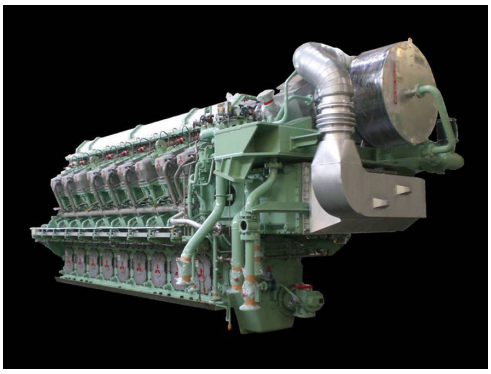
An Environmentally Friendly and Highly Efficient Combined Heat and Power Plant with a MACH II-SI (KU30GSI) Gas Engine for the University of Central Florida in the United States



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Mitsubishi Heavy Industries, Ltd. (MHI) has launched the marketing of the new gas spark-ignition MACH II-SI (KU30GSI) engine derived from the best-selling micro-pilot (MP) MACH-30G (KU30GA) engine, which uses a small amount of advanced fuel injection to ignite the fuel. This engine was developed for various customers' need as a combined heat and power (CHP) plant or as a backup standby generator for distributed power system or renewable energy sources power generation sites, including windfarms. We have received the first order for the United States market due to the high performance of the engine, including the total efficiency and plant engineering ability. This review introduces the features of the MACH II-SI (KU30GSI), which is easy to operate and does not require diesel fuel for MP injection, and describes the CHP plant being built for University of Central Florida(UCF) in the United States to promote sales in domestic and foreign markets.

1. Introduction

The introduction of a combined heat and power (CHP) plant with a spark-ignition (SI) MACH II-SI (KU30GSI) engine, which uses the clean energy of natural gas, provides customers with three benefits: a reduction in carbon dioxide (CO_2) emissions; a reduction in the load of existing air-conditioning facilities, since the plant provides chilled water from an absorption chiller utilizing the engine waste heat; and a corresponding reduction in the facility running cost. Our CHP project received an order from the University of Central Florida (UCF), a state university in Florida. We will provide this customer with the additional advantage of prompt after-sales service, in cooperation with Mitsubishi Power Systems America (MPSA), one of our local corporations, by procuring the generator (excluding the engine), absorption chiller, exhaust gas after treatment device, and auxiliary units, in the United States. The operation of the CHP plant is planned to start in the second half of 2011.

2. Features of the MACH II-SI (KU30GSI) Engine

The new MACH II-SI (KU30GSI) engine provides an electrical generation output of 3.65 to 5.5 MW at 60 Hz, or 3.8 to 5.75 MW at 50 Hz with 12 to 18 V cylinders. This is the same output at the same engine speed as the conventional MACH-30G (KU30GA) engine. By optimizing the Miller cycle and the air-to-fuel ratio, the MACH II-SI (KU30GSI) engine realizes a high total efficiency including an electrical generation efficiency of 47%, which is greater than that of the MACH-30G (KU30GA) by 1%. The efficiency of the engine waste heat recovery is also improved since the exhaust gas temperature is raised by approximately 20°C.

2.1 Main Engine Specifications

Through continuous technical development, Mitsubishi Heavy Industries, Ltd., (MHI) has accumulated the technological knowledge required to improve the efficiency of gas engines. A strong demand exists for spark-ignition gas engines that are not affected by changes in crude oil

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prices by not using diesel fuel. The new MACH II-SI (KU30GSI) engine was developed in response to these needs based on the abundant operational experiences cultivated for the MACH-30G (KU30GA) engine, the accumulated knowledge of high-efficiency technology, and the extension of design concepts from the MACH-30G (KU30GA) engine.

