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# CONSIDERATIONS ABOUT SHIP CLASSIFICATION SOCIETIES RULES FOR INSTALLATION ON BOARD OF NAVAL PROPULSION SYSTEMS WITH GAS TURBINES

**Ion Adrian GIRBA[1]**
**Anastase PRUIU[2]**
**Beazit ALI[3]**
**Levent ALI[4]**
[1]Eng. PhD attendee Military Technical Academy, Bucharest
[2]Professor, PhD. Eng. , "Mircea cel Batran" Naval Academy, Constanta
[3]Professor, PhD. Eng., "Mircea cel Batran" Naval Academy, Constanta
[4]Eng. PhD attendee Military Technical Academy, Bucharest

***Abstract:*** *The work has been done on the study of bibliography and experience in the operation of the doctoral students in the field of gas turbine power plants.The paper highlighted that rules of ship classification societies concerning of the arrangement of gas turbine propulsion plants to ships, and a brief overview of the role of ship classification societies.*

## INTRODUCTION

In the field of marine, gas turbines are used increasingly more in energy propulsion systems.

As compared to the advantages of the gas turbines, the propulsion of internal combustion engines are preferred. Due to technological developments in recent years in the construction of gas turbines and oil price developments, have convinced the shipowners to reconsider the advantages of using marine gas turbine propulsion plants.[7]

Naval propulsion plants with gas turbines (NPPGT) experienced a continuous development on board of the ships, being found in several configurations separately or combined cycles, depending on the operating characteristics of the vessel. The main NPPTG constructive configurations are:

- CODOG(COmbined Diesel Or Gas turbine),
- CODAG (COmbined Diesel And Gas turbine),
- CODELAG (COmbined Diesel-Eectric and Gas turbine ),
- COGOG (COmbined Gas Or Gas turbine),
- COGAG (COmbined Gas And Gas turbine),
- COGAS (COmbined Gas And Steam turbine)
- COGES (COmbined Gas Electrical Steam turbine),being used in commercial and military vessels. The combined cycle propulsion combined COGAS according to studies is very good yield and can reach up to 60% for rated power.[8]

The advantages of the gas turbines to the internal combustion engines and steam turbines in marine propulsion systems are:

- the mass of the plant is small in relation to effective power (2 ÷ 5[kg/kW]);
- low consumption of oil in comparison to the energy systems with internal combustion engines;
- cooling subsystem has a simplified construction;
- gas turbines used in naval propulsion develops powers between 2000÷80000kW.

## AUTORITIES AND CLASSIFICATION SOCIETIES

Classification societies have emerged in shipping as non-governmental organizations, which were aimed at establishing and maintaining technical standards for the construction and operation of ships and maritime facilities adjacent coasts.

***The main role*** of these companies ***is to classify vessels and validate their design and construction***in accordance with applicable standards and their periodic inspection. All classification societies are responsible for classifying all structures installed offshore and subsea**.**[2]

Currently there are over fifty ships classification societies, but thirteen of them are members of the International Association of Classification Societies, ***IACS***.

In the table 1 are listed the ship classification societies. IACS has its origins in the International Convention on Load Lines (International Load Line Convention) of 1930.

Convention recommends collaboration between classification societies to ensure„*...as much uniformity as possible in the application of the standards of strength upon which freeboard is based*..”[12].

*Table 1* – **The Members of IACS** [3]

| ***LOGO*** | ***NAME*** | ***ABRV.&Founded*** | ***HEADQUARTERS*** | ***OFFICIAL SITE*** |
|---|---|---|---|---|
| | American Bureau of Shipping | ABS 1862 | HOUATON, Texas, USA | eagle.org |

