Mech. Adv. Technol., Vol. 9, No. 1, 2025, pp. 40–50

DOI: 10.20535/2521-1943.2025.9.1(104).316213

UDK 621.73.16

Increasing the Sensitivity of the Tactile Sensor to Detect Shredders in the Patient’s Body

Olexandr Salenko[1] • **Nataliia Gavrushkevch**[1] • **Vadym Orel**[2] • **Bohdan Salenko**[3] •
Viktor Cherniak[4] • **Kostiantyn Karpenko**[5]

Received: 12 February 2025 / Revised: 3 March 2025 / Accepted: 12 March 2025

Abstract. *Means of increasing the sensitivity of a tactile sensor for detecting foreign bodies in the wound of patients, the wound channel, which is advisable to use in field conditions in emergency situations, have been analyzed. Such a sensor is a device consisting of a probe and a block of mechanical and electronic means held by the paramedic's hand. To detect a foreign body, a probe containing an elastic thin flexible probe with an external quasi-elastic shell is inserted through the wound channel until contact with the foreign body. The signal from the dynamic contact is visualized and displayed on a display device, which allows the paramedic to make a decision on further medical care for the affected person.*

Since the probe receives additional mechanical excitation, the signal has a long-lasting form, which increases the efficiency of primary diagnostics. However, at the same time, using the probe as a waveguide for both mechanical excitation and for transmitting vibrations to the means of amplification and spectral analysis significantly distorts the informativeness of the signal, impairs the accuracy of the studies.

It is proposed to use the probe shell as a waveguide for transmitting vibrations, while the probe acts directly as a waveguide for the contact signal.

It has been established that in this case it is possible to increase the signal-to-noise ratio in the range of 0.92...2.5 kHz to 2 dBA, which is extremely important for analyzing the spectral density patterns of vibrations from contact conditions in a viscous medium.

Keywords: *special tool diagnostic; noise emission; wound; non-radiocontrast foreign object.*

Relevance of the topic and research objectives

Military operations, a significant increase in the number of wounded both civilians and military personnel leads to the fact that there is now an urgent need to create highly effective, reliable and simple methods for field diagnostics of shrapnel, bullets and other penetrating objects in the patient's body in the shortest possible time, [1], [2].

Trauma, injury to the body can lead to the fact that foreign particles, fragments and fragments enter the tissues, and they cannot always be detected and identified by traditional methods, [2].

The task is complicated in field conditions, [3] when the condition and even the life of the wounded person depends on the efficiency of pre-hospital diagnostics, speed, accuracy and reliability of wound treatment.

That is why the development of a simple and reliable diagnostic tool is relevant and important, especially given the increase in traumatic mine-explosive and other injuries of military personnel and civilians.

Currently, there are a large number of means of detecting fragments in the human body, which to one degree or another can be used outside the inpatient departments of hospitals. Usually these are CT, [4], MRI, [5], [6] ultrasound, X-ray machines [7].

✉ *Olexandr Salenko*
salenko2006@ukr.net

[1] *Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine*

[2] *Kharkiv National University of Internal Affairs, Kremenchuk Flight college, Kharkiv, Ukraine*

[3] *Poltava National Technical University, Poltava, Ukraine*

[4] *Taras Shevchenko National University of Kyiv, Kyiv, Ukraine*

[5] *National Military Medical Clinical Center "Main Military Clinical Hospital", Kyiv, Ukraine*

In work [9] we proposed to use tactile probing and a special elastic probe, with which a direct search for a foreign body in the tissues of the wounded is carried out. It is shown that for the introduction of the probe it is advisable to use a wound channel, which can be open for a certain time. Searching for fragments in this way is effective, since upon contact with the probe, such interaction leads to the generation of vibrations that propagate through the elastic part of the probe, and upon reaching the membrane, they are converted into noise emission, which is subsequently visualized by an oscilloscope into a signal, which, based on comparison with sample pictures, allows us to draw a conclusion about the presence and approximate size of a foreign body.

Along with the undeniable advantage of such a method as simple and not requiring complex equipment, a significant disadvantage is that the accuracy of detection and identification of the object will be determined not least by the doctor, his qualifications and experience; at the same time, the presence of a fragment in the body, its encapsulation and changes in the body over a certain period of time can cause certain violations of the laws obtained in [8]

Improvement of the device according to [9], along with undeniable advantages (due to the involvement of a mechanical exciter of vibrations of the probe tip), has a number of other disadvantages: the elastic rod of the probe itself is both an exciter of vibrations and a conductor of emitted disturbances from touching a foreign body, as a result of which the useful signal is sharply degraded by the frequencies of its own vibrations, vibrations forced from a mechanical exciter, etc. etc.

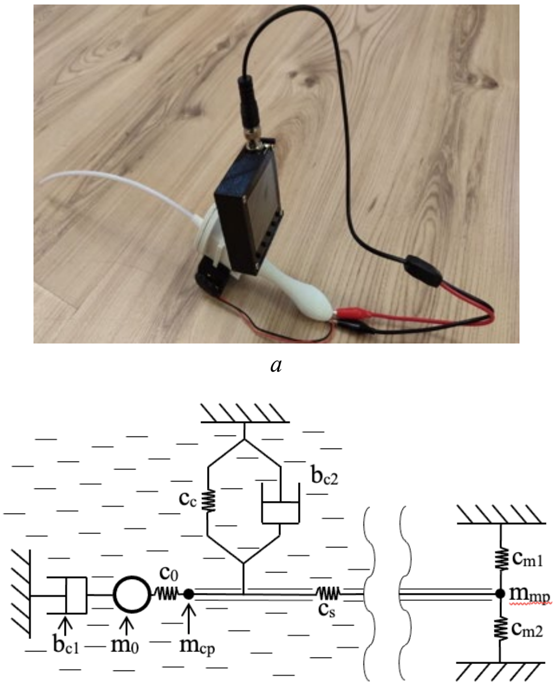
Therefore, **the purpose of the work** is to increase the sensitivity of the effectiveness of the tactile sensor for detecting fragments in the patient's body by using mechanical elements of the probe.

