UDC 629.783:5233+519.7+62-69

BASIC PRINCIPLES OF BUILDING OF E-NETWORK MODEL OF A COMPLEX TECHNICAL SYSTEM

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Methodological bases of building of dynamic models of hybrid systems using principles of a «block» modelling are exposed on the basis of the E-network formalism. The presented methods are based on use of mechanisms of hierarchical interaction of dynamic model elements. Principles of organization of E-network hierarchical circuits with use of rigid and flexible structures are shown. The mechanism of interaction of static and dynamic components is specified.

At the present an essential complication of the automated control systems of various technological processes is occurring. It places new, more rigid requirements to training of the attendants of the given systems. The complete use of multipurpose computer simulators (MCS) is possible only in the case if its software is capable to function in real time or accelerating process which is simulated.

To solve the given problem it is necessary to develop the general approaches to organization of the E-network [1] analytical-imitating model (AIM).

The important question in building of analytical-imitating model (AIM) of the system to be researched is development of the general approaches in the organization of E-network model. The methodology of building of AIM for complex systems is based on the objective approach to the organization of the model to be researched and consists of the following basic positions:

1) Any model represents the set of the unidirectional objects (further the term – component *Comp* is used), interacting each with other, that allows to realize the cause and effect approach in building of the model;
2) Components of the model are chosen taking into account the minimal number of interrelations between components of the model and the minimum level of interaction (i.e. intensity of data exchange) between components;
3) Data exchange occurs with help of connection channels;
4) Components of model are built by a hierarchical principle;
5) Some processes being independent from each other can be executed in the model, i.e. components can function in parallel and independently from each other;
6) Model components can correspond both to concrete technical objects of system and its elements, and to abstract mathematical objects, for example, transformation operators.

AIM of the technical system Σ_0 to be researched are presented as integration of components with the certain interrelation. The quantity of components of the model is defined by mode of MCS operation and degree of detailed elaboration of the system. Every component of the technical system model, realized on the E-network imitating apparatus, can be presented by hierarchical structure «an input – a condition – an output». Functioning of model component is considered in the E-network apparatus, on accounting set of the time moments $T=\{t_0,t_1,...,t_?,...\}$.

As a result of interaction of model components with each other and processings of a data stream from an environment model the set of events $E=E'\cup E''$ is occurred, where E' – is a subset of external events, $E'=\{E'_1,E'_2,...,E'_\mu\}$, characterizing occurrence of input signals $\{X_\mu\}$, E'' – is a subset of internal events, $E''=\{E''_1,...,E''_K\}$. As internal events the beginning, the ending of computing process, as well as sending of the message (chip) to other components can act. Action of model makes change of the system state vector $Z(t_v)\,z\in R$. Generally the system state can have hierarchical structure. The state of any object is characterized by phase variables $Z_l(t_v),\{z_l,l=\overline{1,L}\}$ at the time moment $t_v\in T$. The state vector $Z_l(t_v)$ is formed due to processing of external (input) influences and inner state of the component in t_{v-1}. Data exchange between objects as it was already marked above, is carried out on a connection channels by moving of chips V_i on the network. Value is assigned $X(t_\mu),\{x_\mu,\mu=\overline{1,M}\}$ to input signals only «from the outside», i. e. at reading of components of chip attributes. Value to output signals $Y(t_\xi),\{y_\xi,\xi=\overline{1,\Xi}\}$ can be assigned only «inside» the model component unit. An input/output is presented by managing commands, including service, physical characteristics of the components, as well as the data on an environment.

At building of an AIM it is proposed to define model as set of *static* Stc_i, $i=\{1,...,N\}$, and *dynamic* Dc_j, $j=\{1,...,M\}$ components $Stc\cup Dc\subset M_D$. The subset of static components $Stc=\{Stci\}$ of technical system model contains the elements which are *constantly* physically presented in the technical system and do not depend on a phase of the technological process proceeding at present moment of time, and carry out beforehand certain function, i. e. are a constant resource of system. Static components (SC) are characterized by certain structure *Struc*, algorithm of functioning *Alg*, the operator of transformation of variables $H{:}X\xrightarrow{\Delta t}Y$ and duration of reaction of the system Δt. Thus, the static components of the model are elements of the control system of technological processes (control PC, executive mechanisms, gauges etc.), as well as elements of the object of control itself. Dynamic components (DC) of the model are variable resources in the technical system and are characterized by the fact that they have qualitative and quantitative change of physical (information) parameters in dependence on TP phase. Dynamic components in technical systems are material (fuel, heat-carriers, electric current etc.) and information streams with the given set of parameters over which the SC makes actions. In the apparatus of E-networks DC is presented by chip V_{DC} with the structured set of attributes: *X, Z, Y, Ind*, where $Ind \in N$ is identification parameter of the chip.

