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RELIABILITY, STRENGTH, AND WEAR RESISTANCE OF MACHINES AND STRUCTURES

Bionics of Spiral Structures

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Abstract—This paper is devoted to the bionic aspects of machine science associated with spiral structures and processes in the human body and other living organisms, the capabilities of spiral bionic devices including spiral hydrowave stimulators, and the hemowave concept of the nonmuscular vibroactuator for the blood flow based on wave forces in vibration of blood proteins in their cyclic conformational changes.

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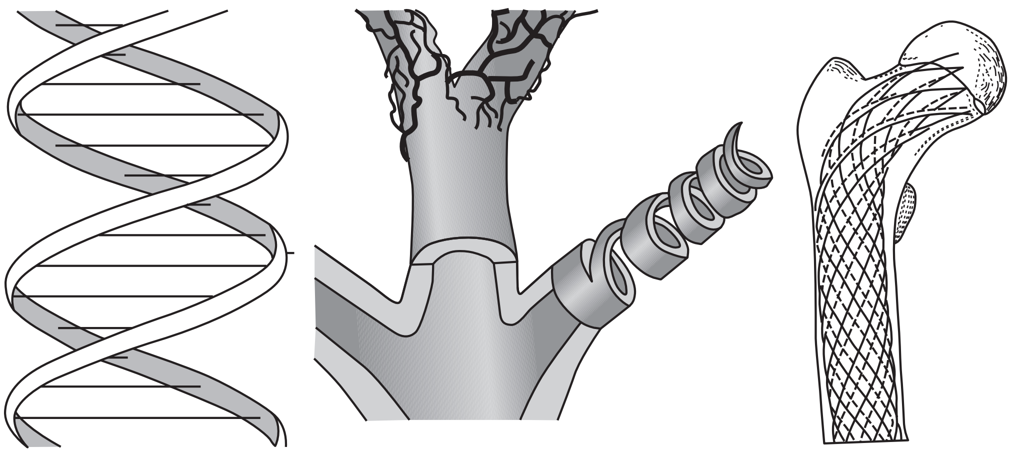
Much attention has been paid for a long time to the human operator as a control link in problems of the reliability of human–machine systems. A characteristic feature of our time is the fact that almost all the organs of the human body can be replaced with prosthetics (heart, bones, upper and lower limbs, liver, kidneys, organs of hearing and vision, etc.), and computer chips can be implanted in the human body. Thus, the average person is becoming more and more a human-machine system (cyborg). Accordingly, design engineers need to increase their knowledge of the fundamental features of biomechanical systems.

In this paper, we present data on the use of the achievements of nonlinear wave mechanics [1, 2] in modeling and understanding of some fundamental features of living matter including the spiral organization of living bodies and processes in them. In this case, special attention is paid to the research of physiotherapeutic hydrowave stimulators based on spiral vacuum pressing jets.

Goethe even called spirals "symbols of life" because of multiple implementations of inherited spiral structures and processes in living bodies at various lines and levels of biological evolution. In the human body spiral structures genetically inherited from one generation to another are presented in the muscles, heart, blood vessels, bones, nerves, organ of hearing (the cochlea), cellular organization of the embryo (zygote), etc. (Fig. 1). The structure of tendons and ligaments consists of spirals, which in turn are com-
1 posed of collagen that has a triple spiral structure. Spiral motions (nutation) are observed during the
growth of roots and shoots, tendrils of plants are spirally wrapped, tissue in the trunks of trees grows spi-



(a) (b) (c)

Fig. 1. Examples of spiral bioconstructions: the DNA double spiral (a), the spiral laying of muscles in the walls of arteries (b), and spiral composite bone tissue (c).

rally, etc. Because of spiral bioconfigurations all the fluids in the body (blood, lymph, and urine) are spiral. The title of a book about biospirals, *Lines of Life* [3] reflects their importance for living matter.

Contemporary cardiology emphasizes the spiral organization of the heart, particularly in connection with the problem of heart failure and use of pacemakers [4]. The heart is formed by one muscle twisted into a spiral. It makes it possible to increase the contractive force of myocardial fibers in order to provide blood flow (similar to the twisting of wet laundry by a laundress to remove water). The spiral-twisting principle is repeated in all levels of the macro- and microstructure of the heart. In addition to providing a sufficient contraction force, this twist is intended to subordinate all of the heart compartments to a specific contraction sequence. All this is important, in particular, for understanding why sometimes the change in position of the pacemaker by 1–2 cm creates a completely different effect on the contractile function of the myocardium, sometimes almost an opposite effect, and the passage of the pulse from the pacemaker to the myocardium increases by 10–12 times. Spiral waves in the heart cause arrhythmias. The account for the spiral nature of blood flow leads to new technologies of surgeries that do not violate this blood flow. It also makes it possible to specify requirements for prosthetic heart valves and blood vessels in order to avoid chaotic turbulent blood flow that leads to thrombosis [5].

