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Automatic control system simulation of the naval propulsion equipment

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Abstract: In this paper the authors present the functional simulations of the open system without and with state reactions as well as of the closed system with power reaction. These correspond to the operating regimes of the propulsion installation, which in naval terms correspond to the regimes: - without protections, manual, automatically. The index responses are presented, corresponding to progressively selected jumps on the combiner curve, covering the most difficult situations of operational maneuvers, responses used for the synthesis of state-by-state reaction regulators and of the effective power regulator using the input-state-output model of the system.

Introduction

The complexity of the ship as a technical product and the multitude of factors involved in its operation required the automation of various naval installations. The safety of navigation meant that, in the first stage, maximum importance was given to the propulsion engines with the related installations, adopting the solution of centralizing the commands and monitoring the parameters from a central command post. A distributed and hierarchical structure was adopted on two levels. The first level has as ordered objects installations grouped according to various functions such as:
- the propulsion system;
- the electricity production and distribution grid;
- the installations of the auxiliary mechanisms that group those of governance, ballast, maneuvering, lifting, fuel transfer, etc.

At this level, the automatic systems made in open and/or closed circuit are not functionally linked to each other, with the main aim being to create simple, safe and easy-to-maintain systems. The realization of the second level of automation was imposed by the need to correlate the various naval installations in order to ensure a functional optimum during navigation, a level usually ensured from the deck, from the navigation bridge.

Complex naval automation emerged as a necessity imposed by:
- the large number of existing mechanisms and installations on board modern ships;
- the economic factor imposed by the tendency to reduce the crew and to save fuel;

- improving working and living conditions on board ships;
- increasing maneuverability.

The optimal degree of automation is that which allows a reduced crew to maneuver the ship in normal and emergency conditions.

Currently, carried out exclusively in numerical technique, complex automation refers to the entire ship with all the problems of its exploitation. Diagnostic systems, based on artificial intelligence elements, introduced especially on the propulsion installations, have extended over the entire operating system of a ship, this can be considered as an "intelligent ship", able to function optimally in relation to the standards of economy and safety, without the intervention of the crew.

1. Naval propulsion systems

From the set of naval installations, the paper addresses automatic control systems for the propulsion installation. There are various constructive variants for this installation adapted to the requirements, performances and register norms imposed by the class of the ship, as:

a) according to the nature of the propellant we have:
   - EPF fixed pitch propeller installations;
   - installations with EPR adjustable pitch propellers.

b) according to the type of main engine, MP, we have:
   - with Diesel engines (fast, semi-fast and slow);
   - with gas turbines;
   - with electric motors.

c) by the number of installations on board the ship:
   - with a single axial line LA;
   - with several engines summed through the Rd reducer to a single propeller.

d) according to the connection method with the electric generator we can have:
   - without generator connected to the propulsion system reducer;
   - with the generator connected to the reducer.

The relatively large number of constructive variants indicates the diversity of automatic control functions related to this installation. In order to ensure a high degree of generalization, the paper deals with automatic control systems for the classic propulsion variant consisting of the assembly: ***Diesel engine-reducer-propeller with adjustable pitch***, system that by adding additional functions can cover most applications.

2. Research Methodology

In this paper are used analogical and numerical modeling, both included in the general category of mathematical modeling. The analogical model is considered to result from systems of algebraic or linear or non-linear differential equations which, by direct analogy with the studied processes, are based on equilibrium equations. The numerical model derives from the analogical model through time discretization formulas, resulting in equations with finite differences (operating with finite sequences) easy to implement on the computer. The integration of the numerical model calls the LLI local iterative linearization procedure, the numerical simulation representing the running of the numerical model on the computer in the Pascal language, for a series of conditions imposed by the program.

According with [1], [2], [7] a control system for propulsion power could be represented as in figure 1.

