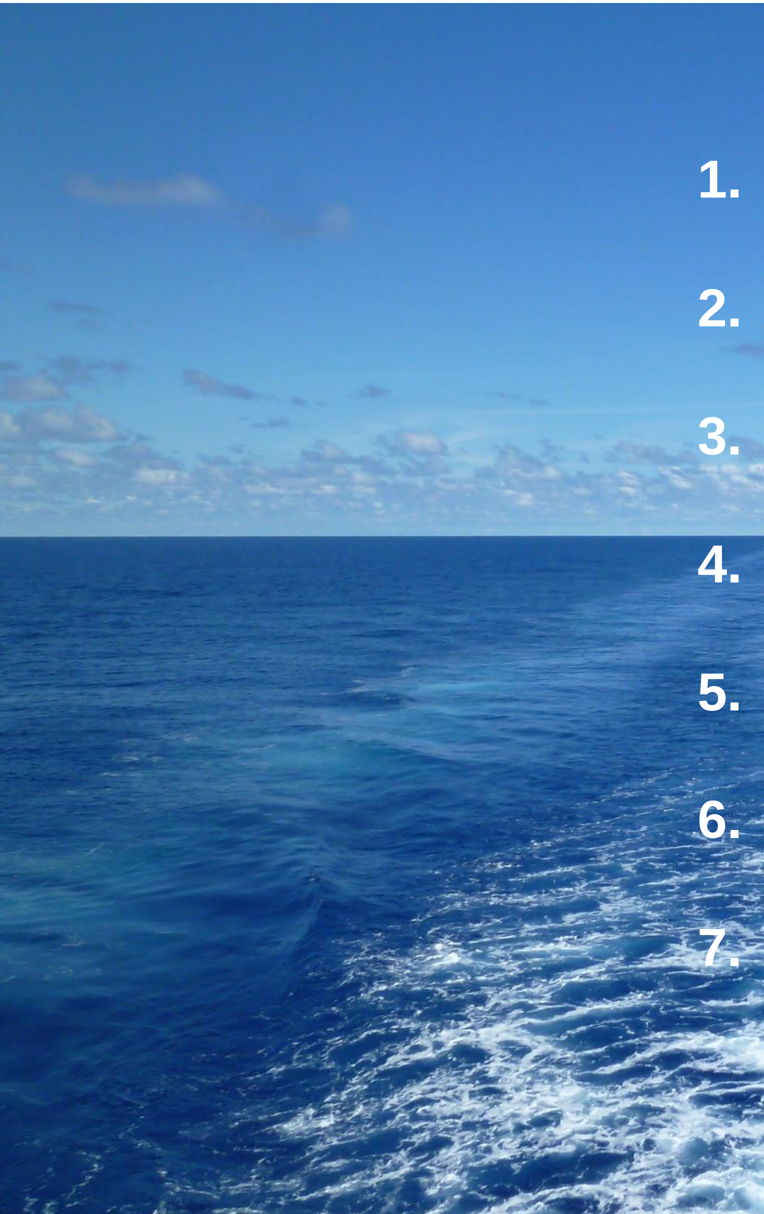
MET Turbochargers and ORC Generator
Value for Environment and Economy

June 16, 2016 Keiichi Shiraishi

MITSUBISHI HEAVY INDUSTRIES MARINE MACHINERY & ENGINE CO., LTD.

MHI GROUP MITSUBISHI HEAVY INDUSTRIES

Contents



1. Summary of topics

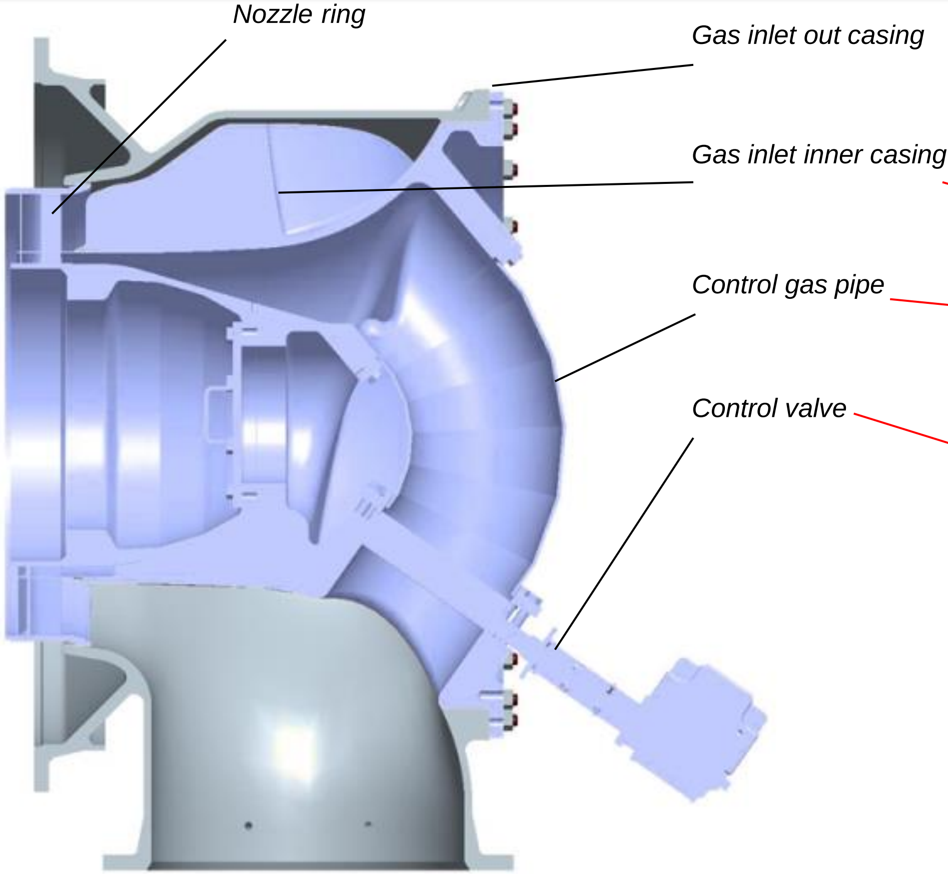
- **Mitsubishi's variable turbine (VTI) accumulates total 65 sets of delivery. Minor problems took place and already found solution.**
- **Turbocharger integrated exhaust gas bypass (iEGB) is ready to apply with great advantages in comparison with EGB on an engine.**
- **World's first hybrid turbocharger MET83MAG has been overhauled at dry dock after 5 years operation.**
- **Electric assist devices to retrofit for MET83SE turbochargers on a container ship**
- **Binary power generation system, Organic Rankine Cycle (ORC) generator has been successfully retrofitted on a large container ship**

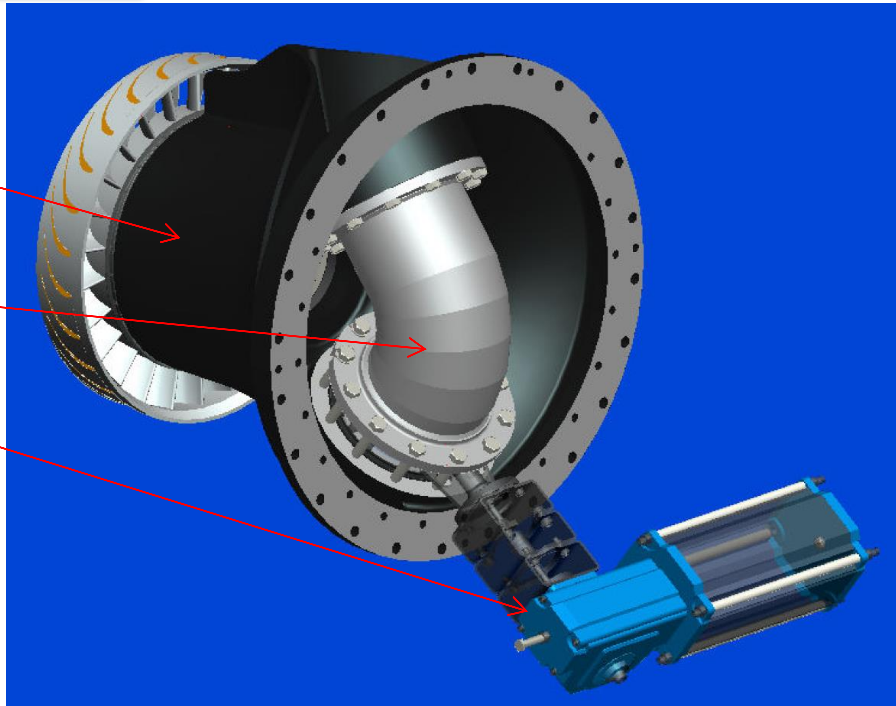
2. VTI – Principles

Two-step turbine area control by reliable butterfly valve

Feed back valve opening position to engine control system

Higher turbocharger efficiency at full load than EGB





But, reduction of nozzle area by VTI can reduce turbine performance at low pressure ratio.

2. VTI – References

Turbocharger type	Engine builder	Engine type	Ship builder	Turbocharger delivery
MET71SE-VTI x 2	MHI KOBE	6UEC85LSII	NAMURA	11-Apr
MET71SE-VTI x 2	MHI KOBE	6UEC85LSII	NAMURA	11-Sep
MET66MA-VTI x 1	HITACHI	6S60MC-C7	IMABARI	11-Nov
MET71SE-VTI x 2	MHI KOBE	6UEC85LSII	NAMURA	11-Nov
MET71MA-VTI x 1	MHI KOBE	6UEC60LSII	OSHIMA	12-Jan
MET71SE-VTI x 1	MHI KOBE	6UEC60LSII	OSHIMA 10701	12-Jun
MET66MA-VTI x 1	MITSUI	6S60MC-C	KOYO	12-Aug
MET66MA-VTI x 1	HITACHI	6S60MC-C7	IMABARI	12-Oct
MET53MA-VTI x 2	MHI KOBE	7UEC60LSE-Eco	OSHIMA	13-Mar
MET71MA-VTI x 2	HHI	7RTA82T-TierII	HHI	13-Apr
MET53MA-VTI x 2	KOBE DIESEL	8UEC60LSII-Eco	IMABARI	13-Apr
MET53MA-VTI x 2	MHI KOBE	7UEC60LSE-Eco	OSHIMA	13-Jun
MET53MA-VTI x 2	KOBE DIESEL	8UEC60LSII-Eco	IMABARI	13-Jun
MET71SE-VTI x 2	MHI KOBE	6UEC85LSII	NAMURA	13-Jul
MET53MA-VTI x 1	MAKITA	6S46MC-C8-T1	IMABARI	13-Sep
MET53MA-VTI x 2	MHI KOBE	7UEC60LSE-Eco	OSHIMA	13-Sep
MET66MAG-VTI x 1	MITSUI	7S60ME-C8.2	SHINKURUSHIMA	13-Sep
MET60MA-VTI x 1	MITSUI	6S60MC-C7-TI	TSUNEISHI	13-Sep
MET53MA-VTI x 1	MAKITA	6S46MC-C8-T1	SHIMANAMI	13-Sep
MET60MA-VTI x 1	HITACHI	6S60MC-C8	IMABARI	13-Oct
MET60MA-VTI x 1	MITSUI	6S60MC-C7-TI	TSUNEISHI	13-Oct
MET66MAG-VTI x 1	MITSUI	7S60ME-C8.2	SHINKURUSHIMA	14-Jan
MET60MA-VTI x 1	HITACHI	6S60MC-C8	IMABARI	14-Jan
MET60MA-VTI x 1	HITACHI	6S60ME-C8	IMABARI 1609	14-Feb
MET60MB-VTI x 1	KOBE DIESEL	6UEC60LSE-Eco-A2	OSHIMA	14-Feb
MET48MB-VTI x 1	KOBE DIESEL	6UEC45LSE-B2	SHINKOCHI	14-Apr
MET53MA-VTI x 1	IMEX	6L42MC6.1	ASAKAWA	14-May
MET60MA-VTI x 1	MITSUI	6S60ME-C8	TSUNEISHI	14-Jun
MET66MAG-VTI x 1	MITSUI	7S60ME-C8.2	SHINKURUSHIMA	14-Jun
MET66MAG-VTI x 1	KOBE DIESEL	7UEC60LSE-Eco-A2	IMABARI	14-Jun
MET48MB-VTI x 1	KOBE DIESEL	6UEC45LSE-B2	SHINKOCHI	14-Jul
MET53MA-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-1	OSHIMA	14-Aug
MET60MB-VTI x 1	KOBE DIESEL	6UEC60LSE-Eco-A2	OSHIMA	14-Sep
MET53MB-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-A2	SHINKURUSHIMA	14-Oct
MET60MB-VTI x 1	KOBE DIESEL	6UEC60LSE-Eco-A2	OSHIMA	14-Nov
MET66MAG-VTI x 1	KOBE DIESEL	7UEC60LSE-Eco-A2	IMABARI	14-Nov

