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SEARCH OF EARTHQUAKE PRECURSORS BASING ON FRASH METHOD FOR IDENTIFICATION MEASUREMENTS OF SEISMOGRAPHIC RECORDS

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ABSTRACT

This work shows the possibility of search of timely earthquake precursors basing on the FRaSH method for identification measurements of the shape of instantaneous values distribution and characteristic frequency from seismographic record. It was found that during an earthquake there can be registered extreme sudden changes in the shape and characteristic frequency when scanning the seismographic record. However, in the time before the earthquake there can be seen smaller in value but still sudden changes of the shape and the characteristic frequency. These facts are used as timely precursors to predict earthquakes. The most suitable threshold value of identification variables that establish the timely short-term earthquake precursor and the corresponding prediction interval were determined. There was created a device that measures statistical variables, shape and characteristic frequency of the seismographic record, as well as searches for possible earthquake precursors. Besides there was elaborated a new method of determination of earthquake precursors based on sequential comparison of identification variables of shape and characteristic frequency to threshold values while getting closer to the time of earthquake.

Keywords: earthquake precursor, identification measurement, FRaSH method, seismographic record.

INTRODUCTION

Currently one of the most urgent tasks of the field is the development of innovative tools that increase the accuracy and efficiency of seismic studies and their implementation in the instrumentation and recording system.

A promising direction of new technologies in the field of seismology is development and implementation of computer programs for detailed processing and visual analysis of digital seismic signals from various collection systems [1-3]. The main purposes of the programs are: 1) timely determination of the earthquake intensity and 2) search for earthquake precursors following meanings of signals.

Today the first problem is highly efficiently solved because the program has a functional interface for user interaction and allows a variety of operations with seismic signals [4-8]. For example, recursive and non-recursive filtering, developing of Bessel or Butterworth IIR filters and FIR-filters of low pass, high pass, band-pass and band-stop, plotting of the signal envelope and smoothing the signal in time domain through by-pass time window [9, 10].

The second problem is the automatic search of earthquake precursors and is not completely solved yet because the possibility of earthquake prediction remains low for a number of reasons. In particular, it is difficult to establish meaningful patterns for mathematical prediction of unpredictably shaped seismographic records through determinate functions. The situation is complicated by noise and interference caused by different phenomena such as wind, changes in atmospheric pressure, temperature changes, human influence, etc. The noise [11] means some background processes of destruction that are of great interest in the search for timely earthquake precursors.

Therefore, higher efficiency of search for timely and informative earthquake precursors can be get through more accurate and efficient methods and algorithms.

In the work [12] the authors proved that the theory of identification measurements is fairly applicable for analysis of seismographic records using S scales which have reference marks as points of symmetric distribution of instant values. The analysis results show that seismic monitoring corresponds to the movement of scale indicator hand within standards, while complicated seismographic record may be seen as a cluster of deviations from reference marks. This approach resulted in determining consistent patterns of changes in seismographic records in the form of timely earthquake precursors (TEP).

The theory of identification measurements as a combination of intelligent methods and tools of processing and analyzing of complex shape and variability signals of different global standards is obviously promising. Similar technology is widely applied in the diagnosis of hydrogen fuel cells, hydroelectric sets and oil equipment [13], demonstrating effective problem solving.

The aim of this work is to improve quality and accuracy of the TEP search by applying FRaSH method for identification measurement of seismographic records and to develop new, more efficient and simply-implemented computer-based method of TEP search for earthquake prediction. Real seismographic records were used during studies to find prediction marks. Consequently, the studies suggested intelligent method

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and quite effective computer device for processing of real seismographic records and search of TEP.

METHODOLOGY AND TOOLS

FRaSH method of identification measurements allows creating of room-saving and multi-functional tools as only one *(K)* type of tester is used. This method includes the following steps.

