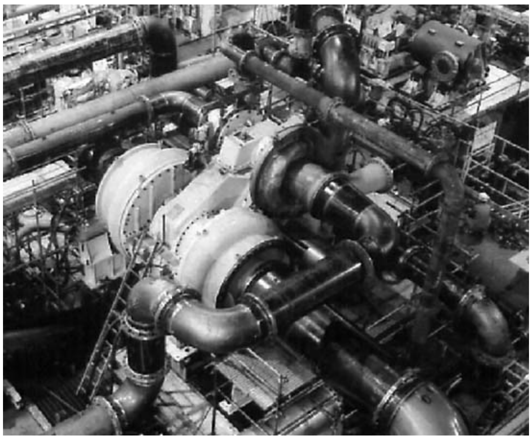


MHI Integrally Geared Type Compressor for Large Capacity Application and Process Gas Application

NAOTO YONEMURA*[1]
YUJI FUTAGAMI*[1]
SEIICHI IBARAKI*[2]

This paper introduces an outline of the structures, features, development, examples of actual deliveries, and the future outlook for integrally geared centrifugal compressors (hereafter called geared compressors) that have been delivered by MHI to various markets since 1967. In this paper, a detailed explanation is presented of large size geared compressor trains used for PTA (purified terephthalic acid) plants and geared compressors used for feeding fuel gas to gas turbines.

1. Introduction

Applications for the geared compressors manufactured by Mitsubishi Heavy Industries, Ltd. (MHI) have been expanding gradually since the first machines were delivered in 1967. The total number of machines delivered since then has reached more than 500 units.

Traditionally, geared compressors have been used as a source of factory air supply, integrated into a package that also includes intercoolers, a lubricating oil unit, and drive unit. Recently, however, as these machines have advanced into various process fields, they have become increasingly larger in size and are being applied in an ever-expanding range of applications.

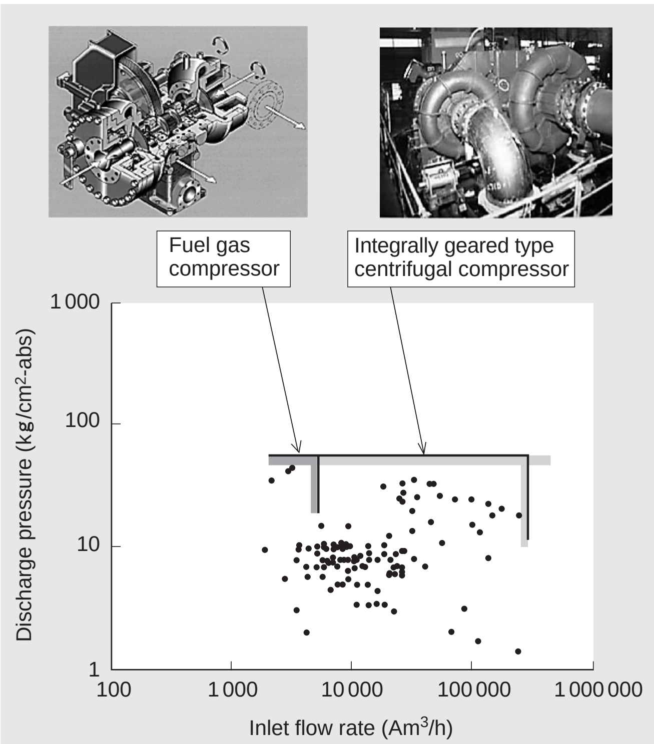


Fig. 1 Scope of application of geared compressors

The scope of application of MHI's geared compressors is shown in **Fig.1**. As can be seen in the figure, MHI's geared compressors are capable of producing pressures as high as 6.0MPa (A) and intake flow rates as large as 300 000Am^3/H, thereby being readily able to fulfill recent market requirements.

This report introduces (1) large geared compressor trains used for PTA plants that are increasing each year, and (2) fuel gas geared compressors used to feed fuel gas to gas turbines used in combined cycle power plants. An overview of the structure and characteristics of a geared compressor is also given.

2. Structure and characteristics

Many centrifugal compressors operate in petrochemical, other chemical, and air separation plants. Centrifugal compressors are roughly classified into two types. The first type is a single shaft multistage compressor consisting of a series of impellers installed together on a single shaft which are the main components for pressurizing the gas [**Fig.2**(a)]. The impellers are located on the shaft between two bearings that support it. In the case of such a single shaft multistage compressor, a gear unit is coupled between the compressor and drive unit, when the rotational speed of the drive unit is less than that required for the compressor.

