Automation of Technical Diagnostics of Digital Signal Synchronization Devices

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Abstract
Modern digital technologies require high-quality frequency-time support. In practice, the use of digital signal synchronization devices (DSSD), the purpose of which is the formation of clock signals, has become widespread. Various methods of technical diagnostics are used to ensure the specified quality of clock signals, increase the reliability and resource of the DSSD. The paper is devoted to solving an urgent problem, which is to develop software and hardware to automate the process of technical diagnostics of DSSD. It also investigates the automated system of technical diagnostics which is constructed on technology of multichannel monitoring with use of the sensor of the adaptive digital phase discriminator protected by the patent for an invention. The authors carried out the practical development and experimental researches of the diagnostic system using the multichannel sensor and the P4000winXP software. The research results confirm the possibility of transmitting the results of measurements of clock signals using IP technologies and conducting automated processing of the obtained data in real time, which increases the reliability of the operator's decision and simplifies the diagnostic process.

Keywords:
automation, technical diagnostics, digital signal synchronization devices, automated system, sensor, adaptive digital phase discriminator, data processing, IP technologies**.**

1. Introduction

State-of-the-art digital information and communication systems, digital substations of SMART Grid electrical networks, other technical facilities using high technology, including the country's critical infrastructure, require high-quality time-and-frequency support. An important role in such a support is played by the processes of formation and transmission of clock signals, which are based on modern digital information processing technologies. In practice, the use of digital signal synchronization devices (DSSD), which are designed to generate and produce synchronized signals that must meet the specified technical requirements, has become widespread to solve the problem of time-and-frequency support [1-6].

Various methods of technical diagnostics are used in order to ensure the desired quality of clock signals, reliability improvement and service life of the DSSD. Technical diagnostics, through the

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timely identification of inconsistencies and their causes, improve maintenance, reliability and efficiency of operation of DSSDs [1-8]. The result of the diagnosis should be an assessment of the state of the DSSD at the time of diagnostics, in terms of its compliance or non-compliance with the established requirements. The real indicators and characteristics of DSSD can be obtained with the help of diagnostic tools (equipment), which together form a diagnostic system. Given the need to use high-precision specialized measuring equipment, which should provide continuous long-term (hour, day and even week) measurements with the formation of large arrays of real-time measurement data, the task of automating the process of technical diagnostics becomes one of the most important and urgent ones.

The current approaches to solving the problems of quality control and diagnostics of DSSD at the stages of production, introduction into service and maintenance do not meet modern requirements for functionality. The existing technical facilities in Ukraine do not have a uniform system for transmitting accurate time signals from reference standards and consequently cannot meet the requirements of all users of frequency-time information [9]; recent publications pay attention to the topical study of new solutions for the transfer of time scales using IP technologies [1-5, 9-12], the measurement of time characteristics of clock signals and the diagnosis of DSSD.

2. Principles of building an automated system for the diagnostics of synchronization devices

According to the results of the analysis of technological processes of production and technical operation (TPP TO) of DSSD, it is established that the formation of clock signals with the specified accuracy and reliability is impossible without the use of automated control of signal quality and diagnostics of the state of devices and synchronization system as a whole [1-12]. In the regulatory document on technical information protection [13], the automated system is defined as the "organizational and technical system implementing the information technology and uniting the computer system, the physical environment, personnel and the information that is processed." As for the Automated Control System, the State Standards of DSTU 2226-93 defines it as "an automated system intended for automating the processes of collecting and forwarding information about the control object, its reprocessing and issuing control actions on the control object".

The automated control system of these technological processes in its structure provides for the use of an automated subsystem of control and testing, which according to DSTU 2226-93 is designed to "automate the testing of industrial products and control its performance for compliance with regulations."

The generalized structural scheme of the automated control system of TPP TO of DSSD with the use of diagnostic results is shown in Fig. 1. The control process receives feedback through digital technologies. In this case, from the standpoint of information functioning, the control process can be represented as a process of forming data that is moved and processed. Therefore, the functional composition of the information part of the control system of TPP TO of DSSD can be represented by the following subsystems: measuring (data collection device), information processing (calculation, storage, decision making and formation of control actions) and transmission.

