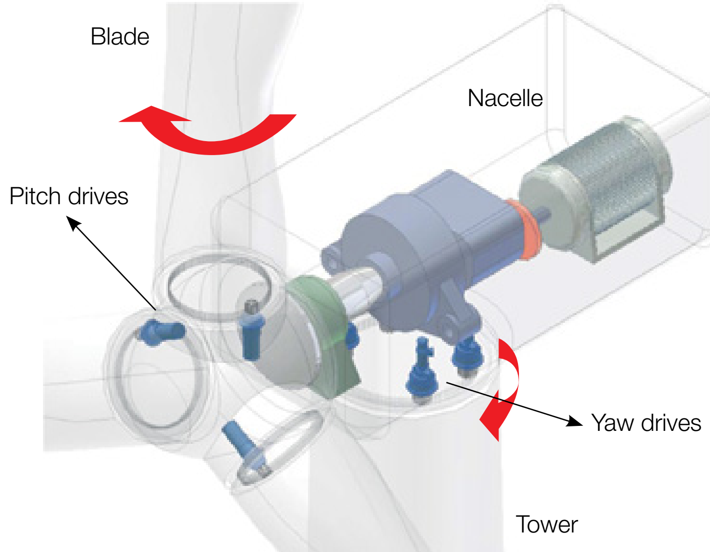
Nabtesco Corporation

Energy, Process and Utilities Case Study

Challenge
Design the most advantageous crowning for pinion gear teeth to minimize stress by increasing contact area and decreasing average contact stress.

Solution
The engineers at Nabtesco used Abaqus finite element analysis (FEA) software to calculate the contact area and stress of various pinion gear designs. With the help of their own subroutine, the engineers were able to model both contact area and stress history for easier design evaluation. Isight was also utilized for post-processing automation and design optimization.

Benefits
Abaqus allowed the Nabtesco engineers to maximize gear contact area, while minimizing average stress contact. This resulted in a significantly more durable gear design that led to decreased maintenance and cost without requiring numerous physical experiments. With Isight, the design time was reduced drastically.



Location of yaw and pitch drives on wind turbine.

Wind turbines have become an iconic symbol of alternative energy with their tall, upright towers and graceful, spinning blades. Choosing a proper site for the towers is certainly the starting point for maximizing the output of a large wind farm. But for the most efficient conversion of the kinetic energy of wind into mechanical energy, or 'wind power,' additional control over the position of each turbine's nacelle and blades is essential. This is the task of the yaw and pitch drives, which adjust the physical orientation of those components in response to fluctuations in the velocity and direction of prevailing breezes.

Located at the base of the nacelle, a yaw drive changes the direction which the nacelle faces. Where each blade meets the nacelle, a pitch drive changes the angle of the blades. Working in tandem, these computer-driven gear mechanisms automatically optimize the orientation of the turbine relative to the wind so power can be generated in the most efficient manner possible.

Gearing up for large wind turbines
Precision yaw and pitch drives for robotic reduction gears are a specialty of Nabtesco Corporation of Japan, known worldwide for unique technology that allows those components to be smaller and lighter than many conventional robotic drives. But when the company expanded into energy harvesting equipment, such as wind turbines and solar energy collector trackers, they realized that 'smaller and lighter' have their limits in large industrial structures. "Particularly in the wind industry, our biggest challenges are ensuring sufficient gear strength and long-term endurance in gusty conditions," says Kazuhiko Yokoji, CAE manager, CAE & material department, whose team provides computer-aided engineering (CAE) services for the entire Nabtesco group. "Our reduction gears are made up of a lot of very complicated assemblies, with many parts that come in contact with one another. For each wind turbine configuration, we have to provide our customers with the best possible design that minimizes overall stress while maintaining durability."