| | | | | |
|---|---|---|---|---|
| | Bureau Veritas | BV 1828 | NEUILLY/SUR/Seine/, Franța | bureaauveritas.com |
| | China Classification Society | CCS 1956 | China | ccs.org.cn/en |
| | Croatian Register of Shipping | CRS 1949 | Split, Croația | crs.hr |
| | Det Norske Veritas | DNV 1864 | Baerum, Norvegia | dnv.com |
| | Germanischer Lloyd | GL 1867 | Hamburg, Germania | gl-group.com |
| | Indian Register of Shipping | IRS 1975 | Mumbai, India | irclass.org |
| | Korean Register of Shipping | KR 1960 | Daejon, Korea | krs.co.kr |
| | Lloyd's Register | LR 1760 | London, United Kingdom | lr.org |
| | Nippon Kaiji Kiokai | NK/Class NK | Tokyo, Japonia | Classnk.or.jp |
| | Polish Register of Shipping | PRS 1936 | Gdansk, Polonia | prs.pl |
| | Registro Italiano Navale | RINA 1861 | Genova, Italia | rina.org |
| | Russian Maritime Register of Shipping | RS 1913 | Saint Petesburg, Federația Rusă | rs-head.spb.ru/en/ |

Following the Convention, the Italian Naval Register (RINA) hosted the first conference of major classification societies in 1939, which also participatedABS (American Bureau of Shipping), BV (Bureau Veritas), DNV (Det Norske Veritas), GL (Germanischer Lloyd), LR (Lloyd's Register) şi NK (Nippon Kaiji Kiokai). Second General Conference of ship classification societies held in 1955 and resulted in the creation of working groups on specific areas and in 1968 IACS formation under the leadership of seven IACS classification societies. The aggregate amount of technical knowledge and their experience has been recognized. In 1969 IACS receive consultative status with IMO (International Maritime Organization) and is the only NGO observer which is able to develop and apply the rules.

Application of IACS Quality System Certification (QSCS) is required for any classification society.

IACS is managed by a Board which is subordinated to general policy group (GPG). The technical work of IACS are generally executed on specialized working groups which are supervised by GPG. The association has a secretariat in London and an operations center QSCS in Shouthampton , UK. Status, procedures, details of the work program, technical resolutions and other publications of the Association, are available on its website.[3]

**INSTALLING THE GAS TURBINES PROPULSION SYSTEMS IN MACHINERY COMPARTMENTS**

When installing NPPGT are taken into account from the design phase of their size and architecture of the machine compartment will be installed and the size of the gas turbines and auxiliary equipment serve. Also take into account the nominal effective power for the ship to operate in the designed parameters.

To install the gas turbines in the machinery compartments, authorities and classification societies naval issued rules that must be followed by ship designers and the shipyard. ABS (American Bureau of Shiping, founded in 1862 founded in 1862 by a record issued by the State of New York), called*„Rules For Building and Classing STEEL VESSEL 2008 / Part 4 – Vessel Systems and Machinery"*, where we find all IACS requirements for NPPGT US Agency supplemented at the time. [1, pag.103].

In Section 3, Point 11 of this register are found clear rules imposed by installing gas turbines. The rules provide that:

- intake and exhaust systems to be located so as to avoid water penetration, condensation and ice. When installing the intake manifold will take into account the recommendations of the manufacturer to provide the turbine airflow at constant pressure and flow rate. Exhaust manifold of the combustion gases will be arranged to avoid their intake to the compressor. On the type LPG vessels are more stringent rules for NPPGT [3, pg.33-48].

- the air supply system of the turbine:

- combustion air must be aspirate from outside the ship by separators, directly in the compressors;

- the combustion air supply system must be designed so that the pressure drops are not greater than those specified by the manufacturer of the gas turbine;

- the system must be designed to withstand variations of the compressor as specified by the manufacturer of the gas turbine;

- is mounted a moisture separator;

The air supply system from figure 1 must meet the technical requirements of construction required by classification societies so:

- the filters assembly of the moisture separators from the level of efficiency in saline or greater than that required in the technical specifications of the manufacturer of the gas turbine;
- is assured supply of fresh water cleaning plant moisture separator filter to reduce the air pressure drop on them;
- the differential pressure transducers are mounted on each air supply system;
- the air intake system is designed to withstand the changes in the compressor;
- the splitter and blades (cascade bands) redirect airflow (90 ° in this case) meets the requirements of entry into the compressor turbine imposed by the manufacturer;
- the manifold is protected against access of foreign bodies.

