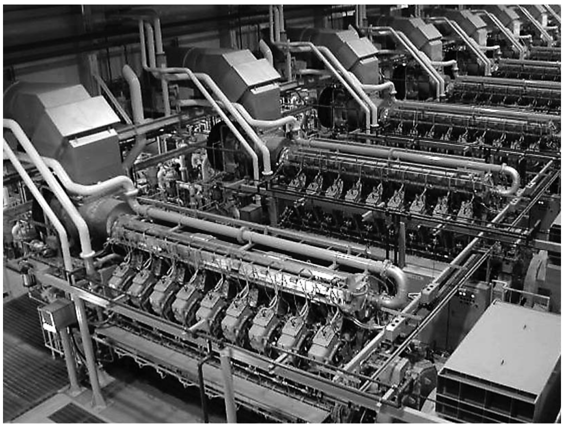

Lineup of Co-generation in Mitsubishi Heavy Industries

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With the environmental regulations becoming more and more severe, there is an increasingly high demand for co-generation with less emission of hazardous constituents such as CO_2, NOx, particles, etc., so that Mitsubishi Heavy Industries, Ltd. (MHI) is taking positive steps towards introducing electronic control, combustion improvements, after-treatment system, etc. Further, in view of the reliability of the co-generation as well as the environment surrounding the power generation plant, reduction of vibration and noise is also counted as an important environmental responsive technology. Hence, MHI is pushing forth for high efficiency equivalent to that of a diesel engine while maintaining the features of a gas engine such as low NOx and low particle emission in the case of a gas engine, and low NOx and low particle emission while maintaining the features of a diesel engine such as high output and high efficiency in the case of a diesel engine. The environmental responsive technology is essential for the aforesaid co-generation. This paper gives an example of the energy management service business (electric power selling business) using the low-pollution, environmental-responsive engines, and introduces Mitsubishi's low-pollution, power generation engines.

1. Introduction

Lineup of power generation engines applying environmental-responsive technology, energy management service business (electric power selling business) and environmental-responsive technology are introduced below.

2. Lineup of power generation sets

Figure 1 shows the lineup of Mitsubishi power generation engines with generating power 10 000 kW or under. The generating power widely ranges from 170 kW to 8 000 kW, corresponding to the customer's needs depending on application.

3. Energy management service business

MHI is positively engaged not only in supplying power generating equipment to on-site power generation companies (or individuals) and power retailers, but also in developing the power generation energy management service.

3.1 Development of power retailing business

Figure 2 shows the MHI Yokohama Power, a power generation company with 100% investment of MHI as an example of power retailing business. The company started service operation of No. 1 and No. 2 MACH-30G gas engines of MHI in October 2002 (5 750 kW X 2 units).

Of the total generated power, the company currently supplies 4 000 kW to MHI Yokohama Dockyard & Machinery Works, while selling the remaining 7 000 kW to specified-scale electric company.

In the future, the company plans to expand its business management to on-site power generation business.

3.2 Development of EMS business

MHI has started the Energy Management Service (EMS) in China since July 2003 as a business similar to the ESCO business (power retailing business, etc.) currently prevailing in Japan.

The EMS is MHI's unique and new energy management service agreement system based on the consortium agreements with several companies such as the finance companies, equipment manufacturers, operation and maintenance companies, petroleum companies, etc.

3.2.1 Background of development of EMS in China

With diesel oil prices soaring high together with the power unit prices lowered down by the electric power companies because of the import ban of the diesel oil into China in 1998, the regular use of diesel generators and the introduction of new diesel generators almost stopped. In the meantime, as the Japanese-affiliated firms in China became all the busier because of the rapid production shift, MHI commenced the EMS business for the Japanese-affiliated firms in 2002 under the background given below.

(1) The power supply (power transmission) of electric power companies in some districts of China has deteriorated both in terms of quality and quantity.

(2) The Japanese-affiliated firms in China intend to outsource the management and infrastructure-related business so as to focus their muscles solely on production.