Turbocharger type	Engine builder	Engine type	Ship builder	Turbocharger delivery
MET53MB-VTI x 1	KOBE DIESEL	6UEC50LSE-Eco-B1	OSHIMA	15-Jan
MET48MB-VTI x 1	KOBE DIESEL	6UEC45LSE-B2	SHINKOCHI	15-Jan
MET53MB-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-A2	SHINKURUSHIMA	15-Jan
MET66MAG-VTI x 1	KOBE DIESEL	7UEC60LSE-Eco-A2	IMABARI	15-Mar
MET60MA-VTI x 1	KOBE DIESEL	7UEC60LSE-Eco-A2	OSHIMA	15-Apr
MET53MB-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-A2	SHINKURUSHIMA	15-May
MET48MB-VTI x 1	KOBE DIESEL	6UEC45LSE-B2	SHINKOCHI	15-Jun
MET53MA-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-1	OSHIMA	15-Jul
MET48MB-VTI x 1	KOBE DIESEL	6UEC45LSE-B2	SHINKOCHI	15-Aug
MET53MB-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-A2	SHINKURUSHIMA	15-Oct
MET48MB-VTI x 1	KOBE DIESEL	6UEC45LSE-B2	SHINKOCHI	15-Nov
MET60MA-VTI x 1	KOBE DIESEL	7UEC60LSE-Eco-A2	OSHIMA	16-Jan
MET53MB-VTI x 1	KOBE DIESEL	6UEC50LSE-Eco-B1	OSHIMA	16-May
MET53MB-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-A2	SHINKURUSHIMA	16-Jul
MET53MB-VTI x 1	KOBE DIESEL	6UEC50LSE-Eco-B1	OSHIMA	16-Jul
MET48MB-VTI x 1	KOBE DIESEL	6UEC45LSE-B2	SHINKOCHI	16-Aug
MET60MA-VTI x 1	KOBE DIESEL	7UEC60LSE-Eco-A2	OSHIMA	16-Aug
MET53MB-VTI x 1	KOBE DIESEL	6UEC50LSE-Eco-B1	OSHIMA	16-Oct
MET53MB-VTI x 2	KOBE DIESEL	7UEC60LSE-Eco-A2	SHINKURUSHIMA	16-Oct

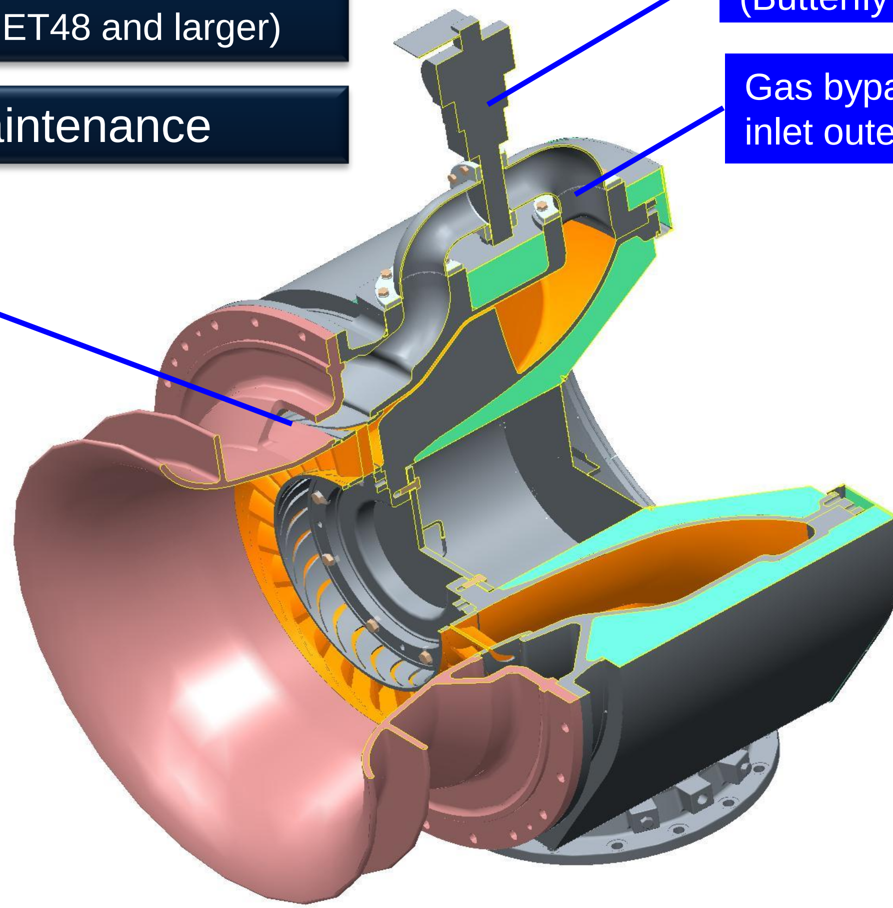
55 ships / 73 turbochargers

(including 6 ships / 8 turbochargers on order)

MITSUBISHI HEAVY INDUSTRIES MARINE MACHINERY & ENGINE CO., LTD.

3. EGB – Don’t you care high load performance ?

- No need for EGB pipe works on the engine
- Easy to retrofit (MET-MA series and later, MET48 and larger)
- Easy access to the control valve for maintenance



Parts to be changed

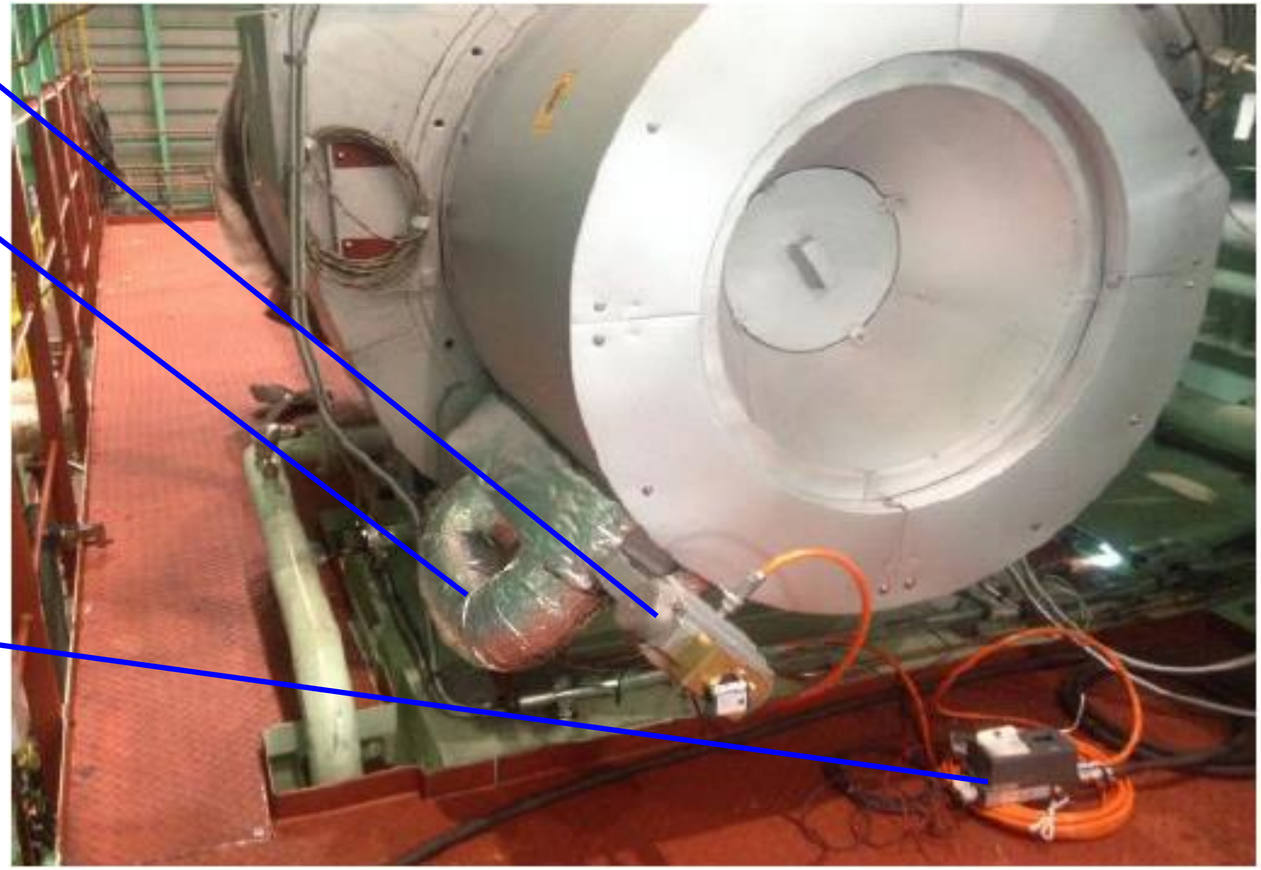
Gas inlet outer casing

Gas outlet guide

クリップステート：XSEC0001

Available for one turbocharger on an engine

3. MET66MA with Integrated EGB on the engine



●Mitsubishi 7UEC60LSE-Eco-A2

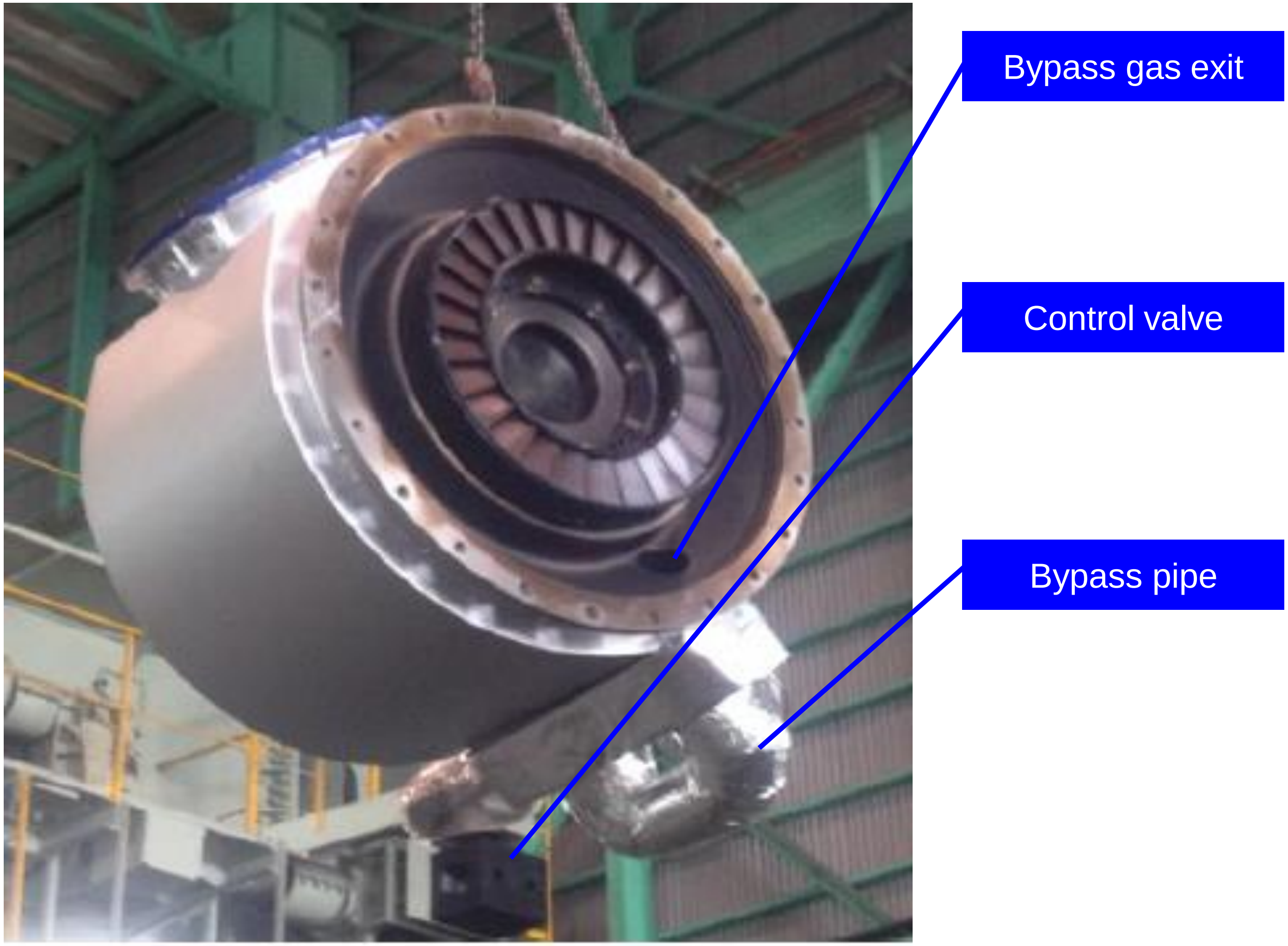
3. MET71MA with Integrated EGB on the engine

Installed on 6S70ME-C8.2 EGB tuning
17,140 kW x 88 rpm

M.V. BERGE DAISEN (ex. Laura D'Amato)

