Precise measuring-computational predictive monitoring – the conditional of self-organization of the life cycle

M I Kiselev

Bauman Moscow State Technical University, Moscow, Russia
E-mail: vip-u@yandex.ru

Abstract. Formation of aviation which was laid down by the fundamental works of N.E. Zhukovsky and its further development at the forefront of scientific and technological progress occurs in the constant overcoming of the information deficit. The biosphere gives samples of successful provision of reliable functioning, but the perfection of living organisms is achieved through natural selection, which lasts for thousands of years. Improving the objects of the technosphere requires an increase in the level of information and metrological support for the production and operation of facilities. At present, the parameters of the basic structural materials are known with relative error at the level of percent or its fractions. The metrological level of the control and diagnostic equipment is the same. The lack of information is compensated by long and costly experimental and production work-up, as well as by the system of preventive maintenance and inspections, but is not a complete guarantee against accidents and catastrophes. The existing information barrier can be overcome by the transition from amplitude to phase measurement methods. The phase-chronometric version of this approach provides effective monitoring of the cyclic systems - from the clock mechanism to the powerful turbo-aggregate with a relative error of at least $5 \times 10^{-4}$% at the industrial frequency. The combination of a precise phase-chronometric system with a mathematical model of the object that is constantly refined from the received measurement data makes it possible to realize a measurement and computational monitoring of its technical state and emergency protection. Simultaneously, the problem of information and metrological support of the life cycle of objects included into the self-organizing system of the Research Institute - Design office - Plant - operated facility is being solved.

Keywords: phase-chronometric method, monitoring, cyclic system, the amplitude-phase method, biosphere, technosphere.

1. Introduction
A transition from aeronautics including a balloon with a motor – a dirigible, to the flight of "heavier than air" apparatus - gliders and aircrafts equipped with engines is associated with the name of N.E. Zhukovsky. An invaluable "consultant" on the most complicated path of scientific and design search was the Nature itself. Thus, the cross sectional profile of a subsonic airplane wing (the famous "profile of the NEZh"), which provides the formation of the lift force in flight, actually repeats a similar profile of the deployed wing of the soaring bird. But, moreover, it became clear over time that the mode of unconstrained soar of a kite spreaded its wings is provided not only by using the ascending air currents that are sensitively captured by the bird, but, that is especially remarkable, by the operative and fine stabilizing correction of the spatial structure of the incoming air flow directly
adjacent to the bird’s plumage. This correction is provided by the information obtained from the nerve (sensory) endings distributed along birds’ body surface, which are transmitted through the nerve network to the muscles acting as the drive for the associated with them feathers - elementary executive organs.

This perfect adaptive system is the product of evolutionary development of the biosphere that lasts thousands of years and a natural selection is playing a decisive role in its improvement (according to Charles Darwin). [1]

Improving the facilities of the technosphere is also stimulated by the processes taking place in the social sphere, where profitability, effectiveness of combat use, reliability are decisive in the competitive struggle of goods. At the same time, the specific characteristics of the biosphere objects are still often remaining an inspiring example for the creators of new technology.

2. The main obstacles to the development of aviation and cosmonautics

Aviation and cosmonautics are the cutting edge of scientific and technological progress, forced to develop on the boundary between knowledge and ignorance. Corkscrew, shimmy, flutter, vibrational burning, sparging is not a complete list of the fundamental obstacles that have stood in the way of development of these technology branches.

Many of these phenomena, primarily flutter, have a threshold character inherent in self-oscillating systems, and are now sufficiently well studied. The incentive to this was the application of aviation technology achievements in power engineering and transport (for example, gas turbine drives of electric generators and pumps for gas transportation, ground and water hovercraft, gliding, underwater wings).

However, besides the whole range of stability and mass dimensional optimization problems arising here, the problem of time-factor influence for a fleet of actively operated equipment becomes more and more urgent. This problem significantly differs from the moral aging one, gaining its value in the conditions of a modern market economy with its mechanisms of competition.

The current situation is that if earlier the main efforts of science and production were aimed at improving the efficiency of the work cycle, then now ensuring the efficiency of a life cycle gets an increasing importance at all its stages. The situation is aggravated by the growing need for a multifactorial optimization of the interaction of the technosphere, the biosphere and the socio-economic sphere.

3. The tasks of ensuring reliability and durability, estimating the residual re-source and obtaining an informed forecast of failure time

At the same time, the tasks of ensuring reliability and durability, estimating the residual resource and obtaining an informed forecast of failure time - an accident or a catastrophe are at the foreground.