Theoretical principles of diagnostics

Earlier, in [10], we noted that the simplest probe for detecting foreign particles in the patient's body is a device consisting of a probe probe, which, together with a protective shell, contacts the sensitive membrane of the microphone capsule and is fixed on a holder. The microphone is connected to an oscillographic device, additionally equipped with a signal-to-noise ratio improvement unit and means of spectral analysis of noise emission generated when the probe touches a foreign body in the wound channel when moving the latter. Contact with a foreign body, which occurs in this case, causes oscillations of the probe tip, which actually fixes the microphone. Noise emission generated when the probe is moved in the wound channel is filtered out, since the signal cleaning means provides for the fixation of only certain frequencies, which provide information about the presence of foreign bodies in the wound channel, their size, degree of roughness or surface damage, etc.

The introduction of a probe in the form of a flexible, non-rigid elastic rod into the wound canal and its contact with the front part, which protrudes beyond the guide elastic-plastic tube by a value of δ, leads to the emergence of resistance to movement both from the side of the canal walls (muscle and fatty tissue, surfaces of bone tissue, blood vessels, cartilage and tendon connections; and at the end of the canal with contact with a foreign body.

The device itself is shown in Fig. 1 *a*, and the diagram of the interaction of the elastic probe with a foreign body is shown in Fig. 1 *b*.



a

b

Fig. 1. General view of the device (*a*) and contact of the elastic probe with a foreign body in the wound canal (*b*)

The detection is identified as the occurrence of dynamic oscillations of the probe tip in the wound canal at the moment of contact with the foreign body. The behavior of the fragment is described by the equation:

$$m_0 \frac{d^2 x}{dt^2} = c_c x_0 + b_{c1} dx - c_0 \left(x - x_0 \right) - R \qquad (1)$$

In this case, the equilibrium of the probe will be determined as follows:

$$m_{cp} \frac{d^2 x_2}{dt^2} = c_0 \left(x - x_0 \right) - c_s \left(x - x_2 \right) - R \qquad (2)$$

The resistance of the medium, [12], is considered both from the tissue side and along the probe axis:

$$R = c_c \left(x_{i-1} - x_i \right) + b_{c2} \frac{dx_i}{dt} \qquad (3)$$

which allows recording membrane vibrations like this:

$$m_{mp}\frac{d^2x_{23}}{dt^2}=c_s\left(x-x_2\right)-\frac{c_{m1}c_{m2}}{c_{m1}+c_{m2}}\left(x_2-x_m\right)-R \qquad (4)$$

This made it possible to construct transient and vibration curves, which showed that such a device has a somewhat limited ability to provide complete information about the fragment, since its position is determined indirectly, and the degree of immersion in the body tissues can be determined only by the length of the inserted end of the probe.

Some improvement of the device will allow to fundamentally increase the informativeness regarding foreign objects in the wound canal.

The device was built on the principle of changing the established vibration characteristics of a dynamic system consisting of a long elastic thread with a distributed mass, which oscillates in a viscous medium, and can contact a foreign quasi-elastic object, which is also in viscous contact with an inhomogeneous medium (the patient's body).

In this case, the moment of interaction will look like this, Fig. 2, *a*.

And the dynamic system of the device will correspond to Fig. 3.

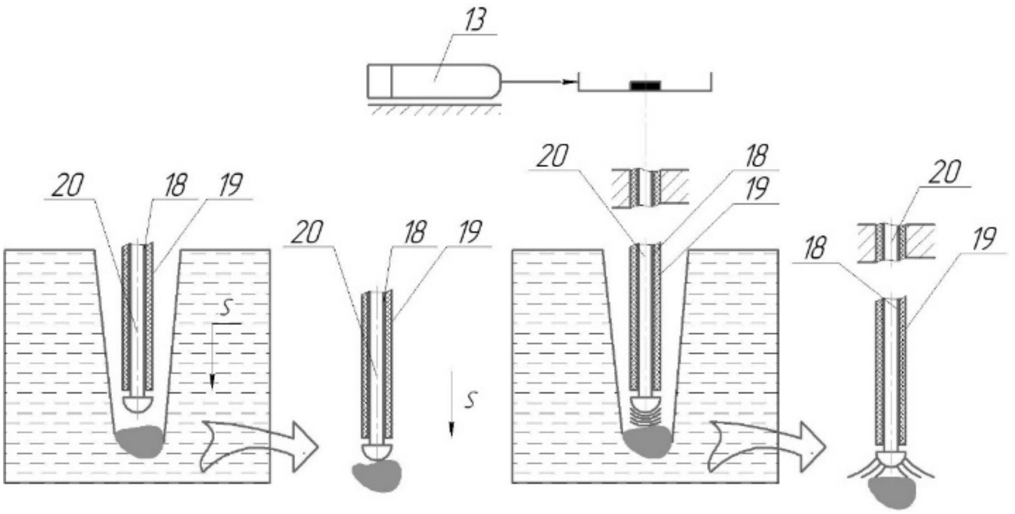
The imposition of vibrations on the probe itself changes the conditions of contact interaction with a foreign object, and in this case, the factors that will affect the amplitude and spectral characteristics of the signal will be:

1) properties of the medium;
2) contact conditions;
3) length of the wound channel,
4) particle size;
5) elastic properties of the fragment.

Based on the research tasks, the main question is the ratio of the amplitudes of oscillations of a weightless membrane at certain frequencies, in accordance with the amplitudes of oscillations from a mechanical exciter.