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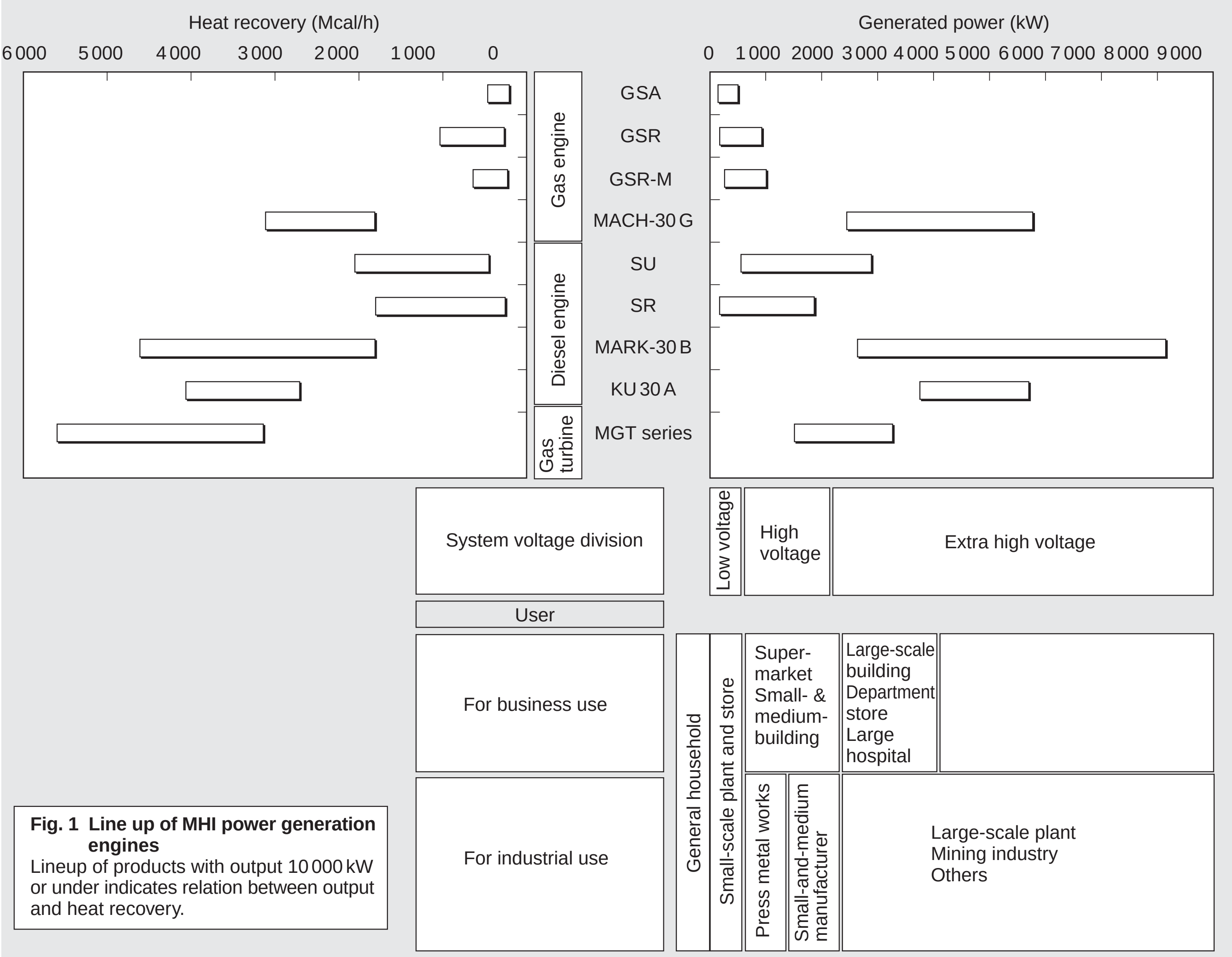

Fig. 1 Line up of MHI power generation engines
Lineup of products with output 10 000 kW or under indicates relation between output and heat recovery.

Fig.2 MHI Yokohama Power Co., Ltd.
In operation at Yokohama Dockyard & Machinery Works.

3.2.2 Advantages of EMS agreement

The EMS agreement has the advantages given below in terms of the problems of the users.