Total running hours : 13,500 rpm

3. Gas Inlet Casing with Integrated EGB



Gas inlet casing assembly with EGB : Mitsubishi MET66MA

3. MAN Diesel & Turbo accepted Integrated EGB

Official comment from MAN Diesel & Turbo June 2016

Turbocharger with integrated EGB valve:

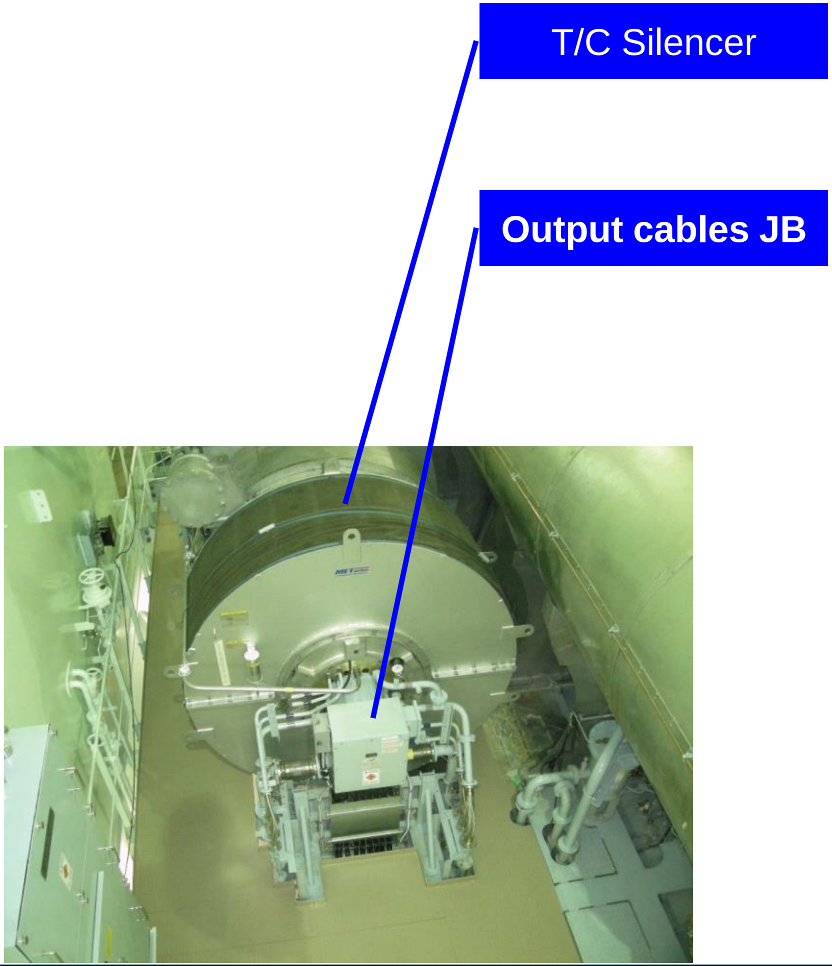
MHI has developed a T/C with integrated EGB connections on the casings. EGB valve to be delivered by the engine-builder (valve type to be approved by MDT).

MDT accepted this concept for engines with one T/C.

4. Hybrid Turbocharger after 5 years

The first vessel with hybrid turbocharger **MET83MAG** was delivered in May 2011

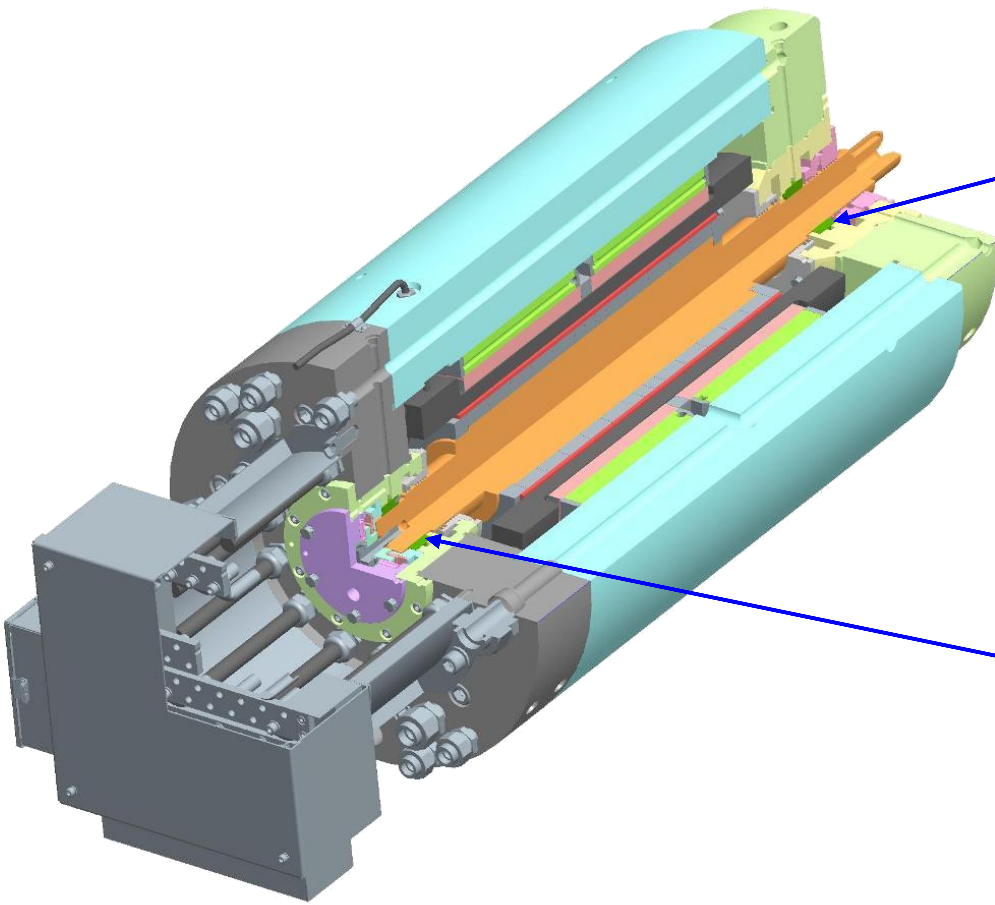
M.V. SHIN KOHO
Powered by 7S65ME-C 16,580 kW – 90 rpm



4. Hybrid Turbocharger after 5 years

Overhauled at dry dock

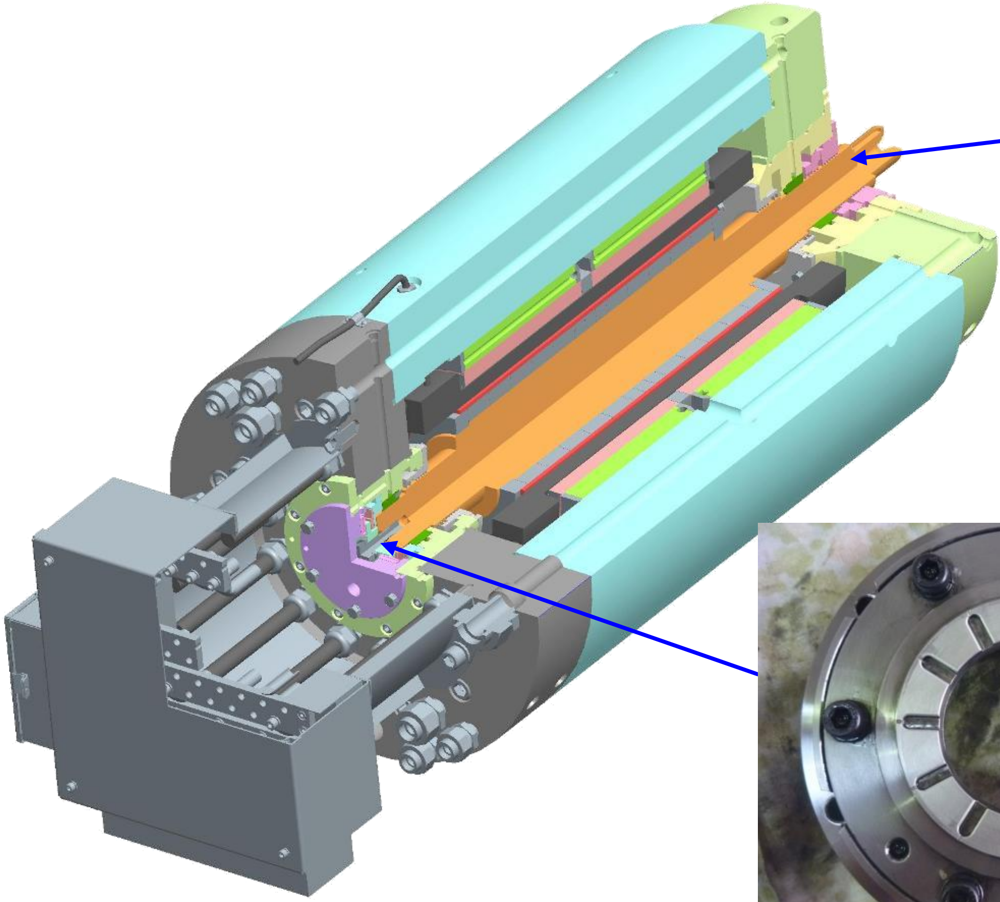
Total engine running hours : 26,591 Hours



4. Hybrid Turbocharger after 5 years

Overhauled at dry dock

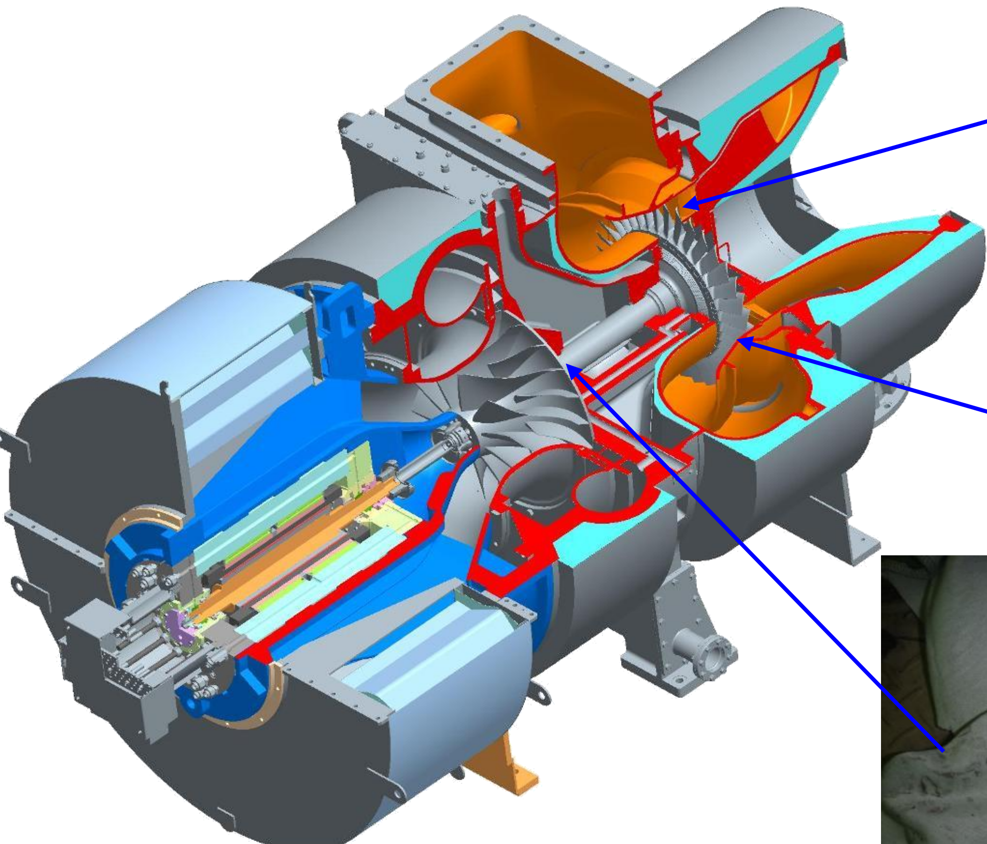
Total engine running hours : 26,591 Hours



