SCIREA Journal of Astronomy

https://www.scirea.org/journal/Astronomy

June 25, 2023

Volume 5, Issue 1, February 2023

https://doi.org/10.54647/astronomy160044

Ultrasonic technology of detection of gravitational waves of neutron stars - pulsars

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Abstract

The work relates to the creation of new methods and instruments for observational astronomy, in particular to gravitational astrophysics. The ultrasonic gravitational method for obtaining information about such exotic objects as neutron pulsar stars has been developed and successfully tested. Gravitational waves are detected by isolated and processed ultrasonic signals propagating in acoustically transparent media. With the help of the developed equipment, it is possible to observe in the gravitational range any star out of many millions of actually detected neutron pulsar stars. The operation of the equipment allows measurements to confirm the stationarity and high stability of the gravitational frequency of a selected neutron star pulsar. The precessions of most neutron pulsars are detected in real time while confirming the high stability of their precession frequencies. Gravitational-wave glitches of some neutron pulsars have been detected, namely, unsteady variations of the frequency and amplitude of their gravitational oscillations, with amplitude increases of individual pulsars up to hundreds or thousands of times when their frequency changes by a small fraction of a percent. The equipment makes it possible to selectively isolate and listen to the selected neutron star-pulsar in the audio frequency range. The importance of the obtained results lies in the possibility of abandoning the expensive projects of creating gravitational observatories based on laser-interferometric methods of observation.

Keywords: the equipment, neutron stars pulsars, detecting gravitational waves.

Introduction

To date, the most popular technology of observational astronomy is gravitational astronomy. During investigations in this direction a new physical phenomenon of the influence of gravitational fields on acoustic and ultrasonic waves of finite amplitude propagating in acoustically transparent media has been experimentally established [1-2]. The phenomenon is the acceleration and deceleration of the speed of acoustic and ultrasonic waves depending on their propagation in the direction or against the direction of the gravitational field strength vector. To acoustic and ultra-acoustic waves in the direct physical sense of this definition becomes applicable the concept of acceleration and deceleration of their speed of propagation. Earlier in physical acoustics such definitions and concepts did not exist, were not applied and did not occur [3]. Positive properties of this phenomenon are that ultrasonic waves under certain conditions of propagation are actually a continuous flow of test bodies, constantly hanging in the gravitational fields. Based on this ultrasonic waves are realized as a perfect mechanism of free-falling bodies, whose fluctuations can be continuously measured and registered as an ideal process of receiving gravitational waves.

Based on the discovered phenomenon, an ultrasonic technology has been developed in the form of precision equipment that allows recording external influences coming from the surrounding space [2,4]. In this case the gravitational oscillatory processes of numerous neutron stars-pulsars are detected in the frequency range from fractions of hertz to tens of kilohertz. Precessions of many neutron pulsar stars are detected. Gravitational-wave glitches of some neutron stars, consisting in a sharp multiple increase of gravitational oscillations intensity and in a relatively small change in the neutron pulsar stars frequency pulsations were also detected [5,6].

Proceeding from the importance of the gravity waves problem detection coming from various cosmic sources and, in particular, from neutron pulsar stars, it is expedient to carry out a multiple recheck of gravity wave detection results, by the proposed ultrasonic technology. To achieve this, the ultrasonic technology and the apparatus for the gravitational waves detection have been further improved. New results were obtained, which confirm and clarify the previously conducted research on the detection of neutron pulsars gravitational oscillations, their precessions and gravitational-wave glitches. The present paper is devoted to these studies and experimental results, as well as to the analysis of their reliability.

1. Theoretical and experimental evidence for the effects of gravity on propagating acoustic waves

The physical essence of the gravity effect on propagating acoustic waves is that in a propagating acoustic wave of finite amplitude due to nonlinearity there is excess density, $\Delta\rho$ associated with the acoustic wave. In turn, the appearance of excess density is equivalent to excess mass, which in the field of gravity generates a force associated with the process of acoustic or ultrasonic wave propagation. For the elementary volume of the medium in accordance with the conclusion of the wave equation in the works [4,6], the equation of motion with the exception of the product of static density ρ on the free-fall acceleration g from this equation is made:

$$\rho_0 \frac{\partial^2 \xi}{\partial t^2} = -\frac{\partial P}{\partial x} + g\Delta\rho, \qquad (1)$$

where: ρ_0 - initial density of the acoustic medium in the unperturbed state;

ξ - displacement of the elementary volume of the medium; P - excess pressure of the medium;

$g\Delta\rho$ - characterizes the additional force equal to the product of the excess mass $\Delta\rho$ generated by the excess density $\Delta\rho$ by the acceleration g of gravity.

In accordance with the transformations given in [4] the equation is obtained:

$$\frac{\partial^2 \xi}{\partial t^2}\left[1 + (\gamma + 1)\frac{\partial \xi}{\partial x}\right] + \gamma g \frac{\partial \xi}{\partial x} = c^2 \frac{\partial^2 \xi}{\partial x^2}, \qquad (2)$$

where: γ - nonlinearity parameter; c - ultrasound propagation velocity.