- There is no need of initial investment because of financing by a finance (lease) company.
- The agreement supplies a package of the stable procurement of high-quality fuel from petroleum company and the exclusive management and maintenance companies as specified by the manufacturer to ensure outsourcing of power and energy management.
- The agreement provides stable and high-quality electric power at power unit price equivalent to that of the electric power companies. This saves the worries about power supplied by unstable electric power companies, such as power failure, instantaneous power interruption, voltage drop, uncertain power supply at the peak of power demand, etc.
- The agreement ensures enhanced generating performance and improvements in maintainability, etc. by replacing the existing power generation equipment of the present plant with high-efficiency, regular-use exclusive equipment as well as by adopting new equipment to a new plant.
- The use of co-generation using exhaust heat together with the supply of electric power goes a longer way toward energy saving.

3.2.3 Case of introduction

Figure 3 shows the power generation equipment introduced by an electric appliances manufacturer in China using the EMS agreement. The equipment is composed of 6 units of 1 000 kW regular-use power generator using MHI diesel engine S6U. The equipment ensures stable supply of power by maintaining reliability through planned maintenance, contributing to stable production of the user.

3.2.4 Future development

MHI intends to take positive steps towards developing the EMS business in Japan by making effective use of its advantages.

4. Environmental-responsive technologies

4.1 Combustion and electronic control

4.1.1 Gas engine

The introduction of Miller cycle is one of the features of the lineup of MHI gas engines. The conceptional diagram of Miller cycle system is shown in **Fig. 4**. The Miller cycle system allows larger difference (work volume) between expansion stroke and compression stroke since the actual compression ratio can be kept to conventional level by closing the inlet valve earlier than usual even when the geometrical compression ratio is improved.

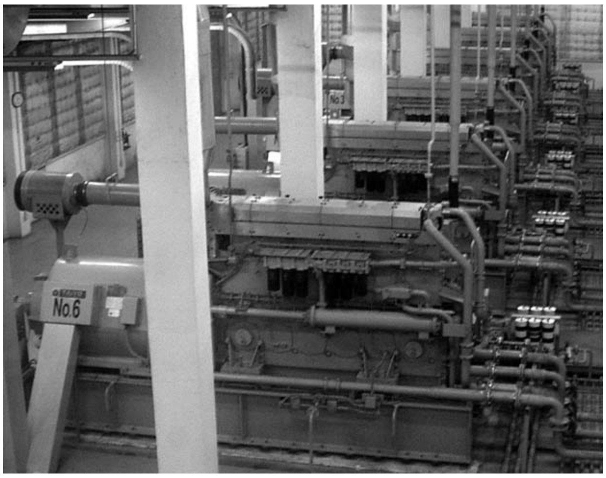

Fig.3 EMS agreement diesel power plant
EMS agreement plant with diesel engine (S6U), 1 000 kW × 6 units.

The adoption of this system has improved the efficiency at generator terminal by 3.4% (as compared with conventional efficiency) to 45.5% for MACH-30G, and by 14% to 40% for GSR-M, with the NOx emission remaining at the conventional level. Further, in the case of MACH-30G, high efficiency is combined with low NOx emission by using the electronic control system shown in **Fig. 5**.

Figure 6 shows the GS12R-M currently in operation.

