An analysis of characteristics of ship gas turbine propulsion system (in the light of the requirements for ship operation in the Baltic Sea)

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ABSTRACT

The paper concerns a propulsion system of merchant ships intended for sailing in the Baltic Sea zone. Such system is to satisfy the ecological requirements determined by relevant international conventions for special zones to which the Baltic Sea also belongs. The paper draws attention to gas turbine used as a prime mover for such ships, because it satisfies the ecological requirements and has also other advantages. Application of gas turbine for ship powering does not require exhaust gas to be purified, however it requires fuel oils of a low sulphur content to be used. If the ecological rules impose the using of the fuel oils of similar quality for diesel engines then gas turbine propulsion system will be comparable – also economically (regarding specific fuel oil consumption cost) – with that of diesel engine. It would be even more favourable in a combine gas turbine /steam turbine system, especially at compound production of electric and heat energy (i.e. COGES systems). In the Baltic Sea zone gas turbines will find application to powering a. o. such ships as : fast car-passenger ferries, fast cargo ships, special vehicles (hydrofoils, hovercraft, motor yachts).

Keywords : ship propulsion system, gas turbines, environment protection

INTRODUCTION

In the world's merchant fleet diesel engines still have prevailed as the prime movers of ships. And, about 70% of ship main diesel engines are low-speed ones. The general reason is their high efficiency even at partial load, and additionally – – a low cost of fuel oil used for low-speed engines (so-called heavy oil).

Gas turbines do not substantially contribute either in total number or total output of ship main engines. For recent years neither number of gas turbines nor their total output has increased significantly [6]. It's worth adding, for instance, that the total output of the low-speed diesel engines adjusted for using heavy oil, ordered in 2002, dropped by 48% relative to the records of the precending year. This is an important circumstance from the point of view of development of gas turbine application as ship prime mover because mainly the above mentioned advantages of diesel engine over gas turbine are brought up in economical comparisons.

Low speed diesel engines working on heavy oil are first of all used to drive large ships. Such engines are disadvantageous for ecological reasons (large SO_X pollution of the environment). However it were not those reasons which made the number of orders for them in 2002, lower. Rather general safety reasons and economical situation in different regions of the world belonged to them [6].

This paper is devoted to a propulsion system of merchant ship intended for sailing in the Baltic sea zone. Hence such system is to satisfy the ecological requirements contained in the relevant international conventions for special zones [1, 12, 14] to which the Baltic Sea belongs too. It draws attention to gas turbine as a main engine for such ship, because it satisfies the ecological requirements, moreover it has another advantages (discussed in detail below).

ANALYSIS OF ECOLOGICAL REQUIREMENTS FOR PROPULSION SYSTEMS OF SHIPS OPERATING IN THE BALTIC SEA ZONE

In accordance with the provision [14] of the International Convention for the Prevention of Pollution from Ships (adopted in 1973, modified in 1978 and amended in 1997) [12] suphur content in marine fuel oils is not to exceed 4,5%. And, in the zones subject to control of sulphur dioxide emission (e.g. the Baltic Sea, ports, costal waters up to 200 NM from land, and other zones specified by IMO) one of the two following conditions is to be fulfilled :

- sulphur content in fuel oil is not to exceed 1,5%
- sulphur dioxide emission is not to exceed 6,0 g/kWh.

A reason for such control and limitation of the environmenal pollution by sulphur oxides is the protection of human health and the environment. Sulphur dioxide penetrates the environment as a product of combustion of natural fuels used for energy production purposes. 80% of natural fuels is combusted on land, and 20% on ships. Most of sulphur dioxide released from ships pollutes the marine environment. Sea pollution due to sulphur dioxide emitted from ships does not participate much in its total content in the marine environment if to compare the total amount of the sulphur contained in sea water (over 10^{15}t) with that contained in natural fuel resources (10^{11}t). However despite that, in some zones of the marine environment, including the Baltic Sea, the amount of sulphur oxides emitted from ship propulsion systems is a threat to the environment.