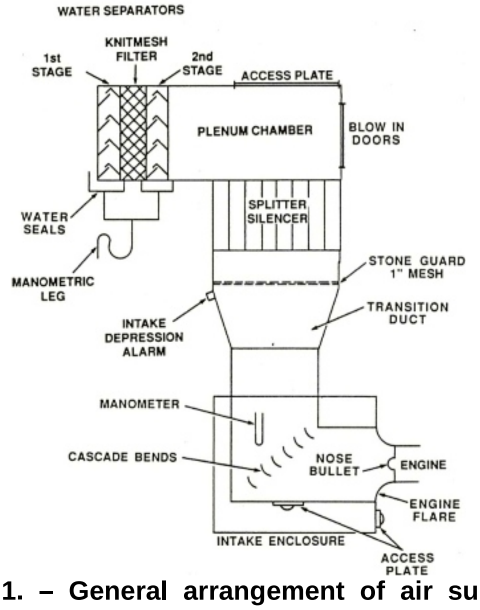


**Fig. 1. – General arrangement of air supply system of the gas turbine to NPPGT [10]**

- **Hot surfaces** from the operating crew areas will be isolated. Hot surfaces that reach temperatures exceeding 220 °C and who may come into contact with any liquid under pressure or otherwise, fuel, oil or other flammable substances shall be insulated with non-combustible and impermeable materials at such liquids. Insulating materials that are impervious to oil will be in turn covered with another sheet or sheets of waterproof. [2, pg.33-48]

- **Thermal and acoustic insulation enclosure of the gas turbine(The module)**

Under Section 7, paragraph 7.1 of the "Guide of naval propulsion systems" issued by ABS (American Bureau of Shiping) in 2005 and completed in February 2014:

- gas turbines will be installed in rigid modular enclosures (modules) as a acoustic and thermal insulation;

- acoustic modules are designed with the purpose to maintain all the turbine at optimum operating temperatures for all operating conditions, minimizing the risk of fire in the engine room from open flame or hot surfaces. This action is taken to prevent damage to equipment adjacent from machinery spaces, products due to engine heat by fire, ventilation and cooling.

***Construction of the module*:**

- fuel piping system will be built with double walls under IACS rules;

- module will be produced from steel and designed to be easily dismantled and removed the main components such as turbine, generator, turbine box or mechanisms;

- module must retain structural integrity when removed access part;

- access roads will be equipped with mode locking and security systems from local and remote them where there are various unsafe operation or damage to the turbine;

- module and cooling gallery must be designed so as to be sealed from the outside and to resist any pressure increases instantanene for short periods from flue gases emanating from the turbine during operation;

- the module that serves two turbines needed construction of split wall;

- gas-tight acoustic module, its interior space is considered as category A machinery space, so the space separating adjacent spaces and its protection against fire shall be in accordance with the Rules for Steel Ships (ABS - RULES FOR BUILDING aND STEEL VESSELS CLASSING - Part 4 2008 / PART April 2014 - VESSEL SYSTEMS aND MACHINERY) and SOLAS 1974, as amended;

- each module will be provided with gaskets and O-rings at each opening for piping, hoses or electrical cables that cross its walls;

- module will be provided with an inspection window or video cameras, through which the operator can visually inspect the turbine and its main components, including accessories, boxes mechanisms, inlet and measuring instruments, and leaks, fire, smoke or abnormal operating conditions;

- inspection windows can be mounted on the access doors where door location qualifies for visual inspection. Access doors shall be arranged in the manner so as to provide easy access to both sides of important components within it. It must be ensured access path to the turbine intake manifold;

- module will be soundproof and heat;

- material used in thermal and acoustic insulation must be isolated to turn off the opportunity to soak with oil, grease, or fuel;

- temperature sensors will be mounted inside the modules near turbines for continuous monitoring of temperature inside;

- will be exposed a plate with occupational safety measures which be respected after entry into how the turbine was stopped;

- every base and module will be provided with spills pipes to avoid accumulation of fluid leaks inside the enclosure. The spills should be positioned so as to prevent fluid flow to the gas turbine exhaust manifold or to the hot areas.

When the enclosure is equipped with an fire extinguisher system on water-based will be considered a permanent bilge drainage system for it.

