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MODELS FOR DETERMINING INDICATIONS OF READINESS OF A PRESENT-DAY ENGINEERING INSTALLATION FOR ITS EFFECTIVE EXPLOITATION

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Abstract

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Some unconventional concepts and models to describe formally the operation of an engineering installation and ways of interactions with it are considered. The criteria for estimating readiness of the installation for its effective and no-failure operation are suggested. The conditions of practical applicability of the models are discussed.

Аннотация

Боровиков А.А., Хромова Г.Н. Модели для определения показателей готовности современной технической установки к эффективному использованию: Препринт ИФВЭ 96-33. – Протвино, 1996. – 16 с., 4 рис., библиогр.: 17.

Рассматриваются нетрадиционные понятия и модели для формального описания работы технической установки и взаимодействия с ней. Предложены критерии для оценивания готовности установки к эффективному и безаварийному использованию. Обсуждаются условия применимости моделей на практике.

INTRODUCTION

One of the problems the designers of unique engineering installations encounter with while using them for the solution of practical tasks [1,2] is the certification of these arrangements. There are no agreed-upon procedures to estimate readiness of such objects for effective and no-failure operation [3]. The documents of the International Standartization Organization [4] give some remarks concerning a degree of applicability of some general recommendations to specific installations. The problem of searching for measures of estimation is of high priority [5].

The paper suggests a number of unconventional concepts and models. By means of them a methodical background for estimating readiness of an engineering installation for its effective usage has been constructed according to the following indications:

- Quality of the final product of the installation.
- Efficiency of its usage for particular tasks.
- Level of determinancy of the operator's actions while controlling the installation.
- Level of control over no-failure operation.

Possibilities of practical usage of the models suggested are under discussion.

1. REFERENCE CONCEPTS AND MODELS

1.1. The concept of the final product and its state

The final product of installation operation (an element of its structural break up) is the result of executing by the installation (element) its functional purpose.

The final product P of installation operation can be described by a large number of its characteristics X: $P = F(\{x_i\})$, $x_i \in X$, where $i = 1, \ldots, l$; l is the number of characteristics for P. Similarly, the final product P' of the element operation of the installation is described by a large number of characteristics Y: $P' = F(\{y_j\})$, $y_j \in Y$, where $j = 1, \ldots, m$, m is the number of characteristics for P'.

A user of the installation is a person who uses the final product of the installation for solving his problems. Fig.1(a) shows a generalized scheme of using the installation for practical purposes; fig.1(b) is its concretization for a charged particle accelerator. The final product P for the accelerator is a beam of accelerated particles with definite characteristics. The list includes, for example, the following beam characteristics: beam current value $I \equiv x_1$; mass composition $A \equiv x_2$; phase volume $\varepsilon \equiv x_3$; energy of particles $W \equiv x_4$. Then $P = F(I, A, \varepsilon, W)$.