A spiral organization principle is observed at both the level of individual muscles and the entire muscular system, in which the muscles are functionally gathered into groups of muscle spirals, for example, for a coordinated operation of the body and limbs due to muscle spirals that pass from one side ~~to the other~~ of the body to another and join the right and left halves of the body. Accounting for biospirality made it possible to put the motion correction suit "Spiral" into use for cerebral palsy patients [6].

Here are some examples of engineering use of biospirals as patents of wildlife. Spiral motion principles are used by many bacteria, which move in the environment using long spiral flagella that rotate at high speed in different modes, and allow bacteria to carry out linear motion, somersaults, and twists. In Switzerland, this patent was transferred from wildlife to the technique of medical spiral microrobots that are put into the patient's body and move using artificial flagella in the form of spiral ribbons under the control of a magnetic field [7].

Spiral DNA genetic molecules are used to develop molecular DNA computers in order to use them inside the body to control the metered release of drugs, etc. [8]. Patented vascular cannula with a working part in the form of a spiral similar to the spiral structure of the muscular lining of arteries allows the optimization of microcirculation and transcapillary exchange [9]. The artificial heart was patented based on the discovery of the spiral blood motion [10]. Often, in natural materials, including polymeric materials, the self-generation of spiral structures is caused by the soliton and domain forming processes [11, 12]. Given this knowledge, the authors develop the concept of artificial muscles based on spiraled polymeric filaments.

Spirals in living matter are quite different from spirals in inanimate nature: (1) they are genetically inherited in the chain of generations and are associated with structures of a molecular and genetic system that is full of spirals and superspirals at different levels of its organization, from DNA to chromosomes, and (2) characteristics of biological spirals are associated with Fibonacci numbers at different levels and branches of the biological evolution, from alpha-peptides to the structure of the integral bodies of plants and animals, which is reflected in the famous biomathematical "laws of phyllotaxis (leaf arrangement)," to which thousands of publications have been devoted worldwide [13, 14].

Hydrowave stimulators of physiological functions (or, briefly, hydromassagers) are promising for physiotherapeutic application. They generate vacuum-press spiral jets for physiotherapy (see patents [15, 16]). These stimulators are currently being investigated at the Institute for Machine Science of the Russian Academy of Sciences (IMASH RAS) and at the Research Center for Nonlinear Wave Mechanics and Technology RAS together with physicians from the Federal Research and Clinical Center for Specialized Types of Medical Care and Medical Technology of the Federal Medical–Biological Agency. This type of spiral hydro impacts combines several types of impacts that have long been individually used in physiotherapy because of their efficiency. Firstly, the idea of the special value of spiral massage came to modern massage textbooks from works of ancient China and Taoist sages. According to them, spiral massage movements strengthen vitality, because they are associated with inherited spiral processes and structures.

Secondly, vacuum impacts have long been used in different branches of medicine (general surgery, dentistry, ophthalmology, gynecology, etc.) to intensify blood and lymph flows of the body, the resorption of inflammation, ease of administration of medicinal compounds, and treatment of wounds (the method of outer vacuum aspiration of the well-known Russian surgeon N.I. Pirogov), etc. [17–19]. A well-known example is medical vacuum cans, which have been used since ancient times to treat colds and many other health problems.

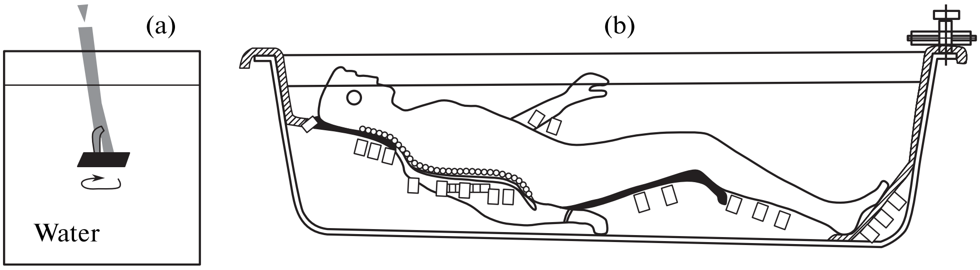


Fig. 2. The illustration of the spiral-vacuum nature of jets of the hydromassager that attracts a light table and makes it rotate at the same time (a). Diagram of a person taking a bath session of hydrowave stimulation on a mat consisting of many hydrowave nozzles (from [22]) (b).

