Mech. Adv. Technol. Vol. 7, No. 3, 2023, pp. 337–349

DOI: 10.20535/2521-1943.2023.7.3.294822

UDK 621

The possibility of detecting non-x-ray fragments in the body of the wounded by the contact method

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Received: 10 October 2023 / Revised: 20 November 2023 / Accepted: 22 December 2023

Abstract. *The types of injuries and types of striking elements were analyzed, the conditions of patients requiring urgent surgical intervention were assessed. The possibilities of existing means of diagnosing fragments in the patient's body were analyzed, and it was concluded that for non-X-ray contrast fragments, the proposed method of mechanical contact with a special flexible and elastic probe is appropriate and effective.*

A special tool for examining wound canals has been developed, consisting of a flexible probe for individual use and a handle-holder with a microphone capsule, the membrane of which is directly connected to the probe and reacts to mechanical contact with an obstacle, and the capsule itself is directly connected to the oscilloscope through a signal amplifier. which has spectral signal processing circuits. The problem of the interaction of the elastic contact of a non-rigid element with a fragment located in a viscous medium is set, provided that the properties of the medium are not constant. Typical solutions of this problem for various types of fragments and parameters of the contacting element itself are presented. A picture of the noise emission accompanying the contact is shown.

The functional dependence of noise emission parameters on the shape and type of the foreign object in the wound canal was revealed. The expediency of using the frequency-amplitude characteristic of noise radiation as a controlled parameter has been proven. A conclusion was made about the functional conditioning of the width of the signal spectrum and basic frequencies at the time of mechanical contact with a foreign object in the wound, depending on its shape and type; it was established that the use of an oscilloscope with a spectral analysis channel allows for the fairly accurate identification of a non-radiocontrast foreign object in a wound.

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

Introduction

A full-scale unprovoked war with the Russian Federation is currently underway in Ukraine. The latter widely uses prohibited ammunition, in particular cluster and phosphorous shells, tries to destroy infrastructure, housing, because of which the military and civilian population receive significant shrapnel and bullet injuries to the body and limbs. Combat actions that do not stop for a long time, as well as the lack of opportunities to evacuate the wounded from the battlefield, quite often lead to significant complications for patients, and the lack of a sufficient number of diagnostic tools reduces the effectiveness of medical care.

It is known that fragments are divided into two groups: fragments of irregular shape and regular shape (Fig. 1) [2]. The wrong ones include pieces of glass, plastic, remnants of projectiles, rockets, parts of objects directly affected by explosive or primary fragmentation action. Fragments of the correct shape are most often found in grenades, shrapnel shells and other types of weapons.

Unlike a bullet, shrapnel has relatively simple ballistics, resembling a cone. A comparison of two shrapnel with the same kinetic energy (Fig. 2) proves that a light shrapnel transfers a significant part of its energy upon contact with the body, while a heavy shrapnel disperses its energy throughout the entire wound channel. At the same time, the largest diameter of the wound is observed at the entrance, gradually narrowing to the end, and the depth of the wound depends on the ratio of mass and speed of the fragment.

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a *b*

Fig. 1. Groups of fragments: *a*) irregular shape; *b*) of the correct form

a *b*

Fig. 2. Ballistics of fragments with the same kinetic energy: *a*) light and fast fragment; *b*) heavy and slow fragment B and the picture of the development of the wound channel in the demonstrator

Usually, it is difficult to predict the behavior of a splinter since the affected tissues have different structures and physical and mechanical properties. The shape of the opening is not a perfect cone, and there are deformations at the beginning of the wound.

The classification of shrapnel wounds in accordance with the international Red Cross is based on 6 indicators (Table 1). Such parameters make it possible to quickly determine the severity of a wound in combat conditions [3], while wounds, in turn, are divided into 3 groups depending on severity (Table 2) [1] [4]:

Table 1. Criteria for evaluating wounds in points

E	The size of the wound entrance	In centimeters
X	The size of the exit opening of the wound	In centimeters, in the absence of an exit hole X = 0
C	Cavity	Will two fingers fit in the wound before its surgical excision?
		C 0 – no
		C 1 – yes
F	Fracture	Are there any broken bones?
		F 0 – no fractures
		F 1 – simple fracture, hole or minor fragmentation
		F 2 – clinically significant fragmentation
V	A vital structure	Is there penetration into the dura mater, pleura, abdominal cavity? Damage to the main blood vessels?
		V 0 – vital organs are not damaged
		V N – (neurology) penetration into the dura mater or spinal cord
		V T – (thorax or trachea) penetration into pleura or larynx/cervical trachea
		V A – (abdominal cavity) penetration into the abdominal cavity
		V H – (bleeding) damage to the main blood vessels up to the brachial arteries or the carotid artery in the neck
M	Iron body	Do you see bullets or shrapnel on the x-ray?
		M 0 – no
		M 1 – yes, one iron body
		M 2 – yes, many iron bodies

Group 1 - E + X less than 10 centimeters, C0, F0 or F1 (low level of energy transmission);

Group 2 - E + X less than 10 centimeters, C1, F2 (high level of energy transmission);

Group 3 - E + X more than 10 centimeters, C1, F2 (extremely high transmission level).

The summative effect in radiation diagnostics is the layering of images of some organs and tissues on top of others, which complicates the objective and high-quality diagnosis of pathological processes. In X-ray diagnostics, there is a layering of various organs located along the path of the X-ray beam.

Table 2. The system of classification of wounds depending on the size and complexity

	ST - Type	F - Type	V - Type	VF - Type
Group 1	A small simple wound	A simple fracture	A minor, life-threatening injury	A minor injury with a life-threatening fracture
Group 2	Medium-sized soft tissue injuries	A compound fracture	Medium-sized, life-threatening injuries	A medium-sized injury with a life-threatening fracture
Group 3	Major soft tissue injury	A severe fracture with comminution, threatening the loss of a limb	Major life-threatening injury	A major wound with a life-threatening fracture

After assessing the injury, it is given the appropriate type depending on the damage to the body structures: Type ST – soft tissue injury, F0 and V0; Type F – injuries with bone fractures, F1 or F2 and V0; Type V – severe life-threatening injuries, F0 and V=N, T, A, H; Type VF – injuries with fractures and damage to important body structures with threats to human life, F1 or F2 and V=N, T, A, H.