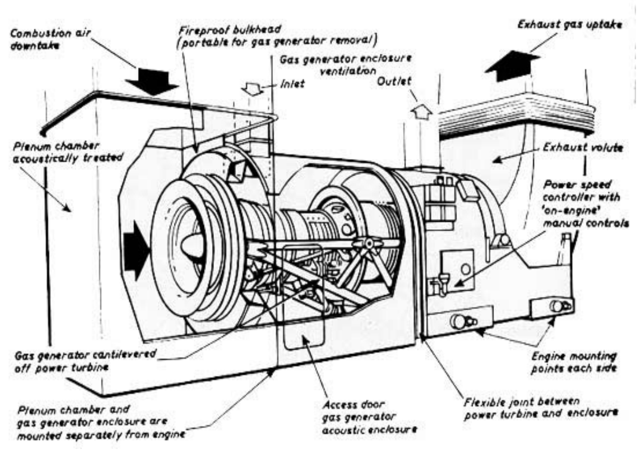


**Fig.2.-Gas turbine mounted in thermal and acoustic isolated enclosure [9]**

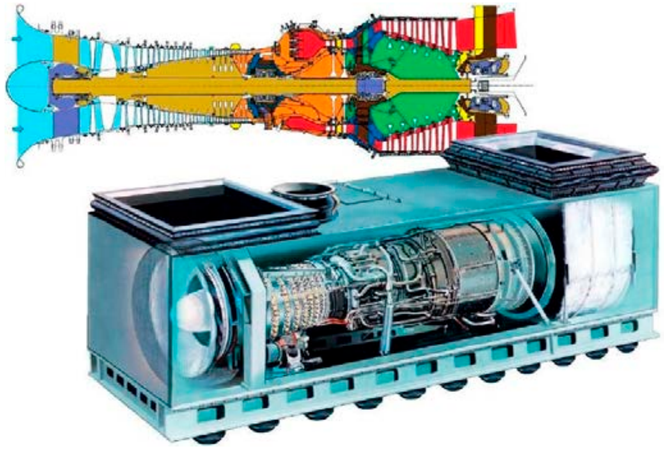

**Fig.3. – Gas turbine manufactured by GE, type LM2500, mounted in thermal and acoustic isolated enclosure [6]**

• ***ventilation of gas turbine module***

In general, the enclosure ventilation system that in witch is mounted gas turbine must meet the following requirements:

- enclosures or spaces containing gas turbines must be provided with ventilation;

- fans should be spark proof construction and engines that drives these fans should be positioned outside airflow cutting;

- the ventilation system will be designed so as to ensure effective air circulation and cooling of the turbine according to the manufacturer's specifications, but the air flow should not be less than 30 volume exchanges per hour relative to the internal volume of the enclosure;

- the NPPGT on the LNG type vessels, on the time that GT is operating on the gas fuel and during operation of the purge valve before the start of maintenance, the ventilation system must always be in operation. Gas supply valve will close automatically if the ventilation system will not provide the required flow of air;

- ventilation system inside the turbine enclosure must be completely separate from other ventilation systems;

- cooling and ventilation air turbine enclosure must be secured directly from the atmosphere;

- calculations on the cooling air entry and venting must verify that appropriate ventilation provided to the gas turbine enclosure.[2]

*Example of calculation of minimum flow verification to be provided by the module ventilation system*

Naval propulsion system type COGOG with main gas turbine type OLYMPUS TM3B, whose enclosure looks like in figure 2.According to the technical specifications of the module and gas turbine, these design values are available [10]:

Environmental conditions:

- water pressure 0.8 bari;
- air temperature 82.2$^{O}$C;

- $V_{SL}$= 17.55 m$^3$ – free space volume of the module (without the volume occupied by the gas generator);
- Dimensions of the module:
- $L_{Mod}$ = 9.1 m – modulelength;
- $l_{Mod}$ = 2.1 m – module width;
- $h_{Mod}$ = 3.9 m – module height;
- $m_{Mod}$ = 3040 kg – module weight;
- $L_{GG}$ = 3.6 m – length of the gas generator that defines the length of ventilated enclosure;
- $D_{GG}$ = 1.3 m - turbine diameter.
- $Q_{AV}$ = 56 m$^3$/min = 3360 m$^3$/h – the volumetric flow rate of air circulated through the module for ventilation of it with an exhaust fan that keeps the pressure lower than the pressure in the machinery space;