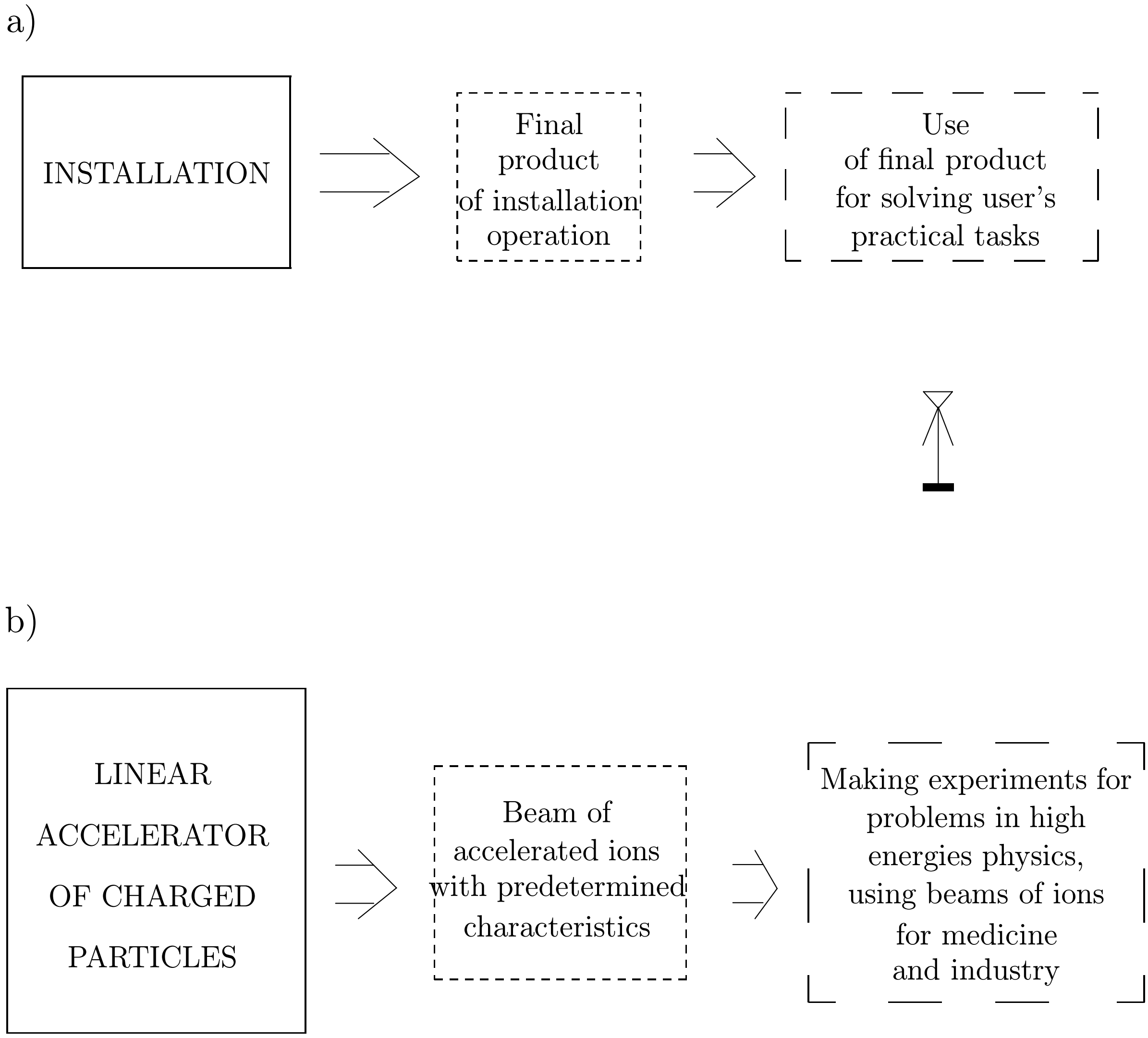

Fig. 1. The scheme of installation utilization: a) general case; b) for linear accelerator of charged particles.

According to specific purposes of the problem being solved, each user chooses those characteristics which he considers to be important. He states the boundaries of permissible values of these characteristics: the set X_{min} and X_{max}, with which the solution of the problem becomes possible. These boundaries might not correspond to those established by the designers to determine the permissible operation of the installation: X_{in} and X_{fin}.

Let us give an example. A beam of particles can emerge at the output of the accelerator. The beam current I is in permissible limits ($I_{in} \leq I \leq I_{fin}$). From a designer's point of view the installation "operates". However, the beam current quantity does not suit the reseach physicist for the solution of his particular problem ($I < I_{min}$). The user will consider that the installation "does not operate".

Application of the traditional estimation of installation operation according to the indication "time-to-failure" [6] gives different values for the user and for the designer. In addition, while operating the installation the personnel finds it difficult to make a decision, if necessary. An agreement in estimating the operation of an up-to-date engineering installation between the user and designer can be achieved in case three but not two ("operates"-"dos not operates") states are introduced.

We propose the state of the installation to be evaluated by the state of its final product. The model of the states of the installation final product is presented as follows:

- state s1 – final product is absent;
- state s2 – final product is produced, but its quality does not meet the user's requirements;
- state s3 – final product meets the user's requirements.

Denote the current state of the final product as S_p . The conditions separating one state from another will be specified by the following rules:

$$S_p = \begin{cases} s1\ , & \text{if} \quad \exists x_i \in X \quad x_i \notin [x_i in, x_i fin]; \\ s2\ , & \text{if} \quad \forall x_i \in X \quad x_i \in [x_i in, x_i fin], \\ & \quad \text{but} \ \exists x_i \in X \quad x_i \notin [x_i min, x_i max]; \\ s3\ , & \text{if} \quad \forall x_i \in X \quad x_i \in [x_i min, x_i max]. \end{cases} \tag{1}$$

The rules may vary depending on the problem being solved by the user or on the chosen mode of installation operation.

1.2. The model of integral and detailed states of the installation

The state of the installation that will be determined by the state of its final product will be called **the integral state**.

The integral state of the installation will be defined in the following way:

$$\left[\begin{array}{lll} \text{if} & S_p = s1 & - \textit{the installation is assigned as} \\ & & \ \ \textit{"inoperative" state (state } \mathbf{S1}); \\ \text{if} & S_p = s2 & - \textit{the installation "operates"} \\ & & \ \ (\textit{state } \mathbf{S2}); \\ \text{if} & S_p = s3 & - \textit{the installation operates} \\ & & \ \ \textit{"normally" (state } \mathbf{S3}). \end{array} \right. \tag{2}$$

Fig.2 shows graphically how by means of the model of three states the view points of the designer, user and operating personnel agree in the estimation of installation operation.

