FURTHER IMPROVEMENTS OF THE SHOCK-WAVE CONTROL EQUIPMENT
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НАПРЯМКИ ВДОСКОНАЛЕННЯ АПАРАТУРИ УДАРНО-ХВИЛЬОВОГО КОНТРОЛЮ
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ВАРИАНТЫ УСОВЕРШЕНСТВОВАНИЯ АППАРАТУРЫ УДАРНО-ВОЛНОВОГО КОНТРОЛЯ
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Abstract. The equipment for operational non-destructive testing by the shock-wave method developed by the Institute for Geotechnical Mechanics under the National Academy of Sciences of Ukraine, was successfully tested in mine conditions and confirmed the results of theoretical and experimental studies on the possibility of using the relaxation time of free oscillations of a metal-polymer anchor to assess the quality of its fastening. At the same time, some drawbacks of the equipment were identified, which can be eliminated by improving both the data processing unit and the sensor part. The areas of improvements, considered in this work, will improve the stability, speed, mobility and ergonomics of the equipment.

It is possible to improve the data processing unit by implementing modern 32/64 bit ARM microprocessors with higher computing power and with greater variability of circuitry solutions. It is possible to develop a new circuit based on these microprocessors or to use available mini-solutions based on the ARM core. It will also improve the oscillator-receiver unit, potentially making it completely wireless. For both options, it will be necessary to develop software, which, due to the increased computing power, can be improved with additional algorithms for data processing. The increased speed and a larger number of I/O ports will also allow transferring the functionality of the analog part to the ARM microprocessor, which, in turn, will reduce the board size, and the freed space can be occupied by additional batteries to increase the battery life.

The introduction of ARM microprocessors will also allow, thanks to a large number of libraries and circuits for wireless data transmission, the development of anchor vibration sensor with Wi-Fi/Bluetooth data transmission to the processing unit, which, in turn, will increase mobility and ease of use. For maximum ergonomics, it is possible to develop a combined design with an automatic stabilized hammer and oscillation sensor.

Keywords: anchor, shock wave method, non-destructive control, geophysical equipment.

Introduction. In the research process to find ways of non-destructive control of anchors fastening, equipment based on the use of the shock wave method was developed. The equipment received name KVAK (complex vibroacoustic control).

Several equipment variants were developed, each with a different functionality. The first version of the equipment, KVAK-1 (Fig. 1), was rather an experimental sample of mobile non-destructive testing equipment in order to confirm the results of theoretical and laboratory studies. Tests of the equipment in mine conditions confirmed the possibility of using the shock wave method and the damping time of anchor oscillations to control the quality of anchor fastening, but also revealed a number of design drawbacks of the equipment, such as insufficient electrical shielding, large data scatter, liquid crystal display artifacts, no solutions to ensure the possibility of working in a spark-explosive environment.
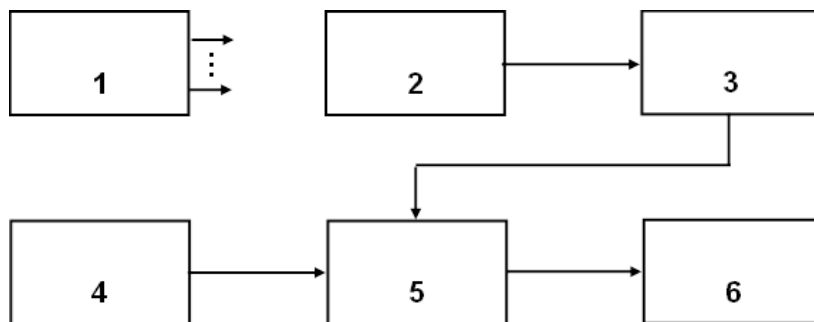
Figure 1 - Set of experimental equipment KVAK-1

These drawbacks were eliminated in the next version of the equipment, which was named KVAK-2 (Fig. 2). The electrical schematic of the equipment was significantly changed to ensure greater explosion safety [1]. The block diagram of the KVAK-2 equipment is presented in fig. 3.

Figure 2 - Set of vibroacoustic equipment KVAK-2

1 - power supply, 2 - sensor, 3 - analog signal processing unit, 4 - frequency grid shaper, 5 - cycle control unit, 6 - display unit

Figure 3 - Block diagram of KVAK-2 equipment

Further improvement of shock wave control equipment was based on the use of microprocessor electronics and modern passive SMD elements.

