Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

AUXILIARY BOILER OPERATION OF VX TYPE INSTALLED IN SHIP COMBUSTION ENGINE ROOM

Jan Roslanowski Ph.D.Ch. (Eng.)

Gdynia Maritime Academy
Faculty of Marine Engineering
81-87 Morska str.
81-225 Gdynia Poland
e-mail: rosa@am.gdynia.pl

Abstract

The following paper presents determination method of auxiliary boiler operation of VX type installed in ship combustion engine room basing on parameters of its work by means of dimensional analysis. Auxiliary boiler operation, as energetic device has been treated, according to J. Girtler, as new physical quality of dimension Joul multiplied by second [Js]. It expresses transformation of chemical energy bring about with fuel to a boilers burner on the outside, in the form of heat through steam enthalpy. Quantity of this kind can be determined on algebraic basis diagram of dimensional analysis constructed by S. Drobot. This diagram allows us to control principles correctness of conclusion in respect of mathematics, used in numerical functions of auxiliary boiler operation, installed in combustion engine department of ship propulsion engine.

Key words: *auxiliary boiler operation installed in ship combustion engine, algebraic diagram of dimensional analysis, physical quantity of Joule second dimension*

1. Introduction

Steam boiler being an energetic device according to boiler regulations is a closed vessel. This vessel is supplied with energy in the from of heat causing the water in the vessel turn into a wet steam with compression higher than atmospheric, used on the outside. Boilers generating such steam in ship combustion engine room are called auxiliary ones and are liquid fuel fired. It means that boiler operation is determined by energy transmission in the enthalpy from on the outside through wet steam.

The basic parameter of such operation is a momentary steam efficiency generated by the boiler witch steady, in advance determined definite pressure. Momentary steam efficiency which determines boiler loading must be equal to steam demand by devices cooperating with it. It causes necessity of cyclic supply of the boiler with adequately definite amount of fuel, air and water according to its load. It forces keeping on steady level such parameters of boiler performance as:

- steam pressure,
- level of water in the boiler,
- excess of air.

In such situation boiler performance is of oscillating character. Parameters describing boiler performance are changeable in time and with permanent demand of steam by the ship and stabilized temperature of supply water, change in identically similar oscillations.

Auxiliary boiler performance as transformation of chemical energy into thermal one, transmitted to the outside through steam enthalpy, during its operation, can be estimated by a physical quantity of dimension Joul multiplied by second [2,3].

2. Dimensional function forms of auxiliary steam boiler performance

Boiler operation is determined by changes of its work parameters during typical, full oscillation. Oscillatory performance of auxiliary boiler, type VX, presented in Fig.1, in dimensional space can be specified by means of the following dimensional function:

$$D = \Phi(B, p, t, m) \qquad (1)$$

where:
D – operation of auxiliary boiler in [J·s] ,
Φ – symbol of dimensional function,
B – consumption of combustible oil by the boiler in [kg/s],
p – steam pressure generated by the boiler in [kg/ms^2],
t – time of boiler operation in [s],
m – boiler efficiency in [kg/s].

Auxiliary boiler operation is a quantity determined by formula (1) belonging to the elements of dimensional space. Characteristics of such spaces allow to describe boiler operation by means of positive real numbers [1]. Dimensional function (1) belongs to three-dimensional space which