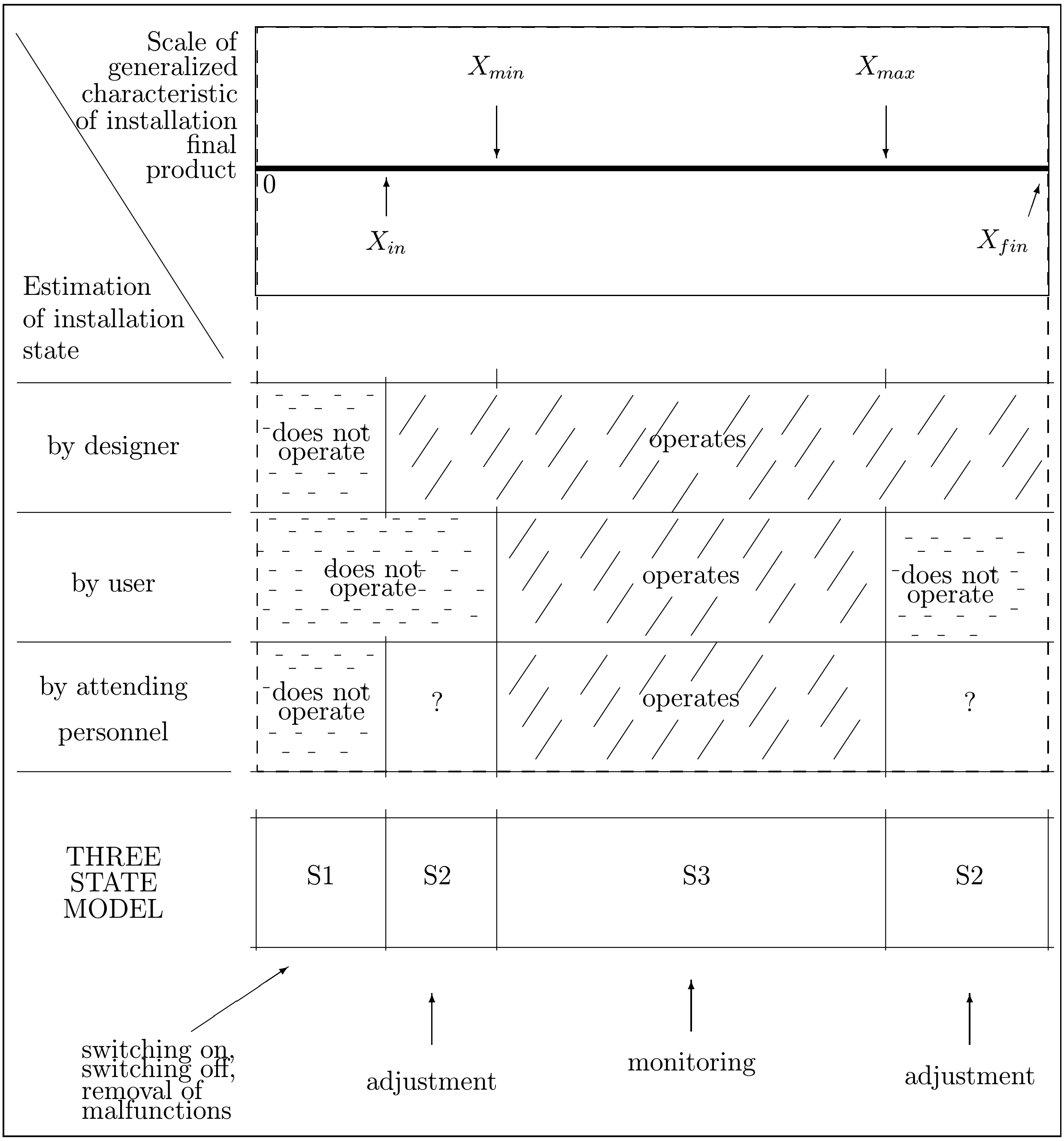

Fig. 2. Three viewpoints on installation operation: designer's (X_{in}, X_{fin}); user's (X_{min}, X_{max}); attending personnel's who make a decision while operating the installation.

The work of the installation is provided by interaction of all elements of its structural break up. In accordance with technological process, each element is given a certain functional role. The result of execution of this role is the final product P' of the element operation. In the general case, two types of restrictions are imposed on the characteristics Y of final product P'. The first restrictions are caused by the conditions of installation functioning as an integral object. The operation of each element must provide the final product P at the output of the installation and must not set up an emergency for the operation of the related elements. Such restrictions are determined by the designers with an account of a chosen mode of operation. We call these conditions technological. The boundaries of technological conditions are specified by the sets Y^t_{min} and Y^t_{max}.

The second type of restrictions is connected with the conditions that allow one to keep $S_p = s3$ in a given mode. We shall consider these conditions to be dependent on the user's requirements for the final product. The boundaries of these conditions are given by the sets Y_{min} and Y_{max}. Evidently, all restrictions should be related by the ratio

$$Y^t_{min} \le Y_{min} < Y_{max} \le Y^t_{max}.$$

The final product P' of the element of installation structural break up may be assigned as one of the three states of the set {s1,s2,s3}. Denote the current state of the final product of the element as $S_{p'}$. Then the rules for determining $S_{p'}$ will be writen as:

$$S_{p'} = \begin{cases} s1, & \text{if} \quad \exists y_j \in Y \quad y_j \notin [y^t_j min, y^t_j max]; \\ s2, & \text{if} \quad \forall y_j \in Y \quad y_j \in [y^t_j min, y^t_j max], \\ & \text{but} \quad \exists y_j \in Y \quad y_j \notin [y_j min, y_j max]; \\ s3, & \text{if} \quad \forall y_j \in Y \quad y_j \in [y_j min, y_j max]. \end{cases} \tag{3}$$

Having determined the state of the final product P' we shall estimate the state of the element according to the state of this final product:

$$\left[\begin{array}{lll} \text{if} & S_{p'} = s1 & , \textit{the state of the element is} \\ & & \quad \textit{considered "inoperative" (state } \mathbf{S1}); \\ \text{if} & S_{p'} = s2 & , \textit{the state of the element is} \\ & & \quad \textit{considered "operative" (state } \mathbf{S2}); \\ \text{if} & S_{p'} = s3 & , \textit{the element is considered to} \\ & & \quad \textit{operate "normally" (state } \mathbf{S3}). \end{array} \right. \tag{4}$$

The element is in state **S1** when the procedures of switching-on and -off are performed, or when a malfunction of the element involved appears in the process of operation. The element is in state **S2**, if it is not adjusted for a given mode after switching-on, or if a detuning occurred during its operation.

