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# The modelling of the energy conversion in the marine electric generating set: gas turbine engine - synchronous generator

SUMMARY

*A mathematical description of the energy conversion and transmission occuring in the marine electric generating set, comprised of gas turbine engine, synchronous generator and its control systems, is presented. The set structure is decomposed and its variables systematized. Power processes in the set are considered as macro-dynamic phenomena and engine-to-consumer energy flow is assumed continuous. A model structure is made suitable for its verification on the basis of measurements during full scale experiments.*

*A purpose and applicability of the model is highlighted.*

## INTRODUCTION

Self-contained electric generating sets with generators driven by heat engines of the same type as those applied to propell vessels are used most frequently to produce electric energy in vessels due to their specific tasks. A progress reached in development of the marine gas turbine propulsion systems have made application of gas turbine engines as generator's drive, apart from diesel engines, more and more frequent. This type of drive is preferred in marine electric generating sets due to its immediate availability, rather a high load flexibility and suitability for automation. As level of vessel's electrification grows, it is also important to obtain a high power available from a single driving unit. This feature makes such a generating set suitable to supply not only vessel's electric network but also its separate electric power systems e.g. main electric propulsion or trawling power systems.

Operation of gas turbine engines in generating sets is characterized by small speed changes of a turbine driving generator and substantial and quick changes of its load in result of switching on and off ship's power consumers. Power of a single electric energy consumer can be relatively high comparing with that of electric generators, but the length of cables supplying the energy consumer short. It makes influence of consumers, often that of impact type, on the work of generating sets substantial, and gas turbine engine working conditions extremely changeable. Therefore it is required to select generators, their driving engines and control systems appropriately to assure a high quality of electric energy supply in any working conditions of ship's electric energy system.

The presented mathematical model was elaborated in order to identify observable variables of a real electric generating set, which are needed to build a control system of its work and then to carry out simulation tests of energy state changes of a gas turbine engine, which happen during its co-operation with ship's electric power system.

## GENERATING SET STRUCTURE AND MODEL BASIC ASSUMPTIONS

Electric energy production by a generating set with a turbine combustion engine can be represented by a chain of the consecutive processes of:

- ❑ heat release from a liquid fuel while burning it in a combustion chamber
- ❑ heat accumulation in a working medium
- ❑ working medium transportation
- ❑ combustion-gas heat transformation into mechanical energy in turbine blade rims
- ❑ mechanical energy transformation into electric energy by a generator.

The processes can be described by mathematical relations the structure of which depends on working medium properties and set's construction. A basic working medium used in turbine combustion engines is the air sucked-in from environment and a combustion gas produced while burning a hydrocarbon fuel in the presence of the air. Auxiliary media are: lubricating oil and cooling water. A dynamic behaviour of the media is governed by design features of the engine.

A generating set system is considered here as a separated part of ship's environment, which is linked with it by input and output quantities. A decomposition of the generating set into sub-systems and their linkages with the environment is shown in Fig. 1.

The system is composed of :

- a two-shaft gas turbine engine
- a power drive transmission system composed of shafts, clutches and a reduction gear

- a main mechanical energy consumer - a synchronous alternative current generator
- a three-core electric network with isolated neutral, supplying ship's electric energy consumers
- engine's air delivery system composed of purifying equipment ( filter, seperator), air inlet and ducts
- engine's fuel supply system aimed at preparation and delivery of fuel in an amount which covers energy consumers demand and all system's losses
- exhaust outlet ducts.

The following assumptions were adopted for the presented model:

✧ an object of consideration is an electric generating set system composed of sub-systems interrelated as shown in Fig. 1

✧ the system is hierarchically structured and its sub-systems are decomposed into less structurally complex components ( ADS, FSS, GG, DTS, R, G, ERR) to make their identification possible

✧ the system in question affects other systems of the environment and this may be considered at different accuracy levels ( which is limited here to an interaction with system's environment and ship's electric power consumers)

✧ investigation of the system is carried out with the use of a model whose structure is adjusted to a selected point-of-view: investigation of the heat-to-mechanical energy conversion processes due to changes in demand of the electric energy, produced by electric generator, and vice versa.

Mutual correlations between the energy conversion and transmission parameters take place with the participation of:

❖ the control and automatic regulation system whose task is to control directly or indirectly: energy transmission to maintain the parameters of energy fluxes on the quality level determined by the producer, feasibility of the expected transient processes, automatic switching on and off the systems into the energy network, communication with operating personnel.