Earlier in [9] we noted that for an elastic rod, which is a probe, the equation of transverse oscillations under the condition of invariance of the bending stiffness *EI* and the cross-sectional area *F* along the entire length will have the form:

$$\frac{\partial^4}{\partial x^4}+\frac{\rho F}{EI}\frac{\partial^2 w}{\partial t^2}=0 \qquad (5)$$



a *b*

Fig. 2. Contact of the tip of the probe with a foreign body without forced oscillations (*a*) and with the use of a mechanical exciter (*b*)

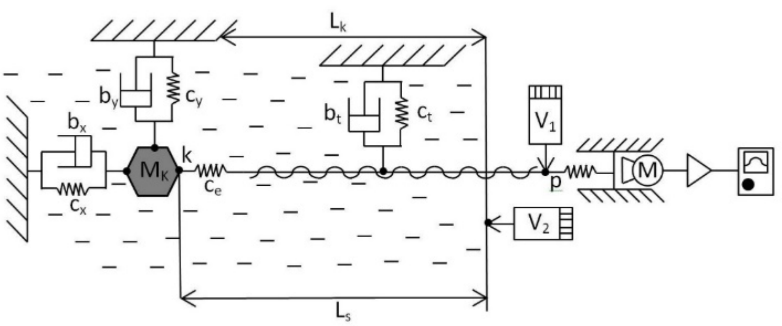


Fig. 3. Dynamic system of a probe in contact with a foreign body during forced excitation

The eigenmodes of oscillations are described by a countable set of ordinary differential equations

$$\frac{\partial^4 W}{\partial x^4} - k_l^4 W_l = 0; \qquad k_l^4 = \frac{\rho F}{EI}\omega_l^2 ,$$

whose partial solutions will be four expressions $e^{\pm ikx}$, $e^{\pm kx}$, which using Euler's formulas are transformed into the functions sin(*kx*), cos(*kx*), sh(*kx*), ch(*kx*), and the general solution of the equations will have the form:

$$W_l = A_l \sin\left(k_l x\right) + B_l \cos\left(k_l x\right) + C_l \mathrm{sh}\left(k_l x\right) + D_l \mathrm{ch}\left(k_l x\right) \tag{6}$$

For a simple long elastic thread, the equation of the eigenmode of oscillations takes on the final form:

$$W_l = \sin\left(k_l x\right);$$

and the natural angular frequencies will be:

$$\omega_l = k_l^2 \sqrt{\frac{EI}{\rho F}} .$$

And $\omega_l = \left(\frac{\pi l}{L}\right)^2 \sqrt{\frac{EI}{\rho F}}$ considering the geometric parameters of the probe tip.

If a mechanical vibration exciter installed in the middle of an elastic rod is in direct contact with it, the oscillation of the probing rod in a viscous medium will be determined from the following.

Assigning a translational motion to the fixed end of the rod in the form of a harmonic function, which is usually obtained using rotating vibration devices (in particular, 2 Fig. 3), causes a corresponding motion in all sections of the probe. Relative displacements will cause deformations and stresses, while inertia forces are absolute displacements, which, based on [8], are calculated as follows: $\varepsilon = \frac{\partial u^r}{\partial x}$; $\sigma = E\frac{\partial u^r}{\partial x}$; $N = EF\frac{\partial u^r}{\partial x}$. Considering the conditions of dynamic equilibrium of the element *dx*, the equation of longitudinal vibrations of the rod in the relative coordinate system will take the form:

$$\rho F \ddot{u}^r - \frac{\partial}{\partial x}\left(EF\frac{\partial u^r}{\partial x}\right) = -\rho F \ddot{u}^e . \tag{7}$$

Here u^r are the variable displacements of the rod sections; u^e is the forced displacement from the vibrating device.

Since the vibrating device is structurally fixed at a certain distance from the fixed end of the probe, the oscillation equations will have the form:

$$\rho F\frac{\partial^2 u}{\partial t^2} - \frac{\partial}{\partial x}\left(EF\left(1 + b_1\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial x}\right) = q\left(x\right)f\left(t\right)$$

$$\rho F\ddot{u} - \frac{\partial}{\partial x}\left(EF\frac{\partial u^y}{\partial x}\right) = \rho F\ddot{u}^e\left(A,t\right)\delta\left(x - A\right)$$

Here *A* is the cross section subjected to longitudinal oscillations. For the case of the device, the area of this cross section remains constant along the entire length.

The patient's body exerts viscous resistance since the probe is immersed through the wound channel until it contacts the fragment. According to the Kelvin–Voicht and Bock–Schlippe–Kolar provisions, considering internal and external viscous friction allows us to write the equations of longitudinal forced oscillations for an elastic, imperfectly elastic and viscoelastic probe rod:

$$\rho F\frac{\partial^2 u}{\partial t^2} - b_1\frac{\partial^2}{\partial x\partial t}\left(EF\frac{\partial u}{\partial x}\right) - \frac{\partial}{\partial x}\left(EF\frac{\partial u}{\partial x}\right) = q\left(x,t\right);$$

$$\rho F\frac{\partial^2 u}{\partial t^2} - b_2\frac{\partial u}{\partial t}\rho F - \frac{\partial}{\partial x}\left(EF\frac{\partial u}{\partial x}\right) = q\left(x,t\right);$$

$$\rho F\frac{\partial^2 u}{\partial t^2} - \alpha_1\left[\omega\right]^{-1}\frac{\partial^2}{\partial x\partial t}\left(EF\frac{\partial u}{\partial x}\right) - \frac{\partial}{\partial x}\left(EF\frac{\partial u}{\partial x}\right) = q\left(x,t\right);$$

and their solution in terms of the eigenmodes of oscillations is as follows:

$$u\left(x,t\right) = \sum_{l=1}^{\infty} U_l\left(x\right)\eta_l\left(t\right).$$

For the case of harmonic excitation of vibrations, the set of equations for the principal coordinates is as follows [8], taking into account internal and external viscous friction:

$$M_l(\ddot{\eta}_l + b_i\omega_l^2\dot{\eta}_l + \omega_l^2\eta_l = q_l\cos\left(\omega t\right)\ldots \text{ and}$$

$$q_l = \int_0^L q\left(x\right)U_l\left(x\right)dx, l = 1, 2\ldots$$

Then:

$$u\left(x,t\right) = \sum_{i=l}^{\infty}\frac{\cos\left(\omega t - \varphi_l\right)}{M_l\sqrt{\left(\omega_l^2 - \omega^2\right)^2 + 4h_l^2\omega^2}}\int_0^L q\left(x\right)U_l\left(x\right)dx \tag{8}$$

