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UTILIZATION POSSIBILITY OF MARINE TRENT 30 GAS TURBINE AS PRIME MOVER ON VESSELS

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Abstract

Gas turbines are used as marine prime movers but the market is dominated by the diesel engines (of course turbocharged but they are still diesels). The share of gas turbines is on a level of 4-5% in the worldwide shipping.

It was presented the chosen parameters of Rolls-Royce gas turbine MT30 with nominal power 36 MW or 40 MW prepared for marine utilization. It is a good example of development of marine gas turbines with the trial to eliminate the effect of ambient temperature especially on turbine load.

It was discussed the significance presented data for possibility of utilization on vessels. It was indicated the advantages and disadvantages of gas turbine sharing.

It was mentioned the installation problems: pressure drop in inlet and outlet ducts on the accessible turbine power and specific fuel consumption.

It was discussed what important parameters ought to be known for safe turbine operation and maintenance. There is a little information lack. The gas turbine ought not to be treat as a black box. In the end, some final remarks are presented.

Keywords: *marine prime mover, gas turbine, propulsion, gas-electric plant, gas turbine utilization*

1. Introduction

Gas turbines (GT) are the engines used as prime movers on vessels but the market is dominated by diesel engines (over 90% of share). For some types of vessels, it may be reasonable to decide on gas turbine propulsion. The advantages of GT are known: high power output, high power to mass density (Fig. 1), power retention throughout life, compact package (Fig. 2), low on-board maintenance burden. The most important disadvantages are: thermal efficiency about 35-42% has influence on high specific fuel consumption (about 30% more than SFC of diesel engines at the same power) and lower time between overhauls (TBO) especially for high pressure turbine (hot end).

The Rolls-Royce developed the Aero Trent 800 gas turbine and marine version MT30 trying to find them area of utilization [3]. For example it was utilized on USS Freedom in CODAG (Combined diesel and gas) arrangement at 85 MW of power with two diesel engines 6.5 MW each and two MT30 with 36 MW each and speed over 40 knots. The American Navy is the biggest consumer of MT30 and RR4500 principally in Integrated Full Electric Propulsion (IFEP) [2].

The parameters of MT30 were extended. In 2004 the nominal power was possible up to 26°C of ambient temperature, now from 2016 it is possible up to 100°F (37.8°C). This is a new situation the power characteristics that are flat from -40°C up to 37.8°C (Fig. 3).

The restricted parameters of ambient conditions for MT30, when the operation is capable, are as following:

- external air temperature form -40°C to +50°C,
- sea water temperature from -2.2°C to +38°C,

- sea water density 1000 kg/m^3 from to 1028 kg/m^3,
- humidity 0% from to 100%,
- machinery space temperature 0ºC from to +55ºC,
- the MT30 control system ought to be located within the ship's machinery and will not relay on external heat exchangers [1].