Thirdly, it is known that vibrating massage in the following frequency bands of vibration has the greatest therapeutic effect: low, 10–50 Hz, average, 100–300 Hz, and high, from 1000 Hz [20, 21]. The hydromassagers mentioned above operate in average frequency bands.

Fourthly, hydromassage relates to the field of hydrotherapy, one of the oldest in medicine, in which generations of physicians developed many water-based medicinal compositions (soda, radon, bromine, carbon dioxide, hydrogen sulfide, etc.), which are also used in these hydromassagers. According to evolutionary theory, living organisms came to the land from the water. Therefore, in water the human body passes into a special physiological condition, the features of which depend on the composition of water and present physical and chemical factors. In particular, in this state, characteristics of skin change, including skin permeability to the penetration of drugs into the body. In contrast to all other primates, human skin has a number of unique features including the absence of a a developed hair covering, sweat glands throughout the body, and openness of the skin to environmental factors, including wave and vibration factors.

When connected to a hose with water pressure of 2 atm or more and immersed into a bath (or other container with water), the described hydromassager forms spiral water jets that have a vacuum pressing effect on human skin (Fig. 2). This is achieved by special channels in this stimulator and interaction between individual jets when they are combined into a common final jet. The vacuum is created periodically with a frequency of 100–300 Hz because of the discontinuity in the center of the outgoing jet and the formation of a steam–air mixture. If a light tablet is brought to the exit area of such a hydromessager dropped into the water along with the exiting jet, it will be attracted to this section and will be rotated around the axis of the nozzle (Fig. 2a), which further illustrates the spiral nature of the exiting jet. Owing to these properties, these hydromassagers are fundamentally different from traditional hydromassaging devices certified by the Ministry of Health, which use a water jet to provide varying pressure fluctuating around the value of the atmospheric pressure without creating a vacuum phase (suction or negative pressure). Currently, there are no certified devices with such functional properties in Russia. With proper medical certification, such hydromassagers can be used in spas and at home in the form of attachments for shower hoses. There are potential applications of these stimulators in physical therapy, since they can be applied as single nozzles and as sets of nozzles incorporated with the bath mat (Fig. 1).

Furthermore, they can be used for many types of physical therapy and cosmetology, for example, for the use of jets with their unique structure to the back, limbs, and face (general baths, baths for feet, hands, face, etc.). According to preliminary data, these hydromassagers have provided a pronounced therapeutic effect in a number of studied cases. In particular, they are promising for rehabilitation processes in a wide range of diseases of bronchopulmonary, digestive, and urogenital systems, asthenic–vegetative and psychosomatic manifestations, sports medicine and traumatology. The relevance of these hydrowave stimulators is also determined by the fact that at present the Russian market of hydrotherapy devices is filled with foreign products. The Russian Government indicates the need to change this abnormal situation through the development and mass production of domestic appliances certified for hydrotherapy.

Nonlinear wave mechanics [1, 2] has meaningful results, which in particular can assist in the modeling of a number of biomechanical and physiological phenomena and development of new medical devices. Here are some examples.

In the study of the problems of stabilization of fluid motion in cylindrical tubes with a flexible coating, it was found that in such systems self-excited waves are accompanied by the occurrence of one-sided spiral flows [1, p. 504]. These flows can have axial velocity components with different directions in near-axial and near-wall areas as well as azimuthal components. These results are associated to the above known phenomena of the spirality of flows of body fluids (blood, lymph, etc.) in elastic channels of a living organism. In this case, the spiral organization of the elements of biological channels can be interpreted as one facilitating spiral flows of body fluids, and therefore is supported by the mechanisms of natural selection in the transmission through the chain of generations of organisms.

Another example. It is known that blood is a multiphase medium that consists of many types of formed elements (erythrocytes, platelets, etc.) along with blood plasma. One problem is the understanding of the biomechanics of how, what, and by what forces blood is delivered to the living tissues to supply them with oxygen and other components through a huge network of capillaries (their average size is 5–10 microns, and the number in the human body is estimated to be 160 billion). In studies of the efficient conversion of energy of oscillations and waves into the energy of powerful one-sided flows of liquid phases in multiphase systems, the occurrence of additional filtration flows in porous media was found (with pore sizes of 1–10 mm). These can occur when creating additional pressure differences of the order of 10–100 atm/m. The increased dissolution of oxygen and other gases from the gas microbubbles in these wave conditions was also revealed. It should be investigated how this knowledge can help in understanding of phenomena of capillary blood flow networks and oxygen supply of tissues, taking into account that in the bloodstream there are vibrations and waves both from heart muscle contractions and major blood vessels and from conformational transformations of blood proteins.