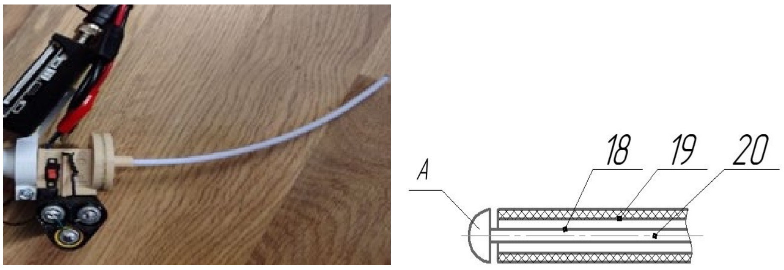
At the moment of contact with a foreign particle in the patient's body, the initial conditions for this dynamic system will change, and the calculation scheme will take the form of Fig. 2 *b*.

In the case when the oscillations are excited by the probe shell, the oscillations of the elastic probe will be transverse. Usually, transverse oscillations are excited more easily, since the stiffness of the probe in the transverse direction is much lower than in the longitudinal direction, especially since such oscillations will still have certain bending effects.

The disturbing force will arise at the points of contact of the probe shell with the elastic probe. However, now the probe becomes a waveguide that transmits oscillations from the point of contact to the device membrane.

Foundations for increasing the efficiency of tactile examination

The formation of vibrations of the probe tip and the transmission of waves through the elastic probe to the membrane are carried out due to the phenomena occurring in the contact zone. To simplify the insertion of the probe into the wound canal, it is located inside a quasi-elastic shell, which together with it forms the probe, Fig. 4.



a *b*

Fig. 4. The probe of the device (*a*) and its model (*b*)

Since the probe provides for contact of the probe with the shell at certain points (since the diameter of the probe is smaller than the diameter of the shell opening, and the latter also has a cylindrical shape), the transmission of vibrations can be carried out from the shell to the probe, and the dynamic system of the device will correspond to that shown in Fig. 5.

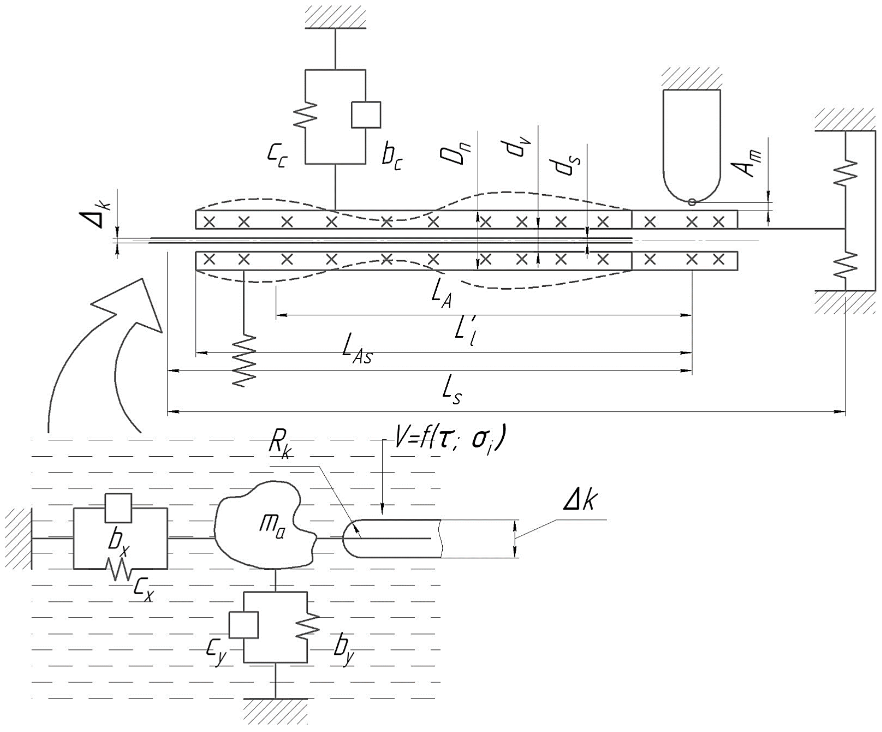


Fig. 5. Dynamic system of the device for the case of excitation of vibrations by the shell

When the probe is fixed based on a conditionally fixed part of the device in the presence of longitudinal forces, the equation of free vibrations of the probe as a rod of constant cross-section has the form:

$$\rho F\frac{\partial^2 w}{\partial t^2}+\frac{\partial^2}{\partial x^2}\left(EI\frac{\partial^2 w}{\partial x^2}\right)-\frac{\partial}{\partial t}\left(N\frac{\partial w}{\partial x}\right)=0 \qquad (9)$$

Since the shell and the probe form a system with pronounced viscoelastic properties, based on [11], the differential equation of forced transverse oscillations of a viscoelastic rod, considering external viscous friction and longitudinal force, will have the form:

$$\rho F\frac{\partial^2 w}{\partial t^2}-b_2\rho F\frac{\partial w}{\partial t}+\frac{\partial^2}{\partial x^2}\times$$
$$\times\left[EI\left(1+\alpha_l\left[\omega\right]^{-1}\frac{\partial}{\partial t}\right)\frac{\partial^2 w}{\partial x^2}\right]-$$
$$-\frac{\partial}{\partial t}\left(N\frac{\partial w}{\partial x}\right)=q\left(x,t\right) \qquad (10)$$

