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On Research, Creation, and Testing of Devices for Electronic Deployment of Permanent Continuous Analog Visible Recording of Low–Frequency Processes

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Abstract. Mechanical methods of deployment of permanent, continuous analog visible recording of signals complicate the design of analog recorders and light–beam oscilloscopes with the continuous visible recording of low–frequency processes and periodic output of recording frames, reduce their reliability and accuracy, make it difficult to adjust deployment steps, increase power and dimensions, and also lead to additional geometrical and optical errors in light–beam oscilloscopes. To eliminate these shortcomings, electronic methods for deployment of continuous analog visible recording are proposed and analysed, on the basis of which corresponding devices are also developed, created, and tested, with the help of which the proposed electronic methods are tested and verified based on *ASEO* type Automatic seismic electrographic oscilloscopes.

Keywords: analog continuous recording, visible recording, recording frames, recording deployment, seismogram, light beam oscilloscope, seismic light–beam electrographic oscilloscope, optical arm.

Introduction

As is known, despite the rapid development and widespread use of various digital recording methods and devices, a variety of analog recorders with a visible recording of low–frequency signals with different recording methods, including helicorders and light–beam photo– and electrographic oscilloscopes, are still also used in the seismology and different other areas, for the permanent continuous visible recording of seismic and other low–frequency processes [1–10].

The permanent continuous analog visible recording of seismic and other low–frequency signals is carried out by a continuous accumulation of signals on the sheet of an information storage medium (different types of papers, photo films, electrographic layer, etc., depending on the used analog visible recording method and corresponding recorder) wrapped around the surface of a permanently and uniformly turning drum, to ensure a helical deployment of signals on the entire surface of the used information storage medium and following periodic output of the accumulated information in the form of separate visible frames (seismograms in the seismology) to provide a continuous visible trace of the recorded signals for the whole recording period [1–4,10–12].

The helical deployment of signals for a permanent continuous analog recording is carried out in visible helicorders and other analog permanent recorders and light–beam oscilloscopes either, by simultaneous uniform movement along its axis of a drum uniformly rotating around its axis together with a signal storage medium wrapped on its surface [6,7], or by uniform movement of the block of measuring galvanometers in parallel with the axis of the rotating drum [6,7,10–12], or by uniform rotation of an additional mirror installed between the measuring light–beam galvanometers and rotating drum in the path of the rays reflected from the galvanometers [7].

Despite their differences, all above indicated mechanical methods used for the helical deployment of signals during their permanent continuous analog visible recording [6,7,10–12], complicate the design of helicorders, light–beam oscilloscopes, and other recorders with permanent continuous visible analog recording, decrease their reliability, reduce the quality and accuracy of recording, increase power and dimensions, and also limit the possibility of smooth adjustment of deployment steps and also in light–beam oscilloscopes and pen recorders during the recording on information storage mediums with a surface parallel to the deployment axis, lead to additional static geometrical and optical errors, which require their elimination or consideration when processing the frames (seismograms) with recorded signals [10,13–15].

Overview of electronic deployment methods for continuous visible recording

To eliminate the above–described shortcomings of mechanical methods of continuous analog visible recording of signals and also for considering and compensating of static geometrical and optical errors of corresponding light–beam oscilloscopes and pen recorders, electronic methods for helical and step deployment of continuous visible recording were proposed, analyzed and verified [10,16,17].

As described in [10,16], the essence of the proposed method of electronic helical deployment of continuous visible recording lies in the fact that to the measuring galvanometers of analog recorders, including the light–beam galvanometers of oscilloscopes, along with the recorded low–frequency signals an additional sawtooth signal is also simultaneously applied, the period of which is equal to the duration of registration of one recording visible frame or seismogram, and the smooth increment during each turn of the drum with the recording medium, or the duration of each line of the visible frame or seismogram, is proportional to the ratio of the required deployment step to the voltage sensitivity of the measuring galvanometer. In this case, the sum of the signals from the sawtooth voltage source and the sensor of recorded low–frequency signals causes a corresponding total rotation of the measuring galvanometer, which leads to a total deviation of the tip of the mechanical galvanometer or the light spot from the light beam reflected from the mirror of the light–beam galvanometer on the surface of the rotating drum with the recording medium [10].

