# WIDE RANGE LINE-UP OF PORTABLE TURBINE UNITS

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**SUMMARY** - This paper presents a line-up of 0.2 MW to 50 MW portable turbine units for geothermal power plants which Mitsubishi Heavy Industries, Ltd. (MHI) has developed and commercialized, explaining in detail a 50 MW modular type turbine for Sumikawa Geothermal Power Plant of Tohoku Electric Power Co., Inc., Japan.

## 1. INTRODUCTION

Fig. 1 shows unit capacity distribution of geothermal power plants in the world. As can be seen from Fig. 1, 93% of all units are 50 ∼ 60 MW or smaller units.

Generally, initial investment per unit capacity tends to be high as the unit capacity becomes small. In order to improve economy of small units, packaging of the equipment and short construction time will be essential, taking full advantage of small size unit.

In view of the above, MHI has developed full line-up of standardized portable turbine to cope with various demands ranging from hundreds kW to 60 MW, and have supplied 29 units of portable turbine out of 64 units of total supply.

This paper introduces our line-up of standardized portable turbine unit and their economical advantages, and also introduces the geothermal power plant to be constructed in Japan using 50 MW class modular turbine (MODULAR-50).

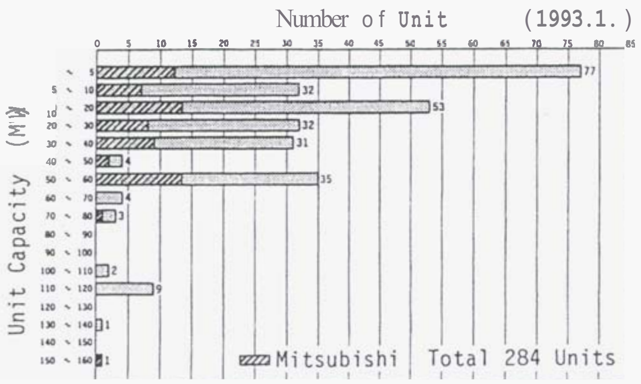



**Figure 1**– Unit Capacity Distribution of Geothermal Power Plants

## 2. LINE-UP OF PORTABLE TURBINE UNITS

Table 1 shows the portable turbine units developed by MHI. Features of the portable turbines are as follows.

### 2.1 Transportability

MODULAR-10 and smaller units are shipped to the site, with turbine, generator, periphery equipment and piping installed on a common steel bed in the shop, though this depends on restrictions on inland transportation.

MODULAR-20 and 25 are normally shipped with turbine, periphery equipment and piping installed on a steel bed, with generator being shipped separately.

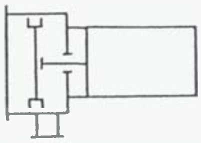
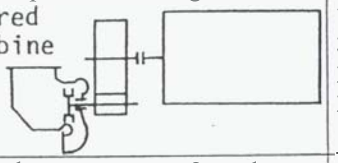
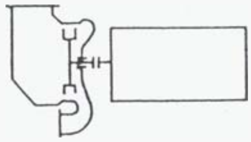
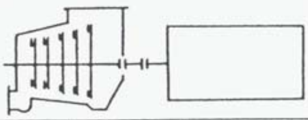
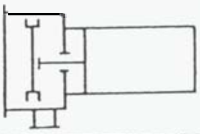
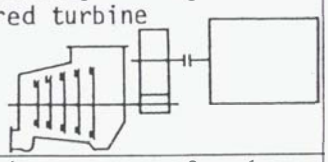
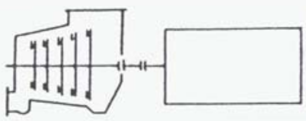
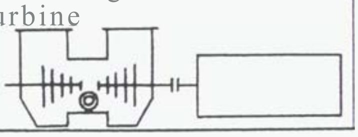
In any case, the turbine including rotor and diaphragm and its periphery equipment can be shipped in a complete set.

In MODULAR-50, which is a 50 MW class capacity unit, weight of the casing only is 88 tons, so casing, rotor and diaphragm are shipped separately in Sumikawa case.

### 2.2 Civil Work and Erection at Site

Since all portable types of units are designed to have top exhaust, such high concrete foundation decks (5 ∼ 7 meters) as required for conventional units are not required, and portable units can be installed on concrete foundation at the ground level.