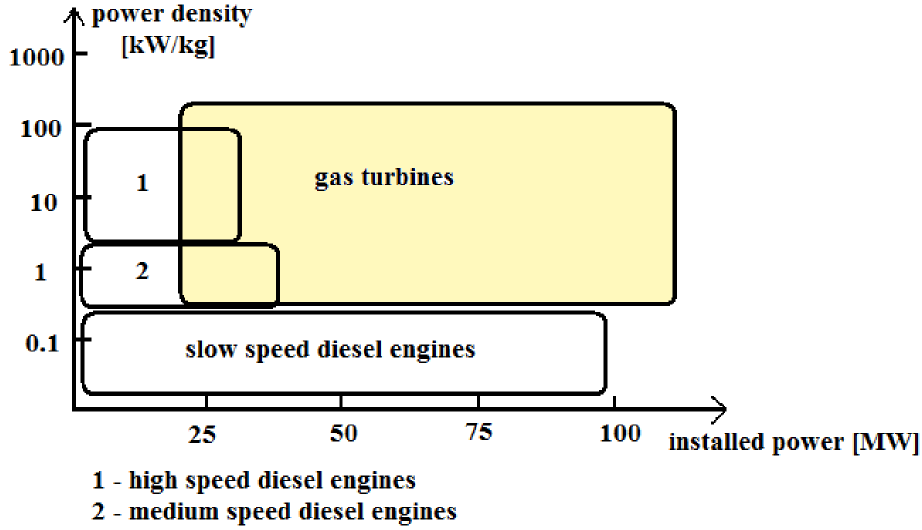

Fig. 1. Prime mover market on type of engines and power density

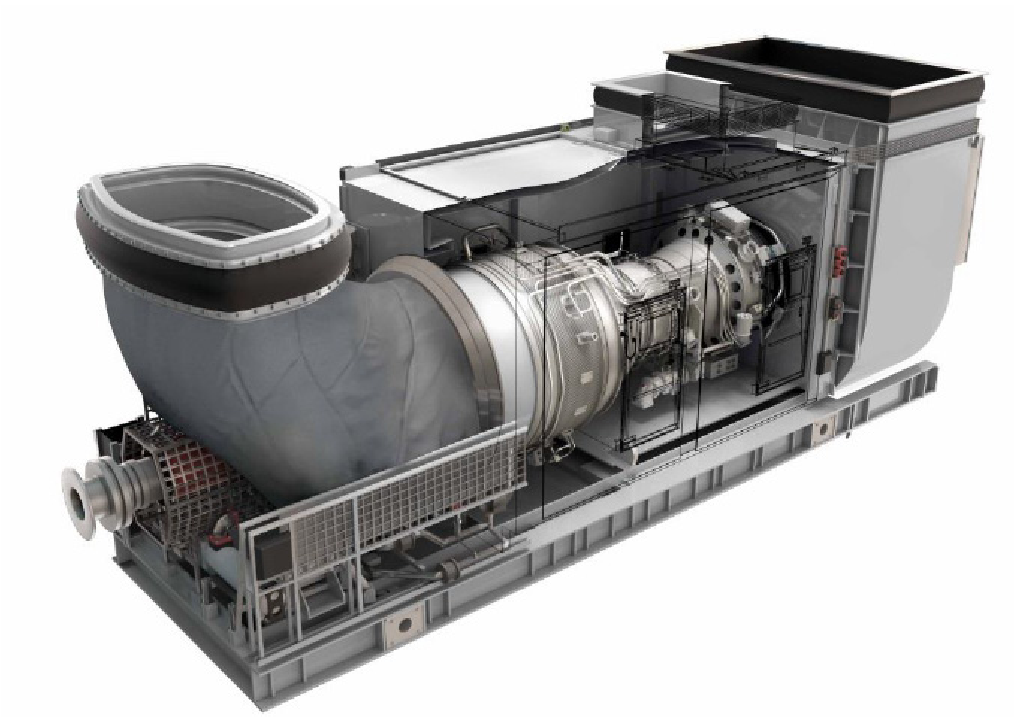

Fig. 2. Marine Trent 30 (MT30) package. Dimensions: length 8500 mm, width 2705 mm, height 3000 mm and mass less than 32000 kg (the power to mass coefficient is 0.88 kg/kW, power density 1.125 kW/kg) [1]

It means that there are no restrictions because the presented parameters represent the minimal and maximal values of media at sea.

Presented characteristics in the Fig. 3 takes into consideration only ambient temperature at ambient pressure of 1.01325 bar (1013.25 hPa). The power of gas turbines has linear dependence on ambient pressure and it is easy to recalculate the possible power of GT.

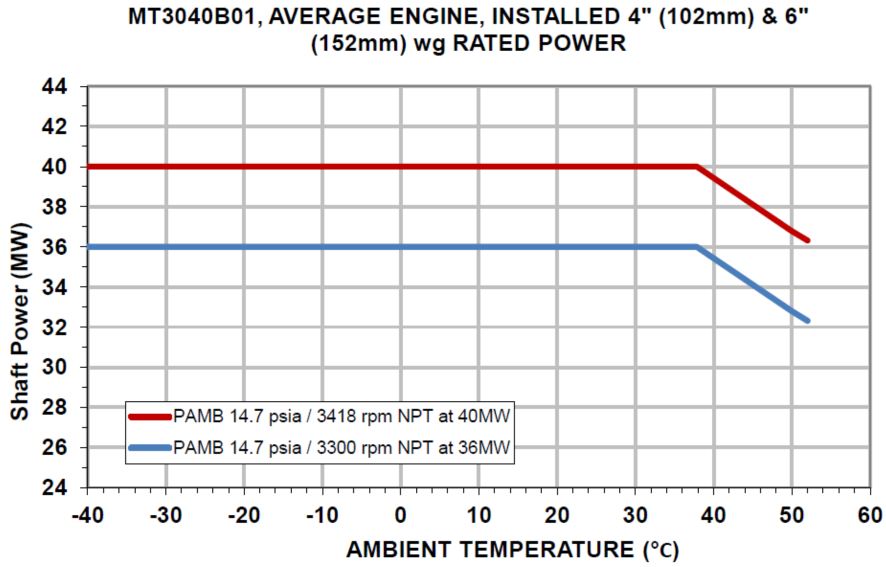

Fig. 3. MT30 shaft power rating [1]