Among other, the Baltic Sea environment is polluted to an extent greater than average. The reason of the susceptibility of the Baltic Sea is its rather small water depth and salinity.

Some reduction of the environmental pollution by sulphur oxides emitted from ships may be obtained in the following ways [4] :

- by lowering sulphur content in fuel
- by increasing propulsion efficiency
- by separating sulphur oxides from exhaust gases
- by applying new energy sources, other than those have been using so far.

However until now, application of an energy source other than fuel oil for ship propulsion has appeared either irrational (e.g. nuclear energy) for economical reasons, or impractical (e.g. wind).

A source of sulphur dioxide in exhaust gas is the sulphur contained in fuel oil. Substitution of a fuel oil of high sulphur content for that of lower one or natural gas would result in a lower sulphur dioxide content in exhaust gas.

However in this case some limitations associated with availability and cost of a fuel oil of low sulphur content, could appear. In present, the sulphur weight content in marine fuel oil amounts to 2.8%÷3.0%. The situtation has not changed for the last ten years. The reducing of the sulphur dioxide content in exhaust gas by 50% , postulated by IMO, would require to lower half as much the present sulphur content in fuel oil. Cost of such fuel oil would reach even 50 USD/t.

For the zones of a more limited sulphur dioxide content in exhaust gas, such as the Baltic Sea, the limitation of the sulphur content in fuel oil down to 1% is considered. Cost of such fuel oil would increase by 58÷85 USD/t.

Due to efforts resulting from competition between ship engine producers diesel engine efficiency of both two-stroke and four-stroke engines has reached a high value (i.e. a low value of specific fuel oil consumption). To attain any higher efficiency would be very difficult. Hence the increasing of engine efficiency has a small influence on the reducing of sulphur dioxide content in exhaust gas.

In marine conditions the washing purification method of exhaust gas from sulphur dioxide by making use of absorbing features of sea water (respective to sulphur oxides) is considered. However this is a sophisticated and expensive system. Moreover, in such case fuel oil consumption increases and – in consequence – also the environmental pollution due to carbon dioxide. Moreover, its effectiveness depends on salt content in sea water, which is low in the case of the Baltic Sea.

In association with the above given comments it seems that some lowering of sulphur content in marine fuel oil may be expected. Trends to lower sulphur dioxide content in exhaust gas emitted from ships would probably lead to elimination of heavy oil application for ship propulsion systems. This seems unavoidable especially in such zones as the Baltic Sea. This way a higher share of diesel oil in total fuel oil consumption for ship propulsion would cause that the gas turbine would become competitive against the high-pressure combustion piston engine, also from the point of view of specific fuel oil consumption cost, especially if applied in a compound gas-steam system (see Tab.1).

The presented (Tab.1) specific fuel consumption of a gas turbine working in a compound gas-steam system is a little higher than that of a diesel engine. However as distinct from the gas turbine, the diesel engine consumes a rather large amount of lubricating oil, which results in that the specific power cost of both kinds of propulsion becomes comparable.

***Tab.1.** Sulphur content in marine fuel oil*

Kind of ship propulsion system	Fuel	Sulphur content [%]	Specific fuel consumption [kg/MWh]	Sulphur emission [g/MWh]
Low-speed diesel engine	liquid :			
	heavy oil	4	170	68
	diesel oil	1.5	170	26
Gas turbine	liquid :			
	diesel oil	1.5	240	36
	natural gas	0	240	0
Compound gas-steam system	liquid :			
	diesel oil	1.5	180	27
	natural gas	0	180	0

COMPARISON OF TWO SHIP PROPULSION SYSTEMS : BASED ON DIESEL ENGINE AND GAS TURBINE, RESPECTIVE TO TECHNICAL, ECONOMICAL AND ECOLOGICAL ASPECTS

Gas turbine used as a ship main engine has many advantageous features, namely :

- low specific initial cost
- small dimensions
- low weight
- modular structure
- low level of vibrations and noise
- long time between successive overhauls.

