2008 Prize of Director General of Regional Bureau of Economy, Trade and Industry

Realization of Energy Conservation by Changing Existing Steam Turbines to Driving by Ultra-high Speed Inverter Motors

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◎ **Keywords: Rationalization of conversion to heat motive power (Cogeneration equipment)**
Other (Centrifugal compressor, condensing turbine, inverter motor, and ultra-high speed drive)

◎ Outline of Theme

The centrifugal compressors of our refinery's petroleum refining equipment have been driven by condensing type steam turbines that are suitable for ultra-high speed and variable speed operation. From the viewpoint of heat loss, the effectiveness of changing the existing system to motor driving had been recognized, but it had been postponed due to restrictions in the on-premises power supply capacity and during the facilities installation. Afterwards, improvements made for the power supply capacity triggered expectations for energy optimization in the on-premises electric power and steam balance, and eventually a change in the driving system was implemented using ultra-high speed inverter motors that could be applied to the centrifugal compressors.

As a result, energy conservation of approximately 8,200 kL/year was achieved when converted to crude oil (Approximating to 22,000 tons of carbon dioxide/year).

◎ Implementation Period for the Said Example

● Project Planning Period	July 2005 – August 2005	(Total of 2 months)
● Measures Implementation Period	September 2005 – May 2007	(Total of 21 months)
● Measures Effect Confirmation Period	June 2007 – December 2007	(Total of 7 months)

◎ Outline of Refinery

- Items Produced LPG, naphtha, gasoline, kerosene, diesel, heavy oil, electric power
- No. of Employees 280 persons
- Type 1 designated energy management factory

◎ Target Facility

Outline of the steam system chart of the refinery is shown in Fig. 1. Four condensing steam turbines were to be subject to the change to motor driving. Among these, a total of three units, consisting of two catalytic reforming equipment hydrogen gas compressor units and one alkylation equipment butane gas compressor, were subject to the change to use ultra-high speed inverter motors.

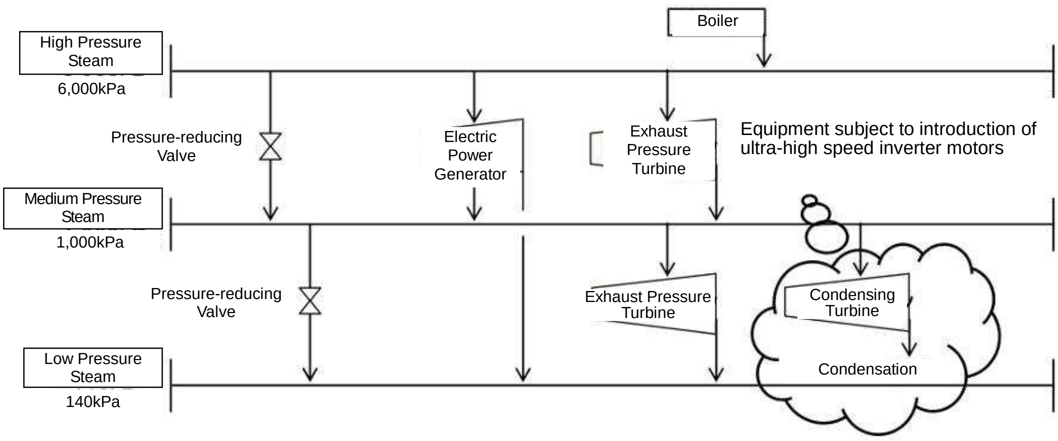

Fig. 1 Outline of the Steam System Chart of the Refinery

1. Reasons for Theme Selection

In 2005 this refinery installed gas turbine combined cycle power generation equipment in addition to the existing power generation equipment that consisted of two boilers and a steam turbine. When we confirmed the energy balance after the gas turbine began operation, we found that there was some surplus in the supplied electric power. By effectively using this surplus electric power supply, the existing centrifugal compressors in the petroleum refining plant could be changed from being driven by condensing steam turbines to being driving by motors, realizing highly efficient energy use.

In the situation where existing steam turbines are changed to be motor-driven, there are many restrictions that must be resolved including the problems of installation space and equipment specifications.

Centrifugal compressors in petroleum refining plants require drivers that have the characteristics of large output, ultra-high speed, and variable rotation speeds.

In recent years, due to the progress made in inverter technology it has become possible to manufacture small-sized ultra-high speed inverter motors that satisfy the required conditions while requiring little space for installation. Accordingly, in this refinery, the various problems occurring when changing the existing centrifugal compressors to being motor-driven were confirmed, and it was aimed to realize energy conservation for this equipment that had previously been left untouched.

2. Progress of Activities

(1) Implementation Structure

The selection of the target equipment, and the trial calculation and evaluation of the energy conservation effects were carried out by our company's process engineers, while the equipment design was carried out by our company's equipment engineers (Rotating machines, electricity, instrumentation, and construction) together with the electrical machinery manufacturers and compressor manufacturers.