**Table 1**– Line–up of Mitsubishi Portable Turbine

| | Type of Turbine Generator | | Output Range, Size & Weight | Features | Supply Record |
|---|---|---|---|---|---|
| Back-Pressure Type | GEO-PACK | Single-stage back-pressure turbine; 2-pole generator  | 3.1 ~ 0.5MW<br>2.6 (Length)<br>1.6 (Width)<br>1.2 (Height)<br>5 tons | · Compact/Superior Transportability<br>· Short Delivery Time<br>· Low cost<br>· Start up without Utility | · Hirose Shouji (1991) |
| | MPT-4 G | Single-stage back-pressure geared turbine; 4-pole generator  | 0.5 ~ 3MW<br>7.5 (L)<br>3.0 (W)<br>2.6 (H)<br>28 tons | · Compact<br>· Low cost<br>· Start up without Utility<br>· Reduction Gear | · Mak·Ban (1979)<br>· Tongonan (1977)<br>· Ahuachapan (1975) |
| | MPT-2L | Single-stage back-pressure turbine; 2-pole generator  | 1 ~ 3MW<br>5.8 (L)<br>2.6 (W)<br>2.5 (H)<br>35 tons | · Compact<br>· Low cost<br>· Start up without Utility | · Suginoi (1981)<br>· Azores (1980) |
| | MODULAR-5 | Multi-stage back-pressure turbine; 2-pole generator  | 3 ~ 10MW<br>3.4 (L)<br>3.7 (W)<br>3.4 (H)<br>57 tons | · Compact<br>· Higher Efficiency<br>· Start up without Utility | · Azufres (1982) |
| Condensing Type | GEO-PACK | Single-stage condensing turbine; 2-pole generator  | 3.1 ~ 0.5MW<br>Same as above | · Compact/Superior Transportability<br>· Short Delivery Time<br>· Low cost<br>· Vacuum Flash (in Ogiri Case) | · Ogiri (1988) |
| | MPT-4GC | Multi-stage condensing geared turbine; 4-pole generator  | 1 ~ 3MW<br>5.5 (L)<br>2.5 (W)<br>2.7 (H)<br>23 tons | · Compact<br>· Low cost<br>· Reduction Gear<br>· Higher Efficiency | · Salton Sea #2 (1990)<br>· Milos (1987) |
| | MODULAR-5,10,20,25 | Multi-stage condensing turbine; 2-pole generator  | 3 ~ 30MW<br>M-10: 11.3(L) 4.2(W) 3.3(H) 85tons<br>M-25: 4.1(L) 6.0(W) 3.9(H) 95tons | · Compact<br>· Lower Cost and Shorter Erection Period than Conventional Central Power Generating Unit<br>· High Efficiency | **Modular-10**<br>· Brawley (1980)<br>W.Ford Flat (1989)<br>· Bear Canyon (1988)<br>Modular-20<br>· Bac-Man (Plan 1993)<br>· Mak-Ban (Plan 1994)<br>**Yodular-25**<br>· East Mesa (1989)<br>· COSO (1987)<br>· Beowawe (1985) |
| | MODULAR-50 | Yulti-stage double flow Condensing turbine; 2-pole generator  | 30 ~ 60MW<br>.6 (L)<br>.5 (W)<br>.2 (H)<br>38 tons<br>(Casing only) | · Large Capacity<br>· Lower Cost and Shorter Erection Period than Conventional Central Power Generating Unit<br>· High Efficiency | Modular-50<br>· Surnikawa (1995) |

· Unit of size: meter
. Size and weight of Modular-25 and 50 are of turbine modules only. Those of other types are of turbine-generator modules.

This results in a great saving on costs of civil work and obviates the necessity of lifting up to high foundation deck a modular close to 100 tons, making erection very easy.
As for MODULAR-25 and smaller units, casing, rotor, diaphragm and oil piping are pre-assembled and flushed in the shop, and only final adjustment and connection with other pipes and electric wires are to be done at the site, contributing to reduction in costs of erection work and shortening of erection schedule.
This also minimize the needs for skilled workers for erection and assembly work of the turbine at the site.
Construction cost including equipment cost and erection cost for 30 MW unit of MODULAR-25 is given in Fig. 2 based on the results of Coso and Beowawe power plants.
Cost for the portable type is US $1,200~1,300/kW whereas the cost for the conventional type is US $1,500/kW.
It is obvious that construction of geothermal power plants using portable units has much advantage on economy and construction schedule.