Since at the end the transverse force *Q* or the moment *M*, as well as the angle of rotation, are not equal to zero, the boundary conditions become inhomogeneous and the problem with inhomogeneous kinematic conditions must be reduced to the kinematic excitation of forced oscillations under homogeneous boundary conditions. For the main oscillations $w_l=a_lW_l\cos\left(w_lt-\varphi_l\right)$ these inhomogeneous conditions will have the form:

$$\frac{d}{dx}\left(EI\frac{\partial^2 W}{\partial x^2}\right)=\pm M_0\omega_l^2W_l\ ,$$

$$\frac{\partial}{\partial x}\left(EI\frac{\partial^2 W}{\partial x^2}\right)=\pm M_0\omega_l^2W_l,$$

$$EI\frac{d^2W}{dx^2}=\pm J_m\omega_l^2\frac{dW_l}{dx}\ ,$$

$$EI\frac{d^2W_l}{dx^2}=0.$$

Here M_0, J_M are the mass and the moment of inertia of the mass, and the sign determines the left and right ends of the probe.

$$\frac{\partial^2}{\partial x^2}\left(EI\frac{\partial^2}{\partial x^2}\right)dx=$$

$$=-k_nwdx-\rho F\frac{\partial^2 w}{\partial t^2}.$$

Considering the natural modes of oscillations $w_l = W_i(A_l \cos(\omega_l t) + B_l \sin(\omega_l t))$, the solution of the differential equation can be presented in a form similar to (6).

The contact of the end of the elastic rod (probe) will affect the change in the oscillation frequencies, as well as the oscillation modes, while the presence of an elastic base (probe shell) will affect only the natural oscillation frequencies. In this case, the compression of the probe (at the moment of contact with a foreign body) will cause a change in the frequency of bending oscillations.

The equation of transverse vibrations of the probe considering internal friction according to the Kelvin–Voich hypothesis and external viscous friction [10]:

$$\rho F \frac{\partial^2 w}{\partial t^2} - b_2 \rho F \frac{\partial w}{\partial t} + \frac{\partial^2}{\partial x^2}\left[EI\left(1 + b_l \frac{d}{dt}\right)\frac{\partial^2 w}{\partial x^2}\right] = q(x,t).$$

The general solution will be:

$$W_n = A_n \sin\left(\frac{\pi n}{L}x\right) + B_n \cos\left(\frac{\pi n}{L}x\right) + \\ + C_n \mathrm{sh}\left(\frac{\pi n}{L}x\right) + D_n \mathrm{ch}\left(\frac{\pi n}{L}x\right). \quad (11)$$

The joint with the outer shell of the probe corresponds to the model of elastic-elastic contact, accordingly, the solution (11) will have additional components in its components:

$$X_i = C_{1i}\sin(k_i x) + C_{2i}\cos(k_i x) + C_{3i}\mathrm{sh}(k_i x) + C_{4i}\mathrm{ch}(k_i x). \quad (12)$$

These given models of the contact of an elastic probe in an elastic-viscose shell located inside a viscoplastic elastic body make it possible to determine the parameters and zones of control over a foreign body when using forced vibration sources.

Equipment and procedure for conducting research

To diagnose fragments and foreign objects in the patient's body, we have created a device that differs from the known one from [12] in that it has an additional source of excitation of mechanical vibrations, which directly floats on the probe shell, i. e. on the outer surface of the probe.

The device consists of a housing that holds a microphone capsule with an amplifier, a flexible guide element, a probe connected to a sensitive membrane, as well as a source of mechanical vibrations (low-frequency vibrator) fixed to the probe, which generates vibrations in the probe. Additionally, a handle-holder is mounted on the housing, an oscillographic fixing device with a board for analyzing vibrations that enter the sensitive membrane of the microphone capsule. Additionally, the device has two vibration sources of a certain frequency and amplitude, capable of transmitting longitudinal and transverse vibrations to the elastic flexible rod – the probe; the latter will propagate inside the protective tube, which now becomes a means of transmitting the exciting and reflected waves from the fragment to the microphone. The working part of the device, unlike the one described by us in [9], [12], is presented in Fig. 6.

Other links of the device were left unchanged, so the moment of interaction was described by the well-known equations of elastic-plastic interaction, through which the vibrations of the string and, accordingly, the membrane were converted into air vibrations, which were actually recorded by the microphone, and the signal was fed to the visualization device through the amplifier. As such a device, an audio spectrum analyser was used, Fig.6 *c*

