

## Efficiency of the Flexible Electronics Exotechnologies

**P. Balaišis, D. Eidukas, A. Žickis**

*Department of Electronics Engineering, Kaunas University of Technology,  
Studentų str. 50, LT-51368 Kaunas, Lithuania, phone: +370 37 300520, e-mail: andrius.zickis@gmail.com*

### The group of exotechnologies

Out of all electronics technologies (ET) related to electronic devices (ED) endotechnologies (ENT) [1] and exotechnologies (EXT) are distinguished among the rest. ENT specifics and efficiency are analyzed in [2], and efficiency of poly-controlled ENT – in [3].

Let's name the flexible (external) ET related with ED and processes inside them as flexible exotechnologies (EXT). These are ET which are often used between activities of ENT and other objects if technology or nature or/and manufacture technologies (their interfaces). Human operator often enters the effectuation of these ET. EXT forms parts of measures of mechatronics [4], aviatronics (avionics), biotronics [5] (biomedical electronics and fitotronics), manufacture or others. Their potential is often applied performing control of mechanical devices (e.g., industrial robots), biological objects, manufacture, production control, measurement systems and other objects.

Main features of EXT are: ET interfaces with mechanical, physical, biological or other processes; frequent involvement of human operator into these processes; dislocation of separate parts of the processes and measures needed to perform them over territory (space); application of specialized communication measures in order to assure interfaces between components; higher dependency of operation efficiency on the quality of external information; relatively lower performance compare to ENT; lower reliability of component interface measures compare to ENT; higher influence of non-stationary environment on reliability; open loop control is used more often than in case of ENT; better possibilities to expand, configure, etc., compare to ENT.

EXT consists of [1] ET of external, research, measurement, control of states, control, service, security and other ET. Efficiency evaluation methods of this group of flexible ET basically do not differ from efficiency evaluation methods of ENT [1, 2], but influence of other factors (information providing, control expedition, decision randomness, etc.) dominates. Let's try to assess it.

### Efficiency of information and control EXT

Efficiency evaluation peculiarities of information and control EXT depend on their structure levels (macrostructures, local structures, process structures, etc.). Let's start from the most general structure of EXT information and control measures (e.g., flexible manufacture control measures) (Fig. 1).

In Fig. 1:  $G$ ,  $P$  and  $R_i$  are the levels of control of manufacture, manufacture measures and manufacture type;  $C_{ij}$  and  $L_{ij}$  are systems of centralist and local control of the  $i$ -th manufacture type in the  $j$ -th manufacture complex;  $K_{ij}$  and  $K_{ij}^{(L)}$  is the  $j$ -th manufacture complex (with its ENT) of the  $i$ -th manufacture type;  $T$  and  $S$  are the systems of transportation and storage;  $T_V$  and  $S_V$  are systems of control of  $T$  and  $S$ . Each component of the graph denoted by circle may have ENT or even sets of ENT and EXT inside of it, which are meant for internal control. The entire graph illustrates general composition of EXT.

It can be seen from Fig. 1 that information and control measures dominate in these EXT. It can be stated that EXT operates efficiently only then, when each  $K_{ij}$  and their entirety will perform efficiently. In this case the efficiency of  $K_{ij}$  (considering its servicing)

