Development of Compressors and Steam Turbines for LNG Plants

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Mitsubishi Heavy Industries Compressor Corporation (MCO) has until now mostly worked in the field of petroleum chemistry such as ethylene plant. We are now aggressively expanding our business into resources and energy market, such as the LNG plant and Floating Production, Storage and Offloading (FPSO), and have completed the technical development of compressors for LNG plants and injection compressors for FPSO. At the world's first Floating LNG plant, our steam turbines are being used for the compressor and generator drive. We have studied the technological subjects to apply our steam turbines for them, and in this report we would like to explain their development.

1. Introduction

Mitsubishi Heavy Industries Compressor Corporation (MCO) has until now mostly worked in the field of petroleum chemistry such as ethylene plant. We are now aggressively expanding our business into resources and energy market, such as the LNG plant brought about by the shale gas revolution and Floating Production, Storage and Offloading (FPSO), based on the technologies we have cultivated in the field of petroleum chemistry. For resources and energy plant, high reliable machines are required. To meet this requirement, MCO developed some technologies, and applied to our machine.

In this report we would like to introduce developed technologies for our compressors and steam turbines.

2. Developed Technologies

2.1 Refrigeration compressor for LNG liquefying process at LNG plant in Indonesia

It is very difficult to predict the performance of refrigeration compressors used in the LNG liquefying process, especially propane refrigeration compressors, as they have a structure that combines the compression gas flow and the process gas in the compressor, as well as a high impeller inlet Mach number.

We have currently received a procurement order for a refrigeration compressor for the LNG liquefying process at an Indonesian LNG plant, and are now proceeding with the production. A performance test was conducted at the factory as shown in **Figure 1**. The measured performance values show good conformance with the calculated performance as shown in **Figure 2**. The planned performance was verified as having been achieved.

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Figure 1 Performance test in propane refrigeration compressor

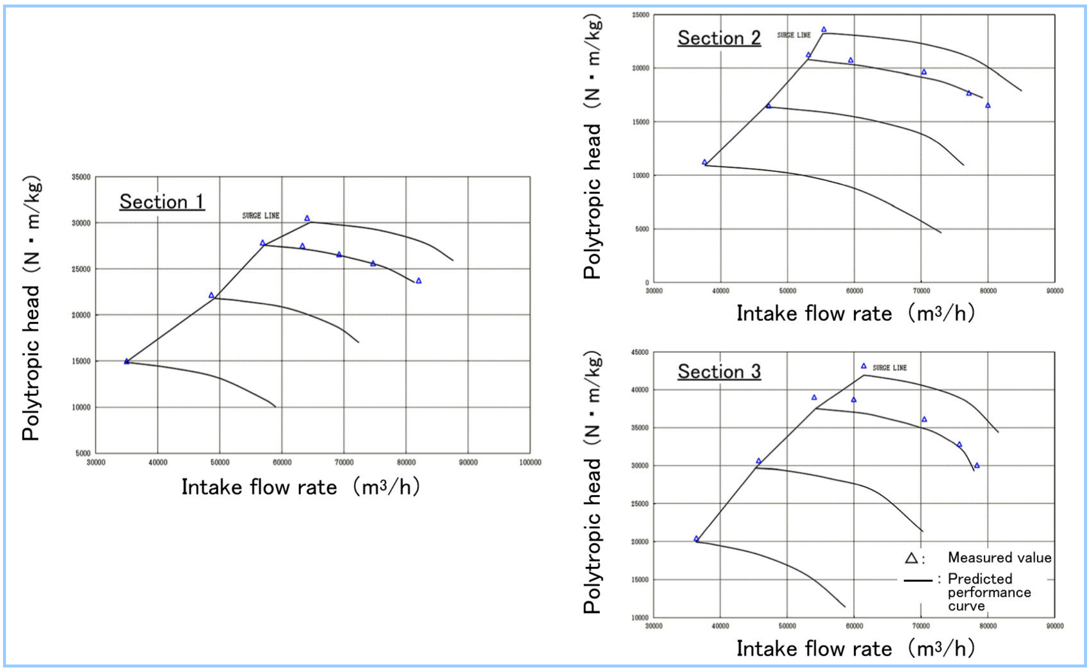

Figure 2 Performance test results of propane refrigeration compressor

2.2 One piece impeller

In a conventional refrigeration compressor for the LNG liquefying process, the impellers are made by welding the blades to a disc and cover. Currently the one-piece impeller (**Figure 3**) is the mainstream in this industry, and it eliminates the welding structure for better quality, a reduction of performance deviation and better mechanical reliability.