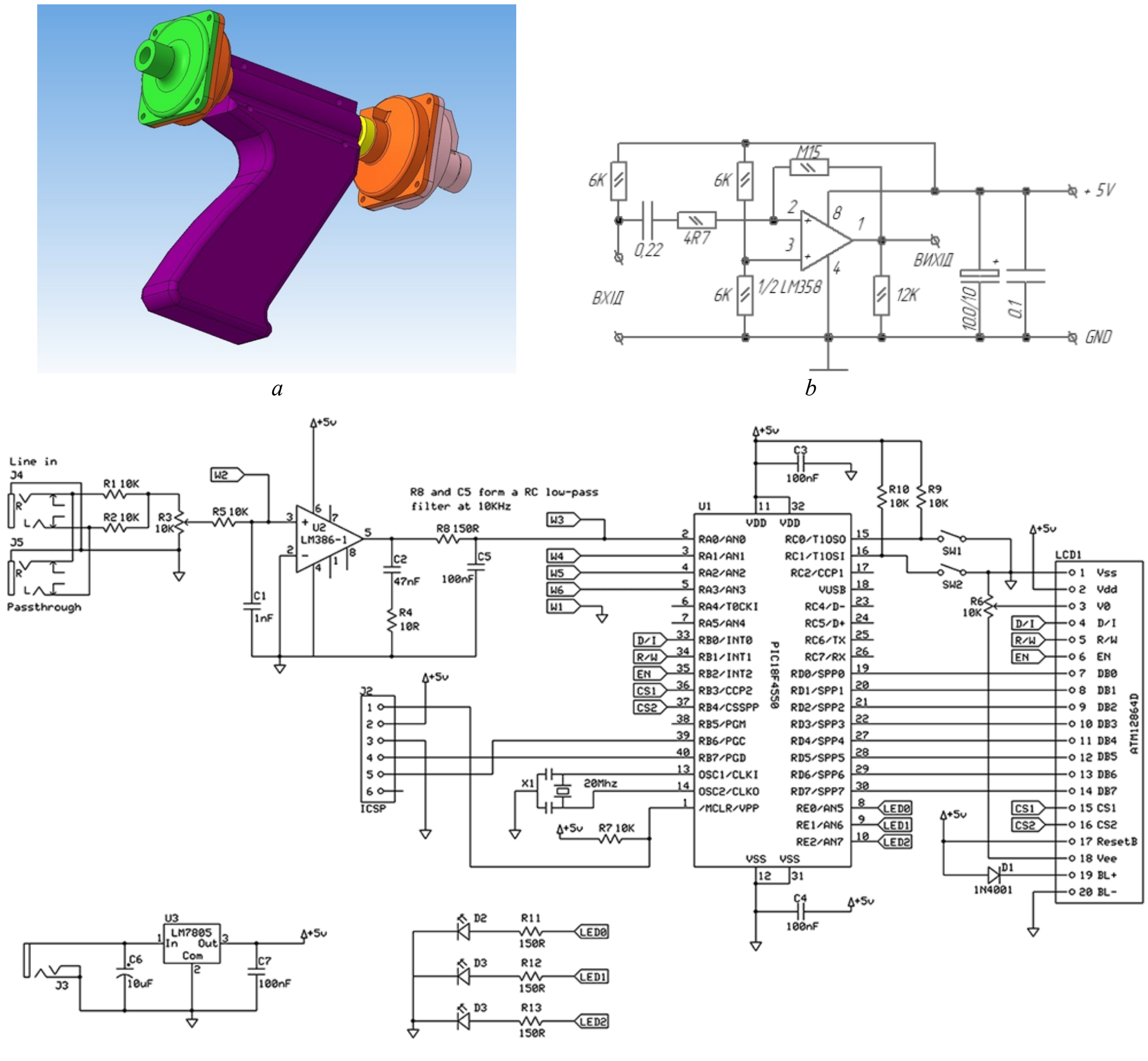
To compare the spectra, the XSA815-TG spectrum analyzer was also used, which is a simplified analogue of the more well-known and more functional SIGLENT SSA3021X device (Plus version), as well as the Spectrum ANALIZER form KEUWLSOFT software product. Detection of foreign bodies in muscle tissue was performed on a demonstrator with similar properties, the immersion of the fragment was from 40 to 100 mm, the length of the elastic probe was 300 mm.

The parameters of the dynamic model were determined based on [12], they are given in Table 1; the mass of the foreign particle, the mass of the elements of the dynamic system Fig. 4 were determined by weighing on analytical balances mod. RADWAG, with an accuracy of 0.005 g, the physical and mechanical properties of the foreign body were determined according to the reference book based on its type. Real fragments and fragments were used for research.

The solutions of the differential equations were carried out by the Runge-Kutt method.

Table 1. Properties of the investigated tissues and K_e ratios for foreign body detection

Medium	Properties of the Medium				Value of K_e
	Elastic Modulus [9]	Viscosity [10]	Poisson's Ratio [9]	Dissipative Properties [9]	
Cortical Bone	10…15 GPa	–	0,05…0,12	–	5,4…12,3
Cancellous Bone	0,5…1,5 GPa	–	0,10…0,35	–	3,9…4,5
Muscle Tissue	–	6,2 mPa·s	–	–	7,8…3,2
Adipose Tissue	–	2,7 mPa·s	–	–	5,9…4,8



a *b*

c

Fig. 6. Model of the device with a vibration exciter in the probe shell (*a*), microphone amplifier (*b*) and spectral analysis unit (*c*)

Results and their discussion

In order to avoid the influence of resonance phenomena and establish rational parameters of the probe elements, the natural angular frequencies of the probe elements were determined and the results were entered in Table 2.

The solution of differential equations and the construction of transient processes of the contact moment with an elastic probe 0.3 m long (Fig. 7, *a*) showed a satisfactory convergence of the results with the data obtained experimentally, Fig. 7, *b*. The latter were obtained based on the characteristics of the contact process of the probe of the device, Fig. 6, with a foreign body, in the form of a glass particle measuring 10 × 15 × 5 mm and weighing 2.145 g. A mechanical device with an operating excitation frequency of 2400…2500 Hz and an amplitude of 0.27 mm was used as an exciter. Such a device made it possible to detune as much as possible from the frequencies of natural oscillations, and at the working end of the probe to obtain a satisfactory amplitude of oscillations, which allows improving the identification process and ensuring its reproducibility.

The experiments were repeated many times, changing the contact conditions, which are generally unstable. The frequency characteristics of the noise emission are shown in Table 3. The signal/noise ratio was estimated at frequencies of 1500–2600 Hz.

The spectral density of the moment of movement of the probe probe through the wound channel remains practically unchanged and has a slightly damping characteristic in the range of higher frequencies. The oscillogram below (case 1 of Table 3) reflects the moment of insertion of the probe into the wound channel and its further advancement with slight resistance.