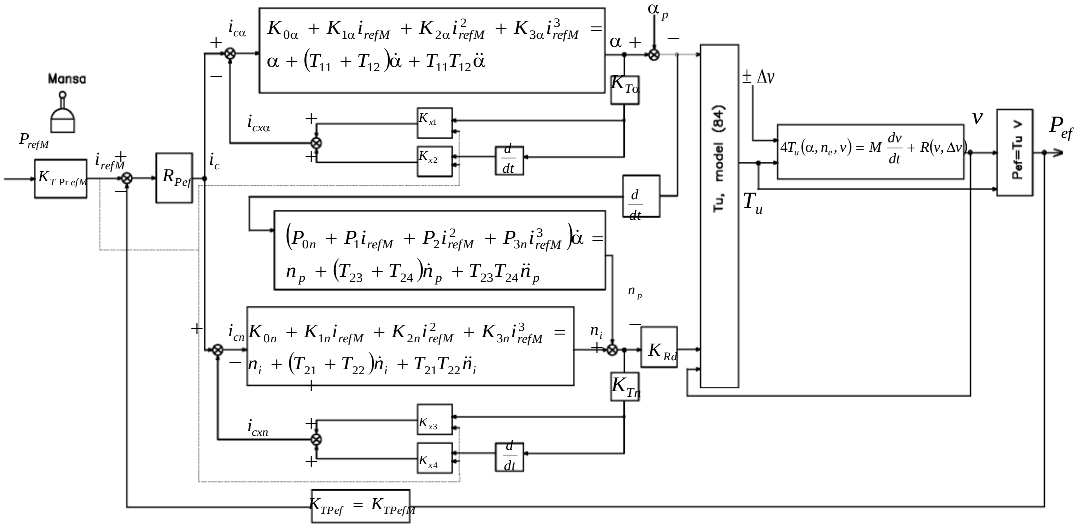

Fig. 1 The structure of the control system according to the condition and the effective towing power for the propulsion plant

The model with state variables for the previous control system is given by the equation system (1). The analog model with state variables (1) allows, by switching to the numerical model and integration according to the LLI procedure, functional simulations for the proposed regulation variant with the block diagram in fig.1 in various operating regimes. The systematization of the numerical simulations, which allow the verification of the proposed solutions and the adjustment of the adjustment devices, was made taking into account the operating regimes of the propulsion installation.

$$\left\{\begin{array}{l}
\dot{x}_1 = x_2 \\
\dot{x}_2 = \dfrac{1}{T_{11}T_{12}}[(K_{0\alpha} + K_{1\alpha} i_{c\alpha} + K_{2\alpha} i^2_{c\alpha} + K_{3\alpha} i^3_{c\alpha}) - x_1 - (T_{11} + T_{12})x_2] \\
\dot{x}_3 = x_4 \\
\dot{x}_4 = \dfrac{1}{T_{23}T_{24}}[(P_0 + P_1 i_{refM} + P_2 i^2_{refM} + P_3 i^3_{refM})(x_2 - \dot{\alpha}_p) - x_3 - \\
- (T_{23} + T_{24})x_4] \\
\dot{x}_5 = x_6 \\
\dot{x}_6 = \dfrac{1}{T_{21}T_{22}}[(K_{0n} + K_{1n} i_{cn} + K_{2n} i^2_{cn} + K_{3n} i^3_{cn}) - x_5 - (T_{21} + T_{22})x_6] \\
\dot{x}_7 = \dfrac{1}{M}[4_u(x_1 - \alpha_p, x_5 - x_3, x_7) - (R_{21}\Delta\nu^2 + R_{22}\Delta\nu + R_{23})x_7^2 - \\
- (R_{11}\Delta\nu + R_{12})x_7 - R_0] \\
Kx_1 = K_{0x1} + K_{1x1} i_{refM} + K_{2x1} i^2_{refM} + K_{3x1} i^3_{refM} \\
Kx_2 = K_{0x2} + K_{1x2} i_{refM} + K2 i^2_{refM} + K_{3x2} i^3_{refM} \\
i_{cx\alpha} = K_{T\alpha}(K_{x1}x_1 + K_{x2}x_2) \\
i_{c\alpha} = i_c - i_{cx\alpha} \\
Kx_3 = K_{0x3} + K_{1x3} i_{refM} + K_{2x3} i^2_{refM} \\
Kx_4 = K_{0x4} + K_{1x4} i_{refM} + K_{2x4} i^2_{refM} + K_{3x4} i^3_{refM} \\
i_{cxn} = K_{Tn}[K_{x3}(x_5 - x_3) + K_{x4}(x_6 - x_4)] \\
i_{cn} = i_c - i_{cxn} \\
T_u = (1 - t)K_T \rho n_e^2 D^4 \\
Q = K_Q \rho n_e^2 D^5 \\
M_{\lim} = 1693 n_e^2 \\
i_{refM} = K_{TPefM} P_{refM} \\
P_{ef} = T_u x_7 \\
i_{rPef} = K_{TPef} P_{ef} \\
i_{aPef} = i_{refM} - i_{rPef}
\end{array}\right.$$

(1)

$$\begin{cases} i_c = K_{RP} i_{aPef} + \dfrac{1}{T_{iRP}} \int i_{aPef} dt \\ \alpha_p = \lambda_1 x_1 \sin \dfrac{2\pi}{\tau_{PP}} t \\ \dot{\alpha}_p = \lambda_1 (x_2 \sin \dfrac{2\pi}{\tau_{PP}} t + x_1 \dfrac{2\pi}{\tau_{PP}} \cos \dfrac{2\pi}{\tau_{PP}} t) \\ K_T = E_0 + E_1 j + E_2 x_1 + E_3 j^2 + E_4 j x_1 + E_5 x_1^2 \\ K_Q = b_0 + b_1 j + b_2 x_1 + b_3 j^2 + b_4 j x_1 + b_5 x_1^2 \\ n_e = K_{Rd} (x_5 - x_3) \\ j = \dfrac{V_A}{n_e D} \\ v_A = (1 - w) x_7 \\ w = D_3 x_7^3 + D_2 x_7^2 + D_1 x_7 + D_0 \end{cases}$$

3. Automatic control system simulation of the naval propulsion equipment

Their classification [3], corresponds to real situations and is correlated with the ways in which the regulation system can work.