The state of the installation expressed through the states of the elements of its structural break ups will be called **the detailed state**.

Since each element of the installation is in one of the three states comprising the set {**S1**,**S2**,**S3**}, the detailed state of the installation is presented by a collection of such sets. Let us construct states matrix **S** [7], which has dimensional representation $n \times r$, where n is the number of the elements of installation structural break up, r is the number of possible states (r =3). The value of matrix element s_{ij} ($i = 1, \ldots, n$; $j = 1, 2, 3$) is defined by the following rule:

$$s_{ij} = \begin{cases} 1, & \text{if i-element is in j-state}; \\ 0 & \text{in other cases}. \end{cases} \tag{5}$$

When the installation is off, matrix **S** is

$$S = \begin{vmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ \dots & \dots & \dots \\ 1 & 0 & 0 \end{vmatrix}$$

and in the mode of normal operation (the final product P is in state s3 , $S_p = s3$) it looks like

$$S = \begin{vmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ \dots & \dots & \dots \\ 0 & 0 & 1 \end{vmatrix}.$$

All other fillings of the matrix reflect the intermediate states of the installation.

Fig.3 shows a simplified scheme of a linear accelerator for the first level of its structural break up. The accelerator operation is provided by interaction of its basic elements: 1) the system of ions injections; 2) the matching channel; 3) the system of accelerating structures; 4) the system of high-voltage high-frequency power supply; 5) technological systems supporting the operation of all elements. The final product (a beam of accelerated particles) depends on the states of final products of each of the five elements. The detailed state of the first level of the accelerator structural break up is presented by matrix **S** with dimensions 5×3. Table 1 shows the functional purposes and corresponding final products for elements 2-4.

1.3. Observability of installation operation

We shall consider the installation observable, if there is a possibility to determine unambiguously its detailed state in any mode of operation.

Fig.4 demonstrates a relationship between the introduced concepts using one element as an example. The performance of each element supports a particular technological process. The behaviour of the process is defined by a number of technological parameters $Z = \{z_k\}$, where k is the number of essential parameters of the process involved.

Let us distinguish three ways of determining the states of element $S_{p'}$. The first way consists of direct measurement of characteristics of P' and their estimation according to rules (3). This estimation is most reliable. The second way is associated with defining the state of the element according to the magnitudes of its technological parameters. Such definition of $S_{p'}$ is indirect. Reliability of the results obtained by the second way depends on whether there are reciprocally unambiguous relations $\{y_j\} \leftrightarrow \{z_k\}$.

Interrelations are revealed by the designers of the installation at the stage of preliminary tests. Providing such relations exist, the restrictions for Y are replaced by restrictions for Z for those characteristics of P', which are assumed to be evaluated by the second way. In rules (3) part of values from the sets Y^t_{min}, Y_{min}, Y_{max}, Y^t_{max} are replaced by the values from the sets Z^t_{min}, Z_{min}, Z_{max}, Z^t_{max}. As an example, technological parameters Z and characteristics Y of the final product P' for one of the elements (fig.3, element 1) of a linear accelerator and possible ways for evaluating $S_{p'}$ during installation operation are given in Table 2.

