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INFORMATION BANKS OF ENERGETIC DEVICES OPERATION FORMED BY MEANS OF DIMENSIONAL ANALYSIS

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Abstract

The following article explains how information banks of energetic devices can be created by means of dimensional functions complex. Operation of energetic devices have been assessed, according to J. Girtlers proposal, by means of physical quantity called Joule multiplied by second [Js]. Interpreted in this way operation is nothing else but energy transfer in the form of work or heat to the neighbourhood and expressed by Joule multiplied second product. Diagnostics of energetic devices, according to J. Girtler in his works [2, 3], can be carried out by means of their operation. As has been indicated there is also a possibility to describe working processes, taking place in energetic devices with the help of parametric dimensional functions, giving reasons for their creation. There are formal rules, presented in this paper, concerning working processes that take place in energetic devices with the help of dimensional analysis. We have also been shown an exemplary diagram of diagnostic activities, making use of information bank of energetic devices operation, and at the same time, being confronted by diagnosis of technical condition of such devices. Exemplary dimensional functions of working processes taking place in piston combustion engine and in ship auxiliary boiler have been presented in information bank of energetic processes.

Key words: *information banks of energetic devices operation, dimensional analysis*

1. Introduction

Technical means that serve to transform information enable us to collect numerous research results of working processes, taking place in energetic devices and their handling in computer informing banks of operation [4].

Energetic devices in thermodynamic formulation, constitutes an object that influences the surroundings. The most of ten reactions between an object and the surroundings or between two objects is represented by energetic influence. It consists in energy exchange. There are two forms of this influence: work and heat in the objects that do not exchange substances between each other. Heat is the form of energy transformation different than work. Energy transformation by energetic devices both in the form of heat and work as well, is subject to a change with the passage of time. Such change does not depend only on performed tasks by energetic devices and conditions in which they proceed, but it also depends on their technical condition.

According to the above, it makes sense to consider the operation of energetic devices, defined at the same time, by the energy brought to them and carried away, while being transmitted. Estimation of energetic devices operation, according to J. Girtler in his works [2, 3], can be compared with dimensional physical quantity with measurement unit called Joule multiplied by second. Such operation can be interpreted as conversion of energy alt a definite time.

Operation of energetic devices in which the exchange of energy takes place, can be a carrier of information about their technical condition.

The basic problem of working process analysis in energetic devices, for operation needs, is building of mathematical models describing their operation. Forming of similar specifications becomes indispensable in undertaking optimal operation decisions in the range of energetic devices repair.

Necessity of such descriptions in other words, mathematical models, results from the need of knowledge about the regularities taking place between the parameters of a device performance and its technical condition. To find mathematical dependence for such complicated realities as working processes in energetic devices in an analytic way is not an easy task [4].

Experimental methods are most often used for this purpose. They consist in collecting and describing scientifically, statistic data which characterize particular parameters of energetic devices performance.

Dimensional analysis enables us to pass from quality descriptions to quantity ones. It also leads the experiment in the right direction or even simplifies it. For this reason it is suitable for creating of mathematical specifications concerning working processes that take place in energetic devices. One function can not be useful as a description of all working processes, and thus it does not reflect all conditions of its mechanisms [4, 5, 6, 7]. For this reason it is necessary to process a great amount of information previously collected in computer banks.

2. Creation rules of dimensional functions, concerning operation of energetic devices

Research is carried out in a defined direction of energetic devices operation. The results of the accomplished experiments are presented in dimensional function quantities or functions of these quantities. Most important in preparing measurements and elaboration of its results is to examine what limitations should be imposed on the functions of device operation, as dimensional quantities are their arguments and not the numerical ones. After fulfilment of the above conditions one can start to determine functional dependence, if such dependence can be determined at all [4, 6].

Dimensional analysis does not determine the number and the kind of quantities. It depends entirely on the knowledge of the working process taking place in the device under examination. One can not use a device working process description without quality recognition, as it would be difficult to achieve any sensible information. Dimensional analysis does not produce any information about the forms of numerical functions. According to Kasprzak and Lysik in paper [4] dimensional analysis ensures only dimensional regularity of the description, not entering however the physical description of the world. By means of the above mentioned analysis, we can achieve dimensional functions of working machines determined exact to a parameter, if only the arguments of a dimensional function are dimensionally independent [1, 4, 6, 7]. The parameter can be determined only by means of the measurements performed on working energetic devices [7].