Thus, we can consider the following operating regimes:

a) Regimes without protections

In operation, it corresponds to that extreme situation where the safety of the ship depends on the speed of maneuvers. Decisions are usually made by the navigational officer operating the installation at maximum performance, making pitch and speed prescriptions either from the common leg when the combiner is used, or from separate prescription legs. Thus, the angle change must be done with the maximum nominal speed of the MSP even if, during the time intervals of the maneuvers, the Diesel engine enters overload mode, a mode that will be ignored until the dangers are avoided. From the point of view of regulation systems, this corresponds to open-circuit operation both in relation to state reactions and in relation to power reaction.

b) Manually mode

Corresponds to situations in which the engine must be automatically protected against transient overload (which is no longer ignored during maneuvers) and its exploitation is done according to the combinator characteristic only in stationary mode. From the point of view of the regulation system, it corresponds to the operation with reactions after the state, but in open circuit after the power reaction.

c) Automatic mode

It corresponds to the situation in which the engine must be automatically protected against both transient and stationary overload determined by the disruptive action of the navigation conditions, and operation is done in stationary and transient mode only according to the combiner characteristic. From the point of view of the regulation system, it corresponds to the operation both with reactions according to the state and with the reaction according to the effective power.

d) The regime of technological breakdowns

Corresponds to the situation in which, due to internal disturbing factors (technical faults), the load on the Diesel engine must be reduced and/or its speed must be reduced to the idling value. From the point of view of the regulation system, it corresponds to the operation as in the manual control mode, respectively with reactions according to state but without the main reaction according to power [3].

Regarding the tuning of the regulators according to the state and the effective power regulator, the validation of the results was done by simulation after the index responses of the regulation system [6].

Two procedures can be considered for index responses. The first one consists in applying the step of the input signal or, when traversing the combiner curve, successively from the values corresponding to a point to an immediately nearby one, the results being associated with the first point.

Therefore, taking into account the non-linear character of the entire process and taking the combinator curve as an adaptive model, the dependencies can be obtained:

$$K_{x1}(i_{refM})\ ;\ K_{x2}(i_{refM})\ ;\ K_{x3}(i_{refM})\ ;\ K_{x4}(i_{refM})\ ;\ K_{RP}(i_{refM})\ ,\ T_i(i_{refM}) \qquad (2)$$

which satisfy the performances required in regulation.

Taking into account the real character of the commands given by the operator to the loop, especially in maneuver mode, to cover the most disadvantageous situations, a second procedure was chosen that takes into account the index responses as a result of applying some command steps to the prescription loop of upon entering the sequences A-B; A-C; A-D; A-E; A-F and A-G. The results obtained for the adjustment parameters, optimally chosen, are associated with the input quantity corresponding to points B, C, D, E, F, G and thus the dependencies of the form (197) are obtained which must ensure the following performances adapted to the specific needs of the field:

- stability in all operating regimes;
- the minimum duration of the transient regime under the conditions of the elimination of the transient overload and the overspeed at MP;
- following the combinator curve in stationary mode with a satisfactory precision and eliminating the stationary overload due to the disruptive action of external navigation factors, expressed by;
- mitigating the effects of the propeller exiting the water, expressed through the action of the disturbance, by avoiding the entry of the MP into the regime of transient overload and overspeed;
- the automatic reduction of the load at the MP when technological failures occur, with the possibility of returning to the initial stationary point, without the MP entering the breakdown mode; - switching from one operating mode to another without the main engine entering failure modes.

The above criteria were verified by graphical and value analysis of the index response in effective power, as well as other intermediate quantities of interest, using the SISTEM5PAS program. Mainly according to the block diagram in fig. 1, the speed of the ship v, the adjustment deviation i_{aPef}, rotation speed n, the angle α, the resistant Q and the limit $M_{\lim}$ torque are of interest.

