IOP Conf. Series: Materials Science and Engineering **124** (2016) 012015 doi:10.1088/1757-899X/124/1/012015

Maintenance with the use of statistical control charts

E I Gromakov[1], T V Aleksandrova[1] and B P Ivanenko[2]
[1]Tomsk Polytechnic University, 30, Lenina ave., Tomsk, 634050, Russia
[2]Tomsk State University, 36, Lenina ave., Tomsk, 634050, Russia

E-mail: gromakov@tpu.ru

Abstract. The possibility of using statistical process control methods for detection of an abnormal condition of the process equipment at early stages of an emergency is shown in the paper. The authors of the paper has concluded that with the use of Shewhart charts it is possible to monitor the real dynamics of the process equipment condition and make decisions on its maintenance and repair

1. Introduction

The efficient operation of the capital equipment is one of the main factors of technological excellence in production. The lack of timely maintenance entails production stop after a breakdown or an immediate inspection of technical supervision and in the event of accidents - deaths and criminal penalties for official business. Many Russian companies lag behind the western ones in technological maintenance: the equipment can be operated irrationally and can stand unscheduled idle, which leads to its costly repairs.

At present, worldwide the highest priority is given the problems of equipment maintenance and repair because of high losses. These problems are considered in terms of cost control and provision of scheduled industrial work, and from the point of view of minimization of industrial risks and tragic consequences.

The aim of this work is to develop and justify the method of statistical processing and control providing the reliability of measurement interpretation and data on the condition of process installations (PI)arriving at the dispatcher workplace in the automated mode.

There are three basic strategies of maintenance and repair management:

- event-triggered;
- preventive maintenance management;
- repair and maintenance according to assessment of the actual technical state.

2. Event-triggered maintenance

This is a maintenance, during which the repair or replacement of the equipment is done only in case of the emergency fail or ending of its service life. The drawback of the event-triggering maintenance is the unreadiness of the enterprise for the maintenance. Unscheduled shutdowns and downtime of the process equipment due to sudden failures lead to more costly repairs. In addition, in the event of a sudden failure of several different units a simultaneous necessity in repair works may exceed the capabilities of the repair service of the enterprise.

3. Preventivemaintenance management (PMM)

A periodic preventive maintenance underlies the preventive maintenance management (PMM) in accordance with recommendations of the operational and maintenance mechanism documentation, taking into account the existing experience of the equipment operation. Periodically, at certain time intervals, it is necessary to perform the monitoring of equipment condition, repair or replacement of units, parts, lubrication etc. In some cases, these requirements are mandatory, in other cases the decisions on repairs and replacements are made according to the results of equipment examination duringunsealing the mechanism or its components.

The advantage of this method, compared with the event-triggered method,consistsin maintaining of the required reliability of the equipment during operation.

The disadvantages of the preventive maintenance management are as follows:

- it does not take into account the actual condition of the equipment (its technological modes);
- a substantial 'margin of safety' is initially laid in the system;
- unnecessary repairs are often carried out;
- outdated standards of maintenance and repair of equipment are laid in the existing system of preventive maintenance management.

The system of PMM, developed many years ago, does not allow one to determine priorities accurately when selecting objects and volumes of work, which, in conditions of the international market of technological installationsdelivery, entails the necessity of laborious total search for suppliers of components and their subsequent order all over the world.

4. Maintenance based on the actual technical stateor actual state maintenance (ASM)

The essence of this technique lies in the fact that maintenance service is conducted not only depending on how long the mechanism has operated, but also with consideration of its actual current technical state, which is controlled during operation without any disassembly and inspection on the basis of the measurement of relevant parameters of an operating mechanism.

If PMM is based mainly on the operating time of the mechanism, ASM takes into account all the factors that determine the service life of the mechanism. It is the fundamental difference. We should note that ASM takes place in a regular manner due to controlling the condition of the equipment, since whatever factors in whatever combination influence the mechanism there is always a combined reaction to these impacts owing to the change of corresponding indicators of its condition. In this case there is an opportunity not only to monitor the technological installation state, but also to determine the real causes of the changes that take place in each particular situation, and, therefore, to make well-founded decisions for their elimination in future.

The advantage of ASM method is minimization of maintenance and repair works. According to experts evaluations the overhaul period increases from 25 to 40 percent in comparison with PMM method.

The disadvantages of this technology are:

- poor operational budget and technical readiness of maintenance services for the arisen event-triggered problem of the equipment state;
- a relatively high probability of false alarms especially in case of sophisticated equipment;
- increased skill requirements for staff.

5. Combined maintenance

Thus, each of the three strategies mentioned above has drawbacks.

That is why there is a stable trend of companies to combine all basic strategies through the use of so-called combined maintenance aimed at reduction of the total amount of required maintenance and to maximize the service life of the equipment.