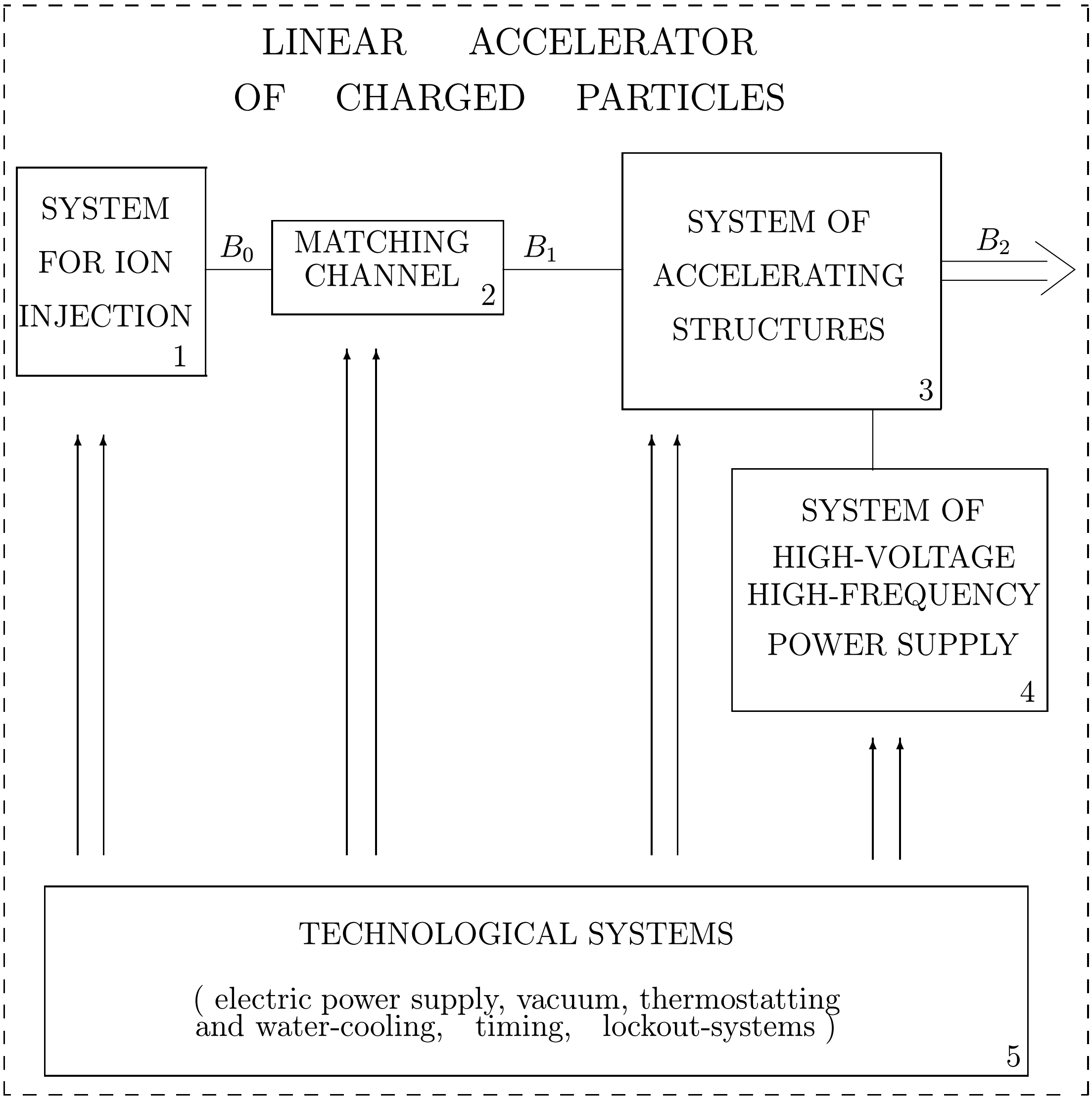

Fig. 3. Simplified scheme of a linear accelerator for the first level of structural break up: B_0, B_1, B_2 is the beam of charged particles in three points of the installation; B_2 is the final product of the installation.

Determinancy of the element operation is a property of the element to make the final product with the same characteristics (within permissible errors) at the same values of its technological parameters.

The third way, probably the most complicated, is an estimation of state of P' resulting from the interaction of the elements. For example, such characteristic as a measure of matching the phase volume of a particle beam (see Table 1) with the input into accelerating structures (element 3) can be determined by the value of beam current passage rate κ ($\kappa = I_2/I_1$) under the condition of normal operation of elements 3-5 .

Thus, one of the characteristics of the final product of element 2 is estimated from the result of interaction of elements 2-4 .

Determination of the conditions for constructing rules (1),(3) might require special experiments [11] to establish the parameters of interactions between the elements for a given mode.