The target of the MACH II-SI (KU30GSI) was a higher total efficiency than that of the conventional MACH-30G (KU30GA) engine. This was obtained using the basic concepts of the maximized heat and power utilization of a cogeneration engine. To improve the total efficiency, the intake and exhaust valve timings, fuel gas supply timing, pre-combustion chamber volume, nozzle diameter of the pre-combustion chamber, and compression ratio were optimized. The high electrical generation efficiency and the high exhaust temperature were realized by suppressing the nitrogen oxide (NO_x) emissions to 320 ppm or less (at O_2 = 0%), ensuring stable combustion even in a rich air-to-fuel mixture.

Eighteen（18）cylinders version MACH Ⅱ-SI (KU30GSI) engine has been operating in a domestic power plant keeping the presence of a stable combustion the high reliability and endurance.

Table 1 shows the main specifications of the MACH II-SI (KU30GSI) engine.

Table 1 Main specifications of the MACH II-SI (KU30GSI) engine

Type		4-cycle gas engine			
	MACH II-SI (KU30GSI)	(Pre-chamber type spark ignition)			
Number of cylinders		12V	14V	16V	18V
Bore/stroke	mm	300/380			
Revolution speed	min^{-1}	720/750 (60/50Hz)			
Generation power	kW	3,650/3,800	4,250/4,450	4,900/5,100	5,500/5,750
Engine weight	ton	40	48	54	60
Combined efficiency (electrical efficiency* /steam efficiency)	%	66.1 (47/19.1)			
NOx (O_2=0%)	%	320ppm			

* Conforming to ISO3046 and based on MHI standard gas properties

2.2 Features of the Engine Construction

The design of the MACH II-SI (KU30GSI) engine was based on the basic design of the MACH-30G (KU30GA) engine, for which we have abundant operational experience. Changes related to the ignition system were kept to a minimum.

The supply of gas to the pre-combustion chamber adopted a control system with a gas-supply solenoid valve, which was used for the main chamber of the time-proven MACH-30G (KU30GA) engine. The air-to-fuel ratio in the pre-combustion chamber is always optimized with this system, and significant improvements in the performance and stability under a high mean effective pressure were realized compared to a conventional engine.

The three new structures were adopted in the MACH II-SI (KU30GSI) engine.

(1) To optimize the independent gas supply to the pre-combustion chamber, automatic non-return valves were provided at the gas-supply solenoid valve and downstream of the line to ensure flexibility and reliability and to control the fuel and air mixture concentration in the pre-combustion chamber.

(2) A strong torch jet was provided in the structure of the pre-combustion chamber to optimize the combustion stability.

(3) By using a bore cooling pre-combustion chamber, the abrasion of the electrode was reduced on the spark plug, so the life of the spark plug was extended by maintaining lower temperature. The interval of possible continuous operation hours depends on the life of the spark plug. A robust electrode condition was verified after more than 2,000 hours of operation in our in-house demonstartion plant.

Other than the structures mentioned above, eighty percent of the engine parts are common to those of the MACH-30G (KU30GA), as shown in **Figure 1** The development of a highly reliable engine was thus completed in a short period of time.

2.3 Control and Monitoring System

The MACH II-SI (KU30GSI) control system consists of a fuel controller that activates and controls the gas supply valves of the main and pre-combustion chambers, an ignition device that controls the ignition system, and the proprietary Mitsubishi Real Time Intelligent Control System (M-RICS) that monitors and diagnoses the combustion condition in each cylinder. Our DIASYS Netmation, a distributed control system (DCS) for power-generating installations, integrates and controls each controller based on operating data, such as information from the diagnostic system and each pressure and temperature sensor in the engine, thereby controlling and monitoring the whole plant, including auxiliaries. A knocking detector is also employed for the MACH II-SI (KU30GSI) for the prompt detection of early knocking signs to ensure safe and proper control. More reliable specifications are realized with the dual protective functions upgraded from the conventional combustion diagnostic systems. **Figure 2** shows the complete control system for the MACH II-SI (KU30GSI) engine.