Information on the vibrodynamics of multiphase media gives rise to a new hypothesis about the additional mechanism of the cardiovascular activity, which can be called the "third heart." The point at issue is the following. Existing notions of drivers of blood in the body are associated mainly with the idea of muscular propulsion: (1) the heart as a vibromuscular bag, (2) the intramuscular peripheral heart that operates because of the natural vibration of skeletal muscles that create the effect of the vibration pump distributed throughout the body [22–24].

However, the operation of the blood supply in the body contains many phenomena that are impossible or difficult to explain from the standpoint of ideas about these muscle drivers, for example: (1) the occurrence of significant local pressure drops along the blood flow including capillaries whose walls are devoid of muscle fibers, (2) the manifold increase or decrease of the volume of blood entering the vessels of an individual organ, while the blood flow in neighboring vessels remains unchanged, (3) the regional blood flow independent of the nervous system that controls muscles [25], and the selective distribution of various fractions of blood by organs [26, 27]. For example, old erythrocytes are selected in the spleen, and blood with plenty of oxygen, glucose, and young erythrocytes is directed to the brain. The pregnant uterus is filled with blood having more nutrients than the femoral artery at the same time.

However, blood is a multiphase system consisting of liquid plasma and suspended corpuscles with many protein micelles. As is known, proteins constantly vibrate because of their cyclic conformational changes including frequencies of the acoustic range [28, p. 75]. Earlier no special attention was paid to these vibrations of protein microvibrators of blood in hemodynamics. We focused on the potential importance of cooperative vibrations of blood proteins for the whole hemodynamics. The study of such multiphase media under vibration impacts on them (including microvibration impacts at nanoamplitudes) presented in [1, 2, 29] shows that in these environments there are specific power factors called *wave forces*. It is in connection with them that the energy of vibrations and waves can be efficiently converted into the energy of other, nonoscillating, forms of motion, such as translational motion. In some cases, wave forces can not only exceed by many times forces or pressure gradients generated by known conventional methods but under certain conditions radically change the pattern of motion in a multiphase system, leading to completely new phenomena and effects. For example, they can give rise to an abnormal additional pressure drop, laminarize and stabilize flows in channels and boundary layers, effectively divide and separate multiphase systems of liquid with similar densities, etc. Thus, these nonlinear mechanisms can be effectively used in biomechanics of blood circulation along with classical hydrodynamic laws of Bernoulli and Poiseuille, which have been in use for a long time. In view of this, the hemowave concept of the nonmuscular vibroactuator based on wave forces (the third heart concept) formulated in this work in addition to two muscle type hearts described at the beginning of the paper requires in-depth development. New methods of diagnosis and treatment of blood circulation are possible based on the analysis of local vibration characteristics of blood proteins, for example, by introducing nanosensors into the blood. The development of appropriate pharmacological and physical therapeutic treatments should also be based on the search for means to address violations of the cooperative vibration of molecular blood components.

REFERENCES

1. Ganiev, R.F., *Nelineinye rezonansy i katastrofy* (Nonlinear Resonance and Catastrophes), Moscow: Regular and Chaotic Dynamics, 2013.

2. Ganiev, R.F. and Ukrainskii, L.E., *Nelineinaya volnovaya mekhanika i tekhnologii. Volnovye i kolebatel'nye yavleniya v osnove vysokikh tekhnologii* (Nonlinear Wave Mechanics and Technologies. Wave and Oscillation Phenomena as a Basis of High Technologies), Moscow: Regular and Chaotic Dynamics, 2011.

3. Cook, T.A., *The Curves of Life*, London: Constable and Co, 1914.

4. Knyshov, G.V., Paradigm of heart's spiral structure: a new stage in cardiac decompensation treating, *Zdorov. Ukrainy*, 2005, no. 123. http://health-ua.com/articles/1103/html

5. Morozov, V.V., Zhdanov, A.V., and Novikova, E.A., *Implantiruemaya sistema vspomogatel'nogo krovoobrashcheniya na baze mekhatronnykh modulei* (Implanting System of Artificial Blood Circulatory on the Base of Mechatronic Modules), Vladimir: Vladimir State Univ., 2006.