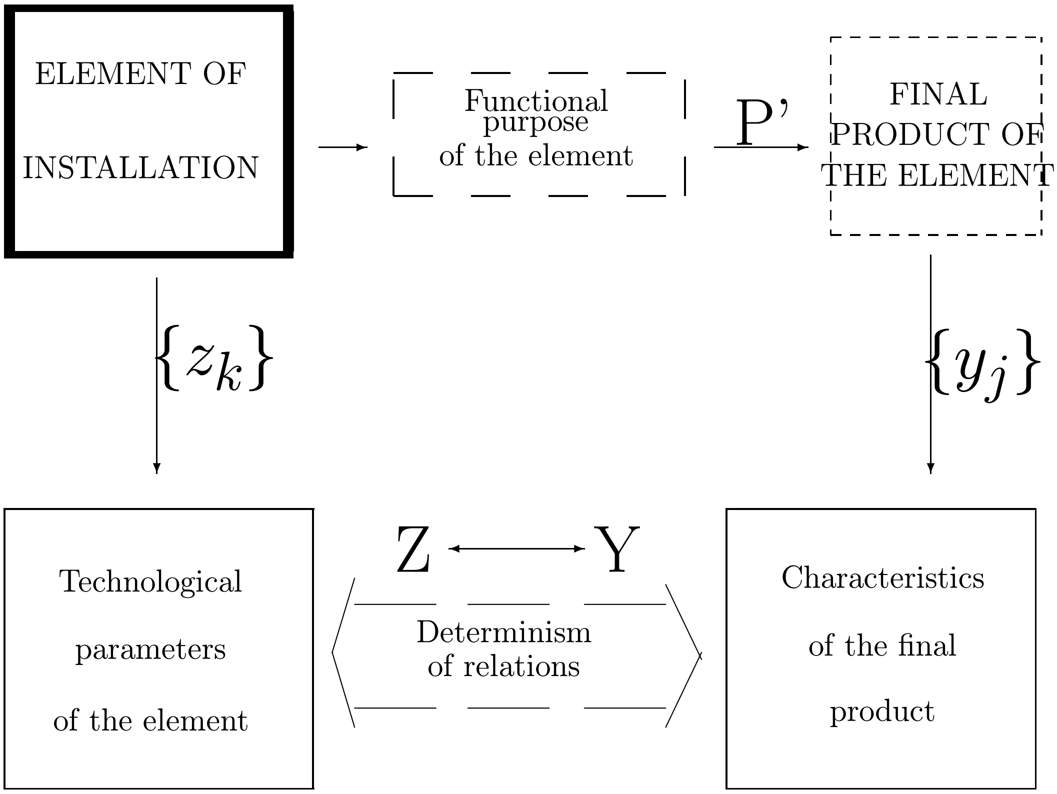

Fig. 4. The scheme of interrelations between the concepts describing the operation of the elements of installation structural break up.

1.4. The model of the installation control process in the mode of its exploitation

Installation control in the mode of its exploitation is the performance of the procedures of switching on, adjustment, switching off and restoration of normal technological operation in the case of a failure.

The procedures of switching on, adjustment and switching off are presented as processes of switching on, adjustment and switching off of the set of the elements of its structural break up. The notions introduced allow us to regard the model of the control process as an execution of two procedures: 1) determination of the current detailed state of the installation; 2) execution of a sequence of steps in order to transfer the installation from its current state to a predetermined one. Controllability of the installation means an opportunity to transfer its elements from one state to another in a definite time.

Formalization of the process of installation control during its exploitation is a presentation of controlling procedures by a set of formal rules, which enable the operating personnel to switch on, adjust, switch off and restore the conditions of no-failure operation of the elements without going into physical processes.

2. ESTIMATION OF QUALITY AND EFFICIENCY OF INSTALLATION OPERATION

2.1. Certification

The task of high priority in installation exploitation is to obtain the final product. Information concerning the characteristics of the final product is necessary in order to answer question [5] whether the quality of the final product meets the user's requirements for solving his problems. Certification means the measurement and statistical estimation of the final product characteristics: $< X >= \{< x_i >, \sigma_{x_i}\}$.

Terms of certification:

1. Certification is performed for each installation mode in which it is supposed to be used.
2. If the installation works in an automatic mode (e.g., a linear accelerator) after starting-up and bringing it to a given operating point, then while making measurements it is prohibitive for an operator to intervene in the work of the elements.
3. Duration of observations is chosen so that to provide reliability of statistical estimates of the final product characteristics.
4. Filtration of the data measured to improve the indications of quality is ruled out.

A list of technical means for measuring the final product characteristics contains primary signal convertors (transducers), secondary convertors (measuring channels) and means of data acquisition and storage (a computer). Conventional primary transducers for sensing the final product characteristics are not always available for specific engineering objects. The development of such trancducers is the problem calling for special attention.

The level of electronic industry development allows the measuring systems to be assembled mainly with unified structural modules. If one finds it necessary to take into consideration some peculiarity in measuring some definite parameters, then one's own developments for the construction of measuring channels are accepted. Certification implies availability of techniques and programs for calibration of primary convertors and measuring channels, procedures of measurement, acquisition and storage of data, models for processing (conversion to physical quantities, computation of statistical characteristics).

As a rule, the technical objects concerned are the complex dynamic installations. A functional feature of some of them, for example, of a charged particle accelerator, is that the final product really exists only in the process of installation operation. Therefore, monitoring over the final product characteristics of the installation should be carried out permanently with predetermined periodicity depending on stability of technical elements operation, e.g., as shown in [12].

2.2. Determination of indications of application efficiency

As was mentioned earlier, every user establishes his own requirements for the quality of the installation final product depending on peculiarity of the problem to be solved. A user wishes to know the real time when the final product with all necessary characteristics is obtained. In case a user sets more stringent requirements than those indicated in the certificate, i.e. $X_{in} < X_{min}$, or $X_{fin} > X_{max}$, then he would like to make real estimation of efficiency the installation can provide for the solution of his particular problem.

The model introduced (see fig.2) permits us to estimate the operation efficiency for the user's goals. To achieve this, an account is to be taken of the time [13], when the installation is in each of the states. If the installation is in state **S1**, then **T1** is the time during which the installation does not operate for the final result. **T1** is the sum obtained from adding the time of switching on the installation elements and systems, the time of their transferring to the mode when the final product emerges at the output, and the time of performing the restoration works in case some failures of technical elements are discovered. If the installation is in state **S2**, then **T2** is the time of its being in state **S2**. **T2** involves the time of the system adjustment to a given mode after switching on and start-up, and the time of removing instabilities arising in the process of operation. The installation operates "normally" when it is in state **S3**. **T3** is the time of operation in a given mode.

