TIME AND FREQUENCY MEASURING METROLOGICAL EQUIPMENT IN THE USSR

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Abstract

The complex of the means of providing time and frequency traceability in the USSR includes the system of time and frequency standards of the National Time and Frequency Calibration Service, time and frequency transfer facilities and local time and frequency standards. Control on measurement correctness is performed by the All–Union State Standard calibration service.

The hardware of most of the above–mentioned systems is provided by the instruments developed by our institute. A common scientific and technological approach allowed us to create a unified system of time — frequency equipment composed of widely used serial instruments, sets, automated systems and complexes. Primary frequency standards of different classes, time and frequency references and instruments are based on the unified system. CH1–70 hydrogen frequency standard and its CH1–70A, CH1–80 modifications are used in the group time and frequency standards. Measuring time and data processing techniques, and also instrumentation specifications on the results of 10–year operation are given in the report. The existing system provides time–frequency measurements with $2 \times 10^{-13} \pm 1 \times 10^{-14}$ ***accuracy.***

Metrological equipment, providing traceability of frequency– time measurements in the USSR, comprises:

- a system of frequency–time standards located in different regions of the country;
- equipment for transmission time and frequency units using different communication links;
- reference and working measuring instruments of the consumers.

The system operation, control and also measurement inspection are performed by the National time and frequency service and the National calibration service of Gosstandard USSR.

The major part of the above–mentioned complexes and systems includes instruments developed by our association during the last 15 years. A common scientific and technological approach allowed to create a unified system of frequency–time measuring equipment composed of widely used serial instruments, sets, automated measuring systems and complexes. This unified system includes CHO–100 primary frequency–time standard of the Main Verification Center of the National time and frequency service, CH0–101, CH0–101B secondary frequency–time standard, CH0-200 reference measuring instruments.

The principle of operation of these instruments is based on time and frequency keeping by the group of hydrogen masers. In this case high precision measurements, achieved by averaging or approximation to the best maser characteristics, and their reliable data are provided.

The frequency and time scale adjustment defined by the comparison between the National frequency–time standard and the given time keeper are taken into consideration in measurements. A multichannel automated measuring system provides the mutual comparison of frequency difference and frequency stability measurement for each pair of hydrogen masers in the group for different time intervals from 1 s up to 1 month. By mutual comparison the measuring system calculates characteristics of each hydrogen maser. Taking into account Allan variance measurement data over short time intervals from 1 s up to 1 day, one performs the choice of the best hydrogen maser as reference, weight estimation of each maser in the group and its operation check. According to the frequency drift measurement the data of each hydrogen maser at intervals per 1 day and more the mean frequency and time scale value of the group in relation to the National frequency standard and also frequency drift and time scale adjustments of each hydrogen maser in relation to the group are defined. The above mentioned data allows to save the history of the group in case of hydrogen maser operation failure or measurement continuity break.

Measurement, data processing and adjustment storage provide sine-wave signals in a wide frequency range and also time scale and various pulse signals at the device output with characteristics approximate to the National standard system.

The output signal accuracy in relation to the National standard depends on the internal and external measurement precision and hydrogen maser frequency stability.

The order of operation of all complex devices is programmed by the software algorithm. All the measurement and diagnostic data are displayed periodically every hour or at any time by the user request.

The consumer may order different equipment: both separate instruments and several measuring systems, including time keepers, complexes or automated measuring systems.

The above-mentioned complexes and systems use the hydrogen maser, type CH1-70 (1980), or its later modification (1987) CH1-80. A detailed discussion of the hydrogen maser characteristics is given in the paper, authored by Dr. Demidov and me for this conference [1]. According to the results of the 10-year operation the frequency-time secondary standards the type CH0-101, in different time and frequency services demonstrate relative time and frequency keeping accuracy about the order of 1to 5×10^{-14} over time intervals from 1 month and more. This information is described in detail in the paper written by Dr. Koshelyaevsky, USSR National time and frequency service expert.

At present the improvement in measurement precision is quite possible with the advent of a new generation of frequency measuring equipment, based on CH1-75, CH1-76 hydrogen masers, CH7-45 frequency comparator and CH7-48 phase comparator, I4-10 time interval meter, frequency precision summer, RU3-39 distribution amplifier and others.

The design and characteristics of CH1-75, CH1-76 hydrogen masers are given in paper [1]. The information on the rest measuring equipment is given shortly below.

Ultrastable frequency signal measurements in the frequency and time domains are provided by conversion of reference and measured signal frequencies. Frequency and phase comparators, spectrum analyzers are based on this principle of operation. In these instruments by frequency conversion a multiplied signal, which is a difference of reference and measured frequencies, is separated, then analyzed by a frequency counter, a time-interval meter or by a narrow-band filter. Mutual spectrum-to-frequency stability conversion and vice versa are also possible. These methods are discussed in detail in papers [2] and some of them have been used in our frequency-time measuring equipment.