The idea behind this service is that at each time horizon of planning of maintenance and repair the proper technologies with a very high planning reliability are used. So the long-term period is used for planning of the milestone indicators of PMM. These indicators are calculated by the direct method. On the operational planning horizons the indicators of maintenance and repair are determined on the basis of statistical processing of data of measuring the condition of the equipment. In case of their absence a financial reserve is formed.

In accordance with the combined maintenance, the consistent refinement of planned performance is carried out as the period of planning horizon reduces. The basis for such refinement is the data of actual equipment state, technological modes of its work, as well as the implementation of plans for equipment maintenance and repair in the prior periods.

The use of combined maintenance on the operational horizon of planning of maintenance and repairs involves a regular evaluation of the technical state of the mechanism without monitoring, in the operating modes and during control using secondary parameters. These requirements can be formulated, for example, as follows:

- controlled parameters should have a single valued quantitative interrelation with the primary parameters of the technical state;
- measurement of the parameters should be provided by the means of the in-use SCADA system as well as, if possible, by simple portable technical devices that do not require special skills from staff;
- during the mechanism operation the range of the monitored parameters from the state of 'good' to the state of 'unacceptable' should be large enough (the parameter can be changed at least 15-20 times) to detect incipient defects early and predict reliably the residual service life of the mechanism;
- The accuracy of the control by the secondary parameters should not be below 80%.

Three methods can be used for statistical processing. The first one is based on Neyman-Pearson criterion and represents a Shewhart control chart [1]. It is historically the very first common tool to control the variable parameters of maintenance processes. The second one is based on the repeated application of Wald sequential analysis results [2]. In practice, it is realised in the form of control charts of cumulative sums. Finally, the third method of detection of the process malfunctions is based on the exponential smoothing of statistical results (EWMA charts) [3]. Hereinafter, the features of the use of the first two methods will be considered.

We believe that in accordance with the recommendations of GOST [1] special statistical processing of regular measurements in the form of Shewhart chart allows solving the problem of identifying the dangerous causes of variations in the equipment state. These algorithms can supplement the algorithms of vibration control technology providing them with additional confidence in the assessment both on the operational and medium-term planning horizons of maintenance and repair.

A control chart, applied to the control of the state, represents a graph of a number of regular samples of measurement of some index, which characterizes technical condition X. An outgoing maintenance parameter can be used as X, for example, the temperature of the bearing assembly, vibration and others [4]. Then the collected telemetric statistic data can be combined in the form of the diagram of sample son chart g(X).

The sample in this diagram represents a sequence of n independent observations $x_1, x_2, \dots, x_n$of indicator X, related to a certain period of time (day, month, year).

The period of measurement samples depending on the planning horizon may be specified in any manner. Moreover, for monitoring of the equipment state one can simultaneously monitor the vibration trends in different spectral ranges and at various intervals of samples.

There are no general rules for selecting the frequency of sampling and sample volumes. Usually 20 - 25 samples with 4 or 5 measurements in each are regarded as acceptable for obtaining preliminary evaluations at each level of planning [5].

Let $f(x, \theta)$ describes a distribution of random variable of observations with some value of the statistical parameter (mean value of samples, scope, etc.) θ.

With the use of the control chart one sets and solves the problem of detecting unnatural variability of the observed parameter, due to which the technical installation have changed. This variability is observed based on the change of the selected for the chart parameter of distribution function $\theta$of consecutive observations *x*.

A peculiarity of monitoring the technical installation state is its slow changes of variability in the form of trends of operating parameters. Let us assume that the statistical properties of the time series that characterizes these states and properties of the reasons generating its changes remain unchanged or change slowly in the selected time intervals of samples formation. The current control is reduced to monitoring the arrival of the next monitoring of sample and detection of deviation (disorder) of the properties of the observed time series of $\theta$from value θ_0 to θ_1. The necessity in maintenance may occur at unknown point of timet_0. This event will be called a disorder of the operational process.

In a common approach the considered range of applied problems associated with the operational state of the technical installation, is characterized by random sequence $\{x_1, x_2, \ldots, x_n\} = \{x_1^n\}$, which at moment $t_0$changes its properties that uniquely defined by the vector of parameters θ, $dim\{\theta\}= r$. beginning with$t_0$the parameter vector becomes $\theta = \theta_1$. Moment of disorder $t_0$is detected by the established criterion for assessment of sequence$\{x_1^n\}$, $N \to \infty$, during appearance of the next point x_n.

Each time for a new sample hypothesis $\theta = \theta_0$ is verified, which indicates the absence of the unnatural variability.

The option of the screen form of equipment condition monitoring is shown in Figure 1.