The resulting wave differential equation (2) is nonlinear and describes the propagation of acoustic waves of finite amplitude in a nonlinear medium, including in the gas, under the action of the gravitational field. It should be noted that the obtained wave nonlinear equation (2) in the first approximation has coincidence with the equation given in [7], obtained there as a special case of wave equations for media with an arbitrary equation of state. It should also be noted that the wave equation (2) passes into the known relations in the equation at "turned off" nonlinearity [8] and into the known equation at "turned off" gravity [9]. In addition, when nonlinearity and gravitation are simultaneously turned off, the equation (2) passes to the usual wave equation known in acoustics [3] with a sufficiently high accuracy. Thus, equation (2) should be considered as reliably grounded theoretically.

The solution of the nonlinear differential equation (2) was found in the form [4]:

$$x_{1,2} = \pm ct\left(1 - \frac{A}{2}\right) - \frac{\gamma A}{4} gt^2 , \qquad (3),(4)$$

where: x_1 - equation (3) of wave propagation along the positive axis direction (plus sign) x; x_2 - equation (4) of wave propagation along the opposite axis direction (minus sign) x; $A = \gamma(\gamma + 1)W$ - nonlinearity parameter related to the absolute value of ultrasonic wave amplitude W .

Thus, justification and calculation formulas (3) and (4) of the new physical model revealing the essence of gravity influence on propagating acoustic waves have been obtained. Equations (3) and (4) show the conditions, the fulfillment of which allows to obtain long-term stability and reliability of measurements in the detection of gravity waves. This conclusion is the main result of the theoretical studies carried out.

Experimental evidence influence on the acoustic waves by gravity propagating effects was obtained in the form of the ultrasonic waves propagation acceleration or deceleration rate in the gravitational Earth field [1,2]. To ultrasonic or acoustic waves on the physical essence of the processes became applicable the concept of acceleration or deceleration of their speed of propagation in the direct physical sense of this definition. To calculate the phenomenon in the acoustic tract having base L, on the basis of equations (3,4) obtained above, the difference $\Delta\tau_g$ of the ultrasonic propagation time T_1 in the direction of gravity and the ultrasonic propagation time T_2 against direction of gravity was determined:

$$\Delta\tau_g = T_2 - T_1 = \frac{gT_0^3}{2L}, \qquad (5)$$

where T_0 is the average time of ultrasound propagation in the medium.

By means of measuring equipment, the results of the established phenomenon registration were significantly supplemented in the direction of their expansion to various gaseous media. In work [2] are presented summarized results of measurements phenomenon in liquid and gaseous media on the acoustic base $\boldsymbol{L}$=2,2 m with reference to the previously obtained results of the phenomenon in carbon tetrachloride measurements. All obtained experimental results accurately correlate with each other through the formula (5), which confirms their high reliability in terms of the established phenomenon.

In order to optimize the detection process, the basic computational relations connecting ultrasonic wave fluctuations with gravitational influences were carried out. Proceeding from the fact that the obtained solutions (3) and (4) of the initial wave equation (2) are valid for both constant and sign-variable values of the free-fall acceleration, in [6] the practical application of the formula for calculating the sign-variable value $g_{\sim}$

$$g\sim = \frac{16L(T_2 - T_1)}{\gamma A(T_1 + T_2)^3}, \qquad (6)$$

where $g_{\sim}$ - a sign-variable value of the free-fall acceleration, proportional to the sign-variable effect of gravitational waves; $(T_2 - T_1)$ - the difference in the propagation time of ultrasonic waves caused by the direct effect of gravitational waves on the acoustic medium.

Thus, on the basis of theoretical and experimental justifications of gravitational effects on the propagating ultraacoustic waves the calculated formula (6) of the method is obtained. Further it is advisable to analyze the advantages of the established phenomenon and its prospects for the gravitational waves detection.

2. Justification of advantages and analysis of prospects of ultrasonic technology for gravitational wave detection

Based on the above mentioned, the most important argument, confirming the new established physical phenomenon application expediency for search and gravitational waves detection, including the gravitational oscillations of neutron stars, is as follows. Gravitational waves as a physical essence are, on the one hand, local sign-variable accelerations which propagate in space with high speed. On the other hand, the established physical phenomenon allows detecting and registering external sign-variable accelerations. Therefore, the proposed ultrasonic technology is a method of direct physical measurements, which sharply increases its status in comparison with other methods and indicates the fundamentality of ultrasonic technology in relation to the detection of gravitational waves.