4. Hybrid Turbocharger after 5 years

Overhauled at dry dock

Total engine running hours : 26,591 Hours

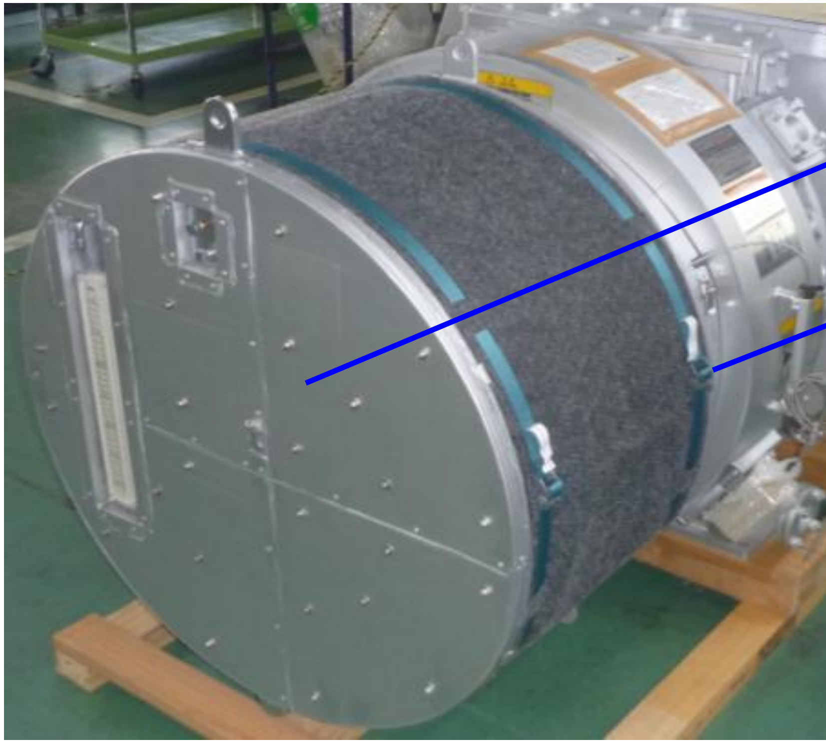


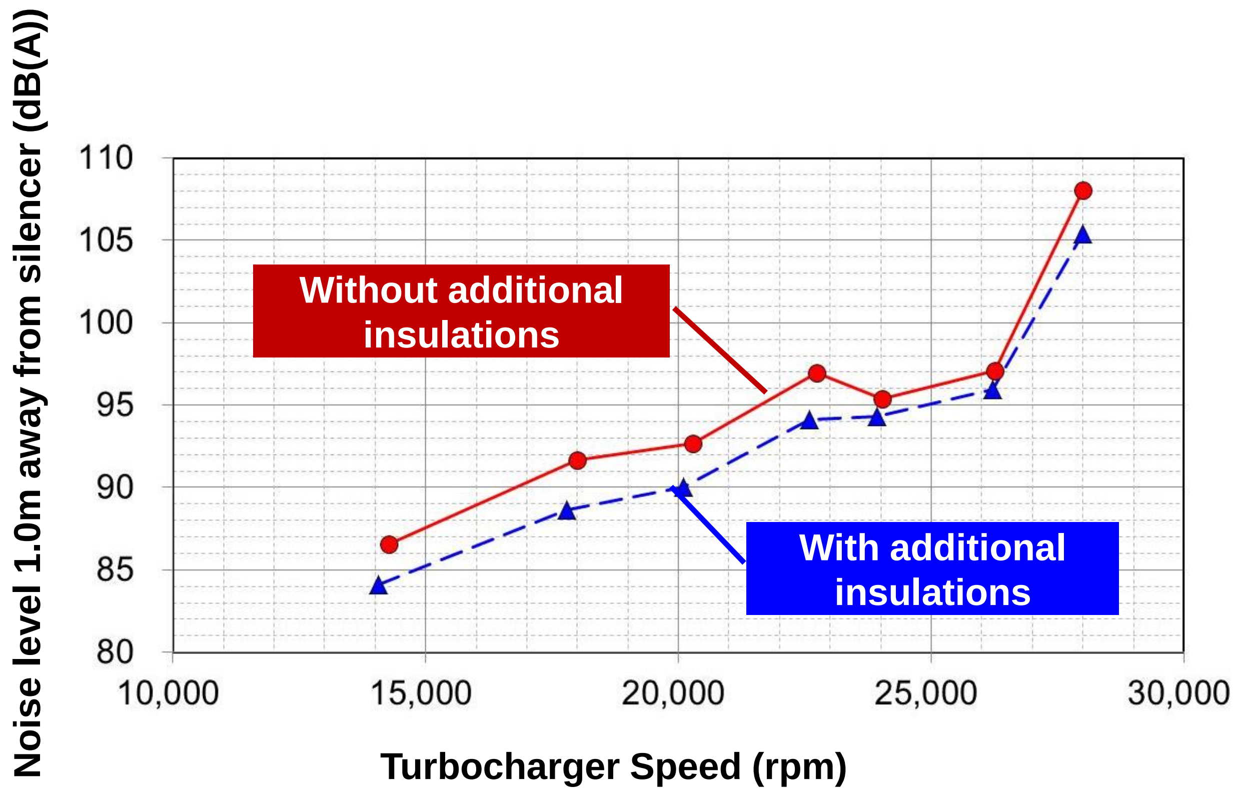
Nozzle ring, Leading edge

Turbine blades

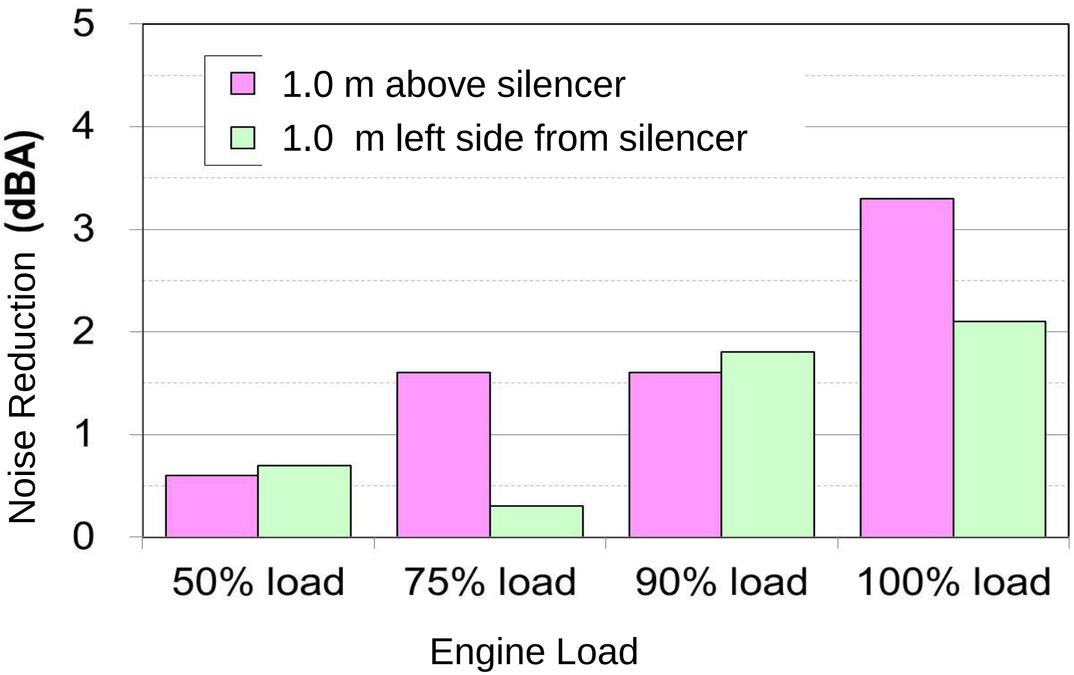
Compressor side journal bearing

5. Approach to Quiet Turbocharger





5. Approach to Quiet Turbocharger



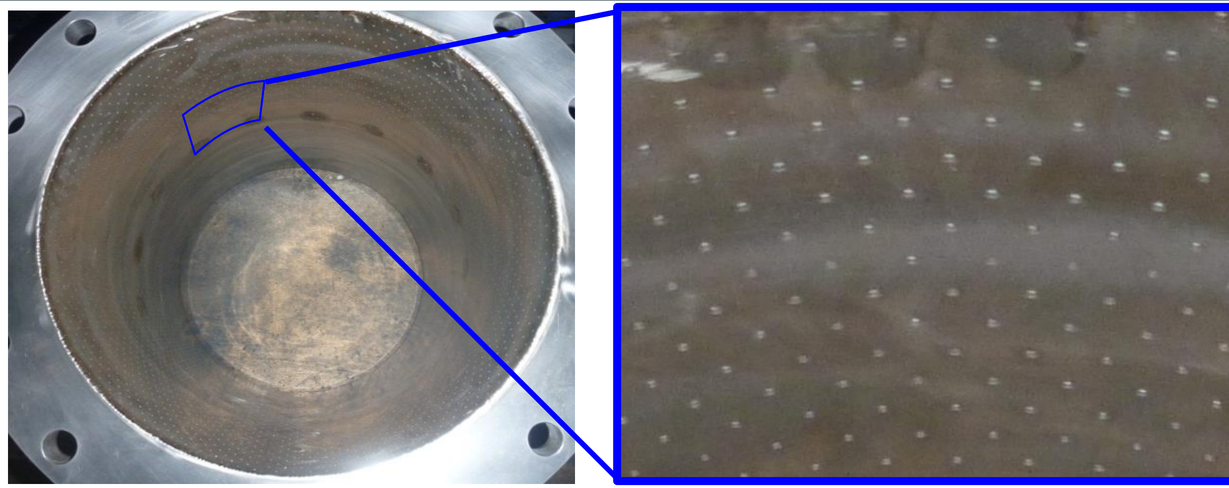
Reduction of noise level from turbocharger silencer on an engine

MITSUBISHI HEAVY INDUSTRIES MARINE MACHINERY & ENGINE CO., LTD.

5. Approach to Quiet Turbocharger

Acoustic Noise Filter

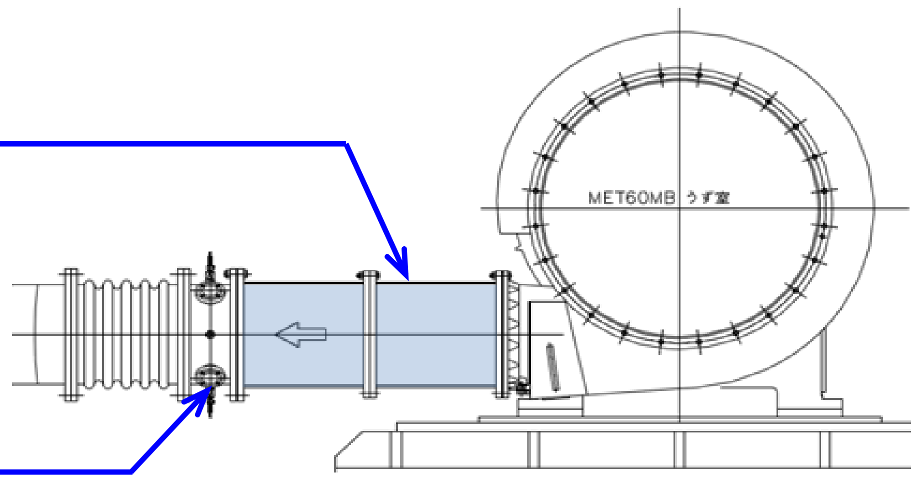
Perforated plate in the air pipe with small distance from the wall dissipate acoustic energy of the air passing through the holes.



Holes 2mm

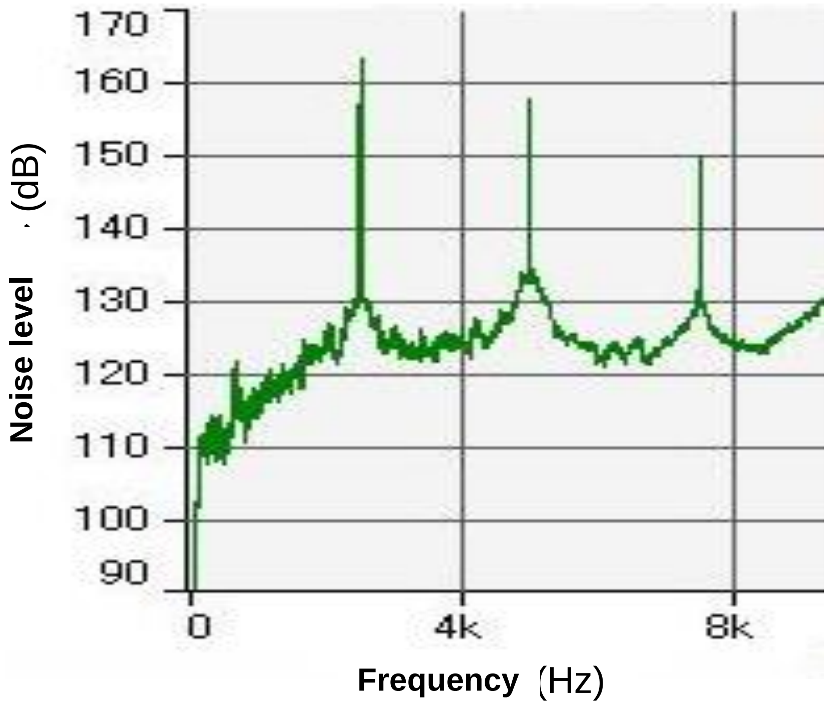
Pipe with acoustic filter (L500mm x 2)

