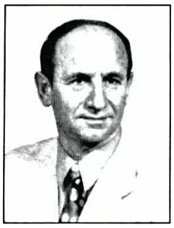

JERZY GIRTLER, Prof.,D.Sc.M.E.
Department of Ship Power Plants
Gdańsk University of Technology

Deterministic and probabilistic interpretation of operation of technical systems with regard to their reliability

SUMMARY

In the paper proposed is a valuing interpretation of the action (operation) considered as a physical quantity measured with the [joule x second] unit, similarly to some actions described in classical and quantum mechanics. Such understood operation is presented in the technical formulation.

An original method for analysis and assessment of operation of an arbitrary technical system with accounting for its reliability, is proposed. Special attention is given to the interpretation of the operation of diesel engines. The uniform Poisson's process was applied to justify usefulness of the so interpreted operation.

INTRODUCTION

The action (operation) is a notion which may be understood differently and defined differently. It is considered in classical mechanics [8 , 26] and quantum mechanics [1, 10, 17], in praxeology [4, 14, 15, 19, 27], engineering sciences [11, 12, 13, 16, 18, 21÷25] etc. In the praxeological formulation the action (operation) can be understood as *a purposeful, conscious and arbitrary human behaviour* [14 , 27]. However if it has to be reasonable (effective) it should be understood as *a purposeful, conscious and organized behaviour consisted of pragmatically realized actions, hence that in which a logical ensuing connection between following and preceding actions exists*. Such definition of the notion of action (operation) results from taking into account that in praxeology the following actions have been distinguished [14, 15, 19, 27] :

- action (of a conscious being, man)
- behaviour (of a living organism other than man)
- functioning or operation (of a system, technical object, device).

Such action (operation) always causes the energy E to be consumed, and it demands some time t in accordance with the following rule : *the less effective an action the greater consumption of the energy or time, or the energy and time.*

However in science and practice, the notion of action (operation) is not attributed solely to people. In engineering sciences *the operation of devices* is considered [8, 16, 18, 21, 22, 23, 24]. It is characteristic that the so understood operation is associated with transforming or transferring the energy. The first results from operation of the engines (i.e. the devices in which energy is transformed), and the next – from operation of other devices, e.g. coolers and heaters. Hence when considering the technical systems as well as antropotechnical and sociotechnical ones it is necessary to take into account the operation in the technical formulation, i.e. that understood as the functioning of devices.

OPERATION IN TECHNICAL FORMULATION

In order to initiate and realize any operation in result of which a goal can be reached within a given time, an appropriate amount of energy which may have different forms, is necessary. To reach a goal can be hence impossible due to,a.o, some defficiency of energy and lack of time (Fig.1).

Therefore the operation in valuing formulation, OP, can be equated to a physical quantity interpreted as the product of the energy E consumed by the system during the time of its operation, t, which is measured in *[joule x second]* units. In the deterministic approach when the energy consumed by a system (e.g. a combustion engine), E, maintains constant within the time interval [0 , t], the quantity can be expressed as follows :

$$OP = E \cdot t \qquad (1)$$

and if this energy changes with time, i.e. when E = f(t) within the time interval [0 , t] then (Fig.1) :

$$OP = \int_0^t E(\tau)\, d\tau \qquad (2)$$

In practice, the efficient operation of the heat engines, the most important in engineering, especially the diesel ones is especially important. They are most commonly used not only in shipbuilding [2, 7, 11, 12, 18, 23, 24]. Reliability and durability of their main tribological units depends on the operational correctness of such engines. The operation of the systems in question consists in transforming as well as transferring the delivered energy. In the case of the combustion engines, it is possible to consider developing the torque T_M at the rotational speed n of the engine. As a result of transferring the torque from the engine to a consumer (e.g. propeller, generator, compressor or pump) the work W_α is done which can be determined (on the assumption : $T_M = idem$) by means of the relationship :

$$W_\alpha = T_M\alpha = T_M\omega t \quad (3)$$

where :

W_α – total work done over the angular travel α
T_M – engine torque
α – rotation angle of a work performing element
t – time
ω – engine angular speed