In [10], a detailed analysis of the features of the proposed electronic method of helical deployment of continuous visible recording was carried out and its advantages over mechanical scanning methods were substantiated. In particular, it is shown in [10] that in light–beam oscilloscopes with an optical arm of *150 mm*, which takes place particularly in the Automatic seismic electrographic oscilloscopes *ASEO*[1], Movable seismic oscilloscopes PEO [6,10–12,16–19], and many other light–beam oscilloscopes, the maximum optical errors of the deployment step do not exceed *0.65%* during the suggested electronic helical deployment. Wherein it is assumed that the light–beam galvanometers are installed evenly across the width of the rotating drum with the recording medium, and in the absence of signals, the optical beams from the galvanometers fall perpendicular to the surface of the recording medium. At the same time, it is shown [10] that the errors of the steps of the mechanical deployment in light–beam oscilloscopes with continuous recording, for example, in the *ASEO* type oscilloscopes, are almost twice large than during the suggested electronic deployment and reach to *1–1.5%*, due to numerous tolerances and backlashes in the mechanisms of rotation of the recording medium, as well as due to movement and return of the carriage with the galvanometers, or signal storage medium.

In addition, it was shown in [10] that in three–channel light–beam oscilloscopes with an optical arm of *150 mm* and a recording medium width of 150 mm, the signal recording static optical errors with electronic deployment are only *3.5%* higher for the middle recording channel, and are almost half for the outer channels as compared with static optical errors during mechanical deployment of signals and grouped galvanometers on a single magnetic block mounted on a movable carriage [6,10, 12,19]. Based on the proposed method, similar analyses, calculations and comparisons of the static optical errors of permanent analog visible recording with known mechanical and the proposed

[1] *ASEO, ASEO–1,* and *ASEO–1M*–type oscilloscopes are designed and manufactured at the Special Experimental Design Technological Institute (SEDTI) of the Academy of Sciences of the RA (Leninakan) according to the technical requirements and in cooperation with the Institute of the Physics of the Earth (IPE) of the SU AS (Moscow, RF).

electronic methods of helical deployment can be made for other analog recorders and light–beam oscilloscopes with different recording media widths, numbers of channels, optical arm length, etc.

It is also indicated in [10,17] that mutual disadvantages of the proposed electronic and known mechanical methods of helical deployment of continuous analog visible recording are the presence of static geometric and optical errors, as well as the fact that the signal recording zero lines are inclined relative to the surface vertical of the recording carrier, due to which the real speed of the signal recording line differs from the speed of the signal storage movement, which in turn leads to additional amplitude and spectral errors in the continuous visible recording of the signal.

In order to eliminate these and some other disadvantages of helical deployment methods and devices, an electronic method for a line step deployment of continuous visible recording was also proposed [10, 17], in which simultaneously with the recorded signal to the measuring galvanometer an additional step signal is also applied, the duration of the steps of which is equal to the duration of one turn of the rotating drum with a signal storage medium or one line of a seismogram or a frame of a record, and the instantaneous increase of the step occurs after each revolution of the drum and is equal to the ratio of the required recording deployment step to the sensitivity of the measuring galvanometer.

In addition, in [10] it is also indicated that if during line step deployment, the discrete angles of the light beam deviation and the magnitudes of the voltage of corresponding additional step signal are determined taking into account the static geometric and optical errors, then electronic line step deployment can be carried out with a constant deployment step with compensation and exclusion of static geometric and optical errors inherent to all mechanical and electronic methods of helical deployment.

The feasibility and efficiency of the proposed electronic methods of helical and linear stepped deployment of the recorded signals, as well as the validity of the calculations and conclusions made, were experimentally tested, verified, and confirmed on an *ACEO*–type oscilloscope (Fig 1) using the corresponding special devices designed, created and installed in the oscilloscope for this purpose, the presentation of which is devoted to this article.