To form the model taking into account the cause and effect relationships it is necessary to enter the following kinds of components: control components and components to be controlled. Objects which *make actions* (technological, control operations etc.) *over other objects* of the system (dynamic), or these actions have dominant character, are named the control components – *Contr_C*. Objects of the system over which the actions are made, or this process is prevailing, are named the components to be controlled – *Dir_C*.

During functioning of the model each component can be either *active*, or *passive* object. The active component has ability to initiate action i. e. to change its data and to send messages irrespective of an external environment. Passive components change data value only at presence of external influence. Active components of the model are:

1) generators of an environment;
2) generators of malfunctions of devices and elements of the system model;
3) the simulator of activity of the operator.

Data exchange between components of the model is made by means of transfer of the message where a data carrier in the E-circuit is the chip.

The block diagram of interaction of the system components is presented on Fig. 1 where each static component of the model has the following structure:

1) the set of input $X^{L(i)}_{stc(k)}$ and output $Y^{L(i)}_{stc(k)}$ channels of the k^{th} component of the model, where L_i – is connection between k^{th} and i^{th} objects;
2) the set of input X_{Mk} and output Y_{Mk} channels between external elements of the model (subsystems of profiling, giver of external influences) and *k-component*;
3) a level of hierarchy $g_k \in N^{Gk}$.

