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PROPOSAL OF ECOLOGICAL PROPULSION PLANT FOR LNG CARRIERS SUPPLYING LIQUEFIED NATURAL GAS TO ŚWINOUJŚCIE TERMINAL

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Abstract

The liquefied natural gas should be delivered to Świnoujście terminal by the biggest and the most modern ships. Ships should be operated by Polish owners. Cargo capacity of these ships is limited by depth of waterway on Świnoujście terminal entry. The largest recently built LNG carriers with cargo capacity 250000 m^3 have drought about 12m which corresponds to waterway depth. The propulsion plants of such a ships should be fuelled by natural gas witch is considered to be an "ecological fuel". The natural gas is widely used in onshore energetic plants however in marine applications the heavy fuel oil is still dominating. It is the result of problems in adaptation of marine diesel engines to burn natural gas. That is why LNG carriers should be equipped with combined propulsion plant COGES (Combined Gas Turbine and Steam Turbine Integrated Electric Drive System) made up of gas turbines burning natural gas from boiled off cargo and thermodynamically connected steam turbine. Such a propulsion plant is successfully competing in efficiency with conventional diesel engines fuelled with heavy fuel oil.

Key words*: marine combined propulsion plants, natural gas as marine fuel*

1. Introduction

Decision to build LNG (Liquefied Natural Gas) terminal in Świnoujście raises the question about types of LNG carries supplying liquefied natural gas to Poland. This is Polish national interest to use Polish ships operated by Polish owners. It should be the largest ships passing the water lane on Świnoujście LNG terminal entry. The largest actually built LNG carriers (cargo capacity 250000 m^3) have draft 12m and can easily pas existing waterway. Analysis show that even LNG carriers with capacity 270000 m^3 can call Świnoujście terminal in the future. LNG Carrier capacity *266000* m^3 is shown in figure 1.

Fig. 1.
LNG carrier Mozah *owner* Qatar Gas Transport CO *steaming at sea*

During sea transport natural gas is kept in liquid form under atmospheric pressure in temperature $-163^{o}C$. One of the basic problem during transport by means of LNG carriers is heat penetration into cargo tanks and evaporation of cargo. Boiled off gas can be liquefied by special reliquefaction system and returned to cargo tanks or can be used as fuel in ship propulsion plant. As the reliquefaction systems consume big amount of energy the better way is to use the boiled off cargo as a "ecological fuel" for ship propulsion plant. However natural gas is widely used in on land power stations the heavy fuel oil still dominates in ship propulsion. After combustion heavy fuel oil exhaust gases are very harmful to environment. Small application of natural gas for ship propulsion comes from difficulties in adaptation of marine diesel engines to burn the gas. That is why LNG carriers should be turbine driven as the turbine propulsion can be easy adopted to gas burning. It should be modern propulsion system COGES (Combined Gas Turbine and Steam Turbine Integrated Electric Drive System) consisting of gas turbines fed with boiled off cargo and thermodynamically connected to them steam turbine. COGES system has high efficiency successfully competing with efficiency of traditional diesel engine propulsion fed with heavy fuel oil.

2. COGES type marine propulsion system

Suggested for ship propulsion COGES system (fig. 2) consists of two gas and one steam turboalternators. They create central electric power station, which supplies the power for ship propulsion and ship electric net. Gas turbines 1 and steam turbine 2 are thermodynamically connected to obtain high energetic efficiency. It consists on use of gas turbine exhaust gases for steam generation in waste head boilers 3. The steam is used for steam turbine drive and for heating purposes of the ship. This way a high rate of energy utilisation is obtained and the main disadvantage of gas turbines i.e. high exhaust loss is eliminated. In addition the ship is not equipped with auxiliary diesel generators since the electric power is supplied by COGES central power station. The energetic efficiency of engine room is considerably increased. Engine room fuel systems, cooling systems and lubricating systems are simplified as well as total investment expanses. Analysis [4] appoint that COGES propulsion system has many advantages comparing to other types of propulsion in particular smaller weight and dimension (up to 30% in comparison to diesel engine propulsion), low costs of overhauls and repairing, high reliability and simple operation. Components of COGES system are shown in figure 3.