In contrast, it should be noted that the observatories created by the LIGO, VIRGO, KAGRA and GEO600 [10-12] collaborations use the indirect method of physical measurements in their functioning for the detection and detection of gravitational waves. Thus, the physical essence of the created observatories LIGO, VIRGO, KAGRA and GEO600 [10-12] functioning is based on the

bodies deformations under the influence of gravity waves measurement. In this case, the measuring system is connected with the bodies, which are both in a state of inertial rest and in a state of connection with the adjacent body frame. Under the influence of the received gravity wave due to local tidal accelerations in the measuring system, a difference in the applied forces along the length of the measuring base must arise. However, all objects and objects of the measurement base, including the interferometric system with reflecting mirrors of the interferometer, have inertia. In fact, there is static inertial resistance to any effect to external spatial forces, including sign-variable and extremely small in magnitude, so this property can be called inertial resistance. Consequently, the known applied method underlying the functioning of the observatories created by the LIGO, VIRGO, KAGRA and GEO600 collaborations [10-12] is based on the expected changes in the inertial resistance measuring system each part due to tidal accelrations, caused by gravitational waves. It is due to the inertial resistance functioning change of the measuring system in the known gravity observatories their sensitivity is low.

The second problem of the created gravitational observatories to achieve a sufficiently high sensitivity to the detection of gravitational waves is related to the speed of propagation of gravitational waves. From the position of unbiased approach, it is reasonable to assume the possibility of huge speeds of propagation of gravitational waves, the speed of which can many times exceed the speed of propagation of light. Then the whole measuring system together with measuring sensors, measuring channels, base, platform, installation, etc., i.e. with all "physical accompaniment" will "fall" in the gravitational wave field everywhere equally and changes of inertial resistance along the measuring system base length, including the interferometric measuring system, will not occur. Thus, due to the huge speed of propagation of gravitational waves there are equal in phase effects on the whole structure of the measuring system, so there is a compensation of the expected results. In this, as well as inertial resistance of the measuring system to the received gravity waves are the main problems of the created gravity observatories to achieve a sufficiently high sensitivity to the detection of gravity waves. Related to this is the opinion, established in many works, about the extreme weakness of the sign-variable gravitational interactions, which is an obstacle to the development of new methods of detection of gravitational waves [13-16].

The organization by the proposed method of measurements of fluctuations of freely falling ultrasonic waves, which by the physical essence of functioning are equivalent to freely falling bodies, is a direct method of detection of gravitational waves. Therefore, there is a huge difference in the physical essence of functioning between the proposed ultrasonic method and the known tidal acceleration method. The revealed difference lies in a completely different degree of sensitivity to the detection of gravitational waves by direct and indirect detection method. This is the advantage and perspective of ultrasonic technology of gravitational wave detection.

3. Improved ultrasonic apparatus for detecting gravitational waves

The theoretical justification of the method, the obtained equation (14), the study of the advantages of ultrasonic technology and the study of previously conducted preliminary experimental studies allow us to conclude that it is advisable to improve the ultrasonic precision apparatus presented earlier in [4,6]. The improved apparatus for the detection of gravitational waves contains a differential measurement scheme, consisting of two included towards each other ultrasonic channels UMCWATM-1 (upper channel) and UMCWATM-2 (lower channel) with acoustically transparent media (figure 1). One of the measurement channels UMCWATM-1 is located in space in one direction of measurement, and the second measurement channel UMCWATM-2 is located in the opposite direction. Functioning of the equipment signals is provided by high-stable set point generator MO, which generates synchronized excitation signals. The generated signals are fed through the phase shifter PS-2 and the buffer amplifier BA-2 to the upper measuring channel of UMCWATM-1. At the same time the synchronized signals are fed through the phase shifter PS-1 and the buffer amplifier BA-1 to the lower measuring channel of UMCWATM-2. Upper channel of UMCWATM-1 includes an assembled construction of the first ultrasonic chamber, consisting of acoustically interconnected emitting ultrasonic transducer UPT-11, the first acoustically transparent medium and receiving ultrasonic transducer UPT-12. Similarly, the lower channel, consisting of acoustically connected emitting ultrasonic transducer UPT-21, the second acoustically transparent medium and the receiving ultrasonic transducer UPT-22.

The essential point of improvement of ultrasonic technology and apparatus for its realization was a significant decrease of instability of the master oscillator MO. For this purpose a special scheme of MO frequency stabilization was applied by using delayed feedback block, and the block functioning scheme was formed on passive elements of high quality delay with zero temperature coefficient. This generally allowed to obtain long-term stability of measurements without the need for periodic hardware tweaks.

The differential measurement scheme is provided by two identical towards each other upper

MO - master oscillator; PS-1, PS-2 - phase shifters; BA-1, BA-2 - buffer amplifiers; MPR-1, MPR-2 - measuring pressure regulators; UPT-11, UPT-12, UPT-21, UPT-22 – ultrasonic piezo transducers; UMCWATM-1, UMCWATM-2 - ultrasonic measuring channels with acoustically transparent media; RDOTI - rotary device of the installation; P-1, P-2, P-3 - preamplifiers; SD - synchronous detector; SA - spectrum analyzer; TSF - tunable selective filter; PC - personal computer; MD - matching device; S - speaker (loudspeaker)