Hence the operation of the combustion engines considered within the time interval [0 , t], when T_M and ω are time functions, can be determined as follows :

$$OP = \int_0^t T_M \cdot \omega \cdot \tau \, d\tau \quad (4)$$

If both the torque T_M and the speed ω are not changeable with time the engine's operation expressed by the formula (4) can be simplified and described in the form :

$$OP = T_M\omega t^2 \quad (5)$$

And, in the case of such devices as the heat exchangers (e.g. coolers or heaters) the internal energy of media flowing through them may become increased or decreased, repectively. In both the cases the heat, considered as being in the steady state, released by the cooled medium or that absorbed by the cooling medium, can be expressed by means of the relationship :

$$Q = mc_s\Big|_{T_1}^{T_2}(T_2 - T_1) \quad (6)$$

where :

Q – heat
m – mass of energy medium flowing through a heat exchanger
c_s – average specific heat capacity of cooling medium within the temperature range from T_1 - at inlet to T_2 - at outlet, of a heat exchanger.

The heat exchanger's operation can be determined by the relationships similar to those given above, namely, if within the time interval [0,t] :

$$Q = idem \quad \text{then} \quad OP_Q = Q \cdot t \quad (7)$$

whereas if :

$$Q = f(t)$$

then

$$OP_Q = \int_0^t Q(\tau)\, d\tau = \int_0^t m(\tau) c_s\Big|_{T_1}^{T_2}(T_2 - T_1)\, d\tau \quad (8)$$

The so interpreted operation can be represented in the *E-t* coordinate system as a diagram which can be called *the operation diagram* (Fig.1).

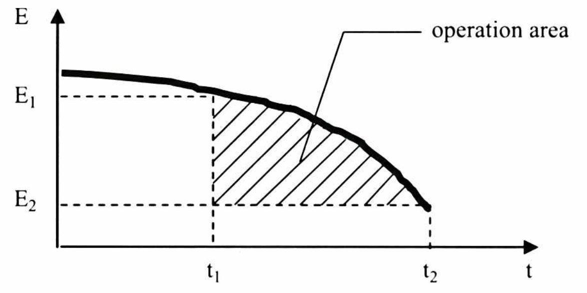

Fig.1. *An example of device's operation diagram : E – energy, t – time*

In given operational conditions of an arbitrary technical system the energy *E* makes it possible, in the case of the combustion engines, to perform a definite work, and in the case of the heat exchangers to transfer a relevant heat. Hence, the operation area represents – in the case of the engines – a work area or heat area, and – in the case of the heat exchangers – a heat area. The work area can be represented in the Clapeyron's system, and the heat area – in the Belpair's system [18, 20, 23, 24].

In order to determine the operation area it is necessary to know the energy-time function : $E = f(t)$. As $OP = f(E, t)$ hence the operation of devices can be represented in the reference system (OP, E, t).

The operation of any technical system can be understood twofold : as the demanded one, OP_d, i.e. that necessary the task for realization of which a given device has been prepared in its design and production phase, could be performed,. or as the possible one, OP_p, i.e. that which can be realized by a given device in a demanded time period, being in a definite technical state and functioning in steady operational conditions. Therfore it can be assumed that every device is able to realize its task, i.e. it is fit to be used to realize the task, if :

$$OP_p > OP_d \quad (9)$$

In the case if :

$$OP_p < OP_d \quad (10)$$

then such system is unfit for realizing the task (hence it cannot realize this task). In the case if a system is able to operate in such a way that the condition (9) is satisfied, then it can be considered as being in the state of full serviceability. And, in the case when a system operates in such a way that the inequality (10) is not true, then it can be considered as being in the state of unserviceability. When not all its task have to be realized within a given time period, but only those for which the condition (10) is to be fulfilled, then it can be considered that the system is in the states of partial serviceability.

Therfore one can conclude about the serviceability of particular systems for realization of definite tasks only after comparing the operation areas : the demanded one OP_d and the possible one OP_p. The consideration of the operation with taking into account both its kinds is equivalent to the investigation of changes of the demanded energy E_d which is necessary, within a given time t_d, for realization of a given task, and the possible energy E_p which can be delivered, within the possible time t_p, by the system used for realization of the task. Hence the task can be realized in accordance with the relationship (9) in the following cases :

- $t_p = t_d$, when in the same time : $E_p > E_d$
- $t_p > t_d$, when in the same time : $E_p = E_d$
- $t_p > t_d$, when in the same time : $E_p > E_d$

The above given considerations can be also related to a human behaviour; then the known praxeometrical measures of universal efficiency can be simultaneously applied [4].

