

Turbocharger Housing Design Based on Impact Resistance Predictions

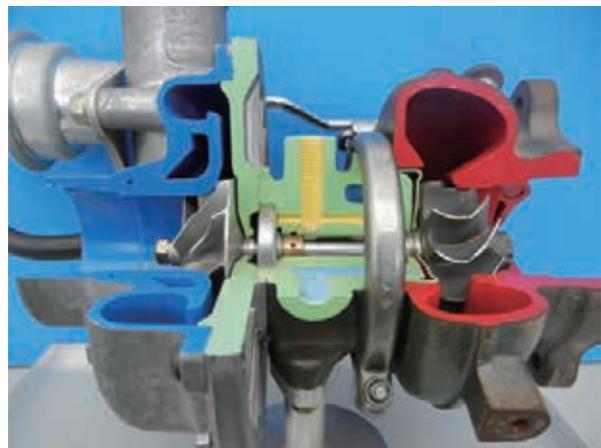
High-speed fracture phenomenon prediction technique enabling safety evaluations to be conducted in advance

We have developed an analysis technique to predict the high-speed housing fracture phenomenon for turbochargers. Imagining severe situations that would normally never occur enabled us to design products with greater safety.

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Turbocharger for automobiles



Automobile turbocharger cutaway view

Demand for turbochargers growing around the world

Against the backdrop of the world-wide promotion of countermeasures against global warming, regulations on the fuel economy of automobiles are also becoming stricter, and automotive manufacturers are engaging in a fuel economy technology development race. In Japan, hybrid vehicles, i.e., automobiles powered by both an internal combustion engine and an electric motor, have become popular. In Europe, on the other hand, engine downsizing using a turbocharger has maintained a certain status as a fuel-saving technology.

A turbocharger is a machine that rotates a turbine using engine exhaust gas while compressing air using a coaxial compressor and delivers the air to the engine. By fitting an engine with a turbocharger, the engine's effective displacement can be increased to achieve a horsepower comparable to that of a larger natural aspiration engine.

As it is an inexpensive and simple solution, this method of improving fuel economy is used for many different types of automobiles, ranging from kei cars (i.e., mini motor vehicles) to heavy-duty trucks, and so the demand for turbochargers is expected to continue growing on a global scale.

Turbocharger design taking contingencies into account

The turbine and the compressor impeller are the most important parts of a turbocharger. As the basic performance of a turbocharger is dependent on these two parts, they are designed making full use of fluid flow analysis techniques. At the same time, the housing enclosing the impeller has scroll flow channels in it to appropriately guide exhaust gas and air, so the housing is also an important part that determines the performance of the turbocharger. Moreover, the housing has another hidden mission.

Generally, a turbocharger impeller rotates at a high speed. For example, maximum rotational speed of a turbocharger for small passenger cars exceeds 200 000 rpm. If this turbocharger breaks (bursts) for any reason, fragments from the circumference of the impeller would fly off at over 500 m/s. Should the fragments penetrate through the engine or vehicle, this failure might lead to a fatal accident. Even in such an unforeseeable situation, the housing must withstand impacts from internal parts and prevent outward penetration, which is the other important role of the housing.

It is relatively easy to design a housing focusing only on impact resistance. Simply making a hefty structure made of a high-strength material would be sufficient for the housing to be resistant to impacts. However, this approach involves an increase in the housing's mass, as well as an increase in the turbocharger's overall size, decreasing its mountability onto the engine. Of course, any design must take into account the balance among safety, mass, size, and performance. To date, we have dealt with this issue by selecting materials and designing configurations based on the knowledge and experience we have cultivated over many years.

Recently, however, operating conditions and mountability requirements have been getting more demanding, and the need has arisen for housing design based on more

quantitative predictions of phenomena.

Development of an analysis technique to predict a high-speed fracture phenomenon

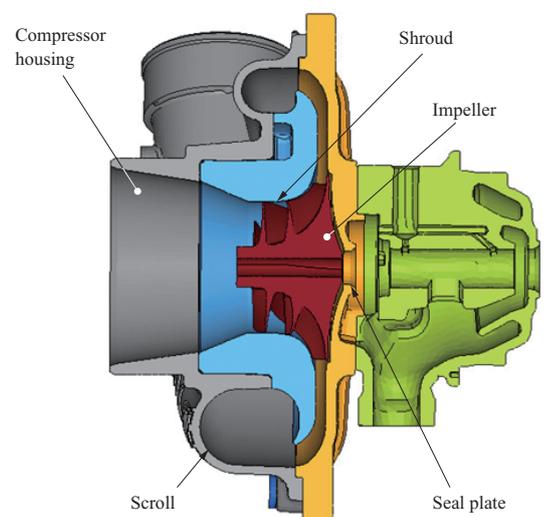
Leveraging numerical analysis techniques, IHI has developed a technique to predict high-speed housing fracture phenomena. Predictions of these phenomena require predictions of the following behaviors ① the behavior of the fragments of the broken impeller flying off into the housing, ② the behaviors of the impeller and housing during their deformation under the impact force resulting from their collision, and ③ the behavior of a crack occurring and developing in the housing. It is a complex phenomenon, which involves multiple phenomena simultaneously and instantaneously. By applying a state-of-the-art analysis technique, we have achieved a prediction of the phenomenon at such a high level that it can be applied in hardware design.