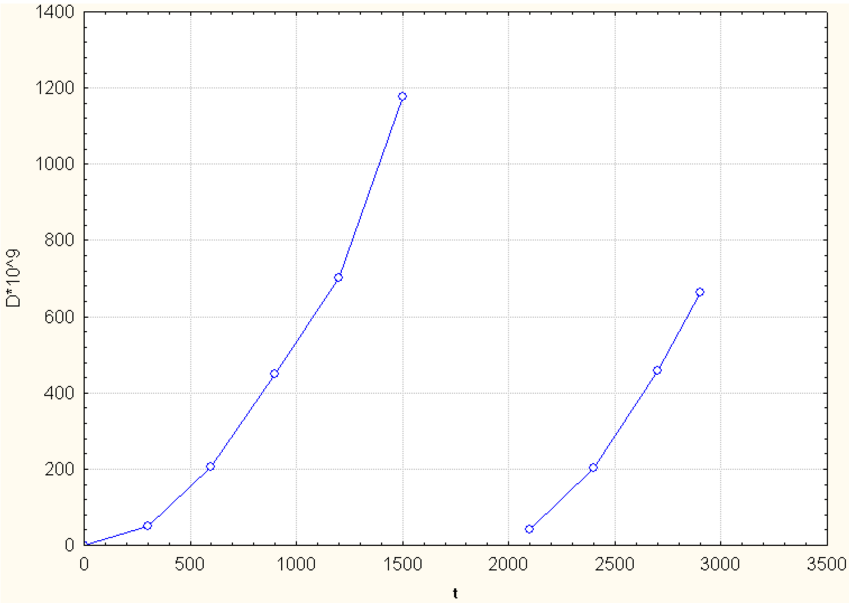

Fig.1. Auxiliary boiler operation of VX type in ship combustion engine room; Explanations: D –boiler operation in [Js], t – time of boiler operation in [s]

allows to choose in two ways, three quantities dimensionally independent of the remaining ones. They fulfil the condition of homogeneity and invariance as well. Such quantities are called space dimensional base [1, 5, 6, 7].

Such bases together with corresponding to them numerical functions have been presented in table 1. Dimensional base created by quantities dimensionally independent like steam pressure from the boile, operation time and efficiency, have been rejected: pressure of outlet steam from the boiler ***p***, time of its operation ***t*** and efficiency of auxiliary boiler ***m***. The base has been rejected because the exponential function did not fulfil assumed assumption. The assumption was to assume that at zero time of boiler operation, its performance is also equal to zero.

Numerical function forms of ship auxiliary boiler with propulsion by combustion engine piston can be determined on the basis of measurements carried out during its work [8].

Table 1. Dimensional bases and corresponding with them functions of auxiliary boiler operation in non dimensional form

ordinal number	Dimensional base	Dimensional function of boiler operation VX in non dimensional form
1	*p; t; m*	$D = f(\phi_B) \cdot \frac{m^3}{p^2 \cdot t^2}, \cdots \phi_B = \frac{B}{m}$
2	*p; t; B*	$D = f(\phi_m) \cdot \frac{B^3}{p^2 \cdot t^2}, \cdots \phi_m = \frac{m}{B}$

Fig. 2 presents notation during parameters of auxiliary boiler operation VX reflecting its dynamics taken from the paper [4].