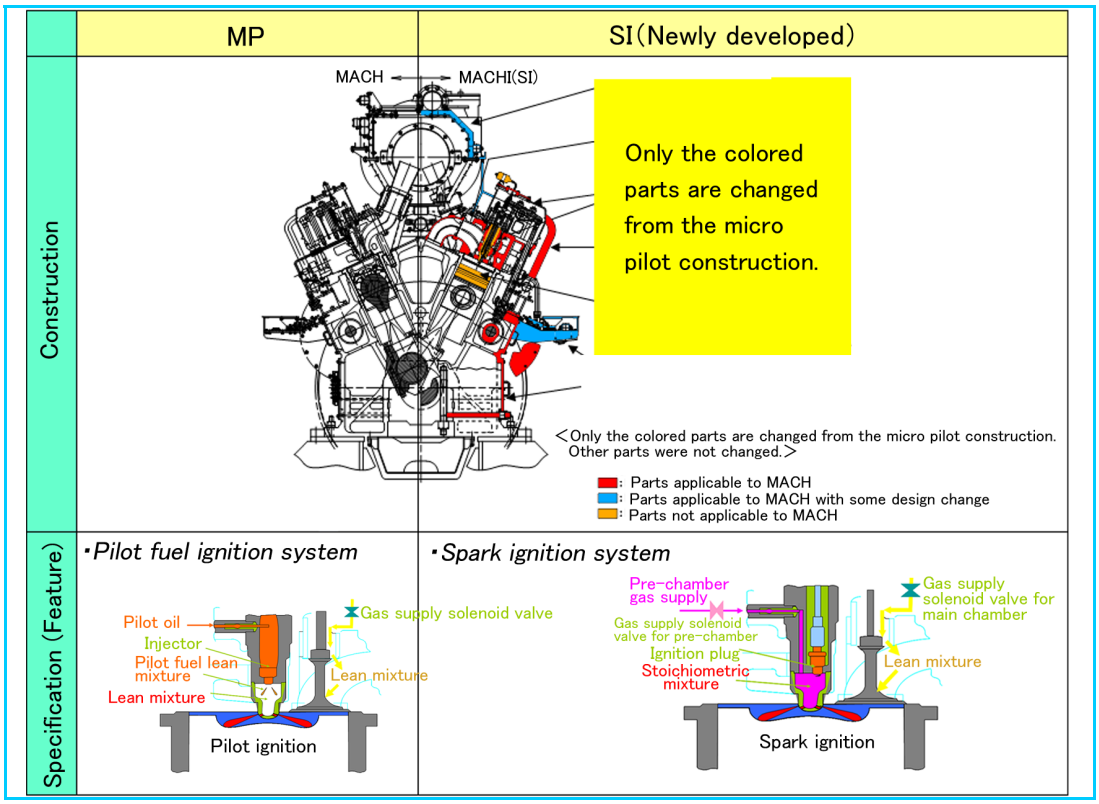

Figure 1 Construction of the MACH II-SI (KU30GSI) engine

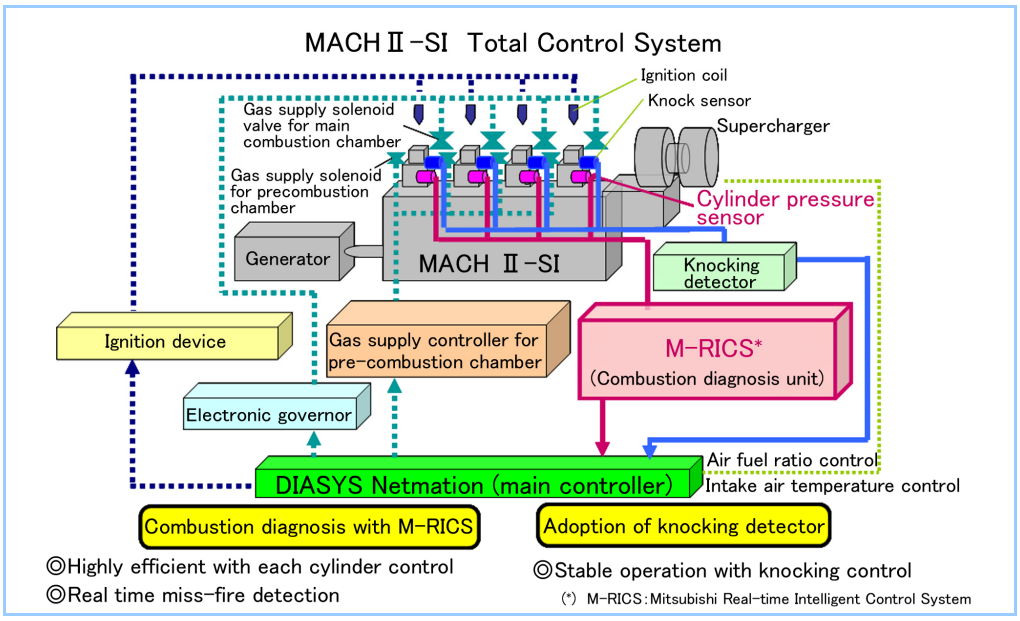

Figure 2 MACH II-SI (KU30GSI) control system

3. Outline of Combined Heat and Power (CHP) Plant for the University of Central Florida (UCF)

UCF, one of eleven Florida state universities, is the second largest university in the US with more than 56,000 students. The location of the university (**Figure 3**) in the suburbs of Orlando, where the climate is warm, faces increasing facility expenses and operating costs associated with air conditioning and electricity demands that peak during summer months. Under these circumstances, a CHP plant public bidding was offered. The contract criteria included reducing the cost of electricity and emissions of carbon dioxide (CO_2) by constructing a new CHP plant based upon a clean energy source. Another goal was to reduce the existing chilled water plant load by utilizing chilled water from an absorption chiller capturing multiple engine waste heat, while also reducing the facility's operating cost. In February 2010, four companies including Mitsubishi Heavy Industries, Ltd. tendered in the supply of equipment, and our proposal succeeded to receive the order gaining an outstanding evaluation compared to those of other companies. The CHP plant project also consists of the Engineering, Procurement and Construction (EPC) contract and the grid interconnection contract. **Figure 4** shows the outline of the whole project.