In the case of the systems, one can determine (with a definite probability) the maximum operation $OP_{p\,max}$ which a new system (i.e. that in the full serviceability state) is able to ensure during realization of the operational task OT. As any failed system cannot operate, the following inequality can be written :

$$0 \le OP_p \le OP_{p\,max} \tag{11}$$

Therefore the efficiency of system's operation can be determined as follows :

$$\eta_{OP} = \frac{OP_p}{OP_{p\,max}} \tag{12}$$

Apart from the operational efficiency defined by the formula (12), the energy efficiencies of operation, defined by the formula (13), can be considered [12, 18, 24] :

$$(\eta_{OP})_e = \frac{W_u}{F_t C_f t_d} \tag{13}$$

where :

- $(\eta_{OP})_e$ – energy efficiency of operation
- W_u – useful work
- F_t – fuel oil consumption per time unit
- C_F – net calorific value of the fuel oil
- t_d – demanded time to perform the work W_u

It is easy to show, with an arbitrary heat engine as an example, a usefulness of the so interpreted operation (of e.g. diesel engine) by considering such engine as an energy converter (Fig.2).

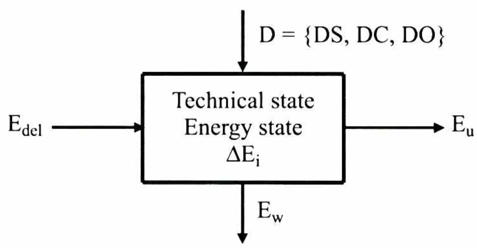

Fig.2. Schematic diagram of a device considered as an energy converter ; D – disturbances, DS – distrurbances of supply, DC – disturbances of control, DO – other disturbances, E_{del} – delivered energy, E_w – waste energy, ΔE_i – internal energy increment, E_u – useful energy.

The transformation of energy in the mentioned engine will be performed with a lower and lower efficiency due to growing wear of its elements, which makes E_w increasing. Therefore at $E_{del} = idem$ the energy E_u (Fig.2) will decrease with time. In order to maintain $E_u = idem$, E_{del} should be, if possible, increasing with time. In the case of a combustion engine it is equivalent to some increase of fuel consumption to obtain the same torque T_M.

In order not to allow for such fuel consumption in result of which the tasks could not be performed it is necessary to decrease E_w, which demands some technical maintenance to be done to restore such system.

For the diesel engines the torque T_M is the basic quantity which unambiguously determines their loading. The torque tightly depends on the mean fuel oil charge F injected to engine cylinders, and thereby on the mean useful pressure p_u. The relationship among the torque, the fuel charge and the useful pressure can be expressed as follows [12, 18, 23, 24] :

$$T_M = C_1 \cdot F = C_2 \cdot p_u \tag{14}$$

where :

$$F = \frac{F_t}{n} k$$

and :

- F – fuel oil consumtion per engine's cycle
- F_t – fuel oil consumption per time unit
- n – engine rotational speed
- k – coefficient of number of strokes per engine's cycle
- C_1, C_2 – quantities constant for a given engine.

The torque T_M and the rotational speed n can be measured. They unambiguously determine the engine's effective power P_u which can be calculated by means of the following formula [18 , 23] :

$$P_u = \omega \cdot T_M \tag{15}$$

where :
$\omega = 2\pi n$ - angular speed of engin's crankshaft.

The engine's useful power P_u and rotational speed n are changeable in course of its operation. The issue may be presented with the main engine propelling the ship which realizes its transport task, as an example. Such operational task can be formally interpreted as follows :

$$TT = \langle OP, C, t \rangle \tag{16}$$

where :

- TT – transport task to be realized
- OP – such engine's operation as the task TT could be realized
- C – conditions under which the task TT has to be realized
- t – time to realize the task TT.

During realization of a transport task by a ship its engine is required to operate for a long time in accordance not only with the external service power characteristics or – with the nominal rating, but also with some intermediate characteristics. Moreover, when a transport task is realized under difficult external conditions, the main engine can be often loaded in accordance with the external maximum power characteristics, not any longer – if possible – than it is permitted.