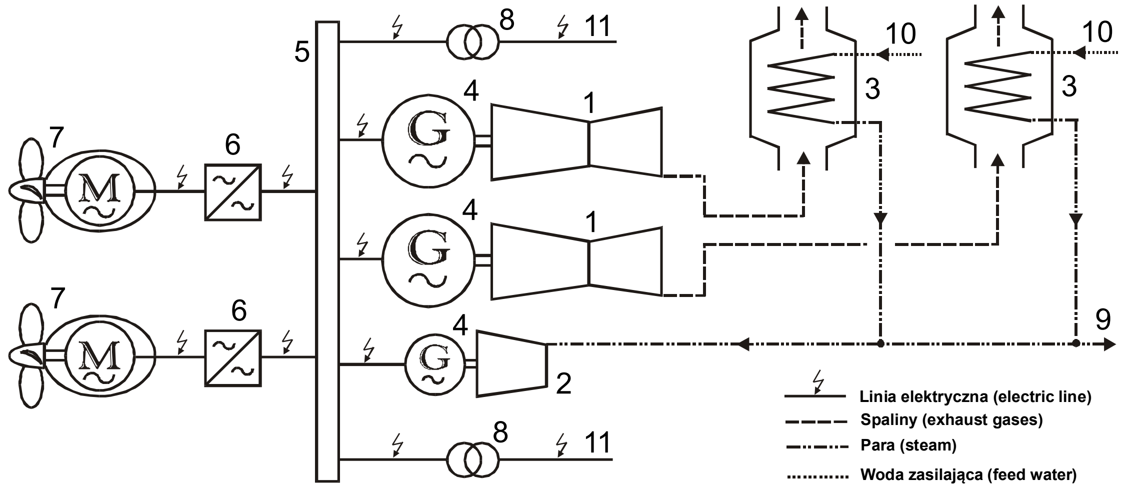

Fig. 2. Combined COGES type propulsion plant
1 – gas turbine; 2 – steam turbine; 3 – exhaust gas steam boiler; 4 – main alternator; 5 – main switchboard; 6 – frequency converter; 7 – azipod propulsor; 8 – transformer; 9 – heating steam system; 10 – feed water inlet; 11 – electric power receivers

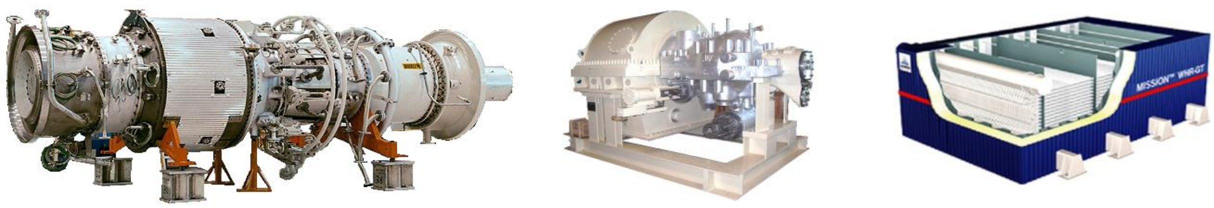

Fig. 3. An example of COGES system components
a) Gas turbine Simens type SGT, b) Steam turbine Simens type SST
c) Exhaust gas heat recovery boiler Aalborg MISSION™ WHR-GT,

Ship propulsion should be executed by modern azipod thrusters (fig. 4). Propellers 2 are driven by electric motors supplied via frequency converters are placed in horizontally rotational pods 1. Thus the high manoeuvring ability of the ship is achieved and the ship does not need classic steering gear. If the draft of the ship is 12 m it is necessary to install two azipod thrusters.

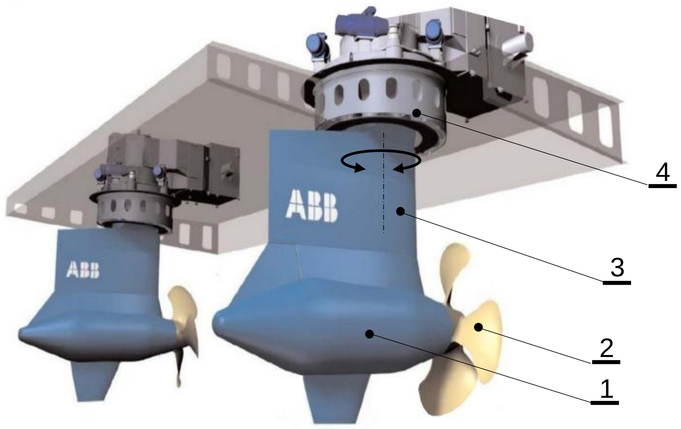

Fig. 4.
Azipod thrusters ABB
1 – pod,
2 – propeller,
3 – azipod rudder fin,
4 – azipod slewing gear

The space of engine rooms with traditional low speed diesel engine and COGES system is compared in figure 5. An additional cargo space 11 is to be noticed on the ship propelled by COGES system due to smaller engine room.