Numeric indicator for estimation of efficiency of installation exploitation for different purposes – a coefficient of effective exploitation (**CEE**) [13] – is defined by the formula

$$\mathbf{CEE} \ = \mathbf{T3} \ / \ (\mathbf{T1{+}T2{+}T3}) \ .$$

Traditional calculation of idletimes in operation can by accounted by means of the coefficient of idletimes (**CIT**)

$$\mathbf{CIT} \ = \mathbf{T1} \ / \ (\mathbf{T1{+}T2{+}T3}) \ .$$

CIT characterizes reliability of operation, and **CEE** shows its efficiency in a particular mode. **CIT** can replace **CEE** only in those cases when the user's requirements are consistent with certification parameters.

Taking into consideration relativity of the boundaries between **S2** and **S3**, one should speak of the relativity of indicator **CEE** as well. Application of the technique of estimating **CEE** at the stage of installation preparation for exploitation will allow us to draw up a chart of operation efficiency in different modes. By means of this chart every user of the final product can plan the duration of his work in a particular mode of functioning. For specific installation a chart of the mode characteristics should be attached to the certificate.

3. LEVEL OF DETERMINANCY OF OPERATOR'S ACTIONS

A control over complex installations envisages the participation of a man. Therefore, effective and no-failure exploitation of installations is explained to a great extent by the answers to the following questions: if there are models enabling one to determine the actions of operating personnel in the process of operation, and, in case such models are available, how well the conditions of their application in real work are provided.

Working out an installation the designers study complicated transitional phenomena and investigate the processes of interaction of many elements. As a rule, conventional models of the states in space of parameters are widely used. Installation usage for solving practical problems shifts from research to exploitation.

Remaining in the frame of traditional concepts concerning the state of the installation, it is difficult to formalize the procedures of switching on, adjustment, switching off and search for malfunctions. Therefore, for a number of engineering objects the operator's work becomes the engineering art. In such cases the construction of complex and potentially dangerous installations requires high-proficient personnel, e.g. for nuclear power plants. That is why a search for alternative approaches to formalization of making decisions in the procedures of operation is needed.

If conventional models describing the state of the installation are directed towards the study of dynamics of occurring processes, the approach suggested is based on estimation of the state of the installation depending on how each element executes its function. In exploitation the structural break up of the installation may be multilevel. This break up is performed up to the levels of those elements which are necessary for an operator to control the installation. The concepts introduced in Section 1 allow us to represent the process of operation by two procedures: the procedure of determining the current detailed state of the installation, and the procedure of executing a sequence of steps for switching on, adjustment and switching off the elements when the installation is transferred from its current state to a predetermined one.

The second procedure, as a rule, is formalized in terms of instructions made up by the designers of installation systems for an attending personnel. If the state of the installation at some specific moment is known, the instruction regulates operator's actions determining what he can do and what he cannot. To formalize the instructions one can use [13] a state matrix $\mathbf{S}$. The instruction is reduced to a number of rules for sequential changes of the contents of matrix $\mathbf{S}$ by (1)-(5), and the contents itself is visualized for an operator.

Operator's actions can be determined only when the estimation procedure of the current state of the installation is automatic. It is impossible to rely on the fact that an operator can watch information on 15-20 monitors [14], where scores of alternating signals are displayed. It has been established [15] that person's attention can be limited by simultaneous recognition of only $5 - 7$ characteristics. Insufficient knowledge of the detailed state of the installation brings about some uncertainty in operator's actions and sometimes the consequences are difficult to foresee. Therefore, we consider automation of the first procedure to be an indispensable condition in organizing the exploitation of up-to-date installations taking into account their large scale and necessity for simultaneous cotrol over many parameters.

If a requirement for automatic acquisition and presenting information about the work of modern installations has become undoubtful [16], an opportunity to determine automatically the current state has not been widely practised yet. Difficulties lie in using the existing models in real time [17]. The concepts and models proposed can be applied to formalization of a procedure for determining the state in the mode of real time.

Automation of the process of determining the state is possible if two conditions are satisfied: provision of observability of the installation detailed state; provision of determinancy of operation of the installation as a whole and its separate elements. Lack of determinism in the element operation points to the presence of essential latent parameters. If there is no opportunity to define the states of all elements and the effects of latent parameters have to be compensated by changes of the known controlled quantities, then it is necessary to estimate how much this compensation complicates the control process and what operator's skills are supposed to be. The models suggested give some criteria to decide whether everything has been done for an operator to perform his duties consciously.

We propose to estimate a level of determinancy of operator's actions in terms of the answers to the following questions: *if there are elements whose states are unobservable, and how many of them are available; if there are significant parameters which have not been realized.* To receive the answers to these questions one must have a number of methods:

- The method of breaking up the installation into elements which are used by the operating personnel during an operation.
- The method of conducting experiments to reveal the determinancy of operation of the installation and elements of its structural break up.
- The method of determining the states of the elements according to the indications of available transducers.