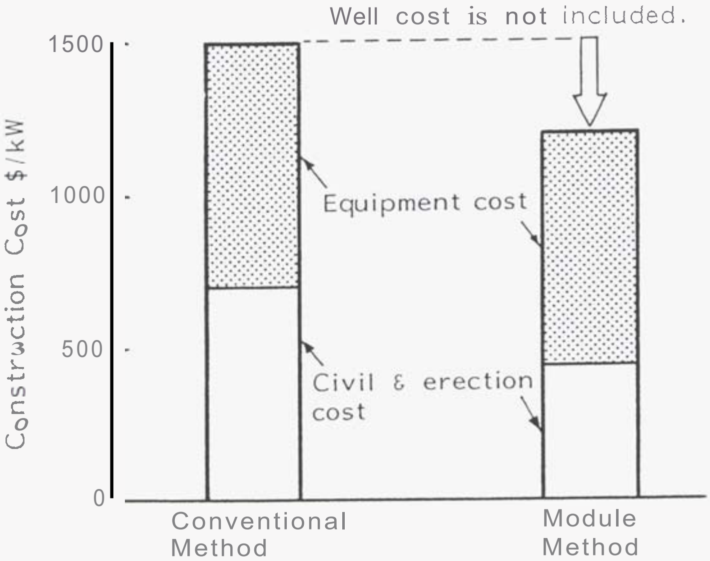



**Figure 2–** Comparison of Construction Cost in 30 MW Double Flash Plant

### 2.3 Circumstance on Utility (Power Grid and Make-up Water)

Back pressure type units can generate electricity even when there is no existing power grid and electricity cannot be received from a power grid at start-up or when there is no source of make-up water for cooling water system.
Therefore, back pressure type units such as GEO-PACK, MPT-4G, MPT-2L and MODULAR-5 are suitable as small capacity wellhead power generation units and units for islands.
These units are very compact, superior in transportability and easy to relocate.

### 2.4 Modular Units for Central Power Generating Station

MODULAR-25 covering an output range up to 30 MW and MODULAR-50 covering an output range up to 60 MW are large-capacity, high-efficiency modular units which have been developed for central power generating stations for which conventional units are used previously.

## 3. MODULAR-50 FOR SUMIKAWA GEOTHERMAL POWER PLANT

MODULAR-50 was developed as a 50 MW turbine for Sumikawa Geothermal Power Plant of Tohoku Electric Power Co., Inc., one of electric power companies in Japan.
Sumikawa is scheduled to start commercial operation in March 1995, and planning and design of the turbine are almost completed at the present moment.
For a 50 MW class unit, a conventional unit installed on a high concrete foundation deck was used previously, but in this project, MODULAR-50 incorporating design concept of portable turbine unit was developed and used to achieve the following purposes.

(1) To minimize height of the turbine house to meet the condition that scenes of the national park in which the power plant is situated should not be spoiled. An appearance of the power plant at its completion is shown in Fig. 3.
(2) To reduce erection cost and shorten erection schedule.
(3) To minimize skilled workers for erectoin.

**Figure 3–** Appearance of Sumikawa Geothermal Power Plant

### 3.1 Features of Power Plant

Table 2 shows design specification of Sumikawa geothermal power plant. Special features of the power plant are as follows.
The turbine is of top exhaust type and installed on the ground level to minimize the height of the turbine house, which is built in the form of a cottage so as to harmonize with the scenes of the national park.
Fig. 4 shows a general arrangement of major equipment viewed from the side,

