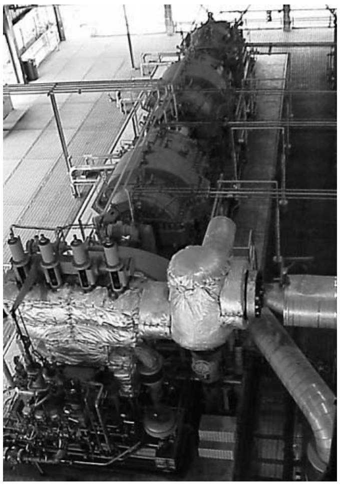

# Mitsubishi Centrifugal Compressors and Steam Turbines for Mega Ethylene Plants

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*Compressors for ethylene plants are the leading machines of the Turbomachinery & General Machinery Department of Mitsubishi Heavy Industries, Ltd. (MHI). In recent years, the size of ethylene plants has been increasing and, following this trend, the size of compressors and steam turbines has increased proportionally. This report introduces some examples of the application of highly efficient large-sized centrifugal compressors and steam turbines that have been installed in ethylene plants, and the technologies applied to increase the efficiencies and reliabilities of these large-sized machines. A proposal is then presented regarding a train configuration of very large-sized centrifugal compressors and steam turbines.*

## 1. Introduction

In recent years, ethylene producers have been increasing the size of their plants in order to reduce the costs associated with them. As a result, the size of such plants has tended to increase rapidly from one million tons/year class (which has been the maximum size of ethylene plants until now) to 1.5 million tons/year and even as high as two million tons/year class. With this increase in size, there has been an ever-greater demand for an increase in efficiency of the compressors and steam turbines, than in the past. In this report, we introduce some examples of the MHI compressors and steam turbines for ethylene plants, showing MHI's significant track record, while describing the transition of the size of ethylene plants. A brief description is also given of the technologies adopted to increase the efficiency and reliability of large-sized compressors. This is followed by an overview of some examples of compressor and steam turbine train configurations, in which these technologies are applied for mega ethylene plants, the market for which is expected to expand in the future.

## 2. Transition of compressors for ethylene plants

**Fig. 1** shows the transition in the size of ethylene plants and the MHI compressor models that were adopted in these plants. The size of ethylene plants has been increasing in size year by year, with the result that the compressor models used in these plants have also been increasing in capacity. In addition, as can be seen in **Fig. 2**, the amount of steam supplied to the steam turbines increases steadily in low-pressure supply lines, but tends to increase dramatically in high-pressure supply lines. The graph indicates that there is a requirement

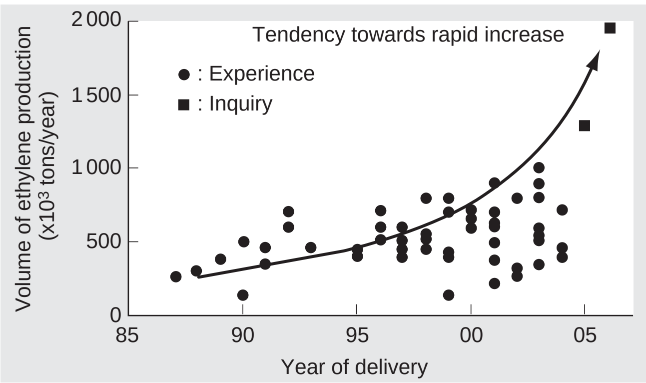


**Fig. 1 Trend in size of ethylene plants**
Plant size tends to increase year by year.

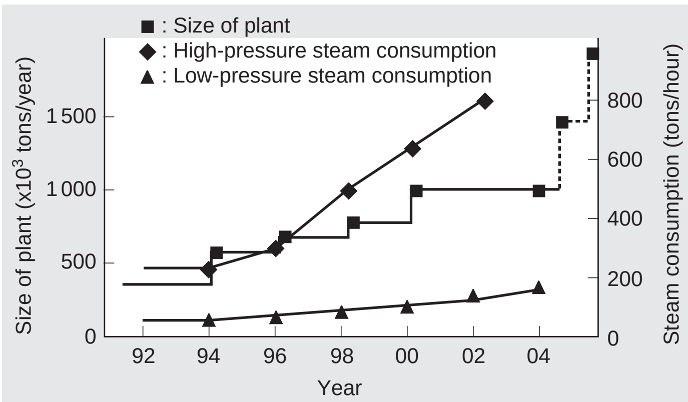


**Fig. 2 Trend in steam conditions in ethylene plants**
The amount of steam in low-pressure supply lines increases smoothly, whereas pressure in high-pressure supply lines tends to increase dramatically.

