Tracking Down Vibrations Fast with **FSI**

With high-speed iterations between mechanical and fluids software, fluid structure interaction quickly pinpointed the cause of damaging vibrations and assessed new designs for offshore oil and gas equipment.

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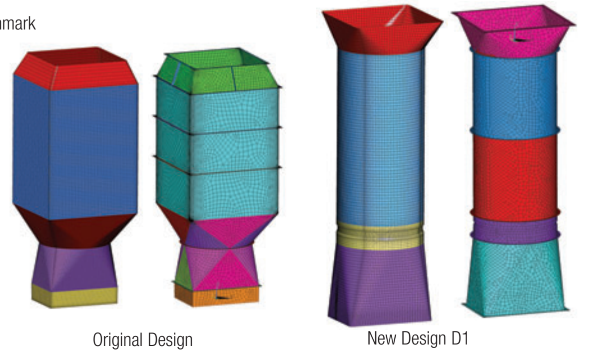
Companies operating offshore oil and gas platforms can lose significant revenue for even a few days of downtime, so they must efficiently study and rectify equipment failures that could shut down any part of the operation. Case in point was the appearance of fatigue cracks and open tears in exhaust stacks for gas turbines, that powered electrical generators and natural gas compressors on a rig in the North Sea. The 10 meter-high welded sheet-metal structures safely direct the flow of 540-degree Celsius exhaust gases, with velocities up to 180 meters per second, up and away from the gas turbine. Field measurements with accelerometers placed on one of the stacks indicated extreme vibration levels at a frequency of approximately 20 Hz, particularly in the lower cone section where most of the cracks occurred.

The operator of the platform, StatoilHydro, engaged the services of engineering consulting firm Lloyd's Register ODS (LR ODS) to study the behavior of the stacks. The purpose of the project was to determine the root cause of vibrations in the existing design and to evaluate vibration levels of proposed new stack designs from two independent suppliers. The existing design was mostly rectangular for the various sections, but both new designs had cylindrical geometries in the mid-section of the stack. One of the new designs, D1, had fairly long plane wall sections.



Engineers performed FSI iterations efficiently within a unified suite of software between models created with the same meshing tool: ANSYS ICEM CFD. Fluid models (left in each group) were constructed with volume elements, while shell elements were used for structural models (right).

Using engineering simulation, LR ODS studied the designs in greater detail than would have been possible through the time-consuming and expensive process of

Anatomy of an Exhaust Stack

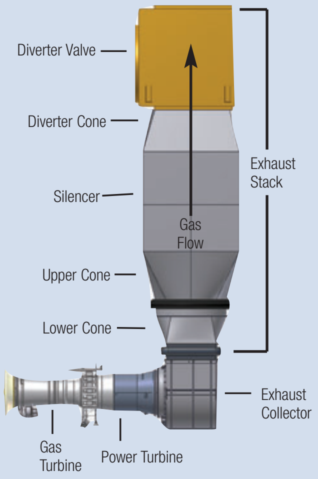


Diagram of exhaust duct

The gas turbine exhaust stack directs hot gases from the gas turbine and power turbine upward to the waste heat recovery unit (WHRU) or the bypass duct (dependent on diverter valve setting). The geometry of the stack is rather complex due to the arrangement of the gas turbine and existing ductwork as well as the need to minimize flow separation of the high-velocity gases.

An exhaust collector with a circular inlet and a rectangular outlet diverts gas flow 90 degrees from the gas turbine axis. In the original design, the collector was followed by a bellow that mechanically decoupled the part from the rest of the stack and allowed for thermal expansion of the duct structure. Next were two transition cones: a lower rectangular-to-circular cone and an upper cone that went back to a rectangular cross section. This double transition was based on historical reasons and not primarily designed for good flow quality. A long rectangular silencer mid-section followed, leading to a smaller-diameter diverter cone connecting the exhaust duct with a valve house. The majority of the fatigue cracks occurred in the lower cone, where FSI simulations were used to study resonant vibrations produced by turbulent flow of exhaust gases in the stack.