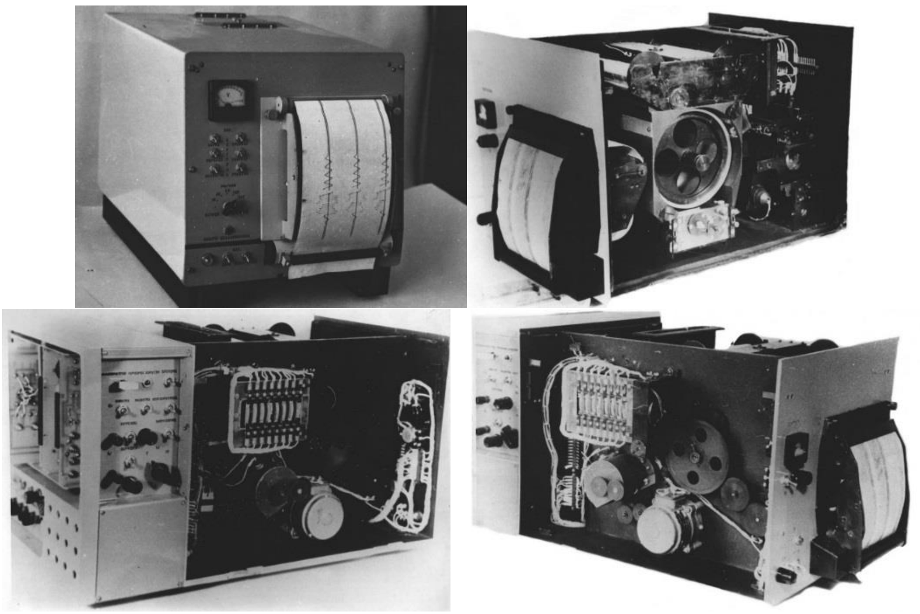

Fig. 1. Some views on the *ASEO* type Autonomous Seismic Light–beam Electrographic Oscilloscopes.

Practical applications and experimental verifications

In Fig. 2 an electromechanical block diagram of one of our proposed options for an electronic helical deployment device [16] for one recording channel is shown, which was designed, made and tested using an *ASEO–1* type light–beam electrographic oscilloscope. When the oscilloscope is turned on, the electrophotographic cylinder *1* rotates uniformly from the drive *2*, and the light rays reflected from the light–beam measuring galvanometers *3* carry out the hidden electrostatic recording of signals on the surface of the pre–electrified electrographic cylinder (galvanometers and seismometers of the remaining two recording channels, which takes place in the *ASEO–1* type oscilloscope, with their external chains are connected to points *a* and *b (2–2, 3–3)*). As can be seen from Fig. 2, signals from seismometers *4* (through terminating resistors R_1, R_2, and *r*) and voltage from a mutual sawtooth voltage source *5* (through separating and terminating resistors Rg' and R_0) are simultaneously fed to galvanometers *3* [16]. In this case, the voltage from the middle variable output of the multi–turn variable precision resistor R_p with the number of revolutions of the regulator shaft $n_в$ is used as the sawtooth signal for the recording helical deployment.

The main leads of the resistor R_p are connected to a stabilized constant voltage source, the middle lead is connected to the galvanometer through resistors R_g' and R_0, and the adjusting shaft is engaged with the axis of the rotating electro photographic cylinder of the information storage medium using interchangeable gears *6* with a gear ratio $n_в/N_ц$. When the cylinder of the information storage, and therefore the adjusting shaft of the variable resistor R_p, rotates, the voltage at its leads *a, b,* and therefore the voltage u_p, increases linearly and reaches its maximum value after the $n_в$ revolutions of the adjusting shaft of the variable resistor R_p, corresponding to $N_ц$ revolutions of the electrophotographic cylinder and recording lines. With further rotation of the resistor R_p adjusting shaft, the deployment voltage u_p instantly drops to zero, and the cycle repeats.

Thus, signals are recorded with a helical deployment without the usage of additional special mechanical nodes and additional mechanical movements of the rotating cylinder and block of measuring galvanometers [16]. Replaceable gears carry out stepped, and the resistor R_g' – smooth adjustment of the steps of the helical deployment. Resistors R_1, R_2, and *r* serve to form the necessary characteristics of the signal registration channel [8,18], and R_0 and Rg – to ensure decoupling and matching of sensors of recorded low–frequency signals *4* and sawtooth voltage source *5*.