Thus, combining groups and types of injuries allows the use of a classification system according to 12 categories (Table 2), [1][5]. Under the conditions of war, this method of classification is universal, because it makes it possible to quickly assess the severity of the injury and, accordingly, take the necessary measures to save the victim's life. In addition, it helps to predict possible complications, to carry out the necessary surgical intervention [6].

The most common methods of finding fragments in the human body in the conditions of field surgery are the following.

Radiography is one of the most common types of diagnostics [7]. The formation of an X-ray image of the examined organ is based on non-homogeneous absorption of radiation by tissues, as well as foreign bodies, because of which there is a weakening of the illumination of the film in different areas (Fig. 3).

Fig. 3. X-ray of a foot with iron fragments

Computed tomography (CT) is a diagnostic method that can be called improved X-ray [8]. Like a traditional X-ray, a CT scan provides imaging using X-rays. However, its design allows you to scan organs using a multi-layer method, which gives a very detailed picture with high spatial resolution. And additional computer image processing makes it possible to visualize the internal organs or structure not just as a collection of slices, but as three-dimensional images where the problem area can be studied from all sides. Computed tomography can be performed without contrast or with the introduction of a contrast agent according to the specific clinical task set before the radiologist.

Thanks to volumetric scanning, the location of the fragment can be determined much more accurately than on an X-ray, the distance error in such studies is about 1 mm. In addition, thanks to the possibility of injecting a contrast agent, it is possible to find not only iron fragments, but also fragments of other materials. However, it should be remembered that most often iodine-containing agents are used as a contrast agent, so an allergy is possible. To carry out such an examination, a tolerability test is mandatory.

Magnetic resonance imaging (MRI) is a tomographic method of examining internal organs and tissues using the physical phenomenon of nuclear magnetic resonance (NMR) [9]. The method is based on measuring the electromagnetic response of atomic nuclei, most often the nuclei of hydrogen atoms, namely on their excitation using a certain combination of electromagnetic waves in a constant magnetic field of high intensity. This is a non-invasive method of medical examination, which is widely used in medical diagnosis and monitoring the adequacy of patient treatment. Unlike computer tomography and X-ray examination, when using this method, the body is not exposed to ionizing radiation. Instead, the image is formed under the influence of a powerful magnetic field and electromagnetic waves with the use of computer processing to obtain a clear detail of soft tissues, bones, and other internal structures of the body. To increase the clarity of the image, contrast agents are often used.

This method cannot be used to find iron fragments. The use of MRI is contraindicated for people who may have metal inside: pacemakers, prostheses, fragments, etc. The strong magnetic field of the tomograph can attract iron objects that are inside the body. Shards can also shift.

The magnet search method is a method that has become widespread recently [10]. It is used when excision of a wound thanks to neodymium magnets, with a breaking load of 100–150 kg (with deep lying 200–300). Due to the interaction of magnetic fields, iron fragments are attracted to the magnet and, accordingly, lead to the formation of a bump on the surface of the body, thanks to which it is possible to conclude about the location of the fragment. In addition, this method is also used in the extraction of fragments: together with the magnet, the latter is removed from the patient's body.

The method of direct observation – the fragment is detected by visual observation in real time. This method is possible only for fragments with low kinetic energy but does not guarantee the complete finding of all fragments.

So, the main methods of diagnosis are: radiography, MRI, the method of searching with a magnet, the method of direct observation. The main disadvantages of these methods are their impossibility of use in the conditions of hostilities.

In addition, some types of diagnostics are contraindicated for certain shrapnel wounds, and some cannot detect shrapnel in the human body at all.

From these positions, the search for simple and reliable means of diagnosing foreign objects in the patient's body (without the use of X-ray machines, complex MRI systems) in the field is an urgent and extremely important task today, the solution of which can save the life and health of thousands of wounded.

The purpose of the work is to develop a new method of diagnosing the presence of non-radiocontrast foreign objects (fragments) in the patient's wound by means of direct contact.

The object of research is a foreign object in the wound channel.

The subject of the research is the identification of a foreign object due to new means of mechanical control that work without opening the wound channel.

Exposition

Given the peculiarities of the wound channel, the device that is introduced into the human body should be flexible enough to be inserted into the wound with minimal damage. In addition, the device must be made disposable to minimize the likelihood of infection, contamination, and other people's blood entering the wound. Also, the device should be able to scan the side walls of the channel.

However, it is worth remembering that for a better recovery of human tissues after a shrapnel injury, it is necessary to perform surgical intervention to remove tissues with primary necrosis. This can be done using a laparoscope probe with a scissor clamp.

The effect of noise emission was used to detect fragments. There are always damages and defects on the surface, so when something is passed over it, a noise occurs. If you take and run something over soft tissues and a solid object (shard), there will be significant differences on the oscillogram. Due to such a difference in noise, it is possible to tactilely diagnose the location of the fragment.

Thus, the device Fig. 4, should consist of 2 parts: 1) a replaceable part that is inserted into the wound; 2) a reusable device with a microphone for capturing noise and the appropriate software (software) for its processing.

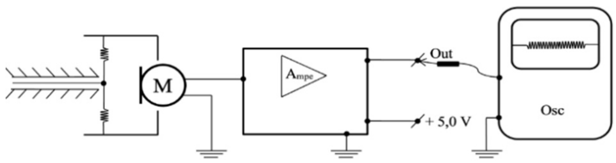


Fig. 4. Principal scheme of the device

A developed laparoscopic tool for inspecting wound channels, consisting of a flexible probe for individual use and a handle-holder with a microphone capsule, the membrane of which is directly connected to the probe and reacts to mechanical contact with an obstacle, and the capsule itself is directly connected to the oscilloscope through a signal amplifier, which has spectral signal processing chains.

The circuit diagram (*a*) and dynamic component (*b*) is presented in Fig. 5. Using the probe connected to the capsules of the microphone M, connected to the low-frequency AM amplifier, the output stage of which is connected to the REGOL oscilloscope, we can form a broadband noise emission in non-stationary contact with shrapnel in the wound channel. The controlled values will be the amplitude A_i obtained after spectral analysis and the width of the band N_i, which can be recorded on the oscilloscope screen. The averaged values of A_i as well as the width of the band N_i in the memory cells of the oscilloscope, which simplifies the transfer of data for further statistical processing.