Every yaw and pitch drive in a wind turbine engages with a pinion gear, made from specialized treated steel, that transmits power from the drive to the nacelle or blade. In a huge wind turbine, the rotation angle between drive and pinion gear teeth is particularly small, so repeated contact over time—particularly under the 'routine' stresses of high winds and tower vibration—has the potential to damage tooth surfaces and cause assembly breakdowns.

Balancing contact for best performance
To minimize such hazards, the engineers strive to balance the contact between ring and pinion teeth so that the 'normal' stress of rotation and the sheer stress of the teeth against each other are reduced. Decreasing the stress on teeth improves their durability—and that of the entire assembly as well.

Since the thinner, outer edges of a tooth are most susceptible to damage, teeth are manufactured with a curved surface ("crowning") so that the edge dips away to either side of the center of the tooth and the contact between teeth occurs somewhere in the middle. Too steep crowning decreases the contact area too much, intensifying tooth stress. Too shallow crowning allows stress to extend too close to tooth edges. Damaging edge contact can also increase if the pitch drive shaft bends. "Since crowning has such a significant effect on contact area and maximum stress, pinion tooth shape is a major focus in our design process," says Yokoji.

Finding that optimum tooth shape is a time-consuming challenge when done manually. The contact area between drive and pinion teeth can be visually identified in a test rig by coating the teeth with a special paint that rubs off where they engage. "But using this method means a lot of pinions have to be manufactured and tested in order to identify which shape is the most desirable," says Yokoji. "And this method doesn't give us the overall stress data that helps us evaluate durability. We felt we could get a more complete picture using an analytical model that could simultaneously analyze tooth contact area and maximum stress."

SIMULIA solutions speed up analysis

Yokoji's team uses Abaqus unified finite element analysis (FEA) to solve a number of wind turbine-related design challenges. "Abaqus' capabilities for reproducing motion, and also investigating fluid-structure interaction (wind is modeled as a fluid) are particularly important to Nabtesco," says Yokoji.

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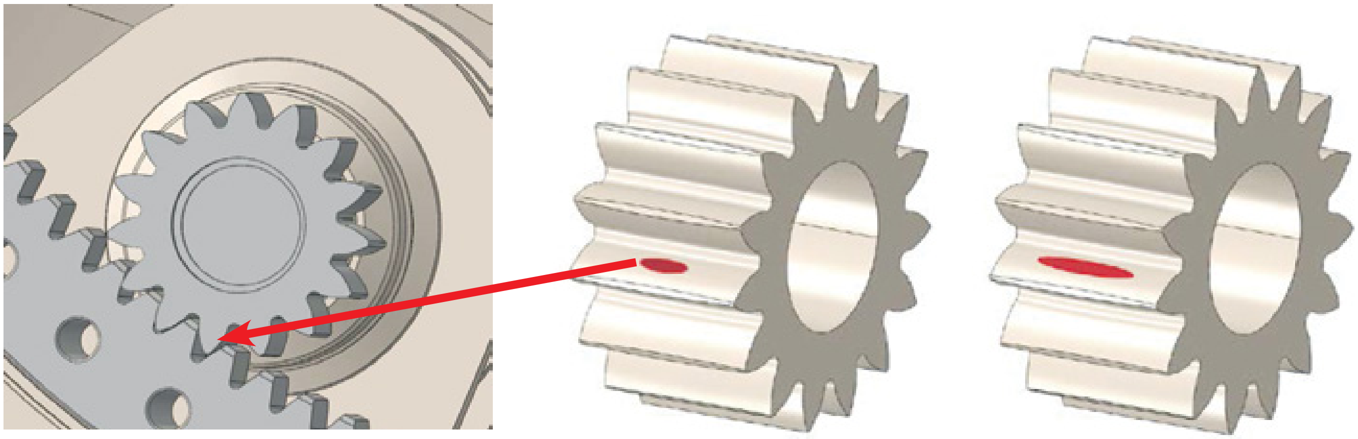
>
> **Kazuhiko Yokoji, CAE Manager, Nabtesco Corporation**

To create an analytical simulation of the pinion test rig, the engineers started from a global Abaqus/CAE model based on imported CAD geometries of rig, drive, and pinion. The bottom surface of the test apparatus was modeled as fixed. Resistance (this data, including the effect of wind velocity, was provided by a Nabtesco customer) was applied to the reduction gear shaft, and the pinion was rotated at a prescribed angle. This allowed the team to see when and where the opposing teeth engaged as the gears rotated, and what the resulting stresses were.