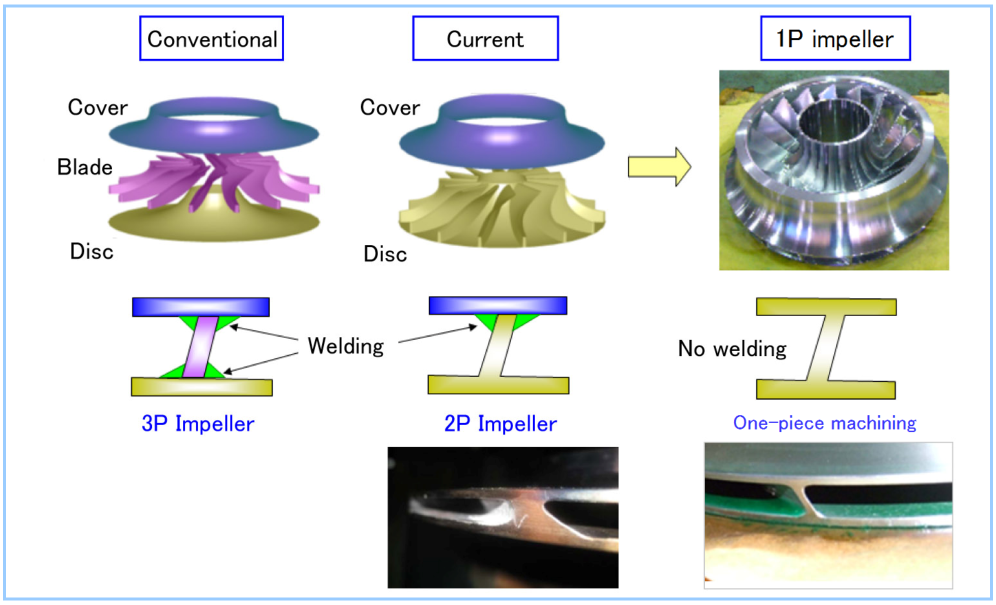

Figure 3 Transition of impeller structure

In addition, the large flow type impeller processed with a 5 axis machine (**Figure 4**), and the very narrow outlet impeller of a small flow type processed with an electric-discharge machining (EDM) (**Figure 5**) have already started to prevail in the actual market.

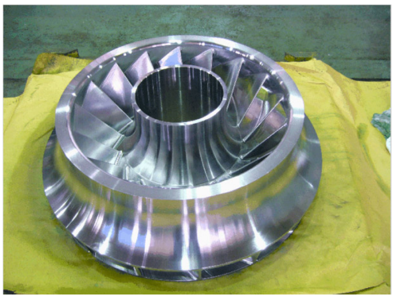

Figure 4　Machined one-piece impeller

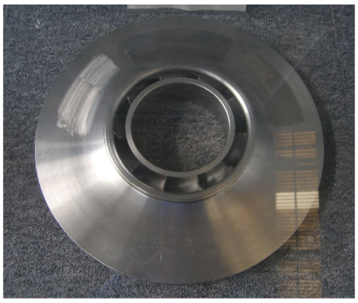

Figure 5　Electro-discharge machined one-piece impeller

2.3　Small diffuser diameter flow path

The smaller the diffuser diameter in the flow path, the more compact the compressor design can be. This allows reducing the product weight. However, the reduction of diffuser diameter (**Figure 6**) results in an increase of the Mach number at the diffuser outlet, and a decrease of efficiency through an increase of the loss head. The lowering of efficiency was recovered by optimizing the return bend shape connected to the gas return path as shown in **Figure 7**, and a compact design was achieved while maintaining the current level of efficiency.