The next version of the equipment, KVAK-4 (Fig. 4), received as a central element of data processing 8-bit microprocessor ATMEL ATMega 32A. The use of this microprocessor expanded the functionality of the equipment and at the same time reduced the size of the board, the physical size of the unit, battery consumption and increased shielding and protection from dust and moisture. The equipment calculates and displays not only the value of the informative parameter, but also, due to the capabilities of the programmable microprocessor, statistical processing of data is performed directly at the place of research [2]. Implementation of the bigger LCD screen with UI programming capabilities displays not only an informative parameter, but also additional values, such as battery level, intermediate values of statistical processing, etc.

Figure 4 – KVAK-4 control equipment

Although the use of the 8-bit microprocessor expanded the capabilities of non-destructive shock wave control equipment, the results of tests of KVAK-4 equipment in mine conditions revealed further opportunities for improving the equipment. In particular, the following drawbacks were identified:

- LCD artifacts;

- with frequent strikes on the anchor it is possible to impose oscillations from the previous strike, which leads to the summation of the values of the relaxation time;

- difficulties of controlling the anchors, that are fixed at a considerable distance from the place of measurement, in particular in the mine roof.

These drawbacks can be eliminated by improving the data processing unit and methods and means of registration of the damping oscillations of the anchor.

Ways for improvement. Data processing unit can be improved by two possible ways. The first option is similar to the solution that was used in the development of KVAK-4, namely in the use of only a programmable processor with the subsequent development of the circuit part. The second option is to use ready-made solutions, which are much more common for 32-bit and 64-bit microprocessors.

As it is mentioned above, the KVAK-4 hardware uses the Atmel 8-bit ATMega32A microprocessor. This microprocessor has a Harvard architecture (program and data are located in different address spaces) and a command system close to the ideology of RISC (Reduced Instruction Set Computing - calculation with a reduced set of instructions), or, according to the manufacturer, an Enhanced RISC Architecture [3]. It has 32 KB of Flash memory, 2 KB of SRAM and 1 KB of EEPROM (non-volatile permanent memory). The maximum clock frequency of this microcontroller, at using an external quartz clock, is 16 MHz's. In the absence of an external generator, it is possible to use an internal RC-generator with a maximum theoretical frequency of 8 MHz, but the real frequency of this generator, due to the peculiarities of the microprocessor, is much lower [4].

Today, almost every electronic device uses 32- and 64-bit ARM microprocessors (Advanced RISC Machine) as a central control unit. Compared to the Harvard 8-bit microprocessors, they have higher maximum clock speeds, better power savings and larger data storage. So, if for the ATMega 32A microcontroller the maximum clock frequency is 16 MHz, RAM is 2 KB, and the data storage, including the program, is 32 KB of memory, the ARM microprocessors are multi-core, with a maximum clock speed in a gigahertz range, the amount of RAM and permanent memory reaches hundreds of KB without taking into account the possibility of connecting additional external storage.

An interesting addition to the ARM kernel design is the use of a 4-bit circumstance code at the beginning of each instruction, which means that the execution of each instruction is conditionally optional. Other CPU architectures typically have circumstance code like branch instructions.

This significantly reduces the encoding of the bit suitable for moving the instruction to the available memory; but on the other hand, it avoids branching instructions when generating code for small *if* statements [5].

Let's compare the characteristics of microprocessors of the same value: ATMega 32A and LM3S5R31-IQC80-C1 [6] (Fig. 5). Their comparative characteristics are presented in table. 1.