The physical basis of the process consists in the fact that during the introduction of the probe in the form of a flexible non-rigid elastic rod into the wound channel, its front part, which protrudes beyond the boundaries of the guide elastic-plastic tube by the amount δ, perceives the resistance to movement from the walls of the channel (muscle and fatty tissues, surfaces of bone tissues, blood vessels, cartilage and tendon connections; at the end of the channel, it begins to come into contact with a foreign body. We will consider that the elastic properties of living tissues are fundamentally different from solid bodies (characteri-

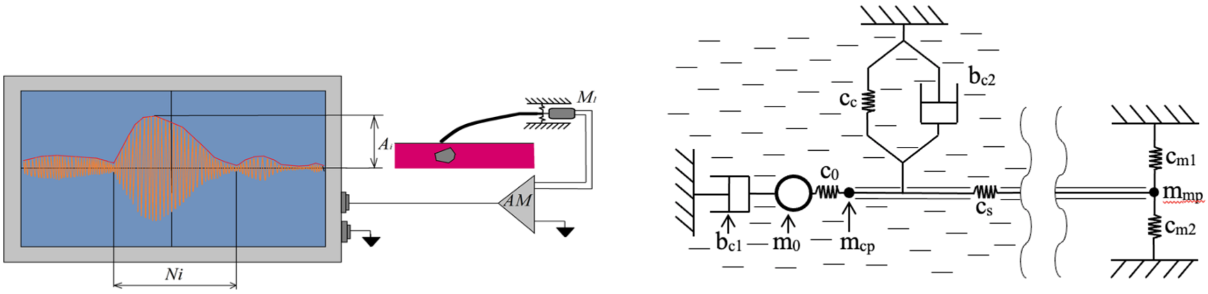


Fig. 5. Circuit diagram (*a*) and dynamic component (*b*)

zed by the reduced elasticity c_c, elasticity b_{c2}), and the dynamic characteristics of a foreign particle mass m_0, significantly differ from the corresponding characteristics of c_c, c_s and b_{c2} bone tissue.

Since the mass of the elastic element with the membrane of the microphone chamber is comparable to the mass of the foreign body and is ms, the moment of interaction will be described by the known equations of elastic-plastic interaction, because of which oscillations of the string and, accordingly, the membrane will occur. Next, the vibration of the membrane will be recorded by the microphone, and the signal will be presented on the oscilloscope through the amplifier.

Detection will occur as a moment of change in the noise emission of the movement of the probe in the wound channel and the moment of movement along the surface (contact) with a foreign body.

Let's set the x axis along the central axis of the dipstick. The balance of the fragment in the body will be determined by the equation

$$m_0 \frac{d^2x}{dt^2} = c_0 x_0 + b_{c1} dx - c_0 \cdot (x - x_0) - R .$$

And the balance of the probe is respectively

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

The oscillations of the membrane will be described as follows

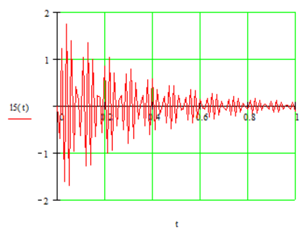
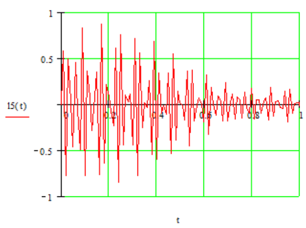
$$m_{mp} \frac{d^2 x_{23}}{dt^2} = c_s \cdot (x - x_2) - \frac{c_{m1} c_{m2}}{c_{m1} + c_{m2}} \cdot (x_2 - x_m) - R .$$

The resistance of the environment is considered both from the side of the fabric and along the axis of the probe:

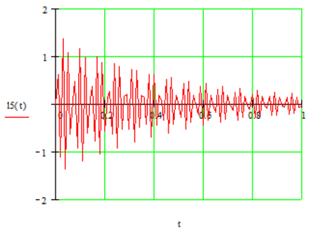
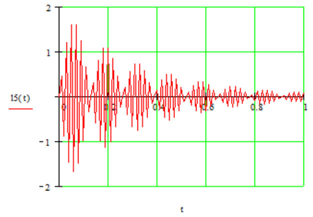
$$R = c_c \cdot (x_{i-1} - x_i) + b_{c2} \frac{dx_i}{dt} .$$

Then, based on principal [8] and using the software environment and specifying as an input influence the interaction of the surface of a foreign body with the end of the probe in the form of a quasi-periodic contact of a certain frequency, which is determined by the state of the surface of the fragment, the radius of rounding of the probe (diameter d_p), we will obtain transient signal patterns, which are expediently summarized in Table 3.

Table 3. Result of modeling noise emission of the contact

#	Conditions	Device parameters	Sample of diagram	Conclusions
1	*V*=low speed, 1 cm/s, contact with	metal probe of small diameter, *d*=0.5 mm, probe length 0.3 m		A low-amplitude noise without the existence of peaks and at fixed frequencies is observed
2	*V*=low speed, 1 cm/s, contact with bone tissue soft tissu e	large diameter metal probe, *d*=0.9 mm, probe length 0.3 m		Existence of peak amplitudes at the moment of contact with the body (inclusion). At resonant frequencies, there is a wide noise spectrum

Continuation Table 3

#	Conditions	Device parameters	Sample of diagram	Conclusions
3	*V*=high speed, 4 cm/s, contact with soft tissue	metal probe of small diameter, *d*=0.5 mm, probe length 0.8 m		A change in the frequency spectrum of the noise emission, certain bursts appear, obviously determined by extraneous influence from the channel walls
4	*V*=high speed, 4 cm/s, contact with bone tissue	metal probe of small diameter, *d*=0.5 mm, probe length 0.8 m		The amplitude burst is smaller, the signal-to-noise ratio is worse

Equipment and method

The research used the methods of spectral analysis of noise emission from the mechanical contact of a flexible probe with a foreign object in the wound, which does not require opening the wound, but allows manipulation by the laparoscopic method; signal processing was carried out using special signal improvement filters, as well as tools for constructing noise emission spectra based on Fourier series decomposition (built into the oscilloscope); statistical processing of information was carried out on the basis of standard statistical approaches. The conclusion regarding the informativeness of the signals is made on the basis of the dispersion analysis of the signal parameters;

The device consists of 2 parts (Fig. 6). The first part consists of elements 7, 6, 5, 4 and 8. This part is reusable. The second of elements 1, 2, 3 and 8. Let's consider each of the parts in detail.