Despite that its share as a ship prime mover in total output and number of applied engines on ships is still low, because gas turbine has some significant drawbacks in comparison with high-pressure combustion engine; these are :

- low efficiency when working in a simple propulsion system
- fast dropping efficiency at decreasing load
- it requires light fuel oil to be applied, which is more expensive than heavy oil used for low-speed diesel engines (covering more than 70% of total power used for ship propulsion).

For this reason the intensive research ordered by US Navy is carried out , aimed at development of a new type of marine gas turbine working on low-cost fuel oil [26, 27, 28].

The gas turbine applied on ships are mainly of an aircraft type (about 95%). Their output is in the order of 3000÷27000 kW, initial gas temperature : 850÷1100°C, compression ratio: 10÷26, efficiency: 27÷40%, specific fuel oil consumption: 220÷260 g/kWh [13]. Most of them is delivered by General Electric, among which LM 2500 turbine is most popular.

The investigations in question are aimed first of all at increasing initial temperature of combusted gas in order to make combusting a lower quality fuel oil possible. Moreover, waste heat recovery from exhaust gas is also planned to lower fuel oil consumption down to 170÷180 g/kWh. The application of exhaust gas recuperation at outlet from turbine, and of interstage compressor cooling makes it possible to decrease specific fuel oil consumption by about 30%. The investigations are also aimed at obtaining a lower fuel oil consumption at partial load levels of gas turbine.

TheRolls-Royce, a British firm in cooperation with the Westinghouse, a US firm has built WR-21 ship gas turbine of a new type in which the interstage cooling and recuperation system (ICR) have been applied. It is a triple-shaft turbine of 25000 kW output and a modular structure.

General Electric has modernized its known LM2500 turbine (now marked : LM2500R) by adding an interstage cooling and recuperation system [26,28].

At outlet either from a turbine or a diesel engine a steam generator supplying a steam turbine can be installed to utilize exhaust gas heat. In the case of gas turbine, exhaust gas transfers to environment more heat than in the case of diesel engine in which a significant part of the heat is absorbed by the water cooling the engine . Therefore in a combined gas turbine/steam turbine system, the steam turbine's output is much greater than that in a combined diesel engine/steam turbine system.

For ship propulsion two kinds of combined gas/steam systems are used :

- in the COGAS system (COmbined Gas And Steam turbine) ship's screw propeller is driven through a mechanical transmission gear
- in the COGES system (COmbined Gas and Steam turbine Electric) the so-called electrical transmission is used. The turbines drive electric generators which supply a common electrical power system (electrical network), and ship screw propeller(s) is (are) driven by electrical motors.

The Deltamarin, a Finnish advising firm has compared the COGES propulsion systems and diesel-electric propulsion systems (fitted with an electric transmission) installed on different merchant ships. On this basis it has specified the following advantages of the COGES propulsion system [17] :

- low initial cost
- high thermodynamical efficency: specific fuel oil consumption equal to or lower than that of a diesel engine of a comparable output (working through an electrical transmission)
- low operational cost (servicing, maintenance, lubricating oil)
- low sulphur content in exhaust gas (exhaust gas purification devices are not necessary)
- low level of vibrations and noise (e.g. passenger cabins can be located in the vicinity of engine room)
- high availability (high reliability, and possible fast operation of repair or replacement of engine)
- much smaller number of auxiliary devices, which makes initial and operational costs lower
- small engine room dimensions resulting in a greater space for cargo.

Technical characteristics

Out of the technical factors influencing choice of a kind of ship propulsion system the following are considered :