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to develop a large steam intake. As shown in **Fig. 3**, the efficiency of the compressors has also been increasing in keeping with the increase in the size of the plants. In 1986, MHI improved compressor efficiency by 5% by applying a highly efficient three-dimensional impeller in the compressors. To improve efficiency even further, MHI actively continues to engage in research and development.

**Fig. 4** shows a schematic of MHI's largest class of charge gas centrifugal compressors and steam turbines for ethylene plants. The train configuration for these machines consists of a steam turbine + an intermediate-pressure compressor + a low-pressure compressor + a high-pressure compressor. The low-pressure compressor is a double flow type, while the intermediate- and high-pressure compressors are a back to back type. In order to reduce the weight, the low-pressure and intermediate-pressure compressors use a fabricated casing[1], and the high-pressure compressor uses a cast steel casing with a high design pressure. In general, a one million tons/year class charge gas train is formed using four compressors. MHI can configure the charge gas trains up to a 1.5 million tons/year class with three compressor casings. The following advantages can be obtained by reducing the number of compressors.

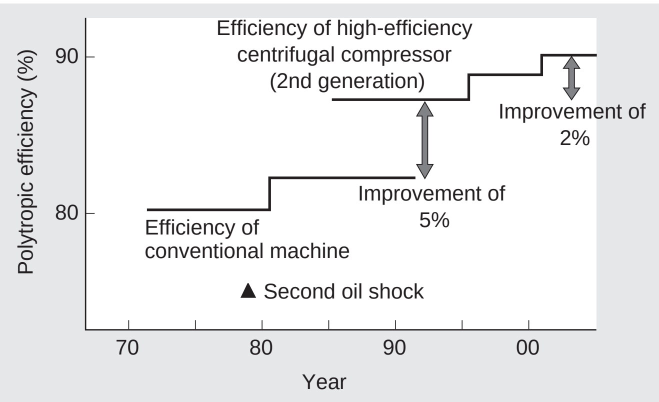


**Fig. 3 Trend in efficiencies of compressors in ethylene plants**
As ethylene plants grow in size, the efficiency of the compressor used in such plants has also been on the rise. This indicates that further improvement in efficiency is necessary.

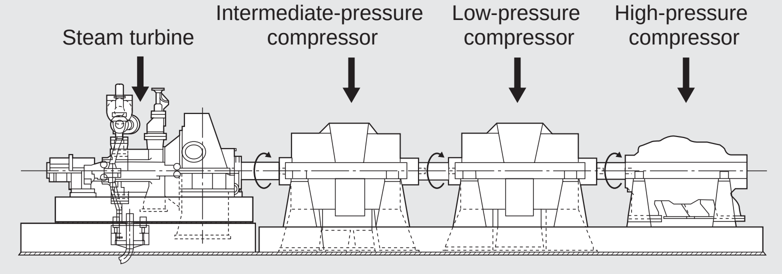


**Fig. 4 Configuration of compressor and steam turbine for mega ethylene plants**
MHI's maximum class centrifugal compressor and steam turbine for ethylene plants are introduced.

(1) Reduction in construction costs by saving space
(2) Reduction in the number of spare parts required
(3) Improvement of maintainability

Another advantage is that MHI can supply both the compressors and steam turbines of the same class without the support of other companies. In general, the centrifugal compressor is said to be limited to ethylene plants of the 1.4 million tons/year class. In order to supply highly efficient and highly reliable centrifugal compressors to larger plants, however, MHI is developing and verifying various technologies that are required for very large-sized compressors.

## 3. Technologies for increasing the capacity, efficiency, and reliability of large-sized centrifugal compressors

### 3.1 Development of highly efficient impellers

As plants have increased in size, the efficiency of centrifugal compressors has come to have an ever-greater affect on the running costs of a plant. The most important factor in increasing the efficiency of a centrifugal compressor is the impeller. To achieve high efficiency, MHI's compressor adopts a three-dimensional impeller at all stages. Further, in order to obtain the maximum level of performance under a wide range of gas conditions and operating conditions, MHI has designed a set of high efficiency impellers[2]. To accommodate the recent trend towards larger sized ethylene plants, MHI has already completed development of new large flow, high efficiency impellers that can be applied to large-sized compressors. **Fig. 5** shows one example of an impeller that is capable of coping with large flows.

