Development and Approach to Future Market of the Eco-Radial Steam Turbine Generator

Atsushi YOSHIDA *[1], Osamu MATSUTANI *[2]

*[1] Refrigeration System & Energy Dept., Compressor Div., Machinery Business
*[2] Shinko Engineering Co., Ltd.

A new power generation system, the Eco-Radial, has been developed and launched into the market. The system employs a radial turbine, designed for steam pressure up to 0.98MPaG. The manufacturing cost has been cut to 50% of the conventional cost as a result of various efforts such as downsizing, reducing the number of components and decreasing the machining time. This paper introduces the development of this new model and our approach to the future market.

Introduction

Kobe Steel originally developed an expansion turbine for the cold generation unit of an air separation system in 1934, launched a steam turbine in 1987, and since has been striving to promote the business of various turbines as professional energy-saving machines. The company has designed and built non-general-purpose radial turbines that can be used, not only for steam, but also for various other gases. Those gases include exhaust gas from the reactors of chemical plants, ammonia gas mixed with water−the gas mixture used for the Kalina cycle for recovering mid-to-low-temperature exhaust heat−liquefied natural gas and city gas. These radial turbines have been favorably received by many users.

Being tailor-made, however, these non-general-purpose turbines are rather costly and have been delivered only to a limited number of customers.

With this background, Kobe Steel has developed and launched a small power generating system (hereinafter referred to as the Eco-Radial [note 1)]) equipped with a general-purpose radial turbine. This system is designed for boiler steam at pressures up to 0.98MPaG, the pressure range commonly used by many users. The newly developed turbine maintains the high efficiency that is an advantage of radial turbines and is less costly. This paper outlines the development of the Eco-Radial and introduces its future market.

note 1) Eco-Radial is a Kobe Steel's trademark registered in Japan.

1. Advantages of non-general-purpose radial turbines developed by Kobe Steel

1.1 High efficiency

Turbines are generally classified into an axial-flow type and a radial-flow type. Kobe Steel adapted a radial-flow type (hereinafter, a "radial turbine"). This radial turbine comprises a built-in reduction gear that makes the speed ratio between its high-speed shaft and low-speed shaft selectable. Optimizing the rotational speed of the high-speed shaft, having a turbine impeller (hereinafter, a runner) at its end, ensures high efficiency.[1)-3)] **Fig. 1** compares the structures of an axial turbine and a radial turbine, and **Fig. 2** shows the power they generate under certain conditions. As shown, the radial turbine is superior to the axial turbine for the conditions of low pressure and small output power.

1.2 High reliability

One of the advantages of a radial turbine is its small number of components. For example, an axial turbine has an impeller with several tens of blades

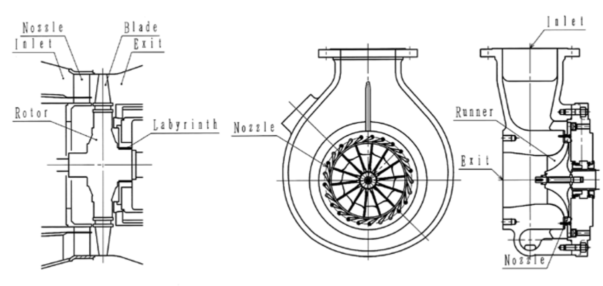


Fig. 1 Comparison of axial turbine and radial turbine

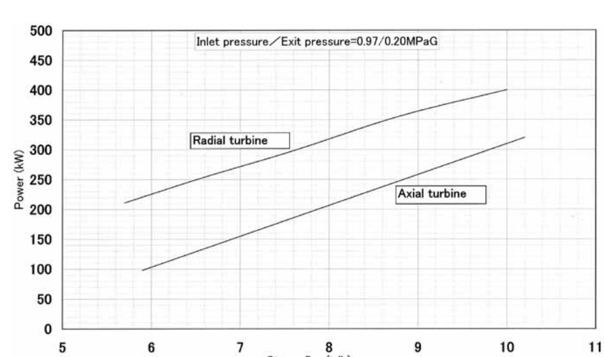


Fig. 2 Power comparison of Eco-Radial and axial turbine

embedded. A radial turbine, on the other hand, has an impeller (runner) incorporating blades that are machined out from a forging stock as a unit, all together comprising a single component. This impeller is attached to an end of a high-speed shaft rotor, which contains fewer than ten components in total. The small number of components results in a simple mechanical structure with the advantage of more easily securing greater reliability.