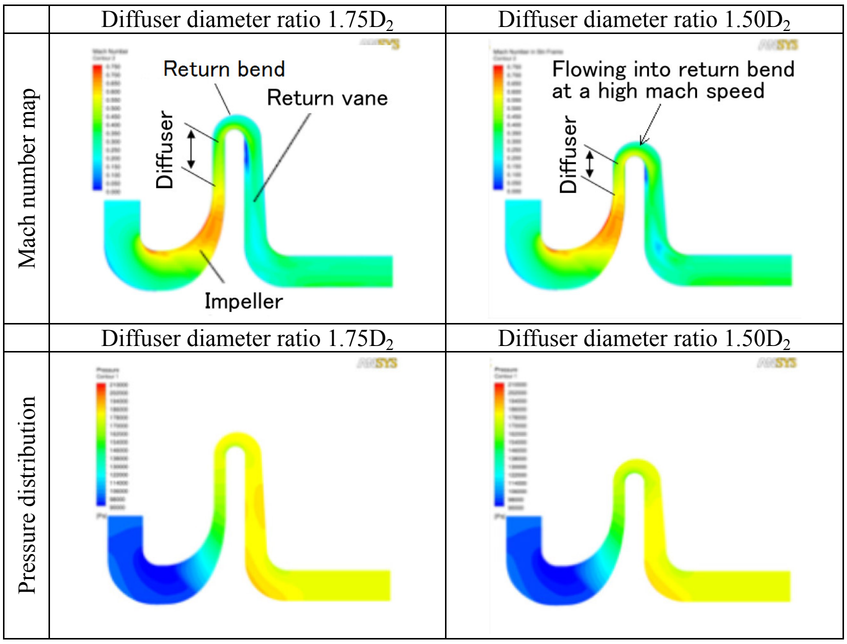

Figure 6　CFD analysis results of diffuser diameter effect

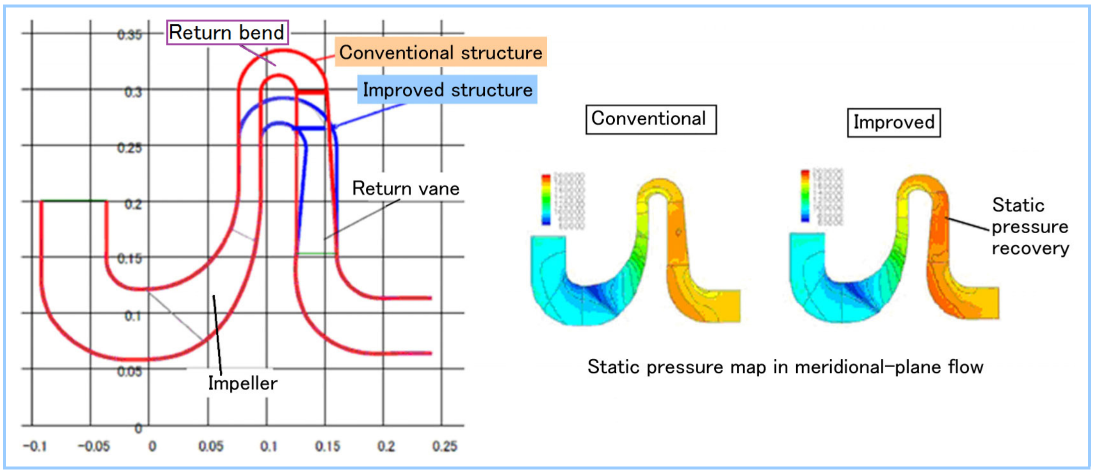

Figure 7　Improved return bend shape for small diameter diffuser

2.4 Large-size bundle roller

In a vertical split type (barrel type) compressor, the inner parts (bundle) are assembled in the axial direction, and the bundle must be pulled out in the axial direction on the occasion of maintenance. This becomes difficult when the compressor is larger, as the bundle is very heavy. Especially in the case of FPSO, the maintenance work is more difficult on the ocean with pitching and rolling.