3.1 Numerical simulations of the open system without state feedback

This situation corresponds to the *regime without protections*, a condition in which in model (1) the following must be imposed:

$$K_{x1} = 0\ ;\ K_{x2} = 0\ ;\ K_{x3} = 0\ ;\ K_{x4} = 0\ ;\ i_c = i_{refM} \qquad (3)$$

and the initial conditions correspond to the functional point A for which from table 8 we have:

$$x_{10} = 17grd.\ ;\ x_{20} = 0\ ;\ x_{30} = 0\ ;\ x_{40} = 0\ ;\ x_{50} = 11{,}66rps\ ;\ \ x_{60} = 0\ ;\ x_{70} = 4{,}54m/s\ ; \qquad (4)$$

The index responses are raised for traversing the combinator curve in power steps at the input, from A to B; A to C; A to D; That is; A to F; A to G.

The performances of the dynamic behavior are analyzed without reactions according to state and without the power reaction, i.e. for the fixed part of the installation, as follows:

a) from the diagrams shown in fig. 2 it follows:

- the system is stable, the response in power i_{rPef}, presents in stationary mode with a dead time followed by a rise time with over-regulation that amortizes without oscillations at $t_r = 60\sec$. , the deviation in stationary mode, in the absence of disturbances, is reduced;

- the transient overload begins to manifest itself only from step A-E (so in the area of the stationary point E), corresponding to a power demand from 7% in A to 58% in E; the phenomenon also manifests itself for requests A-F and A-G; the overload manifests itself during the period when the resistant torque Q exceeds the limit $M_{\lim}$ curve of the motor (blackened area);
- the angle increases from 17 to 23 degrees, a periodically with a transient regime of short duration ≅ 8 sec, ensured by the preset performances of the automatic positioning system;
- the rotation speed n reaches a stationary regime through a transient regime when the temporal evolution is affected by the component n_p;
- the speed of the ship v reaches the steady state, corresponding to point E in approx. 72 sec.

b) from the diagrams shown in fig. 3 it follows:
- the overspeed can occur at the sudden decrease of the required power from point G (100%) to E (58%) when the speed rotation n in transient mode, due to the n_p component, shows a jump that exceeds the protection value of 17.5 rps. (1050rpm).

c) from the diagrams shown in fig. 4 it follows:
- in the power zone corresponding to point F (83%) a stationary overload may appear when the navigation conditions change corresponding to an involuntary drop in speed $\Delta v = 22\%$; the presence of overload is represented by the blackened area when Q it exceeds $M_{\lim}$; in the program, the disturbance Δv is applied at the time $t = 70\,\text{sec}$.

d) subject to the previous approximations of the diagrams shown in fig. 5 results:
- in the power zone corresponding to point F (83%) the effects of the propeller exiting the water under the conditions of a disruptive step α_p can be evaluated, with a sinusoidal variation having the amplitude $0{,}08\alpha$ and the period $\tau_{pp} = 25\,\text{sec}.$;
- the time intervals in which the transient overload occurs when Q it exceeds $M_{\lim}$ and the overspeed when n it exceeds the threshold of 17.5 rps. are observed;
- the system operating in open circuit, the disturbance α_p affects the component n_p, therefore the rotation speed n_e and hence all the intermediate signals that depend on n_e.

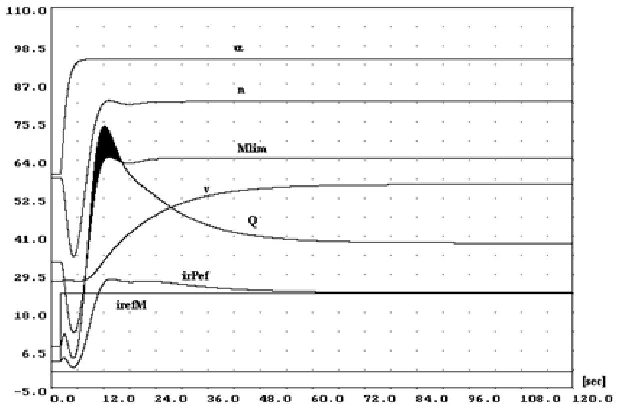

Fig.2 Index response in power from A(7%) to E(58%) of the open system - transient overload

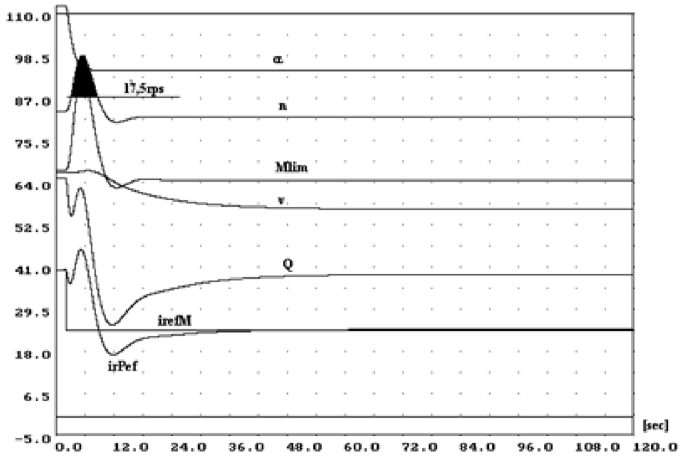

Fig.3 Index response in power from G(100%) to E(58%) of the open system – overspeed