Consider the static model of the device. The flexible tube 1 (Fig. 6*b*), connected to the fastening element 2, enters the wound channel. Buge 3 is slightly longer than the tube and looks out of it. During the passage of the wound channel, it touches it and creates noises, and accordingly oscillations, which are transmitted through probe 3 to the

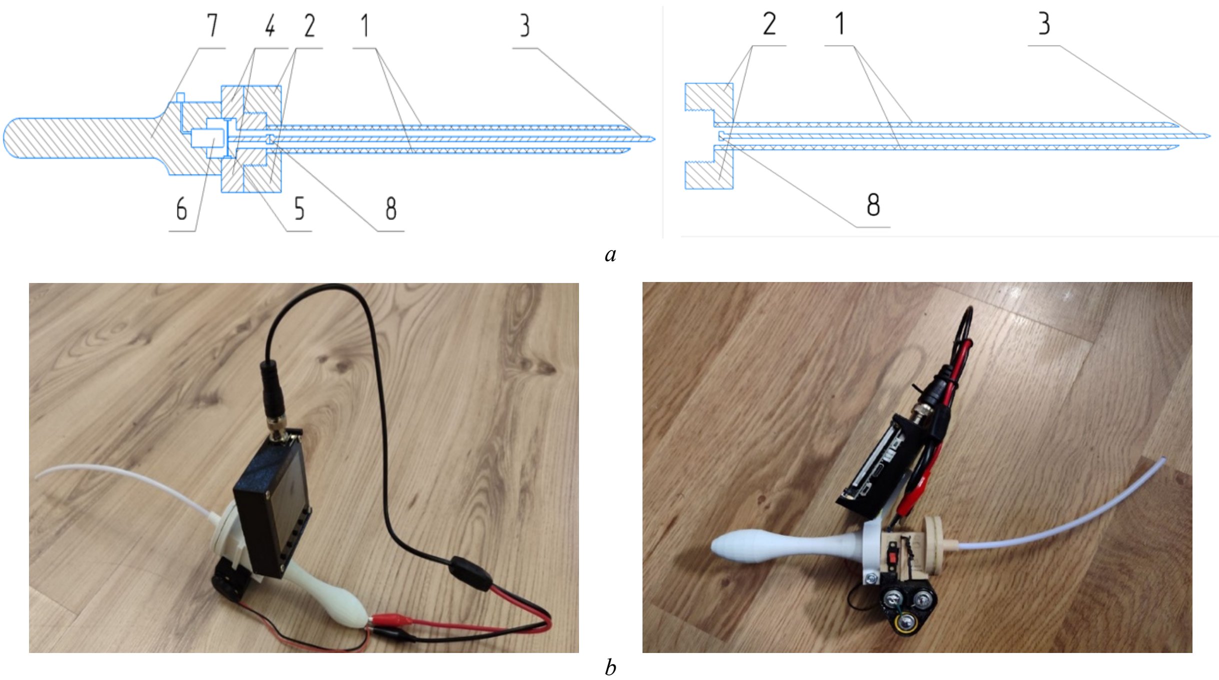


Fig. 6. Drawing of device for detecting fragments in the body (assembled) with replaceable part of the device (*a*) and photo of device (*b*)

reusable part. Fastening element 2 is attached to element 4 using a threaded connection. Let's consider the dynamic model of the device. Before the start of use, part 1 and part 2 are fastened together with fastening elements 2 and 4, and with an element 8. Holding the device by element 7, tube 1 with an element 3 is inserted into the wound. When in contact with the surface, noise occurs, which is transmitted in the form of vibrations, transmitted by the bushing 3 through the connection 8 to the noise-generating membrane 5, the microphone 6 picks up this noise and transmits it in the form of electrical signals to the device with the appropriate software for further processing of the signal.

Before the start of use, part 1 and part 2 are fastened together with fastening elements 2 and 4, and with an element 8. Holding the device by element 7, tube 1 with an element 3 is inserted into the wound. When in contact with the surface, noise occurs, which is transmitted in the form of vibrations, transmitted by the bushing 3 through the connection 8 to the noise-generating membrane 5, the microphone 6 picks up this noise and transmits it in the form of electrical signals to the device with the appropriate software for further processing of the signal.

In addition, the experiment used: 3D scanner "Revopoint Pop I", software for the scanner, oscilloscope "RIGOL DS-1054", optical microscope "Digital microscope ADSM301" with 40x magnification, microphone, amplifier of low-frequency signals built on KT315B transistors, a fragment plastic, a piece of meat, a knife, tweezers.

A fragment of plastic was used as a foreign body - a model reproduced by 3D printing from a metal prototype obtained from the rupture of a cluster munition. Such fragments can be formed when a bullet pierces plastic protective equipment of a low protection class. The size of the demonstrator is 10.0×5.5 mm. The demonstrator was placed in a surgical simulator, in which a hole was made and a shrapnel was inserted, simulating a shrapnel injury.

With the help of a 3D scanner (Fig. 7), a spatial picture of the connection of the demonstrator in the simulator was obtained, which made it possible to clearly determine the position of the demonstrator even in the presence of a wound channel of a complex shape.

In the dissected tissues, the interaction between the probe of the device and the demonstrator was also assessed visually using a microscope.

Now of contact of the bougie with the demonstrator, a pattern of noise emission was observed on the oscilloscope screen, subjected to spectral analysis at low and high frequencies. The used device made it possible to establish average values of amplitudes at fixed frequencies, spectrum width, basic frequencies, and harmonics for concrete contact conditions.

The position of the demonstrator was recorded in the sweep along the time axis, which made it possible to determine its position before removal.

