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PHYSICAL GROUNDS AND METHODS OF ULTRASONIC DIAGNOSTICS

The article deals with the physical characteristics and method of ultrasound diagnostics. Described features and examples of the main methods of ultrasound diagnostics, such as echographics, transmission and Doppler (based on the doppler effect). Introduced historical information about the development of ultrasound diagnostic techniques. Described and grounded stable and labile methods of ultrasound diagnostics procedures. Introduced behaviors ultrasonic waves reflected from the biological object.

Keywords: *ultrasound, transmission method, transmission method, Doppler method, labile technique, stable technique, impulse, signal, piezoelectric transducer.*

Entry. Use of ultrasonic vibrations for research of underlying structure of matter, conducts beginning from works of soviet physicist of S. Sokolov, which in 1928 created the method of ultrasonic fault detection, that is a method of exposure of shells, pores, cracks is in the metallic founding. Physical basis of this method is a difference in the key-in of ultrasound by a continuous metal and at presence of in him heterogeneities. Measuring intensity of passing through cast of ultrasonic wave it is possible to reduce the presence of the defects indicated higher. In 1935 S. Sokolov was the worked out method of exposure of ultrasonic echo that is reflection from meeting on the way of distribution of ultrasonic wave of different defects and foreign particulates. Both methods created by Falcon methods found the use in medicine. In the forties for research of intracranial damages intensity was measured to the ultrasound, yaks got through a skull and brain of patient, and medical vehicles that work on principle of echo appeared in fiftieth years.

Statement of the problem. Presently ultrasonic diagnostics became the generally accepted diagnostic method, substantially complementing the basic method of visualization of internals - radiograph. In many respects an ultrasonic method has substantial advantages as compared to x-ray photography. Practically complete absence of some side effects allows to conduct the protracted frequent ultrasonic researches of any parts of body, plugging research of fruit in all periods of pregnancy. A high sensitiveness to acoustic heterogeneities enables to get the echograms of soft fabrics, for example, of mastoncuss, violations in an eyeball et cetera the Rapid scan-out allows to look after the dynamics of internals - reduction of heart, aorta and other. Finally, for help to the ultrasound exact enough determination of sizes of internals and their parts is possible, that in many cases has an important diagnostic value. These and other features and advantages of ultrasonic diagnostics stipulated her wide confession and introduction in many areas of medicine: general surgery, ophthalmology, obstetrics and gynecology, oncology and other.

Staging tasks. In ultrasonic diagnostics apply three basic methods: echographics, transmission and Doppler (Doppler based on an effect). Will consider basic physical grounds and technical features of the indicated methods.

Explanation of the basic material. Echographic method is based on the supervision of the removed ultrasonic waves, which arise up on the borders of environments which differ in the acoustic resistance.

Acoustic resistance of environment Z is determined as work of closeness of environment ρ on speed of distribution in her of ultrasonic wave c; $Z = \rho \bullet c$ (g/cm^2·s).

The relation R of amplitude of vibrations of the removed and falling ultrasonic wave is named a reflectivity:

$$R = \frac{Z_1 - Z_2}{Z_1 + Z_2},$$

where Z_1 and Z_2 are acoustic supports of the first and second environments.

Acoustic supports for water and different soft fabrics differ insignificantly: water is 1,49×10^5 g/cm^2·s; muscular fabrics are 1,66×10^5 g/cm^2·s; fat is 1,32×10^5 g/cm^2·s. Accordingly the coefficients of reflections on the borders of division of these environments do not exceed 0,05-0,08. For solids acoustic resistance in several times anymore, so for the bones of skull it folds 6,22×10^5 g/cm^2·s. Air has a considerably less closeness, and speed of distribution in him to the ultrasound also less. Acoustic windage is 42,6 ×10^5 g/cm^2·s. From the brought data over it goes out that on a border between soft fabrics and bones a reflectivity arrives at 0,6. In case if there is an air layer on the way of ultrasonic wave, there is practically a complete reflection of wave.

Emitter to the ultrasound - a piezoelectric plate which becomes excited by an electric impulse creates the brief impulses of ultrasonic vibrations, which recur periodically. At presence of acoustic contact between an emitter and body of man an ultrasonic wave spreads in fabrics of body. Passing a fat-muscle through the borders of division of environments, muscle-bone and other, an ultrasonic wave loses part of the energy, which is reflected towards a source. Getting through a border wave, meets the new border of environments, in turn yields to the partial reflection. This process lasts to the complete fading of ultrasonic vibrations, which is related to the losses of energy due to the friction of particles of environment, which hesitate, and also with losses on a reflection.