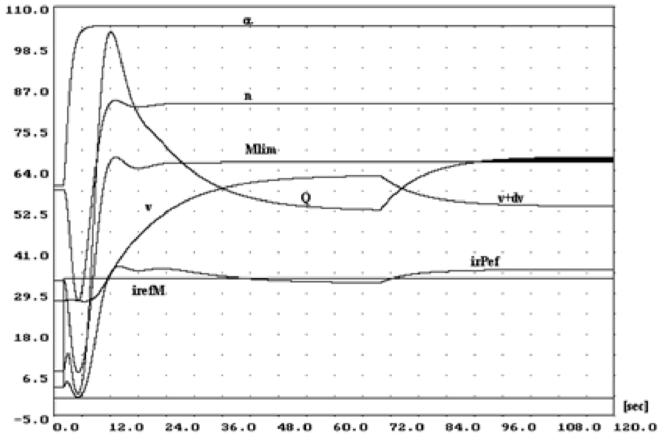

Fig.4 Index response in F(83%) to involuntary speed drop to the open system – stationary overload

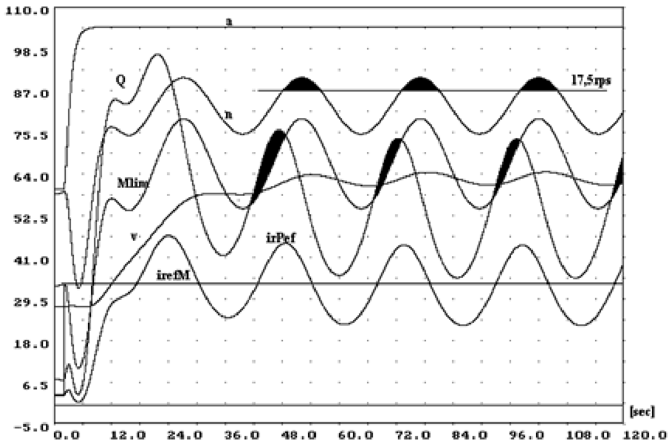

Fig.5 The effects of the propeller exiting the water around point F(83%) of the open system – transient overload and overspeed

3.2 Numerical simulations of the open system with state feedback

This situation corresponds to the manual operating mode of the installation, in which two cases can occur in the model (1):

- manual mode without technological breakdowns
- manual mode with technological failures

3.2.1 Manual mode without technological breakdowns

According with [1], the coefficients $K_{x1} = 0$, $K_{x3} = 0$ are imposed and the coefficients K_{x2} and K_{x4} are verified by simulations in order to eliminate the transient overload that appears at the jumps on the combiner curve from A-E, A-F and A-G. As can be seen from the index response, without reactions after the state, from fig.2, the effective power at the output of the system presents an overshoot, as a result of the faster increase of the angle α compared to the speed n. Reducing this effective power overshoot by choosing K_{x2} and K_{x4}, so that subsystems 1 and 2 become slower and dynamically harmonized allows the automatic elimination of the transient overload. Under these conditions, the index response of the effective power approaches the appearance of an aperiodic response, possibly characterized by two equivalent time constants T_{1EX} and T_{2EX}.

From the estimation of these constants, a subsequent adjustment can be made, according to the module criterion, of the effective power regulator. With these observations, traversing the combinator curve through the associated values of i_{refM}, a first evaluation of K_{x2} and K_{x4} can be made using the values t_{r1} and t_{r2} are also imposed by the manufacturer of the propulsion complex, respectively of the Diesel engine [5].

With the values obtained in this way, it is checked whether the index responses to jumps A-B; A-C; A-D; A-E; A-F and A-G also present areas of transient overload, so otherwise, the values should be adjusted so that the time path of Q, is lower than $M_{\lim}$. Based on this last criterion, for the case under study, table 1 resulted in the values of K_{x2} and K_{x4}. The equivalent values resulting for the response times t_{r1} and t_{r2}.