The other type of centrifugal compressor has a built-in gear, namely a geared compressor. A geared compressor has an overhang type pinion shaft. Each impeller is attached to the end of its own high-speed pin-

*1 Hiroshima Machinery Works
*2 Nagasaki Research & Development Center, Technical Headquarters

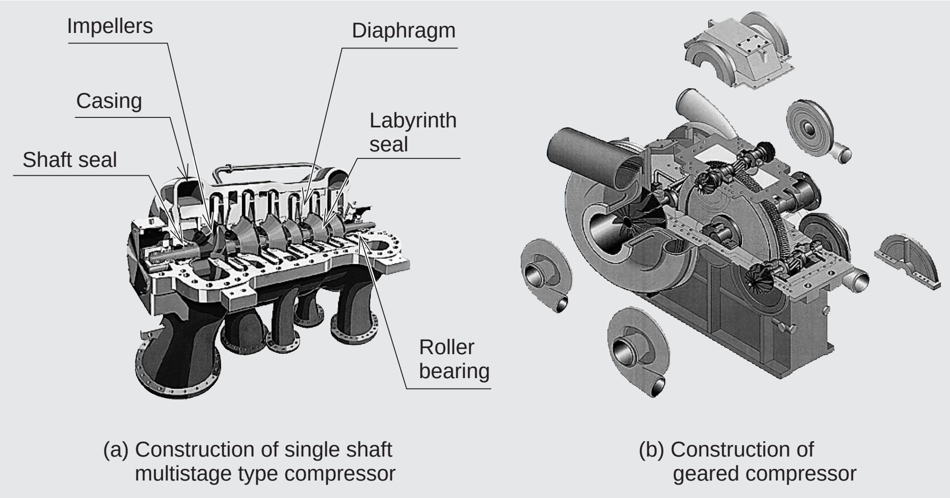


Fig.2 Comparison of single shaft multistage compressor and geared compressor (Integrally geared type compressor)

ion shaft within the gear unit. The pinion shafts are located around the circumference of a bull gear that rotates at a low speed [Fig.2(b)].

The speed of each pinion shaft can be set by matching the number of teeth in each pinion to conform to the optimum speed of each impeller.

When designing a geared compressor, it is very important to conduct an overall technical evaluation of all the basic mechanical components of the compressor such as the impellers, gears, bearings, shaft seals, casing, etc., since each impeller is directly installed onto pinion shafts that rotate at high speeds. MHI can produce and supply all the geared compressors to high levels of mechanical reliability, by designing each component based on design criteria established through extensive tests carried out within the company.

Fig. 3 shows the results of an analysis for the vibration stability of a pinion shaft, as an example of component design. There is an aerodynamic exciting force that is generated in the impeller, one of the various exciting forces that cause the shaft to vibrate. Fig. 3 shows a comparison of the analysis results, when the aerodynamic exciting force is considered, and when it is not considered. From the figure, it can be seen that stability is reduced when the aerodynamic exciting force generated in the impeller is considered.

