Picking Up Steam

The design of many products is complicated by conflicting design objectives. For example, minimizing pressure drop for heat recovery steam generator inlets also requires maintaining uniform flow velocity at the entry to the boiler. KeelWit engineers developed an optimization algorithm that was applied by leveraging ANSYS ACT to manage trade-offs and reduce pressure drop by up to 25 percent across two families of boilers. This substantially improved performance.

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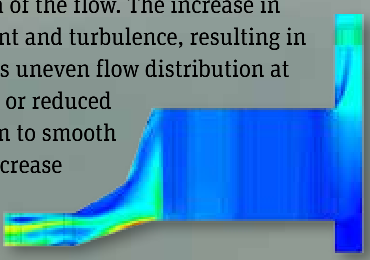
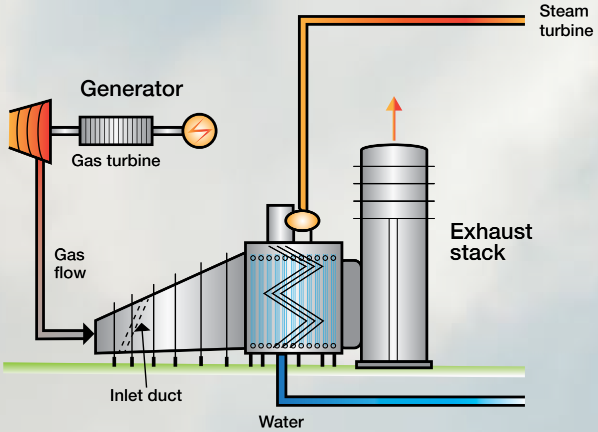
Heat recovery steam generators (HRSGs) improve the efficiency of gas turbines by recovering heat from their exhaust gases. These exhaust gases are piped into the HRSG boiler where they flow around tubes through which water is pumped. The heat from the exhaust gases transforms the water into steam, which is used to generate electricity. The inlet duct of the HRSG connects the flow from the exhaust duct of the turbine to the boiler, which requires greatly increasing the cross-sectional area of the flow. The increase in cross-sectional area tends to create flow detachment and turbulence, resulting in nonuniform velocity. This nonuniformity generates uneven flow distribution at the tubes, which causes energy losses in the boiler or reduced performance. Inlet duct designers adjust the design to smooth the flow distribution, but these changes usually increase pressure drop in the inlet duct, which creates energy losses.



^ Side view of velocity contours at the midplane of a typical HRSG

The challenge for the inlet duct designer is to balance these conflicting objectives to produce a sufficiently uniform velocity distribution while simultaneously minimizing pressure drop. Engineers must also keep the inlet duct as short as possible to reduce its manufacturing and assembly cost. Engineers have used computational fluid dynamics (CFD) in the past to improve inlet duct designs by manually exploring a limited design space. KeelWit has developed the multiobjective structured hybrid direct search (MOST-HDS) shape optimization algorithm, which explores a much broader design space to develop radically different inlet duct designs than those previously considered or to dramatically improve current designs. This substantially improves performance. The MOST-HDS algorithm was developed as an ANSYS ACT application. It communicates with ANSYS Fluent CFD to simulate design points, and also interfaces with ANSYS DesignXplorer to create correlation matrices to determine the impact of each design parameter on pressure drop and velocity uniformity.



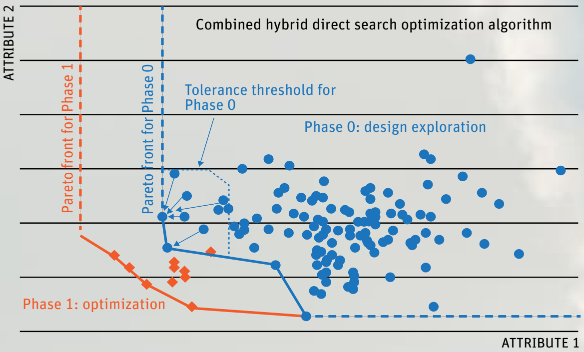
^ Diagram of a generic heat recovery steam generator

With ANSYS ACT, engineering teams can create a customized simulation application to capture and use expert knowledge, specialized processes and best practices. With ACT, engineers can encapsulate APDL scripts, create custom menus and buttons to incorporate a company's engineering knowledge, embed third-party applications, and generate tools to manipulate simulation data. KeelWit used ACT because it makes the workflow easier, faster and more reproducible. ACT provided a robust, simple and straightforward platform for the development of optimization algorithms to interface with simulation. The MOST-HDS ACT app is proprietary to KeelWit, but KeelWit is considering making it available in the ANSYS App store.

> **"KeelWit leveraged ANSYS ACT to manage trade-offs and reduce pressure drop up to 25 percent across two families of boilers to improve performance."**

THE OPTIMIZATION PROCESS

AMEC Foster Wheeler is a worldwide provider to the infrastructure, manufacturing and process industries with 40,000 employees. The company contracted with KeelWit to improve the design of the inlet duct for a number of new families of HRSGs. KeelWit engineers imported the inlet duct geometries of the previous generation of boilers into ANSYS DesignModeler and parameterized two angles on the top wall, two angles on the lateral wall, two angles on the bottom wall, and the total length of the inlet. Designs with curved walls or intermediate angles were not considered because they would be too expensive to manufacture and assemble. As a starting point, engineers used ANSYS DesignXplorer to create a design of experiments with 120 design points and perform CFD on each to provide an initial approximation of the design space.