Sometimes, especially when an engine is weared to a large extent, the following situations may appear :

- the engine cannot operate according to the external maximum power characteristics at all, and in accordance with the nominal rating characteristics it can be loaded for a definite time interval only, not possible to be established in advance, before the transport task is commenced
- the engine can be loaded within the whole range to which it was initially prepared, but a situation arose during realization of the task, does not permit to run the engine under the load which could prevent the ship from causing an accident in usual conditions.

Therefore it can be concluded that there is a need to consider the engine's operation in such formulation as to be able to analyze engine's usefulness for realization of a given transport task from the point of view of possible definite loading the engine for a demanded time. Such complex analysis can be performed by considering the new physical quantity which represents the entire useful work W_u expressed in the form of the product of the torque T_M developed on the angular travel α and time t, called *the engine operation.*

The mechanical energy produced by the engine under strictly determined conditions, can be deemed a measure of its capacity to perform the work W_u. The work can be determined with the use of the formula (3) which, in this case, can be presented as follows :

$$W_u = T_M \cdot \alpha = T_M \cdot \omega \cdot t \tag{17}$$

under conditions : $T_M = idem$, $\omega = idem$.

From (17) and the presented considerations it results that the engine operation considered within the time interval $[t_0, t_n]$, may be described as follows :

$$OP_M = \int_{t_0}^{t_n} T_M \cdot \omega \cdot \tau \, d\tau \tag{18}$$

If (14) is taken into account, the operation OP_M can be also expressed by the relationships :

$$OP_M = \int_{t_0}^{t_n} C_1 \cdot F \cdot \omega \cdot \tau \, d\tau \tag{19}$$

or

$$OP_M = \int_{t_0}^{t_n} C_2 \cdot p_u \cdot \omega \cdot \tau \, d\tau \tag{20}$$

In order to make use of the formula (19) values of F_t and n should be measured. It is easy to measure values of n, but sometimes exact measuring F_t values may be difficult. Similarly, making use of the formula (20) may be inconvenient; because in practice it is necessary at first to indicate the engine and next to calculate the pressure p_u with the use of the following formulas [21, 18, 23, 24] :

$$p_u = p_i - p_f$$

or (21)

$$p_u = \eta_m \cdot p_i$$

where :

p_i – mean indicated pressure
p_f – mean friction pressure
η_m – mechanical efficiency of engine.

It is most convenient to measure the torque T_M by means of a torsiometer. As the application of the torsiometer makes it possible to measure the crankshaft torsional angle φ or the shear stresses s occurring in the shaft under torsion, which depend on the engine torque T_M in accordance with the following relationships, respectively :

$$T_M = r \cdot \varphi$$

or (22)

$$T_M = s \cdot W_o$$

where :

r – shaft torsional rigidity
s – shear stresses
W_o – torsional strength modulus of a considered shaft's part

therefore the engine's operation can be determined also by means of the following expressions :

$$OP_\varphi = \int_{t_0}^{t_n} r \cdot \varphi \cdot \omega \cdot \tau \, d\tau \tag{23}$$

or

$$OP_s = \int_{t_0}^{t_n} s \cdot W_o \cdot \omega \cdot \tau \, d\tau \tag{24}$$

The so understood engine's operation can be presented in the $W_u - t$ coordinate system as shown in Fig.3.

The engine operation OP_M may be understood as :

★ the demanded operation $(OP_M)_d$ i.e. that necessary for realization of a transport task by a ship, to which the ship's engine has been prepared
★ the possible operation $(OP_M)_p$ i.e. that possible to be realized by an engine being in a given technical state and realizing a transport task under definite external conditions.