This new impeller has the following characteristics.

(1) High efficiency

The high efficiency impeller has been developed using CFD (**Fig. 6**), and polytropic efficiency is increased by 2%. **Fig. 7** shows the results of performance tests on the system.

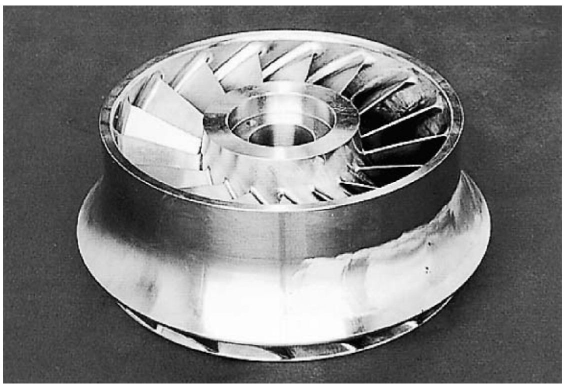

**Fig. 5 Large flow impeller**
This photo of an impeller capable of coping with large flow rates shows that the impeller has a wide suction flow passage and a shape that is nearly cylindrical in form.

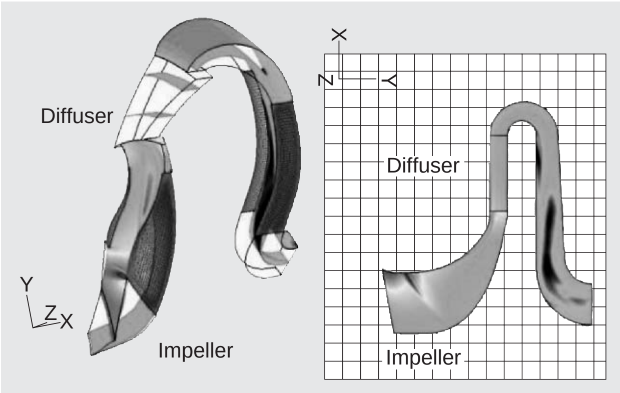


**Fig. 6  Analysis of impeller CFD**
A highly efficient impeller has been developed using CFD in order to realize a high performance impeller.

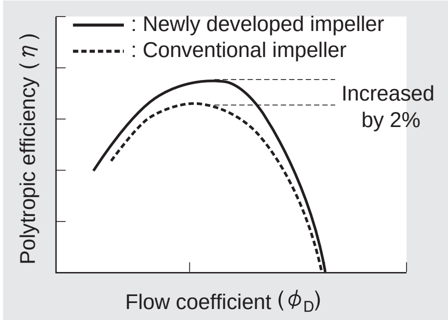


**Fig. 7  Comparison of impeller efficiency**
The efficiency of impellers has increased by 2% compared with that of conventional systems.

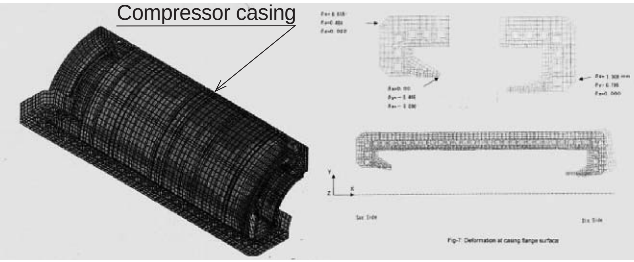


**Fig. 8  Design of casing using FEM**
In order to cope effectively with the increase in size, highly reliable design is carried out using FEM analysis.

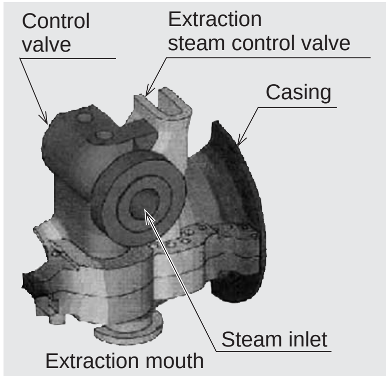


**Fig. 9  Steady temperature distribution of high-pressure casing**

(2) High pressure coefficient

To cope with an increase in large flow due to the increased size of plants, MHI has developed highly efficient impellers with a high pressure ratio.

(3) High boss ratio

In order to reduce shaft vibration, which causes problems with large rotating bodies, the impeller shaft diameter is increased by 5 to 10% (high boss ratio). This results in the realization of a highly rigid rotor.