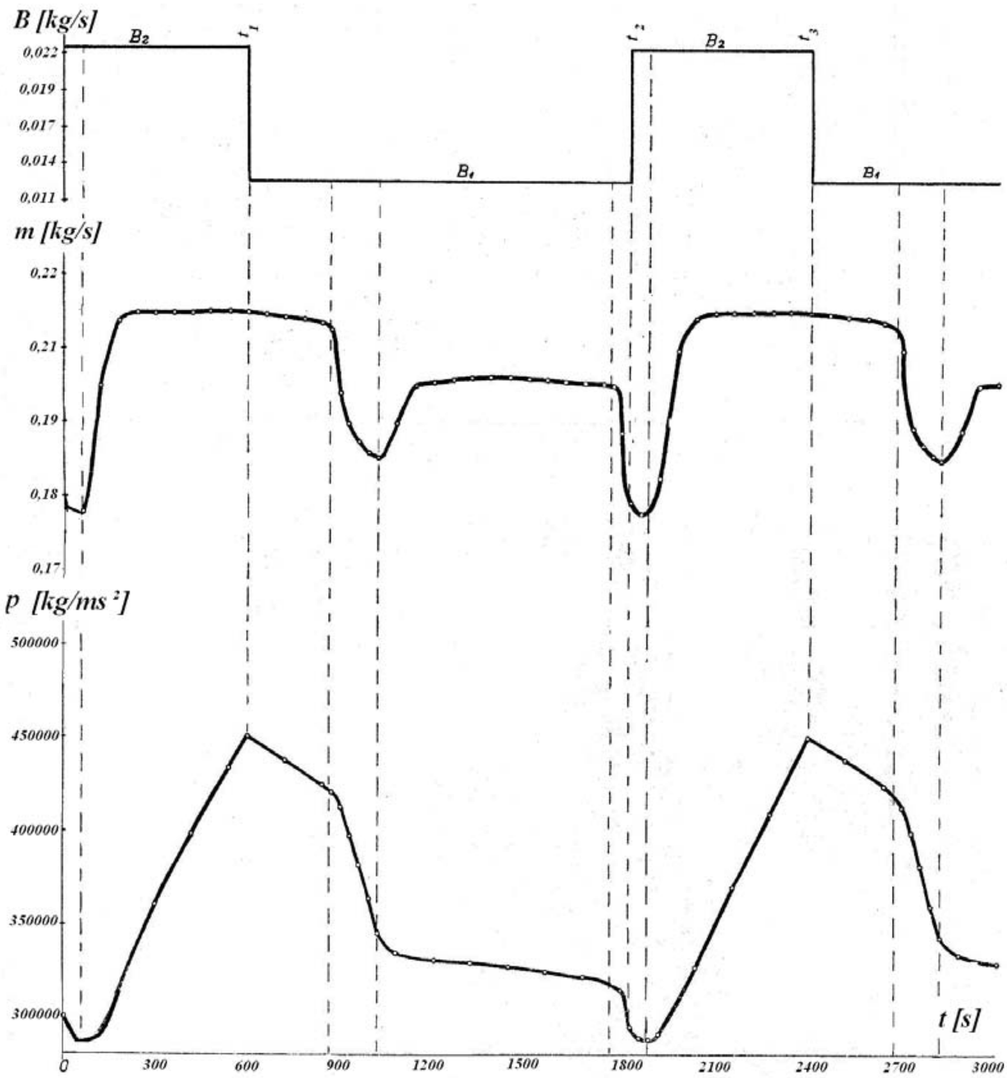

Fig. 2. Notation during boiler operation parameters VX reflecting its dynamics [4]; Explanations: t – time of boiler operation in [s]; B-fuel consumptions; B_1 – work of first nozzle; B_2 – work of two nozzles; m- boiler efficiency; p – overpressure of steam in the boiler

3. Way of determination and measurements of dimensional function arguments of auxiliary boiler VX operation

To measure dimensional function arguments of auxiliary boiler operation, specially for this purpose, standard control – measurement apparatus was used. Measurements were carried out during heating process of propulsion combustion engine before the voyage of the ship. Under these conditions steam demand in combustion engine room is constant and heavy. This ensures stability of dimensional parameters modification in oscillatory operation of the boiler [8].

Fuel consumption by the boiler depends on working time of each nozzle. Boiler operation with heavy demand of steam takes place during continuous work of one nozzle and the other periodically.

Working time measurement of nozzle burner was carried out by means of spring stopper (in the range of 0-30 minutes, exact to 0,2 [s]) basing on light signal observation of oil burner.

Fuel consumption by the boiler during work of one and two nozzles was determined with the help of measuring tank of 0,0071 [m^3] volume and linear dependence of heating oil density on temperature such dependence was determined basing on the knowledge of heating oil density in two different temperatures specified on the bunkering receipt.

Measurement of heating oil temperature was carried out with the help of mercurial thermometer exact to 1 [^{0}C], placed on the oil burner heater.