As an ultrasonic wave is a short impulse (4-5 periods of attenuation eigen-tones of piezoelectric plate), then an emitter in the interval of time between impulses is used as a transceiver to the ultrasound. Due to direct piezo-effect piezoelectric plate of transformation ultrasonic vibrations in electric signals. The described process is schematically shown on fig. 1.

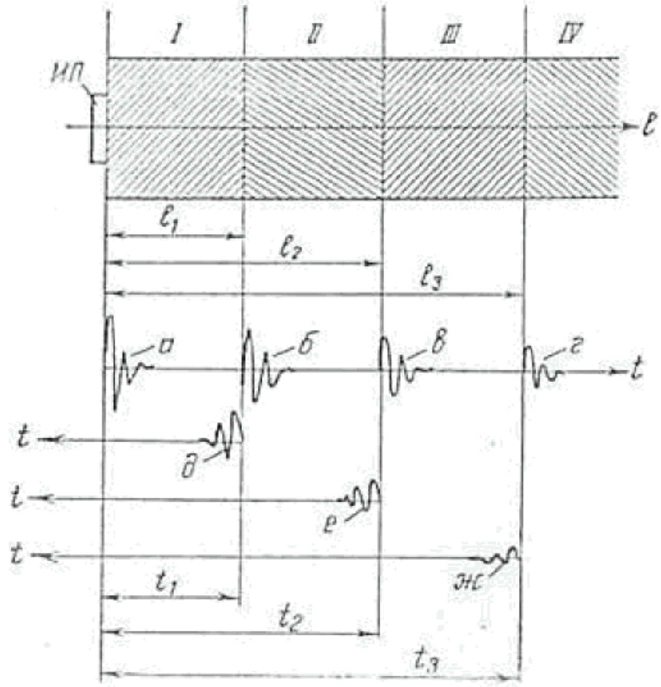

Fig. 1. Scheme of formation of the reflected ultrasound pulses:
ИП - piezoelectric plate; I - IV - tissues with different acoustic resistance; impulses distributed in the forward direction: а - medium I, б - medium II, в - medium III, г - medium IV; reflected impulses distributed in the opposite direction as a result of reflection from the boundary environments: д - from the border between environments I-II; е – from the border between environments II-III; ж – from the border between environments III-IV. For convenience, the reflected pulse temporal axis facing in the opposite direction

Time t_1, t_2 etc., during which an ultrasonic impulse passes distance from a transformer to the beating back surface (fig. 1), it is determined after formulas:

$$t_1 = \frac{l_1}{c};\ t_2 = \frac{l_2}{c} \text{ etc.,}$$

where l_1, l_2 is distance to the surface; c it is speed of distribution to the ultrasound in fabrics (as speeds of distribution to the ultrasound in soft fabrics differ insignificantly, it is accepted in formulas, that these speeds in the layers of fabrics levels).

Through the interval of time $2t_1$, $2t_2$ after a radiation an impulse, removed by a corresponding surface, will go back to a piezoelectric transformer. Electric signals which arise up on the butt ends of transformer as a result of operating on him of the removed impulses increase, transform and observed on the screen of cathode-ray tube. In order that the removed impulses could be perceived, a period of observance of excitant impulses must be large enough. In this case an impulse, removed from the most far located border of environments, will have time to come back to piezo-transformator to the receipt on him of next excitant impulse. Middle speed of distribution of ultrasonic waves in fabrics folds a 1500 m/s. At the period of reiteration of excitant impulses of 1 ms, a most value $t_{\max}$ folds 0,5 ms, that answers the value $l_{\max} = 75$ of cm. Practically there is not a necessity of research of structures, 30-40 cm located farther from the surface of body. The supervision of the removed signals can be conducted at the immobile location of piezoelectric transformer or at his moving on a certain law. Accordingly distinguish one-dimensional and two-dimensional echo-graphic methods.