Determine the gross volume of the module, $V_{ModP}$:

$$V_{ModP} = L_{Mod} \cdot l_{Mod} \cdot h_{Mod} = 75\ m^3 \quad (1)$$

Calculate the minimum amount of air required for ventilation of a volume equal to the gross volume of the module:

$$\dot{V}_{ModP} = 30 \cdot V_{ModP} = 2236\ m^3 \quad (2)$$

The minimum volume flow to be provided by the ventilation module must be reported to $V_{ModP}$ , is:

$$Q_{ModP} = 2236\ m^3/h$$

It is noted that the minimum volume flow is below the actual volume flow ventilation system provided by the module and respects the rule imposed by classification societies in this respect.

$$Q_{ModP} < Q_{AV} \quad (3)$$

Calculate the internal volume of the module ventilated VImod, what is the amount of free space volume of module,$V_{SL}$ and the volume occupied by the gas turbine generator,$V_{GG}$.

$$.V_{IMod} = V_{SL} + \pi \cdot \left(\frac{D_{GG}}{2}\right)^2 \cdot L_{GG} = 22\ m^3 \quad (4)$$

$$\dot{V}_{IMod} = 30 \cdot \dot{V}_{IMod} = 670\ m^3 \quad (5),$$

Minimum volume flow to be provided by ventilation system in relation to the internal free volume of the module is:

$$Q_{Imod} = 670\ m^3/h < Q_{AV} \quad (6)$$

It notes that respect the rules imposed by ship classification societies, based on the actual amount of air flow ventilation system$Q_{AV}$ circulated module.

• ***Ventilation of machinery spaces***

<u>*Capacity*</u>:

- each machinery spaces must be equipped with at least two air supply mechanical ventilators with a total capacity of at least 30 air changes per hour relative to the total volume of space without taking into account the combustion air for aspiring diesel engines, air from machinery space and other ancillary facilities (air compressor);
- if one of the fans becomes inoperable, the other one fan must provide at least 100% of the necessary air flow.

A comparative example calculation for ventilation of machinery spaces is detailed in Table 2 for both propulsion systems with gas turbines and internal combustion engines.

*Table 2. – Calculation of air flow required for ventilation of machinery space for NPPTG and NPPICE (naval propulsion plant with internal combustion engines) with the various actual values of the nominal power developed by it*