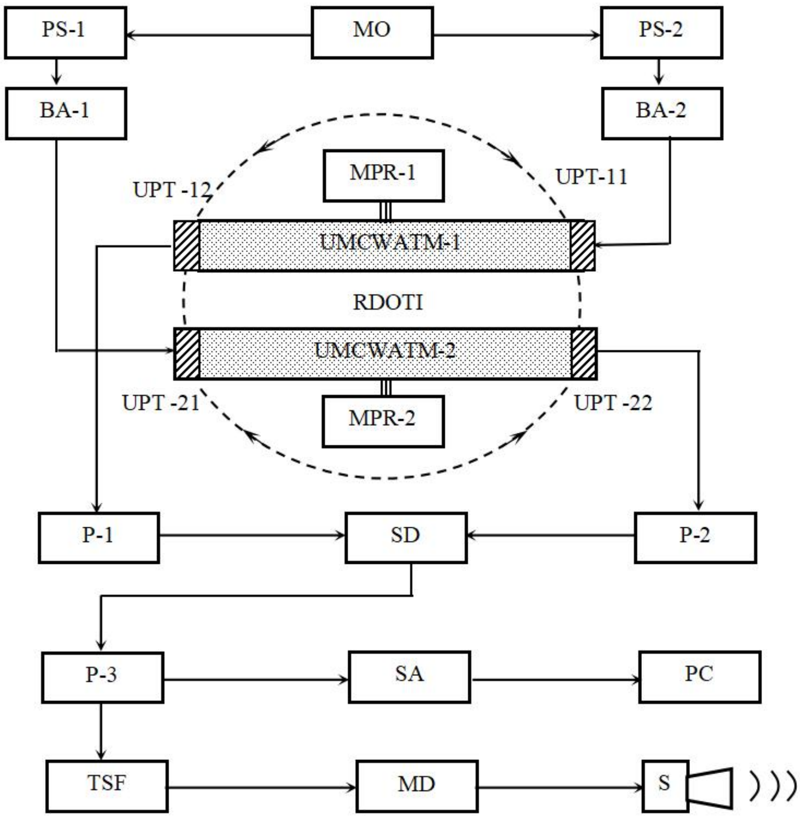

Fig. 1. Block diagram of an improved ultrasonic instrumentation for detection of gravitational oscillations of neutron pulsar stars

ultrasonic measurement channels directed towards each other and lower ultrasonic measurement channels, the received ultrasonic signals of which are fed through the preamplifiers P-1 and P-2 to the synchronous detector SD. Such realization of the circuit solution and organization of the differential measurement method provides maximum sensitivity to alternating gravitational accelerations.

In the ultrasonic instrumentation the measuring pressure regulators MPR-1 and MPR-2 are used, which allow to set the internal pressure in the first acoustically transparent medium of the ultrasonic channels UMCWATM-1 and independently set the internal pressure in the second acoustically transparent medium of the ultrasonic chamber UMCWATM-2. This allows by changing the pressure to regulate both the physical state of the first and second acoustically transparent media, and the rate of ultrasound propagation in the media in order to enter the measurement system in the working point to obtain the maximum effect of the received gravitational waves on the propagating ultrasonic waves in accordance with the above obtained equation (14).

The essential point of improvement was the modification of ultrasonic transducers UPT-11, UPT-12, UPT-21, UPT-22 by increasing their conversion coefficients. Signals from outputs of receiving ultrasonic transducers UPT-12 and UPT-22 are fed to different inputs of synchronous detector SD through low-noise preamplifiers P-1 and P-2, which allows to get higher noise immunity. In addition, the sensitivity of the installation increases due to the fact that through the phase shifters PS-1 and PS-2 achieves accurate mutual adjustment of the signals of the ultrasonic measuring system at the maximum transfer function of the synchronous detector. Methodically, this is done by adjusting the mutual phase shifts of the propagating ultrasonic waves by mutual matching of the amplitude-frequency characteristics of the ultrasonic channels and by the signal level of the synchronous detector SD.

From the output of the synchronous detector SD the signals are fed through a matching preamplifier P-3 to the spectral analyzer SA, which in comparison with the spectral analyzer (given in [3]) has the function of increasing the frequency resolution. After spectral decomposition by frequencies the resultant signals as a result of gravitational wave detection are fed to a personal computer PC for subsequent registration and long-term storage of the results obtained. From the other output of the P-3 preamplifier, the signals through a narrowband tunable selective filter TSF and a matching device MD are fed to speaker S. This technical solution makes it possible to listen to the gravitational vibrations of a selected neutron pulsar star.

For the purpose of spatial scanning, which is necessary for detection and reception of gravity waves from different vector directions of space, the whole structure of the primary ultrasonic transducers is mounted on the horizontal platform of the rotary device RDOTI. This allows free rotation of the ultrasonic measuring channels UMCWATM-1 and UMCWATM-2 by 360˚ in the horizontal plane and partially up to 30˚ in the vertical plane.

