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A CONCEPT OF ENTROPY APPROACH TO THE PROBLEM OF MULTI-ALTERNATIVE OPERATIONAL MODES CONTROL

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It is made an attempt to solve a problem of optimal control for the situation of multi-alternativeness and conflictability of operational modes active element's individual preferences. A special case substantiation of the optimal mode choice for marine electro-hydraulic steering gears has been considered. The optimal controlling mode has been found without imposing any restrictions upon the angle of the ship's helm blade deflection. It is suggested measuring the positiveness of the individual's preferences conflict with the use of the pseudo-entropy function. Fulfilled appropriate mathematical modeling is illustrated with corresponding diagrams.
Keywords: positive conflictability, pseudo-entropy function, subjective analysis, subjective entropy, individual's preferences, multi-alternative situations, conflicts of preferences, canonical distributions, active systems control.

Introduction. Initiated in [1] a discussion on the topic of the rational modes of operation for a four-arm tiller electro-hydraulic steering gear (EHSG) equipped with the piston hydro-cylinders with respect to multi-alternativeness and individual's subjective preferences; also in [2] on the theme of the conflictability of operational situations in terms of entropy paradigm is now being prolonged in this paper.

Urgency of researches. It is important to research a process of a multi-alternative operational modes control for a few special cases of alternatives and their possible conflicts from the point of view of the active system controlling element's individual subjective preferences entropy approach concept.

It is always an actual scientific problem to find a general principle by which a set of phenomena is guided.

Analysis of the latest researches and publications. In the previous publications [1, 2] we analyzed advantages of a four-arm tiller EHSG equipped with the piston hydro-cylinders compared to the traditional plunger type EHSG of 4EP220, Stork (the Netherlands); the nominal moment equals 1,167 kNm [3].

Main characteristics of an EHSG are normalized by the standards and regulations of International Maritime Organization and, accordingly to them by all Classification Societies. These are: the time of putting helm from 35° of one board up to 30° of the other; the number of the pumps (not less than two); availability of preventive devices (automatically acting valves and others); doubling of the controlling lines; possibility of emergency control over the helm; and some others [3].

Also, in [1, 2] it has been considered at least one specific alternative operational mode combined out of two the simplest elementary conflictable ones.

With the use of the entropy approach [1, 2, 4-9] to such a problem of control in an active system, we will be studying not covered before situations.

The task setting. In this paper we will be finding optimal control decisions for the choice of a needed operational mode without imposing any restrictions upon the angle of the ship's helm blade deflection. Entropy approach explains the principle.

The main content (material). The idea is to continue studying of operational modes combinations started in [1, 2] in order to generalize modeling dependences of control in situations with possible conflicts. The entropy of preferences is a tool.

The problem formulation. Accordingly to [1, 2] we have got three elementary operational modes described with the expressions of forces acting in the piston hydro-cylinders of the retrofitted EHSG with the four-arm tiller in the view of

$$F' = \frac{M_b}{2r\sin(\alpha+\beta+\gamma+\delta)},\quad F'' = \frac{M_b}{2r[\sin(\alpha+\beta+\gamma+\delta)+0.75\sin(\beta-\alpha+\gamma-\delta')]},$$

$$F''' = \frac{M_b}{2r\left[\sin(\alpha+\beta+\gamma+\delta)+\sin(\alpha-\beta+\delta''-\gamma)\right]}, \tag{1}$$

where M_b – moment acting on the rudder [1-3]; α – angle of the tiller turning; r, β, γ, δ, δ', δ'' – structure geometrical parameters of the four-arm tiller steering gear equipped with the piston hydro-cylinders [1, 2].

The conflict free combined of (1) mode of operation is being written with the conditional system of equations [1, 2]

$$F_{cn} = \begin{cases} F'', & \alpha < \alpha_0; \\ F', & \alpha = \alpha_0; \\ F''', & \alpha > \alpha_0, \end{cases} \tag{2}$$

where α_0 – angle of deflection of the ship's helm blade at which the corresponding hydro-cylinder changes its-own mode of operation.