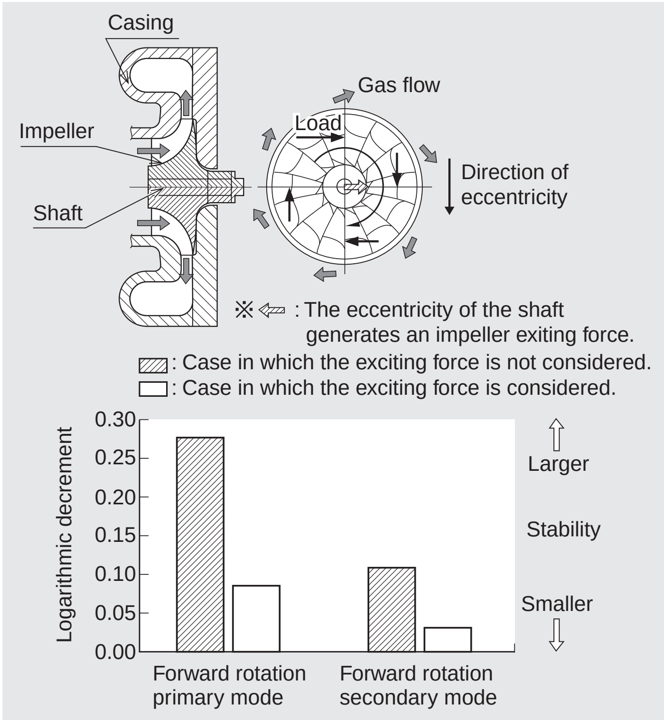


Fig. 3 Comparison of change in shaft system vibration stability depending on existence of impeller exciting force
The logarithmic decrement that indicates shaft stability has a tendency to decrease with the existence of an exciting force.

As indicated by the above, it is necessary to conduct a prior examination taking the exciting force into consideration in order to analyze the vibration behavior of a geared compressor. In addition, the behavior of the rotor varies significantly as the tangential force produced in the gear due to the operating condition changes. Hence, it is also important to analyze the vibration of the pinion shaft under partial loads.

Depending on the type of plant, the main compressor train may be composed of different rotating machines such as a geared compressor, single shaft multistage compressor, expander, steam turbine, and a drive motor. Despite such a complex train, MHI can also propose the train that is best suited for a given plant because the company has extensive experience in the design and manufacture of every kind of rotating machine. The train is selected based on careful mechanical examinations of the component machines, a comprehensive evaluation of the train composition satisfying all requirements for the plant (gas balance and power balance), and its operating method.

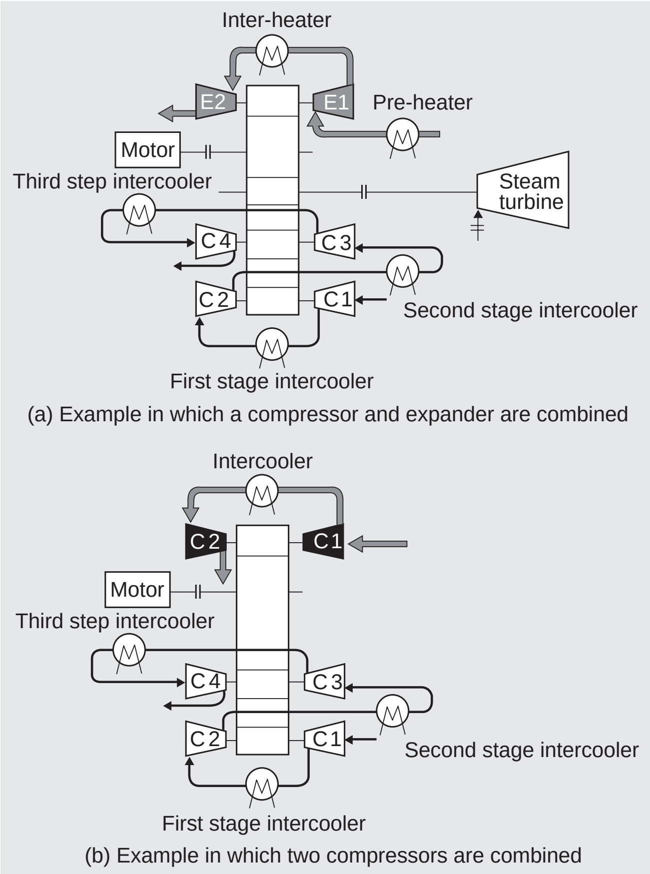


Fig. 4 Example of combined geared compressor

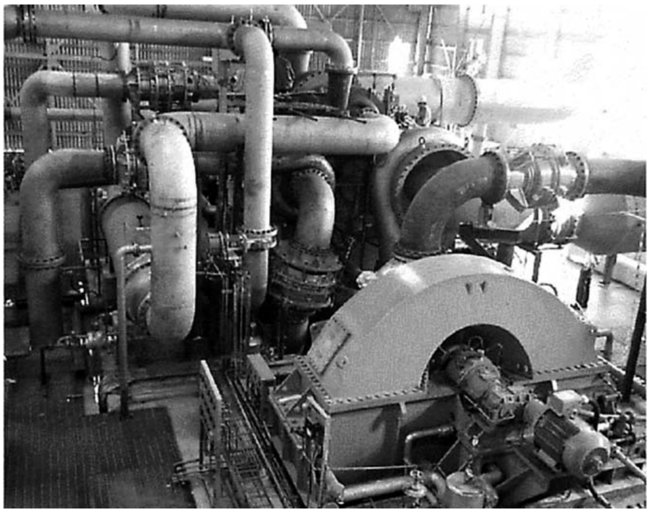


Fig. 5 Combined geared compressor for PTA plant
(Type in which a compressor and expander are combined)