An important solution is the creation of various means of protection against external influences of vibration, acoustic, including ultra-acoustic noise [4-6]. Principle circuit solutions are made with the consideration of ensuring the minimum noise parameters in combination with obtaining the maximum signal to noise ratio when processing the received signals. A specific acoustic environment has been selected, in which the necessary internal pressure and temperature are maintained, allowing to ensure the stability of the nonlinearity parameter A, which provides long-term stability of the measurements according to the formula (14). Also, electronic components with a minimum allowable noise level, which provides equivalent noise of the apparatus, reduced to the input not more than 2 x 10-9 V per root of Hertz, that is - 2 nV/ $\sqrt{Hz}$, are used. The peculiarity of the unit is also complete electrical protection of the hardware part of the unit from external electrical, electromagnetic and magnetic disturbances. This is achieved by the use of internal battery power of all units.

The sensitivity of the precision ultrasound device for measuring gravitational alternating accelerations is no worse than one ten millionth of a meter per second (10-7 m/s2) in the frequency range from 0.5 Hz to 1.0 kHz, and in the extended frequency range up to 20.0 kHz the sensitivity is no worse than one millionth of a meter per second. Such parameters of sensitivity are provided with an average accumulation time and signal processing not more than two-four seconds with preservation of long-term stability of measurements for many hours.

4. The main experimental results

A large number of gravitational waves caused by pulsations of neutron stars. This is the first important result of the experimental data obtained, which indicates a large number of neutron pulsar stars in our Galaxy. In figure 2 the given spectral characteristic belongs to the high-frequency range from 7.612 kHz to 7.614 kHz. The peculiarity of the given spectral response is the frequency resolution, which is 0,04 Hz (40 mHz). Approximate calculations show, that more than ten spectral components of signals in a narrow band of frequencies 1 Hz are selected from the received spectrum of signals in the specified resolution of the spectrum analyzer with accumulation and with averaging of the received data not less than by four cycles of measurements. Each of the components of this signal corresponds to the gravitational oscillatory process of a separate neutron pulsar star. It is not difficult to calculate that in the frequency band of 1 kHz it is possible to identify at least ten thousand individual pulsar stars.

When applying and extending the developed technology and the created hardware complex to lower frequencies, for example in the range of frequencies up to 100 Hz, based on the principle of functioning of the spectroanalyzer, its resolving power increases to the level of 0.00001 Hz (10 μHz). Experiments carried out in the low frequency region have shown that in the region of a few

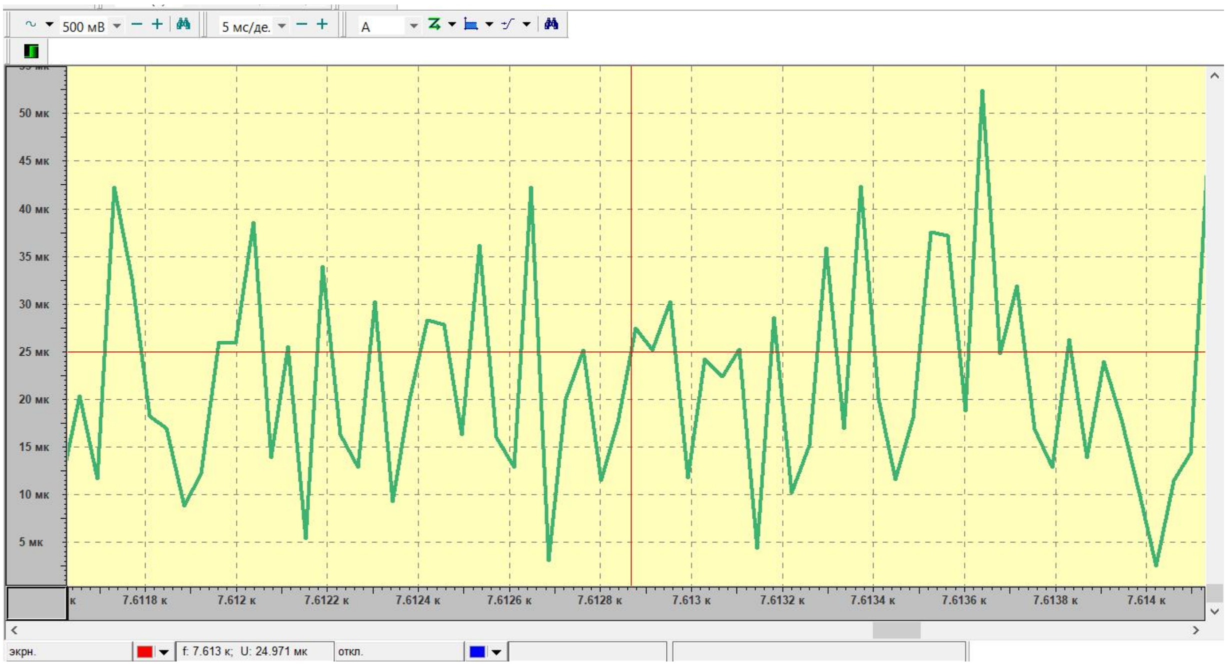

Fig. 2. Spectrum in the 2 Hz band in the high-frequency range from 7.612 kHz to 7.614 kHz as a result of neutron star gravitational signal detection

hertz (up to several tens of hertz) the specific amount of detected gravitational vibrations of neutron pulsar stars increases sharply. For example, in the narrow frequency band of 1 Hz in the low-frequency region of the spectrum thousands of neutron pulsar stars oscillations can be detected. This means that the number of low-frequency neutron pulsar stars in the Universe is tens of thousands times greater than the number of high-frequency neutron pulsar stars. And this applies only to one vector direction of measurements in space.