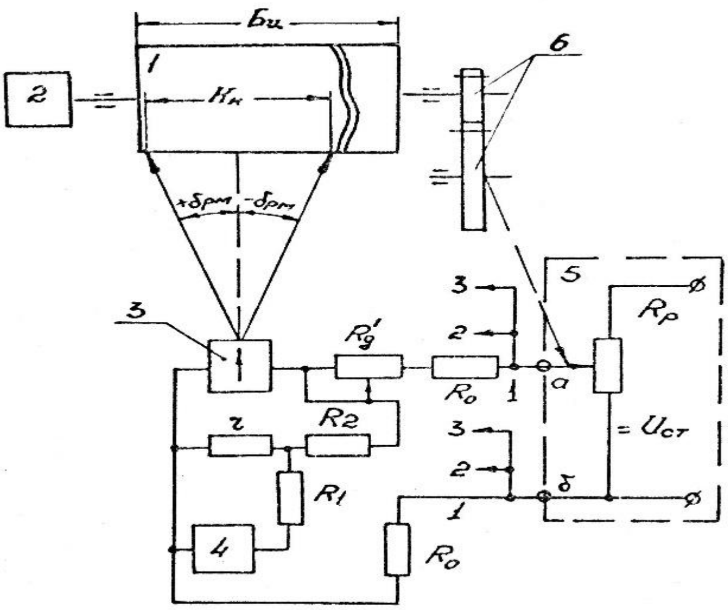

Fig. 2. Electromechanical diagram of the layout of the created device for electronic helical deployment of permanent continuous recording of along low–frequency signals on the basis of the *ASEO–1* type oscilloscope:
1 – electrophotographic cylinder *(EPC); 2* – drive; *3* – light beam measuring galvanometers; *4* – seismometers or other sensors of recorded low–frequency signals; *5* – sawtooth voltage source; *6* – interchangeable gears.

The experimental testing, verification, and numerous practical records and sample seismographs obtained, some of the samples of which are presented in Fig. 3, confirm the practical possibility, efficiency, usefulness, and expediency of implementing of suggested electronic helical deployment of seismic and other low–frequency signals in light–beam oscilloscopes and other devices with permanent continuous analog visible recording and periodic frame and seismogram output of accumulated signals.

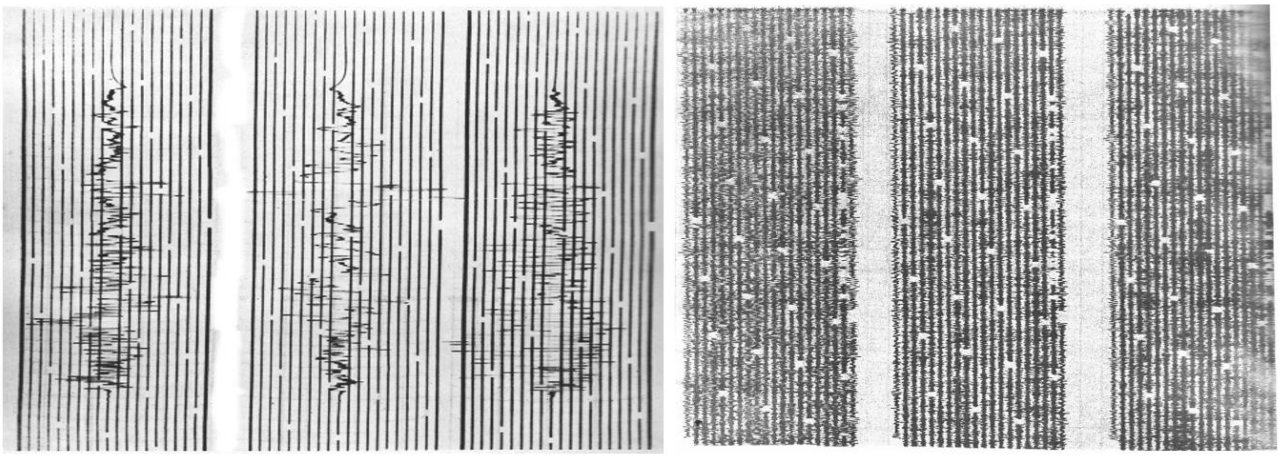

Fig. 3. Some samples of experimental continuous recording and frame output of accumulated information with an electronic helical deployment, obtained on the *ASEO–1* type oscilloscope.