| **Naval propulsion plants** | **Internal combustion engine** | | **NPPICE** | **NPPICE** | **NPPICE** | **NPPICE** | **NPPICE** |
|---|---|---|---|---|---|---|---|
| | **Gas turbines** | | **NPPTG** | **NPPTG** | **NPPTG** | **NPPTG** | **NPPTG** |
| *Nominal Effective power [kW]* | | | 2000 | 5000 | 20000 | 50000 | 80000 |
| | | | 2000 | 5000 | 20000 | 50000 | 80000 |
| *Specific nominal consumption of Fuel* $c_{en}\left[\frac{kgcb}{kWh}\right]$ | | | 0.2÷0.18 | 0.18÷0.175 | 0.18÷0.175 | 0.18÷0.175 | 0.18÷0.175 |
| | | | 0.33÷0.3 | 0.3÷0.29 | 0.29÷0.27 | 0.29÷0.27 | 0.29÷0.26 |
| *Standard diesel fuel with lower heating value* $Q_i\left[\frac{kj}{kg}\right]$ | | | 42707 | 42707 | 42707 | 42707 | 42707 |
| | | | 42707 | 42707 | 42707 | 42707 | 42707 |
| *Theoretical mass air for burning a 1 kg cb*$m_{aert}\left[\frac{kgaer}{kgcb}\right]$ | | | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 |
| | | | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 |
| *Nominal coefficient of air excess for gas exchange* $\alpha_{sgn}$ | | | 2.2÷4.5 | 2.2÷4.5 | 2.2÷4.5 | 2.2÷4.5 | 2.2÷4.5 |
| | | | 2÷5 | 2÷5 | 2÷5 | 2÷5 | 2÷5 |
| *Specific nominal air flow*$d_{an}\left[\frac{kgaer}{kWh}\right]$ | | (8) | 5.94÷8.2 | 5.35÷10.63 | 5.35÷10.63 | 5.35÷10.63 | 5.35÷10.63 |
| | | | 8.91÷20.25 | 8.1÷19.57 | 7.83÷18.23 | 7.83÷18.23 | 7.83÷17.55 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Specific nominal flow rate of gas* $d_{gn}\left[\frac{kgaer}{kWh}\right]$ | (9) | 6.41÷8.2 | 5.53÷10.8 | 5.53÷10.8 | 5.53÷10.8 | 5.53÷10.8 |
| | | 9.24÷20.55 | 8.4÷19.86 | 8.12÷18.5 | 8.12÷18.5 | 8.12÷17.81 |
| *Debitul nominal masic de aer* $\dot{m}_{aern}\left[\frac{kgaer}{s}\right]$ | (10) | 3.3÷4.55 | 7.43÷14.77 | 29.7÷59.06 | 74.24÷147.7 | 118.8÷236.3 |
| | | 4.95÷11.25 | 11.25÷27.19 | 43.5÷101.25 | 108.8÷253.13 | 174÷390 |
| *Nominal air volume flow* $\dot{V}_{aern}\left[\frac{m^3}{s}\right]$ | (11) | 3.023÷4.17 | 6.81÷13.55 | 27.25÷54.19 | 69.12÷135.5 | 109÷216.75 |
| | | 4.54÷10.32 | 10.32÷24.94 | 39.9÷92.89 | 99.77÷232.26 | 159.6÷357.8 |
| *Nominal flow rate of air mass required for ventilation of machinery space* $\dot{m}_{VCMN}\left[\frac{kg}{s}\right]$ | (13) | 6.6÷9 | 11.14÷29.53 | 44.55÷118.1 | 111.38÷295.3 | 178.2÷472.5 |
| | (16) | 1.5÷3.38 | 1.69÷4.08 | 6.52÷15.188 | 16.31÷37.96 | 26.1÷58.5 |
| *Nominal volume air flowrequired for ventilation of machinery space* $\dot{V}_{VCMN}\left[\frac{m^3}{s}\right]$ | (14) | 6.05÷8.34 | 10.22÷13.55 | 40.87÷108.4 | 102.2÷270.9 | 163.5÷433.5 |
| | (17) | 1.32÷3.1 | 1.55÷3.74 | 12-30 | 14.97÷34.83 | 23.95÷53.67 |

For example, considering a machinery space with following dimensions:

- lenght L (m);
- widthinw(m);
- height h (m);

$$\dot{V}_{AVmin} = 30(L \cdot w \cdot h)[m^3] \quad (7)$$

$\dot{V}_{AVmin}$- is the minimum air volume flow that is circulated by the ventilation system in an hour.

$$d_{an} = c_{en} \cdot \alpha_{nsg} \cdot m_{aert}\left[\frac{kg_{aer}}{kWh}\right] \quad (8)$$

$$d_{gn} = c_{en} + d_{an}\left[\frac{kggaze}{kWh}\right] \quad (9)$$

$$m_{aern} = \frac{d_{an} \cdot P_{en}}{3600}\left[\frac{kgaer}{s}\right] \quad (10)$$

$$\dot{V}_{aern} = \frac{\dot{m}_{aern}}{\rho_{aer}}\left[\frac{m^3}{s}\right] \quad (11)$$

- $\rho_{aer}$ = 1.09$\left[\frac{kg}{m^3}\right]$– the air density considered at the pressure $p_0$ =$\left[\frac{kg}{m^3}\right]$, R=0.287 $\left[\frac{kj}{kg \cdot grd}\right]$and temperature
  T=318[K]

$$\rho_{aer} = \frac{p}{R \cdot T}\left[\frac{kg}{m^3}\right] \quad (12)$$

$$\dot{m}_{VCMN} = (1,5 \div 2) \cdot \dot{m}_{aern}\left[\frac{kg}{s}\right] \quad (13)$$

$$\dot{V}_{VCMN} = \frac{\dot{m}_{VCMN}}{\rho_{aer}}\left[\frac{m^3}{s}\right] \quad (14)$$