- **operational reliability**
  The gas turbines show low failure frequency and high availability greater than that of the diesel engines and steam turbines. Reliability of gas turbines used as ship prime movers amounts to about 98% [9]; the result is based on multi-year service experience on aircraft, ship and industrial turbine engines.
- **overhaul labour consumption**
  Due to a modular structure of gas turbine, access to its particular units and replacement of failed parts is very fast. It is possible to overhaul the engine without taking the ship out of operation. Gas turbine engine may be replaced within less than 24 h. Its small weight and gabarites make it possible to handle the whole engine at once, if necessary.
- **power transmission**
  In the case of fully mechanical powering, the gas turbine propulsion system requires a mechanical transmission gear to be applied. It is also required in the case of using high- and medium-speed diesel engines as ship prime movers, however low-speed diesel engines do not require it.
  As applications of the electrical transmission are still growing the way of power transmission from both gas turbine and diesel engine becomes analogous.
- **manoeuvrability**
  Diesel engines are reversible; gas turbines are irreversible as a rule. The stage of controllable guide vanes which makes reversible action of gas turbine possible, is rarely applied. The disadvantage of gas turbine can be overcome by using reversible transmission gears or controllable pitch propellers. Small gabarites of gas turbine rotor result in its very small inertia. Due to this, manoeuvrability of gas turbine ships is very high. Starting operation of gas turbine is very fast; starting from cold state, it is capable of developing full output within several minutes.
- **automation of operation**
  In comparison with diesel engines, gas turbines can be automatically controlled in a more easy way. It leads to possible reduction of a number of operators.
- **vibrations, noise**
  Vibrations generated by gas turbine in operation are much smaller than those due to diesel engine. They are easier damped due to their higher frequencies than those generated by diesel engines. Noise intensity due to gas turbine operation is much lower than that generated by diesel engine. Moreover, gas turbines are usually covered by an acoustic insulation.

Economical characteristics

Economical characteristics of the considered kinds of ship propusion system were compared by using a selected ship as an example.

It was the fast Ro2000 ship of 10.000 DWT load-carrying capacity, built by German Flender shipyard [2,3]. Its two controllable pitch propellers driven by two medium-speed, four--stroke diesel engines of 50 MW total output , propell the ship up to 28 kn speed. The ship's propulsion system was compared with a system of the same power but driven by a gas turbine, as well as with the COGES, a combined gas/steam system.

As far as the diesel engine propulsion system is concerned the following information was assumed valid :

- Two MAN-B&W 12V 48/60 medium-speed diesel engines, each of 12600 kW output at 600 rpm, were assumed to be the ship's prime mover
- Electrical power was produced by four generating sets of 1000 kW output each, driven by four HFC5 632/14K--T260L-EX Yanmar diesel engines
- It was assumed that four waste heat boilers delivered each of 1000 t/h of steam
- The amounts of consumed electric and heat energy were estimated on the basis of available data dealing with a ro-ro ship of a similar load-carrying capacity.

As far as the gas turbine propulsion system is concerned it was assumed that :

- the system consisted of two WR-21Northrop Grunman / Rollce-Royce gas turbines of 25000 kW output each, driving two ship screw propellers
- the turbines are equipped with an interstage cooling and recuperation systems due to which the turbine's efficiency amounts to 40%
- Exhaust gas from the recuperator supplies a waste heat boiler.

- Specific fuel oil consumption of the turbines not much varies within 50÷100% interval of the rated output.

As far as the COGES system is concerned it was assumed that two LM2500 General Electric gas turbines of 22400 kW output each, as well as a steam turbine of 10000 kW output, was applied.

In order to compare the above specified propulsion systems the following measures were used :

propulsion efficiency :

$$\eta = \frac{P_e \cdot \eta_g \cdot 3600}{B_h \cdot W_d}$$

energy efficiency :

$$\eta' = \frac{(P_e \cdot \eta_g + P_{el}) \cdot 3600 + Q}{B_h \cdot W_d}$$

specific fuel oil consumption :

$$b = \frac{B_h}{P_e \cdot \eta_g}$$

where :

B_h - total fuel oil consumption per hour (by main engine, auxiliary engines and boilers)
P_e - main engine output
P_{el} - generated electric power
Q - hourly flow rate of produced heat
W_d - net calorific value of fuel oil
η_g - transmission gear efficiency.

Appropriate values of the economical characteristics of the ship propulsion systems in question are compared in Tab.2.