Step 1. Finding of identification figure from the samples of N size of the input signal $X_1(t)$ and its increment $\Delta X_1(t)$ according to the formula

$$Y_1(N) = \frac{|\Delta X_1(t)|}{|X_1(t)|}. \quad (1)$$

Step 2. Finding of identification figure from the samples of N size of ranked function $X_2(t)$ of the input signal $X_1(t)$ and its increment $\Delta X_2(t)$ according to the formula

$$Y_2(N) = \frac{|\Delta X_2(t)|}{|X_2(t)|}. \quad (2)$$

Step 3. Finding of virtual frequency of the seismographic record:

$$F = \frac{Y_1(N)}{Y_2(N)}. \quad (3)$$

Step 4. Finding of identification variable indicating the distribution shape of the seismographic record

$$A = 2 \times Y_2(N) \times N. \quad (4)$$

Step 5. Finding of identification figure of different gradations (resolution)

$$R = \frac{N}{F}. \quad (5)$$

The relationship between the identification parameters can be shown in the identification scale (Figure-1).

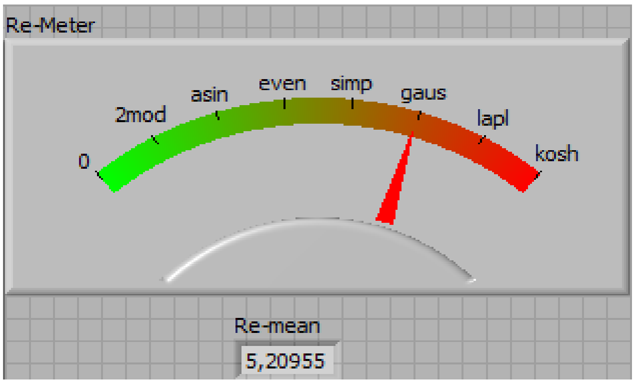

Figure-1. Picture of IS at measuring some signal.

When using the Identification Scale (IS), measurement result is the value of the numeric reading on the scale (Table-1) and the result of identification is the name of the symmetric distributions (2mod means bimodal, asin - arcsine, even - even, trap - trapezoidal, simp - Simpson, gaus - normal, lapl - Laplace, kosh - Cauchy). These names are from the dictionary of distribution names that are used in the static measurements and that serve in this case as “digitized” marks of IS.

Due to the limited number of digitized marks of IS and rounding of readings up or down to the nearest marker (Figure-1), the measurement result is of classification nature where all the variety of signals can be assigned to 8 classes. However, more "thin" distinguishing of signals belonging to the same class can not be achieved, so an additional procedure - the procedure of "linguistic interpolation" (LI) - shall be used.

The idea of LI is that not only the one nearest mark, but all the marks of IS shall form the results of the analysis in proportion to the influence the involved distributions exert on the overall result. In this case, the measurement result will be expressed in a list of names of the distributions at IS, ranked according to their degree of importance (top-down).

For the purpose of the research there is used a new structure of the computer device that implements the intelligent analysis of seismographic records by FRaSH method of identification measurements. Structural scheme of the device is shown in Figure-2 where the FRaSH-tester is a device for identification measuring of the seismographic record and SUTV is for setting analysis and processing unit for threshold values of identification variables.

Table-1. Identification scale of FRaSH-method for random signals.

N=10000, *L*=100	Distribution type of random signal							
	2mod	**asin**	**even**	**trap**	**simp**	**gaus**	**lapl**	**kosh**
α, rad	4	6,28	8	10	12	20	36	3000
F, Hz	2500	2027	1667	1380	1167	733	417	6

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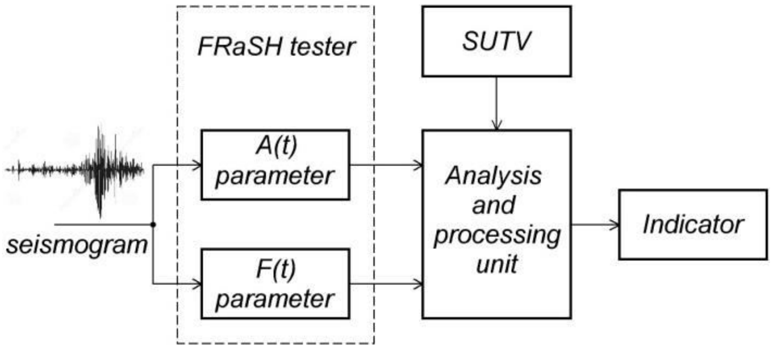

Figure-2. Block diagram of the computer device.