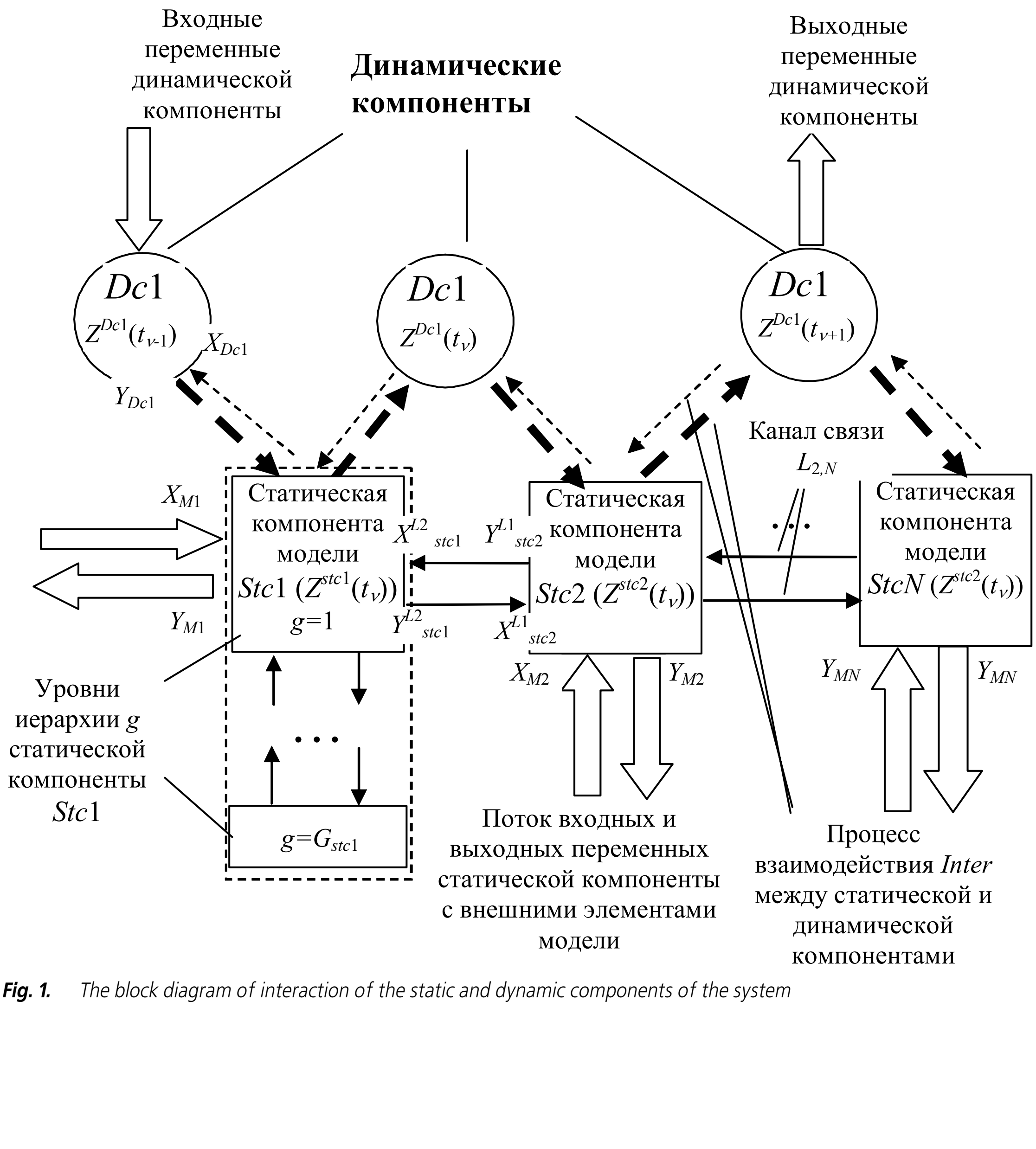

Fig. 1. *The block diagram of interaction of the static and dynamic components of the system*

Dynamic components also have input, output variables: X_{Dc}, Y_{Dc} and the state vector Z_{Dc}.

Process of interaction of the model components in a general view is wrote in the following form: $Inter(Stc_1(\{x_1,x_2,...,x_l\}), Stc_2(\{y_1,y_2,...,y_p\}),\Delta t,Alg)$, where *Inter* – is a rule of interaction of the two components of the model according to given algorithm *Alg* on the time interval Δt; $Stc_n(\{x_1,x_2,...,x_l\})$ – is the n^{th} component of the model with parameters $x_1,x_2,...,x_l$; $Stc_m(\{y_1,y_2,...,y_p\})$ is the m^{th} component of the model with parameters $y_1,y_2,...,y_p$.

The interrelation between the static and dynamic components is shown on Fig. 1 by dashed lines, and thickness of lines reflects a level of an information stream between the system components. Process of interaction between SC and DC can be illustrated on the following example: network water (*Dc*) which is set in the model by a stream of chips, has a set of characteristics: temperature $z_1(t)=T$ and concentration of impurity (salts) in the heat-carrier $z_2(t)=N_s$. At flowing of the heat-carrier on the pipeline (*Stc*) the physical generalized characteristics – pressure of water, velocity of water, turbulent/laminar current, pressure difference an input and an output, temperature on an output – are formed at dynamic components in process of interaction with the static element of the model. By consideration of physical processes in a long time interval (days, months), i. e. modelling of long time interaction of the two considered component, occurs increase of hydraulic resistance of the pipeline due to deposition of salts. At excess of hydraulic resistance over critical one the component [pipeline] state accepts new value {«MALFUNCTION» $P>P_{max\_out}$}.

Realization of the static components of the model is based on use of a set *of EN*-elements: transitions, positions, turns with a structure being constant in time. It is expediently to realize the dynamic components with the help of chips which provide property of changeability of the presence in the system by means of moving on E-network scheme with calculation of endogenous parameters.

At creation of AIM in *EN*-basis it is expedient to assign the following functions onto E-network transitions /macrotransitions:

1. realization of events *E*, i. e. transition C_j makes action of some element of the system.
2. generation of external influences;

Accordingly the positions of E-network model executes the following functions:

1) define a condition of transition operation, i. e. execute function of protective predicate of transition;
2) define a qualitative condition of the system, for example presence of a chip in the position tells that the device is switched on etc.