The conception of dimensional function is of great importance in applications of dimensional analysis. Dimensional function of energetic devices operation is just a function defined in dimensional space π, arguments of which are parameters of working devices, being elements of the same dimensional space [1, 4, 6, 7].

It is necessary for dimensional function, created on the basis of energetic device work, to fulfil consistently interpretation rules together with the notions that suit its description. Working process description that takes place during the device performance and all information we have to obtain about its work is expressed in the language of some discipline with the help of defined notions which are dimensional quantities. They imitate real technical conditions of the device and all resulting operation features that are included in working processes [4, 7]. Parameters of working process under examination are physical quantities marked by dimensions. Therefore exponent matrix of dimensional arguments concerning operation functions of energetic device forms (1) in the basic unit set of measure *SI,* is of the third order. It means that in case of dimensional function of the form (1a), three quantities form among five arguments are dimensionally independent, and two arguments are dimensionally dependent on the three, mentioned above. For this reason one can choose arguments dimensionally independent form the dimensional function (1a) and separate them from the remaining ones, that is, to accept a dimensional base of this function in ten ways. Not all accidentally accepted dimensional bases will be appropriate which results from dimensional independence of the unit set. Making use of Buckingham theorem [1,4,6,7] in the function (1), after previous acceptance of dimensional bases, one can obtain different forms of these functions [1,5,6].

Exemplary forms of such functions are represented by the following formulas:

$$\begin{aligned} &a)\cdots D_S = \Phi(M,n,G,p,t) \\ &b)\cdots D_S = \Phi(N,n,G,t) \\ &c)\cdots D_K = \Phi(B,p_K,t_K,m) \end{aligned} \tag{1}$$

where:

Φ – symbol of dimensional function,

D_S – propulsion engine operation in [Js],

D_K – auxiliary boiler operation in [Js],

M – the engine torque in $\left[\frac{kg \cdot m^2}{s^2}\right]$,

n – revolution speed of the engine in $\left[\frac{1}{s}\right]$,

G – volumetric fuel consumption by the engine in $\left[\frac{m^3}{s}\right]$,

N – effective power of ship propulsion engine in $\left[\frac{kg \cdot m^2}{s^3}\right]$,

p – supercharging air pressure in $\left[\frac{kg}{m \cdot s^2}\right]$,

t – time of engine operation in [s],

B – firing oil consumption by the boiler in $\left[\frac{kg}{s}\right]$,

P_K – steam pressure generated by the boiler in $\left[\frac{kg}{m \cdot s^2}\right]$,

m – boiler efficiency in $\left[\frac{kg}{s}\right]$,

t_K – time of boiler operation in [s].

In table 1 there is a notation concerning dimensional functions of energetic device operation in a quality form.

3. Creation of dimensional banks concerning energetic device operation

Chosen dimensional quantities must interfere in a description of a device operation in a radical way and restrict considerably the possibility of its description. Selection of these quantities must be preceded by their detailed analysis.

According to formal principles of dimensional function creation, concerning energetic device operation, presented in point 2 of the paper, their work is defined by a composed function of the form (1). Their different parametric forms, while using Buckingham theorem, are presented in table 1.

Table 1. Notations of dimensional function operation of energetic devices in a quality form.

<table>
<tr><td>Schedule of measure units</td><td colspan="2">Dimensional parameters describing the signals of the above energetic device</td><td>Dimensional quantities describing energetic device operation</td><td>Non normalized information about energetic device operation</td></tr>
<tr><td>Process class</td><td>entrance</td><td>exit</td><td>Features</td><td></td></tr>
<tr><td></td><td colspan="3">Description of working process taking place in a piston combustion engine of the ship</td><td></td></tr>
<tr><td>kg; m; s;</td><td>$G = \varphi_G \cdot \frac{M \cdot n}{p}$
$p = \varphi_p \cdot \frac{M}{n \cdot G}$</td><td>$M = \varphi_M \cdot \frac{p \cdot G}{n}$
$n = \varphi_n \cdot \frac{1}{t}$</td><td>$D_S = f_1 \cdot \frac{M}{n}$
$D_S = f_3 \cdot \frac{G \cdot p}{n^2}$
$D_S = f_5 \frac{M^2}{G \cdot p}$
$D_S = f_4 \cdot G \cdot p \cdot t^2$
$D_S = f_6 \cdot M \cdot t$
$D_S = f_8 \cdot \frac{N}{n^2}$
$D_S = f_9 \cdot N \cdot t^2$</td><td></td></tr>
<tr><td></td><td colspan="3">Description of working process taking place in ship auxiliary boiler of VX type</td><td></td></tr>
<tr><td>kg; m; s;</td><td>$B = \varphi_B \cdot m$</td><td>$m = \varphi_m \cdot B$</td><td>$D_K = f_{10} \cdot \frac{m^3}{p_K^2 \cdot t_K^2}$
$D_K = f_{11} \cdot \frac{B^3}{p_K^2 \cdot t_K^2}$</td><td></td></tr>
</table>

