Designing Turbomachinery for Higher Efficiency: choosing the optimal design or saving engineering hours? Both!

With today's trend to minimize energy consumption, slash emissions and preserve ecology, there is an ultimate demand for switching to more efficient, cost-saving turbomachines. Finding a trade-off between efficiency and manufacturing cost, also having an eye towards reliability and size of machine, can be considered the biggest engineering challenge.

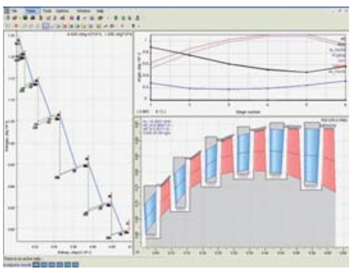
Generally, the development process of a flow path, from setting all parameters to comparing analysis results, is a time-consuming task. To create a competitive product, able to make a difference and meet the growing industry demands, an engineer has to keep in mind multiple critical factors, such as product life cycle, quality, innovation and development costs. How to shorten time to results without sacrificing accuracy? Is it possible to minimize engineering costs while designing a high-efficiency flow path?

Beside having the appropriate education background and industry experience, advanced design tools can help engineers overcome these challenges, giving them an edge over the competitors. Although the characteristics of such an ideal "tool" may differ from user to user, some general principles can be easily assumed:

1. Availability of modules for preliminary design, meanline and streamline flow path analysis, profiling and 3D blade design, structural and modal analysis, and 3D flow analysis.
2. Ability to automate multivariate calculation results to select the optimal one.
3. Integration of all modules: interactive structure allowing the user to return to the previous step at the each phase of design.
4. Easy data input/modification/export to other engineering systems.

Let's consider these features in detail to see their effect on the design process:

1. The first and utterly important step of conceptual workflow is preliminary design, also known as sizing or design from scratch. In this step, we determine the key parameters influencing efficiency, manufacturing cost and reliability of the final design are set, e.g. number of stages, diameters, blades heights and cascades metal angles, reactions of future flow path etc. The preliminary design process calculates optimal flow parameters and performance with regard to design constraints, by using the "inverse problem formulation" where the selection of flow path dimensions is grounded on definite geometrical and operational constraints. Finally, when the flow path is analyzed using the "direct formulation" process where performance is estimated with fixed geometrical parameters and operating conditions.

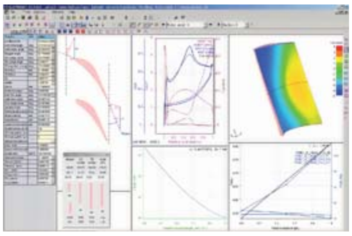


   The next step is meanline (one dimensional or 1D) analysis in direct formulation to validate the obtained solution and derive a more precise estimation of flow leakages. When 1D analysis is performed, and the geometric parameters are distributed along the radii, steamline (two dimensional or 2D) analysis is used to refine design, taking into account such crucial factors as redistribution of metal angles in the spanwise direction, gauging angles and outlet pressure.

To select the optimal blade twist law, Design of Experiment (DoE) methods are used. At this phase of design, the engineer can estimate the influence of geometrical and operational dimensions, variation on power, efficiency etc. which results in better performance of the turbomachine.

After 1D/2D analysis, airfoil cross-section profiling is performed to find the appropriate airfoil outline using flow calculations in planar profile cascades with regard to the boundary layer and compressibility effects. Such geometrical and aerodynamic criteria of profile quality as minimum of integral curvature and minimum of profile losses are taken into consideration while optimizing the profiles. The profiling process may also include analysis of flow charts with velocity, pressure, momentum, thickness values, Buri criterion and distribution of heat transfer coefficients along the profile outline.

At the stage of structural and modal analysis, geometric parameters are selected using simplified formulations, so that the optimal strength conditions will be achieved. Before starting the analysis, boundary conditions and material properties are specified. Thus, the outputs for structural analysis calculations are stresses in the blades and tensor components, while outputs for modal analysis calculations are represented by values of the specified number of the first four natural frequencies for analyzed blades and generation of Campbell diagram.