To solve these problems, it is necessary to provide operational precision measurement control (monitoring) not only for the deviation of the parameters of the structural elements of the functioning technical facilities, but also for the physical and mechanical characteristics of the structural materials themselves.

It is obvious that the stability of the parameters of the used information-measuring system should be as high as possible.

It is known that the technical tools of chronometry possess the greatest stability, and time and frequency are physical quantities measured with minimal error. The situation most objectively characterizes the fact that the physical properties of structural materials - metals, alloys, various plastics and composites are known, as a rule, with accuracy up to the third or fourth decimal place, which corresponds to (0.1-1.0)% of the nominal value.

If we take into account that the relative errors in measuring the parameters characterizing the technical state of functioning objects with modern control and diagnostic instruments based mainly on vibro-acoustic principles have practically the same accuracy level, we can also judge the level of metrological support of the technosphere as a whole.
As a result, the maintenance of the working capacity of national equipment is largely ensured by the established system of preventive maintenance and preventive inspections and by a thorough and long-term multi-stage experimental development of the created equipment, starting with laboratory studies of the first models and makets to pilot-industrial tests of the head samples of the series.

4. Systematic monitoring of measurement of technical condition of cyclic aggregates

Studies have shown that it is expedient to maintain precise systematic measurement control of the technical state of cyclic, primarily rotary machines and mechanisms, recording the passage moments of the boundaries of the working cycle phases intervals. It is most rational to ensure the equality of these intervals, and to make their boundaries like contrasting marks applied to one of the elements of the running gear performing periodic (oscillatory or rotational) motions. It is established that the variations of the working cycle phase passage duration, formed from cycle to cycle, contain information about the technical state of the measured object and its evolution.

Indeed, such an approach, both to miniaturized clockwork and to powerful (up to 300 MW) turbine units has opened fundamentally new opportunities for their study directly in the process of functioning. [2]

Thus, for a clock mechanism, a long-distance and contactless (optoelectronic) recording of the oscillation periods of its balanced wheel made it possible to study the response of the mechanism to all possible perturbing effects such as shock, vibration, temperature variations, etc. Obtaining essentially new measurement information was achieved by reducing the errors in measuring the oscillation period of the balance to 1 ť, using the "quartz" time. Traditional watch calibration devices, previously used in the watch industry, were based on the vibro-acoustic principle and had a greater error. It guaranteed only the level of qualitative research.

Attempts at interpreting the results of optoelectronic measuring control of clockwork mechanisms functioning led to the need to refine the mathematical model of their functioning. The result was the substantiation of the principle possibility of creating not only a system for automatic designing of watch movements, but also the rationale for the intellectualization of their production without the participation of personnel. [3] However, the practical implementation of the current concept in the watch industry did not take place due to the loss of relevance of their mass industrial production in our country.

Nevertheless, the developed approach attracted the attention of specialists in the field of electric power engineering in connection with the emerging problems of self-excitation of emergency-dangerous torsional oscillations of the running gear of the turbine unit and the physical aging of the power generating equipment. The seriousness of the problem was evidenced by the well-known accidents that occurred at Kashirskaya (2002) and Reftinskaya (2006) electrostations. In connection with this the indispensable, windv systems of systematic precise measurement control of the technical condition of turbo-aggregates were required. Such systems were realized using the phase-chronometric approach. Significantly, in the transition from miniature clock mechanisms to massive and large-sized industrial turbo-aggregates (power ~ 200-300 MW), the absolute error in measuring the period and its multiple fractions of the turn of the running gear was 10^-7 s, which corresponds to a relative error of ~5· 10^-4 at the industrial frequency. [4]

The efficiency of the application of such a phase-chronometric system is characterized by the possibility of providing a detailed registration of the rotational mode of the turbo-generator shaft at a level of 19 (one corner minute). Due to this, constant torsional oscillations of the rotating undercarriage of the turbine unit in a stationary mode of operation and bursts of torsional vibrations of the rotating undercarriage of the turbine unit, excited by incoming current and voltage impulses coming to the stator windings of the generator, coming from the network where they were excited by lightning discharge were detected (Figure 1).
Figure 1. Reaction (surge of torsional vibrations) of a rotating multi-ton turbine unit to a lightning discharge

The effectiveness of the approach is also evidenced by the spectra of torsional oscillations of the shafting line, obtained as a result of mathematical processing of the regular periodograms (Figure 2) for the case of the normal functioning mode (Figure 3) and in the presence of defects (Figure 4).