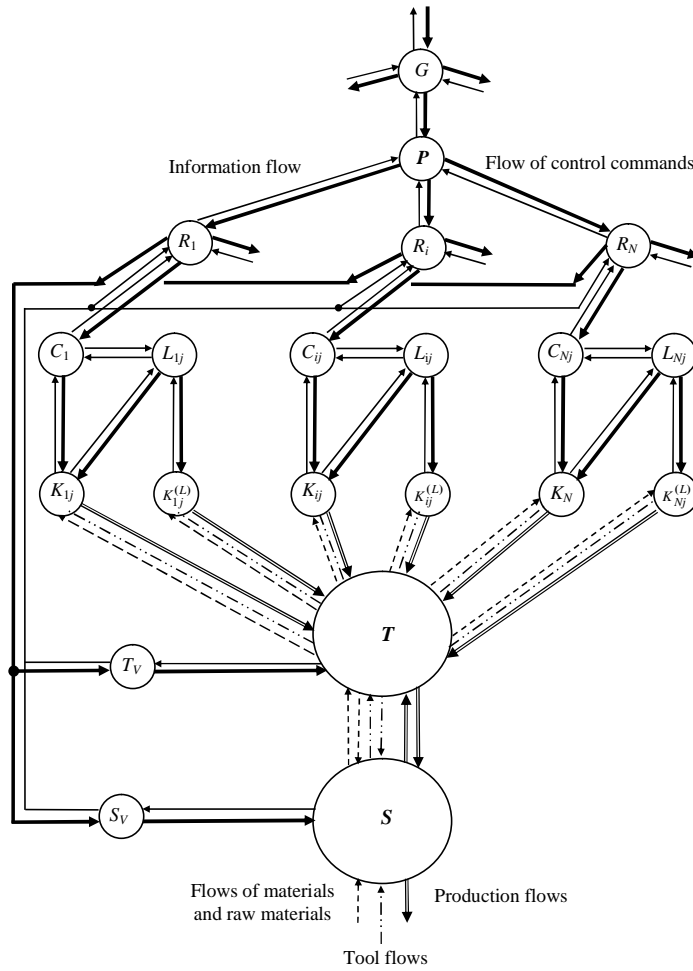
$$E_{Kij} = K_{oS\downarrow}^{(ij)} \cdot K_{oS}^{(ij)} \cdot K_{oS\uparrow}^{(ij)} \cdot K_{oS_V}^{(ij)} \cdot K_{oT}^{(ij)} \times \\ \times K_{oT\uparrow}^{(ij)} \cdot K_{oTV}^{(ij)} \cdot K_{oi\Sigma}^{(ij)}; \quad (1)$$

$$K_{oS\downarrow}^{(ij)} = K_{oM}^{(ij)} \cdot K_{oI}^{(ij)} \cdot K_{oI}^{(ij)}; \quad (2)$$

here  $K_{oM}^{(ij)}$ ,  $K_{oI}^{(ij)}$  and  $K_{oI}^{(ij)}$  are the coefficients of operative preparedness of external complexes to supply the storage with materials, tools required by the complex  $K_{ij}$ , and to take its production;  $K_{oS}^{(ij)}$  and  $K_{oT}^{(ij)}$  are the coefficients of operative purpose of  $S$  and  $T$  systems to perform tasks assigned to them by the complex  $K_{ij}$ ;  $K_{oS\uparrow}^{(ij)}$  and  $K_{oT\uparrow}^{(ij)}$  are coefficients of operative preparedness of

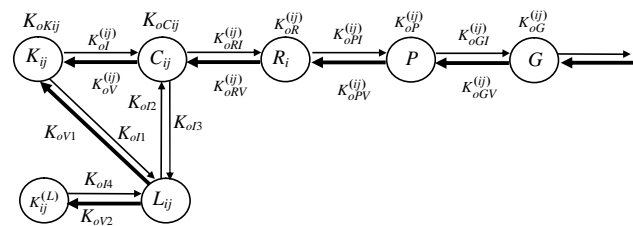
storage and transportation systems to supply their outgoing material flows intended for the complex  $K_{ij}$ ;  $K_{oSV}^{(ij)}$  and  $K_{oTV}^{(ij)}$  are coefficients of operative preparedness of

centralist control measures of storage and transportation systems when performing functions related to activities of the complex  $K_{ij}$ .



**Fig. 1.** Interfaces of components of the flexible manufacture

Calculating  $K_{oij\Sigma}^{(ij)}$  excluded control structure of the  $K_{ij}$  macrocomplex (Fig. 2).



**Fig. 2.** Scheme of control of the complex

Control efficiency of the lowest complex  $K_{ij}$

$$E_{\dot{z}_{ij}} = K_{oKij} \left[ 1 - \left[ 1 - K_{oI}^{(ij)} \cdot K_{oCij} \cdot K_{oV}^{(ij)} \right] \times \left[ 1 - K_{oI1} \cdot K_{oI2} \cdot K_{oI3} \cdot K_{oV1} \right] \right] \quad (3)$$

$$K_{oCij} = K_{oCij}^{(')} \cdot K_{oRi}^{(ij)} \cdot K_{oR}^{(ij)} \cdot K_{oRV}^{(ij)}; \quad (4)$$

here  $K_{oCij}^{(')}$  is coefficient of preparedness of endotechnologies of  $C_{ij}$  system.