Table 1

Parameters	MU	Stationary points						
		A	*B*	*C*	*D*	*E*	*F*	*G*
i_{refM}	mA	1,1	2,154	4,92	7,15	9,42	13,43	15,99
K_{x2}	-	10	15	20	25	30	35	42
K_{x4}	-	5	10	15	18	20	22	25
t_{r1}	s	394	338	237	207	203	202	202
t_{r2}	s	280	259	229	204	176	149	149

From table 1 can be observed that the equivalent values for t_{r1} and t_{r2} are very high, being generated from the condition of eliminating the transient overload in the extremely harsh conditions of jumps A-E; A-F; A-G. It follows that subsystems 1 and 2 have become very slow, which is transmitted to the entire system, which responds more slowly in speed and effective power. This apparent disadvantage, will be eliminated by adjusting the entire system according to the effective power. With the values from table 1, the analytical expressions result in terms of value, which allow the adaptation of the coefficients K_{x2} and K_{x4} when traversing the combinator curve, respectively:

$$K_{x2}(i_{refM}) = K_{0x2} + K_{1x2}i_{refM} + K_{2x2}i^2_{refM} + K_{3x2}i^3_{refM} \qquad (5)$$

$$K_{x4}(i_{refM}) = K_{0x4} + K_{1x4}i_{refM} + K_{2x4}i^2_{refM} + K_{3x4}i^3_{refM} \qquad (6)$$

where the coefficients take the values:

$$K_{0x2} = 6{,}409\,; K_{1x2} = 4{,}005\,; K_{2x2} = 0{,}2562\,; K_{3x2} = 0{,}009\,; \qquad (7)$$

$$K_{0x4} = 1{,}024\,; K_{1x4} = 4{,}514\,; K_{2x4} = 0{,}382\,; K_{3x4} = 0{,}0112\,; \qquad (8)$$

The index responses were collected under the same conditions as in point 3.1, and the effects of the reactions by state will be analyzed, through the coefficients K_{x2} and K_{x4}, comparing with the regime without protections that do not use these reactions.

Thus, we have:

a) from the diagrams shown in fig. 6 it follows:

- the system is stable, the power response i_{rPef} has an aperiodic evolution, the duration of the transient regime being $t_r = 72\,\text{sec}$. (for the A-E jump);
- the deviation in stationary mode, in the absence of disturbances, is reduced;
- no transient overload occurs throughout the combiner curve; compare with fig.3 for the same jump from A to E (Q it does not exceed $M_{\lim}$, there is even a power reserve);
- the angle α and speed rotation n enter the stationary mode after a transient mode of approx. 70 sec. (10 times longer than in the absence of reactions by condition);
- the speed of the ship v reaches the steady state, corresponding to point *E*, in approx. 90 sec., with 20 sec. more than in the absence of reactions;

b) from the diagrams shown in fig. 7 results:

- there is no overspeed when the required power drops suddenly from point *G* to *E*, as it happened in fig.3, in the situation without reactions after the state (the curve n is below the limit of 17.5 rps);

c) from the diagrams shown in fig. 8 it follows:

- in the power zone corresponding to point *F*, the stationary overload is maintained at the involuntary drop in speed of $\Delta v = 22\%$, expected result, the system working in open circuit in relation to the speed v or P_{ef};

d) from the diagrams shown in fig. 9 results:

- in the area of the operating point *F*, at the exit of the propeller from the water, for $\alpha_p = 0{,}08\alpha$ and $\tau_{pp} = 25\,\text{sec}$. as in fig.80 , introduction of lui K_{x2} and K_{x4} does not produce an elimination of overload and overspeed but only an improvement of them;
- because α_p it is a fictitious disturbance and the reaction K_{x2} is taken after the real step α, this reaction has no effect;
- since the rotation speed n also includes the component n_p, directly related to α_p, an intervention is expected only through K_{x4};
- it is found that by doubling its values of K_{x4} compared to those indicated in tab. 11 and used in normal navigation conditions, oscillations in speed are reduced and over speeding is avoided;
- the transient overload is maintained, but the level of variation of Q it is over of $M_{\lim}$, so that the mechanical and thermal stresses of the engine are reduced.

By comparison with the open system, without the reactions K_{x2} and K_{x4} it follows that the main advantages introduced by them consist in the elimination, under normal sailing conditions, of transient overload and overspeed. Regarding the ship's speed response, the propulsion system is slower, a disadvantage that will be eliminated by the main reaction after the effective power.

