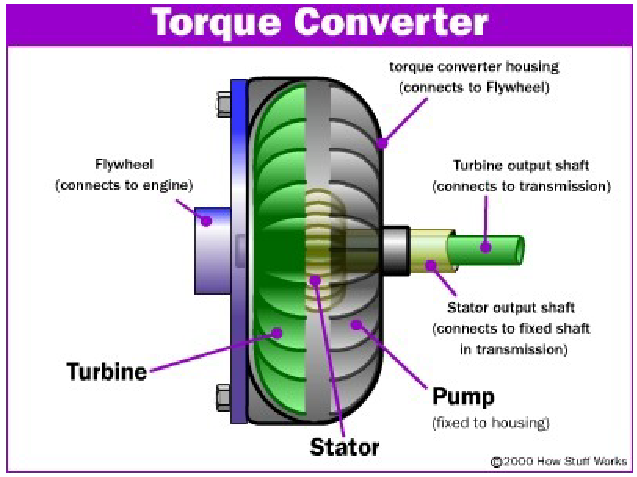

Figure 1. *Torque Converter Cross Section.*

blades, which in turn rotate the turbine output shaft producing the driven load.

The torque converter's ability to create a fluid coupling and multiply the drive motor torque depends on the fluid flow generated within the assembly. This fluid flow is created by the interaction between the fluid and the blades of the pump and turbine.

The geometry of the blades alters the velocity and path of the fluid flow from the pump to the turbine, and therefore can be analyzed and modified to allow a pump to have maximum performance for a specific set of design criteria.

CFD Analysis of Pump Flow using ANSYS

As part of the standard engineering design process of a torque converter pump, the internal blade-fluid flow interaction was modeled using the CFD finite element program ANSYS. The fluid flow was determined for a specific shroud and hub design angle, while interacting with the surrounding fluid in a set operating range.

A single analysis of the fluid flow model took approximately 30 minutes to run using 4 CPUs. The most critical result, and therefore chosen as the objective of this optimization, was the overall pump torque.

Shape Optimization of the Pump Blade

To optimize the blade design of the pump for maximum torque, the ANSYS CFX model would be used as the analysis model in a HEEDS MDO project. In addition to the CFX tools used for applying boundary conditions, solving, and post-processing the CFD models within ANSYS, the geometry creation and meshing of the components was performed using the Blade Gen and Turbo Grid tools.

For specific cases, the HEEDS MDO software provides CAE portals that simplify the input of data and setup of the optimization project. In this case, the series of tools used to create and complete the entire analysis will be controlled using batch files and scripting options. These options are available within each tool (Blade Gen and Turbo Grid) and can be easily executed and automated within HEEDS MDO to complete the design optimization.

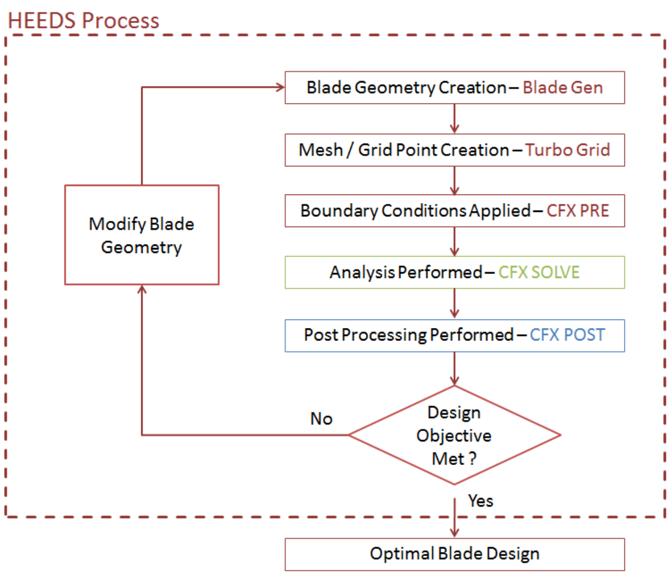

***Figure 2**. Pump Blade Design Process and ANSYS CFD Tool Integration.*

To prepare for the design optimization, a series of input and batch files must be created for each tool from the baseline blade CFD analysis. The full design analysis sequence, which later makes up the HEEDS automated optimization process, consisted of the following steps:

1. **A Blade-Gen Batch Input File** (.bgi) – Created using the File>Export>Batch Input File within ANSYS Workbench. This file contains the values for the pump blade physical characteristics. Baseline values for the design variables are defined here.

2. **Turbo Grid Session File** (.tse) – The session file for Turbo Grid records the steps taken to generate a mesh for use in an analysis. The recording of a new session file is started before beginning any work within Turbo Grid and stopped when the meshing is complete and a mesh file has been created. The previously created blade geometry file is used as input and a .gtm file containing the mesh is exported upon completion.

3. **CFX PRE Session File** (.pre) – Similar to the Turbo Grid Session File, a CFX PRE session file is recorded during the creation of an input file containing the previously created mesh and application of the boundary conditions for the analysis. Again, this file is exported upon completion of all related pre-processing tasks when the analysis is prepared to be submitted to CFX SOLVE.