Figure 2. Periodogram of the turbine unit shaft rotation, nominal mode
These results served to justify the scheme for obtaining the frequency characteristics of a turboaggregate as a multimass system formed by a set of running parts of a high-pressure turbine, two medium pressure turbines, a low-pressure turbine, an electric generator and an exciter connected by sections of a single shafting line.

The achieved accuracy makes it possible to use the accumulated detailed information about the current technical state of the turbo unit, its evolution and to build its forecast (estimate of the residual resource).

The effectiveness of these works will undoubtedly increase if they are accompanied by the development of precise materials science, which will ensure the achievement of the necessary accuracy of the values of physicomechanical parameters of structural materials. Their substantial refinement can be achieved by conducting studies using

- self-oscillators with resonators, made from the studied materials in the form of strings, shells, tuning forks, etc.,
- the apparatus of the thermodynamics of nonequilibrium processes and, if necessary, mesomechanics.

The achieved level of development testifies to the reality and expediency of applying the phase-chronometric approach to cyclical machines and mechanisms in transport, in the processing and extractive industries, up to the housing and communal sphere. [5] - [9]
Special mention should be made of the reality and prospects of the developed approach to information and metrological support of the life cycle of industrial products in the mode of its self-organization. [10]

It seems not so much the expediency of such approaches as their inevitability in connection with the entry of our civilization in the era of the fourth industrial revolution ("Industry 4.0" or "Internet-things"), when unoccupied industrial production on the basis of intellectual technology with its mathematical support using Neural networks are more efficient and competitive than its traditional forms. [11]

An example of active interest in "Industry 4.0" at the level of industrial enterprises and departments is demonstrated by the Republic of Kazakhstan. [12]

It is known that an increase in the accuracy of measurements of the functioning objects parameters of the technosphere provides not only an improvement in the quality of the assessment of their technical condition, but also broadens the horizon of its forecast. At the same time, the problem of emergency mathematical analysis of a fast working cycle (for example, for a gas turbine engine) becomes more urgent with the aim of making a decision promptly.

5. Conclusion
But what is more, modern science demonstrates undoubted achievements in reliable mathematical support of scientific forecasts in the socio-historical sphere. [13], [14].

References
[1] Kiselev M I 2013 Why do we need this accuracy? Metrology 7 pp 4-7
[2] Kiselev M I and Pronyakin V I 2001 Phase method of investigation of cyclic machines and mechanisms based on the chronometric approach Measuring technique 9 pp 15-18
[3] Kiselev M I and Pronyakin V I 2003 Measuring-computational creation of watch mechanisms Measuring technique 5 pp 22-28
[4] Kiselev M I, Zroychikov N A, Pronyakin V I and Chivilev Ya V 2006 Precision study of turbo-aggregate operation by optoelectronic means Heat power engineering 11 pp 10-13
[5] Kiselev M I 2016 Phase chronometry: problems and prospects Instruments 10 pp 51-54
[6] Kiselev M I and Komshin A 2012 Features of dynamics of diesel-generator sets of diesel locomotives Bulletin of UNN. N.I. Lobachevsky 5 (2) pp 107-112
[7] Komshin A S, Kiselev M I and Syrytsky A B 2015 Introduction of measuring and computing systems for maintaining the life cycle of metalworking equipment and tools based on the phase-chronometric method Stankoinstrument 1 pp 89-96
[8] Syrytsky A B and Boldasov D 2015 Phase-chronometric monitoring system for wear of cutting tools Metalworking 5 pp 2-10
[9] Potapov K G and Syrytsky A B 2014 Implementation of the measuring phase-chronometric system for diagnosing the technical condition of lathes Instruments 5 pp 18-22
[10] Kiselev M I 2014 Features of information support of the life cycle of engineering objects in connection with the tightening of the requirements for their quality All materials Encyclopedic reference book 6 pp 2-9
[11] Kiselev M I and Novikov S V "Industry 4.0": some problematic issues Stankoinstrument 2 42-46.
[12] "Industry 4.0" and measurement in industry Experience of Kazakhstan (https://kazinmetr.intopress / news / 2/176 /)
[13] Turchin P V 2007 Historical Dynamics: Towards a Theoretical History (Moscow: URSS) p 368
[14] Korotaev A V and Malinetshy G G 2009 Problems of Mathematical History: Historical Reconstruction, Forecasting, Methodology (Moscow: URSS) p 248