Using the 3D model of the simulator, the angle and length of the probe entrance, it was possible to clearly determine the location of the fragment in the body. After that, the simulator was dissected with a scalpel and the fragment was removed with tweezers (Fig. 8).

a *b*

Fig. 7. Process of 3D scanning of the simulator: *a*) scanning process; *b*) obtained 3D model with an inlet (highlighted in red)

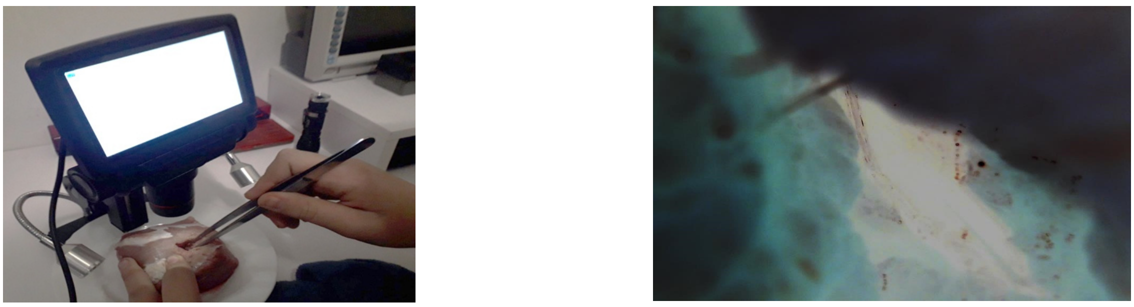
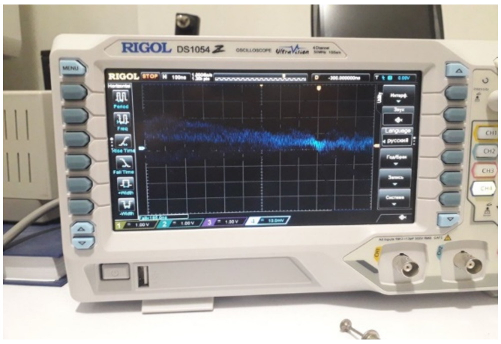
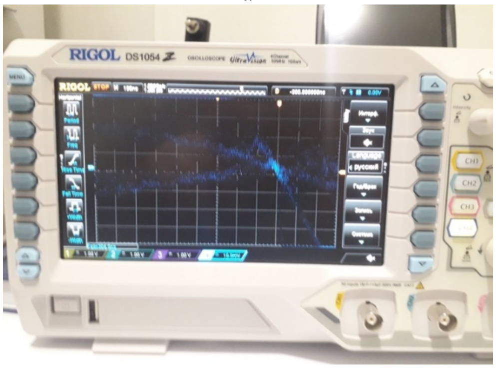


Fig. 8. Removing a fragment from the simulator

When determining the location of the fragment in the surgical demonstrator, its location was fixed both with the help of a 3-D scanner and by inserting the probe of the proposed device (fig.7). At the same time, the level, amplitude, and spectrum of the noise emission signal were monitored on the oscilloscope screen, fig. 9.



a



b

Fig. 9. Noise patterns during the movement of the probe (*a*) and at the moment of detection of the demonstrator (fragment) (*b*)

In the future, the signal was processed using the statistical processing program Statgraphik+. Three types of fragments were considered: plastic fragment, glass fragment and stone fragment (mineral). These parameters are qualitative. Thus, this parameter is the level of variation of foreign body factors in the wound channel. The output (controlled) values are the amplitude A_i and the width of the channel.

Result and discussion

In accordance with the formulated hypotheses and based on the [9], the research checked whether the sample of A_i and N_i values belongs to one general population (using the assessment of the normality of the distribution of the entire sample and a sample from a series of experiments (considering the small size of the sample, we use the ω-criterion).

The histograms constructed by the software and the calculation results are shown in fig. 10 proved that the prerequisites for further statistical analysis are fulfilled.

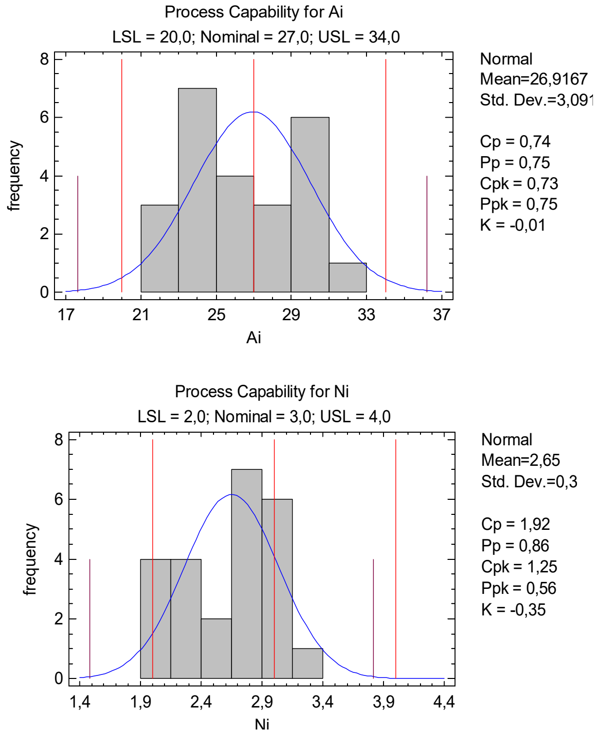


Fig.10. Histograms of subdivisions of general populations A_i and N_i

Checking the distribution of controlled parameters within groups, within one sample (Fig. 11), showed that in the first case, the general set of data as a whole does not obey the law of normal distribution, and in the second case, we have such obedience, which indicates the existence of differences among the series of observations, while each measurement can be characterized by the mean value of the controlled parameters with a 6σ-scatter interval established by standard statistical procedures. All signal mixing according recommendation [10].

A comparison of the presented diagrams proves that in the first case the amplitude A_i does not depend on the type and size of the inclusions, while the width of the frequency N_i emission band is quite clearly determined by the type and size of the fragments.