Table 1 – Comparative characteristics of ATMega 32A and LM3S5R31-IQC80-C1

	AVR Atmel ATMega 32A	ARM LM3S5R31-IQC80-C1
Bitrate, bit	8	32
Clock frequency, MHz	16	80
RAM, kB	2	48 x8
ROM, kB	32	256 (256 x 8)
I/O ports	32	67
Timer/counter	2 8-bit, 1 16-bit	2 16-bit / 1 32-bit
ADC	8-channel 10-bit	16-channel 10-bit
Interfaces	TWSI, UART/USART, SPI	I²C, IrDA, Microwire, UART/USART, SPI, SSI, USB
Supply voltage	2,7 V ~ 5,5 V	1.08 V ~ 1.32 V
Temperature range	-40°C ~ 85°C	-40°C ~ 85°C

Figure 5 – 32-bit ARM microprocessor LM3S5R31-IQC80-C1

Also, the increased speed and functionality will allow ARM microprocessor to take over analog part functionality of KVAK-4 [7]. The improved equipment will be smaller, lighter and more productive. The freed space can be allocated for additional batteries to increase the autonomy of the equipment, which in combination with the reduced consumption of the microprocessor will give higher operational time then the KVAK-4. The block diagram can take the form presented in fig. 6.
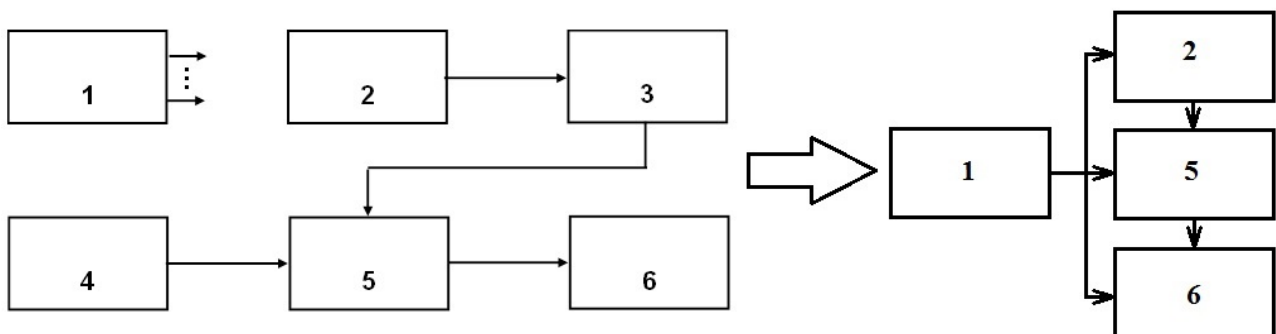
1 - power supply, 2 - sensor, 3 - analog signal processing unit, 4 - frequency grid shaper, 5 - cycle control unit, 6 - display unit

Figure 6 – Block diagram of KVAK-2 equipment and block diagram of further possible improvement

However, the use of ARM microprocessors also requires the development of software adapted for this microprocessor. It is possible to use the same programming language, C / C ++, but the machine code will be different, which in turn requires the use of another software package to compile the code.

Another significant advantage of the ARM microprocessor is the ability to program it when connected via USB, unlike the AVR, which required the purchase of an additional special programmer for hardware programming.

The Proteus software package, which used for emulating hardware and test program code, is also suitable for similar tasks for ARM microprocessors.

The use of 16-bit microprocessors is also possible, but at a cost close to 32-bit microprocessors, the speed of such microcontrollers is between 8-bit and 32-bit, their use seems inefficient.

Another promising, but more expensive, way to improve the digital data processing unit is to use ready-made solutions, so-called mini-computers, or single-board computers, for example, the Raspberry Pi [Fig. 7].
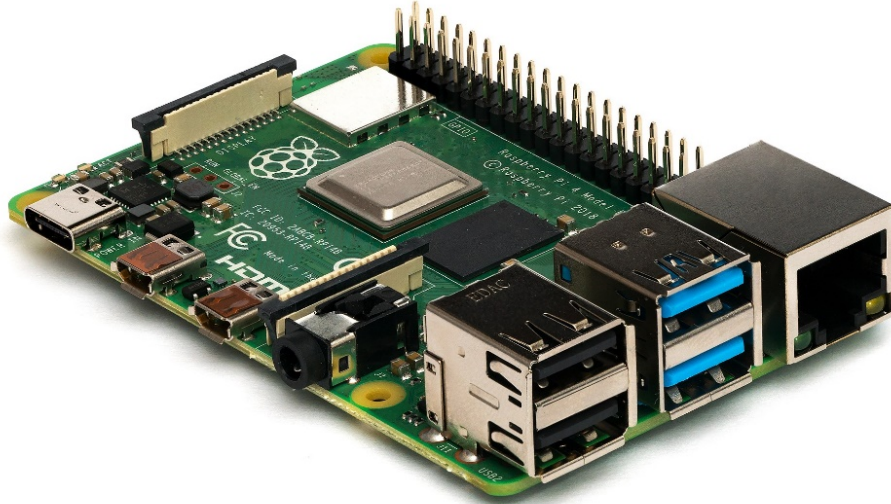