2. Ship motion limitations

Marine engines especially propulsion prime movers have limitations on ship motions (change the hull position on sea waves). The MT30 gas turbine is designed to operate with the following ship motions and attitudes [1]:

- ship inclination (list and trim) 22.5° list and 10° rake,
- roll and pitch 0 ±45° and 0 ±10° respectively,
- the turbine may be installed with up to a rake angle ±5° relative to ship centreline (Fig. 4),
- the turbine is designed for limit loads of 1.5 g vertically, axially and laterally in addition to 1 g vertically downwards due to static engine weight.

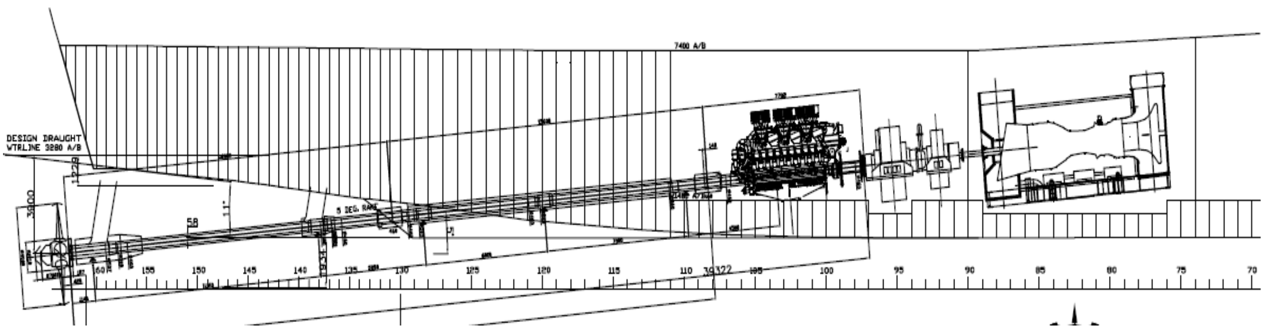

Fig. 4. The possibility of turbine location relative to ship centreline [1]

3. Installation effects on power and specific fuel consumption of MT30

The accessible power of GT depends on installation effects especially on pressure losses in inlet duct, in combustion chamber and exhaust gases outlet. It accepted the 4 inch (100 mm) of water gauge (wg) of nominal inlet loss and 6-inch (150 mm) wg of nominal exhaust loss. If the pressure drops are bigger, it ought to be recalculate the accessible power and specific fuel consumption.

The characteristics of installation effects for MT30 are presented in the Fig. 5. If the pressure drop increases to 400 mm wg:

- on inlet side decrease the power about 5% and increase the SFC about 0.9%,
- on exhaust side decrease the power about 1.7% and increase the SFC about 1.1%.