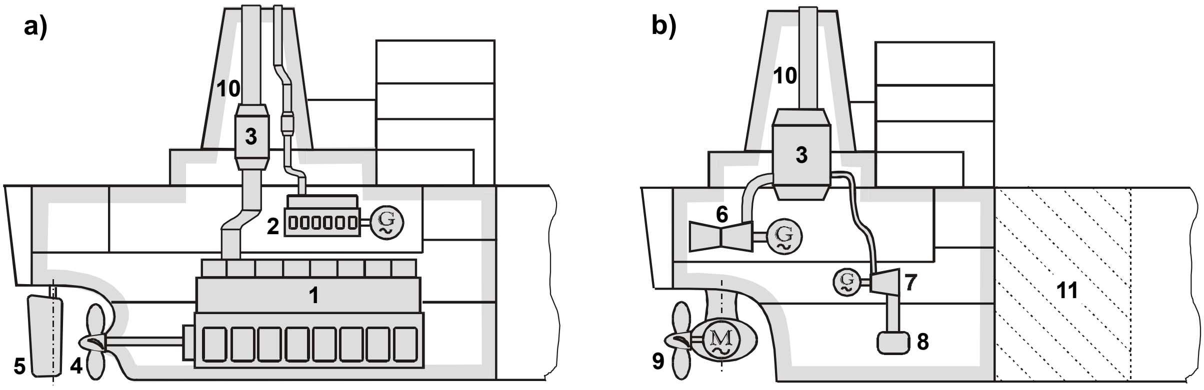

*Fig. 4. Comparison of machinery space of LNG carrier propelled by low speed diesel engine (*a*) and COGES system (*b*)*

1 – low speed diesel engine; 2 – diesel generator unit; 3 – steam boiler; 4 – propeller; 5 – rudder; 6 – gas turbine generator unit; 7 – steam turbine generator unit ;8 – condenser; 9 – azipod propulsor; 10 – exhaust gases outlet; 11 – additional cargo space

2. Rating power and efficiency of suggested ship propulsion plant

- shaft power needed for LNG carrier with capacity $250000m^3$ and speed *19,5 knots* is [6]:

$$N_w = (1{,}34571 + 0{,}00003091 \cdot D_n) \cdot v^3 = 37481\ kW \quad (1)$$

where:
D_n = 120000 ton - deadweight of 250000 m^3 capacity LNG carrier,
v= 19,5 knots - assumed ship speed,

- electric power needed by ship network during sea passage is assumed as *2000 kW*,
- hence the total power of COGES central electric station turbines is:

$$\Sigma N_{COGES} = \frac{N_w}{\eta_{em} \cdot \eta_{fc} \cdot \eta_G} + \frac{N_{el}}{\eta_G} = 42364\ kW \quad (2)$$

where:
$N_w = 37481\ kW$ – power needed for ship propulsion,
$N_{el} = 2000\ kW$ – electric power needed by ship network,
$\eta_{em} = 0{,}97$ – main electric motors efficiency,
$\eta_{fc} = 0{,}99$ – frequency converters efficiency,
$\eta_G = 0{,}97$ – generators efficiency.

Table. 1. The influence of the power distribution between gas turbines and steam turbine, specific fuel consumption and effective efficiency of the COGES propulsion system driven by heavy fuel oil HFO

Power distribution between gas turbines and steam turbine N_{GT}/N_{ST} *[%]*	80/20	75/25	70/30	65/35
Gas turbines rated power [kW]	2 x 16946	2 x 15887	2 x 14828	2 x 13768
Steam turbine rated power [kW]	8472	10590	12708	14828
Specific HFO consumption of the COGES system [kg/kWh]	0,188	0,176	0,165	0,153
Effective efficiency of the COGES system [%]	46,7	49,8	53,4	57,5

The efficiency of COGES system depends on the rate of gas turbines exhaust gases utilisation i.e. power distribution between gas turbine and steam turbine. In modern onshore power station power distribution between gas and steam turbines is *65/35%* [9]. Today it is possible to achieve in marine applications power distribution *75/25%* and *70/30%* in the future. Table 1 shows characteristic data of COGES propulsion system for suggested ship according to [3].

3. Natural gas fuel system of COGES type propulsion plant

Nowadays COGES propulsion systems are used on passenger cruise liners. Gas turbines are fed with gas oil. Gas turbines of LNG carrier should be fed with natural gas.

Schematic diagram of COGES propulsion plant fuel system on LNG carrier is shown in figure 5. Liquefied gas is carried in cargo tanks under atmospheric pressure in temperature -163^oC. Boiled off gas is drawn from tanks by low pressure compressors 4 (discharge pressure about *0,2 MPa*, gas temperature on compressor outlet about $-111,5^oC$) and pressed to heaters 5 where the temperature raised to about -10^oC. Low pressure gas in temperature about 30^oC can be used for auxiliary boiler firing. To feed gas turbines due to pressure in combustion chambers the pressure of gas should be raised in high pressure compressors 6 to *2,5 MPa* and temperature about 30^oC.

The rate of cargo evaporation depends on outside ambient temperature. In case to small amount of boiled off gas in cargo tanks the system can be supplied with liquefied gas by using pumps 2 and gas vaporisers 3.