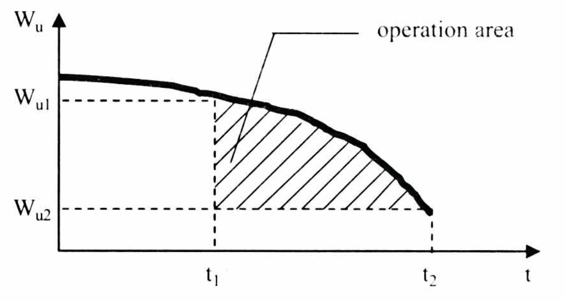

Fig.3. *Example operation diagram of a device : W_u – energy, t – time*

Hence it can be stated that every engine is in the state of serviceability (is able to realize its task) when the condition (9) is fulfilled. Otherwise i.e. when the condition (10) is satisfied it should be admitted that the engine is in the state of unserviceability. It means that the engine should be considered as unsericable despite the energy transformation occurs in it. The relationship (9) will be surely fulfilled when the engine can be loaded in accordance with the external maximum power characteristics within the time interval recommended by its manufacturer (e.g. for 15 min). In the case when the engine cannot be so loaded (without any failure) then the relationship (9) can be satisfied only if during realization, by a ship, of its transport task no need to load the engine in compliance with the characteristics, appears. Otherwise the relationship (9) will not be satisfied and the engine should be deemed failed.

Of course, in the cases when not all transport tasks realized by a ship during a given time require its engine to be loaded in accordance with the external maximum power characteristics, then the engine is able to realize the tasks. Hence it can be concluded that the engine is :

➲ in the state of full serviceability when it can be loaded within the entire range to which it has been initially prepared (during its designing and manufacturing), i.e. also according to the external maximum power characteristics in the mentioned time intervals
➲ in the states of partial serviceability when it can be loaded according to its external maximum power characteristics however for a shorter time than that established by its manufacturer, and the states will the more differ from the full serviceability state the less it can be able to be loaded without any risk of being damaged in a short time.

Hence it would be possible to conclude about the usefulness of particular engines for realization of their definite tasks after comparing the engine operation areas : of that demanded, $(OP_M)_d$, and that possible, $(OP_M)_p$. From the above presented discussion it results that the consideration of the so formulated engine operation is equivalent to the investigation of :

✱ changes of the demanded work $(W_u)_d$ which should be done by an engine during the demanded time t_d, i.e. that in which ship's transport task should be finished
✱ changes of the possible work $(W_u)_p$ which an engine is able to do during the possible time t_p, i.e. that during which the engine is able to operate correctly.

In order to use the engine operation as a measure of engine's capability to perform definite tasks it is necessary first of all to determine classes of the standard states among which its technical state could be numbered. In the case of the main propulsion engines of transport vehicles of any kind it is essential to be aware whether a given engine is in the state of full serviceability.

Also, equally essential is to know whether such engine, not being in the state of full serviceability, is in a state of partial serviceability which would make realizing a given transport task under expected external conditions, possible. In each of the cases it may be concluded that, in accordance with the formula (9), an engine is in the state of serviceability when :

- $t_p \geq t_d$ if simultaneously $(W_u)_p \geq (W_u)_d$
- $t_p = t_d$ if simultaneously $(W_u)_p = (W_u)_d$ (25)
- $t_p \geq t_d$ if simultaneously $(W_u)_p = (W_u)_d$
- $t_p = t_d$ if simultaneously $(W_u)_p \geq (W_u)_d$

In the case when any of the conditions (25) cannot be fulfilled the engine should be considered unable to realize its task despite it is still able to transform the chemical energy, comprised in the combusted fuel oil, into the mechanical energy making performance some work W_u by the engine, possible. Therefore the operation of an arbitrary serviceable engine, $(OP_M)_p$, analyzed with taking into account the conditions (25) may be considered as its reliability index. In the case if the relations (25) are not satisfied, i.e. the inequality (10) is valid and an accident may occur as a result, the operation of a given engine, $(OP_M)_p$, can be considered as a measure of its operational safety.

Of course the commonly known similar indices, if only related to the engine's operation proposed in this paper, may be also used as indices of operational reliability and safety of the main engine. In this case the probability of satisfying the relations (25), i.e.the probability of correct engine's operation and thus realization of its demanded task, may be taken as a reliability measure. For elaboration of such indices the uniform Poisson's process can be used as a model of dropping the useful energy (i.e. the work W_u) due to engine's wearing [3, 5, 8].