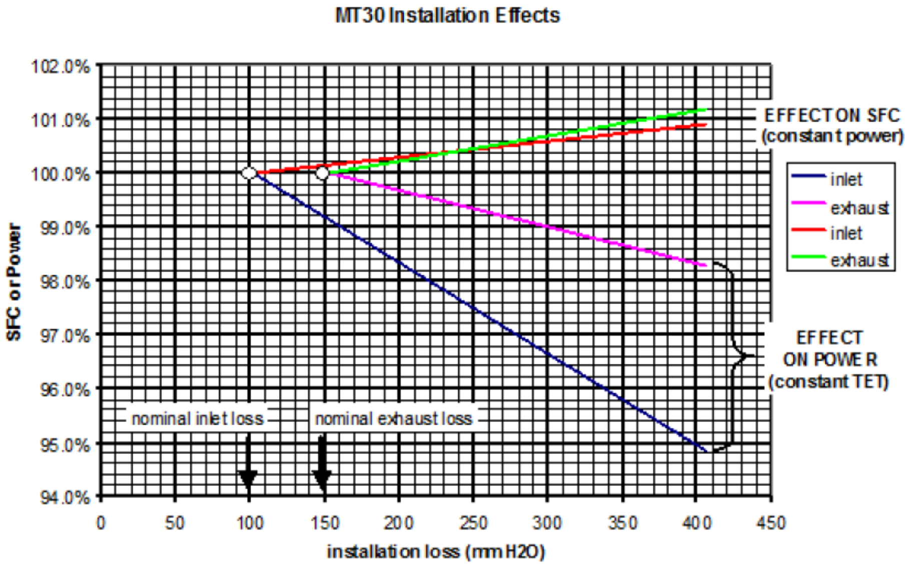

Fig. 5. Indicative effect of installation pressure loss on SFC and power [1]

The important parameter of gas turbines is specific fuel consumption. It is calculated for standard lower caloric heat value (LFHV) equal to 42800 kJ/kg. The real SFC has inversely proportional dependence on real LFHV. The characteristics of SFC for MT30 is presented in the Fig. 6.

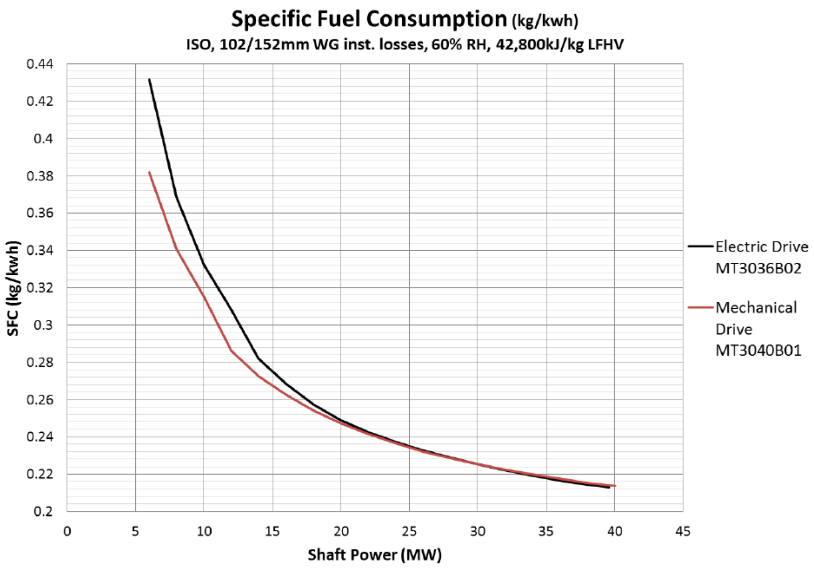

Fig. 6. Specific Fuel Consumption of MT30 in electric and mechanical drive [1]

At nominal power 40 MW for MT30 the SFC is 0.216 kg/kWh. It means that the fuel consumption reaches 8640 kg/h. If the real LFHV is only 40000 kJ/kg the SFC will be 0.245 kg/kWh and 9246 kg/h respectively. Knowing the characteristics of SFC, it may be calculated the efficiency of GT using the equation:

$$\eta = \frac{3600}{SFC \times LFHV},$$

where:

η – efficiency [-],
SFC – specific fuel consumption [kg/kWh],
$LFHV$ – lower caloric heat value [kJ/kg].

The efficiency of MT30 at nominal point of power is 39.0% (this is a thermal or gross efficiency), but at 25% of load decreases to 26.3% and 21% at 12.5% of nominal load.

3. Gas turbine parameters at engine idle

The MT30 is three shaft gas turbine where the IP compressor (8 stages, three first stages have variable vanes) is driven by IP turbine (single stage), the HP compressor (consists of 6 stages) is driven by HP turbine (single stage) and the remaining spool is dedicated to free power turbine (4 stages). An annular combustion system consists 24 fuel injectors. The parameters: torque and power at engine idle are presented in the Fig. 7.