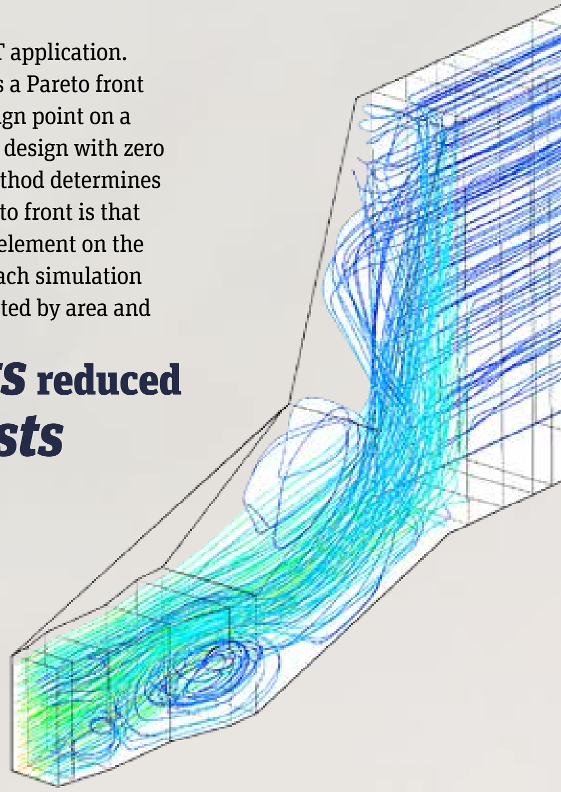


^ Pareto front generated by initial design exploration (blue) and first phase of optimization (orange)

The KeelWit engineers then created the MOST-HDS optimization as an ACT application. The MOST-HDS algorithm reads the results from DesignXplorer and generates a Pareto front diagram that arranges the pressure drop and velocity uniformity of each design point on a two-dimensional graph; the axes of the graph are configured so that an ideal design with zero pressure drop and perfect velocity uniformity is at the origin. This Pareto method determines the outer shell of performance values facing the origin. The value of the Pareto front is that those elements not on the front are never the best choice; there is always an element on the front that is at least as good for every objective. The velocity uniformity for each simulation iteration was calculated as the difference between the average velocity weighted by area and

“The *optimized design points* reduced manufacturing and *assembly costs* by up to 95,000 euros.”

the average velocity weighted by mass flow as the flow leaves the inlet duct and enters the boiler. KeelWit engineers found this method to be one of the most robust approaches to address minor mesh irregularities that can yield misleading results if the minimum and maximum velocity values are used to calculate the velocity nonuniformity.



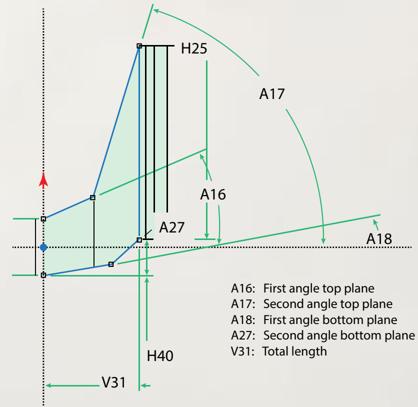
^ Detailed isometric view of velocity magnitude streamlines in inlet duct of HRSG

GENERATING NEW DESIGN POINTS

Next, the optimization algorithm selects pairs of design points to be parents of the next generation of design points. The design parameters in each parent are crossed with the design parameters of the other parent to produce “children,” combining elements of genetic, gradient and swarm search into a hybrid algorithm. The child designs are then simulated automatically through ACT. Some of these designs provide improvements over their parents, advancing the Pareto front toward the origin or optimal design. The procedure is repeated over and over until the Pareto front stops advancing. In this application, the MOST-HDS algorithm produced a number of unconventional design points that were non-intuitive yet provided very high performance.

SUBSTANTIAL PERFORMANCE IMPROVEMENTS

The result of the optimization process was a Pareto front for each of the HRSG families. A Pareto front is superior to a single optimized design point because it allows engineers to trade off pressure drop against velocity nonuniformity based on the requirements for each of the HRSGs in the family. Individual designs in these Pareto fronts improve pressure drop by up to 40 percent and velocity uniformity by up to 15 percent. However, because these improvement values were achieved at different points on the Pareto front, making each of these improvements requires sacrificing other performance values. Optimum trade-off design points with pressure drop reductions of 20 percent to 25 percent and velocity uniformity equal to the existing design were achieved for each family of HRSGs. The total length of the inlet duct and its lateral surface were also calculated for each design point as a proxy for manufacturing and assembly cost. Optimum trade-off design points with lateral surface reductions of up to 38 percent and length reductions of up to 16 percent were achieved for each design family without any sacrifice in performance. The optimized design points reduced manufacturing and assembly costs by up to 95,000 euros.



^ Only some of the variables used to parameterize inlet duct design points

Ever since HRSGs began to be used in power plants, the shape of their inlet ducts has been varied over a relatively narrow design space. KeelWit engineers used an innovative optimization algorithm in an ANSYS ACT application to make major improvements to two families of AMEC Foster Wheeler HRSGs. The result was a substantial improvement in pressure drop along with a manufacturing cost reduction.