Position where pressure and noise was measured

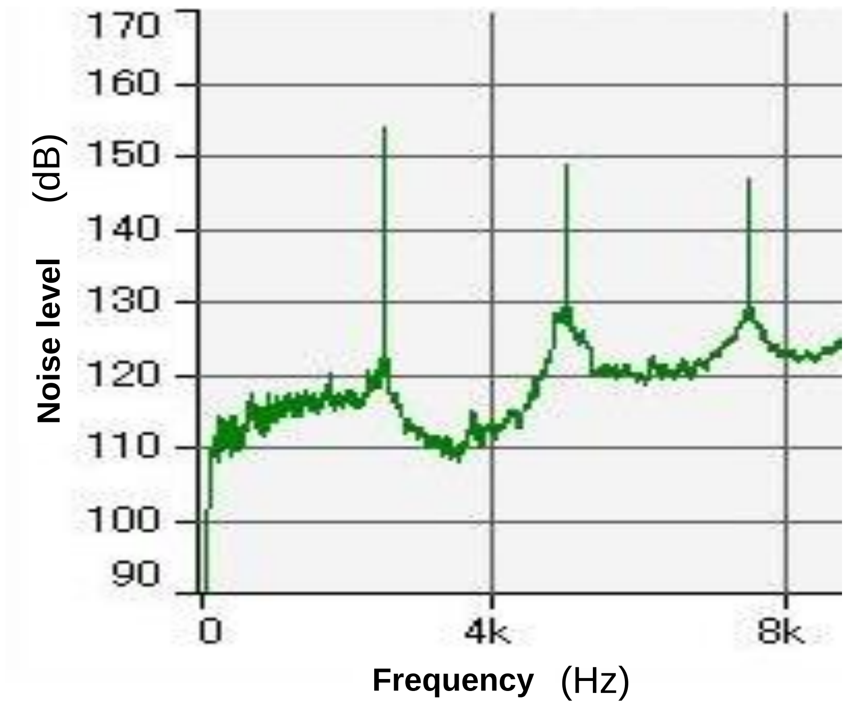


Test Apparatus for acoustic filter with MET60MB turbocharger on a test bed

Noise level in the air pipe with / without acoustic filter

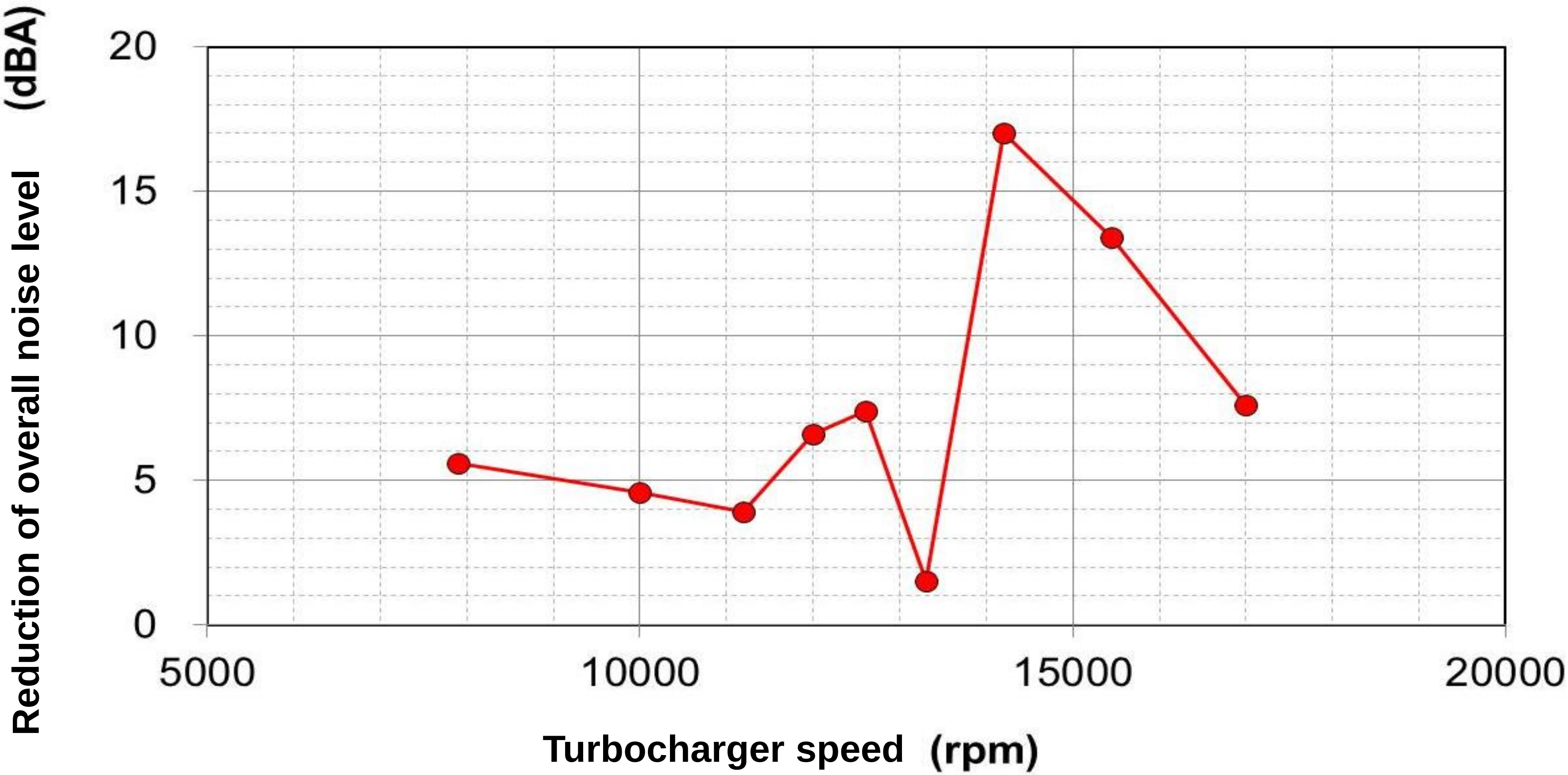


Without acoustic filter



Without acoustic filter

Noise level in the air pipe with / without acoustic filter

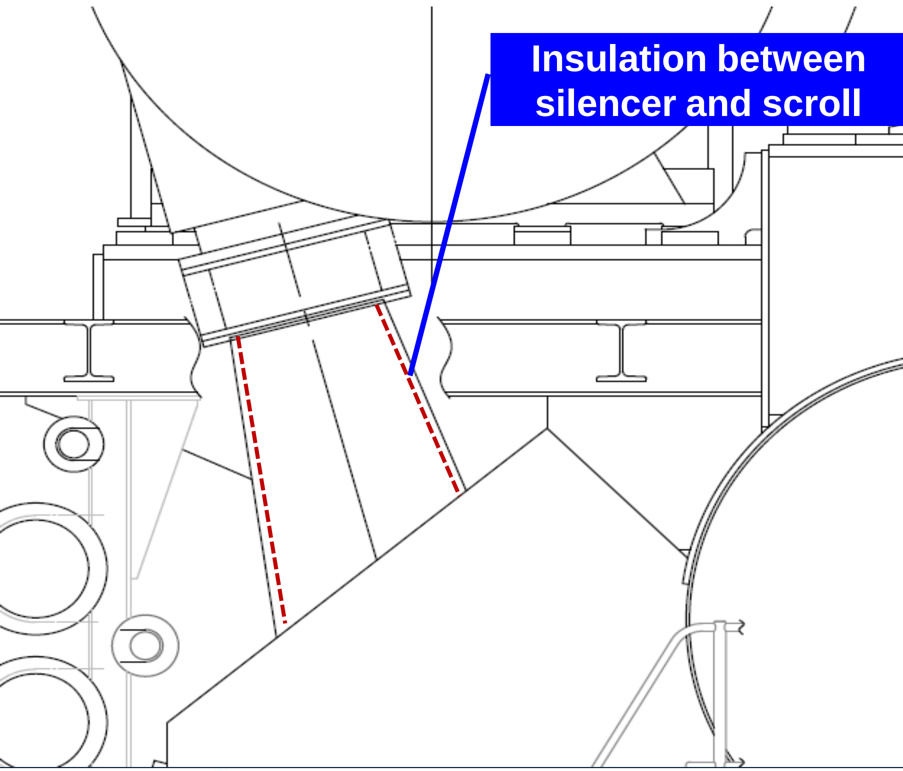


5. Approach to Quiet Turbocharger – on engine

Length of acoustic filter : longer than 1.0m for MET83MB

It can not be integrated in the turbocharger scroll

Possible location : air duct after turbocharger outlet




The duct with acoustic filter


Inner surface of the duct

5. Acoustic filter – verification schedule

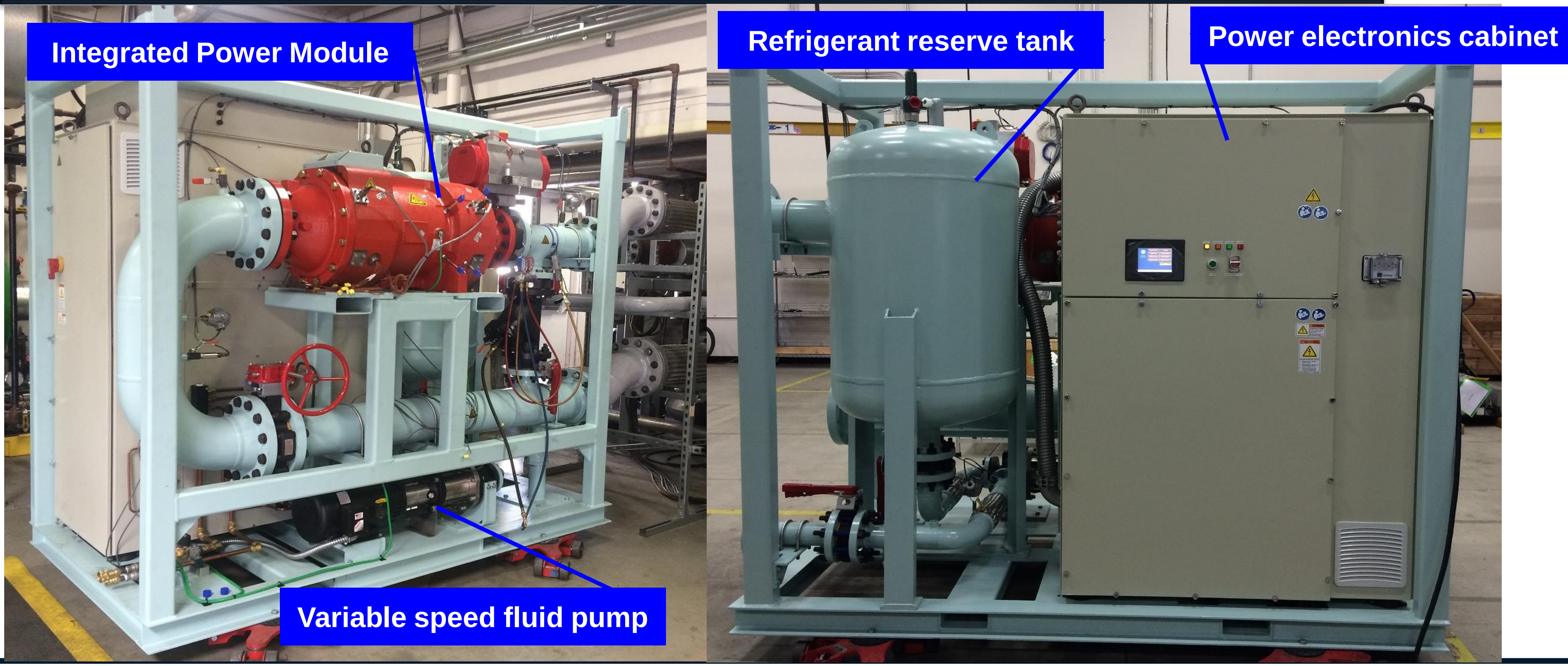
Verification Items	Month			
	Jun.	Jul.	Aug.	Sep.
Verification test on turbocharger test bed	~6/M →			
Verification test on the engine at HHI (8G95ME-C9.5 with MET83MB x 2sets)		~7/E →		
Turbocharger matching and noise measurement at Doosan (11G95ME-C9.5 + MET83MB x 3sets)				★ 9/E
Turbocharger matching and noise measurement at Doosan (11G95ME-C9.5 + MET90MA x 2sets)				★ 9/M