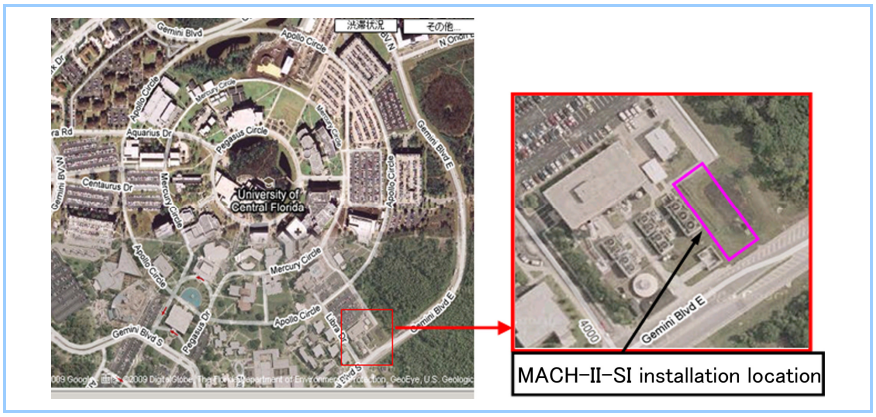

Figure 3 Location of the university

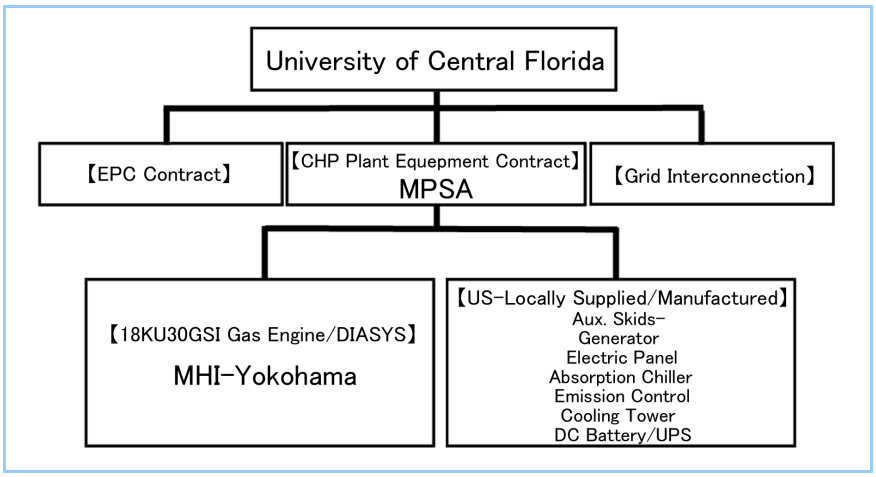

Figure 4 Outline of the entire project

The characteristics of the plant order include:

3.1 Plant Equipment Configuration

To receive the order, we suggested procuring the generator, electrical panels, absorption chiller, exhaust gas after treatment and auxiliary equipment in the US to comply with US standards, speed-up maintenance and emergency response and shorten parts delivery time in cooperation with Mitsubishi Power Systems America (MPSA), one of our local corporations of MHI Power Systems Headquarters. These added advantages also supported the high evaluation marks. **Figure 5** shows equipment configuration. The main features of the plant equipment include:

(1) Multi-energy absorption chiller incorporating heat recovery from exhaust gas and hot water

(2) Integrated silencer incorporating exhaust gas muffler and oxidation catalyst

These devices provided a compact arrangement designed to fit within the limited construction space. Also this plant introduces the first engine into the US market with the following features:

(3) Minimized local work by applying modular design of the locally procured plant auxiliaries
(4) Ensure high product quality and shorten delivery time of auxiliaries cooperating with US suppliers
(5) Smoothen builders' scope civil engineering, construction and errection to reduce field piping and wiring work

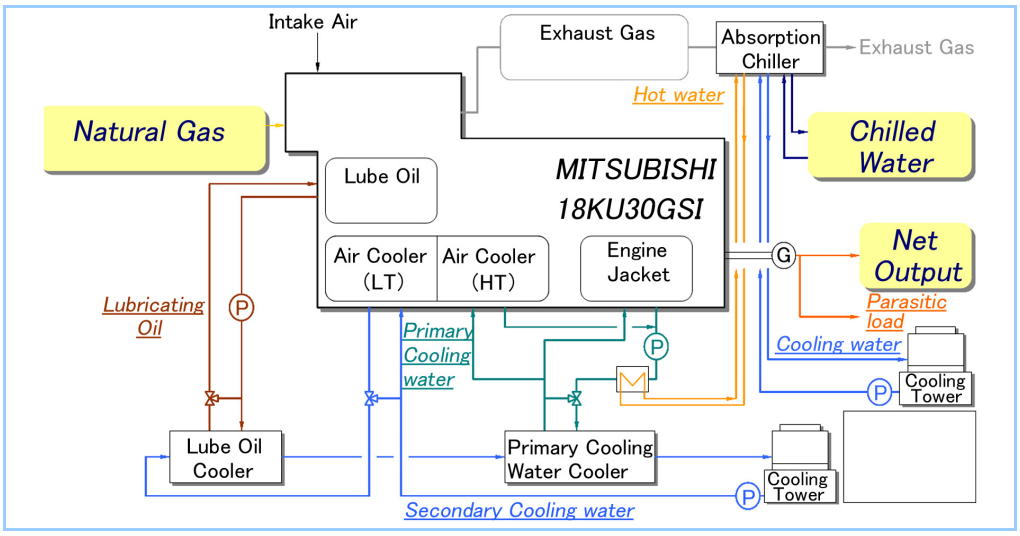

Figure 5 Plant equipment configuration

To achieve these ideas the plant arrangement was visualized from its inception by using with a 3-dimensional model as shown in **Figure 6** to visualize key components for reducing fabrication and installation work risk, and expediting delivery and construction schedules.