Figure 7 – Raspberry Pi single board mini-computer

The Raspberry Pi is a series of small single-board computers (SBCs) developed in the United Kingdom by the Raspberry Pi Foundation in association with Broadcom. The original model became more popular than anticipated, selling outside its target market for uses such as robotics. It is widely used in many areas, such as for weather monitoring, because of its low cost, modularity, and open design. The Raspberry Pi hardware has evolved through several versions that feature variations in the type of the central processing unit, amount of memory capacity, networking support, and peripheral-device support.

At the time of writing, the latest model of the Raspberry Pi is version 4 and its variants.

The Raspberry Pi 4B model was presented on June 23, 2019. Despite the preserved dimensions of the previous series (85.6 mm × 56.5 mm), the rest of the system has undergone significant changes. Among other things, the new arrangement of mounts and I/O ports makes the new series incompatible with the housings of the previous series. However, compatibility with expansion cards from the previous series is maintained.

The new series is based on the BCM2711 chip system (SoC) which uses a quad-core 1.5GHz ARM Cortex-A72 processor with a clock speed of 1.5 GHz, manufactured with using a 28 nm tech process.

This microprocessor supports the standard ARM GIC (Generic Interrupt Controller), which significantly speeds up the operation of virtualization systems. Wi-Fi support remains at the level of the 802.11ac standard, but unlike the previous series, Bluetooth version 5.0 support is added.

The fourth series is available in three RAM configurations: 1, 2, and 4 GB of LPDDR4 standard RAM. In June 2020, a model with 8 GB of RAM was released.

Unlike the previous series, the Gigabit Ethernet network adapter now runs at full bandwidth, and is not limited to the 300 Mbps USB 2.0 gateway in the third series.

Like the previous series, the Raspberry Pi 4B supports Ethernet (PoE) power technology with an optional expansion card.

Instead of one HDMI port, the new series has two micro-HDMI ports. It is able to output HDMI 2.0 4K @ 60 Hz signal to one monitor, or 4K @ 30 Hz to two monitors, play 4K video. Thanks to the system's existing VideoCore 6 accelerator, the new computer will be able to play H.265 and 4K @ 60 frames per second video.

The system is powered by the USB Type-C port.

The Raspberry Pi runs mainly on operating systems based on the Linux kernel. The Raspberry Pi Foundation provides the Raspberry Pi OS (formerly called the Raspbian), a Debian-based (32-bit) Linux distribution for download, as well as third-party Ubuntu, Windows 10 IoT Core, RISC OS, LibreELEC (specialised media centre distribution) and specialised distributions for the Kodi media centre and classroom management [8]. It promotes Python and Scratch as the main programming languages, with support for many other languages. The default firmware is closed source, while unofficial open source is available. Various operating systems for the Raspberry Pi can be installed on a MicroSD, MiniSD or SD card, depending on the board and available adapters.

Also, unofficial operating systems include such flexible systems as FreeBSD, OpenWrt and even Android. The NOOBS tool is used for installing the operating system.

Another convenience of the Raspberry Pi is the ability to program via a regular USB and SD-card connection, without the need to use a special programmer.

The use of Linux-based operating systems and, with some limitations, Windows, makes it possible to install specialized programs (such as spectrum analyzers) to process data directly at the site of the experiment.

In this case, to use the same display as in KVAK-4, would be irrational. For normal, comfortable work with the equipment a display with a diagonal of at least 3.5 " and a resolution of 320x480 pixels is required (Fig. 8).


Figure 8 – 3.5" 320x480 pixels display module based on the ILI9481 controller

Although the Raspberry Pi-based solution has advantages in computing power, usability and areas for further improvement, it also has a significant drawback - the cost of the Raspberry Pi 4B, display module and accessories can exceed $ 200.

In addition to the data processing unit, the equipment and methods of obtaining data of the anchor oscillating process also need further improvement.