6. Marine ORC Generator - Objective

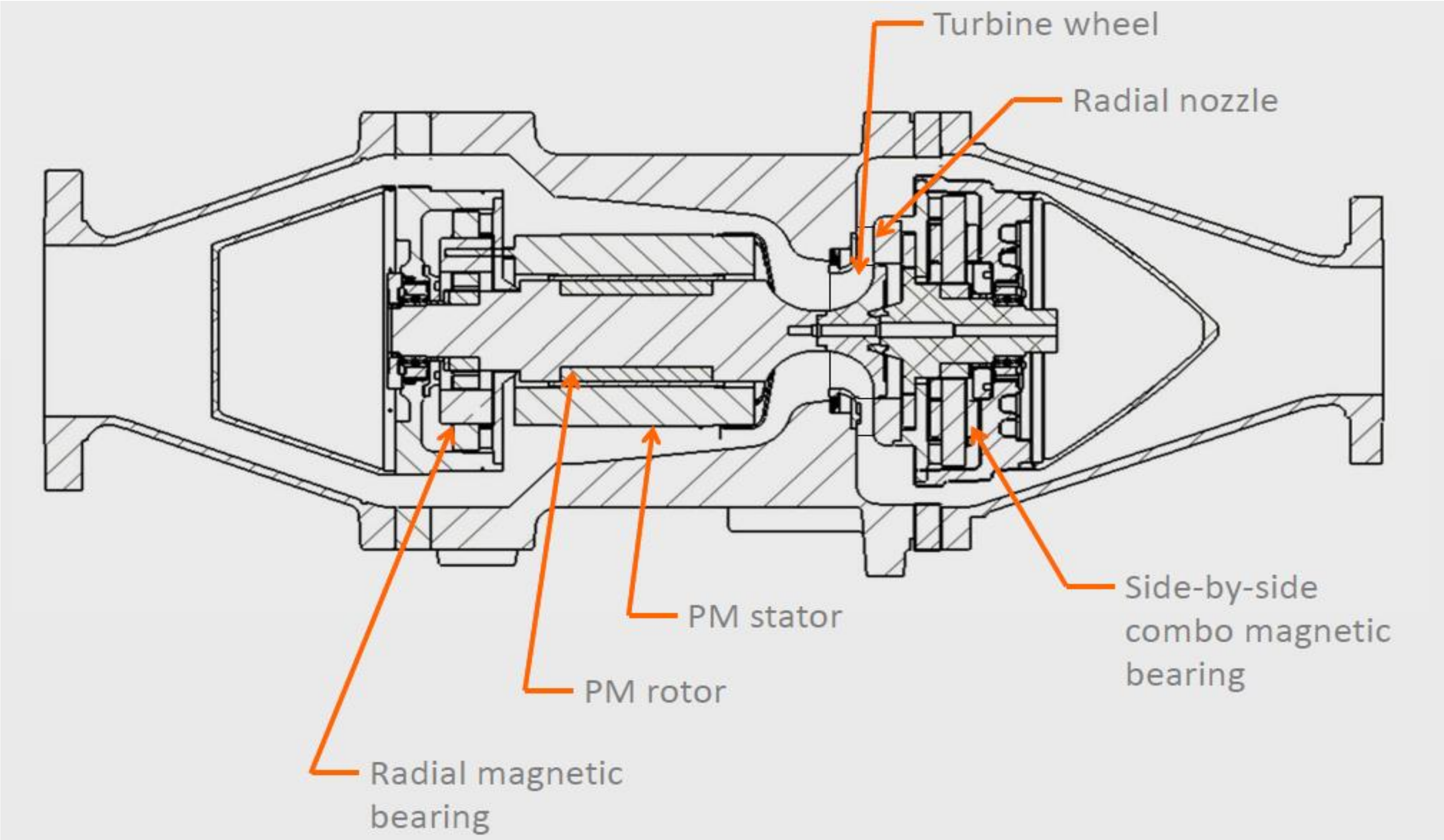
Capture the heat from main engine jacket cooling water of 85 deg.C (296m^3/h)

Generate gross 125 kW of electric power (net 110 kW, according to test data)

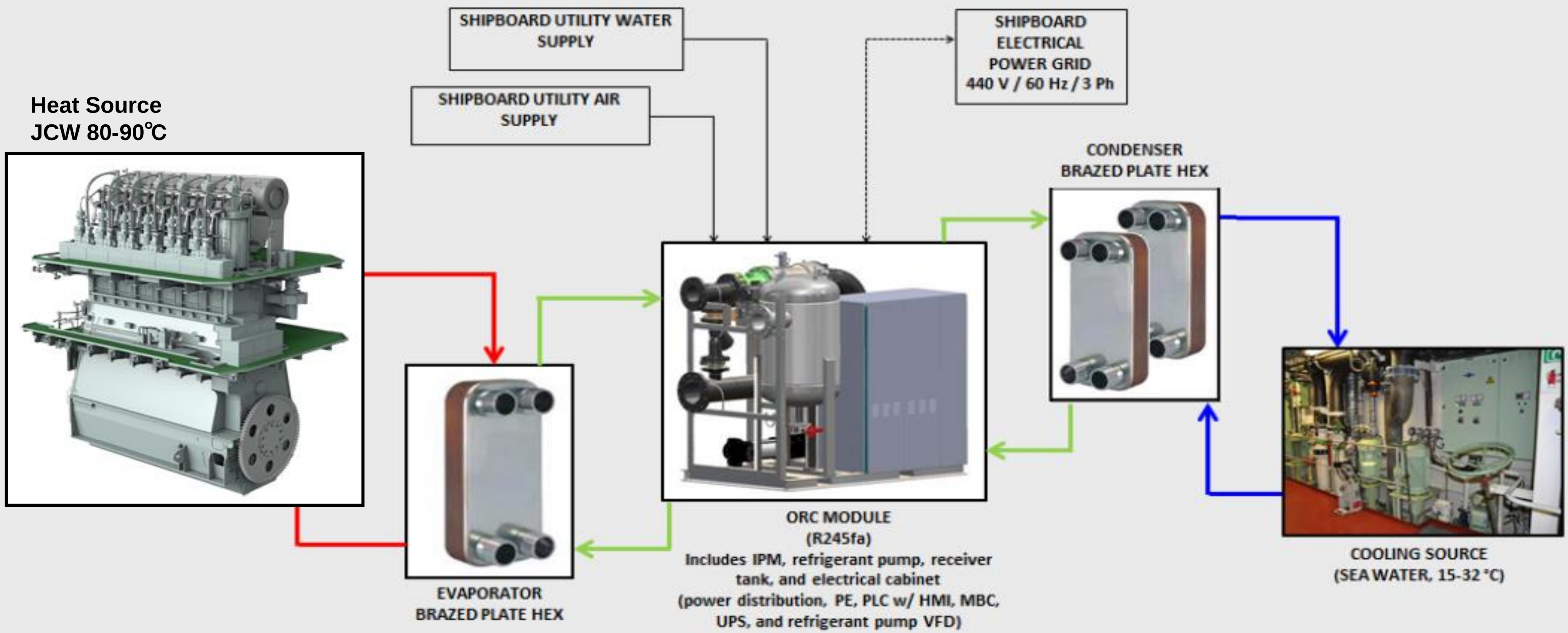
Minimum 75 deg.C of jacket cooling water after evaporator – sufficient for fresh water generator



6. Marine ORC Generator – IPM

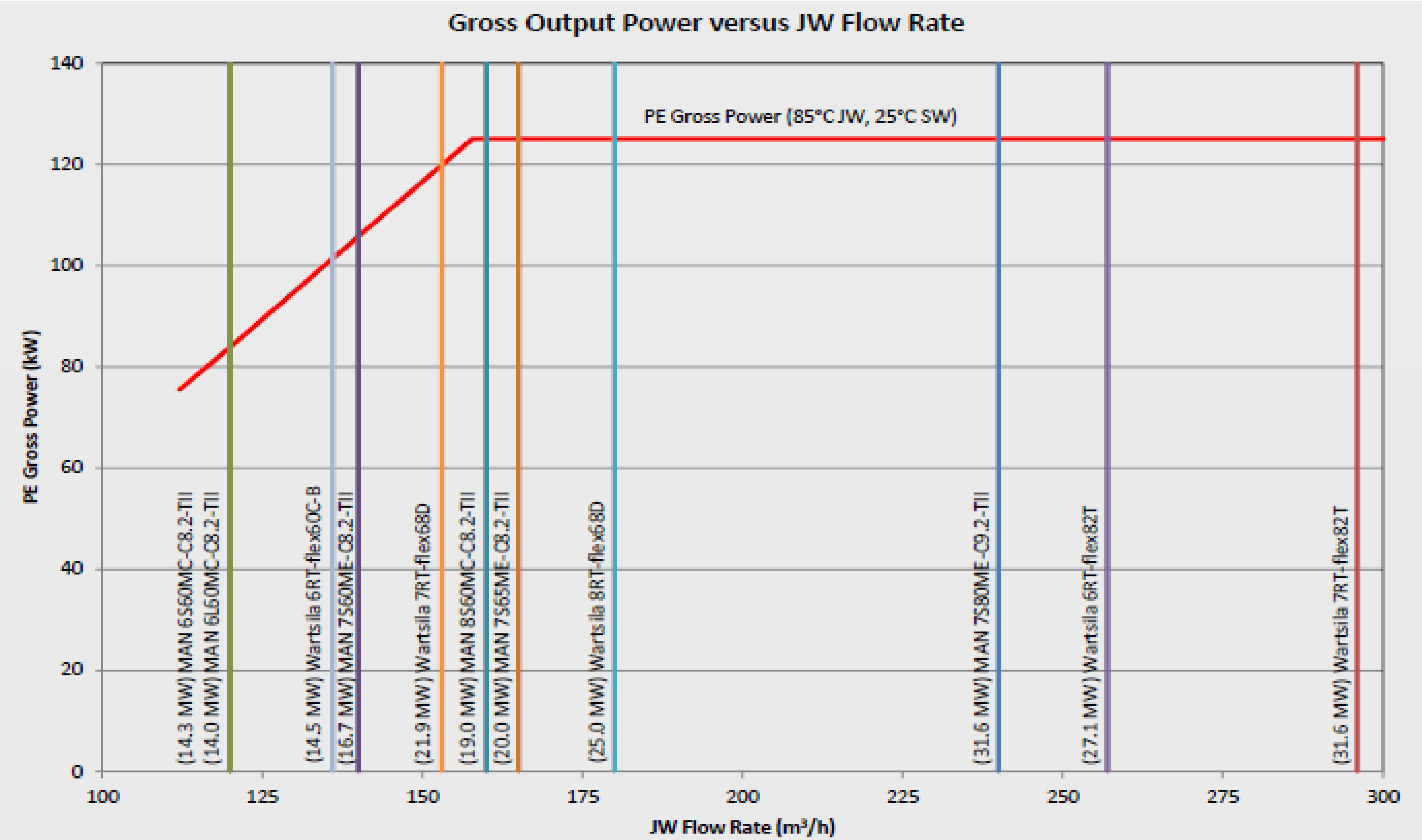


6. Marine ORC Generator – Diagram



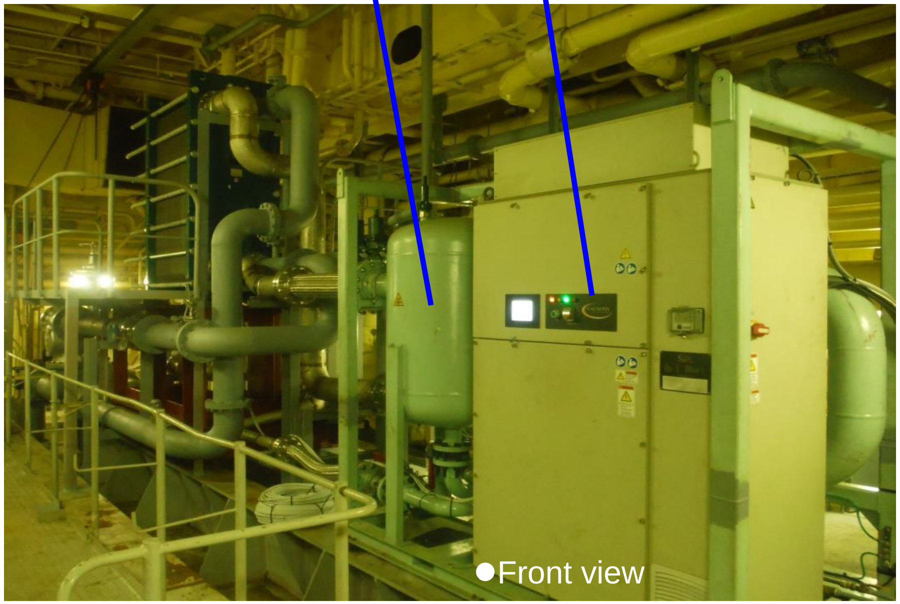
MITSUBISHI HEAVY INDUSTRIES MARINE MACHINERY & ENGINE CO., LTD.

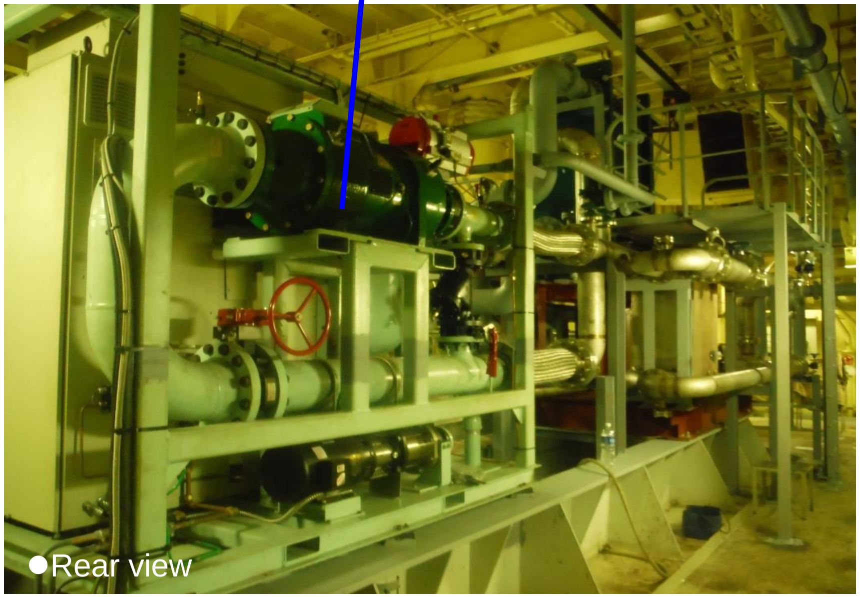
6. Marine ORC Generator – Required heat



MITSUBISHI HEAVY INDUSTRIES MARINE MACHINERY & ENGINE CO., LTD.