In accordance with the structural scheme shown in Figure-2 the computer device was performed in LabVIEW12. External control panel of the computer device for identification measurements of seismographic records by FRaSH method is shown in Figure-3.

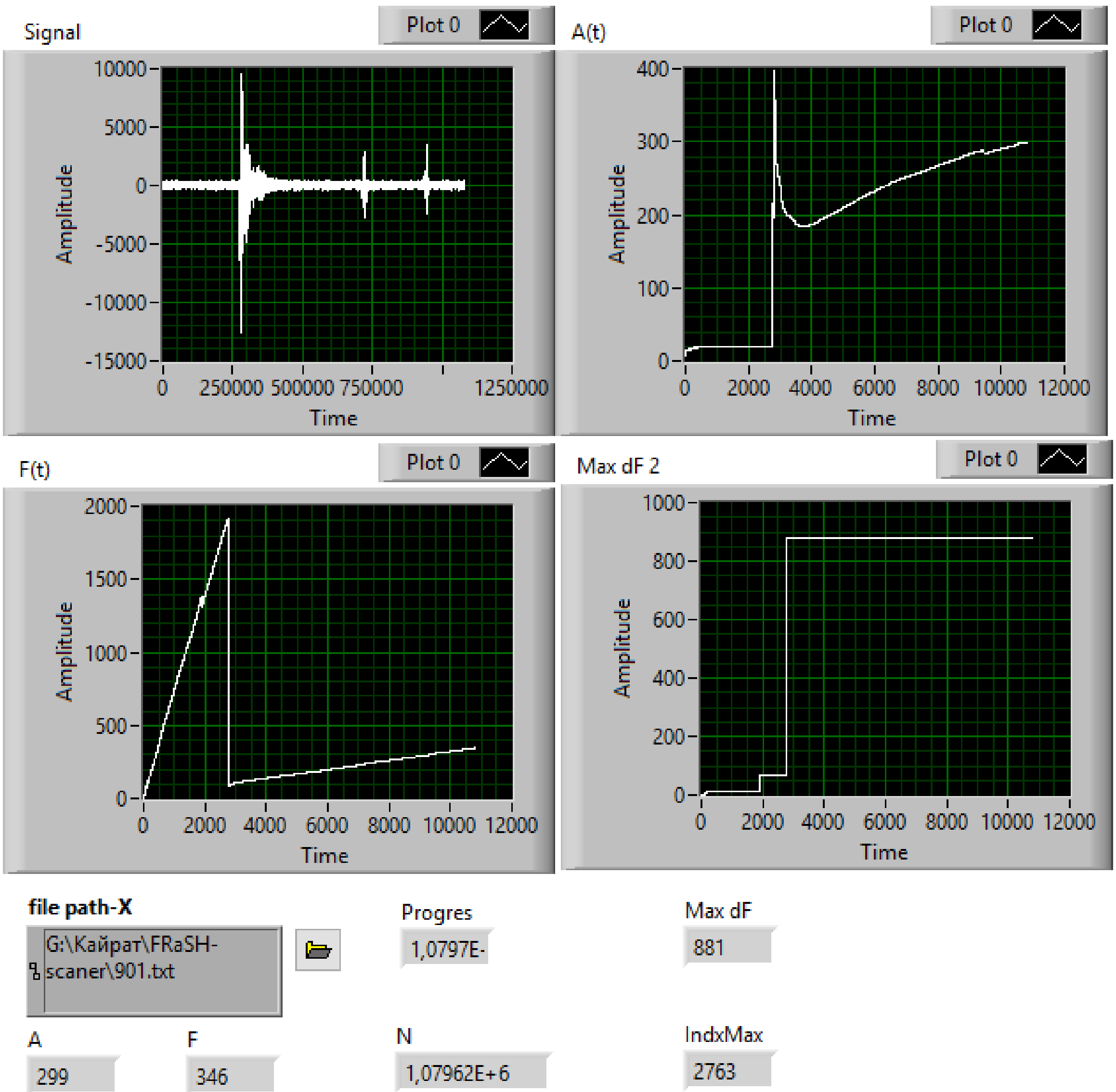

Figure-3. External control panel of the computer device for identification measurements of seismographic records by FRaSH-method.