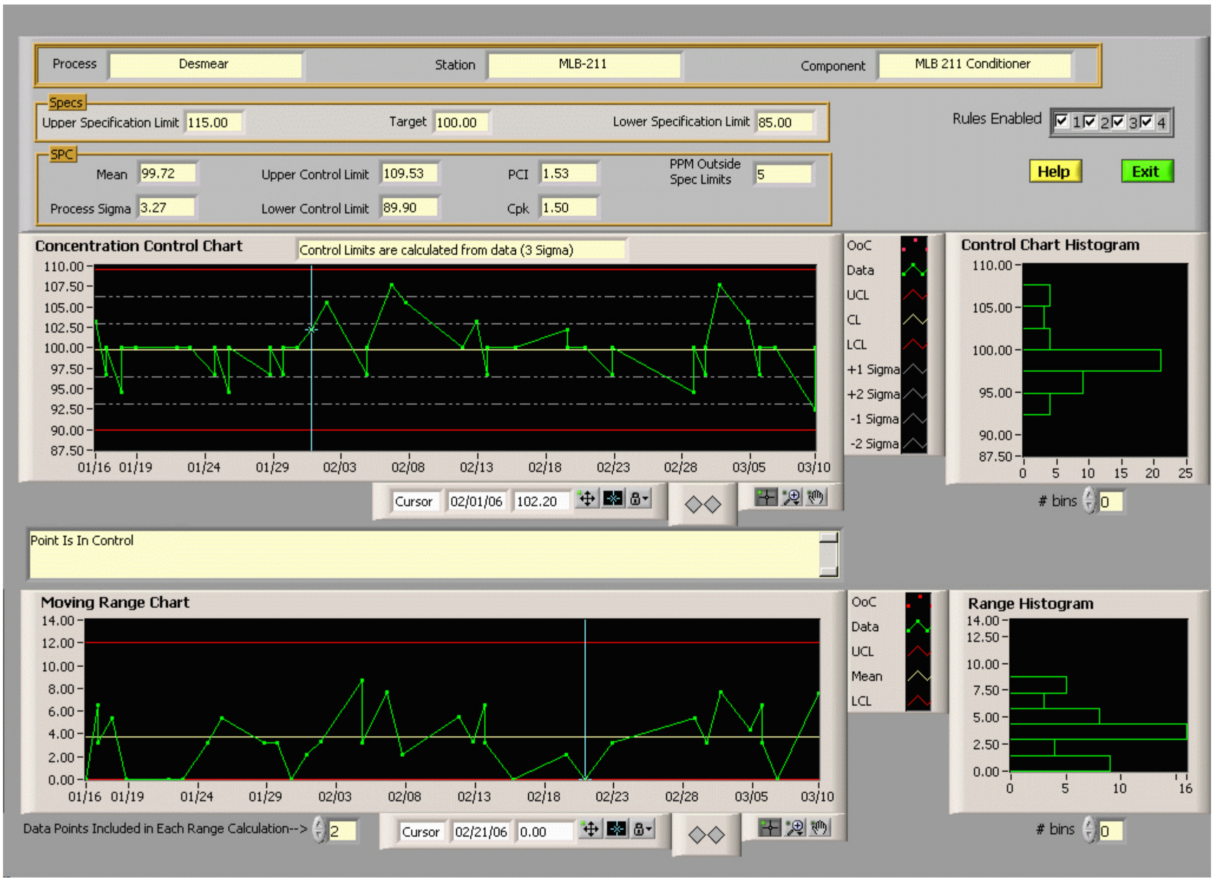

Figure 1. Shewhart control charts displayed on the screen.

To interpret a process flow on the base of Shewhart chart we can use an expert system that is configured to diagnose equipment malfunctions. The recommendations are displayed on the monitor screen. The display form should not be obtrusive except for alarm signals. The choice of a particular decision depends on the operator' will.

The proposed monitoring method allows implementing the monitoring of the operational state of the technical installation with low error level of decision making at least in three dimensions of real time:

- in the operational real-time daily management of an oil field exploitation;
- in retrospective, archive real-time, with profundity established by the regulatory documents;
- in the forecast time determined by strategic objectives of the enterprise.

6. Conclusion

The temporal analysis of the monitored parameters using Shewhart charts allows tracking the real dynamics of changes and predicting reasonably the timing and content of adjustment and alignment, maintenance and repairs of equipment both of rotary and non-rotary types.

Periodic updating of Shewhart charts on operational planning horizons of maintenance and repairs allows their use in any range of equipment parameterization.

Introduction of operations of statistical condition monitoring of technological equipment according to GOST R 50779 and, if necessary, its adjustment can significantly improve the quality condition of the machinery after undergoing repairs.

References

[1] 1994 *State Standard of Russian Federation* P 50779.42 99
[2] Wald A 2004 Sequential analysis (Mineola, Courier Corporation).
[3] Rabyk L and Schmid W 2015 *Metrika* 1-35.
[4] Aleksandrova T and Gromakov E 2015 *IOP Conf. Ser.: Mater. Sci. Eng.* **93** 012053
[5] Wheeler D and Chambers D 1992 *Understanding Statistical Process Control* (Knoxville, SPC Press)