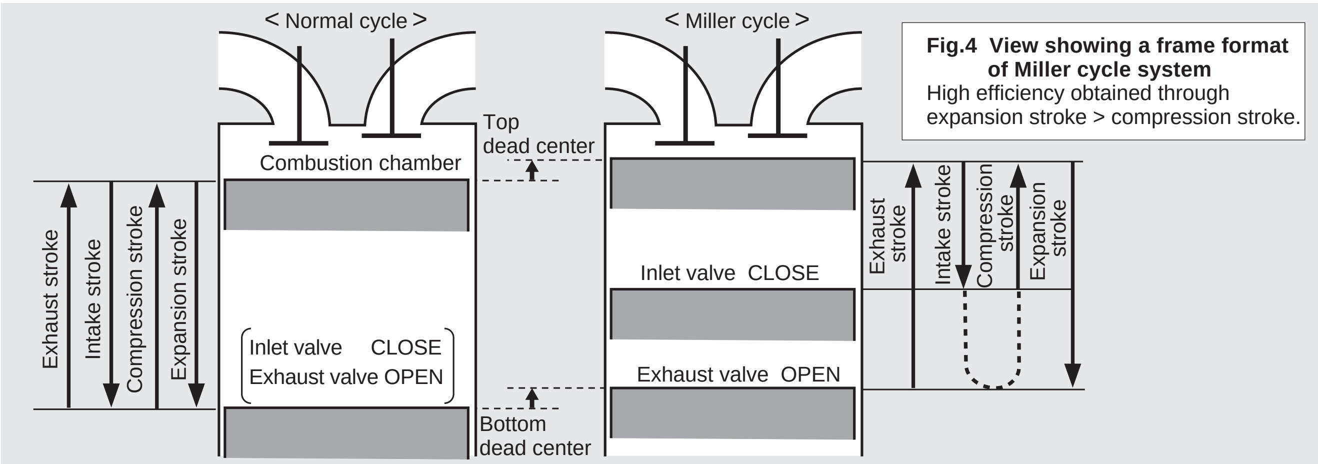

Fig.4 View showing a frame format of Miller cycle system
High efficiency obtained through expansion stroke > compression stroke.

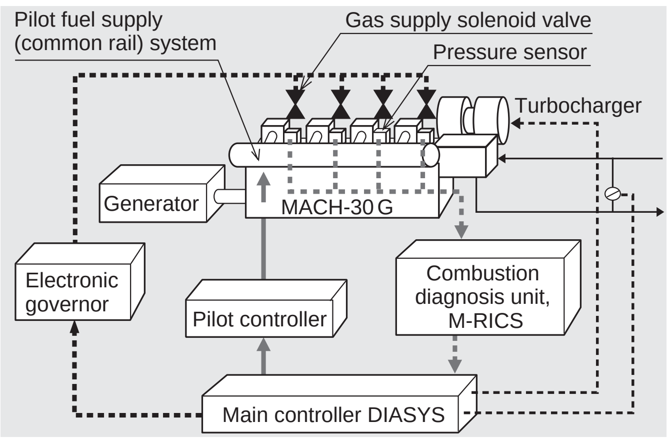

Fig.5 Electronic control system
Installed by standard to MACH-30G, with the engine combustion constantly controlled to optimum state by using main controller DIASYS.

Fig.6 GS12R-M in operation
Thermal efficiency is drastically improved by applying Miller cycle.

4.1.2 Diesel engine

Figure 7 shows the configuration of electronic control common rail system under development for installing on KU30B. The system is composed of two pressure rails: high-pressure rail and low-pressure rail, and their injection timings are separately controlled by two solenoid valves, ensuring free fuel injection mode. This provides a high injection pressure right from the start, leading to drastic reduction in particle emission at start/stop and at low-load.

Figure 8 shows a 15% reduction of NOx emission using the same fuel as the conventional injection system by using the injection ratio control by restraining the initial fuel injection rate.

Further, the stratified water injection system shown in **Fig. 9** can also be installed to this system. The injection system makes it possible to reduce the NOx emission by maximum 50%, by injecting fuel and water into the cylinder in stratified form after injecting 50% water against the fuel.

4.2 Aftertreatment system

In addition to the research and development of low-pollution combustion, MHI is engaged also in the aftertreatment of exhaust gas, reductions of vibration and noise, paying substantial consideration to the environment in the entire power generation system.