Tab. 2. *Comparison of the economical characteristics of the considered ship propulsion systems*

Characteristic elements	MAN-B&W 12V 48/60 diesel engine	WR-21 gas turbine	COGES system
propulsion efficency, [%]	43.6	40	46.8
specific diesel fuel oil consumption, [g/kWh]	194	214	183
energy efficency, [%]	49.7	45.6	49.1
specific lubricating oil consumption, [g/kWh]	1.0	~ 0	~ 0
price of marine diesel oil, [USD/t]	~ 140	~ 140	~ 140
price of lubricating oil, [USD/t]	~ 2000	~ 2000	~ 2000
specific cost of marine diesel oil, [USCent/kWh]	2.72	3.00	2.56
specific cost of lubricating oil, [USCent/kWh]	0.2	~ 0	~ 0
price of heavy oil, [USD/t]	~ 91	–	–
specific cost of heavy oil, [USCent/kWh]	1.64	–	–

It was assumed that both the diesel engine and gas turbine is supplied with the same kind of fuel oil (marine diesel oil). In such conditions the specific fuel oil consumption of the COGES system appears the smallest, somewhat smaller than that of the medium-speed diesel engine in question. However, the diesel engine also consumes lubricating oil (much more than the combined system COGES), which makes that the specific power cost of the COGES system amounts to about 0.88 of that of the diesel engine propulsion system (see Tab.2).

The specific power cost of the gas turbine propulsion system (of a simple configuration) is only a little greater and it amounts to about 1.03 of that of the diesel engine propulsion system.

The specific cost of heavy oil is given in the last row of Tab.2. On its basis it can be stated that the specific power cost of the COGES system amounts to about 1.4 of that of the low-speed diesel engine propulsion system.

As a matter of fact at partial load diesel engine's efficiency decreases much slower than that of gas turbine. At the half-load, diesel engine's efficiency drops e.g. by 5% relative to its value at the rated load, whereas the efficiency of LM2500 gas turbine drops by 10%. However, in the COGES system 50% of the rated load can be obtained by keeping in operation at its rated load only one of the two gas turbines.

Ecological characteristics

Exhaust gas from diesel engines contains more not only sulphur oxides but also nitrogen oxides due to a greater effectiveness of fuel combustion processes, in consequence – a greater temperature. The exhaust gas also contains more carbon oxide and hydrocarbons. Tab.3 enables to compare in this respect the considered ship propulsion systems.

Tab. 3. *Comparison of the ecological characteristics of the considered ship propulsion systems*

Kind of propulsion system	Kind of fuel	Sulphur content (weight) [%]	Sulphur emission [g/MWh]	NO_x emission [g/kWh]	CO emission [ppm]	HC emission [ppm]
diesel engine	heavy oil fuel oil	4 1.5	68 26	11÷16 (medium-speed engine)	60	180
gas turbine – simple configuration	fuel oil natural gas	1.5 0	36 0	3÷5	25	5
gas turbine – COGES system	fuel oil natural gas	1.5 0	27 0	~ 0	25	5

The necessity of complying with the environmental protection rules entails undertakings dealing with construction of the diesel engine itself, as well as with the exhaust gas purification devices [31]. Such undertakings are costly. However the gas turbine propulsion system can satisfy the environmental protection rules without any additional devices.

COMPARISON OF SHIP POWER PLANT CHARACTERISTICS RESPECTIVE TO A KIND OF SHIP PROPULSION SYSTEM

A kind of ship propulsion system (a kind of prime mover) influences such characteristics of the ship power plant as : its weight, volume of occupied space , number of operators. They play an important role from the economical point of view. By decreasing the volume of its space it is possible to increase amount of cargo or number of passangers to be shipped. The lower the weight of the power plant, the smaller the power demanded for ship propulsion (the smaller fuel consumption). A smaller number of operators leads to a lower personnel cost.

Comparison of the ship power plant respective to its weight and volume with taking into account a kind of its propulsion system, can be performed by using two indices : the so-called specific mass and power density (concentration). The specific mass is defined as the ratio of the total power plant mass (of main engine, auxiliary devices, and empty piping systems) and the engine's rated output. The power density is defined as the ratio of the engine's rated output and the engine room volume. Values of the indices, presented in Tab.4, make it possible to compare the example power plant with the respect to the three considered kinds of propulsion system.