In the KVAK-4 equipment, two variants of sensors and a special oscillator are used for registering the anchor oscillations (Fig. 9).
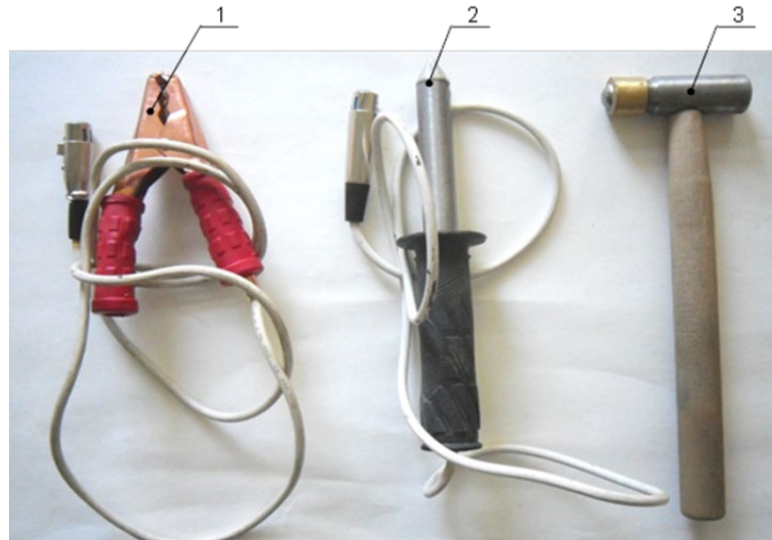
1 - cap sensor to register the vibration of the anchor; 2 - contact sensor for vibration detection of arbitrary structures; 3 – hammer with a stabilized impact force

Figure 9 – KVAK equipment components

Obtaining data on the condition of the anchor involves the following sequence of actions. If possible, install a cap sensor on the free end of the anchor, otherwise, use a clamping conical sensor. The corresponding sensor is connected by a cable to the input of the electronic unit. Applying periodic strikes to the end of the anchor with a special hammer, record the corresponding values of the informative parameter. In the latest version of the KVAK-4 equipment there is an automatic rejection of anomalous data from the sample and statistical processing of the sample array for this control point.

The short cable connection restricts the freedom of action of the operator, complicates the control due to the need to keep the processing unit, the sensor and the oscillator, especially when monitoring the condition of the anchor in the upper part of the working. Certain inconveniences are also associated with the need for the operator to strike a large number of strikes, preferably of with the same force, on the end of the anchor, which in the case of mass control is a heavy task.

These shortcomings can be corrected in two ways:

- the sensor is fixed on the free part of the anchor, is connected by a cable to the data processing unit, the oscillations are excited by an automated exciter, without the participation of the operator;

- the sensor is attached to the free part of the anchor, is connected to the data processing unit wirelessly via Bluetooth or Wi-Fi, vibrations are excited by an automated exciter, without the participation of the operator.

The second option, together with the use of the Raspberry Pi 4B mini-computer with built-in support for Bluetooth and Wi-Fi protocols, gives non-destructive shock wave control equipment flexible computing capabilities, maximum mobility and ease of use.

The main inconvenience of working with KVAK-4 equipment and high load on the operator is the application of a series of consecutive strikes with a given time interval, so as not to impose oscillations at too frequent strikes, and control the impact force to average it, for more stable results.

Development of the oscillator with automatic strikes will eliminate this drawbacks and increase the convenience of working with the equipment.

The development of such device depends on the possibility of using wireless data transmission methods in mine conditions. If Wi-Fi and Bluetooth data transmission protocols work smoothly, with sufficient reliability and integrity of the transmitted information, when located next to the functioning mine equipment, it will bring the ergonomics of non-destructive mine control equipment to a new level, compared to previous developments. The possibility of using wireless data transmission needs further research.

Automatic strikes to excite the anchor oscillations can be implemented using programmable electric motors, which themselves would strike and return the hammer to its original position. Control of this device can be transferred to the data processing unit. To do this, additional button on the front panel needs to be added and a motor control algorithm, that would release the hammer, force it to strike, and return to its original position and have a time delay to dampen the current oscillations before the next strike, needs to be developed. Also, for more efficient use of the equipment, it is proposed to display a message about the readiness the next impact.

Conclusions. The possible directions of further improvement of the non-destructive shock-wave control equipment were considered.