Rollers were installed at the lower part of the bundle to ease maintenance of the inner parts and reduce the required crane capacity in the field. However, the roller was subject to a heavy load, and roller breakage and damage to the inside of the casing was a concern. FEM analysis (**Figure 8**) was conducted, and a roller shape design method that included aspects such as a proper crowning value was established. In addition, a factory test using an actual piece of equipment was conducted as shown in **Figure 9**, and the validity of the bundle pull-out procedure and roller design were verified.

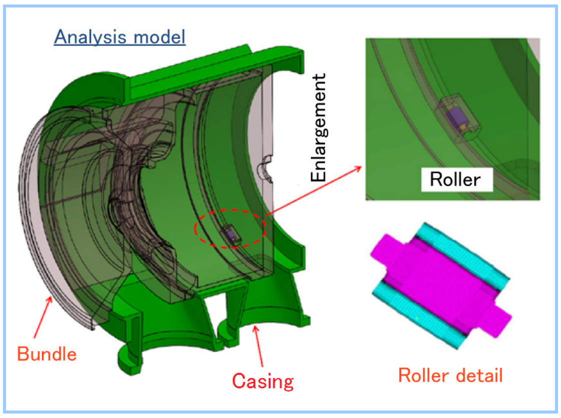

Figure 8 FEM analysis model of roller in bundle

Figure 9 Bundle pull-out test in plant

2.5 Short span / high boss ratio impeller

In the design of compressors to be used at off-shore such as in FLNG plants, a method of minimizing the weight and installation area is important. An impeller with a short axial-direction span and increased impeller boss ratio (inside/outside diameter ratio) allows for a shorter shaft bearing distance, larger shaft diameter, increased shaft system rigidity and high-speed operation (**Figure 10**). With high-speed operation, a reduction of compression stages and a smaller diameter can be attained, making a compact and high-performance compressor design possible.

However, short span/high boss ratio impellers tend to cause secondary flow and flow separation, resulting in efficiency degradation and a restricted compressor operation range in flow.

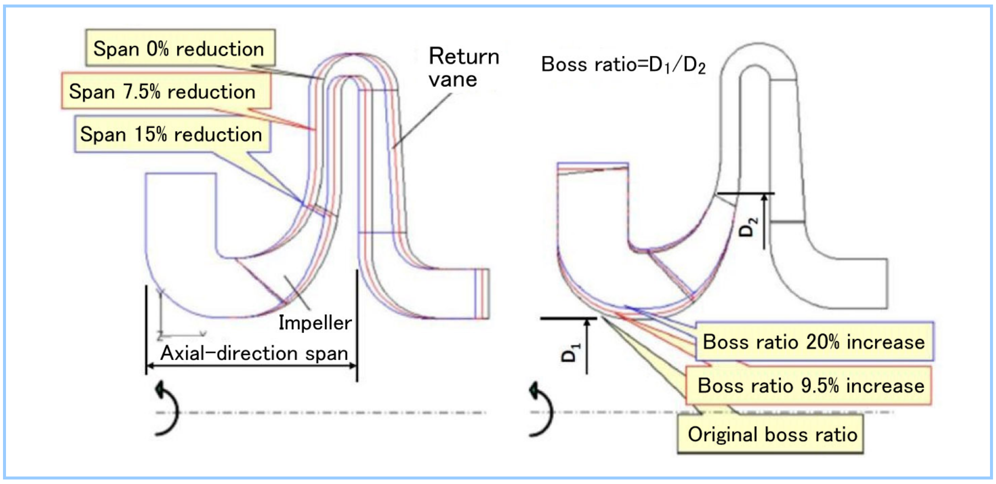

Figure 10 Planning of short span / high boss ratio impeller

As countermeasures, the number of impeller blades was reduced as indicated in **Figure 11**, the frictional loss was reduced and the blade load distribution was optimized to reduce the rapid speed-lowering area and efficiency degradation.

The development of a short span/high boss ratio impeller with a favorable performance compared with conventional units was achieved through these efforts.

