COMPUTER DIAGNOSTICS AND FORECASTING OF PULSE ELECTRON LINAC FAILURES

V.N. Boriskin

National Science Center "Kharkov Institute of Physics and Technology", 1 Akademicheskaja st., 61108, Kharkov, Ukraine. E-mail: boriskin@kipt.kharkov.ua

ABSTRACT

Most failures of linear electron accelerators (LEA) are caused by malfunctions in the systems of RF-feeding, modulators and clystrons. And a great part of malfunctions lead to the increased dispersion of amplitudes of output signals of the system. In this paper we consider the algorithms of failure prediction based on some indication functions and the use of these algorithms in the LEA control systems.

I. EVALUTION OF A POSSIBILITY FOR FAILURES IN THE ACCELERATOR PULSED SYSTEM

Let us consider two strategies of resource expenditures for troubleshooting the LEA systems. The first strategy, we shall call it as "de facto", envisages the resource expenditure only after failure detection by the accelerator operator. The second or the probabilistic strategy is based on the prediction provided by the control system computer.

Let n be the mean number of failures in a system for some time period, e.g. per year. Then, for the "de facto" strategy, the annual average expenditures for troubleshooting in this system are

$$e_1 = d_1 \cdot n \,, \qquad (1)$$

where d_1 is the specific cost of the unexpected troubleshooting.

In the case of the probabilistic strategy we should set a criterion of evaluating the probability of a system malfunction p for some time interval, for example, a day forward, as well as a threshold value of this criterion, p_0. We shall begin a planned problem detection and troubleshooting with $p \geq p_0$. In this case the annual average expenditures for troubleshooting will be equal to

$$e_2 = d_1 n_1 + d_2 n_2 + d_3 n_3 + C_{pr} \,, \qquad (2)$$

where d_2 is a specific cost of the planned maintenance; d_3 is a specific cost of the pseudotrouble finding; C_{pr} - the prediction cost; n_1 - the annual average value of the non predicted failure number; n_2 - the annual average value of predicted failure number; n_3 - the annual average number of false alarms.

The total annual average failure number will be $n = n_1 + n_2$. It is evident that the specific cost of the planned maintenance d_2 is less than that of the unexpected one d_1 and d_3 is less than d_2, since the trouble finding in the case of the false alarm is performed without losses of beam time.

One can see from the above formulas taking into account existing limitations that there are such values of p_0 and C_{pr} for which $e_1 > e_2$, i.e. the probabilistic strategy is more preferable than the "de facto" one.

As the prediction criteria do not usually possess entire universality one should select a criterion being sensible to as much as possible failures that can occur.

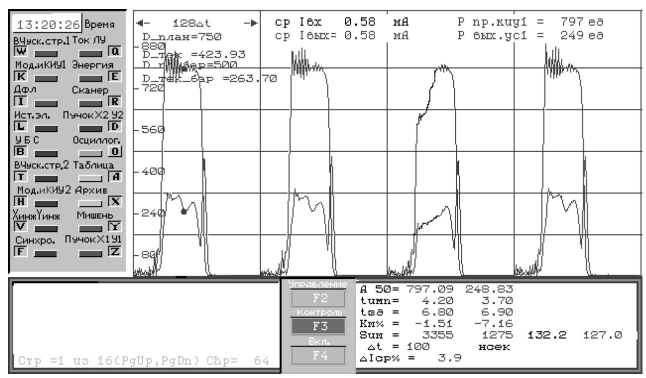

FIG.1. Videograms of the RF –systems signals measurement on the EPOS accelerator.

In our case more than a half of accelerator failures are caused by malfunctions in systems of RF-feeding, klystron modulators, control- and block-system [1]. Moreover, most of accelerator section malfunctions lead to the impermissible RF-field pulse amplitude deviation from the given value {Fig.1} or to the loss of some pulses. These two situations increase the measured signal dispersion. The increase of output signal dispersion on the system can be caused by the failure of any element in the system as well as by external perturbing actions. Therefore, one can increase the efficiency of accelerator failure detection by combining the prediction methods and diagnostic testing checking [2].

2. DETERMINING THE VALUES OF PREDICTION CRITERION

The estimation of the pulse amplitude dispersion D change will be more convenient with the use of the variation coefficient

$$K=\sqrt{D}\,/\,M\ , \tag{3}$$

where M is the average value of the pulse amplitude.

To clarify the possibilities of using the variation coefficient as a criterion ("forecaster") of accelerator system failures we compared the results of a sample estimate of changes in K with data of the trouble record log concerning the failures of the 50-section linear electron accelerator LEA-2000 [3] and technological accelerators KUT and EPOS [4]. Analysis of more than 150 failures in the systems of these accelerators has shown that 70% of failure events in the system are preceded by increasing dispersion of the output parameter of this system.

Let us assume that a and b are the limit values of the variation coefficient used for the failure prediction. The pre-emergency set point value a, enabling one to respond to the first group of failures, was selected somewhat higher than K_0 , the upper bound of the 90% confidence interval of the variation coefficient of the serviceable accelerator system.

In our case a was equal to 1.1 K_0 for most LEA systems. The emergency set points b revealing the failures of the second group are selected on the base of conditions for accelerator systems and we established them ten times as high as pre- emergency set point values. Based on experimental results [5] for the accelerator RF-feed, the set points were selected as a =0.05% and b =0.5%, respectively.