The CH7-45 frequency comparator is intended for measuring 5 MHz and 100 MHz signal frequency difference and frequency and phase stability (with external heterodyne input frequency range 2 – 100 MHz). The comparator allows to measure characteristics of crystal oscillator and frequency — time standards and operates in time and frequency measuring systems. The measuring and data calculation processes are performed by a built-in microprocessor, and results are indicated on the liquid-crystal display in the convenient form.

The instrument frequency stability which is defined by the sensitive level of the comparator, is better than 1×10^{-13} for 1 s time interval and better than 1×10^{-15} for 1 h and more. The input frequency difference relative to multiplication factor is $K = 10^3,\ 10^4,\ 10^5$; passbands are 10, 30, 100, 300 Hz, 1, 10 kHz; measuring time intervals are from 10 s to 3600 s.

The CH7-48 phase comparator comprises four parallel channels. It is intended for operation in multichannel frequency measuring systems. The input frequency is 5 MHz or 100 MHz. The instrument frequency stability is better than 1×10^{-15} for 1 h.

The I4-10 time interval meter is designed for precision measurement of time interval between two pulses and time pulse parameters. The principle of operation of this meter is based on the method of "charge-discharge capacity by stable currents". The systematic error of measurement is 1 ns. The time resolution is 0.1 ns for time interval 0 – 10 s. The I4-10 operates with pulses of any polarity up to 10 V amplitude and the repetition rate up to 10 MHz. For repetitive sequences it has the measuring mode with noise time base modulation and averaging factor up to 10 which allows to increase the time resolution up to 5 – 10 ps.

Sine-wave and pulse signal distributing amplifiers are designed to provide all systems of the measuring complex and also external equipment with highly stable standard frequency signals. The amplifiers have a low internal noise, a high temperature stability and a high isolation between channels.

The basic characteristics of The RU3-39 sine-wave signal distribution amplifier:

- operating frequencies: 1, 5, 10, 100 MHz;
- input voltage: 0.3 V - 1.5 V;
- input and output resistance: 50 Ohm;
- instrument frequency stability not more than 2×10^{-13} per 1 s;
- temperature stability 0.02 ns/deg.C;
- isolation between channels 100 dB.

The instrument has two distribution channels with distribution factor 1:10.

The basic characteristics of pulse signal amplifier:

- the number of inputs - 6;
- the number of outputs - 16;
- switching in any combination;
- input and output signals - TTL square pulses at 50 Ohm load with 0 - 10 MHz repetition rate;
- the time scattering of signals, formed from one input - not more than ± 1 ns.

Time-scale corrector is designed to convert discrete calibrated phase shift to 5 MHz reference signal to provide adjustable coordinate time scale. The instrument is used, mainly, in the time–scale shaping systems of the frequency-time standards. Its principle of operation is built on the pulse sequence summation method, widely used in the frequency synthesis technique. The instrument allows to perform discrete signal phase correction in 0.1 ns–100 ns range with 0.1 ns minimum steps. The basic instrument error — temperature phase shift— not more than 0.05 ns/deg.C.

The frequency precision summer permits to synthesize a signal, the frequency of which is equal to the mean weighted frequency of the group from 2 to 4 5 MHZ highly stable reference signals. It is designed to form and generate average frequency and time scale signal of the group frequency-time standards.

The principle of operation of this instrument is based on the crystal oscillator automatic frequency control by the sum of signals passed from the frequency discriminators. Each discriminator compares crystal oscillator frequency with the frequency of one of the summed signals. The CH7-48 phase comparator is used to improve sensitivity.

The basic summer characteristics:

- instrument frequency instability — 2×10^{-13} per 1 s, 4×10^{-15} per 100 s, 1×10^{-15} per 1 h and more;

All the above-mentioned instruments may be integrated into measuring systems controlled by a computer via IEC 625 bus.

On the base of the above-mentioned instruments and other auxiliary equipment a new generation of frequency-time keepers and standards has been developed. This very generation also uses the group principle of time and frequency keeping and the basic techniques to control the instruments.

Unlike the currently used equipment, a new generation of instruments provides output signals on the basis of converted mean weighted frequency; the assessment and quality control criteria of masers and measuring equipment have been added using the latest measuring techniques and processing of larger data arrays; besides the RF-cavity operating temperature in the hydrogen frequency keepers has been reduced that decreases frequency drift of CH1-75 hydrogen masers by 3 – 4 times. The research on new frequency standards has confirmed a substantial improvement of their characteristics in comparison with the currently available models. They have demonstrated frequency and time scale keeping accuracy not more than 2×10^{-14} or less for intervals up to 1 month.

The use of such frequency standards in the last ten years shows that the improvement of their characteristics by 2 – 3 times compared to the characteristics achieved under the workshop conditions may be possible.

References

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