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The panel of the computer device for the identification measurements of seismographic records by FRaSH method has the following controls and indications:

- data file access hole (File path-X);
- indicator (Progress) of scanning signal (the current time of the analysis);
- indicators of the parameter of form (A) and virtual frequency (F) of the full signal of the N amount;
- meter (Max dF) of maximum value of the virtual frequency jump at the time of an earthquake; the time of earthquake start is related to the number of counts as 100:1;
- indicator (Signal) of input signal changes over time;
- indicator (A(t)) of changes of the signal shape during scanning;
- indicator (F(t)) of changes of the signal virtual frequency during scanning;
- indicator (Max dF) of changes of the maximum value of the virtual signal frequency during scanning.

The structure of the program code of the computer device for identification measurements of seismographic records by FRaSH-method in LabVIEW is shown in Figure-4.

The main part of the computer device for identification measurements of seismographic records by FRaSH method is FRaSH.vi Identification Tester set in the scanning cycle.

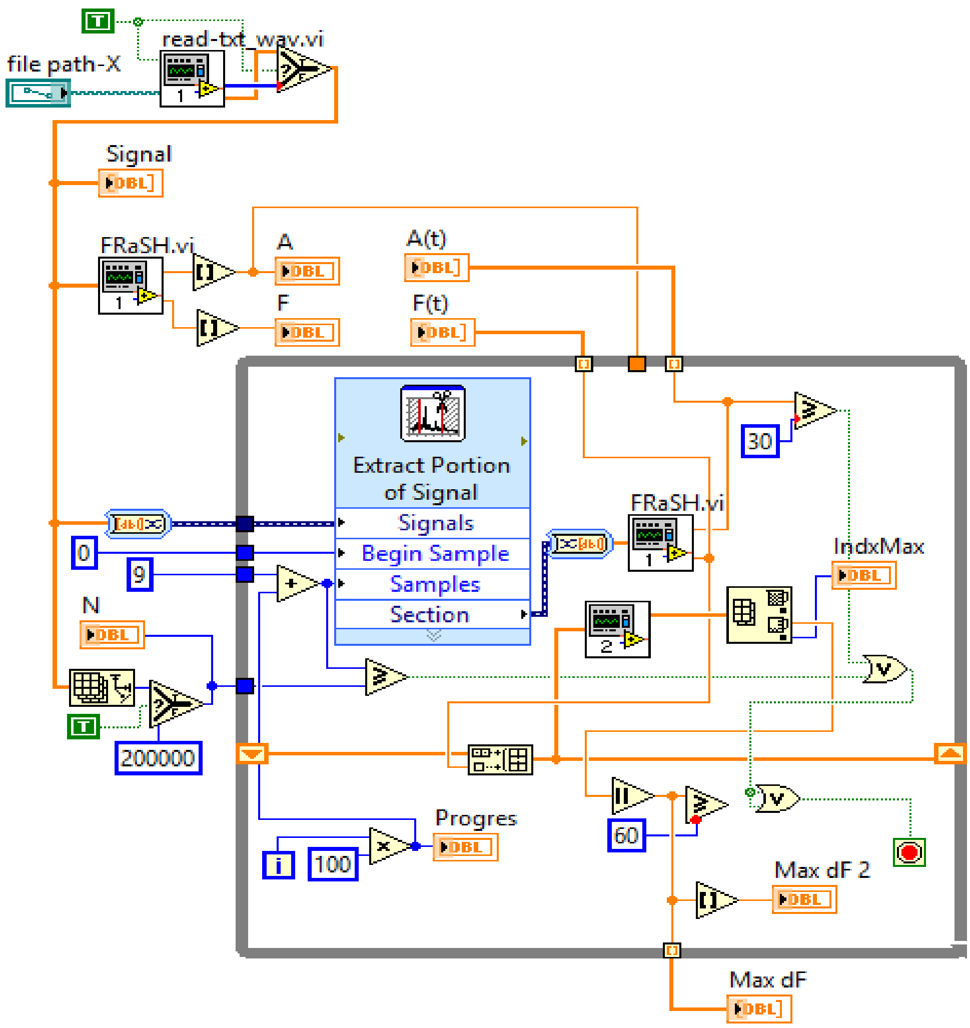

Figure-4. Structure of the program code of the computer device for identification measurements of seismographic records by FRaSH-method.