Analogously

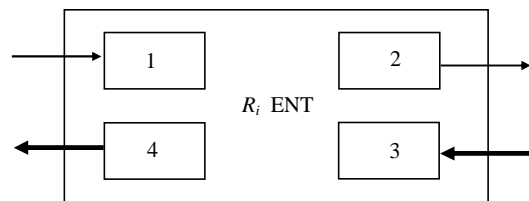
$$K_{oR}^{(ij)} = K_{oR}^{(')} \cdot K_{oPI}^{(ij)} \cdot K_{oP}^{(ij)} \cdot K_{oPV}^{(ij)}; \quad (5)$$

here  $K_{oR}^{(')}$  is coefficient of operative preparedness of endotechnologies of system  $R_i$ , when performing control tasks of the complex  $K_{ij}$ . Therefore

$$K_{oP}^{(ij)} = K_{oP}^{(')} \cdot K_{oGI}^{(ij)} \cdot K_{oG}^{(ij)} \cdot K_{oGV}^{(ij)}; \quad (6)$$

here  $K_{oP}^{(')}$  is coefficient of operative preparedness of endotechnologies of manufacture measures control system when performing tasks of control of the complex  $K_{ij}$ .

When calculating  $K_{oCij}^{(')}$ ,  $K_{oR}^{(')}$  or  $K_{oP}^{(')}$  the scheme of the components of this node (e.g., scheme presented in Fig. 3 can be used when calculating  $K_{oR}^{(')}$ ).



**Fig. 3.** Internal structure of the system  $R_i$

In this structure: 1 and 2 – measures of information reception from the lower control level and transmission to higher level; 3 – measures of reception of control commands from the higher level; 4 – measures of external presentation of control commands formulated in  $R_i$  system and intended for system of lower level. Thus

$$K_{oR}^{(l)} = K_{oR1} \cdot K_{oR2} \cdot K_{oR3} \cdot K_{oRi} \cdot K_{oR4}; \quad (7)$$

here in this formula the coefficients of operative preparedness of all components presented in Fig. 3 are indicated.

When calculating value  $K_{oRi}$  it is possible to use (considering situation specifics) efficiency evaluation methods of control decision making models, control algorithms and other [6,7] attributes.

Then

$$K_{oP}^{(l)} = K_{oP1} \cdot K_{oP2} \cdot K_{oP3} \cdot K_{oP} \cdot K_{oP4} \quad (8)$$

and

$$K_{oCij}^{(l)} = K_{oC1} \cdot K_{oC2} \cdot K_{oC3} \cdot K_{oC} \cdot K_{oC4}. \quad (9)$$

Here all denotations are identical to ones described after formula (7). After inserting expression (8) into formula (6), (7) – into (5), (9) – into (4), and the newly received: (6) – into (5), (5) – into (4) and (4) – into (3) we have that

$$\begin{aligned} K_{oij\Sigma} = E_{Zij} = & K_{oKij} \cdot \left[ 1 - \left[ 1 - K_{oI}^{(ij)} \cdot K_{oC1} \cdot K_{oC2} \cdot K_{oC3} \times \right. \right. \\ & \times K_{oC} \cdot K_{oC4} \cdot K_{oRI}^{(ij)} \cdot K_{oR1} \cdot K_{oR2} \cdot K_{oR3} \cdot K_{oRi} \cdot K_{oR4} \times \\ & \times K_{oPI}^{(ij)} \cdot K_{oP1} \cdot K_{oP2} \cdot K_{oP3} \cdot K_{oP} \cdot K_{oP4} \cdot K_{oGI}^{(ij)} \cdot K_{oG}^{(ij)} \times \\ & \left. \left. \times K_{oGV}^{(ij)} \cdot K_{oPV}^{(ij)} \cdot K_{oRV}^{(ij)} \cdot K_{oV}^{(ij)} \right] \times \right. \\ & \left. \times \left[ 1 - K_{oI1} \cdot K_{oI2} \cdot K_{oI3} \cdot K_{oV1} \right] \right]. \quad (10) \end{aligned}$$