(2) Understanding of Current Situation

In the refinery, there were several compressors that used condensing steam turbines as driving sources which had low energy usage efficiency. A summary of the operation conditions are shown below.

Table 1 Compressors using Condensing Steam Turbines as Driving Sources

	Steam Usage Amount	Shaft Power (Normal Use)
Hydrogen Gas Compressor No. 1	13 ton/h	1,840 kW
Hydrogen Gas Compressor No. 2	6 ton/h	800 kW
Hydrogen Gas Compressor No. 3	7 ton/h	900 kW
Butane Gas Compressor	8 ton/h	1,000 kW
Total	34 ton/h	4,540 kW

From this it could be understood that an electric power supply of 5,000 kW or greater would be necessary for improving the energy efficiency by changing to motor driving.

On the other hand, when the surplus electric power supply from the on-site generation was investigated, it was found that there was a surplus of approximately 9,000 kW in the electric power supply due to the alleviation of the electric power balance by introducing the gas turbine power generator.

In order to determine whether or not there was enough of a surplus to supply the electric power, an investigation was carried out into the refinery's in-house power generation equipment. (Table 2)

Table 2 Operation Condition of In-house Power Generation Equipment in the Refinery

Power Generation Equipment Name	Rating	Operation Condition	Power Generation Surplus Power
No. 1 In-house Power Generation Equipment	15 MW	9 MW	Excluded for the reason that operation is required to realize the steam balance
No. 2 In-house Power Generation Equipment	149 MW	143 MW	6 MW
No. 3 In-house Power Generation Equipment	20 MW	17 MW	3 MW
Total	184 MW		9 MW

Due to the electric power balance alleviation resulting from the introduction of the gas turbine generator No. 3 in-house power generation equipment, it was found that there was 9,000 kW of surplus electric power supplied even at peak times, which would be capable of fully absorbing the increase in electric power demand following the change of the condensing steam turbines to motor driving.

(3) Analysis of Current Situation

Because confirmation had been made of the presence of condensing steam turbines having low energy usage efficiency, together with a surplus of in-house generated electric power which could be used for the change to motor-driving, we were then able to proceed with investigating and analyzing the actual operation after motor-driving, and the following necessary items were confirmed.

Table 3 Design Items required from an Operations Point of View for Changing Each Compressor to Motor Driving

Compressor Name	Items required from an Operations Point of View
Hydrogen Gas Compressor No. 1	Low rotation operation will be required during ultra-high speed rotation and when starting and stopping the equipment
Hydrogen Gas Compressor No. 2	Necessity to allow for capacity that will be required in the future
Hydrogen Gas Compressor No. 3	No particular requirements
Butane Gas Compressor	Large variations in loading according to seasons, etc.

Table 4 Design Items required from an Equipment Point of View, and Pending Problems for Changing Each Compressor to Motor Driving

Compressor Name	Items required from an Equipment Point of View, and Pending Problems
Hydrogen Gas Compressor No. 1 Hydrogen Gas Compressor No. 2 Butane Gas Compressor	① Equipment must be able to fit into the installation space of the existing steam turbine (Pending Problem) There is insufficient space for the motor and speed-increasing gear combination It is necessary for the weight to remain within the existing foundation strength range ② Must be capable of variable speed operation up to ultra-high speeds (10,000 rpm class) (Pending Problem) There are very few actual results of ultra-high speed inverter motor operation, and there are no cases of utilizing these to change an existing compressor to motor-driving
Hydrogen Gas Compressor No. 3	No technical problems, since it is a fixed speed low rotation reciprocating compressor

(4) Target Settings

Although it was necessary for the Hydrogen Gas Compressors Nos. 1 and 2 and the Butane Gas Compressor to support the pending problems described in Table 4, all of the condensing steam turbines in Table 1 could be changed to motor driving due to the adoption of ultra-high speed inverter motors, achieving the following large energy conservation effects.

a. Reduction in steam usage amount

Total 34 ton/h (Crude oil conversion of 19,300 kL/year)

(Out of this, the heat loss reduction amount due to halting the condensers was approximately 8 ton/h, a crude oil conversion of 4,700 kL/year)

b. Electric power usage amount following electric motor introduction

Total 4,540 kW/h (Crude oil conversion of 11,100 kL/year)

(Out of this, the electric power usage reduction effect due to using inverter control was 1,470 kW)

c. Anticipated energy reduction due to electric motor introduction (= Target)

Crude oil conversion of 8,200 kL/year

(5) Problem Points and Their Investigation

The main problem areas were identified from the current situation analysis as the following.