At the same time, in comparison with the mechanical deployment, the design and construction of oscilloscopes and recorders for permanent continuous recording and periodic output of frames and seismograms with the proposed electronic helical deployment were significantly simplified due to the exclusion of carriages and complex mechanisms for transverse movements of galvanometers or rotating drum with a recording media; the reliability of work increased due to the simplification of the design and the exclusion of mechanical movements and shocks of the construction; optical and mechanical errors of the deployment step and static recording errors decreased; as well as the possibility of smooth adjustment of the deployment step were provided.

On the basis of the *ASEO–1* type oscilloscope, experimental testing and verification of suggested electronic line step deployment of continuous visible recording of signals were also carried out [17], using a special device developed, created, and installed for this purpose in the oscilloscope, the generalized electromechanical block diagram of which is shown in Fig. 4.

When the oscilloscope is turned on, the electrophotographic cylinder *1* rotates from drive *2,* and the light rays reflected from the light–beam measuring galvanometers *3* carry out hidden electrostatic recording on its pre–electrified surface. In this case, with the signals from seismometers or other sensors of the corresponding low–frequency signals *4* an additional voltage from a step voltage source *5* is simultaneously fed to the galvanometers, which causes a total deviation of light rays on the surface of the electrographic cylinder [10,17].

After each complete revolution of the cylinder *1*, the cylinder revolution indicator *6* sends a pulse to the counting input *C* of a binary counter *7*, from the outputs of which the binary parallel code of the number of revolutions of the cylinder *1* is fed to the inputs of a *DAC 8* and logic element *9*. So, after each revolution of cylinder *1*, the voltage on the analog output of the *DAC 8* increases abruptly, the value of which is regulated by the reference voltage u_{op} and the resistor R_p. After $N_ц$ revolutions of cylinder *1* and recording one frame or seismogram, the output of logic element *9* generates a logical unit signal, which, at the input *R* of the counter *7*, brings it to a state of logic zero. At the same time, the signal at the output of the *DAC* drops to zero, the light beam returns to its original position, and the cycle repeats while continuing to rotate the cylinder of the recording medium *1*. As in the device for electronic helical deployment of the recording signals (Fig. 2), the galvanometers and seismometers of the other two recording channels of the oscilloscope *ASEO–1* with their external circuits are connected to the points *2–2* and *3–3*.