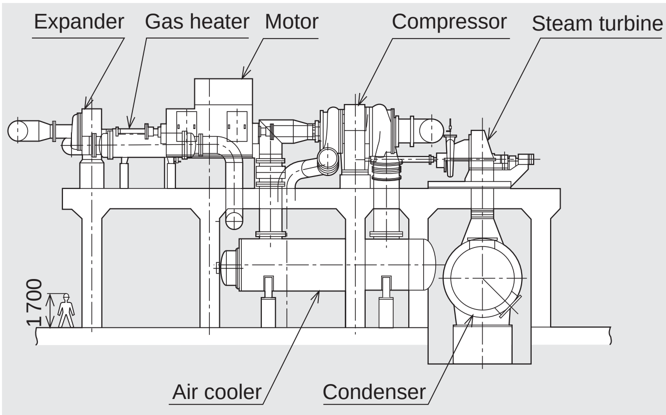


Fig. 6 Compressor train for a 500 000 tons/year PTA plant
The compressor train consists of an expander, motor, compressor, and steam turbine.

MHI also provides combined type geared compressors that utilize the characteristics of geared compressors, in which the rotational speed of each pinion shaft can be freely selected. In this type of geared compressor, different application impellers or expander impellers for recovering power are installed in one gear unit casing.

Fig. 4 shows examples of combined type geared compressors. Adopting a combined type geared compressor offers the benefit of remarkably reducing the amount of space necessary for installation, since the different compressor casings can be integrated into a single casing and saving can be made on auxiliary equipments. In addition to the above-mentioned merits, various losses including mechanical losses of rotating machines, such as bearing losses can be reduced, and the size of the lubricating unit can be significantly reduced. The overall result is that significant savings in required power can be achieved.

Fig. 5 shows a photograph of a combined type geared compressor that consists of a compressor and expander for a PTA plant.

3. Expansion of applications for geared compressors

3.1 Large size geared compressors

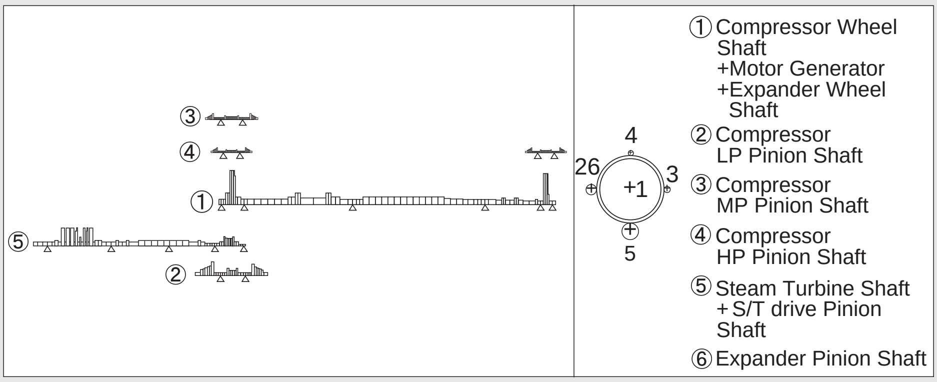
A typical example of an application for large geared compressors is a compressor train used in a large PTA plant.

The capacity of PTA plants has been steadily increasing in recent years. Plants generally ranged in size from around 250 000 to 400 000 tons/year in the 1990s. In this decade, PTA plants recently installed have capacities ranging from 500 000 to 700 000 tons/year, with future plants expected to increase even further to capacities as large as 1 million tons/year.

Fig. 6 shows an example of a compressor train used for a 500 000 tons/year PTA plant. It is essential to optimize the equipment arrangement and operation method used in the compressor train of a PTA plant. The reason for this is that, in addition to electric motors, admission low pressure steam turbines and off-gas expanders are also used as drive units, in order to recover the power. The low pressure steam and off-gas generated in the plant are used for these drivers.

Extremely high mechanical reliability is required for this type of compressor train, since it plays a major role as the so-called heart of the plant feeding air to the reactor.