By applying such process the following physical interpretation of the process of decrease of the work W_u by the constant value u, can be offerred: beginning from the instant of engine's start-up till the instant of the first record (measurement) of the event A which consists in decreasing the work W_u (due to engine's wearing) by the value $\Delta W_u = u$, any value of the work W_u (including the maximum one) can be performed in particular time intervals of engine's operation. Further wearing of the engine along with time, makes next records of decreasing the work W_u by the successive equal u values to appear. Hence, in the case of recording, till the instant t, the cumulated number of A events, B_t, described with the uniform Poisson's process, the total decrease of the work W_u by the sucessive values of $\Delta W_u = u$ counted till the instant t, can be expressed as follows :

$$(W_u)_t = u \cdot B_t \qquad (26)$$

and, the random variable B_t is of the following distribution function [2 , 4] :

$$Pr(B_t = k) = \frac{(\lambda t)^k}{k} \exp(-\lambda t); \quad k = 1,2,...,z \qquad (27)$$

where :

λ – a constant (λ = idem) considered as the intensity of decreasing the work W_u by the constant u values recorded during the tests; $\lambda > 0$.

The expected value $E(B_t)$ and the variance $D_v^2(B_t)$ of the process of increasing the number of A events, hence of decreasing the work W_u by the sucessively recorded u values can be presented as follows :

$$E(B_t) = \lambda \cdot t$$
$$D_v^2(B_t) = \lambda \cdot t \qquad (28)$$

Therefore in accordance with (26) and (28) the expected value E and the standard deviation σ_L of the decreasing of the work W_u performed by the engine till the instant t can be expressed as follows :

$$E[\Delta W_u(t)] = uE(B_t) = u \cdot \lambda \cdot t$$
$$\sigma_L(t) = u\sqrt{D_v^2(B_t)} = u\sqrt{\lambda t} \qquad (29)$$

By taking into account that a new engine (at $t = 0$) is able to do the largest work, i.e. $W_u(0) = (W_u)_{max}$ it is possible to express the relationship which describes the work decreasing with time as follows :

$$W_u(t) = \begin{cases} (W_u)_{max} & \text{for } t = 0 \\ (W_u)_{max} - u\lambda t \pm u\sqrt{\lambda t} & \text{for } t > 0 \end{cases} \qquad (30)$$

The expression is shown graphically in Fig.4.

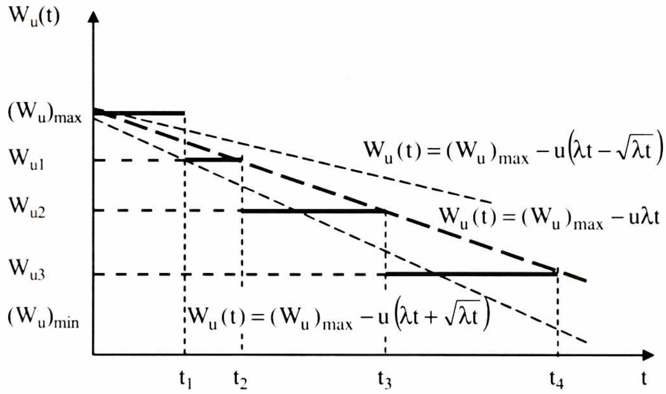

Fig. 4. *Graphical interpretation of an example realization of decreasing process of the useful work with time : W_u – useful work, u – quantum by which the work W_u is changed*

From (30) it results that it would be possible, at a given instant t, to determine the work W_u which can be done by an engine, and from (27) – that it is possible to determine an occurrence probability of such decrease of the work W_u resulting from the engine's wearing, which would be able to make realization of a given task impossible. Hence the probability $Pr(B_t = k\,;\, k = 1, 2, ..., z)$ defined by (27) can be deemed an engine's reliability index. The probability may be also taken as an engine's operation safety index in the case if it concerns such decrease of the work W_u which is able to lead to a sea accident (or another transport accident).