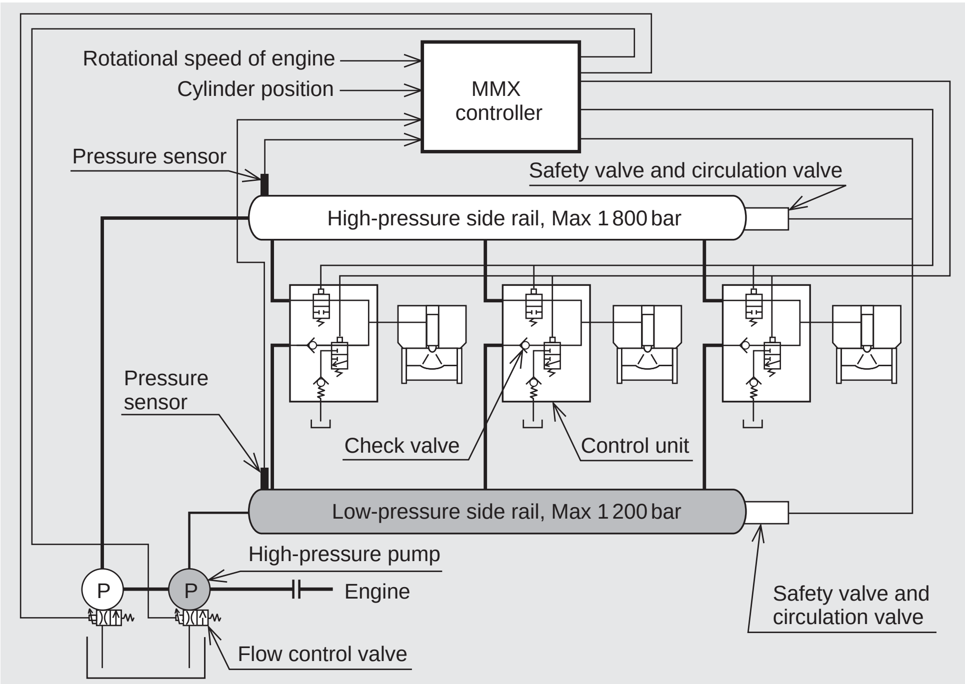

Fig.7 Common rail system
Since the fuel control solenoid valve is externally installed to each drum, it is possible to install the system to the existing engine. Further, the injection pattern can be controlled through combination of 2 types of rail pressure.

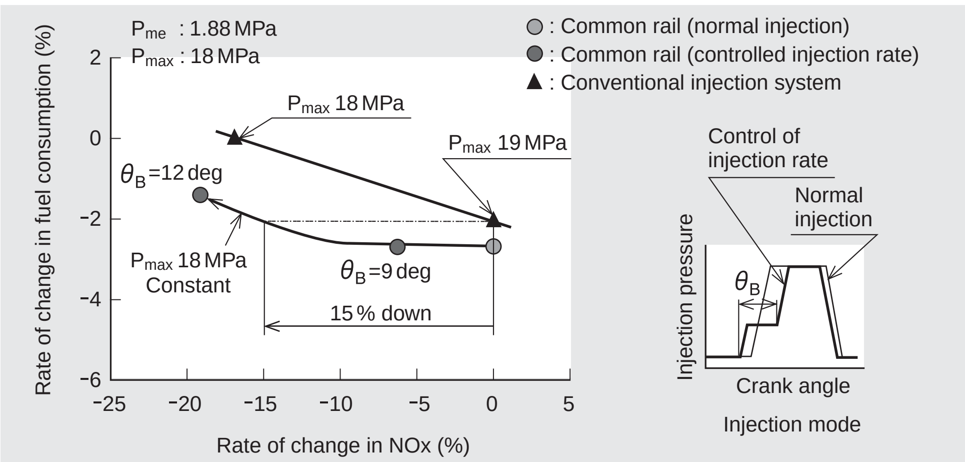

Fig.8 Relation between NOx and fuel consumption
Low NOx emission and low fuel consumption are simultaneously realized by adjusting the injection pattern at common rail.