It was established, that the data processing unit as well as the exciter and receiver of the anchor oscillations need to be improved. The data processing unit can be improved if more efficient ARM microprocessors are used as the basis of the computing node. This can be done in two ways: by developing a new circuit based on the ARM microprocessor, or by using ready-made multifunctional solutions based on the ARM core. It will also improve the oscillator-receiver unit, potentially making it completely wireless.

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Анотація. Розроблена в ІГТМ НАН України апаратура оперативного неруйнівного контролю ударно-хвильовим методом пройшла успішні випробування в шахтних умовах, підтвердивши результати теоретичних та експериментальних досліджень про можливість використання часу релаксації вільних коливань металополімерного анкера для оцінки якості його закріплення. Водночас, були виявлені де-які недоліки роботи апаратури, усунути які можливо при вдосконаленні як блока обробки даних, так і сенсорної частини. Розглянуті в роботі напрямки вдосконалення дозволять підвищити стабільність, швидкодію, мобільність і ергономічність апаратури.

Покращити блок обробки даних можливо шляхом імплементації більш сучасних 32/64 бітних ARM мікропроцесорів з більшою швидкодією та більшою варіативністю схемотехнічних рішень. Можлива як розробка нової схеми, що заснована на зазначених мікропроцесорах, так і використання серійних міні-рішень. Для обох варіантів буде потрібна розробка програмного забезпечення, в яке, за рахунок підвищеної обчислювальної

здатності, можливе впровадження додаткових алгоритмів обробки та видачі даних. Збільшена швидкодія та більша кількість портів вводу-виводу також дозволить перекласти на ARM мікропроцесор частину функціоналу аналогової частини, що, в свою чергу, знизить розміри плати, а звільнений простір можливо зайняти акумуляторами більшої ємності, для збільшення часу автономної роботи апаратури.

Впровадження ARM мікропроцесорів також дозволить, завдяки великій кількості бібліотек та схем для бездротової передачі даних, розробку датчика коливань анкера з Wi-Fi/Bluetooth передачею даних до блока обробки, що в свою чергу збільшить мобільність та зручність роботи з апаратурою. Для максимальної ергономічності, можлива розробка комбінованої конструкції з автоматичним стабілізованим збудником та датчиком коливань.

Ключові слова: анкер, ударно-хвильовий метод, неруйнівний контроль, геофізичне обладнання.

Аннотация. Разработанная в ИГТМ НАН Украины аппаратура оперативного неразрушающего контроля ударно-волновым методом прошла успешные испытания в шахтных условиях, подтвердив результаты теоретических и экспериментальных исследований о возможности использования времени релаксации свободных колебаний металлополимерного анкера для оценки качества его закрепления. В то же время, были обнаружены недостатки работы аппаратуры, устранить которые возможно при совершенствовании, как блока обработки данных, так и сенсорной части. Рассмотренные в работе направления совершенствования позволят повысить стабильность, быстродействие, мобильность и эргономичность аппаратуры.

Улучшить блок обработки данных возможно путем внедрения более современных 32/64 битных ARM процессоров с большим быстродействием и большей вариативностью схемотехнических решений. Возможна как разработка новой схемы, основанной на указанных процессорах, так и использования серийных мини-решений. Для обоих вариантов потребуется разработка программного обеспечения, в которое за счет повышенной вычислительной способности, возможно внедрение дополнительных алгоритмов обработки и выдачи данных. Увеличено быстродействие и большее количество портов ввода-вывода также позволит перевести на ARM микропроцессор часть функционала аналоговой части, что, в свою очередь, снизит размеры платы, а освобожденное пространство можно занять дополнительными аккумуляторами, для увеличения времени автономной работы аппаратуры.

Внедрение ARM процессоров также позволит, благодаря большому количеству библиотек и схем для беспроводной передачи данных, разработку датчика колебаний анкера с Wi-Fi / Bluetooth передачей данных в блок обработки, что, в свою очередь, увеличит мобильность и удобство работы с аппаратурой. Для максимальной эргономичности, возможна разработка комбинированной конструкции с автоматическим стабилизированным возбудителем и датчиком колебаний.

Ключевые слова: анкер, ударно-волновой метод, неразрушающий контроль, геофизическая аппаратура.