Table 2. Natural angular frequencies of probe elements

<table>
<tr><td colspan="2" rowspan="2">Element</td><td colspan="8">Parameter, Hz</td></tr>
<tr><td colspan="2">d_1</td><td colspan="2">d_2</td><td colspan="2">d_3</td><td colspan="2">d_4</td></tr>
<tr><td rowspan="3">1</td><td>Probe l_1</td><td colspan="2">780</td><td colspan="2">960</td><td colspan="2">1100</td><td colspan="2">1280</td></tr>
<tr><td>Probe l_2</td><td colspan="2">670</td><td colspan="2">820</td><td colspan="2">1030</td><td colspan="2">1140</td></tr>
<tr><td>Probe l_3</td><td colspan="2">630</td><td colspan="2">760</td><td colspan="2">890</td><td colspan="2">1030</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">d_1</td><td colspan="2">d_2</td><td colspan="2">d_3</td><td colspan="2">d_4</td></tr>
<tr><td>D_{min}</td><td>D_{max}</td><td>D_{min}</td><td>D_{max}</td><td>D_{min}</td><td>D_{max}</td><td>D_{min}</td><td>D_{max}</td></tr>
<tr><td rowspan="3">2</td><td>Shell l_1</td><td>560</td><td>670</td><td>820</td><td>910</td><td>940</td><td>950</td><td>990</td><td>1100</td></tr>
<tr><td>Shell l_2</td><td>540</td><td>620</td><td>790</td><td>880</td><td>910</td><td>930</td><td>955</td><td>1040</td></tr>
<tr><td>Shell l_3</td><td>490</td><td>590</td><td>740</td><td>870</td><td>880</td><td>905</td><td>910</td><td>1030</td></tr>
<tr><td colspan="2">Accepted probe lengths</td><td colspan="3">l_1 =250 mm
l_2 =350 mm
l_3 =400 mm</td><td colspan="5">d_1 = 0,35 mm
d_2 = 0,48 mm
d_3 = 0,60 mm</td></tr>
<tr><td colspan="2">Geometric parameters of the shell</td><td colspan="3">d_1 = 0,55 mm
d_2 = 0,55 mm
d_3 = 0,90 mm</td><td colspan="5">D_{max} = 4,2 mm
D_{min} = 3,8 mm</td></tr>
<tr><td colspan="10">Material Probe – Still X18H10T, Shell – PET-G</td></tr>
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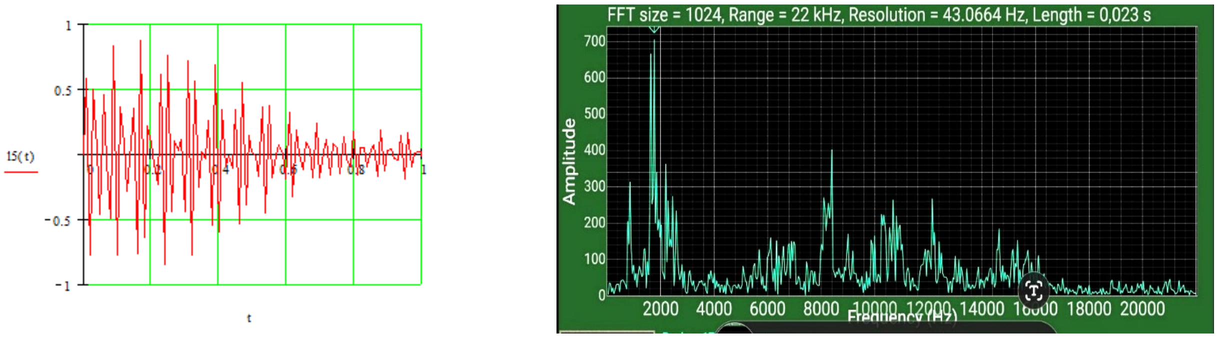


a *b*

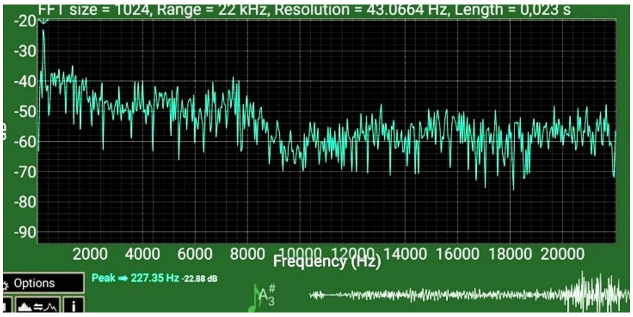
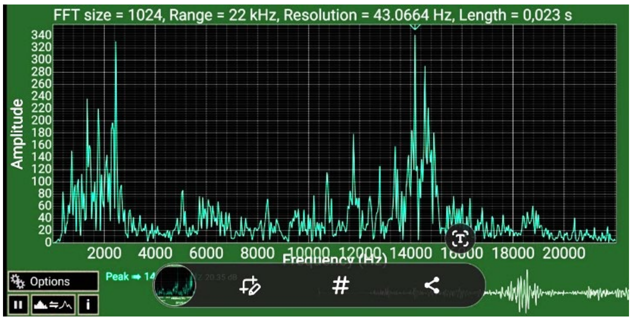
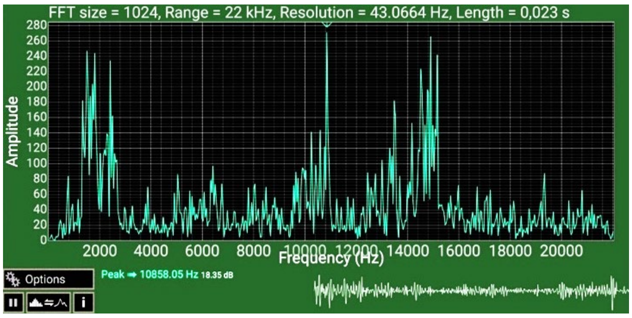
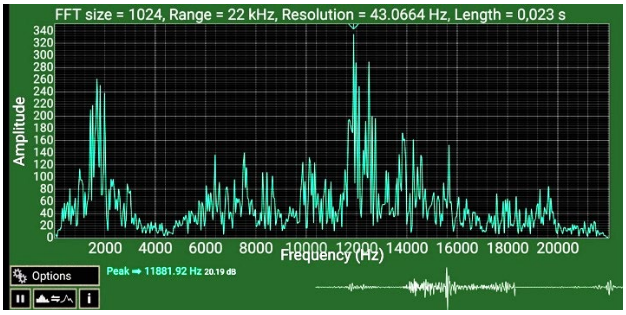
Fig. 7. Simulation results (*a*) and vibration pattern (*b*), taken for conditions of probe contact with a foreign body in the patient's muscle tissue

From the studies it becomes obvious that the maximum ratio of the search parameter was achieved under the conditions of excitation of the elastic probe by a mechanical exciter that was in contact with the probe shell.

However, clear peaks of the useful signal frequencies in the specified range are observed in both cases. Higher oscillations (over 12 kHz), and in the third case – in the range of 8…10 kHz arose due to the interaction of the device components and were not taken into account; at the same time, the natural oscillation frequencies according to Table 2 somewhat distorted the histogram and were subsequently removed by a conventional input filter.