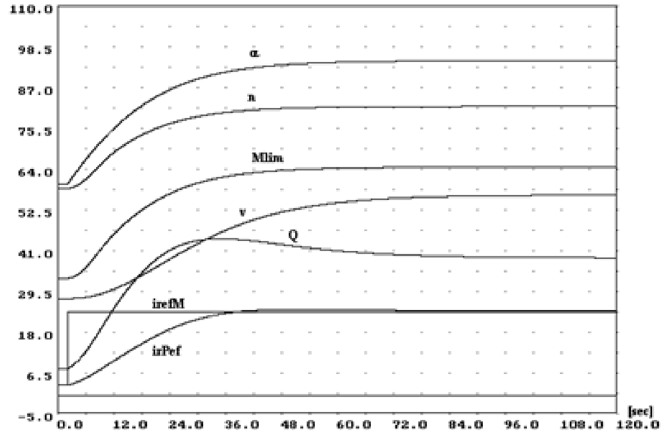

Fig.6 Index response in power from A(7%) to E(58%) of the open system but with reactions according to state

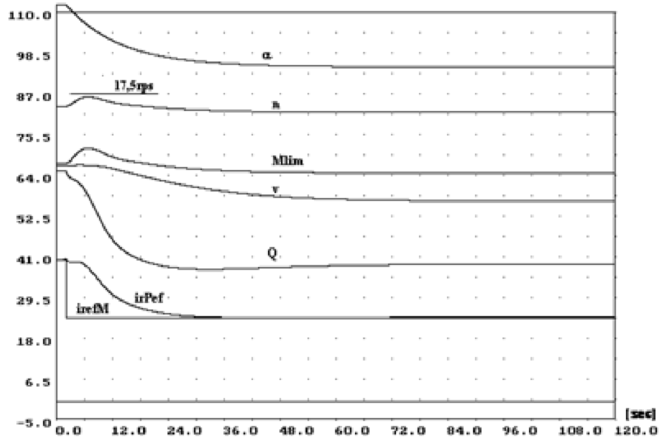

Fig.7 Index response in power from G(100%) to E(58%) of the open system with reactions by state

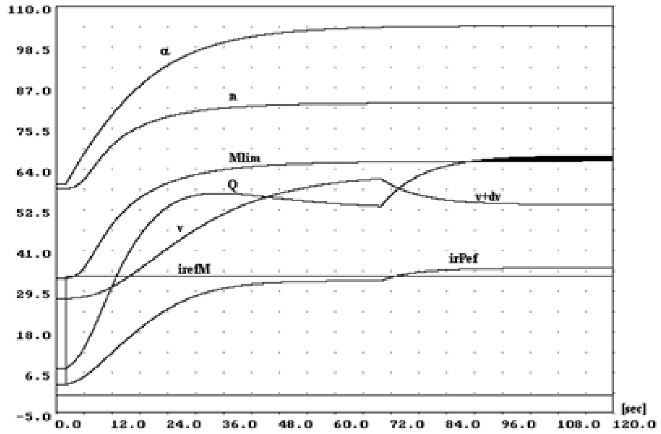

Fig.8 Index response in F(83%) to involuntary speed drop in the open system with reactions by state

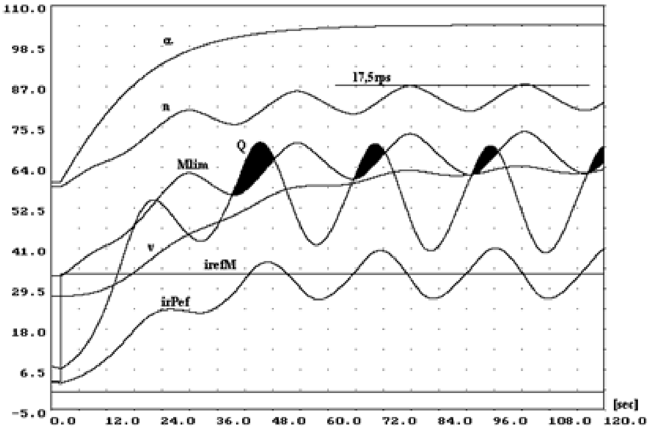

Fig.9 The effects of the propeller exiting the water around point F(83%) of the open system with post-state reactions

3.2.2 Manual regime with technological breakdowns

Having established the values of the coefficients K_{x2} and K_{x4}, according to point 4.2.1, when technological failures occur, the system allows the protection of the heat engine by reducing its load by activating the reactions K_{x1} and K_{x3}.

The values of these coefficients are determined by following the combinator curve when the lower limit values $\alpha_{\min}$ and $n_{\min}$.. For the case under study choosing $\alpha_{\min} = 0{,}5grd.$ and $n_{\min} = 8.3rps.$ (500rpm) the values from table 2 resulted.