One-dimensional method. At an immobile piezoelectric transformer an ultrasonic wave spreads along one axis. Got at the supervision of the removed impulses information gives the picture of on a way head-seas of heterogeneity, borders of different layers of fabrics, about distances between these structures. On the screen of cathode-ray tube an unidimensional echogram (conditionally adopted by a type A) is a horizontal baseline, which is a timebase on which the vertical impulses of perceived are located by a plate and the increased removed signals (fig. 2). The first on the left signal is on fig. 2 is an excitant impulse, consilient with the reflection of ultrasonic vibrations from the external surface of cornea. The second and third signals are caused by the reflection of ultrasonic wave accordingly from the front and back surfaces of lens of the eye. A fourth signal is conditioned by a reflection from an eyeground and further handings down on amplitude of reflection from the layers of retrobulbar fabric. As follows from figure, chamber moisture, lens of the eye and vitreous body, are acoustic homogeneous fabrics and does not give reflection.

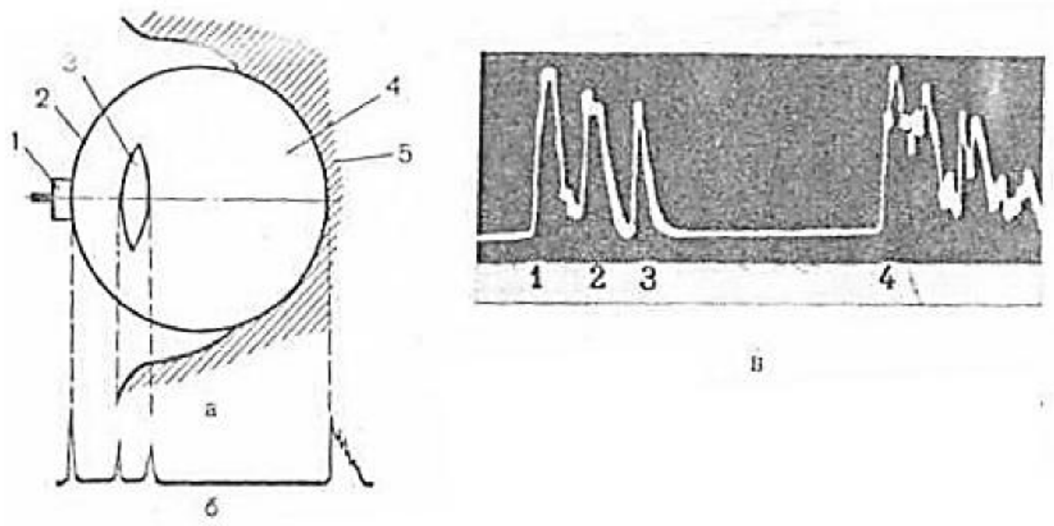

Fig. 2. Scheme one-dimensional ultrasound eye:
a - scanning scheme; 1 - radiating plate; 2 - eyeball; 3 - the lens; 4 - vitreous body; 5 - retrobulbar tissue; b - schematic sonogram; in - real sonogram

In connection with direct dependence between time and corresponding distance which is passed by an ultrasonic impulse, a baseline is simultaneously and by the axis of distances and can be calibration in units of length. Will mark that measuring of distances within the limits of the investigated structure simpler all to execute on a millimetric scale on the screen of cathode-ray tube. However such system owns the row of inconveniences. At the change of duration of involute, that allows to change the scale of echogram for consideration of her separate details, the cost of point of scale changes on the screen. In addition, a parallax due to the thickness of glass of tube reduces measuring exactness. After these reasons in the cases when high exactness of measuring of distances is needed, a mobile mark - negative impulse position of which on wasp of time can be set by an operator is used. Displacement of mark is carried out by means of precision potentiometer, the axis of which is shown out on a control panel and provided with a scale, graduated in millimeters. Combining a mark with the removed impulse, after a scale a potentiometer it is possible with an error which does not exceed 3%, to define distance from a radiative transformer to the corresponding structure.

An one-dimensional echo-graphic method does not give the usual on radiographs picture of internal fabrics and organs, however in many cases provides the receipt of necessary information. So, for example, in ophthalmology an one-dimensional echo-graphic method is used for measuring of anatomy-optics structures of eye, determining size and form of eyeball, diagnostics of tumors, removing layer by layer of retina and vascular shell, exposure and localization of foreign bodies and other. In neurology an one-dimensional method provides high exactness of determination of middle structures of brain (so-called M-echo), that allows to diagnose different sort of tumor and hemorrhage in a brain.

In obstetric practice an one-dimensional method is successfully used for determination of decubital, position and type of fruit, for measuring of intraparietal diameter of head of fruit, that allows to watch after a fetation and set his mass (beginning from 28-30 week of pregnancy), for measuring of sizes of pelvis and other.