❖ the control and protection system against exceeding the limiting values of operation parameters to avoid danger or breakdown

❖ natural correlations between energy system's components.

The generating set decomposed in this way is the basis of a mathematical model which contains:

- a time base
- sets of model variables which characterize all possible input excitations and output reactions
- functions which determine output reactions in response to each input excitation.

## MODEL VARIABLES

A generating set in service is assumed a source of observable data (Fig. 2). It is separated from the entity of ship's electric power system by an observation barrier introduced with an account for taking measurements on ships in service. Observable variables were assumed those which can be found usually in the typical measuring instruments ( outside the observation barrier shown on the scheme), but non-observable variables were assumed those being outside control during the generating set operation.The latter are indispensable however in the case of application of an automated operation control. Then, a special measuring and recording system of the magnitudes with means of possible processing and analyzing them further is needed [2]. Empirical knowledge of the magnitudes at a given operation phase is also required to build a rational model [6].

Each system's element is influenced, according to the assumed model structure, by factors deciding on quantity of energy and its transformation quality , which can be described by the following observable variables:

- purposeful control input signals coming from the control organs, controlled interactions, automatic regulation and natural correlation between system's elements:

$$U(\tau,\theta) = [\dot{m}_{fu}(h, n_1, n_2, Y_G, \tau, \theta)] \quad (1)$$

- values describing operation conditions, constant within a considered time period and consisting situational parameters of the air, water and oil supplied:

$$W(\theta) = \big[t_0, p_0, t_{fu}, p_{fu}, t_{w.co.eng.}, t_{w.co.R}, t_{ol.eng.}, p_{ol.eng.}, t_{ol.R}, p_{ol.R}, I_f, U_f, I_D, U_D, \theta\big] \quad (2)$$