1) Installation space

Because there was insufficient space for installing combinations of high speed motors with speed-increasing gears, it was judged that ultra-high speed inverter motors would be essential. As a result of investigating the dimensions and weights of the ultra-high speed motors, it was found that it would be possible to install them on the existing equipment.

2) Concerning the requirement for variable speed at ultra-high speeds, and the lack of its past implementation results

The compressor and motor resonant frequencies and the operation rotation speeds were confirmed both at ultra-high speeds in their normal operating bands (10,000 rotations/min class) and during equipment starting and stopping low rotation bands (1,000-2,000 rotations/min).

For the point relating to the lack of past implementation l results, it was judged that support was possible due to implementing a design that considered the inverter motor specific torsional resonance phenomenon based on the technical know-how of the electrical machine manufacturers and compressor manufacturers. Specifically, it was determined to implement an inverter circuit design that was resistant to torsional vibration, and to confirm the coupling torsional resonance rotation speed and the operation rotation speed.

(6) Details of Measures

1) Equipment configuration

The driving equipment of the existing centrifugal gas compressor was changed from the configuration in Fig. 2 to that in Fig. 3.

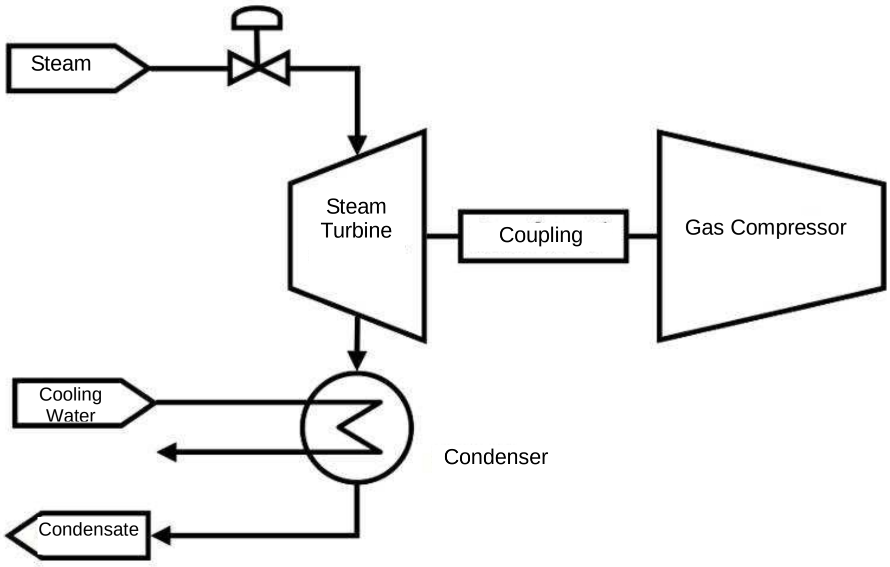

Fig. 2 Configuration of Driving Equipment of Gas Compressor (Before Changing)

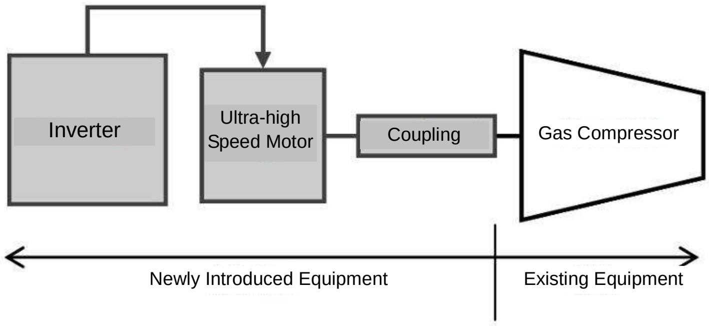

Fig. 3 Configuration of Driving Equipment of Gas Compressor (After Changing)

2) Specifications of the newly introduced driving equipment

The equipment specifications of the ultra-high speed motors and inverters are as shown below. (Table 5 and Table 6)

Table 5 Motor Specifications

Target Equipment	Rated Conditions	Normal Range
Hydrogen Gas Compressor No. 1	1,840 kW x 10,000/min	6,000-10,000/min
Hydrogen Gas Compressor No. 2	1,840 kW x 12,000/min	6,000-12,000/min
Butane Gas Compressor	1,380 kW x 8,000/min	5,500-8,000/min

Table 6 Inverter Specifications

Power Supply	6,600V－60Hz
Inverter Type	Synchronized Pulse Width Modulation (PWM) Type

3) Result of investigation of measures for resolving problem areas

a. Investigation of operating rotation speed and resonant rotation speed

Concerning the rotational bodies of the compressors, motors, and coupling, confirmation was carried out into their resonant frequency speeds.

The resonance rotation speeds (critical speeds) and torsional resonance speeds of each part were calculated, and the relationship between the equipment operation speed over the normal range and the rotation speeds when starting and stopping were adjusted. (Fig. 4)

Comparison and adjustment between the equipment operation methods was carried out, and it was possible to secure a control rotation range that would not interfere with the operation.