Based on the data we can calculate that the ultrasonic technology created by scanning along different vector directions of space with the application of narrowband signal filtering allows us to observe any star out of at least ten million neutron pulsars, if necessary. For comparison, we can point out that, according to the results of earlier studies [6], the previous hardware complex allowed the detection of up to several tens of thousands of gravitational pulsar stars from different space vector directions.

The gravitational detection of precessions of neutron pulsar stars confirms the reliability of the detection of gravitational waves generated by neutron pulsar stars. Figure 3 shows the filtered gravitational signal of the neutron pulsar star with a frequency of 2.174 Hz (gravitational rotation period of 459.972 ms) obtained in real time by narrow-band filtering.

From the signal we can see that in the time section of the diagram four to six seconds, there is a 180º phase shift in the signal. This means that in the vicinity of time five seconds the direction of the pulsar rotation axis relative to the Earth provided a minimum of its gravitational emission.

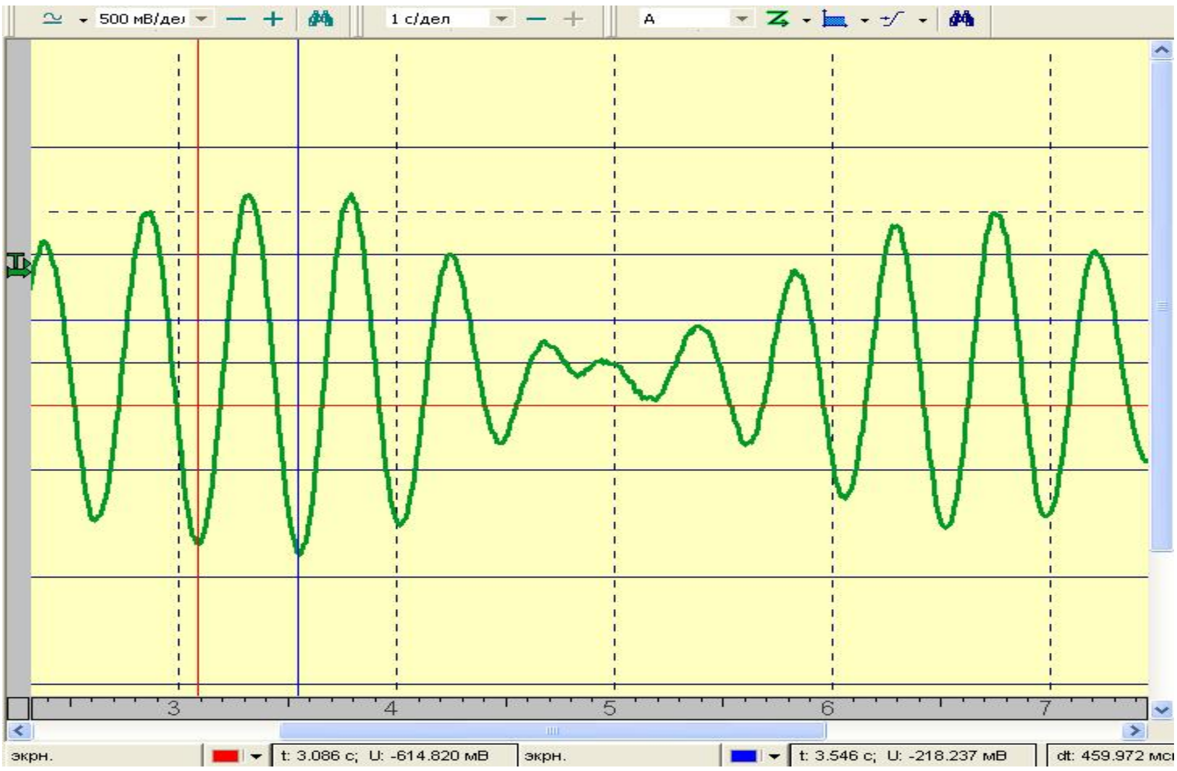

Fig. 3. The filtered gravitational signal of the neutron pulsar star at a frequency of 2.174 Hz with precession of its rotation axis

At the same time, it is not necessarily that at this point in time the rotation axis of the pulsar was directed toward the Earth. A rigorous analysis shows that the phase reversal of the received gravitational radiation occurs at the moments of maximum and minimum deviation of the pulsar rotation axis from the direction to the Earth (from the direction from the pulsar star to the direction to receive signals by the ultrasonic equipment).