When all complexes (from  $K_{11}$  to  $K_{NM_N}$ ;  $M_N$  – number of complexes of  $N$ -th group) form a set of manufacture types, then their joint efficiency

$$E_{\Sigma} = \sum_{i=1}^N \sum_{j=1}^{N_i} \beta_{ij} \cdot E_{Kij}; \quad (11)$$

here  $\beta_{ij}$  is the significance coefficient of  $i$ -th group  $j$ -th complex.

When all complexes form integral macrocomplex of manufacture, then their overall efficiency

$$E_{\Sigma}^{(l)} = \prod_{s=1}^D E_{Ks}; \quad (12)$$

$$D = \sum_{i=1}^N M_i; \quad (13)$$

here  $M_i$  is the number of complexes of  $i$ -th group;  $E_{Ks}$  is the efficiency of the  $s$ -th (in a row) complex.

It can be seen from formula (10) that when efficiency of ED is not considered,  $E_{\Sigma}$  mostly depends on efficiencies of supply of procedures with information and their control efficiencies.

## Efficiency of informational EXT

Efficiency of supply with information depends on information itself, preparedness to transmit it, quality of transmission, reception and usage. If we can limit ourselves to the statement that all the received information is objective, adequate to the characterized object, and individual data items are of required precision, then when assessing its quality it should be considered where from and when was it received, how largely it is systematic, what is its amount and how good it is suitable to solve the selected problem. By following the principle of the application of the first information source, it can be stated, that at each control level it will be additionally distorted and delayed.

Thus the efficiency of its transmission (Fig. 3) from 1<sup>st</sup> component to the 2<sup>nd</sup> can be expressed by probability that it will remain of sufficient quality

$$P_{RiI} = P_{Ri}^{(I)} \cdot P_{Ri}^{(S)}; \quad (14)$$

here  $P_{Ri}^{(I)}$  and  $P_{Ri}^{(S)}$  are probabilities that  $R_i$  component will not distort information and it will not get out of date while staying in it:

$$P_{Ri}^{(I)} = e^{-\lambda_{IRi} \cdot t_{Ri}}. \quad (15)$$

$$\lambda_{IRi} = \lambda_{IORi} \cdot \theta_{Ri}; \quad (16)$$

here  $\lambda_{IORi}$  is the intensity of distortion of information amount unit;  $\theta_{Ri}$  is the amount of information transmitted from 1 to 2 (with respective components);  $t_{Ri}$  is the duration of information delay in component  $R_i$

$$P_{Ri}^{(S)} = e^{-\lambda_{SN} \cdot t_{Ri}}; \quad (17)$$

here  $\lambda_{SN}$  is the intensity of ageing of information. When ageing intensity is not constant, then

$$P_{Ri}^{(S)} = e^{-\int_{t_{Ri1}}^{t_{Ri2}} \lambda_{SN}(t) dt}; \quad (18)$$

here

$$t_{Ri} = t_{Ri2} - t_{Ri1}. \quad (19)$$

Thus probability that information of sufficient quality will reach component  $G$

$$P_{I\Sigma} = P_{CijI} \cdot P_{RiI} \cdot P_{PI}; \quad (20)$$

here  $P_{CijI}$  and  $P_{PI}$  are probabilities that information will remain of sufficient quality in components  $C_{ij}$  and  $P$  (Fig. 2).

Level of information systematicity can be characterized by ration of numbers of assessed (when registering and transmitting data) and required for quality decision making interfaces, or by function of losses ( $C_{SS}$ ) due to not-assessed interfaces

$$P_{SS} = f_{SS}(C_{SS}). \quad (21)$$

Influence of information amount on the precision (reliability) (if it is not being redundant) of decision which is made on its base is evaluated only then, when control is performed using statistical control methods. Statistical method is more precise when more values are taken. In Chebyshev's opinion, it would be in this way: for each random value  $\xi$ , which has dispersion  $D$ , for the precision of each result  $\varepsilon > 0$  the following inequality is valid

$$P\left\{\xi - M[\xi] \leq \varepsilon\right\} \leq \frac{D[\xi]}{\varepsilon^2}; \quad (22)$$

here  $M[\xi]$  is mathematical mean of  $\xi$ .