The greatest challenge in the development of this technique was to predict crack occurrence and its development. General structural analysis generates meshes on the target 3D model and calculates the balance of stress among mesh groups based on boundary conditions, thereby calculating displacement and strain. Moreover, we predicted crack occurrence and propagation by removing meshes whose stress reached criteria (e.g., rupture stress). However, this technique provides an accurate result in case of simple shape on simple stress field. We therefore needed to determine appropriate conditions (physical quantities and values) in order for the technique to accommodate actual stress fields, i.e., three-dimensional complicated stress fields.

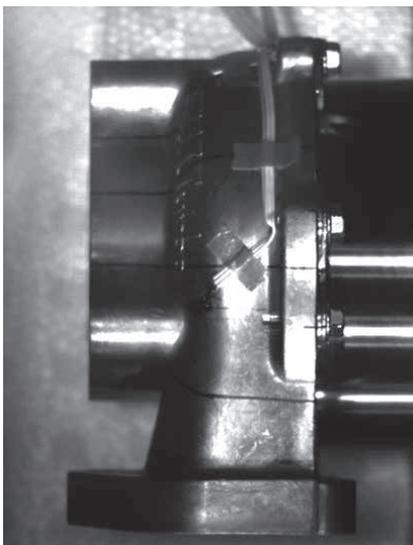
Then, we conducted crash tests using actual housings to determine crack occurrence conditions. Of those crash tests, this paper introduces the one conducted on the compressor housing. The test used gelatin spheres to simulate the shock from the impeller. Gelatin balls were shot so that they hit the housing along the direction of a turbine shaft, which was



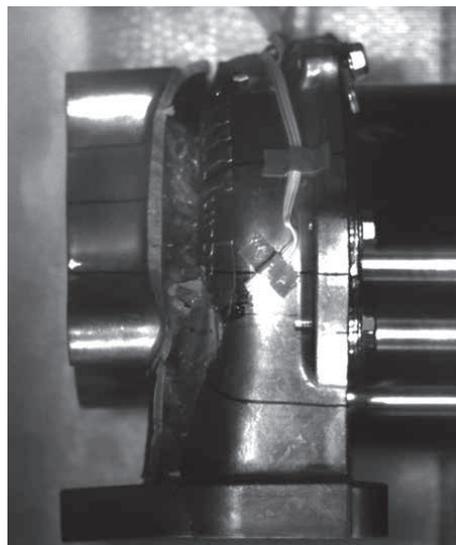
Compressor housing that fractured in the impeller burst test



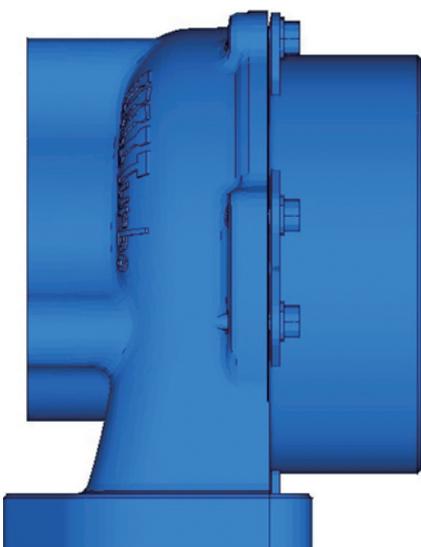
Impeller burst analysis model profile



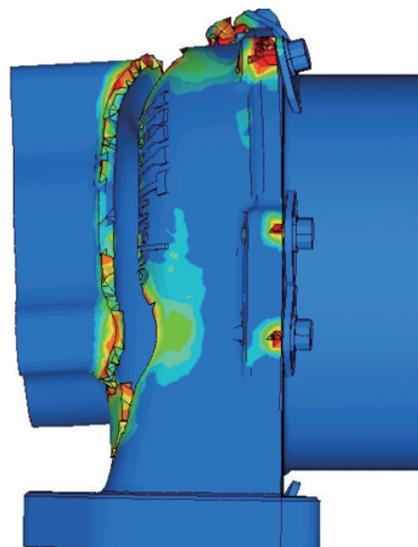
Compressor housing before the crash test



Compressor housing after the crash test



Simulation result of the compressor housing crash
(before bursting)



Simulation result of the compressor housing crash
(after bursting)