For machinery spaces (MS) cu NPPGT, air neededGT is drawn directly from the environment. MS ventilation air requirement is calculated according to the working machines (air compressors).

$$P_{enMAux} = (8 \div 15)\% \cdot P_{enMP} \quad (15)$$

$$\dot{m}_{VCMN} = \frac{d_{an} \cdot 0.15 P_{en}}{3600} \cdot 2\left[\frac{kg_{aer}}{s}\right] \quad (16)$$

$$\dot{V}_{VCMN} = \frac{\dot{m}_{VCM}}{\rho_{aer}}\left[\frac{m^3}{s}\right] \quad (17)$$

**• *Arrange of the NPPGT on the ship***

Naval propulsion plant gas turbine is a complex system which together with steering system are designed to ensure the safety and operational reliability. To achieve these goals vessel must meet the requirements imposed by classification societies.

• Depending on the requirements of ship owners propulsion system with steering system were constructed and classified according to their arrangement on the ship and were adopted following classification markings (Figure 5):

**R1** – vessel equipped with multiple propulsion machinery, but with a single propeller and one with a rudder steering system;

**R2** – vessel equipped with propulsion machinery, propellers and steering systems multiple;

**R1-S –** vessel equipped with a single propeller, but that have machinery propulsions positioned in different machinery spaces such that a fire or flood in one of the compartments will not affect propulsion machinery from other compartments;

**R2-S –** vessel equipped with multiple propellers which have multiple associated propulsion machinery and steering systems installed in different machinery spaces (main machinery space and rudder room, for example), so that fires and floods in one of these spaces can not affect the propulsion system , propeller and rudder from other machinery spaces;

• • The symbol "**+**" is added to the notations above the end thereof (**R1 + R2-S +**, etc) for those vessels whose propulsion after damage, can retain or restore immediately propulsive power to navigate the conditions safety in bad weather without losing course or handling.

For gas turbine from propulsion naval installations, it's identify with propulsion machinery and follow the same rules of planning within the facility, except that there will always be mounted in enclosure acoustic and thermal isolating (figures 4, 6, and 7 ) [1]

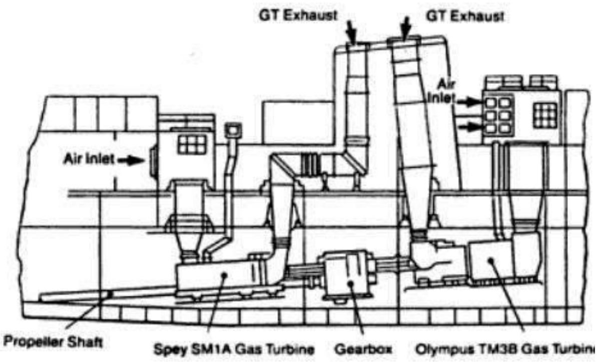


***Fig.4. – Compartments layout of naval propulsion gas turbine plant type GOGAG , on the class HATAKAZE destroyers from Japan Navy [4]***