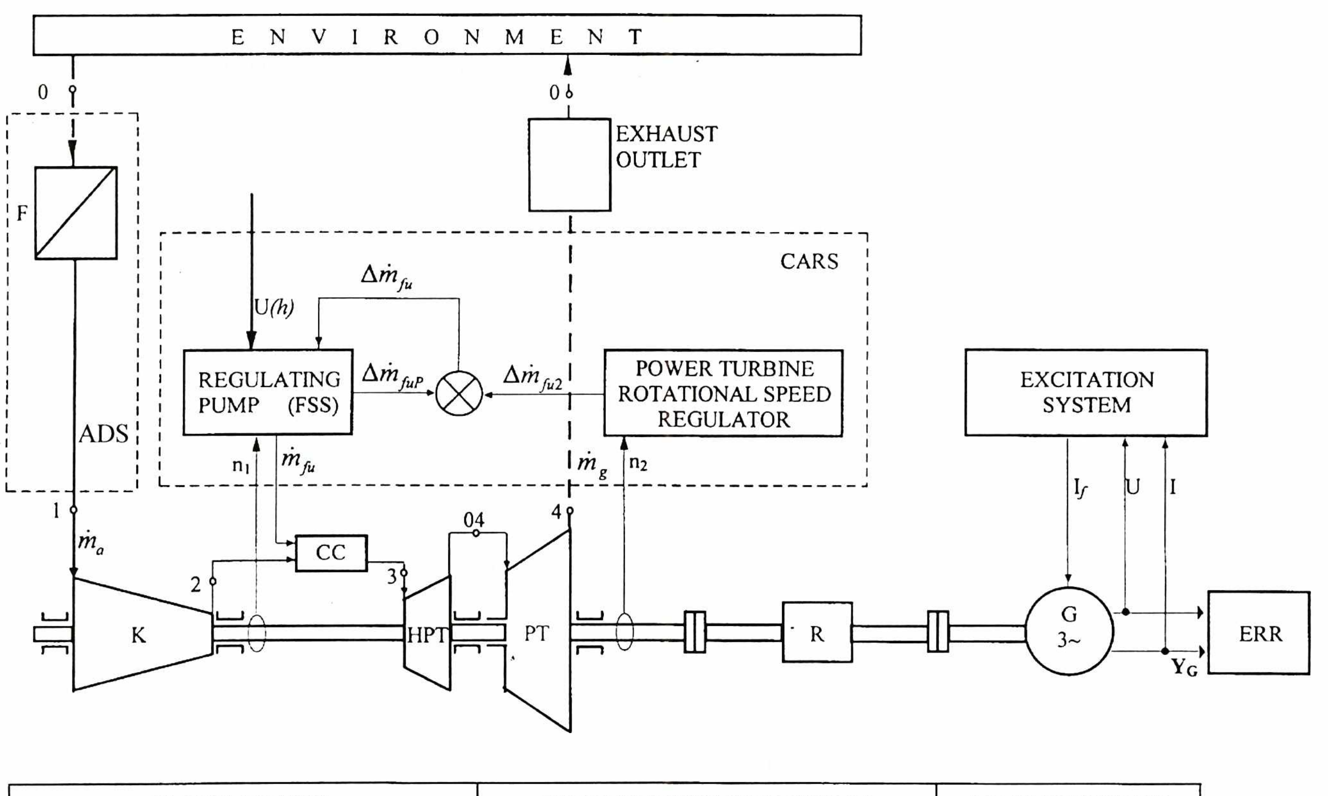


*Fig. 1. A simplified scheme of generating set sub-systems and their interactions ( Abbreviations - see Nomenclature )*