Detection of gravitational-wave glitches of neutron pulsar stars was carried out by determining the difference in the amplitudes and frequencies of gravitational oscillations of pulsars measured at different times. As an example, Figure 4 shows the gravitational glitch of the neutron pulsar star with a frequency of 117.216 Hz.

By comparing the gravitational parameters of the pulsar oscillation amplitude and frequency, the following was found. The amplitude of the gravitational oscillations of the pulsar by the time of the glitch has increased 1200 (one thousand two hundred) times, i.e. from 2 mV to 2.5 V. No changes in the gravitational frequency of this neutron star during the three years of observations within the measurement error (one millionth) were observed. A detailed analysis of the detection of

gravitational-wave glitches of this and other neutron pulsar stars allowed us to establish that a significant increase of the gravitational wave radiation intensity during the glitch is a repeatedly verified and reliably established fact.

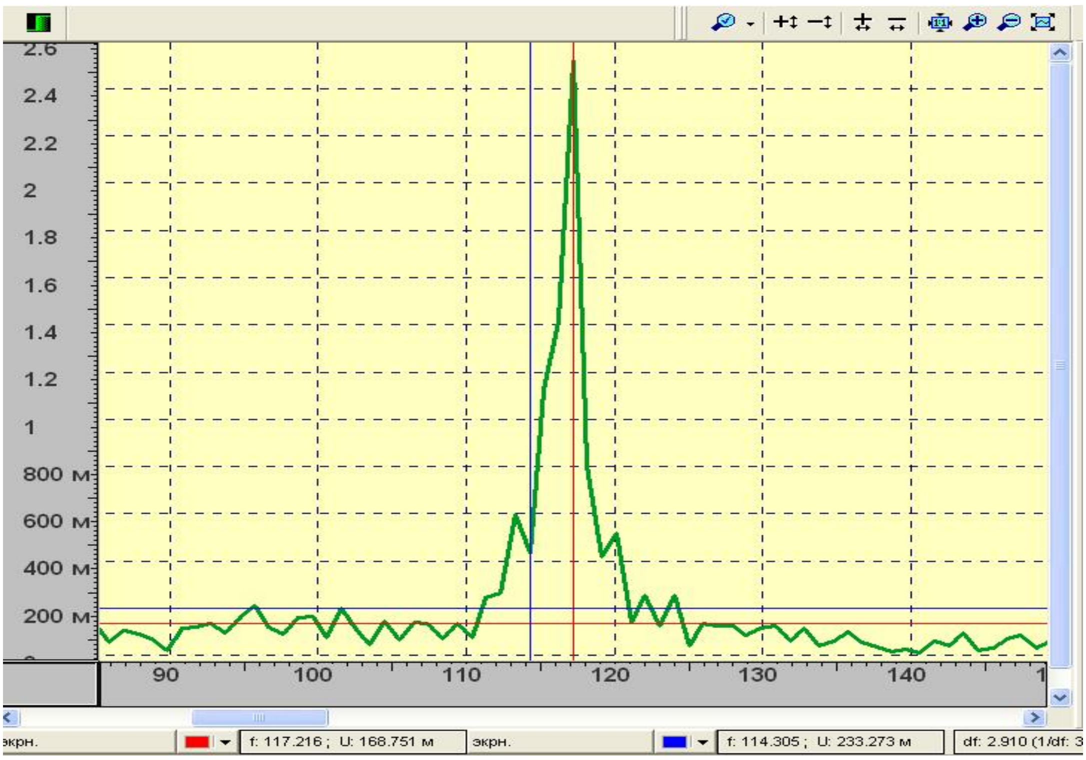

Fig. 4. Spectrogram of the gravitational-wave glitch of the neutron pulsar star at 117.216 Hz with precession of its rotation axis

The previously obtained and many times measured phenomenal in magnitude gravitational bursts of fluctuations of some pulsars on the magnitude of their gravitational-wave glitches have been rechecked. Thus, for many years of observations pulsar with a frequency of 40.031 Hz has an amplitude of gravitational oscillations at the level of several conditional millivolts, and its second harmonic component with a frequency of 80.062 Hz has a slightly larger amplitude [4]. However, two or three times a year the intensity of gravitational radiation of this neutron star increases many times, sometimes up to 1000 (one thousand) times, which is confirmed by earlier studies [4-6].

In order to demonstrate the functionality of the improved ultrasonic technology the time-scale oscillogram of the gravitational glitch of the neutron star-pulsar with a frequency of 40.031 Hz is presented in Figure 5 in real time.

The oscillogram was obtained in the decaying section of the glitch in the broadband measurement mode without the use of selective filters. Figure 5 shows that the gravitational pulses related to the glitch have a repetition period close to 40.031 Hz. In addition, the glitch gravitational pulses are relatively high-frequency and short. This characterizes a rather wide spectrum of the detected gravitational glitch signals and explains the occurrence of a large number of harmonic components in the detection of gravitational-wave glitches, which was confirmed in the previous paper of the author [4].