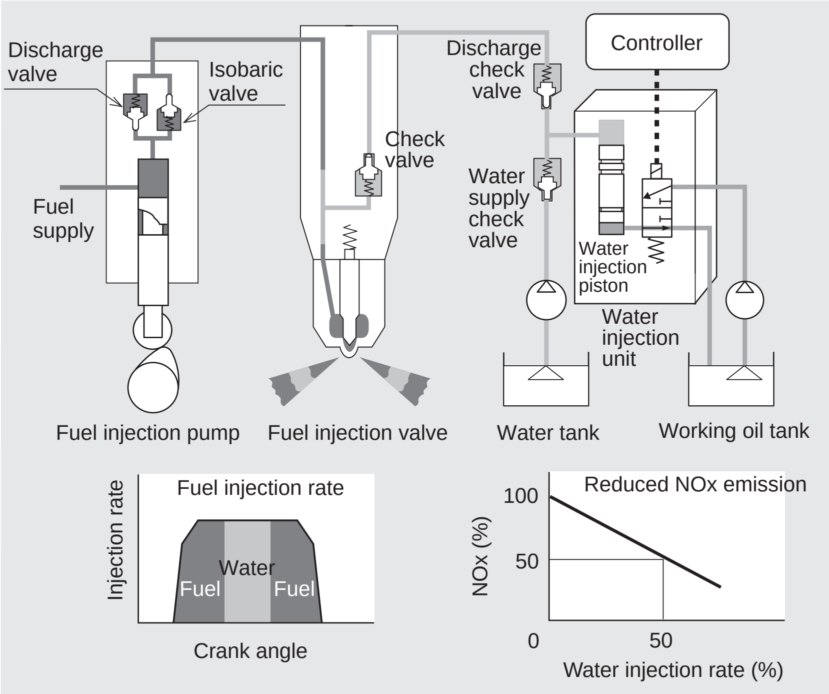

Fig.9 Stratified water injection system
NOx is reduced to 50 % by 50 % water injection.

Fig.10 MHI de-NOx system for industrial power plant (De-NOx rate is exceeding 90 %.)

It is important to improve the thermal efficiency of a machine using fossil fuel in order to curb the emission of CO_2, one of the substances causing global warming. MHI is carrying out further technical development in order to reduce the CO_2 emission by making the effective use of the features of diesel and gas engines capable of providing thermal efficiency higher than the other thermal engines.

Further, with the emission of NOx and particles from diesel engine becoming a social problem, MHI is conducting research and development on both the improvement of combustion and the aftertreatment of exhaust gas.

The noise and vibration from engines are becoming problematic in urban areas, so that MHI is taking appropriate countermeasures, such as reducing the noise by using bonnets with higher soundproof effect, using anti-vibration support for power generation set, etc.

4.2.1 Exhaust gas aftertreatment equipment

It is possible to reduce the environment pollutants (harmful constituents) such as NOx, particles, etc. by improving the combustion inside the engine. In addition to this, technologies have been developed to remove NOx and particles from a diesel engine and NOx from a gas engine through aftertreatment in order to clean the exhaust gas.

(1) De-NOx system

MHI manufactures products involving combustion such as gas turbine, boiler, incinerator, etc. in addition to diesel engine and gas engine, and has commercialized MINT series, the de-NOx system using the aforesaid exhaust gas aftertreatment technologies.

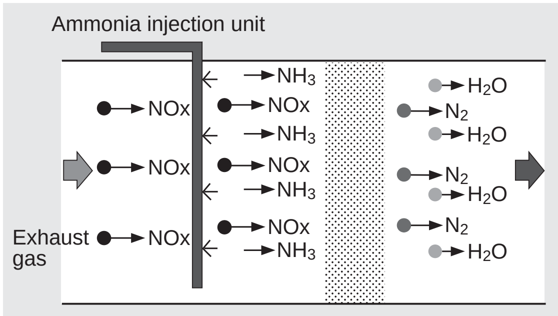

Fig.11 Ammonia removal equipment
NOx is dissolved into N_2 and H_2O by using a reactor.

Figure 10 shows MHI industrial power plant.

As shown in **Fig. 11**, the industrial power plant injects ammonia water into the exhaust gas, and turns NOx into N_2 and H_2O in the reactor, with the de-NOx rate exceeding 90%. Further, the MINT series covers a wide output range between 250 kW and 50 000 kW, and is delivered to a large number of plants both in Japan and abroad.

(2) Particle removal equipment

Since a diesel engine for power generation has constant rotational speed and is constantly used at around rated output, and has less sharp load fluctuation likely to cause a large amount of particles to generate, it is possible to adjust the combustion to an appropriate level within the normal operating range so as to restrain the emission level of particles. Hence, it is possible to keep the particle emission within the specified level ever without using the aftertreatment equipment.