6. Kozyavkin, V.I., Babadagly, M.O., Lun', G.P., et al., *Sistema intensivnoi neirofiziologicheskoi reabilitatsii* (The System of Intensive Neurophysiologic Rehabilitation), Lvov: Dizain-studiya Papuga, 2012. http://www.reha.lviv.ua/242.0html?&L=3

7. Popov, L., Spiral Robot Adopts Bacterium Swimming Manner. http://www.membrana.ru/particle/1108

8. Benenson, Ya. and Shapiro, E., Computers Made of DNA, *V Mire Nauki*, 2006, no. 9, pp. 34–41.

9. Bagaev, S.N., Zakharov, V.N., and Orlov, V.A., RF Patent 2233632, 26.12.2002.

10. Drobyshev, A.A., Itkin, G.P., Zimin, N.K., et al., RF Patent. 1803133, 23.03.1993.

11. Petukhov, S.V., *Biosolitony. Osnovy solitonnoi biologii* (Biosolitons. Foundations of Soliton Biology), Moscow: GP Kimrskaya tipografiya, 1999.

12. Kandaurova, G.S., Magnetic domains life, *Nauka Zhizn'*, 2007, no. 5, pp. 26–32.

13. Petukhov, S.V., *Biomekhanika, bionika i simmetriya* (Biomechanics, Bionics and Symmetry), Moscow: Nauka, 1981.

14. Jean, R.V., *Phyllotaxis: a Systemic Study in Plant Morphogenesis*, Cambridge: Cambridge Univ. Press, 1994.

15. Ganiev, R.F., Mufazalov, R.Sh., Zakharov, V.N, et al., RF Patent 200881, 15.031994.

16. Ganiev, R.F., Vasil'ev, R.Kh., Mufazalov, R.Sh., et al., RF Patent 2010559, 15.04.1994.

17. Davydov, K.L. and Larichev, A.B., *Vakuum-terapiya ran i ranevoi protsess* (Vacuum Therapy for Wounds and the Wound Process), Moscow: Meditsina, 1999.

18. Korobkov, A.V., Physiological changes under accelerated reduction processes by using local negative pressure, in *Tr. Otdela fiziologi sporta* (Scientific Works of Sports Physiology Department), Korobkov, A.V., Ed., Moscow, 1974.

19. Mikhailichenko, P.P., *Osnovy vakuum-terapii: teoriya i praktika* (Foundations of Vacuum Therapy: Theory and Practice), St. Petersburg: AST/SOVA, 2005.

20. Fedorov, V.L., *Vibratsionnyi massazh* (Vibration Massage), Moscow: Fizkul'tura i sport, 1970.

21. Nazarov, V.T., *Biomekhanicheskaya stimulyatsiya* (Biomechanical Stimulation), Minsk: Polymya, 1986.

22. Arinchin, N.I. and Nedvetskaya, G.D., Intramuscular peripheral heart, *Dokl. Akad. Nauk SSSR*, 1973, vol. 210, no. 1, pp. 244–246.

23. Arinchin, N.I. and Nedvetskaya, G.D., *Vnutrimyshechnoe perifericheskoe serdtse* (Intramuscular peripheral heart), Minsk: Nauka i tekhnika, 1974.

24. Nazarov, V.T., *Optimizatsiya cheloveka* (Human Optimization), Riga: Zinatne, 1997.

25. Konradi, G.P., *Regulyatsiya sosudistogo tonusa* (Vascular Tone Control), Leningrad: Nauka, 1973.

26. Harvey, W., *Anatomicheskoe issledovanie o dvizhenii serdtsa i krovi u zhivotnykh* (Anatomic Research on Heart and Blood Motion in Animals), Moscow–Leningrad: USSR Acad. Sci., 1948.

27. Chizhevskii, L.A., *Strukturnyi analiz dvizhushcheisya krovi* (Structure Analyses of Moving Blood), Moscow: USSR Acad. Sci., 1959.

28. Shnol', S.E., *Fiziko-khimicheskie faktory biologicheskoi evolyutsii* (Physicochemical Factors of Biological Evolution), Moscow: Nauka, 1989.

29. Ganiev, R.F., Problems of machine mechanics and technology. Prospects of the development of the Blagonravov Institute of Engineering Science, *J. Mach. Manuf. Reliab.*, 2010, vol. 39, no. 1, p. 1.

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SPELL: 1. nutation