Now, we apply the postulated in subjective analysis functional of the general view of [5, P. 119, (3.38)] in the view of [1, 2]

$$\Phi_\pi = -\sum_{i=1}^{N} \pi_i \ln \pi_i - \beta \sum_{i=1}^{N} \pi_i \left|F^i\right| + \gamma \left[\sum_{i=1}^{N} \pi_i - 1\right], \tag{3}$$

where π – function of the individual's subjective preferences; N – number of possible elementary (simplest) operational modes (achievable alternatives); β, γ – structural parameters, they can be considered in different situations as Lagrange coefficients, weight coefficients or endogenous parameters that represent certain properties of the individual's (active element's) psych; $\sum_{i=1}^{N} \pi_i = 1$ – normalizing condition.

Compiling functional (3) with the formulas (1) accordingly to the three modes mentioned above, we acquire corresponding expressions, for the cases of the specific operational modes control on conditions of their multi-alternativeness only, in one of the following view

$$\Phi_\pi = -\sum_{i=1}^{2} \pi_i \ln \pi_i - \beta\left(\pi_1\left|F'\right| + \pi_2\left|F''\right|\right) + \gamma \left[\sum_{i=1}^{2} \pi_i - 1\right], \tag{4'}$$

$$\Phi_\pi = -\sum_{i=1}^{2} \pi_i \ln \pi_i - \beta\left(\pi_1\left|F'\right| + \pi_3\left|F'''\right|\right) + \gamma \left[\sum_{i=1}^{2} \pi_i - 1\right], \tag{4''}$$

$$\Phi_\pi = -\sum_{i=1}^{2} \pi_i \ln \pi_i - \beta\left(\pi_2\left|F''\right| + \pi_3\left|F'''\right|\right) + \gamma \left[\sum_{i=1}^{2} \pi_i - 1\right], \tag{4'''}$$

$$\Phi_\pi = -\sum_{i=1}^{3} \pi_i \ln \pi_i - \beta\left(\pi_1\left|F'\right| + \pi_2\left|F''\right| + \pi_3\left|F'''\right|\right) + \gamma \left[\sum_{i=1}^{3} \pi_i - 1\right]. \tag{4''''}$$

The preferences functions π_i in (4) in their canonical view [5, P. 115-135], being got from the necessary conditions of extremum in the view of

$$\frac{\partial \Phi_\pi}{\partial \pi_i} = 0, \tag{5}$$

though having the same subscripts, have different values for those four variants of (4)

$$\pi_1 = \frac{e^{-\beta|F'|}}{e^{-\beta|F'|} + e^{-\beta|F''|}},\ \pi_2 = \frac{e^{-\beta|F''|}}{e^{-\beta|F'|} + e^{-\beta|F''|}}; \qquad (6')$$

$$\pi_1 = \frac{e^{-\beta|F'|}}{e^{-\beta|F'|} + e^{-\beta|F'''|}},\ \pi_3 = \frac{e^{-\beta|F'''|}}{e^{-\beta|F'|} + e^{-\beta|F'''|}}; \qquad (6'')$$

$$\pi_2 = \frac{e^{-\beta|F''|}}{e^{-\beta|F''|} + e^{-\beta|F'''|}},\ \pi_3 = \frac{e^{-\beta|F'''|}}{e^{-\beta|F''|} + e^{-\beta|F'''|}}; \qquad (6''')$$

$$\pi_1 = \frac{e^{-\beta|F'|}}{e^{-\beta|F'|} + e^{-\beta|F''|} + e^{-\beta|F'''|}},\ \pi_2 = \frac{e^{-\beta|F''|}}{e^{-\beta|F'|} + e^{-\beta|F''|} + e^{-\beta|F'''|}},$$

$$\pi_3 = \frac{e^{-\beta|F'''|}}{e^{-\beta|F'|} + e^{-\beta|F''|} + e^{-\beta|F'''|}}; \qquad (6'''')$$

because all of them are obtained on different conditions; except for (5), of course; of multi-alternativeness, conflictability, circumstances, and operational situations control etc.

Considering this case with the two reachable alternatives we might discover a certain analogue to the stimuli perceptions relation from psychophysics. Really, let us compose a functional from the prototype (3)

$$\Phi = -\sum_{i=1}^{2} F_i \ln F_i - \beta \sum_{i=1}^{2} \pi_i F_i + \gamma \left[\sum_{i=1}^{2} F_i - 1 \right], \qquad (3')$$

where F_i – play the role of stimuli; π_i – have the sense of perceptions.