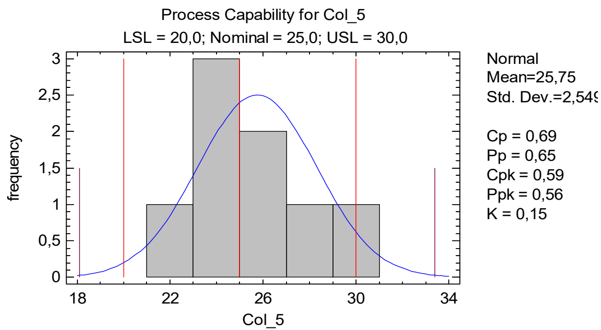


Fig. 11. Histogram of N_i distribution by sample of observations. Corresponds to the law of normal distribution determined using the ω-criterion

Since the scattering fields A_i of each sample are compared with each other and compared with the general scattering field, there is no functional conditioning (fig. 12). So, with a 95% probability, it can be assumed that the controlled amplitude does not depend on which fragment is in the wound but appears randomly.

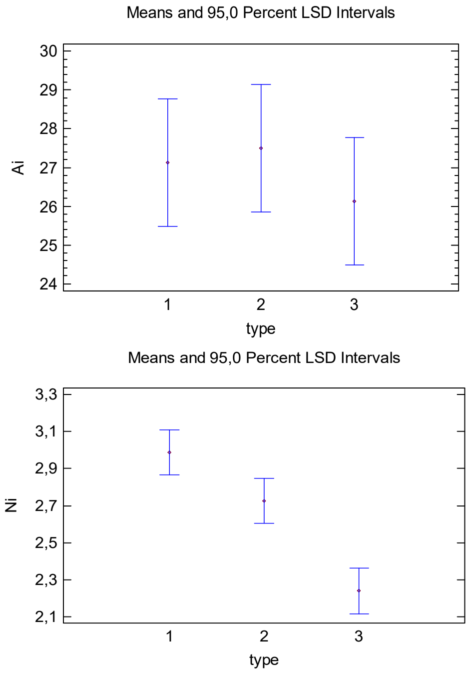


Fig. 12. Comparison of variances of samples for 3 types of fragments for A_i (*a*). The total scattering field compared to the fields of each sample of observations, and comparison of variances of samples for 3 types of slivers for N_i (*b*). The total scatter field for each observation is much smaller than the total range of parameter changes

Having accepted the type of scallions as a conditionally digital factor, a regression analysis was conducted, which showed the presence of a close correlative functionally determined relationship, fig. 13:

$$t = 6,57 - 1,7 N_i \ .$$

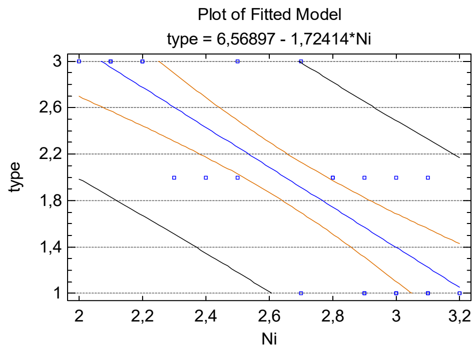


Fig. 13. Regression field of conditioning of a deterministic type of rolling pin, depending on the set width of the noise emission band

Statistical processing of the array of data showed that the A_i scattering fields of each sample are compared with each other and copared with the general scattering field, there is no functional conditioning. So, with a probability of 95%, we can assume that the controlled amplitude does not depend on which fragment is in the wound but appears randomly.

Unlike the amplitude, which does not depend on the type and size of the fragments, the width of the frequency band is quite clearly determined by the type and size of it.

Thus, control of the frequency emission band can be a reliable indicator that determines not only the presence of a fragment in the patient's body, but also its type and relative size.

The functional conditioning of the width of the spectrum of the noise emission signal at the time of mechanical contact with a foreign object in the wound, its shape and type has been proven; it was determined that the use of an oscilloscope with a spectral analysis channel allows fairly accurate identification of a non-radiocontrast foreign object in a wound.

To improve the informativeness of the signal, it is processed according to a certain procedure, according [11], [12].

To process the signal and increase the signal-to-noise ratio, special software is used, aimed at separating the useful signal from the broadband signal received after the low-frequency amplifier. The principle of operation of this software is given below [8].

Note that in the notation of functions, a discrete argument will be indicated in square [discrete] brackets, and a continuous argument – in round (continuous) brackets.

The concepts of amplitude spectral density $X(f)$ and spectral energy density $E(f)$ are primarily related to the spectral representation of continuous and discrete deterministic signals, which describes the distribution of energy by frequency.

For time-continuous deterministic signals $x(t)$, the concept of amplitude spectral density $X(f)$ is related to the Fourier transform pair, [8]:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-2jft\pi} dt,$$

$$x(f) = \int_{-\infty}^{\infty} X(f) e^{2jft\pi} df \ .$$

The energy E of the signal $x(t)$ as a function of the spectral density $E(f)$ is determined by the relation:

$$E = \int_{-\infty}^{\infty} x^2(t) dt = \int_{-\infty}^{\infty} E(f) dt \ .$$

In the case of a discrete representation of a continuous function in the form of a set of samples $x[n]=x(t)|_{t=nT}$, taken with a period T, the concept of the spectral density of the amplitude of the sequence of readings is determined by a pair of discrete-time Fourier transform:

$$X_p(f) = \sum_{n=-\infty}^{\infty} x[n] e^{-2j\pi fnT} \ ,$$

$$x[n]=\int_{-\frac{1}{2T}}^{\frac{1}{2T}} X_p(f)e^{2j\pi fnT}df, \quad n=0\pm 1 .$$

or for a sequence $x[n]$ of finite length in N counts:

$$x[k]=T\sum_{n=0}^{N-1} x[n]e^{-2j\pi fnT/N}, \quad 0\le k\le N-1 ,$$

$$x[n]=\frac{1}{NT}\sum_{k=0}^{N-1} x[k]e^{2j\pi fnT/N}, \quad 0\le n\le N-1 .$$

The latter relations are called a pair of discrete Fourier transforms (DFT), and their difference from traditional ones containing T and $1/T$ factors is due to the desire to ensure the correctness of scales when calculating energy and power.

The signal $x[n]$ cannot be simultaneously limited in duration and spectrum bandwidth. However, it can be characterized by a certain interval T_e seconds, in which most of its energy will be concentrated when presented in the time domain, and some interval B_e hertz, in which most of its energy will be concentrated when presented in the frequency domain.