Parameters measurements of a device work in the form of dimensional functions concerning operation, and defined on the basis of working processes that take place in different technical conditions of the device, can be collected in so called computer dimensional bank of energetic device operation. Such operation bank should have at is disposal an analytic notation of dimensional function described qualitatively, the form of which, is presented in table 2. Such table enables one to select work parameters of a device or to record them in the bank according to the code included in it.

Parameters that are measured and calculated by means of numerical functions should be comparable with the parameters used in respective theories. Interpretation principles presenting connections between the calculated parameters and the observed quantities during energetic device operation make such comparisons possible.

Numerical function φ that can be found there, are called similarity invariants. If similarity invariants define the points of dimensional space, then the quantities determined on their basis, suit working processes that place in energetic devices [4, 5, 6, 7].

Table 2. Notation of measured parameters during working process of energetic device and calculated operation functions in a computer dimensional bank of their operation

Information of experimentally examined realizations taking place in a propulsion combustion engine of the ship, described qualitatively in table 1.					
1	2	3	4	5	6
G p t M n	$f_1(\varphi_G, \varphi_t)$	$f_3(\varphi_M, \varphi_t)$	$f_4(\varphi_M, \varphi_n)$	$f_5(\varphi_n, \varphi_t)$	$f_6(\varphi_n, \varphi_G)$
N n t G	$f_8(\varphi_t)$	$f_9(\varphi_n)$			
Information about experimentally examined realizations of the working process taking place in a ship auxiliary boiler of VX type, described qualitatively in table 1.					
B p_K t_K m	$f_{10}(\varphi_B)$		$f_{11}(\varphi_m)$		

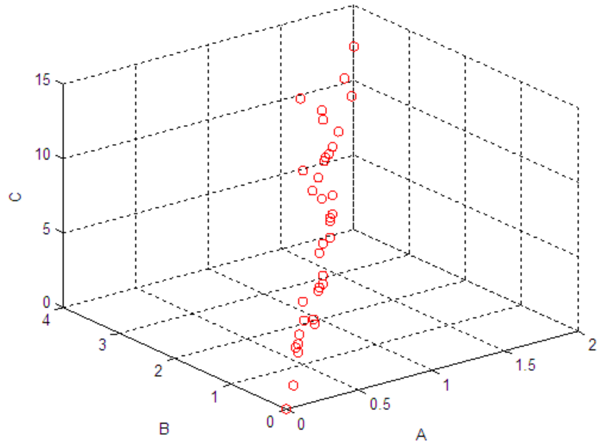
Table 3 presents exemplary numerical function adjustment of propulsion engine operation and its auxiliary boiler VX by the method of least square estimator at linear regression of its non dimensional arguments in the accepted dimensional bases.

Table 3. Function adjustment of energetic device operation by the way of least square estimator, at linear regression of its non dimensional arguments and accepted dimensional base