Two-dimensional method. Echogram which turns out on the screen of oscillographic tube, at a two-dimensional method in a far greater measure, what at one-dimensional, answers a task to visualization of underlying structures of organism, approached after a kind to x-ray photography to the picture.

For the receipt of image of certain plane radiative ultrasound a piezoelectric transformer must move for the surfaces of body. Line which an ultrasonic wave spreads on, here also moves in space, forming the wired for sound plane at the motion. Thus, at two-dimensional echo-graphic research the image of crossing of the investigated object goes out inplane, to the parallel not surface of body as on a radiograph, but in a perpendicular plane.

The removed ultrasonic impulses are accepted by a piezoelectric transformer and increase the same as at an one-dimensional method. However the method of presentation of the removed signals on an oscillographic tube differs substantially. Baseline not immobile as at an one-dimensional method, but moves on the screen of tube according to moving of piezo-converter for the surfaces of body. Thus signals are given not on the peak baffle plates of tube, but on her electrode which manages the brightness of ray, and the removed impulses are observed as light patches on the line of sentinel involute. As speed of moving of involute is proportional to the rate of movement of transformer, then an echogram on the screen from after-lightening in scaled is the brightness-modulated image of structures, located in the wired for sound plane (echogram of type B, fig. 3).

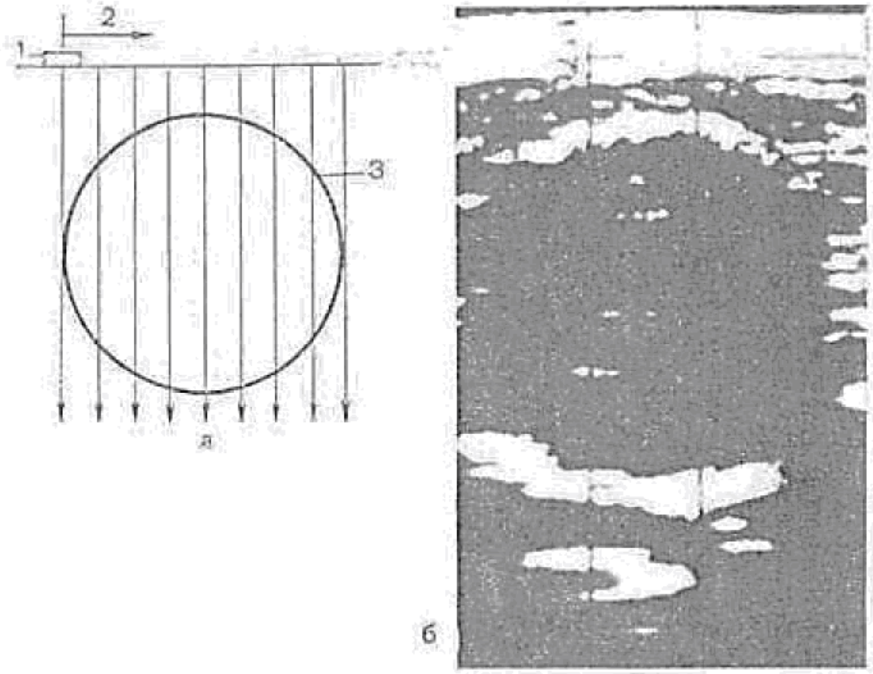

Fig. 3. Scheme of two-dimensional ultrasound fetal head:
a - scanning scheme; b - real sonogram; 1 - radiating plate; 2 - the direction of movement of the radiator; 3- fetal head

Moving of piezo-converter, and thus, and ultrasonic ray - a scan-out can be executed by different character. Distinguish a simple and difficult scan-out. At the simple scan-out of piezo-converter carries out simple motion, so that on every point of the wired for sound plane an ultrasonic wave falls only one time under a certain corner. Mostly used moving of piezo-converter and ray on a linear law (a linear scan-out is fig. 4, a), and also rotatory motion of piezo-converter, that results in the angular moving of ray (a sectoral scan-out is fig. 4, b).