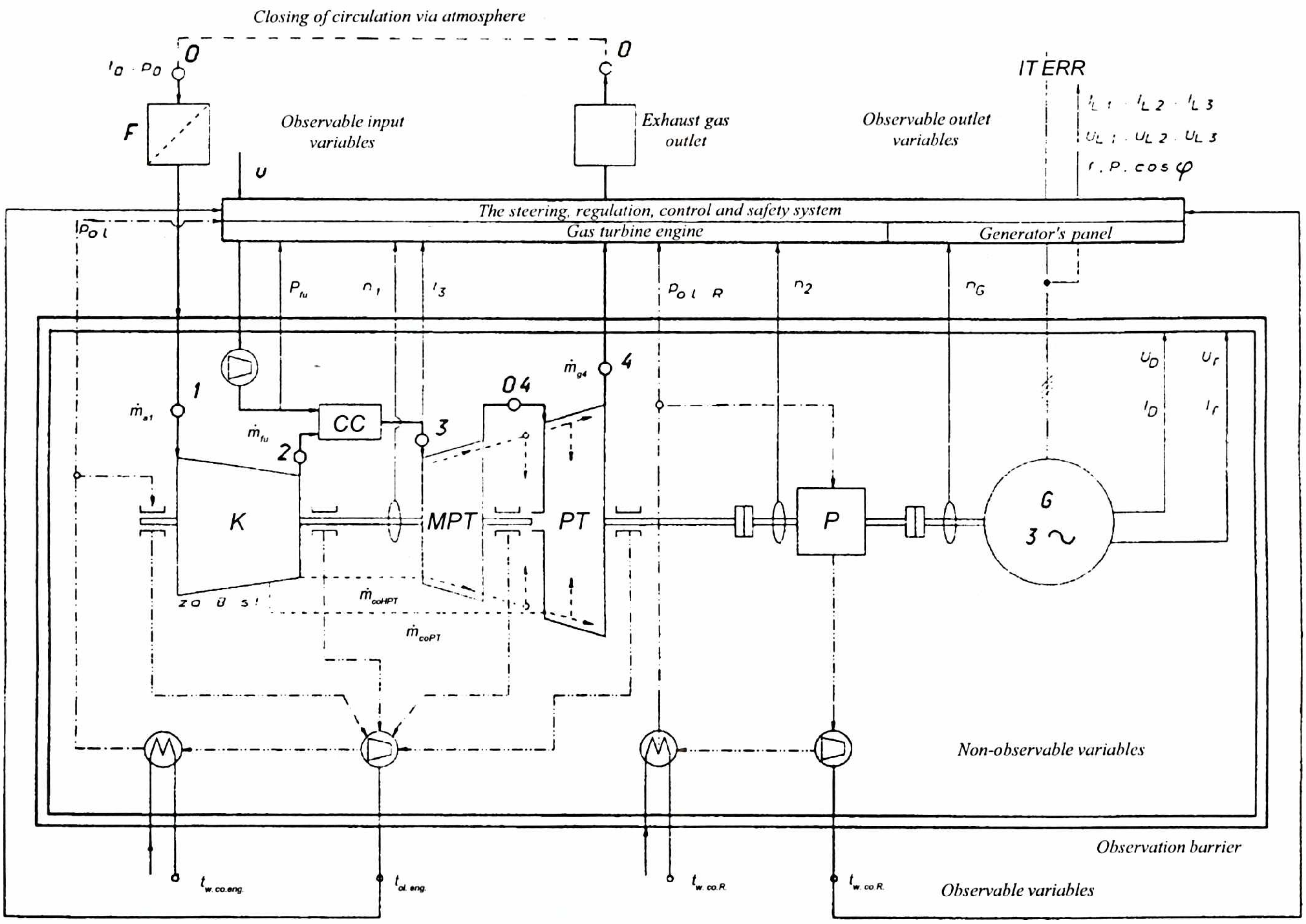


*Fig. 2. Systemized variables of the generating set mathematical model*

● interferences dependent on a decision variable of a signal controlling the load range U(τ,θ), the operation conditions W(θ) and the machines' technical state changes, expressed by X(τ,θ) state variables:

$$Z(\tau,\theta)=\left[U(\tau,\theta),X(\tau,\theta),W(\theta)\right] \qquad (3)$$

The set of interferences consists of many elements and is of random character. Practically, causes of the interferences do not appear simultaneously, the most frequent are single or only few of them at a time. Many interference variables cannot be measured directly, but their effects may be disclosed indirectly, e.g. while observing X(τ,θ) state variables.

● system's output variables:

$$Y_G(\tau,\theta)=\left[I_{L1},I_{L2},I_{L3},U_{L1},U_{L2},U_{L3},f,P,\cos\varphi,\tau,\theta\ \right] \quad (4)$$

Some system's state parameters (variables) should be monitored during operation. This is due to the necessity of providing operation safety of the generating set. Moreover the values arising from natural correlations between system's elements are added to the above mentioned values, which are limited by:

✧ control and automatic regulation system

✧ system protecting the generating set against surpassing the limits defined by the following set of constraints:

$$H=\{n_{1li},n_{2li},t_{3li},t_{ol.eng.li},p_{ol.eng.li},t_{ol.R.li},p_{ol.R.li},$$
$$I_{L1acc},I_{L2acc},I_{L3acc},U_{L1acc},U_{L2acc},U_{L3acc}\} \qquad (5)$$

Moreover, the steering, regulation, control and safety system provides:

• system's interaction with starting and network- switch-off installations

• system's interaction with ship's electric network

• communication with system's operator and operation parametres control.

## GAS TURBINE MODEL

A simplified mathematical model of a gas turbine engine cooperating, through a drive transmitting facility, with a synchronous generator, which supplies ship's electric energy consumers, was investigated at first.

A precise mathematical description of medium flow and energy transformation processes in blade systems of a compessor and turbines as well as in a combustion chamber is not possible with all its peculiarities and dissipative processes taken into account.

In the engine three groups of sub-assemblies were distinguished on the basis of a functional criterion. First of them are rotary machines ( compressors and turbines) in which total heat and mechanical energy transformation is accompanied by a heat exchange between working medium flux and material of engine parts. The combustion chamber, which is aimed at producing a hot combustion gas stream, belongs to the second group. Basing on chamber's work principles it was assumed that heat flow and mixing processes are dominant features for dynamic simulation and that they can be determined with a high precision when applying the laws of conservation. The air inlet ducts and filter (ADS) as well as the exhaust gas outlet installation together with the silencer, which are aimed at working medium transportation, form the third group.

In synchronous generator driving engines, of a special role are phenomena which cause a rotative speed pulsation and deviations of a set value, the speed which determines the electric current frequency. The dynamic phenomena which generate rotative speed fluctuation were divided as follows:

❑ engine's micro-dynamic phenomena which are caused in the case of gas turbine engines by:

- periodical changes of values of parametres of the air and combustion gas flux in engine's flow channel, which are due to flow velocity and pressure distributions on blade wheel profiles

- a pulsatory character of combustion process due to periodical changes in fuel supply

❑ system's macro-dynamic phenomena when assuming energy flow from the turbine engine to a main consumer to be continuous, and velocity, pressure and temperature values in any transverse cross-section point to be constant, which reduces consideration of their changes to those along one spatial variable only, viz. along engine's axis. Due to this, the system's micro-dynamic phenomena could be totally neglected in the proposed model.

The following simplifications in relation to the real phenomena were introduced into the mathematical model of the processes which occur in a gas turbine engine:

✧ combustible mixture combustion occurs immediately (i.e. just while shifting a fuel flux regulator) and its quality does not depend on load range changes

✧ volumes and heat capacities of the flow channels, which are not seperate sub-assemblies, can be neglected (e.g. those between compressors and turbines)

✧ heat capacity of turbine and compressor elements can be neglected as it is low in comparison with the energy flow values to be transformed

✧ the gas turbine engine is thermally insulated, therefore there is no external loss of heat

✧ the air inlet duct, engine flow and exhaust gas channels are ideally tight, i.e. there is no external loss of medium's flux.