On the other hand, the sharp rise of engine at the time of start causes black smoke to generate. MHI has, therefore, developed the aftertreatment equipment to remove the black smoke. The equipment leads the exhaust gas to a filter only at the time of engine start to remove the particles, while burns the particles arrested during normal operation. **Figure 12** shows the black smoke removal equipment.

(3) ECCOTM filter system

MHI is currently developing the particle removal equipment, ECCO™ (Eliminating Technology of Carbon by Catalytic Oxidation) filter system which presumably is to use high-sulfur fuel[1].

The particle removal equipment in item 4.1.2 aims at removing the particles at engine start, while the ECCO™ filter system is constantly used for removing the particles when the engine is in operation.

The Diesel Particulate Filter (DPF) developed for vehicles has the catalytic performance degraded when high-sulfur fuel is used, while the ECCO™ filter system keeps the performance intact even when high-sulfur fuel is used.

The system has already been subjected to various tests using actual engine, and has been confirmed to have excellent performance; and the tests are further being conducted for commercialization.

4.3 Vibration and noise

4.3.1 Reduction of noise

MHI delivers power generation package with extra-low noise for large-scale stores, hotels and hospitals in urban areas. At the early stage of development, the low-noise power generation package had mainly the noise specification of 85 dB (A), while the present package noise specification is 75 dB (A), and the demand for 70 dB (A) noise specification is also being made.

MHI has currently developed and put on sale the power generation package with extra-low noise of 70 dB(A) (**Fig. 13**).

Fig.12 Installation of black smoke removal equipment
Capable of removing black smoke even when high-sulfur fuel is used.

In order to reduce the noise, the transmission loss of the package panel with high contribution rate for noise reduction is improved and the splitters and exhaust mufflers of inlet air silencer and air-exhaust duct are intensified.

Figure 14 shows the test results of transmission loss of a panel with highest effect as compared with the panel with noise specification 85 dB (A). The transmission loss of the panel is 43 dB (A) on average, approximately 10 dB (A) up from the 33 dB (A) level of the panel with noise specification 85 dB (A).

MHI is determined to further reduce the noise by improving the low-frequency zone.

4.3.2 Reduction of vibration

One of the low-pollution demands getting more and more severe every year is reduction of low-frequency vibration. In the field of mechanical vibration, the vibration with comparatively low frequency viz. 100 Hz or under gets propagated to external atmosphere through the foundation, etc. of the building, affecting the indoor living space (environment). Hence, the industrial power generator located near a residential area has a serious problem of low-frequency vibration, calling for excellent anti-vibration device.

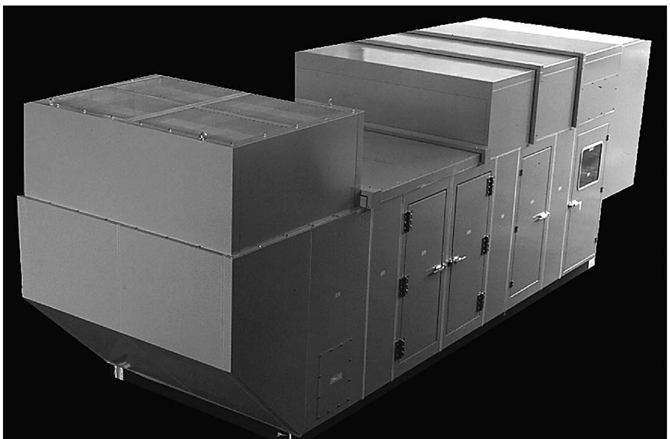

Fig.13 Package with extra-low noise specification 70 dB (A)
Designed for extra-low noise lower than the 85 dB (A) package.

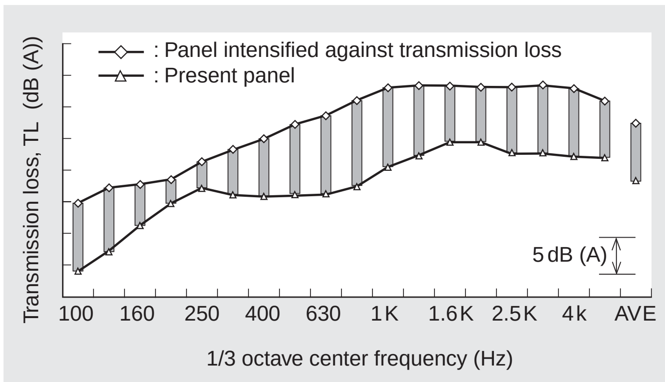

Fig.14 Result of measurement of panel transmission loss
Indicates drastically improved transmission loss of package and panel.