6. ORC generator installed on board





- M.V. Arnold Maersk (Odense L-187)
- Doosan 12RTflex96C 63,000kW – 100 rpm

6. ORC generator installed on board

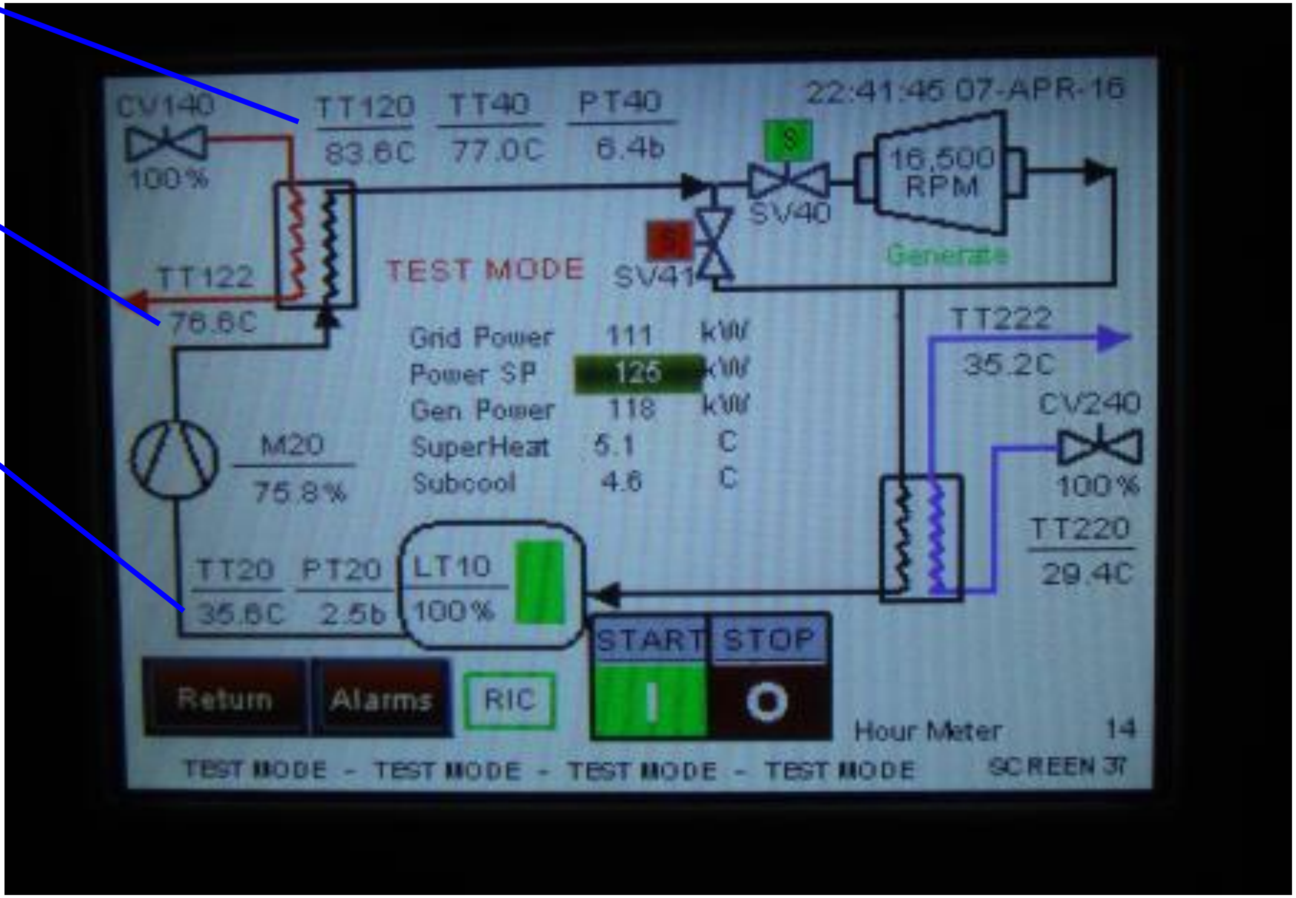
- M.V. Arnold Maersk (Odense L-187)
- Doosan 12RTflex96C 63,000kW – 100 rpm

6. ORC generator installed on board

JCW temperature before evaporator

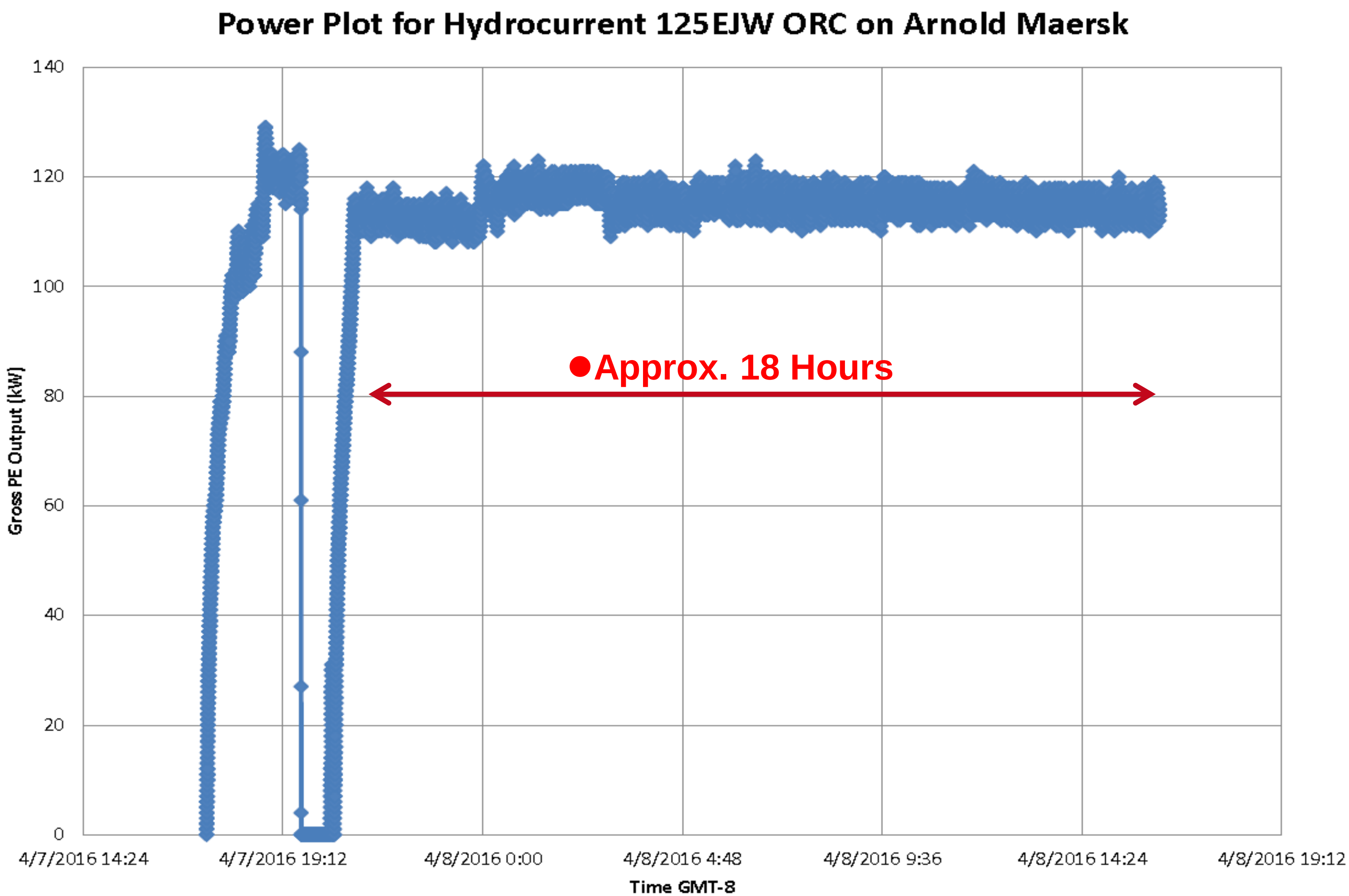
JCW temperature after evaporator

Refrigerant temp. before evaporator



- M.V. Arnold Maersk (Odense L-187)
- Doosan 12RTflex96C 63,000kW – 100 rpm

6. ORC generator installed on board



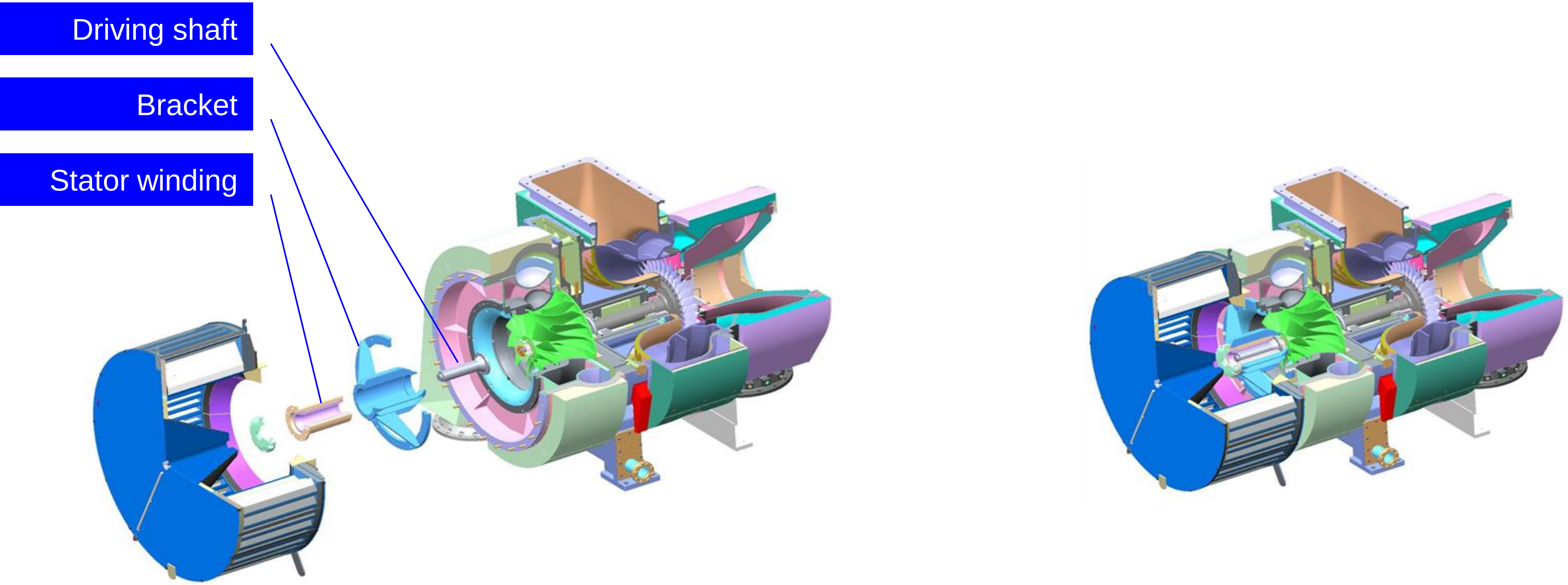
7. What is electric assist turbo ?