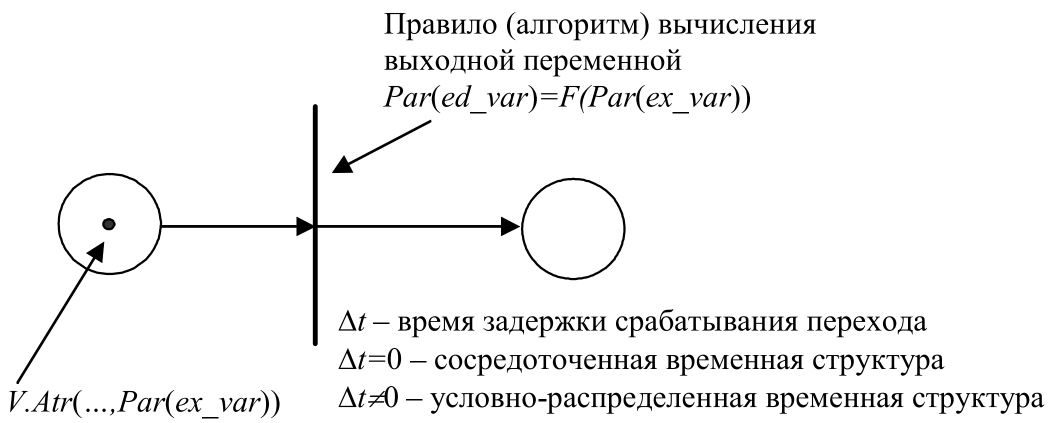

Fig. 2. *Realization of the model component with concentrated or conditionally – concentrated time characteristic*

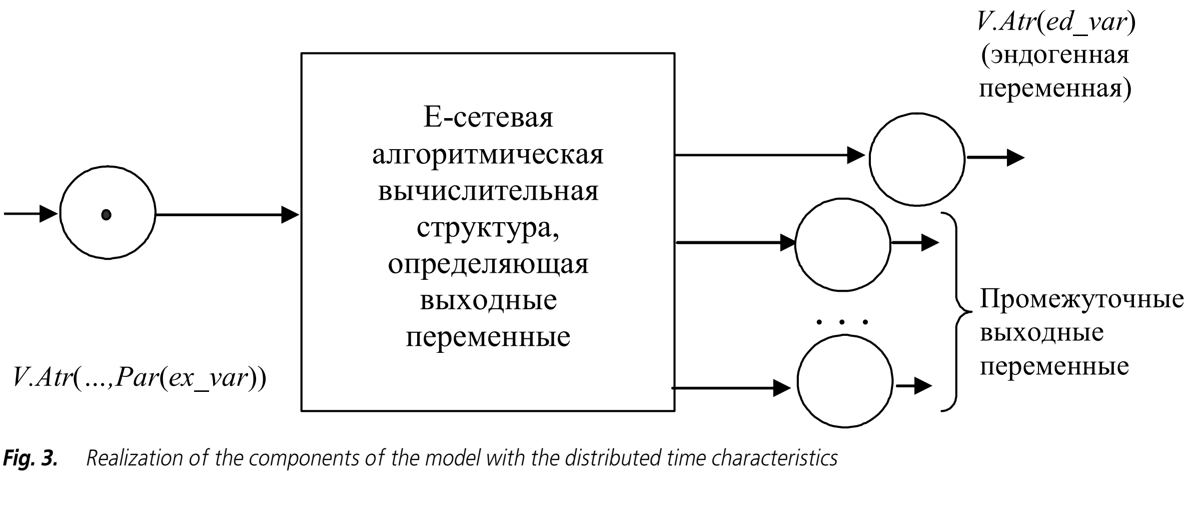

Fig. 3. *Realization of the components of the model with the distributed time characteristics*

A chip is an information carrier of the system sate, its objects, as well as internal and external commands. The chip attributes contain the following data: exogenous and endogenous variables, identifiers of physical value, parameters of the model components etc.

In addition to presentation of AIA as the interacting space hierarchical components between them, the method of simulating of the system is based on the important principle of decomposition of processes in time [2]. In relation to a simulation time all the model components are divided on three categories: *concentrated, conditional – concentrated and distributed.* The concentrated components in the simulation time always are executed instantly. Execution of anyone of other elements usually has nonzero duration and can be distributed between some consecutive imitation steps. Conditionally – concentrated and the distributed elements differ from each other by modes of occurrence in the time of the results as which it is necessary to understand new values of any phase variables. For conditional – distributed element they are defined only at the moment of its ending, and this component generated no data which appear on intermediate steps for immediate use the by other model components. At work of the distributed component calculations are carried out at the intermediate stages.