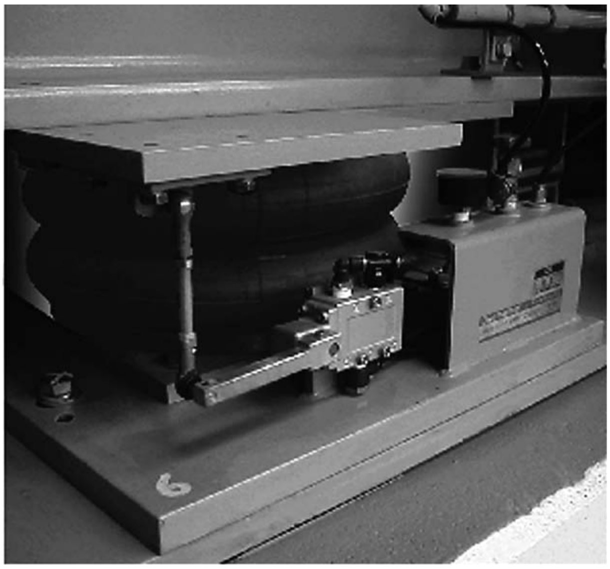

Fig.15 Example of actual air suspension
It is composed of air suspension, shock absorber, stopper, etc.

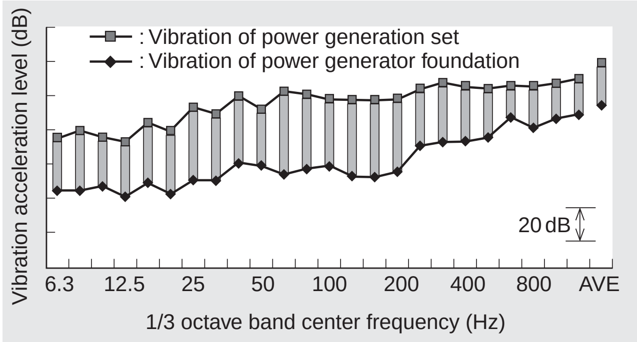

Fig.16 Result of measurement of air suspension vibration
Air suspension type with higher attenuation than the conventional vibration-proof rubber type.

The anti-vibration device has the anti-vibration effect increased by using softer spring elements supporting the device, but this in turn makes it difficult to design and install the device in consideration of the swing of the power generator.

MHI tested the air suspension shown in **Fig. 15** as the anti-vibration device, and obtained excellent results. The result of vibration measurement of the SU engine adopting the air suspension is shown in **Fig. 16**.

Compared with the vibration-proof rubber system with damping rate about 10 – 20 dB, the air suspension has fairly large anti-vibration effect.

Besides, the shock absorber to absorb the sharp swing at load variation and the large-displacement stopper are also installed as subsidiary devices to the air suspension. Thus, the optimization of these devices and costdown and improved durability are also regarded as future problems.

5. Conclusion

MHI has attained high efficiency of power generation equipment for power sale and cogeneration, and is positively engaged in environmental-responsive technologies. MHI has become successful in improving the efficiency and purifying the exhaust gas by introducing Miller cycle system and electronic control system to improve the combustion, contributing to effective utilization of fuel resource and reduction of CO_2 emission. MHI has developed and added the de-NOx system and black smoke removal equipment, the aftertreatment system for exhaust gas in order to further reduce the pollution. Further, MHI is engaged in measures for low-noise and low-vibration, taking account of the reliability of engines, and improvement of the installation environment for power generation engines.

With the higher needs to correspond with the environment expected in the future, MHI never fails to take one step ahead, and leaves no leaf unturned in developing low-pollution power generation engines. Further, MHI strongly believes that it can meet the customer's needs of high-efficiency co-generation, power selling business and low-pollution at low cost by installing the power generation engine equipped with environmental- responsive technologies to the on-site co-generation business.

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