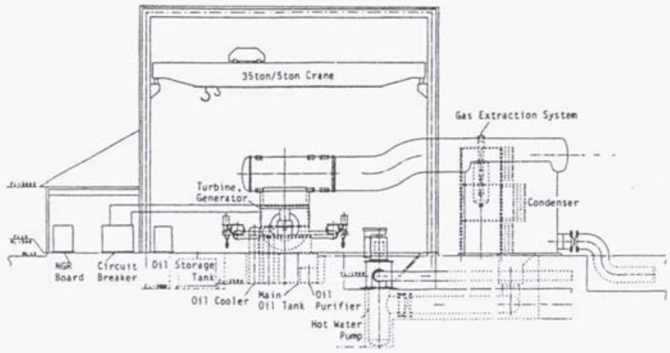



**Figure 4**– General Arrangement of Major Equipment

To minimize operators and reduce operational cost, the unit was designed for remote control and supervising from Kazuno city located at 30 km away from the power plant.
Start-up, synchronizing, load adjustment and scheduled shut-down are performed from the control room in the power plant but monitoring of operating condition and unit trip in an emergency can be made from Kazuno city.
Operating condition can be supervised visually by a television set as well as supervising instruments.

The minimum atmospheric temperature in winter is expected to be -20°C, and with a normal wet type cooling tower, visible plume discharged from the fan will stick to surrounding trees and freeze, producing adverse effects on ecology of trees and causing problems of sunshine shortage and freezing of the ground and structures.

**Table 2**– Design Specification of Sumikawa Geothermal Power Plant

| Equipment | Item | | Unit | No.1 Unit |
|---|---|---|---|---|
| Turbine | Type | | – | Single Pressure Double Flow Impulse-Reaction Condensing Turbine |
| | Rated Output | | kW | 50.000 |
| | Maximum Output | | | 50,000 |
| | | | | 3,000 |
| | Condition at MSV Inlet | Pressure | $kg/cm^2g$ | |
| | | Temp. | °C | 151.1 |
| | | Gas Content | | 0.17 |
| | Exhaust Pressure | | $kg/cm^2a$ | 0.11 |
| | Steam Consumption at Rated Output | | t/h | 389 |
| | No. of Stage | | – | 5 x 2 |
| | Last Stage Blade Height | | mm | 584 |
| Generator | Type | | – | Air Cooled |
| | Capacity | | kVA | 55,600 |
| Condenser | Type | | | Spray Type Jet Condenser |
| | Shell Pressure | | $kg/cm^2a$ | 0.10 |
| | Cooling Water Temp. | | °C | 22 |
| | Hot Uater Temp. | | °C | 43.5 |
| | Uater Quantity | | $m^3/h$ | 9,100 |
| Gas Extraction system | Type | | – | Two Stages of Steam Jet Ejector |
| | Suction Pressure | | $kg/cm^2a$ | 0.095 |
| | Discharge Pressure | | – | Atmosphere |
| | Steam Consumption of Ejector | | kg/h | 4,610/6,130 |
| Cooling Tower | Type | | – | Dry and Wet Type of Cross Flow Mechanical Draft |
| | No. of Cell | | – | 4 |
| | Water Quantity | | $m^3/h$ | 9,650 |
| | Hot Water Temp. | | °C | 43.5 |
| | Cold Water Temp. | | "C | 22 |
| | Design Wet Bulb Temp. | | °C | 14 |
| | Fan Motor Power | | kW | 200 |
| Hot Well Pump | Type | | – | Vertical Centrifugal Double Suction |
| | No. of Set | | – | 2 |
| | Capacity | | $m^3/h$ | 5,100 |
| | Motor Capacity | | kW | 650 |

These problems were solved by adopting a dry and wet type cooling tower, which consists of a conventional wet type cooling part, a dry type air cooling part and common fans, performs air heating in the dry air cooling part and delivers dry air to the atmosphere from the fan outlet.
Fig. 5 shows an outline of the dry and wet type cooling tower.