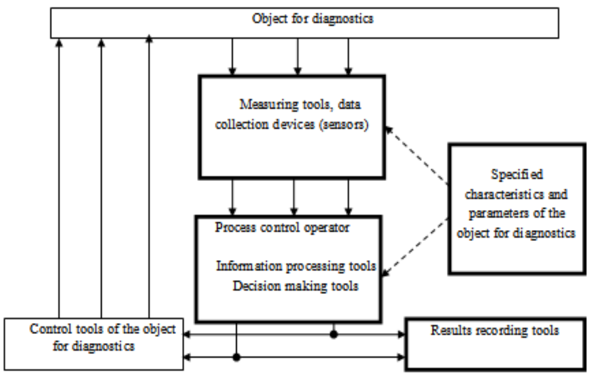

Figure 1: Generalized structure diagram of the automated process control system TPP TO of DSSD

The analysis of the process of diagnosing DSSD under the conditions of their production and technical operation based on the system approach determines the expediency of using multichannel monitoring technology, which provides multiple productivity of the diagnostic process and increases the reliability of data analysis results used to make decisions on TPP

TO technological process parameters [2, 3, 8, 10]. The multiple constitutive elements of an automated diagnostic system are sensors, which are measuring transducers that convert physical quantities into digital electrical signals [14]. This is due to the fact that the technology of multi-channel monitoring is based on the use of sensors (hardware), geographically distributed by objects, that perform continuous long-term measurements (days, weeks) of several clock signals. The data received from the sensors are processed and transmitted via the IP network to the information processing facilities where additional processing, including statistical processing, is carried out.

Decision-making tools are specific components of an automated diagnostic system. Being a control unit, they are composed of a number of specialists and a body of knowledge, competence and methods they possess.

It is important that, in fact, it is on the basis of these sensors that a decision is made on the formation of the necessary control actions.

Measuring multichannel tools, sensors inclusive, have reference oscillators. Reference oscillators (RO) are based on the principle of automatic frequency control of a quartz oscillator with deviation control and adaptive digital phase discriminator (ADPD) [15]. GO directly or due to the process of automatic frequency control from external sources, forms the reference (sample) time readings, which serve as references for measuring the time intervals of the controlled DSSD clock signals.

It is scientifically substantiated that calculations and estimations of DSSD characteristics need to be carried out on the basis of directly measured in time domain discrete samples of an error of time which form the basic, first level [14].

In case of time error measurement at τ interval, starting from the t moment, time interval error function $TIE_t(\tau)$ is used, which has the following mathematical definition:

$$\begin{aligned} \mathrm{TIE}_t(\tau) &= \mathrm{TI}_t(\tau) - \mathrm{TI}_{\text{оп}}(\tau) = \\ &= \left[\mathrm{T}(t+\tau) - \mathrm{T}(t)\right] - \left[\mathrm{T}_{\text{оп}}(t+\tau) - \mathrm{T}_{\text{оп}}(t)\right] = \\ &= \left[\mathrm{T}(t+\tau) - \mathrm{T}_{\text{оп}}(t+\tau)\right] - \\ &- \left[\mathrm{T}(t) - \mathrm{T}_{\text{оп}}(t)\right], \end{aligned} \quad (1)$$

where $\mathrm{T}_{\text{ОП}}(t)$ – time function of the reference (sample) signal;

$\mathrm{TI}_t(\tau)$ – time interval function, which is determined from the expression:

$$\mathrm{TI}_t(\tau) = \mathrm{T}(t+\tau) - \mathrm{T}(t), \quad (2)$$

that "is a measure of the τ time interval, which begins at time t, for the studied signal (provided that there is an ideal reference signal)" [15], and the time function T(t) is determined by the complete phase P(t) for the nominal value of the frequency $\omega_н$ of the DSSD signal out of the equation:

$$\mathrm{T}(t) = \frac{P(t)}{2\pi\omega_н}. \quad (3)$$

The next levels of the hierarchy of the process of diagnosing DSSD should provide calculations of *TIE*rms and *MTIE*, characteristics of instantaneous frequency, frequency fluctuations, DSSD operating modes.

For example, the *MTIE* estimate can be made for the τ_0 sampling period based on the results of N measurements of evenly spaced discrete x_i samples, using the formula [14, 15]:

$$\begin{aligned} MTIE(n\tau_0) \cong \max_{1 \le k \le N-n} \Big(& \max_{k \le i \le k+n} \left[x_i\right] - \\ & - \min_{k \le i \le k+n} \left[x_i\right] \Big), \end{aligned} \quad (4)$$

where $n = 1, 2, ..., (N-1)$.