If  $\xi_1, \xi_2, \dots, \xi_N$  is the series of random independent values with dispersion, characterized by one and the same constant  $D[\xi_1] \leq C; D[\xi_2] \leq C; \dots; D[\xi_N] \leq C$ , then regardless of the value of the constant  $\varepsilon > 0$ , we have

$$\lim_{N_b \rightarrow \infty} P\left\{\left|\frac{1}{N_b} \sum_{i=1}^{N_b} \xi_i - \frac{1}{N_b} \sum_{i=1}^{N_b} M[\xi_i]\right| < \varepsilon\right\} = 1. \quad (23)$$

Expressions (22) and (23) are fundamental and they express the precision. As we can see from expression (23), precision depends on the number of attempts. When number of attempts is high, equality between average arithmetical average and mathematical mean is obtained. It is obvious that

$$P(\xi) = \frac{m}{N_b}; \quad (24)$$

$$M[\xi] = \frac{1}{N_b} \sum_{i=1}^{N_b} \xi_i; \quad (25)$$

here  $m$  is number of successful attempts;  $N_b$  is number of all attempts;  $\xi_i$  is possible value of random quantity.

Assume that we have a series of independent tests  $N_b$ , for each of them we receive one of the possible values of random quantity  $\xi_i$ . We find dispersion and mathematical mean

$$\bar{\xi} = \frac{\xi_1 + \xi_2 + \dots + \xi_{N_b}}{N_b}; \quad (26)$$

here  $\bar{\xi}$  is the average arithmetical average of random quantity.

Assume that

$$M[\bar{\xi}] = M[\xi]; \quad (27)$$

$$D[\bar{\xi}] = \frac{D[\xi]}{N_b} = \frac{\sigma^2}{N_b}; \quad (28)$$

here  $D[\bar{\xi}]$  is the dispersion of random quantity ( $\bar{\xi}$ ).

When  $N_b$  are not large, quantity  $\bar{\xi}$ , is distributed in the following manner:

$$P(\bar{\xi} > \alpha) \approx \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi D[\bar{\xi}]}} \cdot e^{-\frac{(\bar{\xi} - M[\bar{\xi}])^2}{2D[\bar{\xi}]}} d\bar{\xi}; \quad (29)$$

here  $\alpha$  is reliability of the result.

From expression (29) we have, that when  $N_b$  is sufficiently large

$$P\left(\left|\frac{\bar{\xi} - M[\bar{\xi}]}{\frac{\sigma}{\sqrt{N_b}}}\right| < \varepsilon \frac{\sqrt{N_b}}{\sigma}\right) \approx \Phi\left(\varepsilon \frac{\sqrt{N_b}}{\sigma}\right); \quad (30)$$

here  $\Phi(\xi) = \frac{2}{\sqrt{\pi}} \int_0^{\xi} e^{-z^2} dz$  is normalized Laplace function;

$\varepsilon$  is desired precision of the result;  $\sigma$  is average square deviation of normal distribution.

By selecting value of probability  $P$  close to unit, we find  $t=f(P)$  value from tables of integrals, which satisfy this condition

$$\Phi(t) = P; \quad (31)$$

here

$$t = \varepsilon \frac{\sqrt{N_b}}{\sigma}. \quad (32)$$

We obtain stochastic estimate of  $\xi$

$$\left|\bar{\xi} - M[\xi]\right| < \varepsilon = t(P) \frac{\sigma}{\sqrt{N_b}}. \quad (33)$$

From expression (33) we have that

$$\left|\bar{\xi} - M[\xi]\right| < \varepsilon = \frac{3\sigma}{\sqrt{N_b}}. \quad (34)$$

Therefore uncertainty of the method does not exceed

$$\varepsilon = \frac{3\sigma}{\sqrt{N_b}} \quad (35)$$

and it grows less with increase of number of attempts, with reverse proportion to square root of  $N_b$ . It is important to select number of attempts before the beginning of tests,

when  $P(\xi)$  and  $\frac{m}{N_b}$  are still unknown. For instance

maximal  $N$  can be assumed, which is received when  $P(\xi) = 0,5$ . Dependence of number of attempts on the desired precision is given in Table 1.