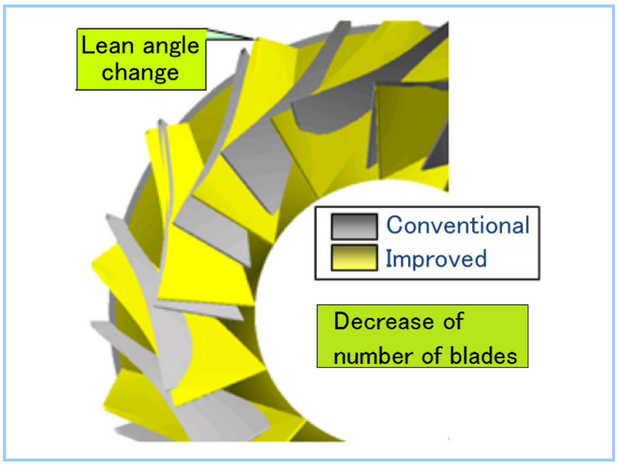

Figure 11 Improved efficiency by reducing impeller blade number

2.6 On-line cleaning of steam turbines

Steam turbines used to drive compressors are usually operated for long periods. In an LNG plant, the maintenance interval is extended as long as possible, and the availability of long-term continuous operation is important for plant management. This tendency is especially noteworthy for FLNG.

The steam that drives the turbine contains impurities from the boiler water, supplied water and purified water. When the steam property is insufficient, the flow path is restricted by the adhesion of scale on the nozzle and blade as shown in **Figure 12**. The steam flow rate is lowered, and the power output is reduced when the casing pressure rises over the allowable pressure due to the fouling. As a result, plant production levels are adversely affected.

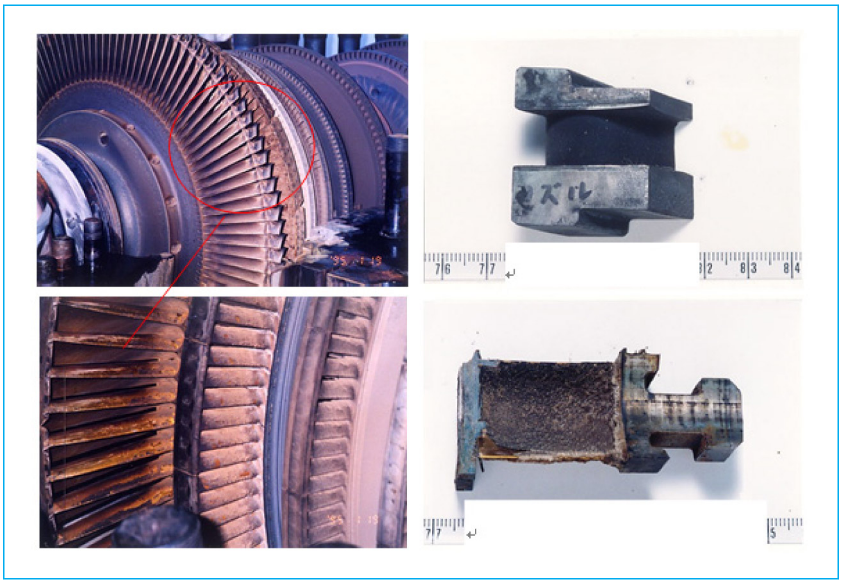

Figure 12 Inside of turbine after 7 years of continuous operation

The methods of removing scale from a steam turbine after a long period of operation are categorized into two big groups; mechanical removal and cleaning. The liquid cleaning method does not require that the turbine casing will be disassembled, while mechanical removal does. However the turbine must be stopped or the steam inlet temperature at the high-pressure stage must be lowered, and the total power output of the turbine must be lowered drastically for the cleaning. In addition, the power outputs of other steam turbines sharing steam with the cleaning turbine are also lowered. This results in a significant effect on plant operations and production levels.

Accordingly, water injection nozzles were installed on the governing/extraction control valve boxes as shown in **Figure 13**, and the steam temperature is only lowered in the turbine being cleaned. Thus an on-line cleaning system for steam turbines that cleans adhered impurities and prevents performance from being degraded was developed.