At a simple scan-out part of necessary information can be forgotten. It is explained by that the reflection of ultrasonic wave takes place after the laws of optics, in particular at a flippy the corner of reflection of ray is evened him to the angle of incidence. As a result, back in piezo-converter a ray, falling on a perpendicular to him surface, can get only. However, as a rule, a not only mirror but also diffuse reflection takes place at the reflection of ultrasonic wave, as inequalities on the investigated surfaces after the sizes are considerably exceeded by lengths of ultrasonic wave (at frequency of 880 kHz, wave-length in muscular fabric a 1,8 mm). A diffuse reflection provides a hit in piezo-converter parts of the removed energy, even if a ray falls under a corner on the investigated surface. But for a clear recreation on the echogram of energy of the diffusely removed wave it can appear not enough and, as specified already, part of information can be lost.

A difficult scan-out allows to promote got information content, additionally to recreate the separate details of the investigated structures on an echogram. It is provided that at the difficult scan-out of piezo-converter carries out not only basic, but yet and additional motion. For example, the linear moving of piezo-converter can be accompanied by the waggle of him on a certain corner. Thus on the same point ultrasonic waves fall under different corners, that provides returning in piezo-converter of the mirror removed wave. The amount of the perceived piezo-converter energy of waves, diffusely removed from this point increases in addition,.

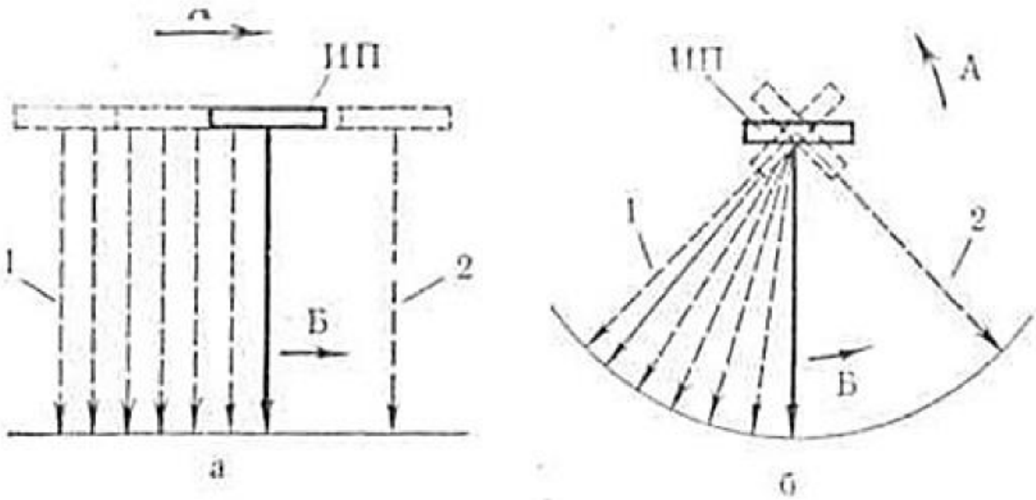

Fig 8. Schematic representation of simple scanning:
a - linear; b - sectoral. ИП - emitting piezoelectric transducer; А - direction of movement Piezoelectric transducer; Б - direction of movement of the ultrasound beam; 1, 2 - extreme directions of the ultrasound beam

The construction of radiative devices of two-dimensional ultrasonic diagnostic devices is considerably more difficult one-dimensional. For the automatic moving of piezo-converter an electro-occasion is used. Additional motion at a difficult scan-out can be carried out both automatically, and by hand.

At a simple scan-out the possible increase of speed of moving of transformer and frequency of change of shots, that is frequency of the repeated wiring for sound of the investigated plane, can be well proven to 10-15 Hz (rapid scan-out). At a rapid scan-out on an echogram possible supervision of reductions of heart, moving of extremities of fruit and some other in relation to rapid motions of internals.

Transmission method. For the aims of metrology - measuring of sizes of separate parts of body - certain advantages are presented by a transmission method. Two piezoelectric transformers are set from two parties of measureable object, for example, of skull. One of transformers radiates the impulses of ultrasonic vibrations, other is their transceiver. The method of presentation of signals on the screen of oscillographic tube does not differ from the method of presentation in an one-dimensional echography. After known time-of-flight by the ultrasonic wave of distance from a radiative transformer to receiving and speeds of distribution of wave can be defined distance between transformers, that is size of object. Devices, which work only after a transmission method, are not made. In many one-dimensional echo-graphic devices as additional possibility, the transmission mode is foreseen.