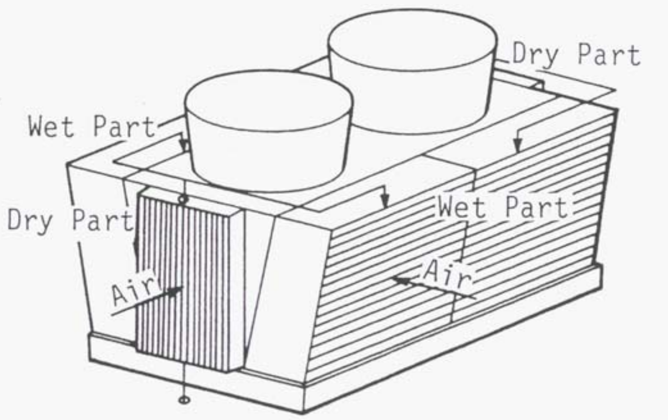



Figure 5– Dry and Wet Type Cooling Tower

## 3.2 Applied New Technologies to Turbine (Refer to Fig. 6; Turbine Sectional Drawing)

The construction of the geothermal turbine is very similar to that of a low pressure turbine for a thermal power plant. However, in terms of impurities in the steam, conditions are excessively worse in a geothermal turbine. Therefore, careful design consideration is necessary with respect to corrosive gas, such as hydrogen sulfide ($H_2S$), salt, scale component, such as silica ($SiO_2$) and calcium (Ca), and solid particles, such as sand and iron contained in the steam. Consideration must also be given to the wetness inside the turbine due to the saturated steam condition at the turbine inlet.

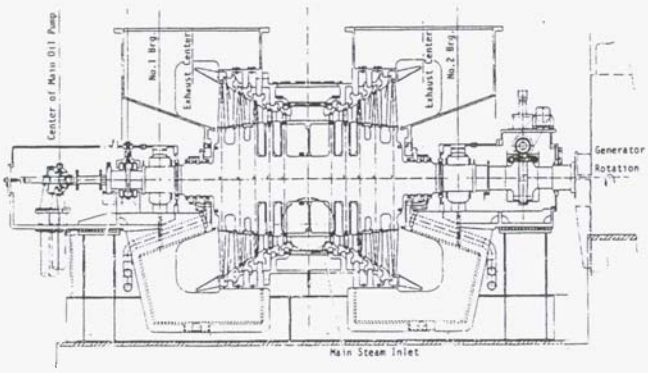



**Figure 6-** Turbine Sectional Drawing

**Material**

To cope with such harmful steam impurities, materials for each part in turbine are carefully selected as described below.

As for the rotor material for geothermal turbines, the following requirements must be satisfied.

(1) High toughness and ductility
(2) Low sensitivity to stress corrosion cracking (SCC)

Super low sulfur CrMoV rotor material has been developed as the rotor material that satisfies the above requirements.

In this rotor material, the content of sulphur has been limited to less than 0.005% for higher toughness and ductility. Nickel content has been limited to less than 0.5% and the quenching temperature has been lowered to 910°C for less sensitivity against SCC.

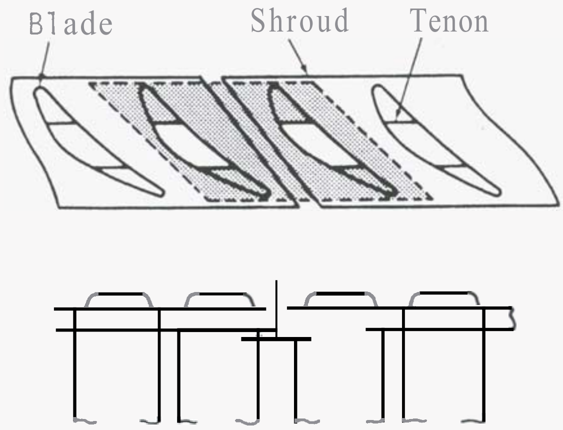
Regarding moving blade in which centrifugal stress and vibratory stress are set up in corrosive geothermal steam, the stress corrosion cracking (SCC) and the reduction of corrosion fatigue strength must be taken into consideration in the material selection.

Based on the field test results, it has been proved 17-4PH steel has higher SCC resistance and corrosion fatigue strength than 12Cr steel, and 17-4PH steel are selected for all stages of moving blades.

**Special damper for moving blade**

In parallel with the selection of the optimum blade material to further upgrade in the reliability of the moving blades, special dampers are used to reduce the vibratory stress.

The vibratory stress is reduced by application of the shroud damper to 3rd and 4th stage blades, shown in Fig. 7, which connects adjacent blade group together.




**Efficiency**

As far as the geothermal turbine is concerned, the difference in leaving loss has great effect upon efficiency of the turbine due to its small heat drop. As shown in Fig. 8, the leaving loss can be minimized by application of 23 inch last blades.