For a deeper understanding of what happens when the teeth interact, the engineers needed to mesh the relatively small area of tooth-face contact with particularly fine C3D8R elements. To reduce

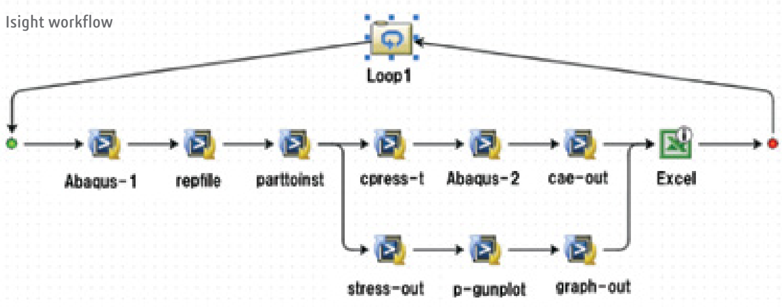


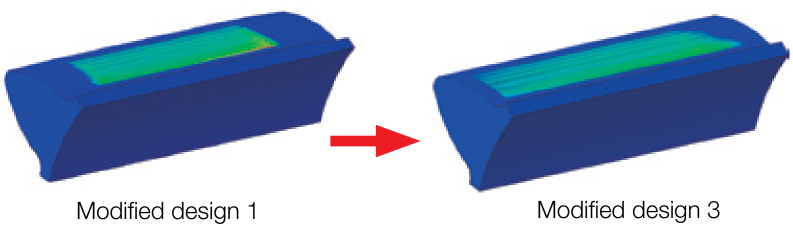
(Left) Smaller pinion gear engages with outer ring gear. Note that rotation angle where teeth intersect is very small; this can contribute to gear tooth damage over time.
A small contact area (red, center) between teeth can be optimized with CAE analysis (red, right) to decrease average stress and prolong gear life.

computation time for this portion of the model, they created a submodel that contained only those areas of acute interest. When compared against the painted gear rig tests, the FEA results showed good agreement.

"We still wanted to get a complete picture of how the total contact area and stresses fluctuated over the course of the entire engagement processes," says Yokoji. "This would provide us with the 'big picture' of contact history that we needed for evaluating tooth designs for durability." So his team developed a proprietary post-processing technique that employed an Abaqus user subroutine to show the history of how stress developed from the start of engagement, through changes in the rotation angle, to the end of engagement. Now they had a complete toolset to start fine-tuning individual pinion tooth shape.

Isight workflow





Optimizing gears with Isight resulted in a design that lowered contact stress across the entire surface.

Optimizing the analysis with Isight

At this point the group turned to Isight process automation and optimization software, coupling their own in-house program for creating contact stress distribution history into the workflow. This allowed them to quickly generate clear results from huge result files and evaluate both the immediate (stress) and the long-term (strength/durability) consequences of every design change. They then plotted the results into three-dimensional stress distribution graphs that tracked all phases of gear engagement and let them see how modifying gear crowning contours affected overall performance.

"Our CAE workflow now enables us to optimize crowning of pinion gear teeth designs accurately and with far less manpower than before," says Yokoji. "This method reduces design times dramatically."

Nabtesco's newly designed gears are just being introduced into the field and the company is gathering data to generate accurate comparisons with previous models. "We believe that there will be a significant improvement in durability," says Yokoji. "Abaqus and Isight give us confidence that we can design durable gears that can stand up to the rigors of wind power generation."

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