4. LEVEL OF MONITORING OVER NO-FAILURE INSTALLATION OPERATION

Emergency situations are caused by two reasons: a failure of a particular element and incorrect actions of the personnel while transferring the installation from one state to another. The level of reliability of no-failure operation can be tested by answering the following questions: 1) *how adequately the conditions of no-failure operation of the installation as a whole and each element of its structural break up are presented*; 2) *if monitoring over the fulfilment of these conditions is provided*; 3) *if attending personnel have a plan of actions to restore no-failure technological conditions in case a failure occurs*; 4) *if there is an opportunity to control the personnel's actions in critical situations.*

The work of any installation is based on interaction of the elements of its structural break up. One common feature of installations is that the work of one group of elements defines technological conditions of another group related to the first one. It is by this fact that a definite sequence of actions during switching on, adjustment and switching off is explained. Thus, the conditions of no-failure operation lie in interaction of the elements. Monitoring over these conditions can be implemented by monitoring over the states of the elements.

For each element a_i, $i = 1, \ldots, n$, where n is the number of the elements of the installation structural break up, we shall make list L_i including those elements which determine technological conditions of element operation. Let us call these lists controlled. For some elements these lists may be empty. The conditions of no-failure operation can be defined as follows:

Technological operational conditions of element a_i are considered to be no-failure providing no installation element being present in its control list L_i is in state **S1**. *The state of the installation working for a user is considered to be no-failure providing technological conditions of operation of each installation element are recognized no-failure.*

Each list L_i will have a corresponding matrix of the states designated as S_{ai} made up of the list of elements. Monitoring over fulfilling the conditions of no-failure operation is made on the basis of the contents analysis of states matrices S_{ai}. The level of monitoring over no-failure operation conditions is estimated according to the execution of the following programs during preparation of the installation for its exploitation:

- drawing up lists L_i and matrices S_{ai}, $i = 1, \ldots,\ n$;
- making means for filling and regular renovation of the contents of matrices S_{ai};
- making means for an analysis of the contents of matrices S_{ai} by a computer and/or with the help of operator's visual monitoring.

A general approach in removing the faults is restoration of technological conditions of each element operation. If an operator cannot restore the functions of the element failed, then, according to a foreseen scenario, he must isolate those elements whose technological conditions are violated.

For each required transfer of the installation from one state to another an operator needs a prompt of permitted actions. The actions which might be faulty and give rise to failures should be performed by a computer to control man's work by a program.

CONCLUSIONS

The models and concepts introduced allow us to analyze the achievements of the designers from the standpoint of preparation of an installation for its exploitation, and to estimate everything that should be done for its effective and no-failure operation. One may say that a present-day engineering installation is brought up to its commercial prototype if:

1. The operation of each element and the installation as a whole is determinated.
2. The procedures of automatic determination of current integral and detail states are realized.
3. The technological conditions of no-failure operation of the elements are formulated and are under control.

Table 1. Some elements of a linear accelerator and related final products.

Element of structural break up	Functional purpose	Final product of element operation	Basic characteristics of final product
Matching channel (element 2)	Filtration of a beam of particles in terms of mass and energy, and making optimum conditions to input a beam into the system of accelerating structures	Transfer function $F = \ B_0 \to B_1$ 1) beam filtration f1: $A_0 \to A_1$ $W_0 \to W_1$ 2) matching of beam phase volume with characteristics of input of accelerating structures f2: $\varepsilon_0 \to \varepsilon_1$	Uniformity of particles of beam B_1 in energy W_1 and mass A_1 at the input into the system of accelerating structures (B_0 is the beam at input of matching channel, A_0 is mass composition of beam B_0)
			Measure of matching of phase volume ε_1 of beam B_1 with input into system of accelerating structures (ε_0 is phase volume of input beam B_0)
System of accelerating structures (element 3)	Capture and accelerating of a beam of particles up to energies required	Beam of accelerated ions with preset characteristics B_2 FINAL PRODUCT FOR A USER	Current of accelerated beam in pulse I_2
			Duration and shape of pulse of beam current
			Energy of beam W_2
			Phase volume of a beam at output ε_2
			Mass composition of a beam at output A_2
System of HF power supply (element 4)	Feed of HF power into accelerating structures and making stable oscillations of HF-field in cavities	High-voltage high-frequency pulse U_{hf}	Operating frequency f_{hf}
			Amplitude of pulse envelop of HF power U_{feed}
			Relation of amplitudes of the signal U_{feed} and reflected signal U_{refl}
			Fall down level of HF field in cavity during the beam

Table 2. Some general information about the system of injection of a proton linear accelerator.

Element of installation break up	Functional purpose of element	Some technological parameters of element	Final product of element	Basic characteristics of element final product	Method of determining characteristics in real time: 1) direct measurements [8]; 2) by measurements of technological parameters [8,9]; 3) by account of interaction with other elements [10]
System of ions injection (1)	Making a beam of accelerated particles	U_{valv} is valtage of valve of hydrogen leak-in into source of ions	Beam of ions B_0	Beam current in pulse I_0	1)
		t_{arc} is the time of arc-discharge ignition after hydrogen leak-in		Duration and shape of beam current pulse	1)
		I_{arc} is arc discharge current		Beam energy W_0	2)
		U_{it1} is accelerating voltage		Beam phase volume ε_0	2)
		U_{it2} is forming voltage		Beam mass composition A_0	3)
		$I_{м}$ is current of ions source magnet			

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