Doppler method. The effect of Doppler consists in the change of frequency of the removed wave at motion of beating back object. If the rate of movement of object has a constituent in the direction of distribution of radiative wave, then frequency of the removed wave diminishes and vice versa. On the use of this effect the Doppler method of watching is based mobile objects. Mainly, this method is used for control of frequency of heart-throbs and hemadromometry in large vessels. Fundamental difference Doppler to the method from echo-graphic is CW of ultrasonic radiation. In this connection, except for radiative, a separate receiving piezoelectric transformer, which becomes excited removed from a mobile structure, is needed, by an ultrasonic wave. For comfort of exploitation both the transformers take place in one added to the surface of body to the ultrasonic head (probe). As a result of comparison of frequencies of radiative and removed ultrasonic waves frequency of difference, proportional to speed of motions of object, is distinguished. The signal of frequency of difference can be regenerate in acoustic (in the case of control of frequency of palpitation), or registered on plotter. In conclusion will consider the basic requirements, which are produced to the echo-graphic devices which fold swinging majority of ultrasonic diagnostic apparatus.

Conclusion. Most essential, such, which determine functional possibilities of device, followings him acoustic parameters are most depth of sounding, deadband, discriminability.

A most depth of sounding is maximal distance from a probe on which it is possible to look after a reflection from the borders of division of environments. At measuring of this parameter as an equivalent of environment can be used organic glass, but as border of environments, fully beating back border, organic glass is air. A research object determines requirements to the most depth of sounding. In ophthalmology she must fold an about 5 cm, while at an encephaloscopy an about 25 cm. The most depth of sounding is determined by many factors: piezo-module plates, by power of radiative impulse, quality of strengthener of signals and other. However a determinative is frequency to the ultrasound. The losses of energy in biological fabrics increase almost arc wise with frequency, that is why for the necessity of supervision of the prolonged objects more subzero frequencies (880 kHz) are used, at the objects of small sizes frequency usually gets out in a range 5-10 Mhz.

With the choice of frequency other parameter - discriminability is closely constrained an ultrasound. As an impulse to the ultrasound has certain duration, then signal from two nearby placed beatings back structures it is possible to look after only at distance between them, that exceeds some minimum. This minimum distance and named a discriminability (on a depth). It answers the half of pulse width to the ultrasound. With the increase of frequency a pulse width diminishes, a discriminability rises accordingly. On frequency of 880 kHz a discriminability folds an about 5 mm, there is 5,28 MHz - about 1 mm on frequency.

A deadband adjoins, to the piezo-converter layer of fabrics (and corresponding to them initial part of echogram), information about which cannot be got. It is explained by the presence of radiative impulse, and also attenuation eigentones of piezo-converter. The size of deadband diminishes with the increase of frequency to the ultrasound (a pulse width diminishes) and on frequency 5,28 MHz does not exceed a 7 mm. At a necessity a deadband can be eliminated by means of layer acoustic very thin material, placed between a probe and surface of body.

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ФІЗИЧНІ ОСНОВИ ТА МЕТОДИКА УЛЬТРАЗВУКОВОЇ ДІАГНОСТИКИ

В статті розглядаються фізичні особливості та методика проведення процедури ультразвукової діагностики. Описані особливості та приклади застосування основних методів ультразвукової діагностики, а саме ехографічного, трансмісійного і доплерівського (основаного на ефекті Доплера). Також наведені історичні відомості щодо розвитку ультразвукових діагностичних методів. Описані та обґрунтовані стабільні та лабільні методики проведення процедури ультразвукової діагностики. Наведено особливості поведінки відбитої ультразвукової хвилі від біологічного об'єкта.

Ключові слова: *ультразвук, трансмісійний метод, ехографічний метод, доплерівський метод, лабільна методика, стабільне методика, імпульс, сигнал, п'єзоперетворювач.*

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ФИЗИЧЕСКИЕ ОСНОВЫ ТА МЕТОДИКА УЛЬТРАЗВУКОВОЙ ДИАГНОСТИКИ

В статье рассматриваются физические особенности и методика проведения процедуры ультразвуковой диагностики. Описаны особенности и примеры применения основных методов ультразвуковой диагностики, а именно эхографического, трансмиссионного и доплеровского (основанного на эффекте Доплера). Также приведены исторические сведения о развитии ультразвуковых диагностических методов. Описанные и обоснованы стабильные и лабильные методики проведения процедуры ультразвуковой диагностики. Наведены особенности поведения отраженной ультразвуковой волны от биологического объекта.

Ключевые слова: *ультразвук, трансмиссионный метод, эхографический метод, доплеровский метод, лабильная методика, стабильная методика, импульс, сигнал, пьезопреобразователь.*