## SYNCHRONOUS GENERATOR MODEL

A synchronous generator, described in the mathematical model of electric energy generation, is a machine with a single stator winding and double rotor winding, excitation and damping winding, and no vortex currents.

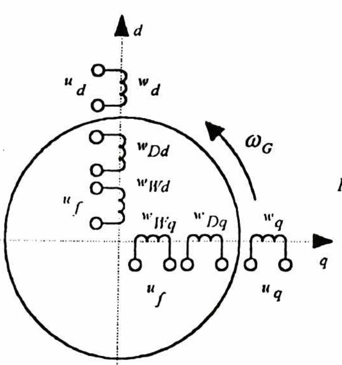


*Fig. 3. Synchronous generator model*

A scheme of the synchronous generator complying with the above stated assumptions is shown in Fig. 3 , where the damping windings, $w_{Dd}$ and $w_{Dq}$ ,along $d$ and $q$ axis respectively, are usually shorted, and thus their voltages are zero, but the excitation winding is provided along one axis only, the longitudinal $d$ axis as a rule. The $d$-$q$ coordinate system bound with the rotor windings was accepted as the most suitable for setting generator's equations. This makes „observation" of the phenomena occurring in the synchronous machine possible from the point-of-view of an observer bound with machine's rotor. In this way, he „sees" the magnetic field, in the air gap, motionless in respect to the rotor. The image will not change if the rotor and magnetic field stop rotating. To maintain currents in the „frozen" machine of the same value as in the rotating one, the rotation e.m.f was introduced into the rotor windings and the current frequency assumed zero.

In this way a simplification in the modelling analogical to that of the direct current was achieved, viz. by assuming $d$-$q$ coordinate system for modelling synchronous generator processes.

A purpose of this consideration is a mathematical description and simulation algorithm of the transformation process of the chemical energy contained in the fuel, delivered to a gas turbine engine, into the electric energy which is spent by ship's energy consumers.

Relationships of the Park model [3] was used to describe phenomena which occur in a synchronous generator.

A gas turbine engine response on an external excitation represented by load changes ( drop or rise ) in the electric power network, in a form of changes of input quantities and non-observable variables is investigated. Parametres of the generating set stable operation, which has to be disturbed by a given excitation, were selected as initial ones at $t_0 = 0$ time instant. Load changes in the electric power network, described by the known (experimentally determined) courses of:

- the phase currents and voltages,

$$i_{L1}, i_{L2}, i_{L3} = i(\tau); \qquad u_{L1}, u_{L2}, u_{L3} = u(\tau);$$

- the rotor rotational speed, $\omega_G$
- the excitation current and voltage, $I_f$, $U_f$
- the damping winding currents, $I_{Dq}$ ,$I_{Dd}$ were chosen as a disturbance of the set stable operation.

On their basis, values of the magnetic linkages along the transverse and longitudinal axes at the time instant($\tau + h$ ), can be obtained, having transformed the phase currents and voltages to those relevant to the longitudinal and transverse axes, and solved the differential equation set with the use of a known numerical method [4] and the integration step $h$, described in the following form:

$$\frac{d\Psi_d}{d\tau} = \Psi_q(\tau)\omega_G - r_a i_d(\tau) - u_d(\tau) \qquad (6)$$

$$\frac{d\Psi_q}{d\tau} = \Psi_d(\tau)\omega_G - r_a i_q(\tau) - u_q(\tau) \qquad (7)$$

$$\frac{d\Psi_f}{d\tau} = -r_f i_f(\tau) - u_f(\tau) \qquad (8)$$

$$\frac{d\Psi_{Dd}}{d\tau} = -r_{Dd} i_{Dd}(\tau) \qquad (9)$$

$$\frac{d\Psi_{Dq}}{d\tau} = -r_{Dq} i_{Dq}(\tau) \qquad (10)$$

Values of the currents in the time instant, ( $\tau + h$ ), can be determined with the use of known generator's load characteristics. The values of magnetic linkages and load currents, thus determined, make it possible to calculate the electro-magnetic torque, demanded by the generator, as follows:

$$M_{em}(\tau) = \Psi_d(\tau) i_q(\tau) + \Psi_q(\tau) i_d(\tau) \qquad (11)$$

## THE CONDITIONS OF MODELLING AND MATHEMATICAL DESCRIPTION OF THE SYSTEM

Many difficulties are faced, while carrying out simulation studies of the energy conversion processes in the sets driven by gas turbines, resulting from the lack of information about the flow system geometry and a number of the parameters appearing in the detailed blade system and characteristics and machine static characteristics. Progressing commercialization of gas turbine production for ships has resulted in significant limitation or lack of information referring to particular constructions.