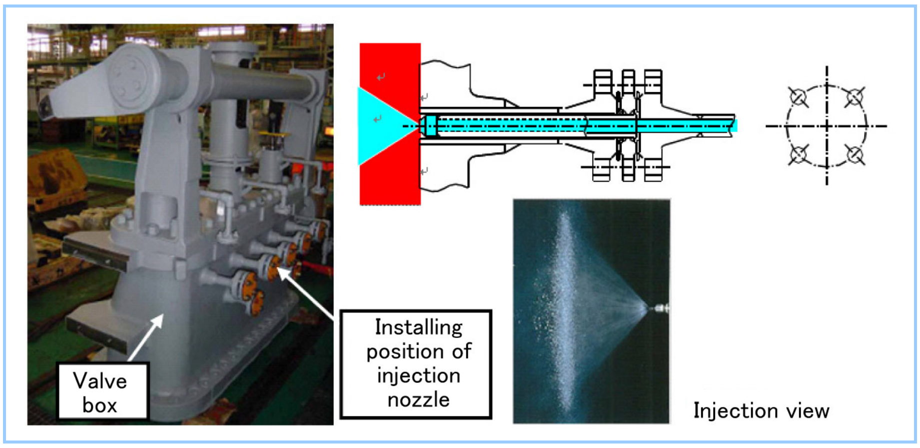

Figure 13 On-line cleaning system for steam turbine

One water injection nozzle and valve/valve diffuser was used for the verification measurement by adjusting the flow speed to the actual piece of equipment. For the internal flow of an actual extraction control valve box, a detailed flow analysis was conducted as shown in **Figure 14**. The flow in each valve was almost independent, and the test results of a single diffuser were verified to be similarly applicable to multiple valves.

The system was applied to an actual piece of equipment as shown in **Figure 15**, and the validity of this system was verified in the field verification test.

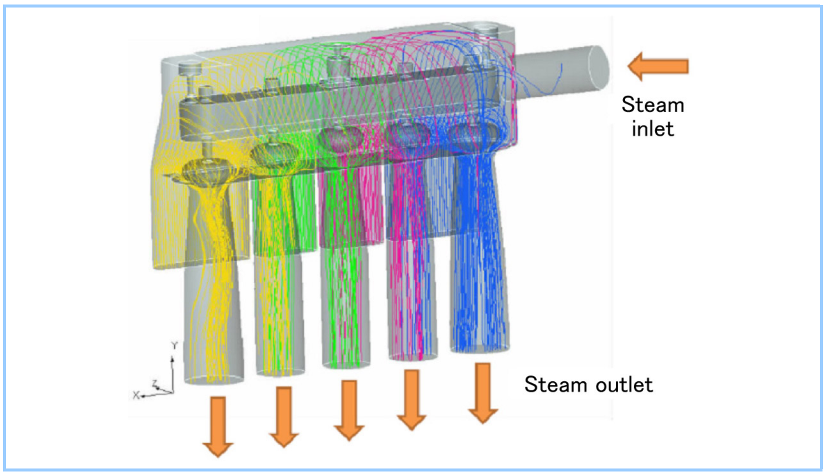

Figure 14 Flow analysis results of steam flow line map in valve box

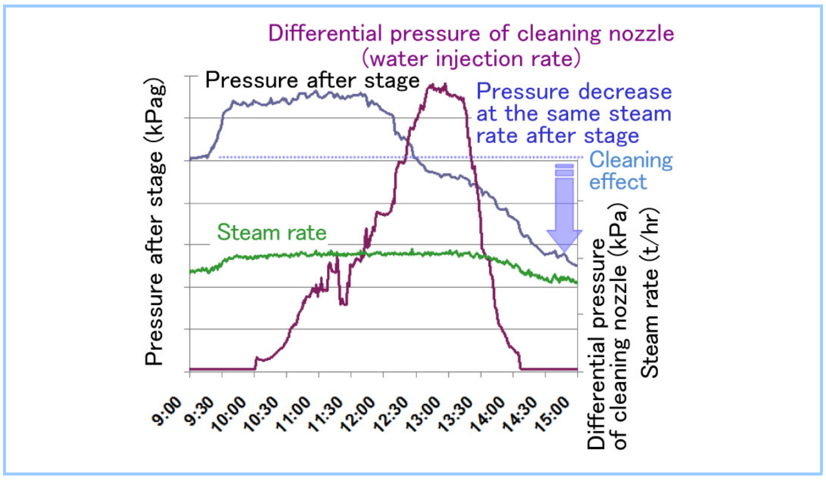

Figure 15 Results of field verification test of on-line cleaning system

2.7 Coating for steam turbines

As described above, long periods of continuous operation are required of steam turbines, and various coatings were developed as countermeasures for blade erosion.