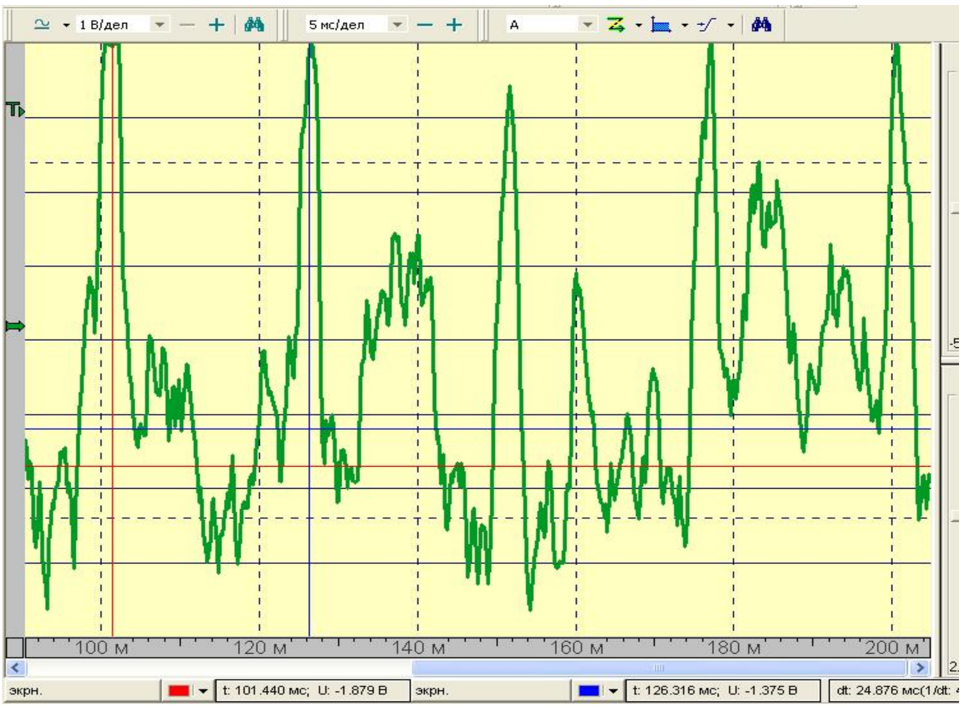

Fig. 5. Oscillogram of the gravitational-wave glitch of the neutron pulsar star at 40.031 Hz, obtained in real time without the use of selective filters

Consequently, experimental data have been obtained confirming a large number of gravitational waves caused by pulsations of neutron stars. This indicates a huge number of neutron pulsars in our Galaxy. Confirmatory experimental data have been obtained about the precession of many neutron pulsar stars, as well as data about gravitational-wave glitches. All conducted studies extend and complement the previously obtained results. In general, the high reliability of the detection of gravitational oscillations of neutron pulsar stars is confirmed.

An additional proof of the reliability of the obtained results can be the synchronization of the gravitational oscillations of neutron pulsar stars with their electromagnetic observations, both in the vector direction in space and in their temporal characteristics. However, the limitations on synchronization are associated with the preliminary results obtained in [6], which show that the rate of propagation of gravity is many times greater than the rate of propagation of electromagnetic oscillations, including optical ones. Therefore, the solution of this problem is a topic of further research.

Conclusions

1. Further analysis and study of a new physical phenomenon previously discovered by the author of the effect of gravitational fields on acoustic and ultrasonic waves of finite amplitude propagating in bodies and media are carried out.

2. It is shown that the implementation of a physical experiment to detect gravitational waves through the application of the established phenomenon has a huge advantage over other methods. Ultrasonic detection technology is a method of direct measurement and allows direct detection and measurement of accelerations propagating in space, which are gravitational waves.

3. Evaluations have shown that the sensitivity of the precision ultrasonic facility created to detect gravitational waves in the frequency band from 0.5 Hz to 1.0 kHz is no worse than one ten-millionth of a meter per second per second. In the broader frequency band up to 20.0 kHz, the sensitivity of the unit is no worse than one millionth of a meter per second per second.

4. One of the important results of operation of the improved facility is a frequency resolution of received signals, which is not worse than 10 micro-Hertz (1x10-5 Hz). This ensures the detection

of a huge number of neutron pulsar stars. According to preliminary calculations, the advanced ultrasonic setup allows to detect in different space vector directions at least ten million gravitational signals of neutron star pulsars in the frequency range up to 20 kHz.

5. Precessions of the majority of neutron pulsar stars are detected in real time, while confirming the high stability of their frequencies. Gravitational-wave glitches of some neutron pulsars have been detected, consisting in unsteady variations of frequency and amplitude of their gravitational oscillations, with amplitude increases of individual pulsars up to hundreds or thousands of times when their frequency changes by a small fraction of a percent.

6. The apparatus allows to selectively detect and listen to the gravitational oscillations of a selected neutron pulsar star in the sound frequency range.

7. Advantages and importance of the obtained results consist in the possibility to abandon expensive projects of creating gravitational observatories based on laser-interferometric methods of observations.

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