1.3 High durability

Kobe Steel's first machine, a small turbine for 500kW class generator, is still running smoothly at a plant owned by the customer. For fluids other than steam, there are many machines that have been running for over thirty years.[4)]

2. Development of Eco-Radial

2.1 Developmental background

In order to cope with global warming and with the power supply problem after the Great East Japan Earthquake, improving power self-sufficiency has become a major industrial issue. In 2007, Kobe Steel began selling a small screw-type steam generator, the STEAMSTAR™ MSEG™ [note 2)] and since then has delivered more than seventy units. Recently, with the increasing demand for power saving, there have been new projects to save power using several generators of the 160kW class. In order to respond to such a high-end market for the STEAMSTAR MSEG, Kobe Steel started to downsize a conventional steam generator−a non-general-purpose type equipped with a radial turbine−to develop a new general-purpose generator, the Eco-Radial (model number: GRT160e, maximum output 400kW), which is a unit type and is less costly. **Table 1** shows the design specifications of the Eco-Radial.

2.2 Generalization and cost reduction

This development project has primarily aims at significantly reducing the cost while achieving a high efficiency that is an advantage of radial turbines. Specific measures for the cost reduction include commonizing components by generalizing the purposes within the scope of the applications of the developed machine, reducing the weight of each component and simplifying the structure. Such commonization includes large castings, such as gear casings and turbine casings, which have been commonized to perpetuate the wooden models used for the casting and thus to reduce the cost of these models. As a result, the production cost has been reduced to approximately 50% of the conventional cost.

note 2) STEAMSTAR and MSEG are trademarks of Kobe Steel.

Table 1 Specifications of Eco-Radial

	Eco-Radial (GRT160e)
Inlet condition: Max. pressure (MPaG) Max temperature (℃)	 0.97 210
Exit pressure (MPaG)	0〜0.5
Steam flow (t/h)	2.5〜10.0
Max. power (kW)	400
Generator type	Induce
Size(mm)	1,900×3,500×1,900
Weight(kg)	3,500
Control system	4 options with inlet valve (power, inlet pressure, exit pressure or flow constant control)

The following section outlines the cost-reduction measures for the major components of a radial turbine, i.e., a turbine runner and turbine nozzles.

2.3 Reducing the number of turbine-runner blades and turbine nozzles

Among the various components that constitute a turbine, the turbine runner is the most costly to machine. This component, however, affects the turbine performance directly; hence no major effort has hitherto been made to reduce its cost. For the same reason, not much effort has been made to reduce the cost of the turbine nozzles. This project has aimed at significantly reducing these costs, while minimizing the adverse effect on the turbine performance. Studies were conducted to reduce the machining cost by decreasing the number of the turbine-runner blades and turbine nozzles.

2.3.1 Reduction of machining time

Decreasing the numbers of the turbine-runner blades and turbine nozzles increases the area of the gas passages inside these components. This enables the use of drill bits with large diameters when machining, which can reduce the machining time. In the present project, these numbers were reduced as shown in **Table 2**, which reduced their machining costs to approximately 60% of what they had been.

2.3.2 Verification of turbine performance using actual machine

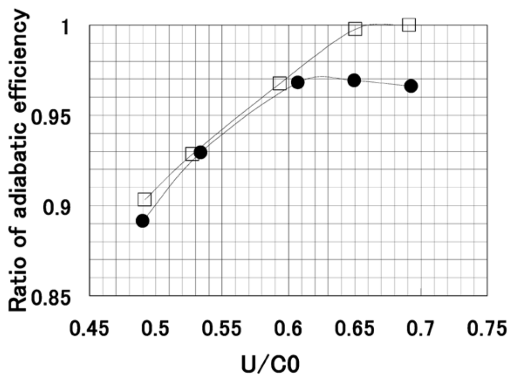
In order to verify the performance of the turbine

Table 2 Processing cost comparison of Eco-Radial and original

	Number of runner blades	Number of nozzles	Processing cost
Eco-Radial	11	14	60%
Original	14	26	100%

Table 3 Test condition

Inlet pressure (MPaA)	Inlet temperature (℃)	Exit pressure (MPaA)	Test Gas
0.3221	184	0.12	Air



□ : Runner blade number =14＋Nozzle number =26 (Original)
● : Runner blade number =11＋Nozzle number =14 (Eco-Radial)
U/C0 : Dimensionless number showing turbine operation condition

Fig. 3 Test result of turbine performance (Ratio of adiabatic efficiency vs. U/C0)

with its numbers of runner blades and nozzles reduced, tests were conducted using an actual machine loaded with air. **Table 3** shows the test conditions.