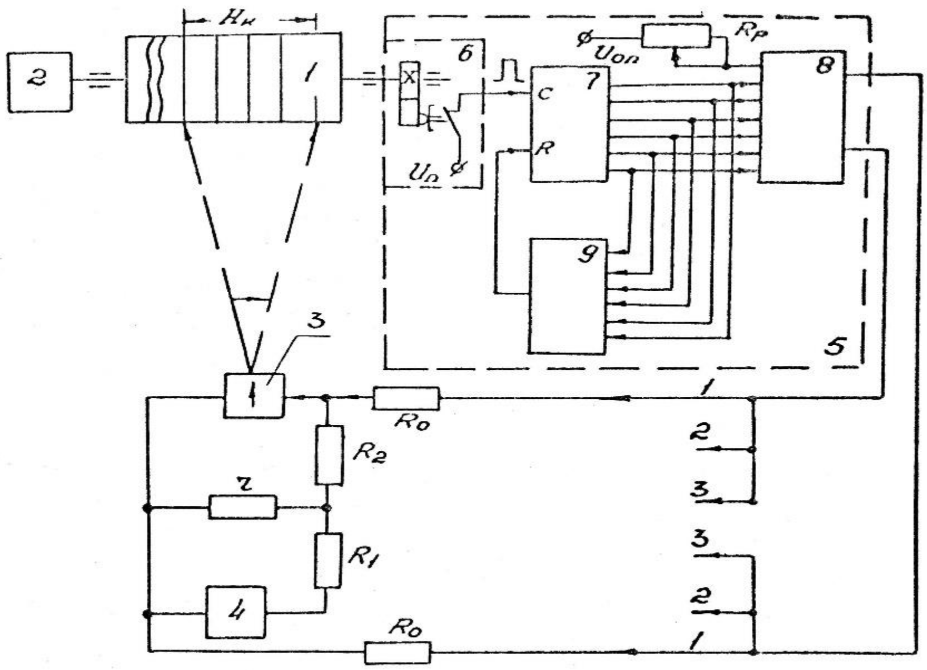

Fig. 4. Generalized electromechanical structural diagram of the layout of the device for electronic line step deployment of continuous recording on the basis of the *ASEO–1* type oscilloscope:
1 – electrophotographic cylinder *(EPC); 2* – drive; *3* – light beam measuring galvanometers; *4* – seismometers; *5* – step voltage source; *6* – EPC turnover indicator; *7* – EPC revolution counter; *8 – DAC*; *9* – logical device.

Thus, electrostatic recording of stepped deployed low–frequency signals is carried out on the surface of a pre–charged electro photographic cylinder *1*, which is then transferred to a paper tape in the form of a seismogram or a recording frame, according to the principle of operation of oscilloscopes *ASEO* [12,17,19]. Depending on the needed deployment step and the number of the recording lines, the corresponding conversion factor of the logic element *9*, as well as the value of the reference voltage u_{on}, are set, and the deployment step is smoothly adjusted by the resistor R_p.

Experimental testing, verification and obtained samples of records (see Fig. 4) also confirmed the practical possibility, efficiency, and expediency of using electronic step deployment of signals in *ASEO* type and other light–beam oscilloscopes and recorders with continuous recording and frame or seismogram output of recorded signals.