(4) Improvement of manufacturing method

To achieve predicted performance by preventing deformation due to welding, the number of weld points for the impeller is reduced, and the manufacturing accuracy is increased. Development of this impeller makes it possible to provide compressors with superior performance and high reliability.

### 3.2 Design of large-sized compressor casings

The increase in size of compressors also results in a demand for more advanced technologies for the design of compressor casings. In order to improve the reliability of the compressor casing, MHI has carefully examined increases in weight, the effects of thermal expansion, and deformations due to internal pressure using FEM analysis techniques at the design stage, as shown in **Fig. 8**.

## 4. High efficiency steam turbines for mega ethylene plants

In order to tackle the problem of scaling up the present design concept and expanding the present design structure, when designing the turbines used for mega ethylene plants, effective solutions need to be found for the following technical areas:

(1) large capacity and high-pressure/high-temperature casings;

(2) large capacity and high-load speed control stage blades; and

(3) high load and high centrifugal force, low pressure stage blades.

MHI has solved these problems as summarized below.

### 4.1 Development of large capacity and high-pressure/high-temperature casings

In order to prevent abnormal strain and deformation caused by transient temperature distributions when the turbine is started and stopped or the load varies due to high pressure and high temperature steam, a nozzle box structure is adopted. In addition, a stress deformation analysis was performed using a three-dimensional solid model for verification in order to evaluate the structure after planning and design, as shown in **Fig. 9**.

In evaluating the leakage of steam from the horizontal joint surface which may occur under conditions of high-pressure/high-temperature and large capacity, bolt materials with small relaxation against bolt tightening force are used, and a thermal shield is also adopted in order to ease the abrupt temperature gradient.

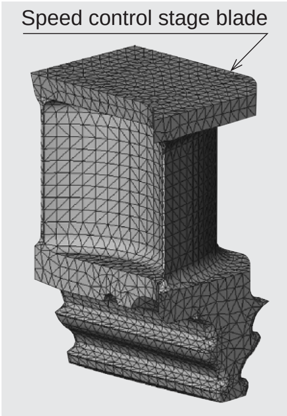


Fig. 10 Three-dimensional solid model of speed control stage blade

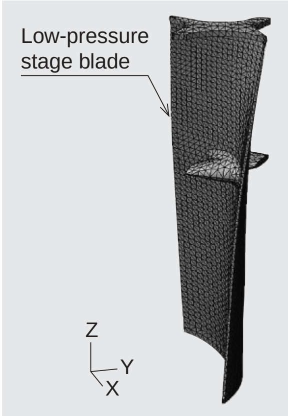


Fig. 11 Three-dimensional solid model of low-pressure stage blade

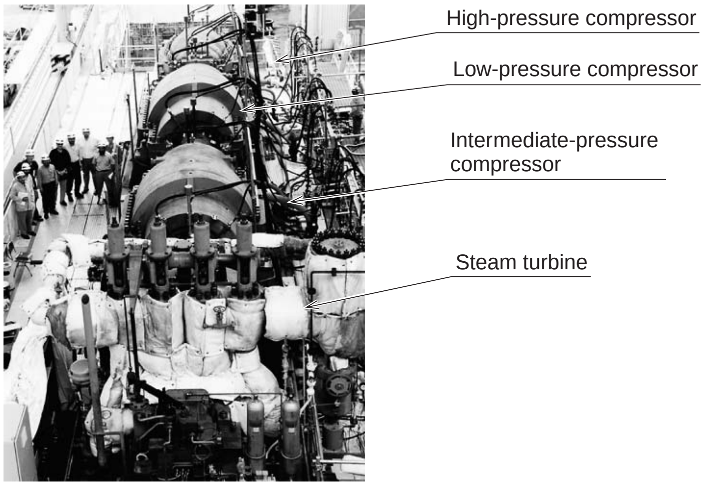


Fig. 12 View of large compressor and steam turbine under string test

### 4.2 Development of large capacity and high load speed control stage blades

To meet the requirements of large capacity and high load, Integral Shrouded Blade (ISB) type speed control stage blades are adopted to increase reliability. In order to design these blades in detail, as shown in **Fig. 10**, various effects and design factors were verified using FEM analysis, and rotor stability tests, cascade tests, and running tests with air were also conducted.

Adoption of the ISB blades confirmed that the frequency of the minimum mode was eliminated, and the reliability of the speed control stage blades was increased to a level greater than that of conventional shrouded blades.

### 4.3 Development of high load and high centrifugal force low pressure blocks

It was essential to develop a variable speed, low-pressure block capable of withstanding high loads and high centrifugal forces that were not seen in the past.