Efficiency measurement of the boiler i.e. steam demand produced by the boiler in time unit, can be treated as density measurement of steam flow in the outlet pipe from the boiler. Measurement of this density was carried out with the help of steam bellows meter in the range from (0-800) [kg/h] and exactitude class 1,5% in the indication range (30-100)%. The meter measured the difference of steam pressure in front of and behind the measuring reducer built in the outlet pipe from the boiler. Basing on manometer readings of steam overpressure in the boiler and barometric pressure of generated steam could be calculated.

Despite the fact that the auxiliary boiler of VX type, possessed steam separator, the degree of its steam dryness was slighter than unity and changed depending on pressure and boiler efficiency. Steam dryness degree of outlet steam from the boiler was defined by choking it is enthalpy way in the calorimeter nozzle.

Temperature of steam overheated in the calorimeter was measured by hydrostatic tube gauge. On the basis of absolute knowledge of pressure and steam temperature behind calorimeter nozzle, it is possible to read in steam diagram enthalpy-entropy, the coefficient value of steam X dryness. Calculated on the basis of the above measurements, pressure value and a degree of steam dryness allow to determine specific enthalpy of steam, produced by the boiler.

Auxiliary boiler VX is periodically supplied with water and fired in an abrupt change way. In this situation the boiler performance is periodically variable in time. We calculate it as intensity product of steam flow with defined specific enthalpy and time square of boiler performance [8].

The above mentioned parameters of boiler performance necessary to determine arguments of its performance were carried out simultaneously every 300 [s] from turning on the second nozzle of the oil burner until it was turned on again. This period of time allowed us to measure work parameters during complete period of boiler performance (Fig. 2).

Results of parameter measurements concerning boiler performance and the following calculations are presented in table 2. Taking advantage of measurements and calculations from table 2 and also from dimensional function base of boiler operation, presented in table 1, we can achieve its non dimensional function of auxiliary boiler operation in ship combustion engine room are presented in Fig. 3

Non dimensional arguments presented in Fig. 3 express numerical indicators of boiler operation in particular conditions of its work. It means that non dimensional indicator of operation is a numerical function of auxiliary boiler load indicator VX (Fig. 3).

Table 2. Results of work parameters measurement concerning ship auxiliary boiler VX, being arguments of dimensional function of its operation

Ord. numb.	Time of operation **$t\ 10^3$**	Fuel consumption by the boiler **B**	Boiler efficiency **m**	Overpressure of outlet steam from the boiler **$p\ 10^5$**	Specific enthalpy of outlet steam from the boiler **h**	Boiler Operation **$D\ 10^9$** **($D = m\ h\ t^2$)**
-	**[s]**	**[kg/s]**	**[kg/s]**	**[Pa]**	**[J/kg]**	**[J s]**
1	0,3	0,0206	0,2133	3,54	2624	50,37
2	0,6	0,0206	0,2153	4,46	2637	204,39
3	0,9	0,0111	0,2108	4,46	2637	450,26
4	1,2	0,0111	0,1856	3,46	2624	701,30
5	1,5	0,0111	0,1978	3,38	2642	1175,82
6	1,8	0,0111	0,1976	3,29	2642	1691,47
second period of boiler operation						
7	2,1 (0,3)	0,0194	0,1667	3,00	2681	40,22

8	2,4 (0,6)	0,0194	0,2153	4,00	2631	203,92
9	2,7 (0,9)	0,0111	0,2150	4,63	2637	459,23
10	2,9 (1,1)	0,0111	0,2078	4,34	2634	662,29