Realization of the concentrated process in the simplest case can be created with the help of *T -transition* (Fig. 2). At the established zero delay of operation of *T -transition* transformation of the chip attributes and recording of exogenous variables in the attributes.

On Fig. 3 E-network algorithmic computing structure carries out process of calculation of required output variables and conditions of the system, i. e. allows to realize the components working in the mode distributed in simulation time.

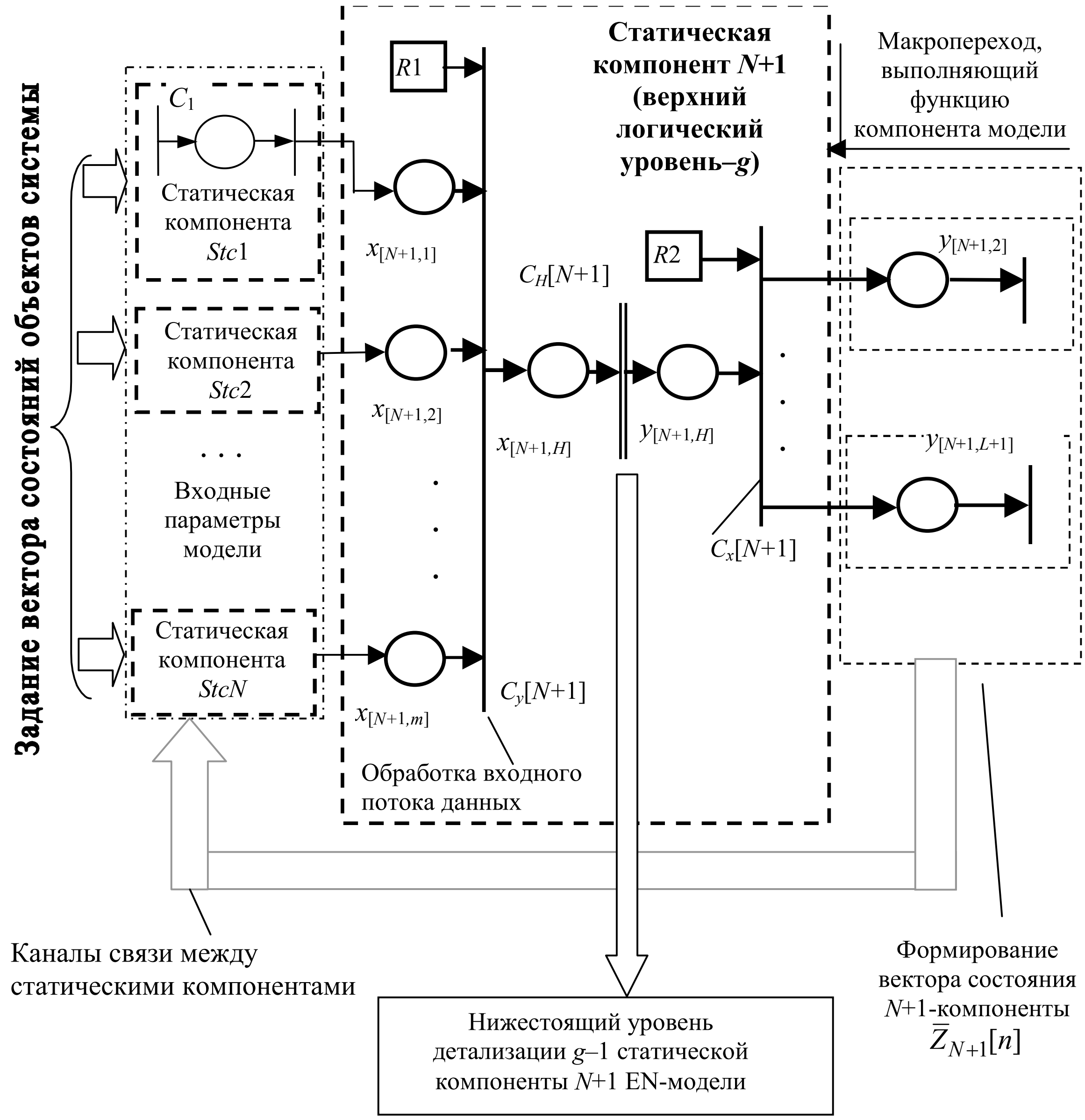

Fig. 4. *The generalized function scheme of components of the dynamic model of the technical system*

If intermediate output channels not to use in algorithmic structure (see Fig. 3) the given scheme can be used as conditionally – distributed time components.