From equation (3') and conditions like (5)

$$\frac{\partial \Phi}{\partial F_i} = -\ln F_i - 1 - \beta \pi_i + \gamma = 0, \qquad F_i = e^{-1+\gamma} e^{-\beta \pi_i}, \qquad \ln \frac{F_1}{F_2} = -\beta(\pi_1 - \pi_2). \qquad (3'')$$

The last equation of (3'') in these terms is interpreted as the Weber-Fechner law.

When the operational functional likewise (3) is given in the view of an operational integral [7, P. 57, (1)]

$$\Phi_\pi = \int_{t_0}^{t_1} \left(-\sum_{i=1}^{N} \pi_i(t) \ln \pi_i(t) + \beta \sum_{i=1}^{N} \pi_i(t) F_i + \gamma \left[\sum_{i=1}^{N} \pi_i(t) - 1 \right] \right) dt, \qquad (7)$$

where t – time; $-\sum_{i=1}^{N} \pi_i(t) \ln \pi_i(t)$ – entropy of subjective preferences of $\pi_i(t)$; F_i – effectiveness function related to the i^{th} alternative; in the simplest problem setting we might consider $x(t)$ and $\dot{x}(t)$, let us, for example, say, the force acting in the cylinder and its rate of change in time as the subjective efficiency functions of the two achievable alternatives with the corresponding preferences of $\pi_1(t)$, $\pi_2(t)$.

With respect to particular combinations of $x(t)$, $\dot{x}(t)$, $x(t)\dot{x}(t)$, and $\frac{\dot{x}(t)}{x(t)}$, we will get the eleven specific variants of the functional (7), which have their common general view of [7, P. 57, (2)]:

$$\Phi_\pi = \int_{t_0}^{t_1}\left(-\sum_{i=1}^{N=4}\pi_i(t)\ln\pi_i(t) + \beta\left[\pi_1(t)x(t) + \alpha_2\pi_2(t)\dot{x}(t) + \alpha_3\pi_3(t)x(t)\dot{x}(t) + \right.\right.$$
$$\left.\left. + \alpha_4\pi_4(t)\frac{\dot{x}(t)}{x(t)}\right] + \gamma\left[\sum_{i=1}^{N=4}\pi_i(t) - 1\right]\right)dt, \quad (8)$$

where α_i – coefficients that consider the differences in the measurement units.

The last functional (8) is the general one and each of the previously mentioned specific variants derives from it with the corresponding $\pi_i(t)$ and α_i.

Conflictability of the preferences distributions is determined through the pseudo-entropy function [8, P. 123, (21)], [9, P. 64, (19)]. Dependently upon intentions expressed in active element's individual preferences it may be positive or negative.

The problem solution. On choosing the desired view of the operational funcitional (4) and getting the canonical distributions of subjective preferences (6), we get optimal conflict free mode of operation in by-passing conditions (2).

Applying the necessary conditions for extremums in the view of Euler-Lagrange equations for the variational problems of (7) or (8) [7, P. 58, (3)]

$$\frac{\partial R^*}{\partial \pi_i} - \frac{d}{dt}\left(\frac{\partial R^*}{\partial \dot{\pi}_i}\right) = 0, \quad \frac{\partial R^*}{\partial x} - \frac{d}{dt}\left(\frac{\partial R^*}{\partial \dot{x}}\right) = 0, \quad (9)$$

where R^* – the under-integral function of the corresponding integral (7) or (8), we get the corresponding expressions of canonical distributions of the preferences for (8) in the traditional form [7, P. 58, (4)]

$$\pi_j = \frac{e^{\alpha_j \beta F_j}}{\sum_{i=1}^{N} e^{\alpha_i \beta F_i}}. \quad (10)$$

The preferences functions for (8) are connected through the generalized equation by Euler-Lagrange in the transformed view [7, P. 58, (5)]

$$\pi_1 = \alpha_2\dot{\pi}_2 + \alpha_3 x\dot{\pi}_3 + \frac{\alpha_4}{x}\dot{\pi}_4. \quad (11)$$