SIMULATION AND EXPERIMENTAL RESULTS

The result of the research of several seismographic records provided by the Scientific Research Institute of Seismology of the Committee of Science of the Republic of Kazakhstan with the strengths of $K = \{9.1, 9.2, 9.9, 10.1, 11.5, 12.5, 13.9, 14.7\}$ showed a set of statistical parameters and characteristics of the seismographic records. Analysis of those allowed to draw the following conclusions.

1) The A(t) and F(t) diagrams show jumps of shape and virtual frequency of the scanned seismographic record. The biggest figures were got at the time of the

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earthquake $A_m = (380 \div 810)$. Figure-3 shows the analyzed diagrams at $K = 9.1$. This means that the largest amplitude in the time of the earthquake reaches the value of A_m=728 at the moment of N=2761 counts.

2) However during the time before the earthquake there is though less compared to the earthquake time but still abrupt change in seismographic records: the range of distribution shape of the instantaneous values is $dA_m = (5 \div 11), \%$ and the range of characteristic virtual frequency is $dF = (400 \div 600), \%$. This can be used as timely earthquake precursors. In particular, Figure-5 shows the same characteristics at $K = 9.1$ before the earthquake. This means that at time of n=1900 counts there are changes in the characteristics of $dA_m = 20.75 - 19.5 = 1.25 = 6.5, \%$ and $dF = 64 - 10.25 = 53.75 = 524\%$. The change of the virtual frequency is clearly seen in the *Max dF* diagram.