For these reasons it is necessary to use, in calculations concerning the engines in question, sparse data available from producers, results of the experimental investigations limited by a specific engine construction, measurement safety conditions and the values obtained from the additional indirect calculations based on the available data.

Studies on the dynamic energy conversion and flow processes in drive systems with gas turbine engines require to analyse processes taking place in the space determined by the flow system and consequently to use three dimensional parameters in their mathematical description.

Due to the above mentioned limitations only the so called zero dimension model could be applied here, assuming physically continuous flux of the main working media, seperate elements with averaged parameters and assigned accumulative capacities. The seperate engine construction subsystems ( inlet air duct, compressor and power turbines, exhaust outlet duct) were substituted by adequate zero dimension objects.

A mathematical model of the generating set dynamic behaviour is built in a form of balance equations at different generalization levels, and is expressed by the ordinary differential equations, which describe energy transformation processes occurring in the gas turbine engine machines of the highest heat and mechanical energy accumulation, as well as magnetic fluxes, currents and voltages in the electric synchronous generator driven by this engine, with interrelations of the sub-systems taken into account.

Changeable values of the differential equation coefficients were determined on the basis of a set of nonlinear algebraic equations, arbitrarily chosen, which describe machine characteristics, medium's state parametres in the heat flow characteristic points and magnetic linkages [1, 5]. The model covers generating set operation stages ranging from the minimum stable operation of the turbine engine, when the generator works with the remanent flux density only, up to the nominal load operation.

In investigation of transient processes the following system of ordinary differential equations, approximately reflecting conservation laws, were used:

❖ for the inlet air ducts - the flow continuity equation (12):

$$\frac{d(\rho_a V_F)}{d\tau} = \dot{m}_{a0}(\tau) - \dot{m}_{a1}(\tau) \tag{12}$$

and the energy balance equation (13):

$$\frac{d(\rho_a V_F i_a)}{d\tau} = \dot{m}_{a0}(\tau)i_{a0}(\tau) - \dot{m}_{a1}(\tau)i_{a1} + V_F\frac{dp_a}{d\tau} \tag{13}$$

❖ for the gas generator and power turbine rotors - the equations (14) and (15) in accordance with the law of angular momentum changeability:

$$\frac{dn_1}{d\tau} = J_1^{-1}\left(\frac{30}{\pi}\right)^2 n_1^{-1}(\tau)\left[P_{HPT}(\tau) - P_K(\tau) - P_{m1}(\tau)\right] \tag{14}$$

$$\frac{dn_2}{d\tau} = J_2^{-1}\left(\frac{30}{\pi}\right)^2 n_2^{-1}(\tau)\left[P_{PT}(\tau) - \frac{1}{pk_R}P_{em}(\tau) - P_{m2}(\tau)\right] \tag{15}$$

❖ for the exhaust outlet ducts - the flow continuity equation (16):

$$\frac{d(\rho_g V_g)}{d\tau} = \dot{m}_{g4}(\tau) - \dot{m}_{g0}(\tau) \tag{16}$$

and the energy balance equation (17):

$$\frac{d(\rho_g V_g i_g)}{d\tau} = \dot{m}_{g4}(\tau)i_{g4}(\tau) - \dot{m}_{g0}(\tau)i_{g0}(\tau) + V_g\frac{dp_g}{d\tau} \tag{17}$$

❖ for the components of the automatic regulation system [2]:
- the regulating pump :

$$T_{rP}\frac{d\dot{m}_{fuP}}{d\tau} + \dot{m}_{fuP}(\tau) = k_{rP}n_1(\tau) \tag{18}$$

- the power turbine rotational speed regulator:

$$T_{r21}\frac{d^2\dot{m}_{fuP}}{d\tau^2} + T_{r22}\frac{d\dot{m}_{fu2}}{d\tau} + \dot{m}_{fu2}(\tau) = k_{r2}n_2(\tau) \tag{19}$$

The conversion processes of mechanical energy into electric energy taking place in the synchronous generator were described earlier by the equations (6) to (10).