Dimensional function of ship propulsion engine operation $D_S = \Phi(M, n, G, p, t)$	
Dimensional base	Numerical form of operation function in a piston propulsion engine of the ship
$p, t, M \Rightarrow D_S = f_6(\phi_n, \phi_G) \cdot M \cdot t$	$D_S = 10^{-12}\, p \cdot G \cdot t^2 + 6{,}27 n \cdot t^2 \cdot M - 10^{-9} M \cdot t$
$M, n, p \Rightarrow D_S = f_1(\phi_G, \phi_t) \cdot \frac{M}{n}$	$D_S = -0{,}02 \frac{M}{n} + 6{,}3 M \cdot n \cdot t^2 - -0{,}03 M \cdot t + 1{,}5 \frac{G \cdot p}{n^2}$
Dimensional function of auxiliary boiler operation $D_K = \Phi(B, p_K, t_K, m)$	
Dimensional base	Numerical function from of auxiliary boiler operation VX type
$p, t, B \Rightarrow D_K = f_{11}(\phi_m) \cdot \frac{B^3}{p_K^2 \cdot t_K^2}$	$D_K = 0{,}02 \cdot \frac{B^3}{p_K^2 \cdot t_K^2} \cdot \exp\left(0{,}72 \cdot \frac{m}{B}\right)$

Diagrams of a variable dependent on dependent variables, being dimensional function arguments of propulsion engine and its auxiliary boiler operation, have been presented in Fig. 1. Non dimensional arguments of dimensional function operation of ship propulsion engine and its auxiliary boiler in the accepted bases have been calculated on the basis of measurements performed on the ship.

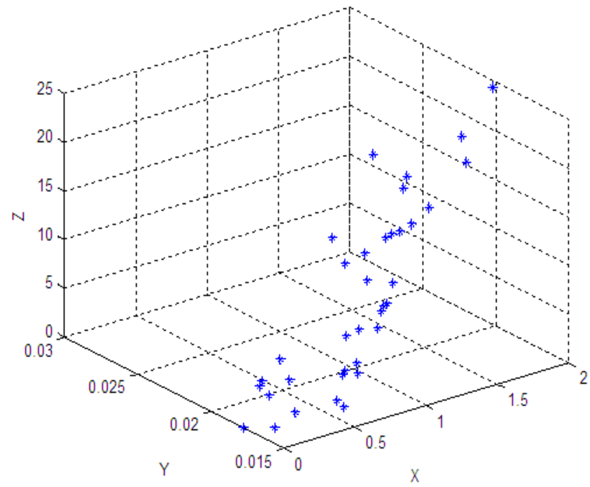
Dimensional base $B,\ t_K\ ,M$



$C = \dfrac{D}{M \cdot t} \cdot 10^6$ - *operation indicator of the engine,*

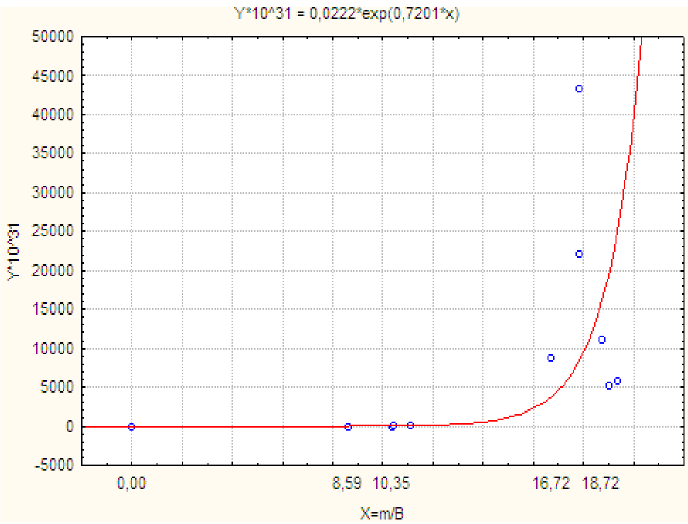
$A = n \cdot t \cdot 10^6$ - *similarity invariant of engine revolution Speed,* $B = \dfrac{p \cdot G \cdot t}{M}$ - *volumetric similarity invariant of fuel consumption by the engine*

Dimensional base $M\ ,\ n\ ,\ p_K$



$Z = \dfrac{D \cdot n}{M}$ - *indicator of engine operation,* $X = n \cdot t$ - *similarity invariant of engine revolution speed,* $Y = \dfrac{G \cdot p}{M \cdot n}$ - *volumetric similarity invariant of fuel consumption by the engine*

Dimensional base $p,\ t_K,\ B$



$Y = \dfrac{D \cdot t_K^2 \cdot p_K^2}{B^3} \cdot 10^{31}$ - *operation indicator of the boiler,* $X = \dfrac{m}{B}$ - *boiler load indicator*

Fig. 1. Non dimensional arguments of a dimensional function of operation, in the accepted bases obtained on the basis of measurements, carried out during steady work of the ship propulsion engine and its auxiliary boiler

Fig. 2 shows the block diagram which presents research planning towards functioning of energetic devices, taking advantage of computer dimensional bank of their operation.