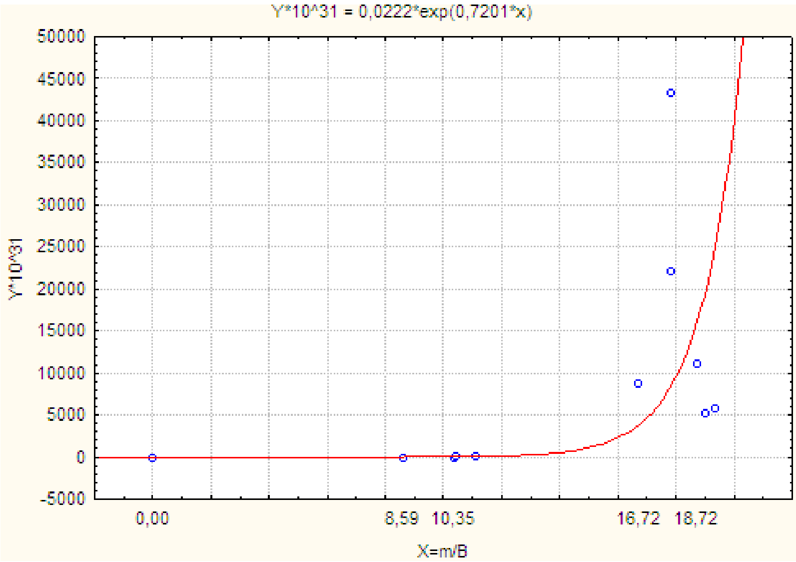

Fig. 3. Non dimensional indicator of auxiliary boiler operation **Y** *in the function of its load* **X** *determined on the basis of work parameters, Explanations:* $Y = \frac{D \cdot t^2 \cdot p^2}{B^3} \cdot 10^{31}$ *- indicator of boiler operation;* $X = \frac{m}{B}$ *- indicator boiler load; D – boiler operation in [s]; p – overpressure of outlet steam from the boiler in [Pa]; B – fuel consumption by the boiler in [kg/s]; m – boiler efficiency in [kg/s]; t – time of boiler operation in [s]*

Such numerical function in domain of real numbers can be determined with the help of least squares estimator by linearizing nonlinear regression. Such regression of defined from of numerical function allows to define its constant coefficients.

Fig. 3 presents measuring coordinates of boiler work parameters during one period of work expressed by means of non dimensional function arguments of its operation. With the help of least square estimator linearizing nonlinear regression, exponential function was fitted to coordinates, obtaining the equation of the fallowing form:

$$\frac{D \cdot p^2 \cdot t^2}{B^3} = 0{,}02 \cdot \exp\left(0{,}72 \cdot \frac{m}{B}\right), \tag{2}$$

where:

- symbols as in formula (1).

Fitting non dimensional arguments (Fig.3) to the form of exponential function i.e. defining its constant coefficients was carried out with the help of STATISTICA programme.

Such dependence fitting (2) among non dimensional arguments of boiler operation is justified by the determination coefficients of correlation relation and correlation itself amounting to 0,59.

However (Fisher) **F** statistic by the assumed level of substance α =0,05 and degrees number of freedom f_1 =1 and f_2 = 8 indicates that correlation ratio η = 0,93 among numerical function arguments of boiler operation is essential ($F = 13{,}48 > F_{kr} = 5{,}32$). It indicates that dependence of non dimensional arguments dependent Y in relation to independent X is defined by curvilinear function of auxiliary boiler operation VX.

Fig. 4 presents auxiliary boiler operation VX at different parameters of its work in defined time moments of one period. Exponential function is also marked in Fig. 4 which describes such