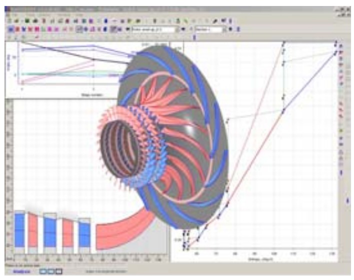


Finally, 3D flow analysis is performed using CFD tools to generate computational mesh for inter-blade channels upon 3D blade and stage geometry. The outputs for turbomachinery analysis are divided into integral flow characteristics (values of mass flow rate, power, efficiency in calculated point of performance curve) and partial flow characteristics (distributions of flow angles, velocities, pressures etc. at any control streamwise and spanwise station.)

2. Ability to generate multiple designs to select the optimal one is critical, as it can considerably cut the design process. It is obvious that, by presenting several designs, it is easier to meet customers' specific requirements, including geometry constraints, budget, time to market etc.

   To achieve this, at the stage of preliminary design, a set of solutions is generated within specified ranges, and the correlation between design parameters and performance is found. Then the design space explorer provides visual comparison of the calculation results, and the best design is chosen. All solutions are filtered by different parameters, e.g. number of stages, meridional and axial dimensions, maximal blades weight etc. This approach allows saving precious engineering hours while selecting the only one right design among thousands obtained solutions. As a result, the development process can decrease from months to weeks and from weeks to days (depending on the design).

3. An integrated environment ensures rapid conceptual design of flow paths. It encompasses the full cycle of design, from preliminary design, through performance map generation, 1D/2D streamline analysis and multidisciplinary optimization to cascade profiling, 3D blade design and 3D FEA/CFD. All modules are integrated allowing the engineer to change the design at



each stage. Another time-saving feature is quick and easy access to visualization which speeds up the engineering process, giving the user more time to improve the design and fulfill the customer's needs for more efficiency and reliability.

Cost of fuel is growing at an exponential rate, therefore, increasing efficiency of turbomachinery is an integral skill for a successful engineer. By comparing multiple calculation results and adjusting the design using different modules in real time, higher efficiency can be achieved, improving the product life-cycle.

4. To overcome the usual challenge of interformat data conversion, the appropriate mechanisms for data input, modification, output and export into other software systems are necessary.

Conclusion

The industry's call for cutting fuel consumption and CO_2 emissions, coupled with the over-growing necessity to preserve energy, paved the way for new, high-end turbomachinery design tools appearing at the market.

An advanced design solution should contain modules for the whole process of flow path development, from sizing to 3D FEA/CFD and data export to 3D CAE/CAD; be able to generate multiple calculation results to allow the user to compare and choose the best one; and have an integrated structure ensuring design modification at each step.

To achieve this result and provide engineers with an integrated and streamlined solution that encompasses the complete process of flow path design, SoftInWay Inc. has developed AxSTREAM Software Suite for conceptual design, analysis and optimization of axial, radial, mixed flow and counter-rotating turbomachinery.

Since its creation, AxSTREAM has consistently set industry standards for reliability, efficiency and better speed to market. It allows designing high-efficiency turbines and compressors, cutting the flow path development process and saving engineering costs.

About SoftInWay

SoftInWay Inc. is a USA corporation, headquartered in Burlington, MA. The company's mission is to serve the high technology community by providing software products, training and engineering services in the areas of research, design and digital prototyping of power generation equipment. SoftInWay develops products for rapid turbomachinery design, provides technical engineering services and uses in-house and industry standard CFD, FEA and CAD tools to address design issues at the earliest possible stage to maximize engineering productivity and increase the efficiency and reliability of equipment. The core product, AxSTREAM, is an integrated solution based on over 600+ years of collective turbomachinery experience of SoftInWay engineering team, with the clear goal of bringing to industry a professional software tool for rapid and optimized turbomachinery flow path design.