PTA PLANT TOTAL TRAIN

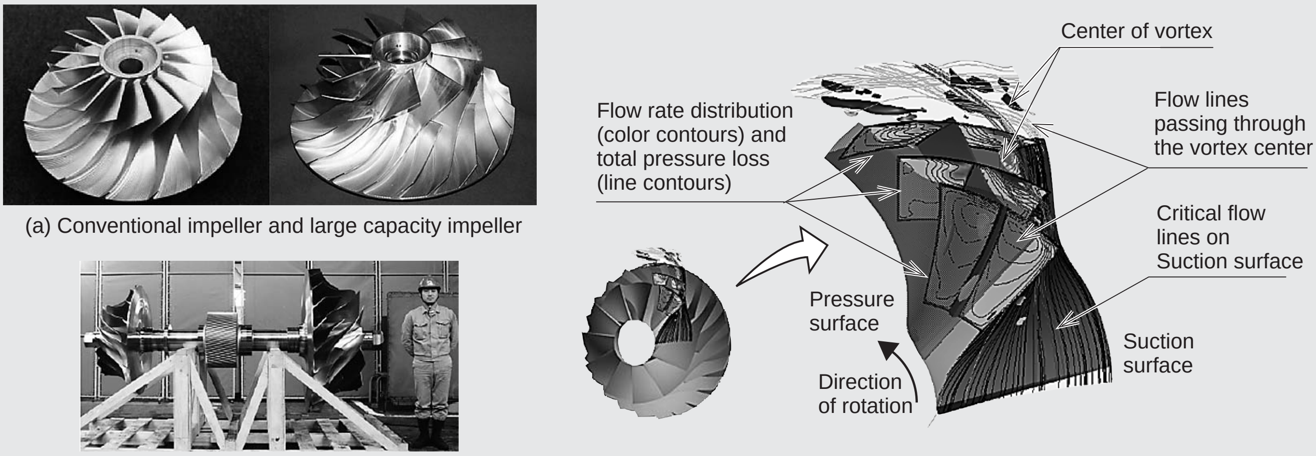


INFORMATION

SHAFT	1	2	3	4	5	6
LENGTH (mm)	10 395.40	2 218.00	1 612.00	1 256.00	6 268.70	1 180.00
WEIGHT (kg)	14 152.67	1 335.04	262.10	116.80	4 589.59	105.58
IP (kgfmms ∗ ∗ 2)	379 095.31	5 466.64	228.23	47.40	47 442.47	52.50

	Wheel Shaft 1 185 rpm	Compressor LP Shaft 7 830 rpm	Compressor MP Shaft 12 790 rpm	Compressor HP Shaft 15 990 rpm	S/T Shaft 4 410 rpm	Expander Shaft 1 185 rpm
1st Mode	9.9Hz (0.49 N)	63.5Hz (0.49 N)	174.4Hz (0.82N)	302.9Hz (1.14N)	50.6Hz (0.69N)	166.6Hz (0.51N)

Fig. 7 Analysis of torsional vibration of compressor train for a PTA plant
Torsional vibration analysis is carried out on the shaft systems of the train as a whole.



(a) Conventional impeller and large capacity impeller

(c) Pinion shaft equipped with a large capacity impeller

(b) Flow analysis of large capacity impeller

Fig. 8 Large capacity impeller

Fig. 7 shows the results of torsional vibration analyses for various shafts, which were conducted to verify the mechanical reliability of the PTA plant compressor train. In these analyses, the overall torsional vibration analysis is carried out through the train as a whole, including the pinion shaft, wheel shaft, and the shafts of all the drive units.

Fig.8(a) shows a large capacity impeller developed to cope with the needs of larger sized plants such as PTA plants, in place of conventional package type geared compressors. The large-scale impeller is made up of main vanes and intermediate vanes, and the number of vanes at the inlet is less than that of a conventional impeller. The height of each vane is about 50% greater than the height of vanes on a conventional impeller, in order to increase the capacity of the impeller. In addition, the number of vanes at the outlet of the impeller is increased, to reduce the load on each vane by about 30%, so that the efficiency of the impeller under high-pressure ratios is improved. Fig.8(b) shows the flow analysis for a large-scale impeller. This is the result of a vortex analysis for complex three-dimensional flow inside the impeller, which is obtained using critical point theory. This is just one example of how MHI improves impeller performance through the use of such flow analysis techniques[1]. A pinion shaft with a large capacity impeller is shown in Fig.8(c).