RECAPITULATION

- Any operation (action) of a human being, as well as of an arbitrary device makes the energy E, within definite time interval t, decreasing. The operation in the presented formulation can be considered as a diagnostic symptom which delineates a state of man's health or a technical state of a device. Neither the energy E nor its emission time t can be solely considered as a symptom of this kind. Yet the consideration of E and t together, i.e the consideration of the operation, can be deemed to be such symptom. In the case of the devices, and also of people, it may so happen that the demanded energy (necessary for realization of a given task) can be generated but in a time interval longer than that permissible. It may also happen that the energy necessary to realize a given task cannot be produced even within a longer, than that permissible, time interval. In both situations the demanded task would not be realized.
- Though the presented interpretation is not known in engineering sciences and such unit as [joule x second] has not been accounted for in the International Standard Units System (SI), the similar interpretation of the operation (action) is known in physics, strictly speaking, in classical mechanics (Hamilton's operation and Maupertius's operation [7, 8, 26]), as well as in quantum mechanics (Plank's constant h - equivalent to the operation [1, 10, 17]).
- Also, the operation interpreted according to the relationship (2) has its equivalents in thermodynamics at consideration of the work W and heat Q, as well as in tribology at consideration of the friction work W_f of tribological systems [8, 20, 25].
- The operation in the presented interpretation has also the advantage that it can be investigated by means of exact measurements and next expressed in the form of :
  - a number dimensioned in [joule x second] units – see formulae : (1), (2), (18), (19), (20), (23), (24), (26), (27)
  - a graphical representation, i.e. the operation area - see Fig.1, Fig.3.

- The operation in the proposed version was examplified with the use of diesel engines delivering some energy to arbitrary consumers. In such interpretation the operation is meant as the generation of the energy by the engine within definite time interval.

Appraised by Jerzy Lewitowicz, Prof.,D.Sc.

NOMENCLATURE

C_F – net calorific value of the fuel oil
D – disturbance
E – energy
E_d – demanded energy
E_{del} – delivered energy
E_p – possible energy
E_u – useful energy
E_w – waste energy
F – fuel oil consumption
F_t – fuel oil consumption per time unit
n – engine rotational speed
OP – operation
OP_d – demanded operation
OP_p – possible operation
OP_Q – heat exchanger's operation
OT – operational task
p_u – useful pressure
P_u – useful power
Q – heat
t, τ – time
t_d – demanded time
t_p – possible time
T_M – engine torque
W_u – useful work
W_α – total work done over angular travel

α – rotation angle
ΔE_i – internal energy increment
η_{OP} – operation efficiency
$(\eta_{OP})_e$ – energy efficiency of operation
ω – engine angular speed

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FOREIGN *conference*

EUROTURBO 5

On 17 ÷ 22 March 2003 the 5th European Conference on :

Turbomachinery Fluid Dynamics and Thermodynamics

was held in Prague (Czech Republic). It was organized by the Association of Czech Mechanical Engineers and Faculty of Mechanical Engineering, Czech Technical University in Prague.

A vast range of its problems and great interest paid to the Conference was manifested in 108 papers prepared by 284 authors from 16 European countries and USA.

13 Polish scientific workers presented the following papers :

- *Measurement of the unsteady flow field due to inlet guide vane interaction with the rotor in an axial flow low speed compressor stage* – by A.S. Witkowski, T.J. Chmielniak, M.M. Majkut and M.D. Strózik (Silesian Technical University, Gliwice)
- *Neural network application for recognition of geometry degradation of power cycle components* – by J.Głuch (Institute of Fluid Flow Machinery of Polish Academy of Sciences, Gdańsk, and Gdańsk University of Technology)
- *Numerical optimization of 3D blading in the LP exit stage of a steam turbine for different load conditions* by P.Lampart (Institute of Fluid Flow Machinery of Polish Academy of Sciences, Gdańsk)
- *Flow investigations downstream of the last stage of a large steam turbine during low-load, start-up and shut-down conditions* – by A. Gardzilewicz, S. Marcinkowski (Institute of Fluid Flow Machinery of Polish Academy of Sciences, Gdańsk) and K.Kietliński, B.Łuniewicz, and C.Szyrejko (Alstom Power, Elbląg)
- *Fluid-structure interaction analysis for aeroelastic behaviour of a turbine last stage under design and off-design regimes* – by R.Rządkowski, co-autor (Institute of Fluid Flow Machinery of Polish Academy of Sciences, Gdańsk)
- *Unsteady performance of an HP turbine stage optimized for steady-state conditions* – by J. Swirydczuk (Institute of Fluid Flow Machinery of Polish Academy of Sciences, Gdańsk).

Moreover, the Committee on Energy Problems, Polish Academy of Sciences, was among 11 international co-organizers of the Conference, and Prof. J.Krzyżanowski (Institute of Fluid Flow Machinery of Polish Academy of Sciences, Gdańsk) served as a member of the International Organizing Committee of the Conference.