First, the specifications of the blades were determined using one-dimensional row-by-row calculation and axisymmetrical flow pattern analysis, while the basic blade shape was determined by examining the strength of the resulting system using shell models. Then, a detailed evaluation of strength was performed for the cascade using a three-dimensional solid model, as shown in **Fig. 11**.

An analysis of static stress was performed under multipoint boundary conditions for each blade. An analysis of vibration characteristics and stress was also conducted using the Cyclic symmetry method. It was confirmed that stresses at all sections satisfy the requirements specified in the design criteria.

By trial-manufacture of actual blades and a rotor stability test, it was also verified that the trial-manufactured blade group had the static and vibrating characteristics obtained in the above analyses.

## 5. Test equipment

As can be seen in **Fig. 12**, MHI already has test equipment capable of performing string tests for various combinations of compressors and steam turbines for ethylene plants of the 1.5 million tons/year class. To supply highly reliable products, performance can be verified before delivery by carrying out a string test and performance test.

For ethylene plants of the two million tons/year class, demand for which is expected to increase in the future, MHI is planning to construct new test equipment, larger than any existing test stand. Once this new test stand is

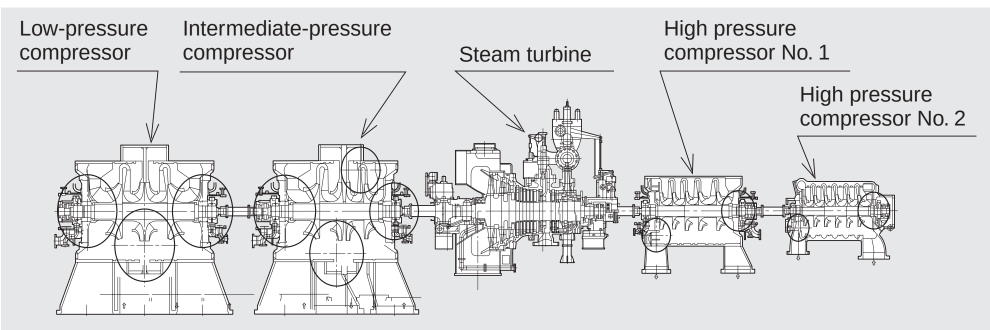


**Fig. 13 Train configuration of very large-sized charge gas centrifugal compressor and steam turbine**
This figure shows an example of a very large train in the future. MHI has been examining such systems in great detail and has been preparing basic plans for these systems.

completed, it will become possible to carry out string tests of very large-sized compressors and turbines, and the reliability of the compressors and steam turbines as a train can be assured.

## 6. Train configuration of compressors and steam turbines for two million tons/year class ethylene plants

An example of a very large-sized charge gas centrifugal compressor and steam turbine is shown in **Fig. 13**. The train configuration consists of a low-pressure compressor + an intermediate-pressure compressor + a steam turbine + a No. 1 high-pressure compressor + a No. 2 high-pressure compressor. The low-pressure, intermediate-pressure, and No.1 high-pressure compressors use welded steel plate casings, while a cast steel casing having a high design pressure, is adopted for the No. 2 high-pressure compressor. The steam turbine is installed between the compressors in the train. With this configuration, the output power is distributed evenly, the output applied to each shaft is lowered, and the train stability is increased.

For the train shown in Fig. 13, the installation height (on the 2nd floor) is increased to as high as 15 m, since the size of the main condenser positioned just below the steam turbine is increased, thereby affecting construction costs. However, by adopting an axial flow exhaust type steam turbine, which is a MHI own special design, the installation height can be set at the same level as before.

## 7. Conclusion

MHI has supplied many high efficiency large-sized compressors and steam turbines that are highly suited for ethylene plants. As plants have increased in size, these machines have also become larger year by year to accommodate the demands of the larger plants. Already, these large-sized compressors and steam turbines have built an impressive track record for high efficiency and quality. MHI has completed the development of the component technologies for ethylene plants of the two million tons/year class. The demand for such plants is expected to increase in the future. As a result, very large-sized compressors and steam turbines can be applied to a growing number of ethylene plants.

A notable advantage of MHI is that both centrifugal compressors and steam turbines can be manufactured with MHI proprietary technologies in the same manufacturing plant. It is our hope that these highly efficient, large-sized compressors and steam turbines will come to assist in increasing the efficiency and reliability of an ever-greater number of plants.

**References**


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