The concentration of nitrogen oxide (NOx) and carbon monoxide (CO) after exhaust gas treatment, will register far below current EPA (Environment Protection Agency) regulations. This was important to UCF as a state university and their strong desire to protect the surrounding environment.

3.2 Heat Balance and Total Efficiency

Figure 7 shows the heat flow of CHP plant. The generator directly connected to the engine will produce 5500 kW and the multi-energy chiller absorbing the waste heat from the exhaust gas and hot water systems will provide approximately 1000 refrigeration ton (RT) of chilled water to UCF.

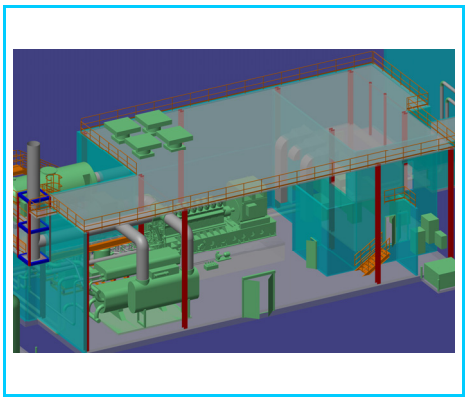

Figure 6 Visualization with 3-dimension model

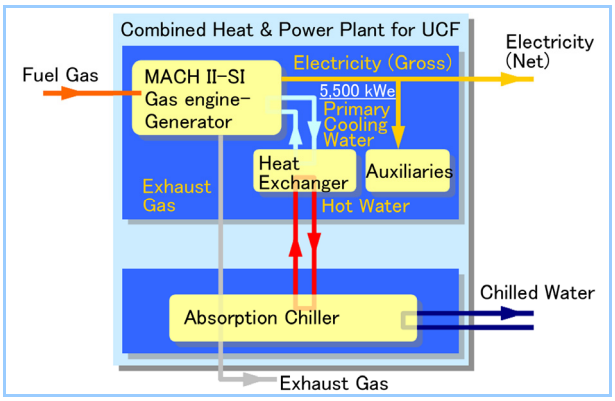

Figure 7 Heat flow of CHP plant

The total efficiency of the plant far exceeds conventional simple cycle power generation systems. The high Co-efficient of Performance of the multi-energy absorption chiller enables UCF to reduce the demand on their existing turbo chillers. Both values are the highest levels evaluated during the bid review.

3.3 After-Sales Service System

We are considering the after-sales service of the plant for a coordinated response taking every necessary and sufficient measure as below:

(1) Parts supply and overhaul work contract for five years with Condition Based Maintenance concept.

(2) Responding periodical and emergency work, together with parts supply by MPSA Orlando Service Center as a primary contact office.

(3) Application of remote monitoring system proven in many applications of MACH-30G (KU30GA) and also MHI Gas Turbines operated in the Americas.

4. Conclusion

MHI has launched the new MACH II-SI (KU30GSI) engine, which eliminated the use of ignition-assisting fuel oil. The accomplishments of this project will contribute to the expansion of MACH gas-engine sales, and will provide a showroom in North America to demonstrate the performance and reliability of MACH engines applied to CHP plants. Our local corporation, MPSA, will enhance customer satisfaction by providing community-based service. Currently, detailed engineering and manufacturing of equipment are in progress. The plant will start operation in the third quarter of 2011, and is expected to be highly reliable to ensure customer satisfaction.

References

1. Ishida et al., CIMAC Congress 2010, Bergen, Paper No. 109
2. Ishida et al., MACH II-SI (KU30GSI) Gas Engine with the World's Highest Total Efficiency (66%), Mitsubishi Heavy Industries Technical Review Vol. 46 No. 2 (2009) pp.26-30