4. **CFX POST Session File** (.cse) – The CFX POST Session File is created by the same method as both the CFX PRE and Turbo Grid Session files. A new session file is started before any post-processing of the results from the CFX SOLVE solution. Once the session file is started the output files from CFX SOLVE are imported and the required values are extracted. This can be done individually or with the use of a pre-determined template file. Once all post processing is complete for the analysis the session file is saved for later use in the HEEDS MDO optimization.

HEEDS Automation and Optimization

After the creation of the session files for each of the analysis tools used, minimal work is required to automate the design process and generate an optimization study within HEEDS MDO. Before the HEEDS MDO project can be created, the requirements of the optimization must be defined. For this project the goal was to maximize the torque of the pump impeller, by modifying the blade angles of both the shroud and hub within a specific range. The design is constrained by stating a minimum head value and limiting design characteristics such as; the number of vanes, rotation speed, and inlet mass flow rate.

Once the design limitations are determined for a specific project, the HEEDS MDO study can be performed. To create a HEEDS MDO study for this application, a new study is started with a process containing an analysis for each of the tools used in the CFD analysis (BladeGen, Turbo Grid, CFX PRE, CFX SOLVE, CFX POST).

Each analysis defined in the HEEDS project contains the execution syntax to run the tool in batch mode as well as the input and output files for each tool. Required input files for each tool are from the session files created

4572 S. Hagadorn Rd. | Suite 3-A | East Lansing, MI 48823 | P: 517.664.1137 | F: 517.664.1175 | www.redcedartech.com

previously. In addition to the session files, the initial input file for the Blade Gen program and the final output file from CFX POST are required. In these files the input variables and the output responses have been defined.

After defining which tool and its associated files for each analysis, the project variables and responses were then defined. This was performed on the Variables tab in HEEDS MDO. For each design variable a baseline value and the desired range needs was defined. In addition to the design variables, each response was defined. Responses can be specific values from an output file, or HEEDS MDO can perform math functions on values read from output files and RMS calculations with predetermined target curves.

Once the design variables and responses are defined for a project, they must be linked to their location in the input and output files defined so that HEEDS MDO can actively change the variable values and extract the responses with each run. HEEDS MDO accomplishes this by “tagging” a specific location within a parsed file and replacing or retrieving the value in that location for each analysis. In addition to tagging a file, HEEDS MDO also has an internal scripting language that can be used to search and retrieve values from user generated scripts if tagging cannot retrieve the required value.

The final step in setting up the HEEDS MDO project is to define the optimization method and the project objectives and constraints. HEEDS MDO contains a number of optimization methods, though the most commonly used method is SHERPA, a method which is an automated, hybrid adaptive approach that requires no tuning parameters, only the total number of runs for the project. When defining the objectives and constraints HEEDS MDO requires the user to define the option of minimizing or maximizing the objective and the value of the constraint(s). Once these have been defined for all objectives and constraints the HEEDS MDO project can be run and HEEDS MDO will automate the running of the analyses until the total number of requested runs has been completed and an optimal design is found.

Results

The HEEDS MDO software automated 58 evaluations (approximately 28 hours run time) using the SHERPA optimization algorithm. Throughout the runs the HEEDS MDO software was able to completely automate the impeller blade CFD analysis and the SHERPA algorithm was able to increase the pump torque by 19.24%, while meeting the constraints set forth. Allowing HEEDS MDO to run additional analyses with a wider range or increased number of variables could potentially further increase the pump efficiency.

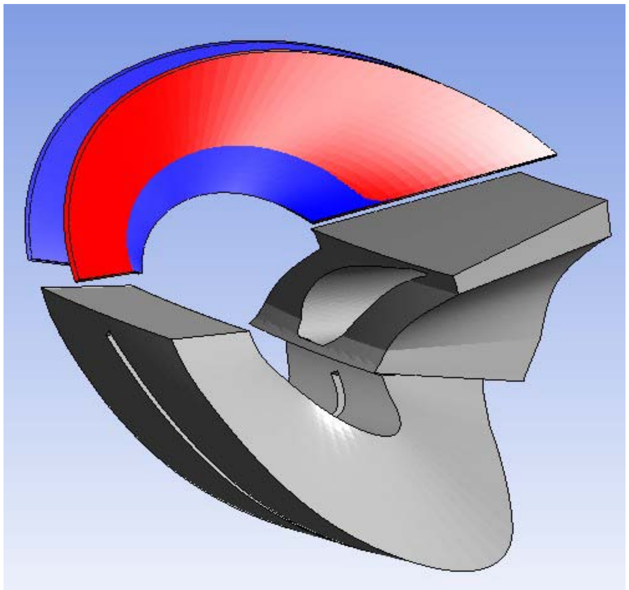

Figure 3*. Optimized pump blade design (red) with baseline blade design (blue), stator, and turbine shown.*

Conclusions

HEEDS MDO optimization software was successfully used to automate and optimize an ANSYS CFX CFD model. The optimization was performed by creating a series of session files that would automatically manipulate design geometry, CFD model characteristics, and CFD model results generated in a number of different tools.

The optimization was limited to modifying only the blade design on the pump side of the torque converter, but still produced almost 20% improvement in pump torque. It should also be noted this same process can be used with any pre, post, and analysis tools that have the ability to create a session file recording of actions taken on a specific set of input or output data.

4572 S. Hagadorn Rd. | Suite 3-A | East Lansing, MI 48823 | P: 517.664.1137 | F: 517.664.1175 | www.redcedartech.com