The generalized differential equation of the second order for (11) will be [7, P. 58, (6)]

$$\ddot{x} = \frac{\pi_1 + A + B + C}{D + E + F}, \quad (12)$$

where [7, P. 58-59, (7)]

$$A = \alpha_2\left\{\beta\pi_2\left(\pi_1 + \alpha_3\dot{x}\pi_3 - \alpha_4\frac{\dot{x}}{x^2}\pi_4\right)\dot{x}\right\},$$

$$B = -\alpha_3 x\left\{\beta\pi_3\left[\alpha_3\dot{x}(\pi_1 + \pi_2 + \pi_4) - \pi_1 + \alpha_4\frac{\dot{x}}{x^2}\pi_4\right]\dot{x}\right\},$$

$$C = -\frac{\alpha_4}{x}\left\{\beta\pi_4\left[-\alpha_4\frac{\dot{x}}{x^2}(\pi_1 + \pi_2 + \pi_3) - \pi_1 - \alpha_3\dot{x}\pi_3\right]\dot{x}\right\},$$

$$D = \alpha_2 \left\{ \beta\pi_2 \left[\alpha_2 (\pi_1 + \pi_3 + \pi_4) - \alpha_3 x \pi_3 - \frac{\alpha_4}{x}\pi_4 \right] \right\},$$

$$E = \alpha_3 x \left\{ \beta\pi_3 \left[\alpha_3 x (\pi_1 + \pi_2 + \pi_4) - \alpha_2 \pi_2 - \frac{\alpha_4}{x}\pi_4 \right] \right\},$$

$$F = \frac{\alpha_4}{x} \left\{ \beta\pi_4 \left[\frac{\alpha_4}{x} (\pi_1 + \pi_2 + \pi_3) - \alpha_2 \pi_2 - \alpha_3 x \pi_3 \right] \right\}. \quad (13)$$

If, for instance, there is an intellectual system that is involved into the process of operational control, we can solve a problem likewise for an artificial intelligence. The operational integral functional in that case will be similar to (7)

$$\Phi = \int_{t_0}^{t_1} \left(-\sum_{i=1}^{N} S_i(t) \ln S_i(t) - \beta \sum_{i=1}^{N} \pi_i(t) S_i(t) + \gamma \left[\sum_{i=1}^{N} S_i(t) - 1 \right] \right) dt, \quad (7')$$

where S_i – stimuli that induce perceptions in the view of preferences π_i.

From conditions like (9) and functional (7') it yields

$$\frac{\partial R^*}{\partial S_i} = -\ln S_i - 1 - \beta\pi_i + \gamma = 0, \; S_i = e^{\gamma-1} e^{-\beta\pi_i}, \; e^{\gamma-1} = \frac{1}{\sum_{q=1}^{N} e^{-\beta\pi_q}}.$$

The members of $\gamma - 1$ and $e^{\gamma-1}$ are the same for any i th stimulus and preference.

$$S_i = \frac{e^{-\beta\pi_i}}{\sum_{q=1}^{N} e^{-\beta\pi_q}}, \qquad \forall i \in \overline{1, N}.$$

From here it follows that for any i and j

$$\ln \frac{S_i}{S_j} = -\beta(\pi_i - \pi_j). \quad (7'')$$

The expression (7'') is the analogue to the main law of psychophysics (3''). In case when $N = 2$, we get relations between the stimuli and effectiveness functions:

$$S_1 = \frac{1}{1 + e^{-\beta(1-2\pi_1)}}, \qquad \pi_1 = \frac{1}{2}\left[1 + \frac{1}{\beta} \ln\left(\frac{1}{S_1} - 1 \right) \right].$$

With canonical distribution for preferences similar to (10)

$$S_1 = \frac{1}{1 + e^{-\beta\tilde{F}}}, \qquad \tilde{F} = \frac{e^{-\beta F_2} - e^{-\beta F_1}}{e^{-\beta F_1} + e^{-\beta F_2}}.$$