The test results verify that the turbine with a decreased number of blades and nozzles exhibits, at maximum, approximately 97% of the efficiency of the conventional turbine (**Fig. 3**). From these results, it has been judged that the effect of the reduced number of blades and nozzles on the turbine performance falls within an acceptable limit.

2.3.3 Verification of turbine performance by CFD analysis

As described in 2.3.2, the reduced numbers of the turbine-runner blades and turbine nozzles were found to cause a drop in turbine efficiency, although the decrease is within an acceptable limit quantitatively.

A computational fluid dynamics (CFD) analysis was performed to clarify the main cause of the efficiency drop.

(1) The effect of the reduced number of nozzles on the turbine efficiency

A test on an actual machine has revealed that the reduced number of nozzles affects the turbine efficiency only slightly. Therefore, the number of nozzles was set at the conventional number (26 nozzles) in the model for this CFD analysis.

(2) CFD analysis model and analysis conditions

The analysis object (range of modeling) consists of a series of flow passages including turbine nozzles, a turbine-runner, outlet pipe and straight pipe (up to the pressure measuring port on the outlet side for the test run on an actual machine) (**Fig. 4**). The analysis conditions were as follows:

- Software used: ANSYS FLUENT R13
- Fundamental equations: Equation of continuity, Navier-Stokes equation, Energy equation
- Turbulence model: k- ε SST2 equation model
- Boundary condition : The same as the actual machine testing condition (Table 3)
- Other conditions including rotational speed: **Table 4**

It should be noted that the numbers of the runner blades were set at 14, the conventional number, and 9. Both of these numbers are different from the number 11, which was used for the test run on the actual machine. This is because conducting analyses on two conditions with vastly different numbers of blades is expected to clarify the cause for the efficiency drop.

(3) Analysis results

As for turbine efficiency, the analysis qualitatively yielded almost the same result as the

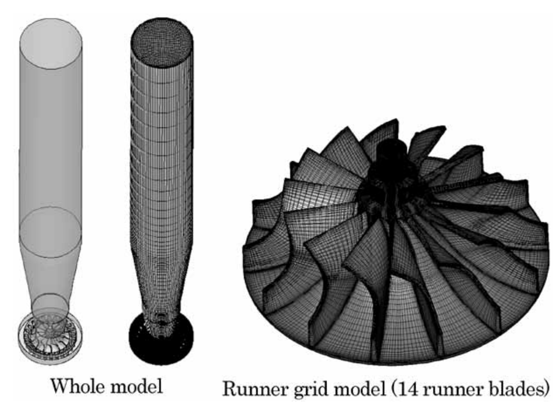


Fig. 4 Analysis model

Table 4 Analysis conditions

Case	U/C0	Rotation speed (rpm)	Number of runner blades
Case1	0.7	39,800	14
Case2	0.6	34,000	14
Case3	0.49	27,200	14
Case4	0.7	39,800	9
Case5	0.6	34,000	9
Case6	0.49	27,200	9

Number of nozzles : 26 in all cases

test run on the actual machine (**Fig. 5**). From the analysis results shown in **Fig. 6**, the relative flow velocity at the runner outlet is as follows:

- For U/C0 = 0.7

  The relative flow velocity at the outlet suction surface near the shroud side was approximately 200m/s when the number of the blades was 14. When the number of the blades was 9, on the other hand, it became 0 to 15m/s, indicating the existence of a low speed region (separated flow region).