Figure 16 shows first stage stationary blades being treated by boronizing. This treatment disperses boron on the metal surface and hardens it by forming a strong metallic boron layer. The layer prevents erosion caused by foreign substances coming from the boiler and piping, which are upstream of the turbine.

Figure 17 shows a ceramic coated blade treated by the ion-plating method. This forms a ceramic (TiN) layer to increase durability against drain attack, as well as a chrome (Cr) layer to ensure the adhesiveness between the TiN layer and the base material. The treatment is applied to the low-pressure block blade except for the final stage, where the steam humidity is rather low.

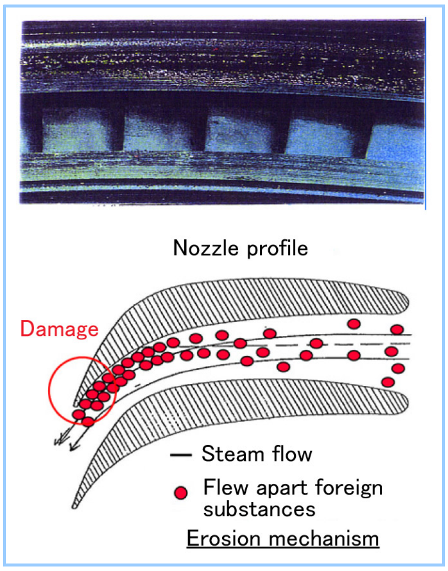

Figure16 Boronized first stage blades

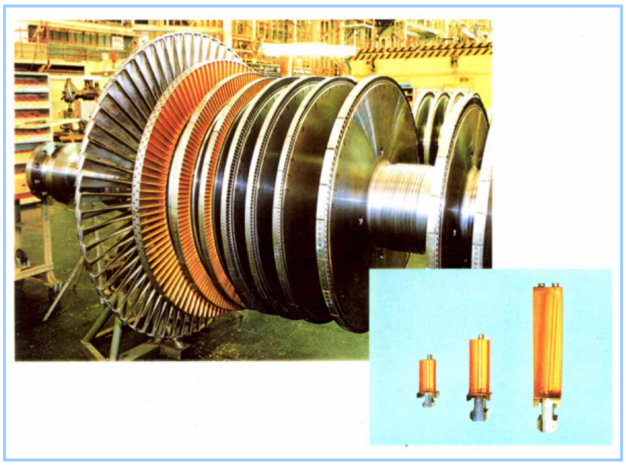

Figure 17 Ceramic coated blade

Figure 18 shows the stellite coating applied to the blade tip in the final stage. This protects the blade tip, for which the circumferential speed is the fastest, from erosion caused by impingement with water droplets in saturated steam flying in a radial direction through centrifugal force. A stellite plate was brazed to the base metal as shown in the Figure on the right in the conventional way. However the cavity between the base metal and stellite plate lowers the fatigue limit of the base metal. The stellite powder-weld overlay is attached by Plasma Transfer Arc (PTA) welding, and the finishing of the area is applied.