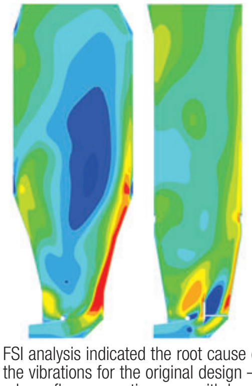
building and testing physical prototypes. First, engineers performed a modal analysis with ANSYS Mechanical software, which calculated relatively low first natural frequencies in the range of 15 Hz to 25 Hz. The mode shapes from this analysis indicated that the maximum vibration amplitude would occur in the lower cone of each structure.

Next, the engineering team performed a fluid structure interaction (FSI) simulation to study the turbulent flow of exhaust gases through the stack and the resulting pressure fluctuations on the sidewalls. By identifying pressure fluctuations from exhaust gas, the team could determine which vibration modes were excited. They could then calculate stress levels experienced by the vibrating structure. For this analysis, LR ODS used ANSYS CFX and ANSYS Mechanical software for fluids and structural computations, respectively.

For this project, the engineering team evaluated different methods for representing turbulent fluid flow, each well suited for particular applications. These included Reynolds averaged Navier–Stokes (RANS), large eddy simulation (LES), detached eddy simulation (DES) and unsteady RANS (URANS), a variant of the efficient RANS method in which flow can vary with time. Given the efficiency of URANS in handling time variations for relatively low-frequency excitations and LR ODS' experience with these various approaches, the company selected the URANS method for the exhaust stack FSI study.

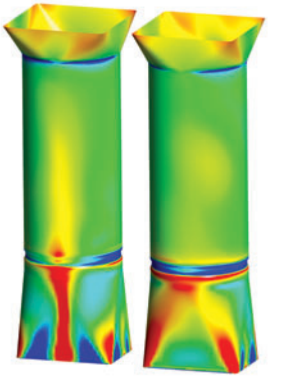
The team performed a two-way iterative FSI coupled-field solution with a one-way limiter using the URANS model for ANSYS CFX calculations of flow pressures. These flow pressures were then fed into ANSYS Mechanical software for calculating the resulting structural stresses as well as sidewall deformations. To meet required solution accuracy, iterations proceeded in one-millisecond time increment steps — small enough to provide sufficient detail.

To simulate one second of stack operation, the software was set to perform 1,000 iterations with a run time of less than 12 hours — extremely fast compared to the six days sometimes needed for an FSI solution using DES models. Such high speed was possible mainly because iterations were completed so efficiently — all performed within a unified suite of software between models created with the same meshing tool: ANSYS ICEM CFD.



FSI analysis indicated the root cause of the vibrations for the original design — a large flow separation zone with low-frequency pressure fluctuations that coincided with very lightly damped duct wall natural frequencies. Simulation demonstrated that the recirculation zone was reduced significantly in the new D1 design.

FSI analysis indicated that the root cause of the vibrations for the original design was a large flow separation zone with pressure fluctuations occurring at the same frequency as the stack wall natural frequency. FSI results showed in a unique way how the large separated vortex structures caused the stack wall to vibrate severely. In these vibrations, cyclical stress levels exceeded material fatigue limits, and deformation amplitudes were greater than 2 millimeters.



ANSYS CFX output from the FSI simulation displays averaged pressure coefficient distribution on the surface of design D1.

FSI stress levels computed by ANSYS Mechanical software for new D1 design at time 1.995 seconds, as seen from two different viewpoints

Simulation demonstrated that the large recirculation zone seen in the original design was significantly reduced. Engineers modified the stack design in cooperation with the manufacturer, Mjørud AS, to increase the first structural natural frequencies beyond the dominant pressure fluctuation frequencies. The modified design also increased the structural damping using the thermal insulation. ANSYS meshing and simulation were instrumental in this design refinement, giving engineers insight into the vibrations and enabling the team to quickly evaluate the impact of various changes.

The manufacturer subsequently built and installed the new stack design on the oil and gas platform for the five gas turbine units. Field tests on one unit showed that the maximum single-frequency vibration amplitude level had been reduced by a factor of 30, and total vibration level was reduced by 80 percent. Since then, the five exhaust stacks have operated reliably for more than two and a half years. In addition to solving this complex FSI problem, the methodology developed by LR ODS has provided Mjørud with an efficient tool to quickly evaluate future stack designs, thus saving significant time and expense compared with troubleshooting problems in the field. ■

References

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Images courtesy StatoilHydro and Mjørud AS.