The main characteristic of the spectral assessment is related to this - the resolution, which is understood as the ability to separately measure the spectral responses of two sinusoidal signals that are close in frequency and amplitude.

Software required resolution is provided using the "window" function, [13].

Thus, a finite record of data $x(n)$ from N readings can be represented as some part of the original infinite sequence $x_u(n)$, depicted through a rectangular window $w(n)$ in the form of a multiplication:

$$x[n]=x_u[n]w[n], \quad w[n]=\begin{cases}1, 0\le n\le -1\\ 0\end{cases}.$$

Frequency spectrum of an important sequence, expressed through the transformation of the sequence $x_u[n]$ and the direct window $w[n]$, a traditional group of these transformations

$$X(f)=X_u(f)D_n(f),$$

where $D_N(f)$ is the Dirichlet kernel, which represents the DCPF of the forward function:

$$D_n(f)=Te^{-j\pi fnT(N-1)}\frac{\sin(\pi fTN)}{\sin(\pi fT)} .$$

The observed finite-sequence PFD is a distorted version of the infinite-sequence PFD. At the same time, the minimum width of the spectral peaks of the finite sequence is limited by the width determined by the main petal of the DCPF window and does not depend on the initial data. The side lobes of the DCPF window, which are called "spectral leakage", will change the amplitudes of the neighbouring spectral peaks, leading to a shift in the spectral estimates. Similar distortions will be observed in the case of non-sinusoidal signals. Leakage leads not only to the occurrence of amplitude errors but can also mask the presence of weak signals and, accordingly, make their detection more difficult. It should be noted the existence of a few window functions, different from the rectangular one, which have a lower level of side petals. However, this is usually accompanied by an expansion of the main lobe of the spectrum. Therefore, the window should be chosen considering the compromise between the width of the main petal and the level of suppression of the side petals.

The Hann window has gained the greatest use for stationary processes. For transients, the best result is obtained when using a rectangular window. The Hamming window allows you to get sharper peaks than in the case of using the Hanna window, but at the same time the level of side lobes (energy leakage) increases. In contrast, the Blackman window and its modification, the Blackman-Harris window, provide a reduced level of side lobes, but with increased blurring of the central peak. The rectangular window allows you to get a more accurate estimate of the amplitudes than the Hanna window, but at the same time it does not allow you to distinguish weak signals in the vicinity of a powerful frequency peak. The rectangular window gives the broadest peak with side lobes like the Hanna window, but the smooth top of the peak allows the most accurate determination of the relationship between the amplitudes as the frequency changes. By smoothing sampling errors, window functions also improve the spectral representation of non-stationary signals (for example, cascade spectrum). A rectangular window that preserves the most accurate relationship between the amplitudes of different harmonic signals can be used in calibration procedures.

Currently existing techniques for analyzing oscillations (namely, such oscillations occur when the probe is advanced in the wound channel) are usually based on the use of various methods of filtering the analogue received signal.

These methods are hardware-implemented by virtual instruments (Virtual Instrumentation), [14] the most famous of which are LabVIEW by National Instruments (USA) and DASYLab by DATALOG GmbH (Germany).

The great practical value of DASYLab is the possibility of using a sound card for input/output of analog signals (with some limitations on the sample rate) and a parallel PC port for digital input/output of a personal computer. This function is performed by a special driver available in the system, which provides real-time operation. This feature of DASYLab allows you to obtain extremely cheap solutions for a wide range of measurement and testing tasks from the point of view of hardware costs.

The input signal in the form of time realization is transformed into low- or high-resolution spectra using the fast Fourier transform procedure and two filtering techniques. To obtain a spectrum of low resolution, the first twenty blocks of data are cut off and filtered by a flat-top (rectangular) window (Flat top window). At the same time, the filtered signal corresponds to the primary one in terms of amplitude.

A Hann window is used to obtain a high-resolution spectrum. At the same time, the frequencies are determined more precisely.

The low-resolution spectrum is used for initial signal analysis and detection of bands with high vibration intensity, while the high-resolution spectrum is used to determine the frequencies more accurately with the highest amplitudes in these bands.

Signal processing was performed in the DASYLab software environment, which allows you to quickly build a circuit for digital signal conversion with the help of graphic programming (Fig. 14).

In the program, the signal is loaded into the Read module, after which the signal is processed according to the following algorithm:

1. The received noise signal is sent filtered, where the largest noise effects are cut off.

2. Next, the signal passes through a Hanna window for high-resolution spectra and for frequency refinement, and through a flat-top (rectangular) window for a low-resolution spectrum (for amplitude level refinement).

When passing through the window, according to the signal, the hardware is multiplied with the function of the window *w(n)* and filtered: $w(n) = 1$ – for a flat-top (rectangular) window; $w(n) = 0.5 - 0.5 \cdot \cos\left(\frac{2\pi n}{N-1}\right)$ – for the Hanna window. Here is the function of the window that depends on the value of the signal n, N is the value of the sample.

3. Next, the signal passes through the Fourier transform unit and the amplitude spectrum is obtained. The signal is transformed using fast Fourier transforms.

Fast Fourier transforms are a method of calculating the discrete Fourier transform for computers (the discrete transform formula has the form

$$X(f) = \sum_{n=-\infty}^{\infty} x(n) e^{-2j\pi f n T} \qquad -\frac{1}{2T} \le f \le \frac{1}{2T},$$

where is the result of transformation, frequency function (amplitude-frequency spectrum); f – reference (sampling) frequency, Hz; T – reference interval in time (sampling), s; $x(n)$ is a discrete signal of n time intervals with an interval T. Discretization allows you to divide the spectrum into time intervals, using an infinite number of which the original amplitude-frequency spectrum can be restored.

The result of signal processing is displayed on the oscilloscope window and allows the surgeon. Determine the size and position of the fragment (fig. 15).

Further research can be directed to the creation of data analysis tools based on fuzzy logic and further study of the influence of the characteristics of the fragments and their location in the patient's body on the width of the noise emission band.

So, we proved that the noise emission that occurs during the non-static contact of a flexible, elastic probe with a foreign body in the wound channel, and which is characterized by the amplitude and width of the spectrum at certain resonant frequencies, can serve as a reliable signal for determining the presence of a foreign object in the wound. The width of the noise emission frequency spectrum reliably determines the type of foreign object (glass, plastic, etc.).