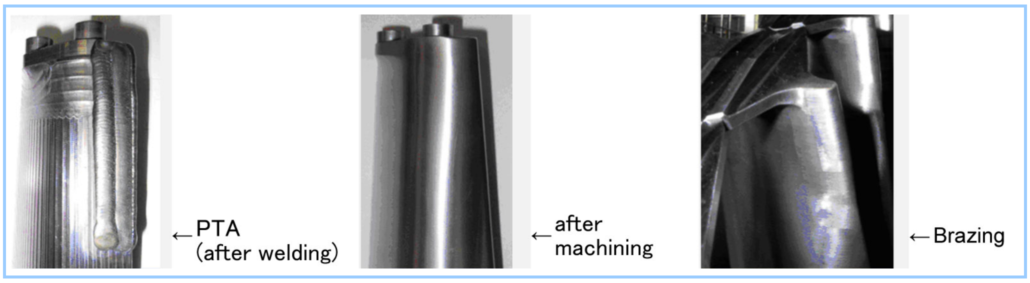

Figure 18 Stellite coating on final stage blades

2.8 Steam turbine blade fracture analysis

Steam turbines are used to drive compressors and generators in FLNG plants. One of the technological subjects is the verification of the design to avoid the dangerous operation of a plant when its operating speed exceeds the over-speed trip setting. In terms of the behavior (transient impingement mode) of final stage blade scattering, the blade scattering condition as shown in **Figure 19** was studied as a risk factor. A multi-body dynamics analysis was conducted to understand the impingement condition between the flow-guide and casing, and lower pressure casing penetration was verified as not occurring.

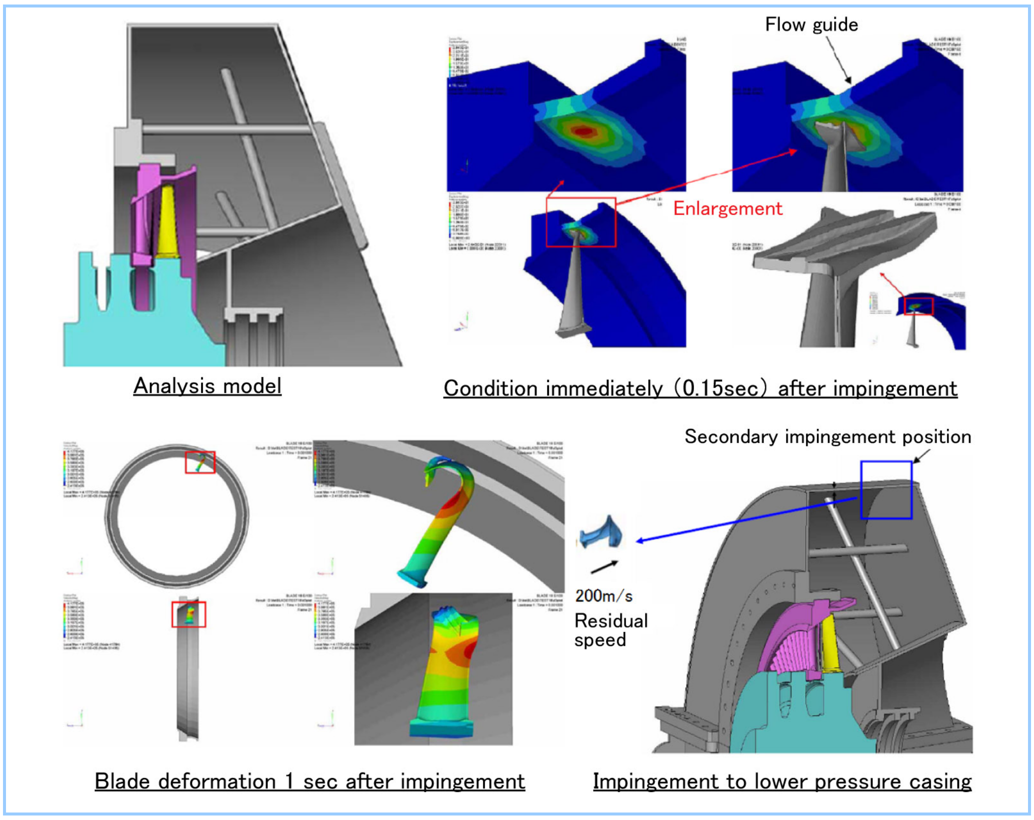

Figure 19 Behavior of final stage blade scattering

6. Conclusion

MCO has developed technologies related to compressors for LNG plants and driving steam turbines initially aimed at FLNG plants, conducting the application of these technologies to actual equipment. We also expect these technologies to be applicable to other resource and energy fields such as compressor trains for FPSO, and effective for the expansion of our business.