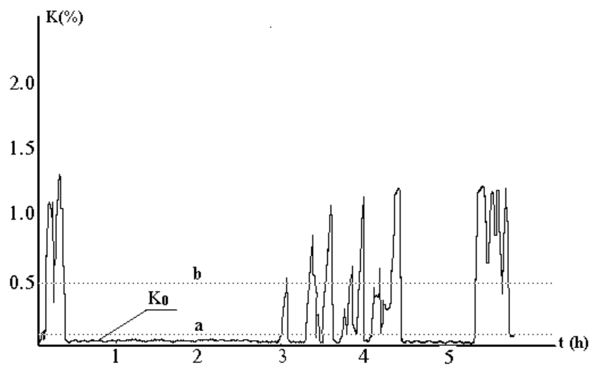

FIG.2. Graph of the coefficient of RF-field pulse-height variation at the section output.

3. PREDICTION ALGORITHM

As it can be seen from (1) and (2) the algorithm of making up prediction should be based on some indicator function taking the value 0 or 1. The experimental research we have carried out evidenced the efficiency of using two threshold values a and b of the variation coefficient. Hence, the indicator function estimating the probability of exceeding $K_i\ (t)$ of the preset value in the i-th LEA system has the following form:

$$m_i(k_i(t),\Delta t)=\begin{cases}1 & if\left[p(k_i>a)>p_a\right]\vee\left[p(k_i>b)>p_b\right]\\ 0 & if\left[p(k_i>a)\le p_a\right]\wedge\left[p(k_i>b)\le p_b\right]\end{cases} \tag{4}$$

From (1) and (2) it follows that the total number of positive predictions per year including also the false alarms is

$$n_2+n_3=B\cdot\sum_{i=1}^{L}\sum_{j=1}^{\gamma}\text{H}_{ij}\ , \tag{5}$$

where γ is the number of control cycles in day; L is the number of tested LEA systems; B is the number of system operating days per year.

In fact, the number of not predicted failures will be $n-n_2$, where n will be total number of failures per year.

So, for realization of immediate prediction the control system must provide the daily control of LEA systems in order to obtain the sample estimation of the probabilities $p(K>a)$ and $p(K>b)$. The number of control cycles γ for accumulation of values $K\ (t)$ is determined by finding $\max\limits_{\gamma}\,(e_1-e_2)$ under condition $(e_1-e_2)>0$.

The determination of values a and b was considered above. The values p_a and p_b will be determined by minimization of the loss function (LF).

$$LF(p)=\min_{p}\sum_{i=1}^{2}\left(NE_i(p)\cdot FE_i\right) \tag{6}$$

at $L\gamma\rightarrow\infty$, where NE_i is the number of errors of i-th kind; FE_i is the fine for errors; $NE_1=n_1$; $NE2=n_3$.

The estimate of probability for exceeding the set points will be found as a ratio of limit exceeding number to total control cycle number

$$p(k\rangle\alpha)=\frac{m(k\rangle\alpha)}{\gamma}\ ;\ p(k\rangle\beta)=\frac{m(k\rangle\beta)}{\gamma} \tag{7}$$

To determine the values p_a and p_b we performed the below-described experimental research at the 50-section linear electron accelerator.

Comparison between expenditures and gained cost effectiveness has shown that at the first stage the 5-cycle (5 hours per day) duty of tracking the accelerator systems proved its value. Respectively, in the daily massive tracking of results for every parameter one can fix up to 5 facts exceeding all set points.

A lot of hypotheses on approaching the failure in systems includes the prediction based on appearance of not less than one, two, three, four and five exceeding of set points. To make a decision about carrying out diagnostic works one should select two working hypotheses from the above-mentioned ten hypotheses for analysis of tracking result array. If we are guided by one of the above hypotheses, then we can make mistakes of the first kind (do not predict a failure) or mistakes of the second kind (give a false alarm). Values of the LF

function were calculated based on an analysis of the *K(τ)* values for 38 failures of the different LEA systems {Fig. 3}. The dispersion increase was registered at 33 failures. The *LF* function was calculated under conditions that $FE_1 = 7, FE_2 = 1$. As can be seen from Fig.3 one could have minimum losses by the fourth hypothesis for making the decision based on exceeding of preset points and by second hypothesis for analysis of arrays of exceeding facts for emergency set points. Both variants supplement each other.

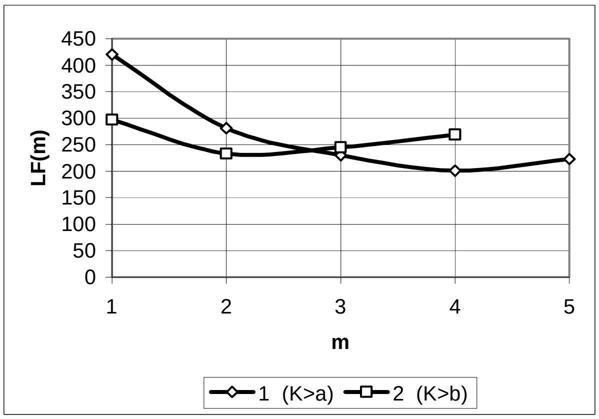

Fig.3. Graphs of total loss because of 1-st and 2-nd kind errors depending on choice of various hypotheses for prediction of failures in accelerator systems based on analysis of arrays of exceeding above pre-emergency set points (1) and emergency set points (2).

The empirical law of failure prediction can be formulated as follows: one can expect a failure during next twenty-four hours if the estimate of sample values $p(k>a) \geq 0.8$ or $p(k>a) \geq 0.4$. The probability of a correct prediction ensured by the method is less than unity, since the signal change is caused not only by failures inside the system but also by perturbing actions of other systems.

CONCLUSIONS

The use of above-described algorithms for accelerator control systems makes it possible to predict failures of LEA pulse systems in the average by more than 50 events. The use of these algorithms for prediction of failures at nuclear power plants also has also been effective [6]. Based on these algorithms, we are currently developing special software for the control system of LEAs.

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