Tab. 4. *Specific mass and power density of the example ship power plant in three considered versions of propulsion system*

Index	Considered ship propulsion system based on :		
	12V 48/60 diesel engine	**WR-21 gas turbine**	**COGES system**
Specific mass [kg/kW]	14.52	2.53	4.56
Power density (concentration) [kW/m^3]	48	247	780

Out of the considered kinds of ship propulsion system, the diesel engine power plant is of the greatest specific mass, about six times greater than the gas turbine one, and over three times greater than that of COGES type. The power density (concentration) of the gas turbine power plant is over five times greater than that of the diesel engine power plant; the greatest power density has the COGES version of the power plant - over sixteen times greater than that of the diesel engine power plant, and over three times greater than that of the gas turbine power plant (see Tab.4.).

As it has been already mentioned , the gas turbine power plants (including their COGES versions) are suitable for automation and control. This way, decreasing the number of power plant operators and simultaneous decreasing volume and mass of power plant as well as lowering its operational cost, can be possible.

Growing interest for application of electrical drive to ship propellers (by using the electrical transmission) also directs greater and greater attention to gas turbines. In this respect it is worth adding that in such version of propulsion system gas turbines can be located on the deck, which eliminates a troublesome arrangement of compressor's air supply pipes delivering air from the deck to the power plant.

SPECIFIC ASPECTS OF GAS TURBINE APPLICATION ON SELECTED SHIPS

Choice of a main engine location depends on a type of ship and applied engine, and a power transmission way from the engine to propeller. For instance application of an electrical drive to ship propeller provides the designer with a great freedom in locating the main engine relative to a mechanical transmission of power. Any propelling engine due to its mass, thrust, torque, transient state loads and sea state must have a suitable foundation firmly connected with ship's hull structure. Such propelling engine as gas turbine is a source of high temperature and noise, hence protective means should be applied to lower noise and high temperature. The features have an influence on location of main engine within engine room as well as on construction of its foundation. In ship power plants based on gas turbines the main engine is usually installed in an individual casing seperated from ship's hull structure. The gas turbine module is connected to air intake and exhaust gas systems. Such solution of the engine's casing (container-like) enhances also fire-safety of the whole power plant.

Location of engine's seating depends on many aspects. One of them is troublesome centering the engine and propeller shafts. To avoid such operation a non-mechanical way of power transmission from the engine to propeller, usually an electrical transmission system, is applied. In this case different variants of the engine's location within ship's engine room are possible. The main engine can be located either aft or fore; if just aft then it is possible to make the shaft between the engine and propeller as short as possible , which reduces engine room's volume. The electrical transmission makes it possible to locate the main engine fore, without applying any long shaft. In most cases ship's power plant is usually located within ship hull's space.

Along with application of gas turbines new possibilities to locate the main engine even on the ship's deck, have appeared. Small mass of gas turbine provides the designer with a greater freedom in locating the power plant. For instance it is allowed to locate ship power plant above the main deck both on large and small ships, also in the case of application of heavy industrial gas turbines.

In Fig.1 is presented a variant of location of a power plant equipped with a heavy gas turbine installed on the main deck of a tanker. In the power plant a gas turbine with heat recuperation system, as well as electrical drive of propeller, are applied. Mass of propeller, shaft, electrical motor and gas turbine determines mass centre location below the main deck level (engine - generator - electrical motor - turbine shaft).

Dimensions of air and gas ducts of gas turbine influence location of the gas turbine itself. If the gas turbine is located high then lengths of inlet and outlet pipes are shorter, hence mass and dimensions of air and gas ducts are also changed.