The generalized Enetwork function chart of the logical-dynamic model of some components of the system is shown on fig. 4. In the model any component is presented even by one level of hierarchy, as a rule, logic.

The low levels contain E-network algorithmic schemes of imitation of dynamic processes [3, 4] for example schemes of solution of ordinary differential equations, the Lagrange interpolation schemes etc, i. e. the presented level is necessary to reproduce dynamic processes in any moment. Semantic sense of transitions of the component, presented on Fig. 4, is following:

$C_1,...,C_n$ – are generators of the vector of the i^{th} object state, $i=\{1, ..., n\}$;

$C_{y[N+1]}$ – is a processor of the obtained data on the i^{th} object state;

$C_{H[N+1]}$ – carries out calculation of endogenous variables;

$C_{x[N+1]}$ – forms the vector of the state of the $N+1^{th}$ object of the system.

Semantic sense of positions:

$b(x_{[n+1,1]}),...,b(x_{[n+1,m]})$ correspond to presence of applications on the state of adjacent static objects of the i^{th} object;

$b(y_{[n+1,1]})$ – the application from i^{th} object is served;

$b(y_{[n+1,2]}),...,b(y_{[n+1,m+1]})$ – positions of the global conditions of the system.

The description of transitions:

$C_{y[n+1]}=(Y(R1,b(x_{[n+1,1]}),...,b(x_{[n+1,H]})),(t1,t2,...,tn\to0),-)$ input of information streams from static and dynamic objects;

$C_{H[n+1]}$=(the hierarchical organization of transition) – executes process of calculation of endogenous variables with use of the algorithmic scheme of modeling;

$C_{x[n+1]}=(X(R2,b(y_{n+1,H}),...,b(y_{[n+1,m+1]})),(\Delta t^*),-)$ – a choice of the global state of the $N+1^{th}$ static component of the system and/or change of physical parameters of the dynamic component. $L1=\{1,...,l1\}$ is the number of global states of the object;

Δt^*: is the delay of operation of transition $C_{x[n+1,2]}$ is defined by velocity of $N+1^{th}$ component and the operation mode of the object (for example, switching on of the Object – 2 s, switching off – 0,9 s). At simulation of processes in the required time scale Δt^*_M is calculated by the formula:

$$\Delta t^*_M=\Delta t^* M_t,$$

where M_t – is the time scale, M_t=[s/(unit of measurement of a variable)].

The chip V_i of the network contains the information on a state object $V_i(v_1,v_2,...,v_n)$. At change of the state of the i- components a transfer of the chip V_i to the input position $x_{[N+1,i]}$ takes place. If the chip is absent in a position $x_{[N+1,H]}$, functioning of transition $C_{y[N+1]}$ occurs. Calculation of a new global state of the $N+1^{th}$-components is made basing of analysis of the i^{th} component state $Z_i[t_v]$ and $Z_{N+1[tv]}$. It is proposed to pin process of calculation of endogenous variables on the algorithmic scheme of simulation [5] realized with the help of macrotransition C_H. Process of activity ACM has, as a rule, the distributed character in time and allows to approximate functional action with required detailed elaboration. Further the chip stream is processed by transition $C_{x[N+1]}$, which carries out record V_i in the position $y_{[n+1,l]}$, $l=\{2,...,L+1\}$ where L is number of states in the $N+1^{th}$ component, which corresponds to the global state of the components ($b(R2)=l$). After that transfer of a chip (information) from object $N+1$ to adjacent components of model occurs.

The presented architecture of building of analytical-imitating model allows to simulate functioning of technical objects taking into account complex relationships of cause and effect connections and the diverse space-time organization of the system components. As the analysis of building of the model components by the E-network apparatus shows, the majority of schemes is realized by principle C_Y–C_H–C_X, where C_H – is macrotransition, realizing a hierarchical sublevel of the model component.

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