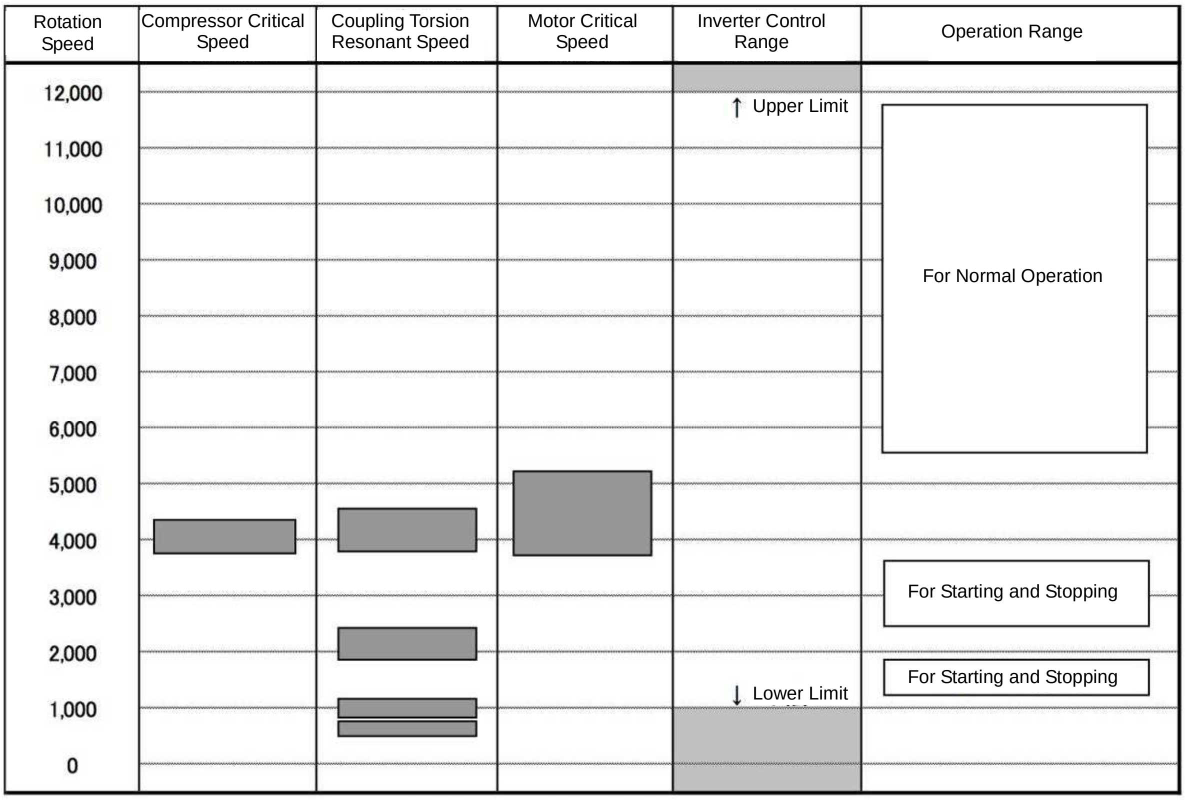

Fig. 4 Relationship Diagram between Operating Rotation Speed and Resonant Rotation Speed

b. Equipment condition

The ultra-high speed inverter motors were installed in the spaces where the steam turbines had been removed.

Fig. 5 Equipment Exterior View (New Inverter Motor and Existing Butane Gas Compressor)

(7) Effects Achieved after Implementing Measures

By implementing a series of measures, energy conservation was realized that achieved the initial target values.

Table 7 Energy Conservation Effect of Changing Condensing Steam Turbines to Motor-driving

Steam Usage Reduction Amount	34 ton/h
Electric Power Usage Amount	4,540 kW
Energy Conservation Amount	8,200 kL/year Crude Oil Conversion
(Carbon Dioxide Reduction Amount)	Equivalent to Approximately 22,000 ton/year

3. Summary

The existing three steam turbines in the plant used for driving the centrifugal gas compressors were replaced with ultra-high speed inverter motors.

For the replacement, it was necessary to confirm the restrictions due to the installation space and the inverter motor unique mechanical characteristics.
As a result, four compressors were changed to become motor-driven, which succeeded in achieving energy conservation of a crude oil conversion amount of 8,200 kL/year due to reducing the steam usage amount.
In this case study, because the development to similar existing equipment in petroleum refineries and petrochemical plants can be expected, it is believed that the measures will be able to contribute to energy conservation activities in the future.

4. Future Plans

It is planned that the knowledge obtained through the actual results of carrying out these activities will be shared within the company so that they can be used to influence the investigations for changing to new energy conservation.