- For U/C0 = 0.6 and 0.49

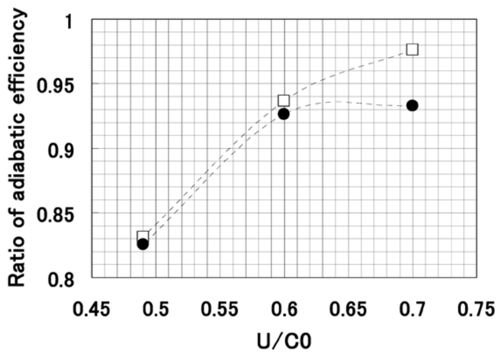
  The flow-velocity profile at the outlet was barely affected by the number of blades.

(4) Summary of the effect of the number of runner blades

Table 5 summarizes the differences in the efficiency ratio and relative flow velocity profile at the runner outlet between 14 blades and 9 blades. From this, it is considered that there is a qualitative relationship (or effect) on the efficiency ratio and relative flow velocity profile at the runner outlet when the number of blades is decreased from 14 to 9.

(5) The reason for the efficiency drop caused by the reduced number of runner blades

From the description in (4), the cause of the efficiency drop when the number of blades is reduced is considered to be related to the difference in the relative flow velocity profiles at the runner outlet. In the case of U/C0 = 0.7, in which the difference in efficiency is large, the effect of the low speed region (separated flow region) generated at



□ : Runner blade number = 14 + Nozzle number = 26 (Original)
● : Runner blade number = 11 + Nozzle number = 14 (Eco-Radial)
U/C0 : Dimensionless number showing turbine operation condition

Fig. 5 Turbine performance curve by CFD analysis (Ratio of adiabatic efficiency vs. U/C0)

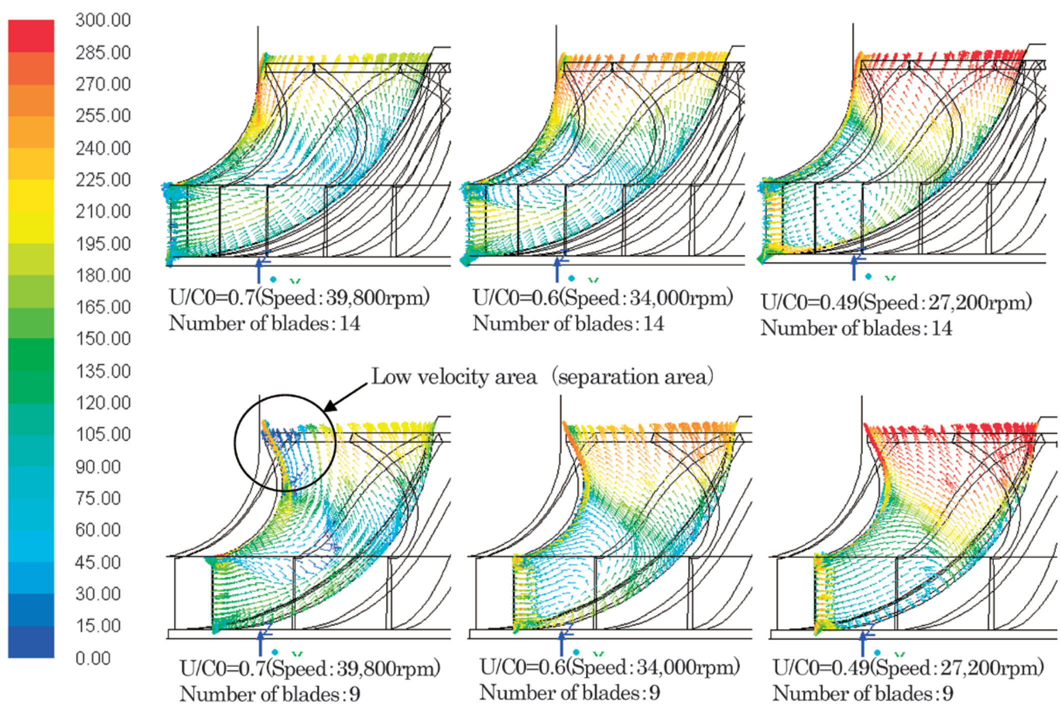


Fig. 6 Relative velocity profile near suction meridian surface by CFD analysis

Table 5 Relationship between difference of efficiency ratio and difference of relative velocity profile at runner outlet

U/C0	Difference of efficiency ratio between 14 blades and 9 blades in measured result	Difference of efficiency ratio between 14 blades and 9 blades in analytical result	Difference of relative velocity profile between 14 blades and 9 blades in analytical result
0.7	big	big	big
0.6	small	small	small
0.49	small	small	small

the outlet suction surface near the shroud side is considered to be rather significant.