Relation (7'') gets the view

$$\ln \frac{S_1}{S_2} = -\beta \left(\frac{e^{-\beta F_1} - e^{-\beta F_2}}{e^{-\beta F_1} + e^{-\beta F_2}} \right).$$

The member within parentheses is called *stimuli effectiveness functions hyperbolic tangent*, since, if the effectiveness functions $F_1 = -F_2$, it becomes $\mathrm{th}(\beta F_2)$ and

$$\ln\frac{S_1}{S_2} = -\beta \mathrm{th}(\beta F_2) = \beta \mathrm{th}(\beta F_1), \qquad S_1 = \frac{1}{1+\exp[\beta \mathrm{th}(\beta F_2)]}.$$

Practical application of the problem solution. For a practical application of the problem solution we consider, for example, a general cargo, universal, dry cargo vessel, DWT 13,500 t, the ship's speed 18.2 knots. The prototype-vessel, let us say, of the «Geroi Panfilovtsy» series. She is presumable equipped with the plunger steering engine, builder's type of 4EP220, Stork (the Netherlands).

The problem solution is applicable to any similar problem formulations of that style of problem setting although.

Because of, for instance, the output of EHSG practically has no limitations [3]. On supertankers, for examples, there are EHSG with the output of up to 800 kW (turning moment more than 20,000 kN·m) installed [3].

The area of EHSG application is also unrestricted. They are used for all types of ships: dry cargo and tankers, ferries and luxury (comfortable) passenger liners, supertankers and launches for recreations, and so on. With any types of ship propulsion [3].

Also the problem solution can be applied in other areas and fields of a certain scientific interest where their controlling influence or individual's choice may be represented through the method likewise (2)-(6).

Using the variational problem setting likewise (7) in the view

$$\Phi_\pi = \int_{t_0}^{t_1}\left(-\sum_{i=1}^{N}\pi_i(t)\ln\pi_i(t) - \beta\sum_{i=1}^{N}\pi_i(t)\left|F^i\right| + \gamma\left[\sum_{i=1}^{N}\pi_i(t) - 1\right]\right)dt, \tag{14}$$

from conditions (9) because of

$$\frac{\partial R^*}{\partial \dot{\pi}_i} \equiv 0, \ \frac{\partial R^*}{\partial \pi_i} = 0, \tag{15}$$

we will get the identical to (5) and (6) result.

Getting back to EHSG, for data prescribed in [1, 2], we have got advantages of the improved EHSG compared to the «old» one in the view of the forces ratio [1], and forces difference

$$\Delta F = |F_{cn}| - |F_c|, \tag{16}$$

where F_c – the force acting in the cylinders of the «old» EHSG 4EP220, Stork [1, 2].

Concerning the forces differences (16), they are illustrated in fig. 1, [2].

In fig. 1, it is shown the differences between forces acting in the cylinders of the improved steering gear drive and in the traditional 4EP220.

Modeling by the method (3)-(6) allows us choosing the optimal conflict free combined mode of operation. We would like to stress ones more that there was not a restriction to the angle of α. In no way and nowhere in the problem setting with the subjective preferences we imply conditions (2).

Modeling for the case (4'''') and (6'''') is illustrated in fig. 2.

In fig. 2 it is shown, in corresponding scales, the forces, entropies, preferences, moment on the rudder. Also it is shown there the value of the maximal entropy which for this problem formulation equals $\ln 3$. Entropy maxima correspond to the first situation when the moment on the rudder equals zero and the second situation when the forces of the three modes are equaled to each other.