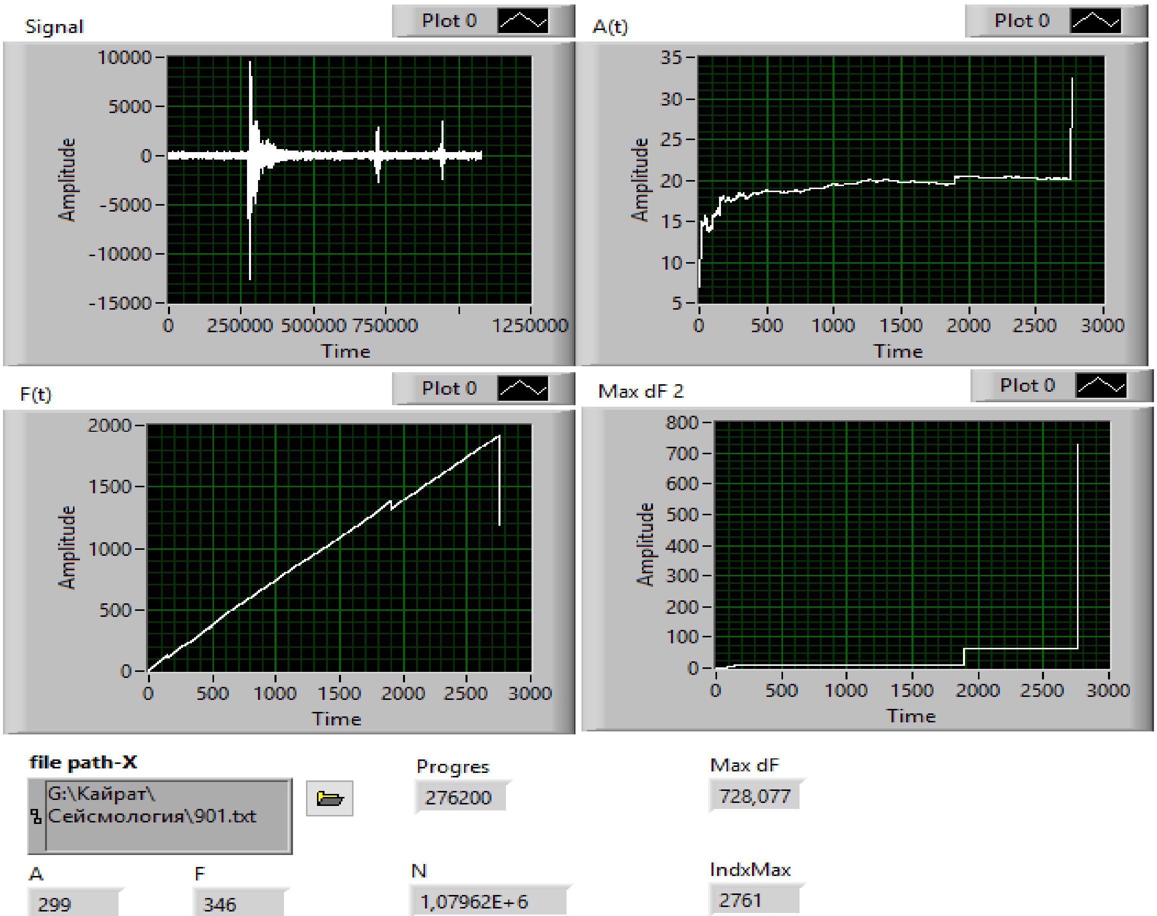

Figure-5. The panel of computer device showing the characters at K = 9.1before the earthquake.

Since the abrupt changes are seen both in shape and virtual frequency, two comparators with respective Ac and Fc response thresholds shall help to find the predicted time interval as follows: Δn $=n_{earth} - n_r$ (n_{earth} - earthquake time, n_r - comparators response time). Modeling and identification measurements of real seismographic reports determined the optimal values of Ac = 20 (rad) and Fc = 60 Hz. That is if the real seismographic diagram is at K = 9.1with the above specified values of shape and virtual frequency, the forecast will be Δn = 2761 - 1900 = 864 counts or approximately T_{prog}= 3355.50 sec = 55 hours.

The panel of the computer device with process diagrams from the start of scanning at t = 0 to the moment t = 1897 of comparator response in the virtual frequency channel (threshold = 60) is shown in Figure-6.

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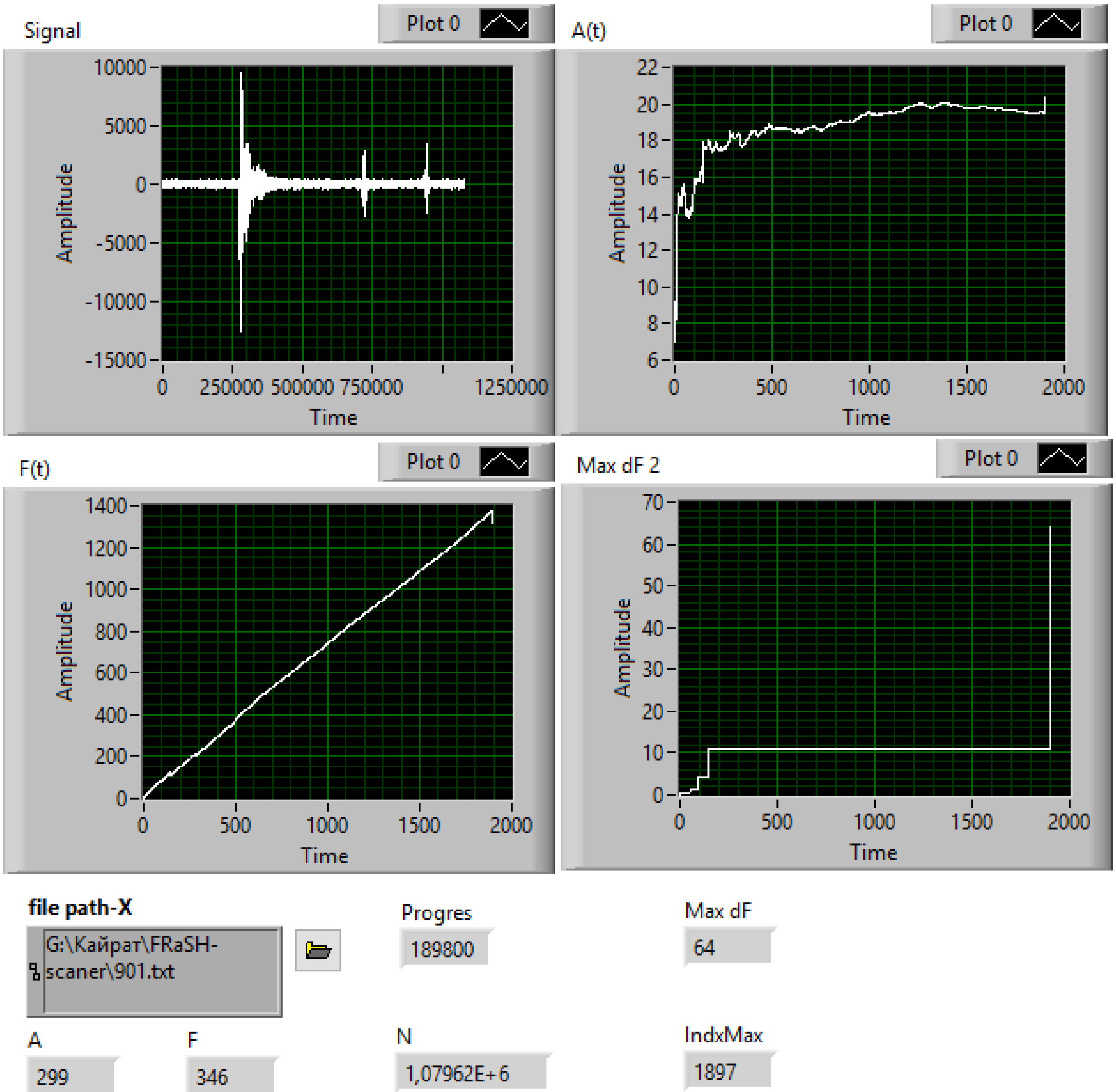