2.4 Test operation loaded with steam

In order to verify the mechanical stability during actual-load operation, the shaft vibration, bearing temperature, leakage and the like were confirmed on an Eco-Radial operated with steam generated by a boiler. The results verified that there was no operational problem.

2.5 Summary of Eco-Radial development

① The production cost has been reduced to approximately 50% of the conventional cost, achieving the original goal.
② As a way of reducing cost, the numbers of the runner blades and nozzles were decreased. The resulting decrease in turbine performance was verified as falling within an acceptable limit.
③ From the CFD analysis, the decreased turbine performance caused by the reduction in the number of runner blades was considered to be attributable to the low speed region (separated flow region) generated at the outlet suction surface near the shroud side. This presumption is considered to be useful in designing special runners based on the current runners and in developing new runners.

3. Advantages of Eco-Radial

Fig. 7 shows the outline of the Eco-Radial package. **Fig. 8** compares the appearance of Eco-Radial package with that of the conventional package of Kobe Steel's non-general-purpose radial turbine (gas recovery turbine; GRT). The Eco-Radial is a compact package including the turbine body, generator, piping, miscellaneous devices, and supplemental equipment such as a control panel, all installed on a common base. As a result, the new package has a smaller foot print than Kobe Steel's conventional radial turbines and reduces the period and cost of the fieldwork, including piping. Standard equipment includes Kobe Steel's original control monitor system, Kobenicle,® note 3) which facilitates maintenance. Kobenicle provides remote 24hr monitoring of operation conditions and alarms. In addition, it can record and store operational data for one year, which is quite useful for long-term operational management, including repair and maintenance.

note 3) Kobenicle is a registered trademark of Kobe Steel.

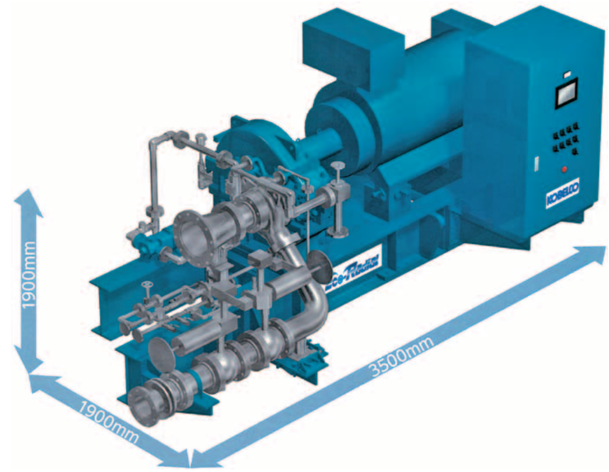


Fig. 7 Eco-Radial outline

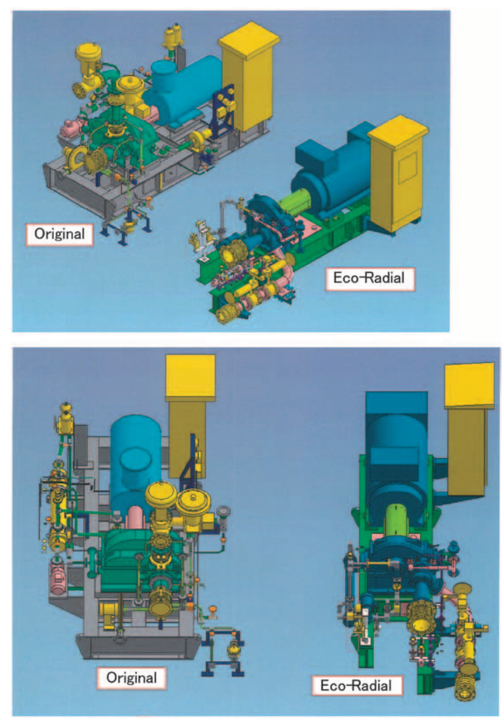


Fig. 8 Outline comparison of original machine and Eco-Radial

4. Applications of Eco-Radial

Fig. 9 shows an example of the application of the Eco-Radial. The Eco-Radial can generate electricity from unused energy using, for example, the surplus steam of factories. It can also be used as an alternative for pressure-reducing valves for process steam. The turbine is used as a key component of a small driver for a compressor, or for a pump. Outside Japan, there is a larger amount of unused steam, such as the exhaust steam from small-scale waste incineration plants. Thus, overseas applications will also be considered.