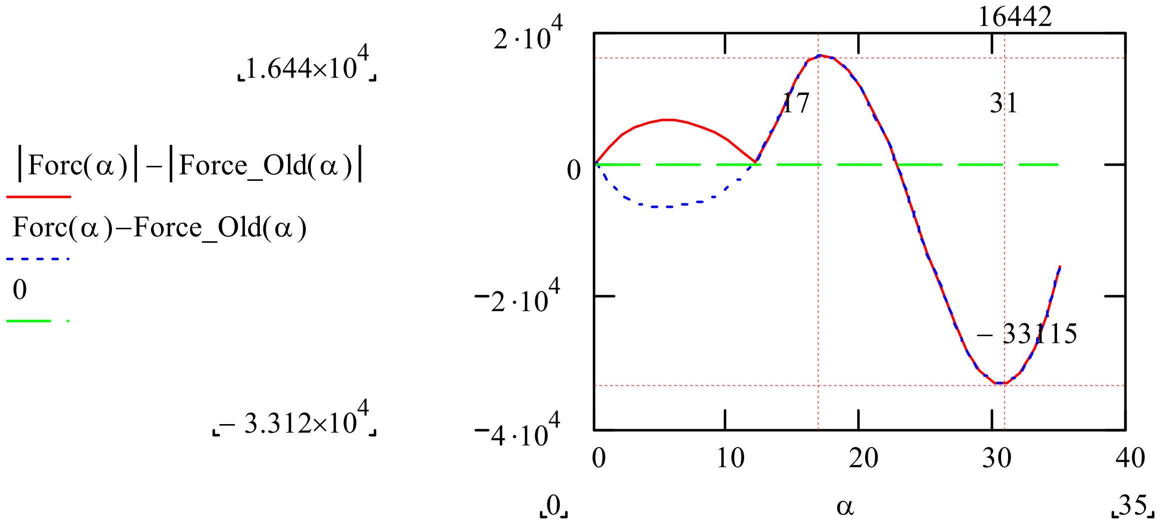

Figure 1 – Advantages of the retrofitted marine steering gear

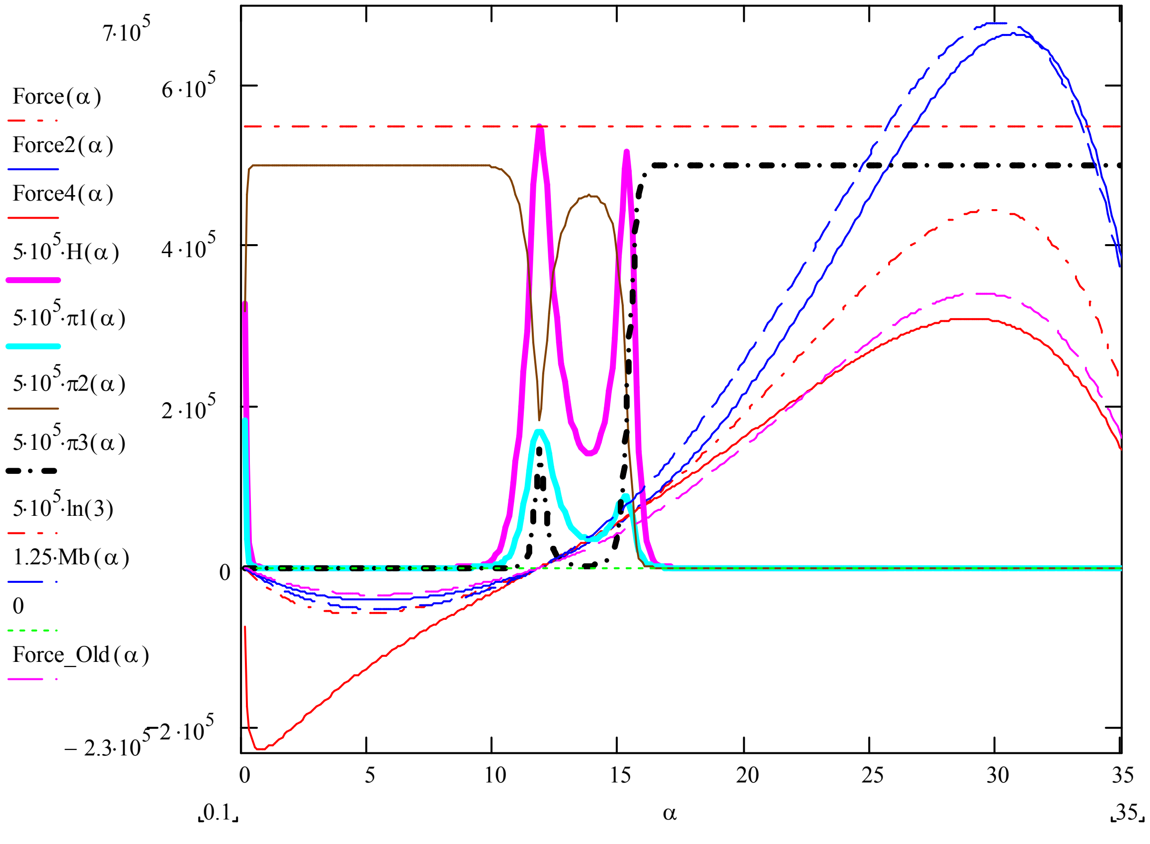

Figure 2 – Entropy and preferences of operational modes

The researches results. In fig. 2, it is obvious the active element chooses rational control since the entropy tends to zero and distribution of his own preferences definitely shows that; and the corresponding absolute values of the forces acting in the piston hydro-cylinders have the minimal magnitudes.

If we indicate the preferences of the minimal forces magnitudes be positive which quite logical, then, for sure, the conflict (contradiction) between the preferences measured by the pseudo-entropy function [8, P. 123, (21)], [9, P. 64, (19)] is also utterly positive which is rather reasonable. This means that positive conflict has a sense of a certain initial factor of the rational control choice and operational strategic behavior within the whole diapason of the angle of the helm deflection.

We might as well trace the same entropy guiding principle in all particular cases (4) and (6) described in the problem formulation section of this paper.

Conclusions. Due to the suggested improvements of the steering gear, we expect a decrease in the mechanical tension. Therefore the mass of the installation can be reduced, reliability – raised.

The subjective preferences entropy maximum concept allows choosing the appropriate control for the rational modes of operation in conditions of multi-alternativeness of operational situations and helps avoid possible conflicts in the system.

The optimal control has the positive conflictability through all the range of the operational situations.

Prospects of further researches. For further researches it is prospective to deal with the entropy paradigm in studying multi-alternativeness of operational situations on conditions of possible conflicts with the use of the methods (3)-(15) applicably to other more general cases of operational control.