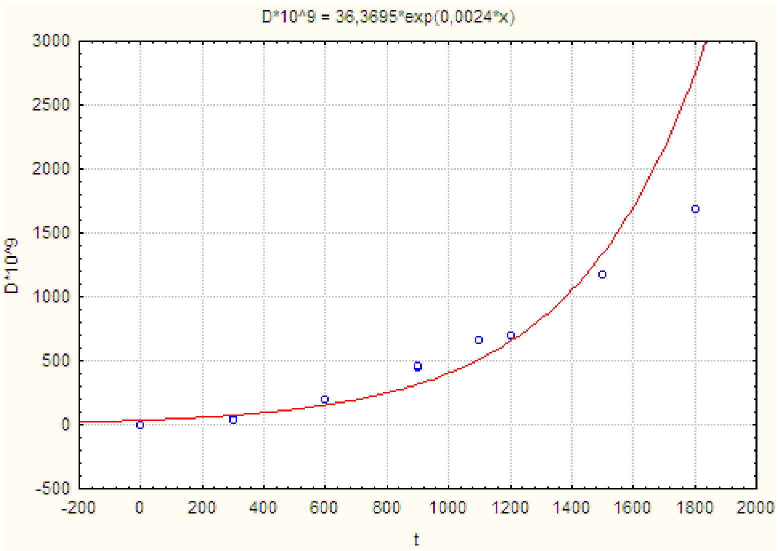

Fig. 4. Operation of auxiliary boiler VX during one period in time function at different parameters of work, Explanations: D – operation of auxiliary boiler VX in [GJs]; t – time of operation in [s]

operation loading of the boiler. This function has the following numerical form:

$$D = 36{,}37 \cdot \exp(0{,}0024 \cdot t) \quad (3)$$

where:
D – Auxiliary boiler during one period VX at different loading in [GJs],
t – auxiliary boiler operation time in [s].

Curvilinear degree of auxiliary boiler operation VX in relation to its time of work, was estimated on the basis of absolute value difference of determination coefficients in aspect of correlation ratio and correlation itself which amounts to:

$$M_{d|t} = |\,\eta^2 - r^2\,| = |\,0{,}9567^2 – 0{,}958^2\,| = 0{,}0025 \quad (4)$$

where:
η – value of correlation ratio,
r – coefficient of linear correlation.

The difference defined by formula (4) gives evidence of linear correlation between boiler operation and the time of its work. However the value of correlation ratio close to unity ($\eta = 0{,}9567$) indicates strong correlation dependence of auxiliary boiler operation on the time of its work. Correlation dependence is of linear character as correlation coefficient is also close to unity ($r = 0{,}958$).

Presented numerical function form (3) of boiler operation, obtained with the help of least square estimator is of simple form and easy physical interpretation. Therefore it is recommended to carry out analysis of auxiliary boiler operation VX during its work.

Fig. 5 presents auxiliary boiler operation of VX type, at two different constant loads and a changeable one as well.