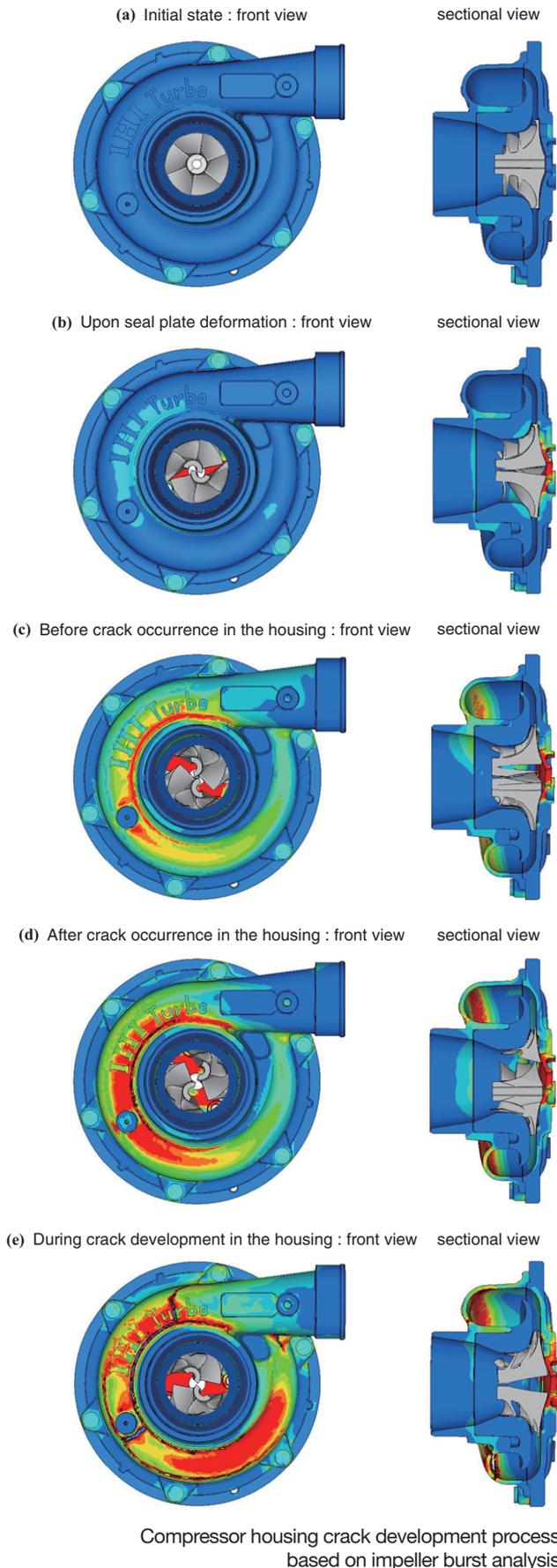
fastened to the stand. We used gelatin spheres because the collision speed could be controlled, and to simplify the calculation of the load time history and the amount of energy transmission.

We then created an analytical model that mimics the crash test and analyzed the fracture behavior of the compressor housing. We adjusted the crack occurrence conditions (physical quantities and values) so that obtained simulation results would be comparable to the crack occurrence conditions (e.g., location, length) during the crash test, then we identified the conditions capable of accurately reproducing the test results.

Housing design based on impact resistance predictions

We analyzed the impeller's burst behavior in the compressor housing using the crack occurrence conditions derived from the crash test. An example of the analysis results is shown here. The analytical model included the impeller, assuming that the impeller would break in half. The following figures indicate multiple levels of magnitude of deformation with different colors.

It was found that slight deformation had already occurred on the internal circumference side of the scroll before the impeller burst, which is attributable to the fact that the simulation took slight deformations that occur during the assembly of the housing into account as well. It can be



understood that upon the impeller bursting, the impeller first collided against part located on the back side called a seal plate and extremely deformed it. Then, fragments of the impeller flew out radially and squeezed themselves into the parallel channel formed by two opposing members, that is, the shroud (the part enclosing the impeller) and the seal plate, causing the seal plate to deform even more. This impact propagated through the compressor housing fixation to the seal plate, causing the surface of the scroll wall with the minimum thickness (the left-hand side of the scroll in the profile) to become extremely deformed and then crack. Once the crack occurred, the impact was propagated to the circumferential area, which was also extremely deformed, resulting in the crack becoming larger. In addition, it was predicted that a crack would occur in the area around the boss as well, where the scroll's wall thickness varies so widely that strain easily occurs.

We have confirmed that this analysis is capable of providing trends that are qualitatively comparable to those in the actual impeller burst crash test, so we are now able to design a shape with a high level of safety taking impact resistance into account.

Future development

From now on, we will use this newly developed analysis technique to design housings while maintaining the balance between mountability and safety, and we will also promote the use of the analysis technique for different types of housings, including bearing and turbine housings. In addition, we will pursue new structures that are smaller in weight and size, but that ensure sufficient strength, by combining the analysis technique with our shape optimization technique. Moreover, we will improve the prediction method to make it possible to take into consideration the non-uniformity of material strength that occurs in the housing manufacturing process.

Even though impact resistance is only an issue in circumstances that should not occur in the first place, by taking the hidden characteristics of the housing into consideration, we can meet our customers' expectations for safety and security.

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