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Гончаренко А.В. КОНЦЕПЦІЯ ЕНТРОПІЙНОГО ПІДХОДУ ДО ПРОБЛЕМИ КЕРУВАННЯ БАГАТОАЛЬТЕРНАТИВНИМИ ЕКСПЛУАТАЦІЙНИМИ РЕЖИМАМИ
Здійснено спробу розв'язати проблему оптимального керування для ситуації багатоальтернативності та конфліктності індивідуальних переваг експлуатаційних режимів активним елементом. Розглянуто обґрунтування частинного випадку вибору оптимального режиму для морської електрогідравлічної рульової машини. Оптимальний режим керування знайдено без накладення будь-яких обмежень на кут повороту пера руля судна. Запропоновано вимірювання позитивності конфлікту індивідуальних переваг із використанням псевдоентропійної функції. Виконане належне математичне моделювання проілюстровано відповідними діаграмами.
Ключові слова: позитивна конфліктність, псевдоентропійна функція, суб'єктивний аналіз, суб'єктивна ентропія, індивідуальні переваги, багатоальтернативні ситуації, конфлікти переваг, канонічні розподіли, керування активними системами.

Гончаренко А.В. КОНЦЕПЦИЯ ЭНТРОПИЙНОГО ПОДХОДА К ПРОБЛЕМЕ УПРАВЛЕНИЯ МНОГОАЛЬТЕРНАТИВНЫМИ ЭКСПЛУАТАЦИОННЫМИ РЕЖИМАМИ
Осуществлена попытка решить проблему оптимального управления для ситуации многоальтернативности и конфликтности индивидуальных предпочтений эксплуатационных режимов активным элементом. Рассмотрено обоснование частного случая выбора оптимального режима для морской электрогидравлической рулевой машины. Оптимальный режим управления найден без накладывания каких-либо ограничений на угол поворота пера руля судна. Предложено измерение позитивности конфликта индивидуальных предпочтений с использованием псевдоэнтропийной функции. Выполненное надлежащее математическое моделирование проиллюстрировано соответствующими диаграммами.
Ключевые слова: позитивная конфликтность, псевдоэнтропийная функция, субъективный анализ, субъективная энтропия, индивидуальные предпочтения, многоальтернативные ситуации, конфликты предпочтений, канонические распределения, управление активными системами.

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