As for impulse stage which consists of 1st and 2nd stages, the following technologies are applied for efficiency improvement.

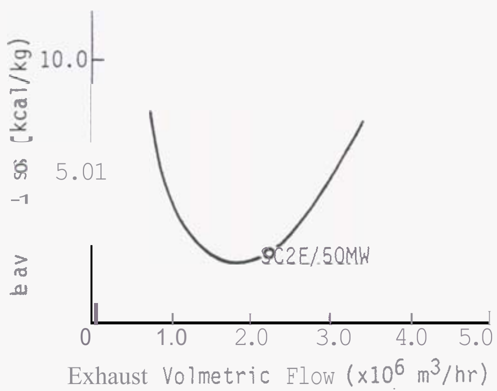



Figure 8- Leaving Loss of 23 inch Last Stage Blade

| Stage | Nozzle/Stationary blade | Movingblade |
|---|---|---|
| 1st | Twist | MSF & ISB |
| 2nd | Bow | MSF & ISB |
| 3rd | Bow | MSF & FHT |

MSF : Multi-seal fin
ISB : Integral shroud blade
FHT : Fox-hole tenon

Twisted nozzle is designed to control the reaction degree and to decrease secondary loss at the moving blade base. Fully 3-dimensionally designed Bow nozzle can minfmize the secondary loss, more positively.
Fig. 9 shows the configuration of Bow nozzle and how Bow nozzle minimize' the secondary loss.
Integral shroud blade and Fox hole tenon are applied to complement the multi-seal fins at the blade tip which can minimize leakage loss.

## 4. CONCLUSION

There is a common perception that a geothermal portable turbine is used for a small capacity wellhead power plant. And it has' been proved that MODULAR-25 for 30 MW class geothermal power plants which was designed based upon the same concept as small portable turbine can realize lower civil and erection cost and shorter construction period.
The output range of modular turbine is being expanded to 50 MW class to take the same advantages as it in Modular-25 case by developing Modular-50.

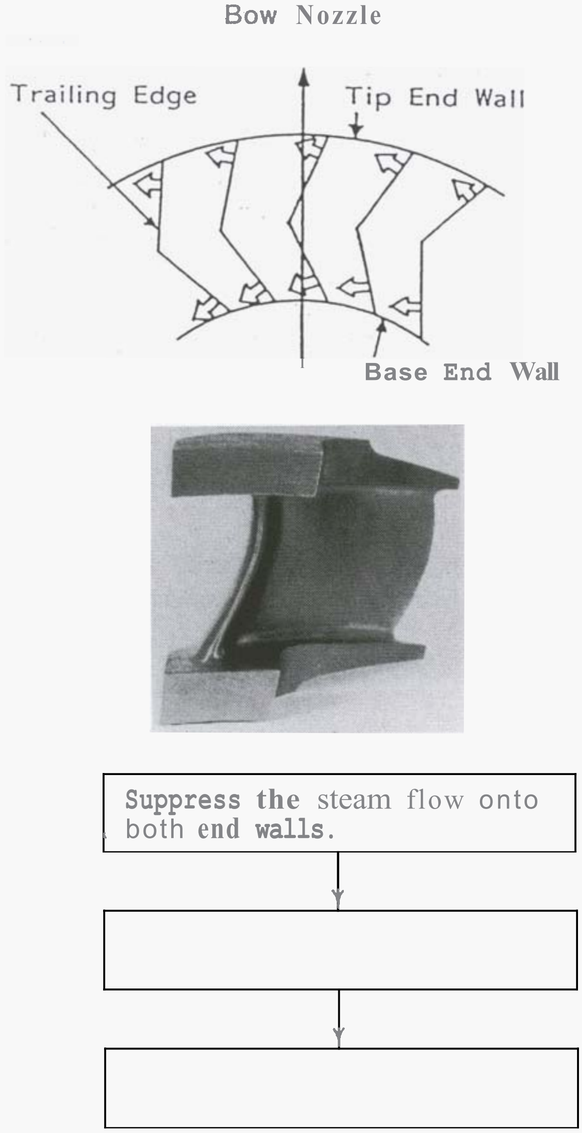



Figure 9– Minimizing Secondary Loss by Bow Nozzle Application