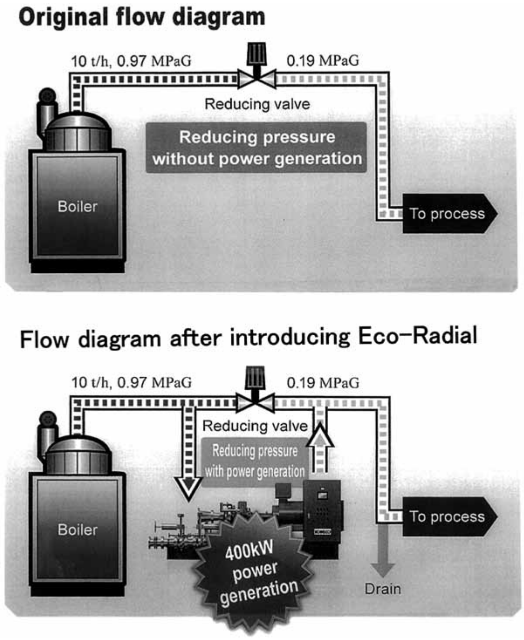


Fig. 9 Example of Eco-Radial application

5. Future initiative

5.1 Understanding market trends and optimizing specifications

Kobe Steel's non-general-purpose radial turbines can be used at pressures up to 45barG, temperatures up to 400℃ and power output up to 6,000kW, judging from the company's experience. The specifications of Eco-Radial can be optimized, without many technical issues, for ever-changing market trends both domestic and abroad. We will focus on markets with high needs, aiming to establish new specifications for Eco-Radial.

5.2 Measures against varying amount of steam

The efficiency of radial turbines is decreased during operation at off-design point (partial load), a type of operation caused by the varying amount of steam. In order to suppress this, our non-general-purpose radial turbines are equipped with "variable nozzle mechanisms." Eco-Radial, on the other hand, is not equipped with any variable nozzle mechanism, because that may enlarge the package size, increasing the number of components and complicating the structure. To alleviate the efficiency drop during operation at off-design point due to the varying amount of steam, an Eco-Radial may be combined with a "STEAMSTAR MSEG" (small steam generator) into a system, the latter being a displacement-type rotating machine, and then the efficiency is much less susceptible to operations at off-design point. The idea is to run Eco-Radial by base-load steam with a constant flow rate and to run STEAMSTAR MSEG by the varying steam. This makes it possible to deal with a varying amount of steam while maintaining high efficiency.

5.3 Activity for dissemination

The Eco-Radial product now sells at about half the price of the power generating system based on Kobe Steel's conventional non-general-purpose radial turbine. We will continue to strive to satisfy our customers' needs and to further reduce the cost. This product was originally designed as a unit for power generating systems; however, it can be used as a pump unit and blower unit by changing the driven unit from a generator to a pump or a blower, respectively. It can also be used as a driver unit (a steam motor) including the end of the output shaft of the reduction gears. Further cost reduction is possible by fixing the major core components of the product while developing models derived from applications thus, bringing the volume effect on production into play. We will continue to develop new models while addressing the market needs.

Conclusions

Kobe Steel owns and is expanding a line-up of products that serves to recover and reuse various types of waste energy: i.e., "STEAMSTAR MSEG", "Microbinary" (the currently sold model is a hot-water-heat-source type, and a steam-heat-source type is being developed), a high-efficiency steam supply system "Steam Grow Heatpump (SGH [note 4])" which has already been commercialized, a small steam compressor, "STEAMSTAR MSRC," and a steam driven air compressor, "Kobelion [note 5] -SD". We will strive to further expand and improve our product menu in anticipation of market expansion and will contribute globally to energy-saving and the effective use of unused energy.

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note 4) Steam Grow Heatpump and SGH are Kobe Steel's trademarks registered in Japan.

note 5) Kobelion is a Kobe Steel's trademark registered in Japan.