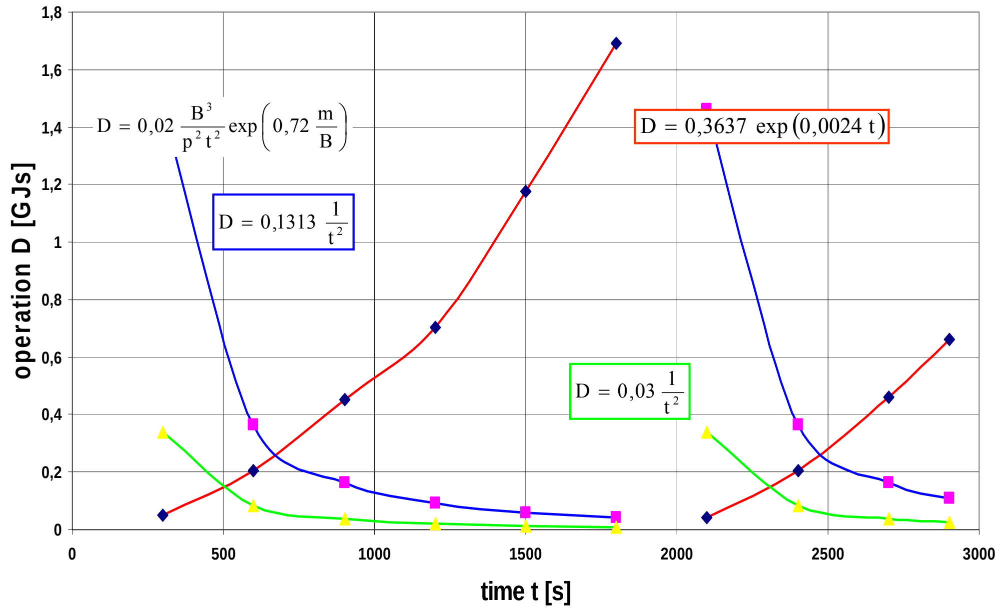

Fig.5. Auxiliary boiler operation of VX type at two different loads and changeable one as well, Explanations: -----boiler operation changeable load conditions; ------ boiler operation during constant work parameters with fuel consumption B = 0,0206 [kg/s], efficiency m = 0,2153 [kg/s]and waste steam overpressure from the boiler p = 4,46 [Pa];-------- boiler operation during constant work parameters: fuel consumption B = 0,0111 [kg/s], efficiency m = 0,1978 [kg/s] and waste steam from the boiler p = 3,38 [Pa]

4. Summary

Dimensional function of auxiliary boiler VX (1) operation has different numerical structures presented in table 1 obtained by means of algebraic diagram of dimensional analysis presented by S. Drobot. These structures allow us to define numerical dependence by means of least squares estimator, linearizing nonlinear regression among dimensional quantities describing boiler operation. Obtained on their basis numerical estimates of boiler operation are defined exact to constant non dimensional coefficients, determined on the basis of its work parameters.

Formula (3) defining auxiliary boiler operation VX in one period of work, can be treated as a correct proposal in dimensional respect.

Dimensional quantities were used while determining numerical function forms. Those quantities characterize boiler operation and are isomorphism with vectors according to S. Drobot and his work in which he proves the above mentioned fact [1]. Treating dimensional quantities as scalars is equally wrong as replacing vectors with scalars.

Numerical function of auxiliary boiler operation is characterized by the fact that it takes into account essential work parameters depending on one period of time. It is dynamic character and in connection with this, can be used for diagnostic and prognostic purpose.

It allows to examine the influence of its particular work parameters on auxiliary boiler operation VX during one period as it presents in a clear way its numerical structure.

On the other hand calculated value dependence of boiler operation VX on the basis of work parameter measurement in time function of one period by method of least squares estimator, does not possess this property. In this case boiler work parameters are hidden in constant numerical coefficients defining its operation during one period of time, being then only time function.

Numerical function from of boiler operation VX can be defined on the basis of calculations carried out by means of measured work parameters during one period.

Operation function of auxiliary boiler VX is correct only for the boiler on which the measurement was carried out.

Possibility of dimensional analysis application depends on measuring of all quantities characterizing auxiliary boiler operation VX in an accepted set of units.

Application of this set of units in problems connected with defining of auxiliary boiler operation VX is indispensable for a complete description of its work with the help of dimensional function.

Dimensional analysis requires also work parameters measurement of auxiliary boiler VX in time of one period in order to obtain exact numerical function of its operation on the basis of an accepted dimensional function.

5. References

[1] Drobot, S., *On the foundation of dimensional analysis*. Dissertation Mathematic, vol. XIV, 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 Grodnu of estimation of their work*, pp. 126-132, Diagnostic 2 (46), 2008.

[4] Mazurkiewicz, J., *Examination of ship auxiliary boiler type VX*, Research Works of Marine Power Plant Institute Merchant Marine College in Gdynia, Gdynia 1976.

[5] Roslanowski, J., *Modelling of ship movement by means of dimensional function*, Radom University of Technology, pp.443-448, Transport No 3(23) 2005.

[6] Roslanowski, J., *The methodology of energetically process model construction in ship propulsion systems by means of dimensional analysis defining their dynamical features.* International Conference Technical, economic and environmental aspects of combined cycle power plants, pp. 59-66, Gdansk University of Technology 2004.

[7] 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.

[8] Roslanowski, J., *Diagnosis possibilities of technical condition of propulsion engine during ships voyage on the basis of engine operation value*, Research work no. 07/09/PB Faculty of Ocean Engineering and Ship Technology, Gdansk University of Technology.