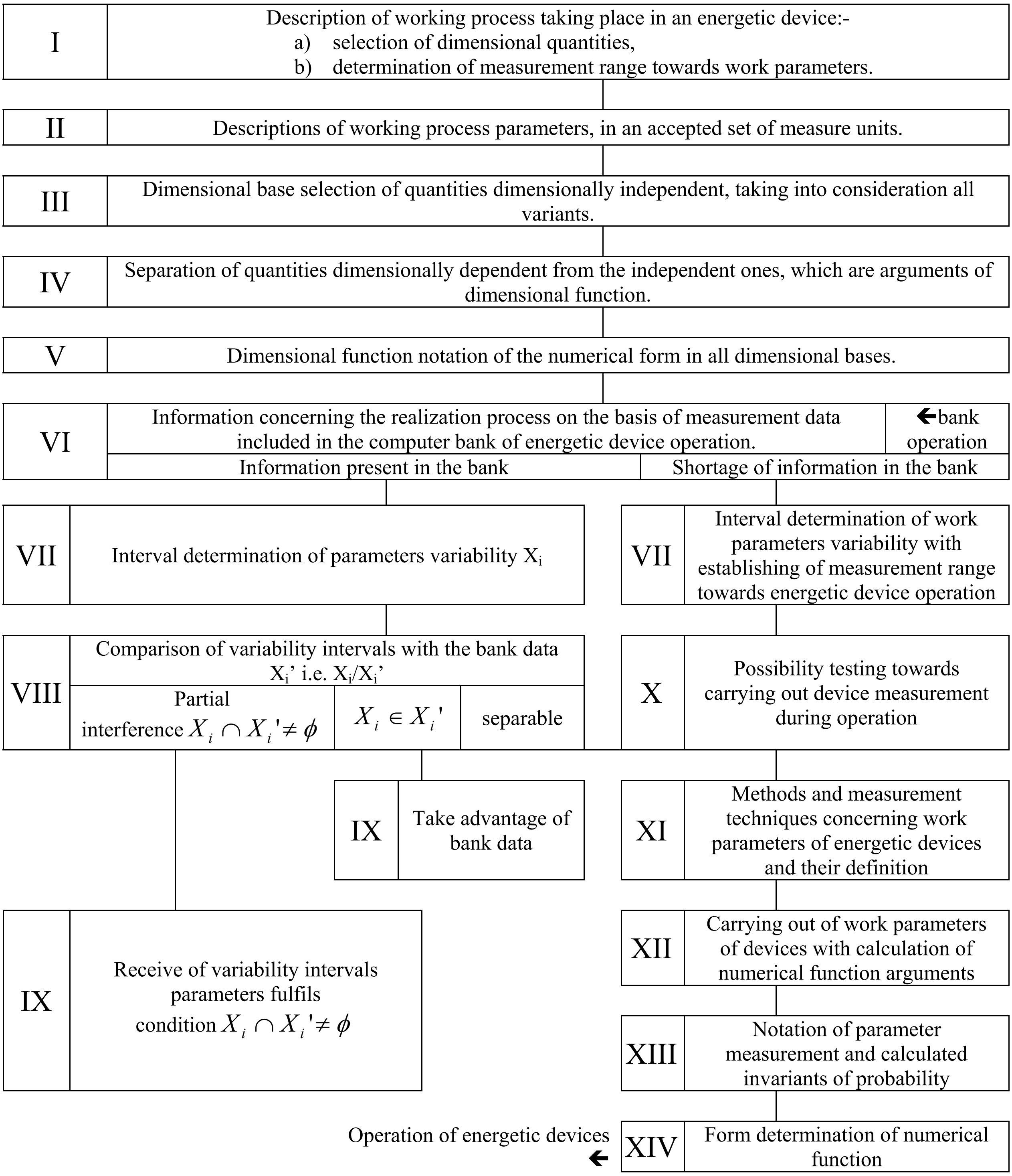
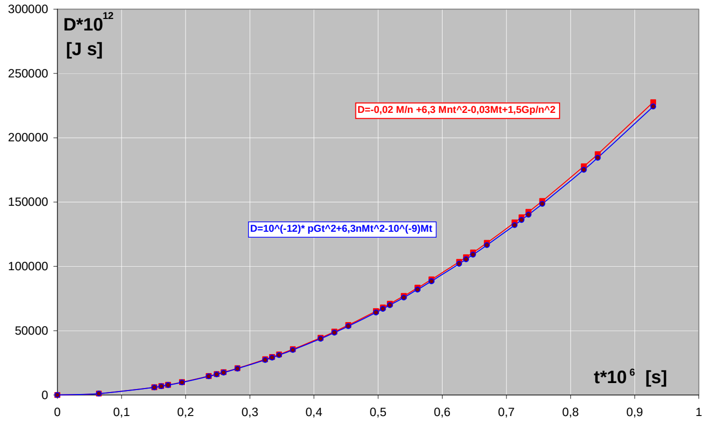