Table 2

Parameters	MU	Stationary points						
		A	*B*	*C*	*D*	*E*	*F*	*G*
i_{refM}	mA	1,1	2,154	4,92	7,151	9,427	13,43	15,9
K_{x1}	-	5	9	20	29	38	54	64
K_{x3}	-	0,05	0,11	0,3	0,46	0,63	0,93	1

With these values, the analytical expressions result in value, which allow the adaptation of the coefficients K_{x1} and K_{x3} also when traveling the combinator curve:

$$K_{x1}(i_{refM}) = K_{0x1} + K_{1x1}i_{refM} + K_{2x1}i_{refM}^2 + K_{3x1}i_{refM}^3 \tag{9}$$

$$K_{x3}(i_{refM}) = K_{0x3} + K_{1x3}i_{refM} + K_{2x3}i_{refM}^2 + K_{3x3}i_{refM}^3 \tag{10}$$

where:

$$K_{0x1} = 0{,}7022; K_{1x1} = 3{,}8439; K_{2x1} = 0{,}0202; K_{3x1} = 0{,}0008; \tag{11}$$

$$K_{0x3} = 0{,}0145; K_{1x3} = 0{,}0299; K_{2x3} = 0{,}0067; K_{3x3} = 0{,}0003; \tag{12}$$

The diagrams in fig. 10 show the evolution of all the signals in the open system with the reactions according to the states K_{x1}; K_{x2}; K_{x3}; K_{x4}, having the values from tables 1 and 2, when at the time $t = 90\,\text{sec}$. the technological failure is triggered and the reactions K_{x1} and K_{x3} are activated .

The system passes from the functional point *E* to the point with reduced load, through an aperiodic transient regime.

The values of K_{x1} and K_{x3} from the moment of the breakdown can be applied according to a technologically established time variation law.

Maintaining the reactions after the condition K_{x2} and K_{x4} allow the system to return to the initial stationary point, without transient overload, when the failure condition is removed and the coefficients K_{x1} and K_{x3} are cancelled.

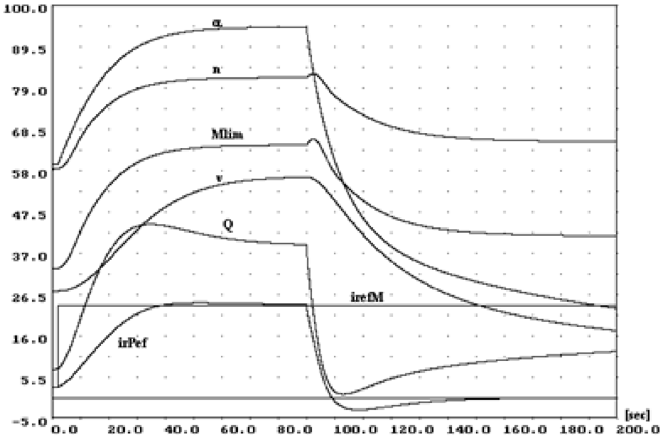

Fig. 10 The response of the open system with state reactions to the triggering of a technological failure from point E and the activation of the coefficients K_{x1} and K_{x3} at the time $t = 90\,\text{sec}$.

Conclusions

The signals represented by the simulation, introducing the fictitious step disturbance related to the exit and entry of the propeller from the water, indicate possible dynamic improvements by applying an increased weight of the reaction K_{x4}, which it makes the Diesel engine slower and therefore less sensitive to load variation in one direction or another.

Solving this problem requires the opening of a new research path that ensures active protection of the installation by changing the pitch of the propellers, performing online prediction of the movement in the stern of the ship.

Control of the propulsion system by state and effective power reactions allows a high degree of generalization, being able to adapt to any naval application. This flexibility of the adjustment solution is due to the fact that it operates with data usually used in the design of the ship and the propulsion installation, namely:

- propeller characteristics, drag characteristic;
- the constructive elements of the pitch change mechanism and the results of the dynamic identification;
- dynamic identification results for the Diesel engine after input and disturbance;
- the combiner curve and the torque limiting characteristic of the Main Engine indicated by the manufacturer.

The technical implementation of the proposed solution does not raise particular problems, taking into account the dedicated hardware and software offers existing on the market in the field of acquisition, processing, data visualization and numerical regulation of processes.

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References

[1] P. Burlacu, C.Bucur, M.Alexa, Sistem de control automat după puterea de remorcare pentru propulsia navală, ISBN 978-606-25-0262-1, Editura MATRIX ROM, 2006

[2] M. Alexa, P.Raica, T. Colosi, Numerical modeling of a naval propulsion control system, International Conference in Automation and Quality Control A&Q 98, Cluj Napoca, ISBN 973-9358-15-2

[3] R.P. Geway, The behaviour of the controllable pitch propellers, International Shipbuilding Progress, nr. 316, pag. 101-116

[4] Hutte, Manualul inginerului, pag.170, ISBN 973-31-0913-4

[5] W.G. Price, R.E.D. Bishop, Probabilistic Theory of ship Dinamics, London Chapman and Halt, 1985

[6] H. Rainer, An electrical digital engine speed controller, Shipbuilding Technology International, 1995, pag 100

[7] T.I. Fossen, Systems for Guidance and Control, John Wiley&Sons Ltd., 1994