The values of magnetic flux and load currents determined in such a way make it possible to calculate the electromagnetic torque $M_{em}$ ,demanded by the generator, and the power appearing in the right hand side of the equation (9):

$$P_{em}(\tau) = \frac{\pi n_2}{30}M_{em}(\tau) \tag{20}$$

The equation system is supplemented by a nonlinear algebraic equation describing relations of the expressions in the right hand sides of system's equations or resulting from the operational linkage between the constructional system and automatic regulation which can be exemplified as follows:

$$\Delta\dot{m}_{fu}(\tau) = \Delta\dot{m}_{fuP}(\tau) - \Delta\dot{m}_{fu2}(\tau) \tag{21}$$

$$\dot{m}_{fu}(\tau + h) = \dot{m}_{fu}(\tau) + \Delta\dot{m}_{fu}(\tau + h) \tag{22}$$

During a transient process the largest changes can be observed of the variables bound with the fastest rotor kinetic energy transformation processes.

Energy transformation processes bound with the main working medium's and heat flows, which proceed much slower, were assumed to be quasi-static. Thus, the quantities describing them in consecutive states of such a process can be determined from the relationships valid for steady work conditions.

Assuming heat accumulation in a combustion chamber to proceed not only in the material of fire pipes and screens, but, to some extent, also in the expansion device blade rims of the first stage of the high pressure turbine and in the working medium inside the combustion chamber, the energy flow equation can be described as follows:

$$c_{CC}m_{CC}\frac{dT_{CC}}{d\tau} + V_{CC}c_{gCC}\frac{d(\rho_g T_{gCC})}{d\tau} = \Delta\dot{Q}_2(\tau) - \Delta\dot{Q}_3(\tau) \tag{23}$$

where:

$$\dot{Q}_2(\tau) = \dot{m}_{a2}(\tau)c_{a2}T_2(\tau) + \dot{m}_{fu}\left(\frac{dn_1}{d\tau}\right)W_d\eta_{CC} \tag{24}$$

represents a heat flow delivered to the combustion chamber, and

$$\dot{Q}_3(\tau) = \dot{m}_{g3}(\tau)c_{g3}T_3(\tau) \tag{25}$$

a heat flow from the combustion chamber.

Moreover a heat absorbed by metal parts was assumed not to be transmitted to the environment.

If pressure changes in the combustion chamber are neglected and heat exchange between working medium and the combustion chamber walls proceeds immediately, viz. $T_{CC} = T_3$ , then combustion chamber dynamic phenomena can be described as follows:

$$\frac{dT_3}{d\tau} = \frac{1}{c_{CC}m_{CC}}\left[\Delta\dot{Q}_2(\tau) - \Delta\dot{Q}_3(\tau)\right] \tag{26}$$

The presented model comprises all possible operational states of an electric generating set with a self-excited generator.

## SIMULATION PROCEDURE

The presented set of equations was solved by using the modified, fourth order Runge-Kutty method with the changeable integration step and the set of state variables assumed as the initial condition and known from the experiment with the electric generating system working under constant load at:

$$\begin{gathered} n_1(\tau_0) = n_{10}\ ;\ P_{HPT}(\tau_0) = P_{HPT0}\ ;\ P_K(\tau_0) = P_{K0} \\ n_2(\tau_0) = n_{20}\ ;\ P_{PT}(\tau_0) = P_{PT0}\ ;\ P_{em}(\tau_0) = P_{em0} \\ T_3(\tau_0) = T_{30}\ ;\ \dot{m}_{a1}(\tau_0) = \dot{m}_{a10}\ ;\ \dot{m}_{fu}(\tau_0) = \dot{m}_{fu0} \end{gathered} \tag{27}$$

A sudden change of the synchronous generator load current was applied as the input initiating the transient process. It was equivalent to the typical load changes appearing in ship's electric power network with regard to the state of a symmetric short-circuit shock of the generator. Simultaneously the resistance-inductance character of the electric power network and zero vector of disturbances were assumed.

## FINAL REMARKS

In result of the investigations the mathematical model, which describes turbine combustion engine-synchronous generator interaction, was proposed in a form of the set of ordinary differential equations, (6) to (22) and (26). It was shown there that such a set of state variables can be selected for the model, which makes calculation of all values of describing variables in each time instant possible, if only values of the state variables in function of time are known. It leads obviously to applying an effective, step-by-step calculation procedure.