It is possible to obtain the values of discrete samples of time interval error *TIE* measured in the time domain by using an adaptive digital phase discriminator (ADPD), which is protected by a patent of Ukraine for an invention [16]. The ADPD generates a code combination about the magnitude of the time interval error of two mutually independent clock signals and provides the presentation of measurement results in a digital format. Fig. 2 shows an ADPD circuit containing an input to which a controlled clock signal is applied (Input 1) and an input to which a reference signal is applied (Input 2) [17]. *K*-inputs of the pre-installation of the impulse counter (numbered as 1…k), are *K* digital inputs of the ADPD pre-installation. The digital outputs of the sensor, which form a code combination that corresponds to the error of the time interval between signals, are the *n*-outputs of ADPD (numbered as 1… n).

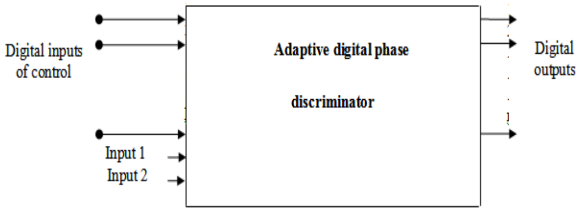

Figure 2: Structure diagram of adaptive digital phase discriminator

The multi-channel measuring tools of the automated diagnostics system have a certain number of sensors which make it possible to measure simultaneously the control of several clock signals. In the process of measurements, the control of the periodicity, amplitude and shape of the clock signals is performed. The results of these processes, presented in digital format, are processed by a microcontroller and transmitted in text format using IP technology.

The principles of construction of multichannel measuring tools make it possible to classify their implementation as intelligent sensors that work on rather complex algorithms and allow to provide the device with additional functionalities, such as signal filtering, adaptation, correction, failure detection, reconfiguration of the measuring circuit, etc.

2.1. The results of implementing the automated diagnostics system

The practical implementation of an automated diagnostic system with a multi-channel meter and the developed P4000winXP software provides the possibility of simultaneous visualization of the measurement results of four clock signals. In addition to dynamic graphs, the monitor screen displays service information (GO mode, availability and format of controlled clock signals, etc.), which expands the possibilities for analyzing the data used by the operator in the decision-making process.

Figure 3 shows an example of the visualization of measurement results obtained in real time from four sensors. Text data generated by two sensors selected by the operator is displayed as dynamic graphs in real time. The figure shows fragments of the parameters of *TIE* controlled clock signals (Channel C0 and Channel C1) of two DSSD, which are in different modes in the observation time interval from 443 s to 1153 s [14]. In case when four clock signals are simultaneously connected to the diagnostic system, generated by the DSSD, the productivity of measurements correspondingly increases by four times compared to the single-channel version.

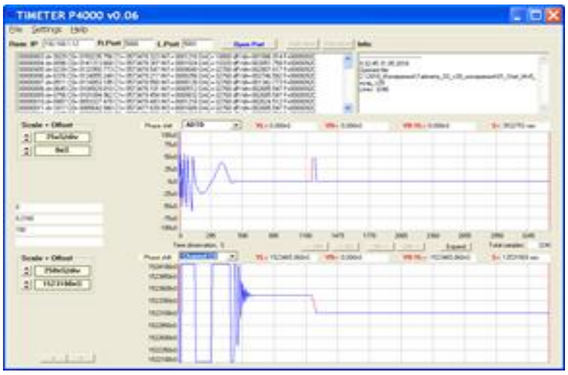

Figure 3: Visualization of the measurements results of *TIE* controlled clock signals

This example demonstrates the ability of the developed software and hardware to provide transmission using IP technology direct and independent measurement results of *TIE* controlled DSSD clock signals. Automated real-time data processing with centralized accumulation provides the presentation of measurement results in an operator-friendly format, which simplifies the diagnostic process and increases the reliability of decision-making.

3. Conclusions

Based on the results of scientific and innovative project developments and experimental research performed within the state budget, it can be stated that the created software and hardware for automated diagnostics of digital signal synchronization devices is the state-of-the-art system developed in Ukraine. The automated system can be used effectively to monitor the timing of clock signals in various sectors of the country’s economy, as well as to enhance the information sovereignty, defense and security of the state.

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