An innovative tool for inspecting wound canals is offered, consisting of a flexible probe for individual use and a holder handle with a microphone capsule, the membrane of which is directly connected to the probe and reacts

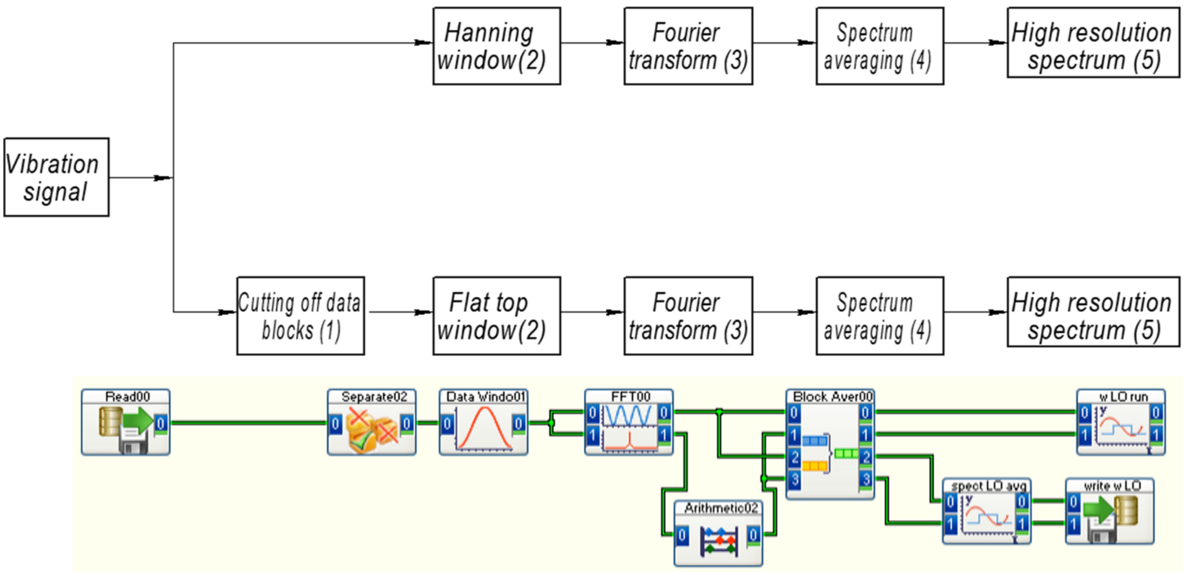
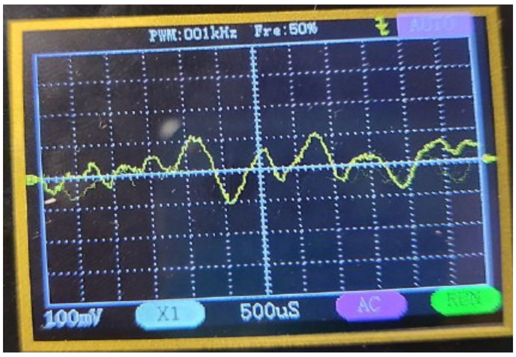


Fig. 14. Schematic diagram of the converter in the DASYLab program: *a*) block diagram of obtaining spectra of different resolutions; *b*) an example of the implementation of signal conversion into a low-resolution spectrum



a

b

Fig. 15. Graphs obtained because of the experiment: *a*) area of tissue, *b*) place with a fragment

to mechanical contact with an obstacle, and the capsule itself is directly connected to an oscilloscope through a signal amplifier, which has chains of spectral signal processing.

Conclusion

Thus, it was established for the first time that the noise emission that occurs during the non-static contact of a flexible spring probe with an external body in the wound channel, characterized by an amplitude and spectrum width at high resonant frequencies, can serve as a reliable signal for detecting the presence of a foreign object in the wound. The width of the frequency spectrum of the emitted noise reliably indicates the type of foreign object (solid, plastic, etc.). An innovative tool for inspecting wound canals has been developed, consisting of a specially designed probe and a three-stroke handle with a microphone capsule, the membrane of which is directly connected to the probe and reacts to mechanical contact and disturbances. y, and the capsule itself, through signal amplification, is directly connected to an oscilloscope, which can perform spectral processing of the signal.

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Можливість виявлення нерентгенконтрастних фрагментів в тілі пораненого контактним методом

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Анотація. *Проаналізовано види поранень та види уражаючих елементів, оцінено стани пацієнтів, що потребують термінового хірургічного втручання. Проаналізовано можливості існуючих засобів діагностики осколків у тілі пацієнта, зроблено висновок, що для нерентгенконтрастних осколків пропонований метод механічного контакту із спеціальним гнучким та пружним зондом є доцільним і дієвим.*

Розроблено спеціальний інструмент для огляду ранових каналів, що складається з гнучкого зонда індивідуального використання та ручки-тримача з мікрофонним капсулем, мембрана якого безпосередньо з'єднана з зондом і реагує на механічний контакт з перешкодою, а також Сам капсуль безпосередньо підключений до осцилографа через підсилювач сигналу. який має спектральні ланцюги обробки сигналу.

Поставлено задачу взаємодії пружного контакту нежорсткого елементу із осколком, що знаходиться у в'язкому середовищі за умови, що властивості середовища не є сталими. Наведені типові розв'язки такої задачі для різних видів осколків та параметрів самого контактуючого елемента. Показано картину шумової емісії, що супроводжує контакт.

Виявлено функціональну обумовленість параметрів шумової емісії від форми та виду стороннього предмета в рановому каналі. Доведено доцільність використання частотно-амплітудної характеристики шумового випромінювання як контрольованого параметра. Зроблено висновок про функціональну обумовленість ширини спектру сигналу та базових частот в момент механічного контакту зі стороннім предметом у рані, від його форми та типу; встановлено, що використання осцилографа з каналом спектрального аналізу дозволяє досить точно ідентифікувати нерентгеноконтрастний сторонній предмет у рані.

Ключові слова: *спеціальний інструмент діагностики, шумове випромінювання, рана, нерадіоконтрастний сторонній предмет.*