**Table 1.** Dependence of number of attempts on the precision

Kai $\alpha=0,95$ $P=0,5$	$\varepsilon$	0,05	0,01	0,005	0,001
	$N_b$	390	9800	39000	98000

If distribution of random quantity is similar to Poisson's distribution with mathematical mean  $M[\xi_i]$  and dispersion

$$D[\xi_i] = M[\xi_i] \quad (37)$$

or

$$D\left[\frac{1}{N_b} \xi_i\right] = \frac{M[\xi_i]}{N_b}, \quad (38)$$

then by using expression (33) we have that

$$\varepsilon = t(P) \sqrt{\frac{M[\xi_i]}{N_b}}. \quad (39)$$

From formula (39) we receive that

$$N_b = \frac{t^2(P)M[\xi_i]}{\varepsilon^2}. \quad (40)$$

It can be seen from expression (40) that number of attempts depends on mathematical mean  $M[\xi_i]$ . To determine the number of attempts when precision is given, law of Muavr-Laplace can be applied:

$$P\left\{\left|\frac{m}{N_b} - P\right|\right\} \rightarrow \frac{2}{\sqrt{2\pi}} \int_0^{\varepsilon \sqrt{\frac{N_b}{Pq}}} e^{-\frac{t^2}{2}} dt. \quad (41)$$

We receive the value of  $\varepsilon$  from the following

$$\alpha = \frac{2}{\sqrt{2\pi}} \int_0^{\varepsilon \sqrt{\frac{N_b}{Pq}}} e^{-\frac{t^2}{2}} dt. \quad (42)$$

By using expression (42) we can find such value of  $N_b$  with which not higher than  $\varepsilon$  frequency deviation from probability of events is guaranteed with probability not less than  $\alpha$ . Precision increase of 10 times conditions hundreds times increased decision duration. For example, let's calculate the dependency  $\varepsilon=f(N_b)$ , when fixed value of reliability  $\alpha=0,99$  is selected. Calculation results are given in Fig. 4.

This dependence shows, that increase of number of attempts over 10000 is not desired, since with the further increase of  $N_b$  precision practically remains the same.

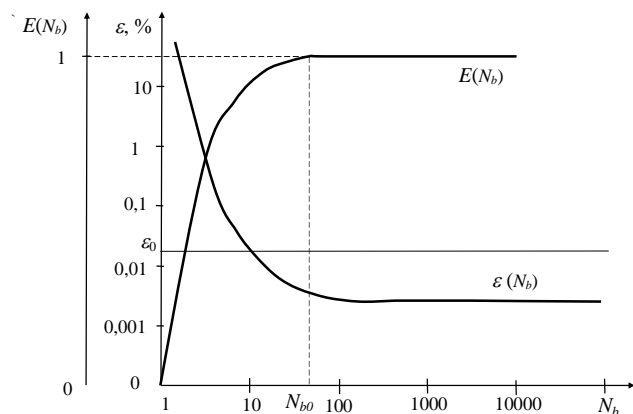


Fig. 4. Calculation precision dependence on number of attempts

If user needs are completely satisfied by precision  $\varepsilon_0$ , then information efficiency  $E(N_b)$  dependence on  $N_b$  at

$N_{b0}$  reaches value close to 1,0. Still,  $N_b$  is a function of time  $t$  quite often

$$N_b = f_N(t). \quad (43)$$

Therefore

$$E(t) = f_E[N_b(t)]. \quad (44)$$

It falls to use the conception of dynamical information. Let's consider information as dynamic, the amount of which and efficiency together varies (e.g., increases) with the change (e.g., increase) of time  $t$ .