After signal processing, it was possible to obtain a clear spectral picture of the moment of interaction, which remained characteristic for 1…1.5 s and which the doctor can orientate himself on, Fig. 9. The contact itself is reflected by a signal at frequencies of 250–630 Hz, which is obviously determined not only by the contact conditions, but also by the surface of the fragment itself; a sharp increase in the amplitude was observed under the condition of providing vibrations to the probe shell, Table 3.

Table 3. Patterns of noise emission spectra from contact with a foreign body

Conditions	The emission spectra	Signal-to-noise ratio	
		The probe is a waveguide	The shell is a waveguide
1 – probe replacement on control surface		2,2 dBA	2,8 dBA
2 – middle probe		2,4 dBA	1,6 dBA
3 – large probe big diameter		2,1 dBA	3,1 dBA
4 – short probe		1,9 dBA	2,1 dBA

In general, it was established that the controlled signal/noise ratio is determined both by the contact conditions of the probe tip and by its design parameters – the probe diameter, the inner and outer diameters of the shell. Particular attention should also be paid to the tip of the probe, since its shape will determine the sliding of the probe tip along the surface of the foreign body. These parameters, in fact, determine the efficiency of the transmission of vibrations to the probe, and from it to the detected body, and in the dynamic model are determined by the damping and elastic properties of the elements of mechanical chains.

It can be concluded that the supply of vibrations from the mechanical exciter to the probe shell has a positive effect on the determinism of spectral patterns, since the probe now transmits vibrations to the membrane of the microphone chamber without additional loading with vibrations from the exciter located near the microphone.

Further research should be aimed at establishing the regularities of the formation of the contact signal by different types of fragments and at increasing the informativeness of the signal from the output link of the microphone amplifier for more accurate prediction of not only the type of foreign body, but also its size and depth of occurrence in the patient’s tissues.

Conclusions

Further improvement of a special device for detecting foreign bodies, including non-radioactive ones, in the body of a wounded person is seen in changing several functions of the main parts of the sensor. Thus, the sensor is a device consisting of a probe and a block of mechanical and electronic means held by the paramedic’s hand and to detect a foreign body, a probe containing an elastic thin flexible probe with an external quasi-elastic shell is inserted through the wound channel until contact with the foreign body. The signal from the dynamic contact is visualized and displayed on a display device, which allows the paramedic to make a decision on further medical care for the injured person.

Since the probe receives additional mechanical excitation, the signal has a long-lasting form, which increases the efficiency of primary diagnostics. However, at the same time, using the probe as a waveguide for both mechanical excitation and for transmitting vibrations to amplification and spectral analysis means significantly distorts the informativeness of the signal and worsens the accuracy of the studies.

It is proposed to change the design of the sensor, ensuring contact of the mechanical exciter with the outer shell instead of contact with the probe. The latter, when harmonic oscillations occur, will transmit them to the probe itself, through separate contact points, reducing the amplitudes of these oscillations. This ensures an increase in the sensitivity of the sensor at frequencies up to 6300 Hz, which is most important for diagnostics.

It has been established that in this case it is possible to increase the signal-to-noise ratio in the range of 0.63…2.5 kHz to 3.1 dBA, which is extremely important for the analysis of the spectral density patterns of oscillations from contact conditions in a viscous medium.

Acknowledgements

The article was prepared as part of the research work (R&D): “Development of an innovative portable device for detecting fragments in a wound, including non-radiographic ones” with the financial support of the National Research Foundation of Ukraine of the competition “Science for Strengthening the Defense Capability of Ukraine” (No. 2023.04/0145).

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Підвищення чутливості тактильного сенсору для виявлення осколків у тілі пацієнта

О. Ф. Саленко[1] • Н. В. Гаврушкевич[1] • В. М. Орел[2] • Б. О. Саленко[3] • В. А. Черняк[4] • К. К. Карпенко[5]

[1] *КПІ ім. Ігоря Сікорського, Київ, Україна*

[2] *Харківський національний університет внутрішніх справ, Кременчуцький льотний коледж, Кременчук, Україна*

[3] *Національний університет “Полтавська політехніка імені Юрія Кондратюка”, Полтава, Україна*

[4] *Національний військово-медичний клінічний центр “Головний військовий клінічний госпіталь”, Київ, Україна*

[5] *Київський національний університет імені Тараса Шевченка, Київ, Україна*

Анотація. *Проаналізовано засоби підвищення чутливості тактильного сенсору для виявлення сторонніх тіл у рані пацієнтів рановий канал, яким доцільно користуватися у польових умовах при невідкладних станах. Такий сенсор являє собою пристрій, що складається із зонду та блоку механічних і електронних засобів, утримуваних рукою парамедика. Для виявлення стороннього тіла зонд, що містить пружний тонкий гнучкий щуп із зовнішньою квазіпружною оболонкою, вводять крізь рановий канал до моменту контакту зі стороннім тілом. Сигнал від динамічного контакту візуалізується та виводиться на засіб відображення, що дозволяє парамедику прийняти рішення щодо подальшої медичної допомоги ураженому.*

Оскільки щуп отримує додаткове механічне збудження, сигнал має тривалий вигляд, що підвищує ефективність первинної діагностики. Однак у той же час використання щупу як хвилеводу і для механічного збудження, і для передачі вібрації до засобів підсилення і спектрального аналізу значно спотворює інформативність сигналу, погіршує точність досліджень.

Пропонується застосовувати оболонку зонду в якості хвилеводу для передачі коливань, тоді як щуп постає безпосередньо хвилеводом сигналу контакту.

Встановлено, що у такому випадку вдається підвищити співвідношення “сигнал/шум” в діапазоні 0,92...2,5 кГц до 2 дБА, що вкрай важливо для аналізу картин спектральної щільності коливань від умов контакт у в’язкому середовищі.

Ключові слова: *спеціальний інструмент діагностики; шумове випромінювання; рана; нерентгеноконтрастний сторонній предмет.*