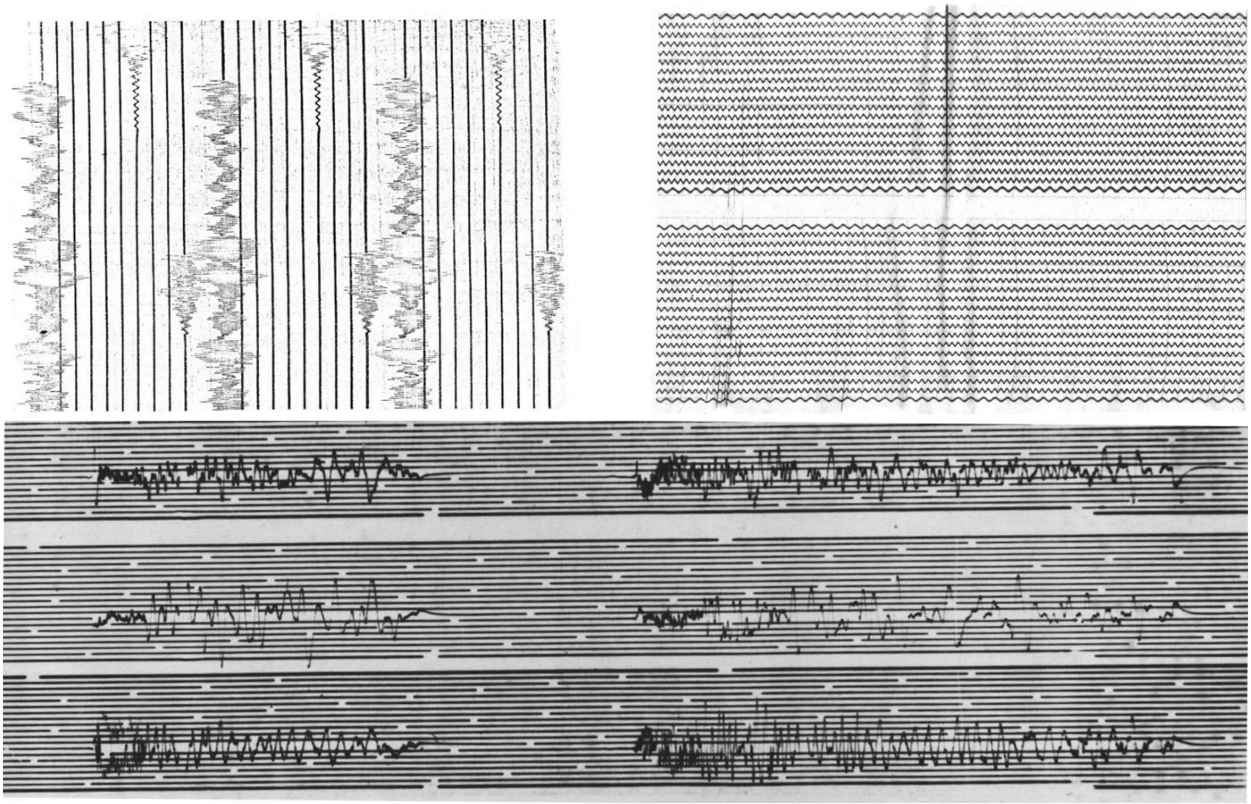

Fig. 5. Samples of experimental continuous recording and frame output of signals on an *ASEO–1* light–beam electrographic oscilloscope using electronic horizontal step deployment of signals.

Completed experimental tests and records showed that, as it was also indicated in [10], along with all the advantages of the electronic helical deployment, the line–stepped electronic deployment also makes it possible to exclude additional static geometrical and optical recording errors, associated with the slope of zero lines, and eliminate the static errors with the condition that they are taken into account when determining step voltage steps in the electronic circuit of the step signal generator.

Thus, summing up the above, we can confirm the following:

- Proposed, implemented, and tested on *ASEO* type oscilloscope, the electronic helical deployment of continuous recording of signals makes it possible to significantly simplify the design and construction, increase the reliability of operation, and provide the possibility of smooth adjustment of steps of recording deployment of analog recorders and light–beam oscilloscopes with a continuous analog recording of information and periodic output of visible frames and seismograms.
- At the same time, the use of electronic helical deployment of recording also makes it possible to reduce errors in the recording and signal deployment steps. In particular, in the *ASEO–1* oscilloscope with a three–channel recording of signals, the relative deployment step errors did not exceed *0.65%,* which is more than two times less than the step errors that occur during the mechanical helical deployment.
- With electronic helical deployment, static optical recording errors are also reduced, which, in particular, in the *ASEO–1* oscilloscope with three–channel registration and uniform distribution of galvanometers, are only *3.5%* larger for the middle channel and almost twice as small for the outer channels compared to the mechanical deployment with grouping of galvanometers on one moving magnetic block.
- The proposed, implemented, and tested on *ASEO* type oscilloscope, the electronic line step deployment of continuous recording, in addition to the above advantages of helical electronic deployment, also makes it possible to eliminate additional recording errors

associated with the slope of the zero lines, as well as to compensate for static optical recording errors, taking them into account when calculating the amplitudes of the stepwise line deployment voltage.

Conclusion

An experimental device for electronic helical deployment of permanent continuous recording of along low–frequency signals is designed, created, and tested, which validated the proposed method for electronic helical deployment of continuous analog visible recording, which makes it possible to significantly simplify the design and construction, increase reliability, reduce power consumption, dimensions, recording errors and sweep pitch, and also provide the ability to smoothly adjust the deployment step of analog recorders and light–beam oscilloscopes with continuous analog registration and periodic issuance of visible frames of records.

An experimental device for electronic line step deployment of permanent continuous recording of along low–frequency signals is designed, created, and tested, which validated the proposed method for electronic line step deployment of continuous analog recording, which, in addition to the above advantages of electronic helical deployment, also makes it possible to eliminate additional recording static geometrical and optical errors with helical deployment associated with the slope of zero lines, as well as to compensate of static optical recording errors, taking them into account in the calculation of amplitudes of steps of the step voltage source.

Declarations and Statements

Conflicts of interest

The authors declare no conflict of interest.

Author Contributions

- The author S.A. Mkhitaryan raised the idea, carried out theoretical calculations, invented, developed, and carried out the experiments, and lead the writing and approval of the article;
- The authors M.A. Hovhannisyan, and R.Y. Chilingaryan participated in the theoretical calculations, experimental activities, and in the writing of the article.
- The authors A.P. Antonyan and A.R. Mnatsakanyan participated in the and experimental activities, as well as in the writing and approval of the article.

Declaration of Competing Interest

The authors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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Compliance with Ethical Standards

All authors have read and approved the manuscript and there are no ethical issues involved.

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