Figure-6. The panel of a computer device with process diagrams of comparator response in the virtual frequency channel.

Measuring of 2 variables at once leads to the increase (approximately 1.4 times compared to the measurement of just one variable) of reliability of earthquakes predicting. On analyzing the set of seismographic records, it was found that T_{prog}= (50/60) hours.

4) There was defined the method of timely earthquake prediction that is algorithmically implemented in the following steps:

Step 1. A continuously-varying signal *X(t)* of the seismographic record is entered into the computer device.

Step 2. The variables of changes of virtual frequency F(t) and distribution shape of instantaneous values A(t) of the seismographic record are cyclically formed using FRaSH method for identification measurements during the scanning;

Step 3. This step concerns cyclical comparison of $A(t) \neq A_C$ and $F(t) \neq F_C$, and if the condition of equality are true, i.e. at the appearance of the timely earthquake precursor, then the conclusion on timely earthquake prediction is made.

5) There was developed a complex computer device that measures distribution shape of instantaneous values and virtual frequency of seismographic record by FRaSH method. Besides it conducts online search of timely earthquake precursors according to the measured identification parameters. The front panel of the computer device displays a variety of quantitative and qualitative indicators of seismographic records: the maximum values, the time intervals of comparators response and prediction, linguistic parameters etc. Also the front panel has informational monitors to display fragments of shapes of identification characteristics.

CONCLUSIONS

Subsequent research shall be aimed at solving the following online problems: a) assessment of strength and direction of forecoming earthquakes; b) assessment of the

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possibility of aftershocks, their number and strength; c) development of intelligent database of seismographic records and finding the consistency of changes in identification variables to the predicted strength of earthquakes; d) finding the accuracy of timely seismographic prediction using the TEP method.

It should be noted that the identification measurements can be used for solving problems of timely prediction of not only earthquakes but also other disasters. That is providing the operator with information in the form of numerical ratings and linguistic descriptions in the terms adopted by the experts in the field. Methodological justification of such conclusions is the fact that the identification measurements allow allocating of unsteadiness sections in the structure of analyzed signal. The unsteadiness sections mean the time intervals when a qualitative change in the state signal takes place.

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