Turbocharger with electro-magnetic driving shaft coupled onto the rotor

Less electric power demand than conventional auxiliary blower

Seamless power assist at any engine load

Higher air flow / surge margin at lower load than auxiliary blower operation

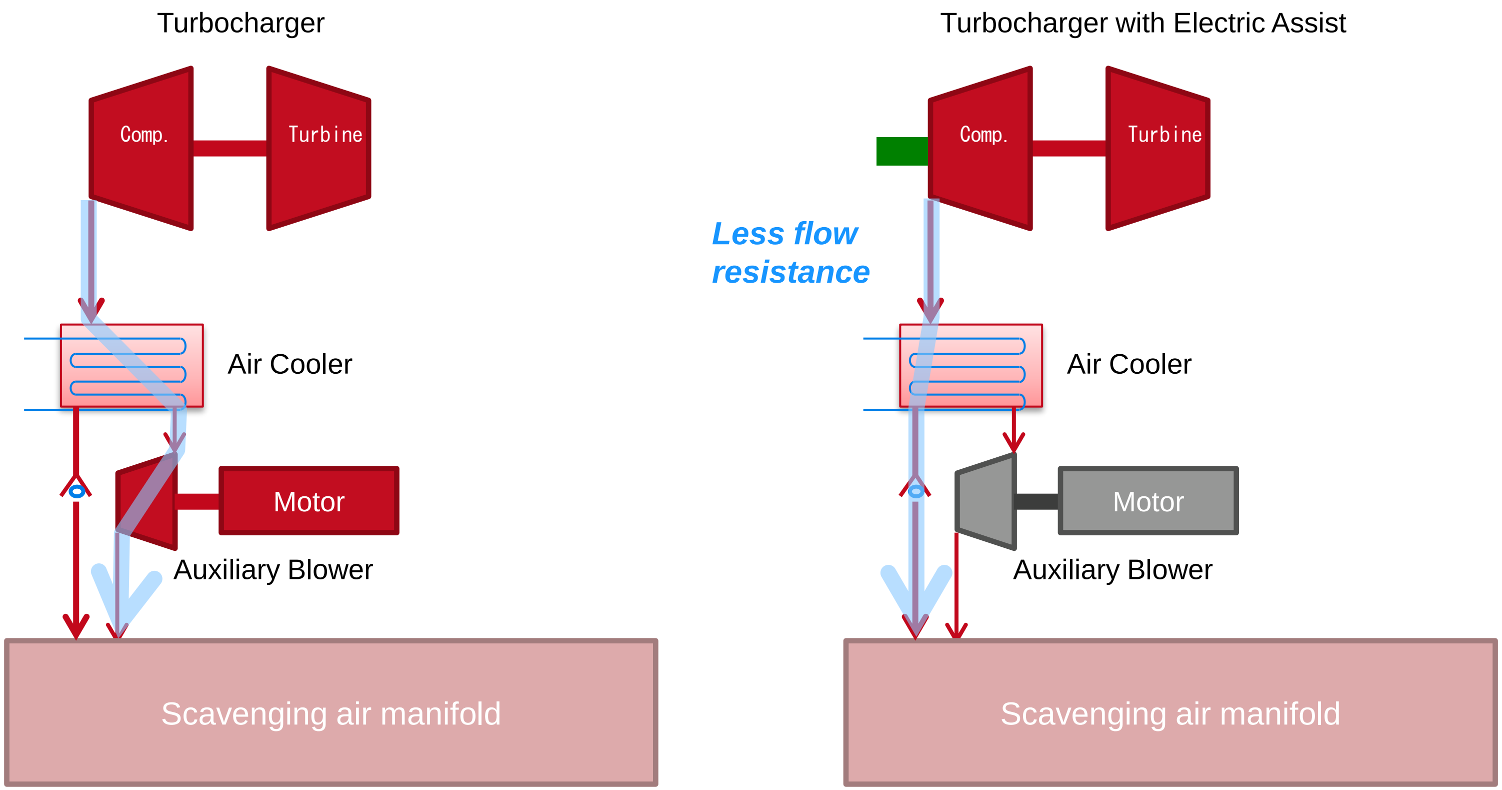


7. Objective of electric assist

Lower power consumption than auxiliary blower

Flexible optimum boost pressure at low load

Lower flow resistance = increased air flow improves fuel oil consumption at low load



7. Test data of electric assist

Tested with MET66MAG-VTI hybrid : motoring mode

25% lower electric power consumption than A/B with the same Pscav

lower fuel oil consumption and higher T/C speed with the same Pscav

Engine Load	20% (2,760 kW)			25% (3,450 kW)		
	Aux. Blower operation	Elec. assist : same Pscav	Elec. assist : high Pscav	Aux. Blower operation	Elec. assist : same Pscav	Elec. assist : high Pscav
Aux blower power (kW)	**86**			**103**		
Electric assist power (kW)		**66**	105		**79**	131
Scav. air pressure (bar G)	**0.46**	**0.46**	0.54	**0.66**	**0.66**	0.73
Turbocharger speed (rpm)	**5,860**	**6,248**	6,698	**6,880**	**7,248**	7,598
M/E ΔFOC (kg/h)	**ref**	**- 2.8**	- 5.1	**ref**	**- 1.4**	- 10.6
D/G ΔFOC (kg/h)	ref	- 3.9	+ 3.8	ref	- 4.7	+ 5.5
Total ΔFOC (kg/h)	ref	- 6.7	- 1.3	ref	- 6.1	- 5.1
Total ΔFOC in g/KWh	**ref**	**- 2.4**	**- 0.5**	**ref**	**- 1.8**	**- 1.5**
Change of gas temp aft T/C (℃)	ref	- 3	- 27	ref	- 8	- 30
Change of NOx (%)	ref	- 1.5	+ 4.0	ref	- 1.1	+ 3.9

ine

7UEC60LSE-Eco with motoring mode.

7. Voice of customer (Hybrid T/C motoring mode)

Vessel : M/V “Deneb Leader” PCC
Main Engine : 7UEC60LSE-Eco
Turbocharger : MET66MAG-VTI

Report from chief engineer

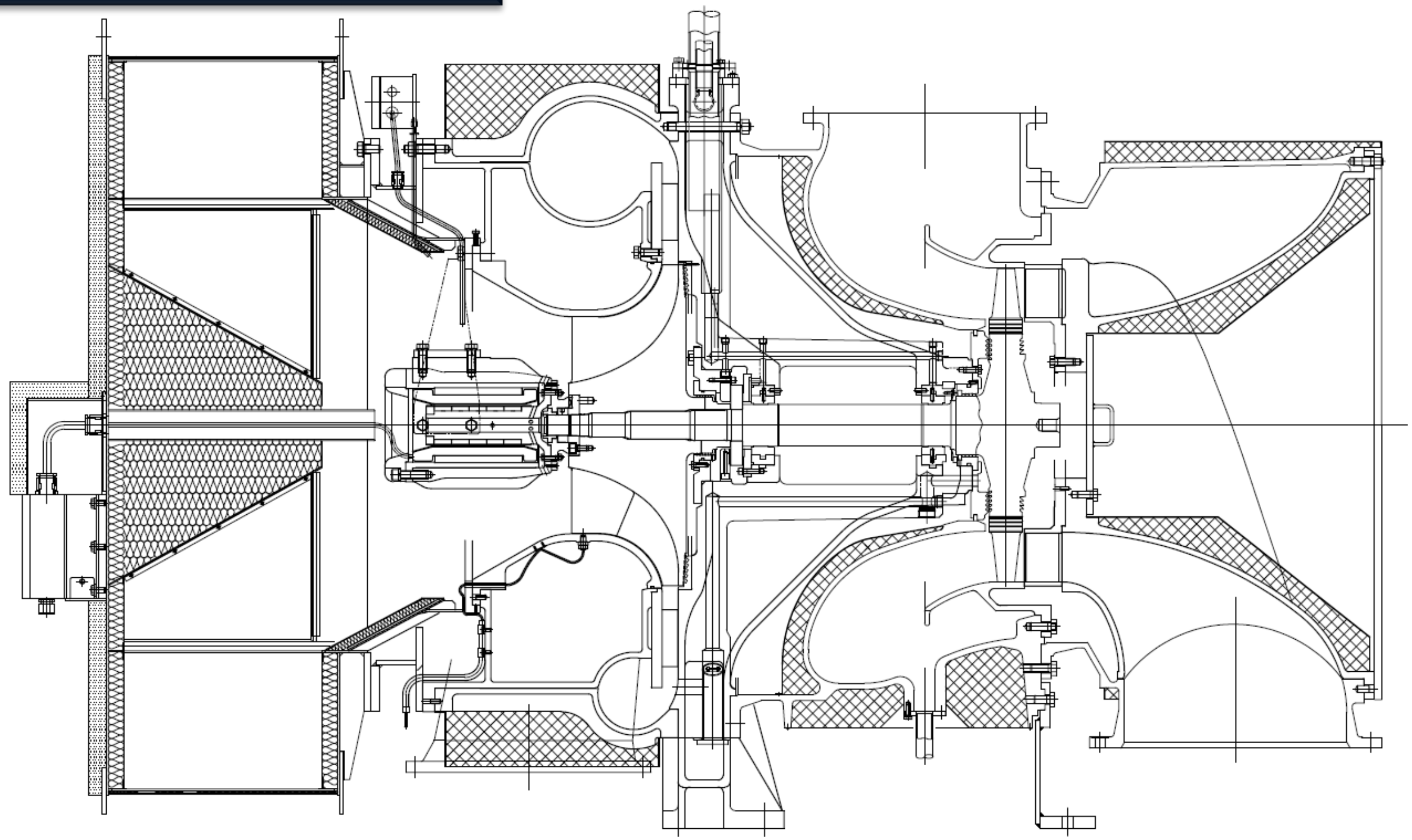
29 July 2015 : “ TCM (turbocharger motor mode) consumes about 35 kW of power where two auxiliary blowers consume 75 kW. TCM reduce power consumption in about 40 kW. This was the first operation of TCM on this vessel and all ship’s engineers were excited. Main Engine load was 45%, Scav. air press. 0.85 bar G.”

7. Retrofit project (Electric assist turbochargers)

Vessel name	:	Olivia Maersk
Shipyard	:	Volkswerft Stralsund Hull #446
Built year	:	Dec. 2003
Main Engine	:	Mitsubishi Wartsila 7RTA96C 38,430 kW – 100 rpm
Turbocharger	:	Mitsubishi MET83SE x 2 sets

7. Electric assist turbocharger

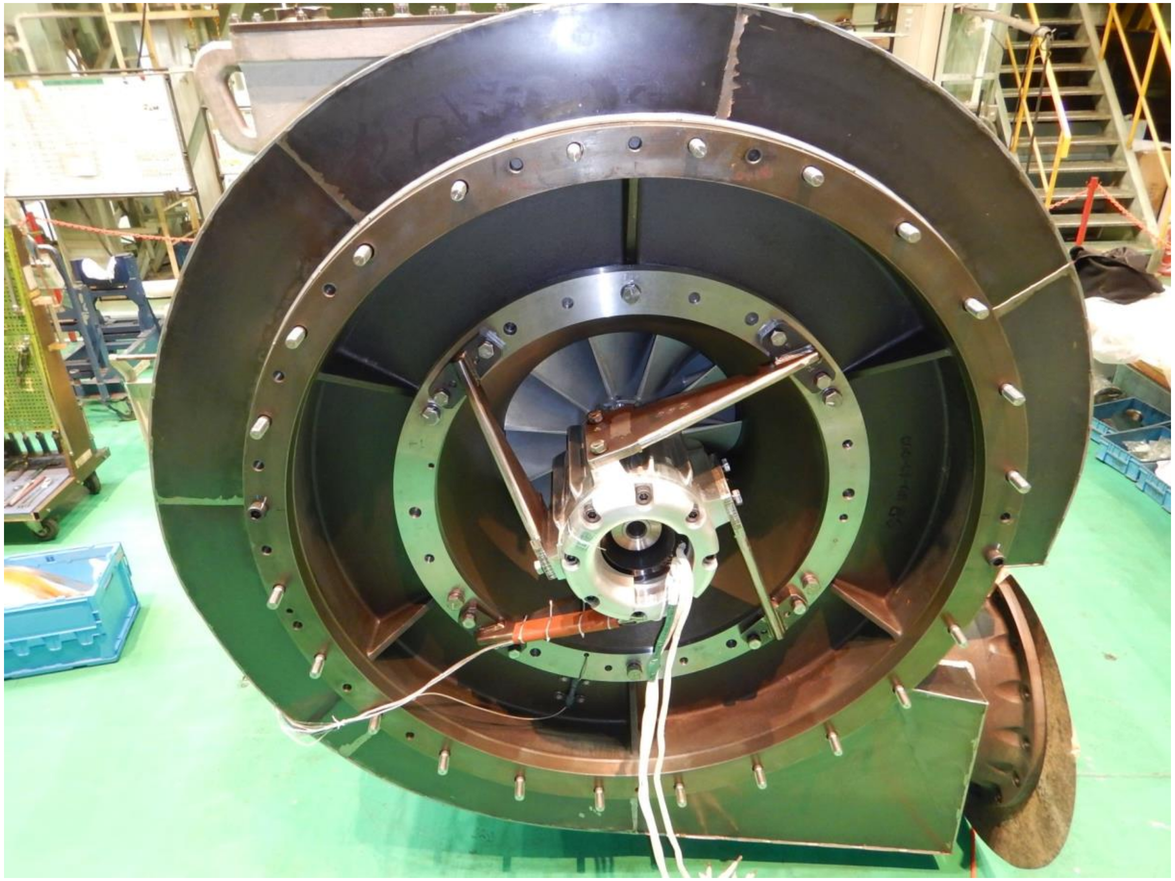
Turbocharger with elctro-magnetic driving device at the shaft end of MET83SE



7. Electric assist turbocharger – Retrofit Project

MET83SE turbocharger being assembled with driving device consist of rotor with magnets and stator coil (left)

Variable Frequency Drive with controller (right)



MITSUBISHI HEAVY INDUSTRIES
MARINE MACHINERY & ENGINE CO., LTD.
Our Technologies, Your Tomorrow

PROJECT MEET

Thank you for your kind attention !!