Since the gears also need to be larger in size as geared compressors increase in size and capacity, MHI also actively carries out R&D concerning large sized gears.

3.2 Application for process gas

In this section, a geared compressor used to feed fuel gas to the gas turbines in a combined cycle power plant is described, as an example of an application for such compressors in the process gas field. **Fig. 9** illustrates the structure of the compressor.

The fuel gas geared compressor is used to pressurize fuel gas and feed it to a gas turbine for power generation. Hence, if the geared compressor fails, the gas turbine stops with the result that all power generation also stops. Consequently, geared compressors need to be extremely reliable.

Providing a highly reliable control system, capable of coping with severe operating conditions such as load rejection operation and DSS operation of the gas turbine, is essential for this type of geared compressor. Accordingly, MHI has established simulation technology for the fuel gas geared compressor. Simulations of the system are to be conducted beforehand in order to assess control response to load changes such as load rejection.

Tandem type dry gas seals are provided for the sealed parts, since the compressor handles high pressure fuel gas with a discharge pressure as high as 5.0 MPa (A).

MHI developed and delivered its first fuel gas feeding geared compressor in 2001. During in-company tests carried out before delivery, performance checks were done on the compressor to confirm that specified performance levels were achievable. Mechanical checks using full load tests were also conducted. Furthermore, in order to demonstrate the reliability at the DSS operation, the train was started and stopped about 150 times. After this series of starts and stops was completed, an overhaul inspection was carried out to check the soundness of the parts. The compressor has been operating stably since delivery without any problems. Based on these actual results, the reliability of MHI's geared compressors achieved a high evaluation, resulting in the acceptance of orders for a total of twelve machines since then.

Since the expansion of combined cycle power generation using gas turbines is anticipated in the future, MHI intends to make further efforts to promote the sale of fuel gas geared compressors, based on these actual experiences.

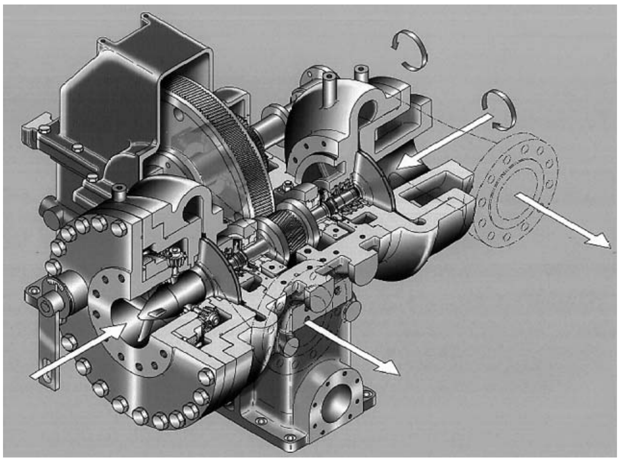


Fig. 9 Fuel gas geared compressor
This image shows a cut-away view of the structure of a two-stage type fuel gas geared compressor.

4. Future development

MHI intends to further improve large size geared compressors so that they can be applied to compressor trains on large PTA plants with capacities as high as 1 million tons/year. Furthermore, it is MHI's intention to apply these compressors to large scale air separation units used for GTL (gas to liquid) plants that convert natural gas into liquid fuel in keeping with environmental regulatory requirements.

Moreover, in the field of process gas, MHI also intends to apply geared compressors to the pressurization of various process gases in petrochemical, oil refinery, and other chemical plants, based on experiences gained with fuel gas geared compressors and the application technology fostered through single shaft multistage centrifugal compressors.

5. Conclusion

The future market for geared compressors will require further increases in capacity and high pressure, and the fields of their applications, including process gases, will continue to expand. MHI will continue its efforts to meet customer demands for ever-more efficient and powerful compressors and other technologies, by carefully assessing such needs from various plant processes and providing the most suitable compressors to meet these needs.

Reference

(1) Uchida et al., The Advanced CFD Technology for The Development Turbo-Machinery, Mitsubishi Juko Giho Vol. 40 No.6 (2003) p. 336


Naoto Yonemura


Yuji Futagami


Seiichi Ibaraki