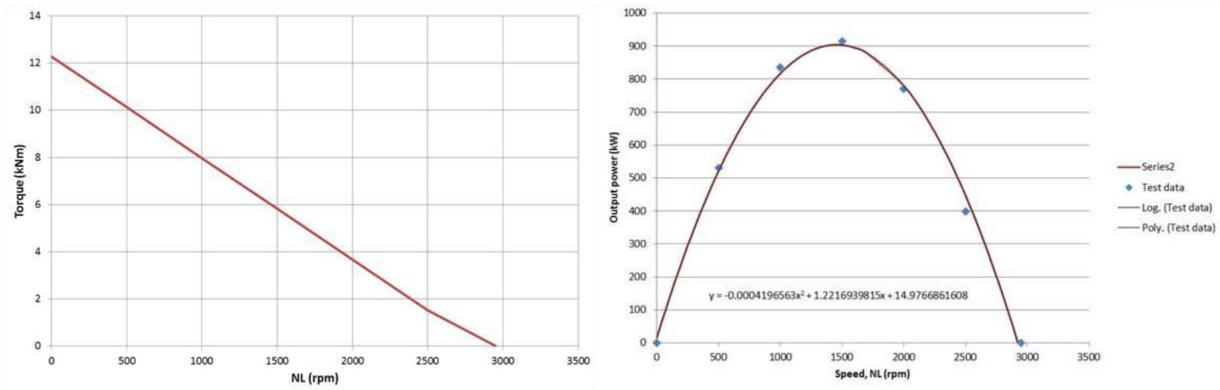

Fig. 7. Torque (on the left) and derived output power (on the right) versus power turbine speed at engine idle [1]

Of course, when the power turbine is stopped it occurs the maximal torque at level 12.2 kNm, which is decreased to zero at about 2950 rpm (almost linear). Looking for the power the maximal power 900 kW (4% of nominal load) it is possible at about 1500 rpm. If the power turbine increased the rotational speed, the power decreased to zero at 2950 rpm. The good known dependence between torque and power is presented in an equation:

$$P = T \times \omega = T \times 2 \times \pi \times n’$$

where:
P – power [kW],
ω – angular speed [1/s],
n – rotational speed [rps],
T – torque [kNm].

At zero speed (n=0) and at zero torque (T=0) always the power will be zero. A big value of torque at zero power turbine speed is a good situation the power turbine will be quickly increased its speed so long as the receiver torque equalized with turbine torque.

The approximation of turbine power at engine idle is in an equation:

$$P = -0.00041965663 \times N^2 + 1.2216939815 \times N + 14.97668616,$$

where:
P – power [kW],
N – rotational speed [rpm].

3. The information lack of other important parameters of MT30

It has not mentioned about many important parameters of gas turbine having important influence on the operation process. The proposed way is the MT30 treatment as a black box. For marine utilization, it may be not good mode especially in emergency situations [4].

The information lack concerns to following parameters:

- the compression ratio – it is only known that there is 14 axial compressor stages, probably the compression ratio will be about 16-18,

- the method of anti-surging – it is known that it was used three first stages of compressor have variable vanes so probably there is no anti-surging valves,
- the temperature in the inlet to HP turbine and the maximal temperatures and the time for turbine shut-down,
- the exhaust gas temperature has flat characteristics on a level of 470-485°C but how it was done (by increasing the air excess ratio?),
- the way of turbine blades cooling is air from IP and HP compressor, unknown the quantity of compressor capacity,
- the needed power for drive the lubricating oil pump, fuel pump, ventilation system etc.,
- the real pressure drop in the combustion chamber and respectively in the air inlet duct and exhaust gas duct (depending on the solution prepared by the shipyard),
- air excess ratio – at nominal power the air mass flow is 120 kg/s and the fuel mass flow 2.4 kg/s, it means that the ratio air to fuel is 50 and the air excess ratio will be about 3.50-3.64,
- too small information about the emission to the atmosphere from exhaust gases in dependence of load and type of fuel.

4. Final remarks

The utilization of MT30 as prime mover on vessels is possible. It was mentioned some advantages like: unrestricted engine operation, flat rated characteristics of power, low emissions levels, modular GT configuration, full electronic control etc. But it ought to be remembered about some disadvantages like: the nominal power is possible as 36 MW or 40 MW (there is no series of types and different number of cylinders as it is possible in the diesel engines), all gas turbines need the gear box for driven the propeller so it decreased the propulsion efficiency, the real (net) efficiency of gas turbine is much lower than above presented – at nominal load it will be about 34-35% and respectively lower at partially loads, the fuel consumption is about 20-30% more than in diesel engines and GT requires distillate fuels (more expensive) – so the cost of used fuel may be about 50-80% bigger.

For some types of vessels, the utilization of gas turbines (and the MT30) may be reasonable.

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