Fig.2 Block diagram presenting research planning of energetic devices functioning, making use of computer dimensional bank of their operation

Temporary operation functions of ship propulsion engine, during steady work and of auxiliary boiler VX as well, have been presented in Fig. 3

a)



b)

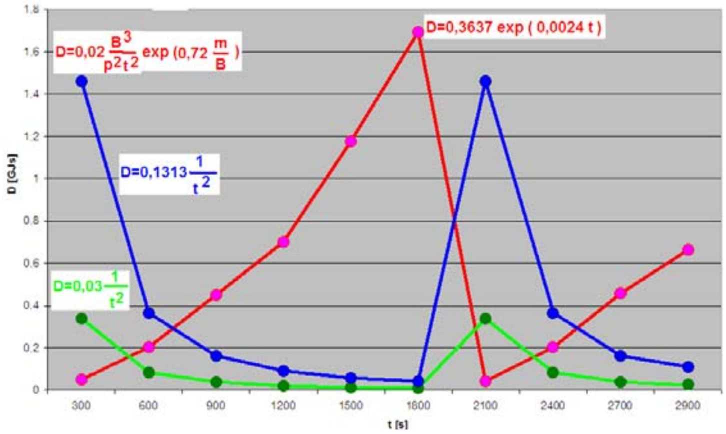


Fig. 3 Operation of propulsion combustion engine during steady work (Fig.a) and auxiliary boiler VX (Fig.b) in time function of their performance

4. Recapitulation

Systematizing of data elaborated in the function from of energetic device operation, enables us to set up an information bank. Such bank can inform about technical condition of energetic devices.

Besides, such bank can be used both for the needs of science and technical information and also for steering a device operation, making use of the accumulated information about their operation.

Computer informing bank of energetic device operation will be able to answer the following questions:-

1) Is the examination of some devices, on the basis of the working process realization, necessary?
2) Isn`t the identification measurement of technical conditions, concerning realization of the working process, similar to the one previously examined in the sense of probability?
3) Does a dimensional function of energetic device operation, have arguments determined on the basis of similarity invariants that have already been known before?
4) Have the operations of energetic device been described dimensionally so well, that their defining will not require the identification of working process?

5. References

[1]Drobot S., *On the foundation of dimensional analysis*, Dissertation Mathematic, vol. XI, 1954.
[2]Girtler J., *Energy-based aspect of machine diagnostic*, pp. 149-155, Diagnostica 1 (45)/2008.
[3]Girtler J., *Identification method of technical state of the objects on the Ground of estimation of their work*, pp. 126-132, Diagnostic 2 (46), 2008.
[4]Kasprzak W., Lysik B., *Dimensional analysis, algorithmic procedures of experiment service*, WNT Warszawa 1988.
[5]Roslanowski J., *Identification of ships propulsion engine operation by means of dimensional analysis,* Journal of polish CIMAC Energetic Aspects, Vol. 4 No. 1, pp. 137-144, Gdansk 2009.
[6]Roslanowski J., *Methodology of model building, concerning energetic processes, taking place in ship propulsion units, by means of dimensional analysis defining their dynamic features,* Scientific brochure no. 8 , pp. 41-64, WSM Gdynia 1982.
[7]Szucs E., *Mathematical modeling in physics and technique,* WNT Warszawa 1977.