Pumps and compressors of boiled off gas reliquefaction system (it is equipment of each large capacity LNG carrier) serves in fuel system. Therefore the fuel system does not any additional equipment, only additional pipe connections between cargo system and engine room are needed.

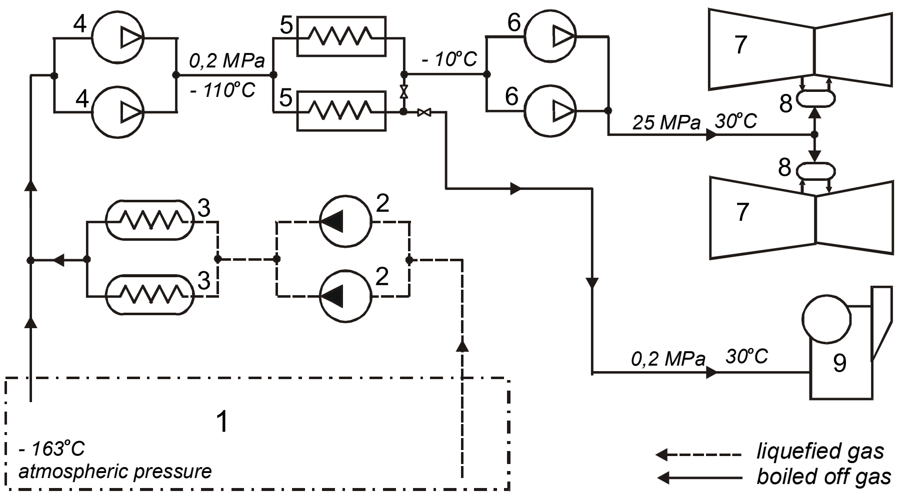

Fig. 5. Gas turbines fuel system on liquefied natural gas carrier
1 – LNG cargo tanks; 2 – liquefied gas pump; 3 – liquefied gas vaporiser; 4 – low pressure compressor; 5 – heater; 6 – high pressure compressor; 7 – gas turbine; 8 – gas turbine combustion chamber; 9 – gas fired auxiliary steam boiler

3. Forecast of fuel consumption for suggested ship COGES propulsion system

Rated power of COGES system turboalternators covers electric power demand during sea passage as well as in remaining operation states e.g. ship manoeuvring, stopover on port roads, cargo discharging, reliquefaction system operation and regasification system operation [2]. During cargo discharging with all cargo pumps in operation the electric power demand is about *10000 kW*.

During boiled off gas reliquefaction this is about *6500 kW*. If the boiled off gas is used as propulsion fuel it decreased to *350÷1600 kW*. In that case:

- daily fuel consumption of gas during sea passage is:

$$G_{dCOGES} = 24 * N_{COGES} * g_{COGES} = 178{,}9\ [ton/dobę], \quad (3)$$

where:

$N_{COGES} = 42364\ kW$ – from formula (2),
$g_{COGES} = 0{,}176\ kg/kWh$ – specific fuel consumption from table 1 for power distribution *75/25%*,

- the amount of daily boiled of gas from (BOG) cargo tanks is about *0,1÷0,2%*, accepted for calculation is *0,15%*, that is:

$$G_{BOG} = 0{,}0015 * D_n = 183{,}8\ [tons/day] \quad (4)$$

gdzie:

$D_n = 250000\ m^3 * 0{,}49\ tons/m^3 = 122500\ tons$ – mass of cargo
$\rho_{LNG} = 0{,}49\ tons/m^3$ – LNG density.

The amount of BOG covers the daily fuel consumption of COGES system during sailing at sea with full cargo loading. In case of smaller cargo evaporation rate auxiliary cargo pumps can be used and liquefied cargo can be vaporised.

- fuel requirement for to and fro trip (loading terminal – Świnoujście discharging terminal – loading terminal):

Assuming the longest trip to and fro 38 days (16 days at sea in cargo condition, 16 days at sea in ballast condition, 6 days cargo operations) gas fuel requirement is about *5500 ton*, which is about *4,5%* of cargo capacity. The special gas fuel tanks exclusively serving for propulsion requirements are not needed. The propulsion system will use gas fuel from cargo tanks. A suitable amount of LNG cargo for return ballast trip should be left in cargo tanks.

4. Conclusions

This paper is the next in turn opinion of authors in the subject of construction LNG carriers delivering liquefied natural gas to Świnoujście terminal and type of propulsion plant for these ships. Undoubtedly advantages of COGES system fed by natural gas lean towards it use on suggested ships. The COGES system is less expensive in construction and operation as well as simple in operation and fed by natural gas recognised as "ecological fuel". In addition increasing prices of marine fuels in the nearest future will be higher than LNG prices, which forces to discussion about the kind of LNG carriers propulsion. Authors of the paper consider obvious the necessity of construction for Poland her own LNG carrier fleet supplying gas terminal in Świnoujście.

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