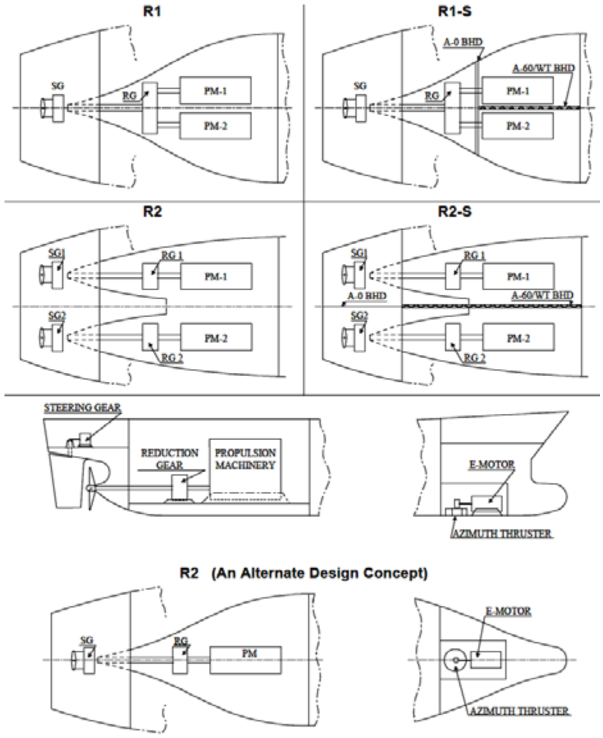


***Fig.5.- Arrangement of naval propulsion system according to ABS classification* [ 1, pg.294 ]**

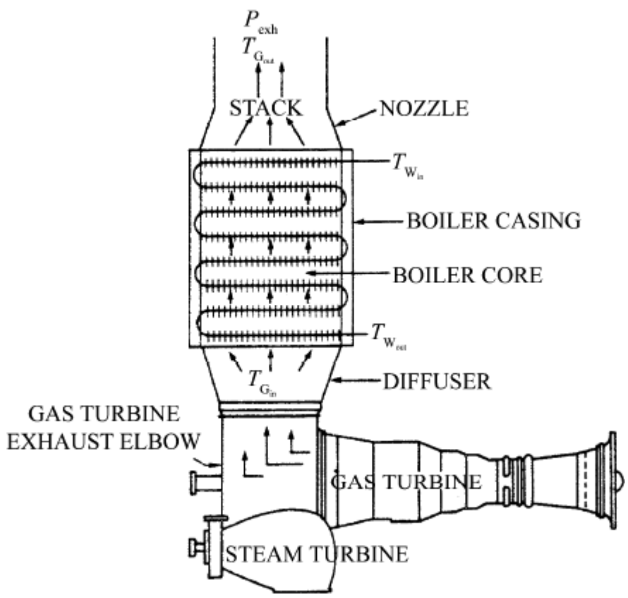


***Fig.6. - Compact arrangement of the propulsion system type COGAS in the engine room* [5]**

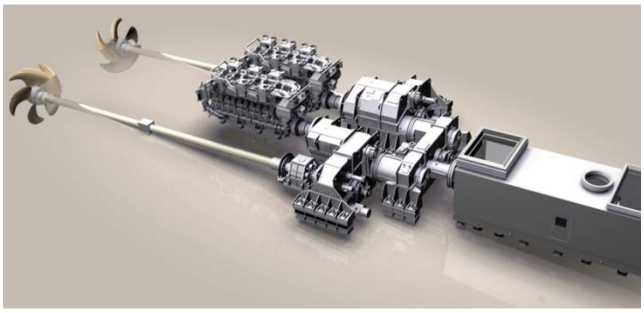

***Fig.7.* –NPPGTmanufactured from Rolls-Royce type AG/ CODAG System (Combined Diesel and Gas Turbine) [11]**

**CONCLUSIONS**

Ship classification societies recognize the functional safety of gas turbines and encourages their use in maritime transport through the development of rules for classification in the design and construction of gas turbines, their installation on board ships, their operation and maintenance.

Gas turbines are found in registers and classification societies attention of states with a highly developed industry in the design and construction of gas turbines and here we find LL, ABS, GL, DNV, RS, NK / ClassNK that put classification bases on this branch, forcing companies to develop permanent building materials and manufacturing technology, and performance.

Due to the installation of the intake combustion air exclusively from the external environment of the gas turbine and its mounting in the thermally and acoustic isolated enclosure, independent fan, is reduced to the ventilation system of the machinery compartments from the point of view of the gauge installation and energy consumption for driving the fan.

Installing gas turbine in acoustic and thermal isolated enclosure, the independent ventilated to maintain a constant pressure lower than in the rest compartment and the existence of warning and fire fighting installations inside, independent from the engine room installations, adds safety fire in terms of propulsion plants, which can be isolated in these premises.

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