Usefulness of this state variables model identification will be proved experimentally in the large-scale simulative tests [2].

### NOMENCLATURE

c - gas specific heat at constant temperature, $kJ\ kg^{-1}K^{-1}$
$\cos\varphi$ - electric power factor
f - voltage frequency, Hz
h - integration step, load setting
H - set of constraint values
i - gas specific enthalpy, $kJ\ kg^{-1}$
*i* - current instantaneous value, A
*I* - current effective value, A
*J* - rotating mass moment of inertia about rotor axis, $kg\ m^2$
k - gear reduction ratio, proportional regulator constant
L - inductance, H
*m* - mass, kg
$\dot{m}$ - mass flux, $kg\ s^{-1}$
M - torque, N m
M - mutual inductance, H
n - rotational speed, $min^{-1}$
p - pressure, Pa
p - number of pole pairs
P - active power, W
$\dot{Q}$ - heat flux, $kJ\ s^{-1}$
r - active resistance, $\Omega$
T - temperature, K
T - time constant, s
*u* - voltage instantaneous value, V
*U* - voltage effective value, V
**U** - steering interaction vector
W - calorific value, $kJ\ kg^{-1}$
**W** - vector of operation conditions
V - volume, $m^3$
**X** - state vector
**Y** - vector of output values
**Z** - disturbance vector
$\Delta$ - increment, difference
$\eta$ - efficiency
$\theta$ - „macro" time, considered here as operation time or time between overhauls, h
$\rho$ - density, $kg\ m^{-3}$
$\tau$ - „micro" time, counted here in a transient process scale, s
$\Psi$ - magnetic linkage due to leakage flux, T
$\omega$ - angular velocity, voltage pulsation, $rad\ s^{-1}$

**Lower indices & abbreviations**

a - air
a, b, c - denotation of generator's phases
acc - acceptable
ADS - air delivery system
co - cooling
CARS - of control and automatic regulation system
CC - of combustion chamber
d, q - related to generator's longitudinal and transverse axis, respectively
D - damping winding
DTS - drive transmission system
em - of electromagnetic moment
eng - of engine
EER - electric energy consumer
f - of excitation winding
fu - of fuel
F - air filter
FSS - fuel supply system
g - of gas
G - synchronous electric current generator
HPT - high pressure turbine
IT - three-wire electric power network with isolated neutral
K - air compressor
li - limiting
L1, L2, L3 - denotation of ship network phases
m - mechanical, to overcome friction drag in bearings
ol - of oil
p - at constant pressure
P - regulating pump
PT - power turbine
r - regulator
R - reduction gear
w - of winding, water
0 - of initial conditions, control cut number
1 - of gas generator rotary system, control cut number
2 - of power turbine rotary system, control cut number
3 - control cut number
4, 04 - control cut number

***Upper indices***

„ - „ - mean value

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***Appraised by Adam Charchalis, Prof.D.Sc.,M.E.***

## Conferences

**WTM**

## Jubilee Symposium on Optimization and Simulation in Ship Design

The symposium took place on 24 October 1995 at Ocean and Ship Technology Institute, Faculty of Maritime Technology, Technical University of Szczecin. It was organized by the Ocean Technology and Ship Design Department ( ZO i PO) which presented a review of its achievements in the last 30 years and actual scientific research projects.

During the jubilee part, 75th birthday anniversary of Mikołaj Thierry, Assoc. Prof., was celebrated after presentation of the past and actual activity of the Department by Tadeusz Szelangiewicz, D.Sc. The distinguished celebrator of the jubilee was granted congratulations by M.Tałasiewicz, D.Sc., the President of Szczecin Province (formerly a Department's employee), representatives of the University management, celebrator's colaborators as well as of shipyards, shipping companies and many other institutions.

During the scientific part the following papers were presented:

- *Multicriterial ship design system* by J.N. Siemionov, Prof., D.Sc.
- *Computer-aided propulsion performance prediction for inland waterway vessels* by J.Kulczyk, Assoc.Prof.
- *Optimization models of the ship and off-shore system with genetic algorithm application* by K. Sanecka, D.Sc.
- *Integration of ship design and production* by W.Chądzyński, D.Sc.
- *Manoeuvrability numerical simulation in ship design* by T.Szelangiewicz, D.Sc.