It is proposed that the mechanical state of turbogenerators be regularly monitored by photoelectric chronometric recording of low-frequency torsional vibrations of their shafts. The vibrations are caused by small sudden changes which are continuously occurring in the operating parameters of the turbine unit.

It is known that a qualitatively new level of experimental study could be reached in involving the operation of machines and mechanisms if the relative error made in measuring the speed of rotation of shafts could be reduced to $10^{-4}\%$. In this article, we present the results obtained from an attempt to precisely monitor the rotation of a turbogenerator shaft (TS) by performing measurements with a photoelectric system. The system has a relative error of $5\cdot10^{-4}\%$ at industrial frequencies, which means that it could reduce the absolute error made in measuring the time of a single revolution $T$ ($T = 0.02$ sec at a frequency of 50 Hz) to $10^{-7}$ sec [1]. A built-in quartz generator is used to ensure such accuracy when a small number of measurements is being made, while a highly stable external oscillator is connected to the system when observations are made over a fairly long period of time.

When the operation of cyclic mechanisms is monitored by successively recording the duration of each cycle and multiple cycles or characteristic stages, the result is a sequence of numbers – a time series and its main form of representation: the chronogram. A more appropriate term would be the “periodogram,” which has already been used in Schuster’s mathematical theory of time series [2]. The variations of the terms of the series contain all of the information on the given mechanism that can be obtained by mathematical analysis with the level of accuracy that has been achieved to date.

An effective method of analyzing time series is modern digital spectrum analysis [3, 4]. However, the use of this approach requires consideration of the so-called “echo” [5] or “window” effect [3, 4] that occurs due to the unavoidable limitation on the duration of the time interval chosen to perform the measurements. In digital spectrum analysis, this effect can cause weak spectrum lines to be masked by the side lobes of stronger lines. (In the same way, the effect reduces the aperture of the optical system, i.e., it narrows the band of “space frequencies,” and it lowers the resolution of the system – which until the creation of the diffraction theory of optical systems led to various incongruities, including false openings). In particular, unsubstantiated use of the least accurate type of window – a “rectangular” window – to study cycles can create the false impression that quasisteady cycles generally cannot be monitored chronometrically by using their steady-state frequencies. In fact, the Fourier transform of a rectangular window whose duration is equal to the period of one cycle $T$ has the form

$$U(f) = T \left( \frac{\sin \pi f T}{\pi f T} \right) e^{-j\pi f T},$$

where $f$ is a frequency that vanishes at frequency of the cycle $f = 1/T$ and its integral multiples. However, the situation changes radically if we change over from a spectral representation to a coordinate-time representation. The effect of such a change can be demonstrated by using the study of the regime of rotation of a TG shaft as an example: if technical chronometry could
reduce the relative error in measuring the period of rotation of the shaft to $5 \times 10^{-4}\%$, it would open up new possibilities for studying the operation of TGs and other cyclic machines [1].

The problem of precisely measuring time intervals during turbogenerator operation in the machine room of a heating and power plant amounts to solving the traditional problem of determining the moment of the signal is received when interference is present. To do this, the circuit that generates the reference signal is closed when the groove in the measurement disk mounted on the TG shaft reaches the position specified for it relative to the light beam which is modeled by the groove and is received by the first lens in the optical channel. In the ideal case when noise is absent, the front of the photoelectric pulse has a characteristic point of inflection that marks the reference point. Under actual conditions, when there is open-channel noise (dust, bias lighting, etc.), vibrational noise, and unstable kinematic parameters characterizing the motion of the shaft, the parameters of the initial pulse are not reproducible. It thus becomes necessary to provide a means of automatically compensating for disturbances of the position of the characteristic reference point.

According to [1], with the level of accuracy achieved thus far, it has been determined that the rotation of the shaft is nonuniform and the control-and-measuring equipment in the electrical system cannot measure the variation: even two successive revolutions turn out to be of different duration, nonuniformity is manifest over the course of a single revolution, and the shaft also undergoes torsional vibrations. The nonuniformity is caused by instability of the pressure head in the turbine and the parameters of the electrical load. Figure 1 shows a typical chronogram describing the rotation of a shaft 46 m long and about 100 tons in weight.

Chronometric monitoring of the regime of rotation of TG shafts entails regular measurement of their time of revolution – the continuously fluctuating period or its fractions. Mathematical analysis of the time series which are obtained makes it possible to calculate the spectral characteristics of motion. However, the space-time structure of the motion is of equal interest. Direct digital spectrum analysis of long-period torsional vibrations of the rotor of a generator is ineffective not only due to possible interference (the side lobes of adjacent spectral lines mentioned at the beginning of the article), but also because of the inadequate resolution. The main reason for its ineffectiveness is the brief time that even the perturbations with the longest periods persist due to the damping system and, thus, the low intensity of the corresponding spectral lines. We will show how information on low-frequency torsional vibrations of shafts can be obtained on the basis of precision chronograms.

Let the angle of rotation of a rotating shaft within the test section of the shaft be specified by the expression

$$\psi(t) = \omega_n t + \varphi(t),$$

(1)

where $\omega_n$ is the nominal angular velocity; $\varphi(t)$ is the perturbation of the uniform motion. In addition to systematic measurements of each period, we measure its $n$ multiples. Thus, $n$ is the number of grooves in the measurement disk. Examining the set of all time readings \(\{i_k\}\), where $i$ is the number of the period and $k$ ($1 \leq k \leq n$) is the number of the reading within