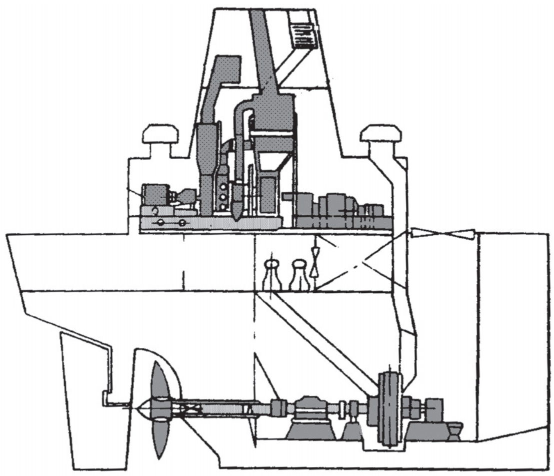

Fig.1. *An example arrangement of tanker's power plant fitted with gas turbine and electrical drive of propeller*

In Fig.2 a gas turbine power plant installed on a container--ship is presented. Location of the gas turbine with compressor aft makes it possible to shorten inlet piping as much as possible.In such location of the gas turbine the reduction gear is placed before the engine, and the propeller shaft is led aft below the engine. This way the length of the power plant appears shorter in comparison with those of other types of heat engines.

Application of gas turbines to ship propulsion makes free access to all devices possible, both during service and overhauls. Moreover, lengths of air and gas ducts can be minimized. The number of devices associated with auxiliary mechanisms is reduced, and the engines themselves do not require to be additionally cooled with sea water (hence sea water pumps, their piping systems etc are not necessary).

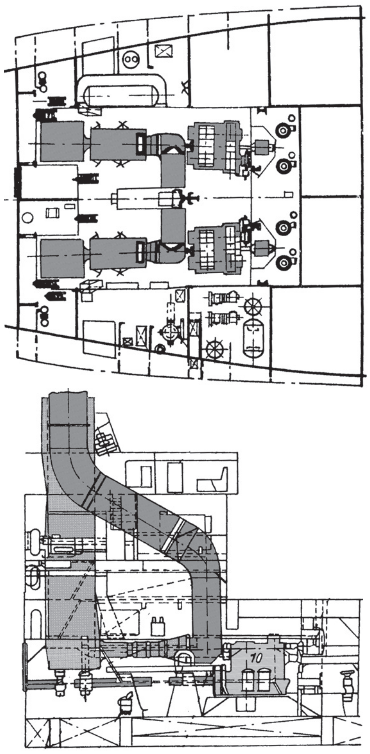

Fig. 2. *An example solution of gas turbine power plant of a containership*

SUMMARY

❍ Application of gas turbines on merchant ships is still limited [6] due to their high operational cost (specific fuel oil consumption cost) especially in comparison with that of low-speed diesel engines working on heavy oil. However the ecological requirements established by the International Maritime Organization (IMO), limiting content of sulphur oxides in exhaust gas from ship propulsion engines [1,12,14], can make it possible – or even force – a broader application of gas turbines as ship prime movers. For special zones to which the Baltic Sea belongs too, the requirements are more stringent.

❍ Fulfilment of the requirements by diesel engines could be achieved by :
- ⇨ using a fuel oil of an appropriately low sulphur content (it would mean to stop using heavy oil)
- ⇨ installing exhaust gas purifying devices.

Both the ways of reducing content of sulphur oxides in exhaust gas are expensive.

❍ Application of gas turbine to ship propulsion does not require exhaust gas to be purified, however it requires a fuel of low sulphur content to be used. In the case if the ecological requirements force application of fuel oil of a similar quality for diesel engines , then the gas turbine propulsion system will be comparable with the diesel engine one also respective to economical aspects (specific fuel oil consumption cost). In this respect it would be even more favourable if used in a combined gas turbine /steam turbine system, especially at common production of electrical and heat energy (COGES system).

❍ Gas turbine propulsion system has many technical advantages which make gas turbine superior , in this respect, over diesel engine. Diesel engines, especially low-speed ones working on heavy oil, are superior over gas turbines only in the respect of specific fuel oil consumption cost. This is why their share in the total propulsion power installed in merchant ships amounts to about 70%.

❍ In the Baltic Sea zone the gas turbines are expected to be more and more used for propulsion systems of such ships as :
- ⇨ fast car-passenger ferries
- ⇨ fast cargo ships
- ⇨ special vehicles (hydrofoils, hovercraft, motor yachts).

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