The amount of information also determines (Fig. 5) value of  $K_{oRi}$ .

$$K_{oRi} = f_I(N_b). \quad (45)$$

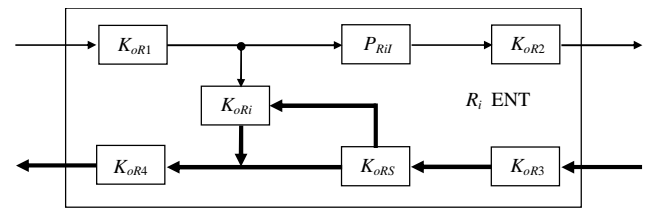


Fig. 5. Efficiency indexes of measures of  $R_i$  component ( $K_{oRS}$  – efficiency index of redistribution of commands of control from the higher level)

In order to conceive evaluation peculiarities of  $K_{oRi}$  it is necessary to analyze efficiency evaluation methods of operation algorithms of this block and decision making models implemented in them. Efficiencies of interfaces between components (values of coefficients of preparedness)  $K_{oI}^{(ij)}$ ,  $K_{oV}^{(ij)}$ ,  $K_{oRI}^{(ij)}$ ,  $K_{oRV}^{(ij)}$  and others can be calculated using methods given in [7].

## Conclusions

It is obvious from the presented material, that macrocomplex on the base of EXT consists of external measures used between its systems, and EXT of separate device (e.g., personal computer) consists of its interfaces with other devices of that level.

Main problems of EXT efficiency assurance – the increase of efficiency of interfaces between components, mostly this is efficiency of measures of transmission of information and control commands. The most important task is to preserve the quality of information, to assure the required amount and timeliness of it, to form (rebroadcast) control commands properly.

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**P. Balaišis, D. Eidukas, A. Žickis. Efficiency of the Flexible Electronics Exotechnologies // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 1(81). – P. 77–82.**

All flexible electronics technologies (FET) are divided into two groups: endotechnologies (ENT) and exotechnologies (EXT). EXT group is discussed. Information and control EXT efficiency expressions were offered. Efficiency evaluation method of the macrocomplex of the flexible EXT, which reflects the influence of information amount on precision of the result. It was determined, that main EXT efficiency assurance problem is the efficiency increase of interfaces between components; in most cases this is the improvement of performance of transmission measures of information and control commands. Ill. 5, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

**П. Балайшис, Д. Эйдукас, А. Жицкис. Эффективность гибких электронных экзотехнологий // Электроника и электротехника. – Каунас: Технология, 2008. – № 1(81). – С. 77–82.**

Все гибкие технологии электроники разделены на две группы: эндотехнологии и экзотехнологии. Охарактеризована группа эндотехнологий. Предложены выражения для расчетов эффективностей экзотехнологий, предназначенных для информации и реализации управления. Предложен метод оценки эффективности макрокомплекса гибких экзотехнологий, учитывающий влияние количества информации на точность результата деятельности. Показано, что основная проблема обеспечения высокой эффективности экзотехнологий – повышение эффективности взаимосвязей между компонентами этих технологий. Чаще всего эти проблемы сводятся к повышению дееспособности средств передачи информации и команд управления. Ил. 5, библи. 7 (на английском языке; рефераты на английском, русском и литовском яз.).

**P. Balaišis, D. Eidukas, A. Žickis. Lanksčiųjų elektronikos egzotechnologijų efektyvumas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 1(81). – P. 77–82.**

Visos lanksčiosios elektronikos technologijos (LET) suskirstytos į dvi grupes: endotehnologijas (ENT) ir egzotechnologijas (EKT). Aptarta EKT grupė. Pasiūlytos informacijos ir valdymo EKT efektyvumų išraiškos. Pasiūlytas lanksčiųjų EKT makrokomplekso efektyvumo vertinimo metodas, atspindintis informacijos apimtį įtaką rezultato tikslumui. Nustatyta, kad pagrindinė EKT efektyvumo užtikrinimo problema yra sąsajų tarp komponentų efektyvumo didinimas, dažniausiai tai informacijos ir valdymo komandų perdavimo priemonių veiksnio gerinimas. Il. 5, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).