370. Research of adaptability of muscle's biotronic system

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Abstract: Paper presents analysis of the optimal working mode of enclosed muscular biotronic system. Clarified, that biotronic system is self adaptive, e. g. adjusts changes of system characteristics, and it works in resonance frequency, on self stimulation mode. Presented results show that for system energy stability as its natural frequency is diminishing, the amplitudes of biosignal's low stimulation frequency approximately grows.

Keywords: muscle's biotronics system, adaptive, self stimulation, natural frequency, mode of working.

Introduction

Many authors [1–5] analyze the muscle as the linear separate dynamic system. Dynamic models of a muscle are forming and its mechanical characteristics are then calculated. Works [6–8] present the nonlinear dynamic muscle model and its mechanical characteristics such as muscle stiffness, natural frequency, and muscle elongation dependency on loading duration, and others are calculated by numerical methods. The calculation results are compared with the experimental ones and presented in other scientific papers [3, 9]. These results are explaining by the decrease of muscle stiffness and its natural frequency in time-span. The muscle was analyzed as a separate mechanical system and mechanical characteristics of this system are calculated. Unfortunately, the muscle hasn‘t widen approach to him, e. g. it was researched only as a subsystem of the biotronic system. But on purpose to derive its endurance parameters and adaptation abilities, all the biotronic system must be explained. Therefore the aim of this paper is to study the whole biolotronic system by estimating its endurance and adaptation abilities, and also evaluating the variation of a muscle biosignals in time-span.

Methods

Analyzing the muscle biotronic system it is very important to evaluate its complicated relation with the cogitative apparatus by the received values of biosigals and their characteristics, stimulation biosignals, muscle biosignals outgoing by the feedback concerning adaptability to a load and stimulation sufficiency. Therefore, the sophisticated biotronic system is obtained and by the first approach it could be explored by the scheme presented in the figure 1. The figure 1 shows that the muscle can't self-sufficiently functioning and all the bound processes are controlled by the feedback, the same all decisions about muscle abilities to perform work are accepted in the module of acceptance the objective solutions and biosignals generation. Thus the muscle endurance abilities could be analyzed only in the contest of all the biotronic system with its circulating information and with the evaluation of muscle loading and quantities of stimulation biosignals. Hereby, the abilities of performing work are solving in the module of acceptance the objective solutions and biosignals generation. This means that in the mentioned module optimal decisions are decreeing.

In our opinion, the optimal decision has such a description - the muscle must perform the maximal work with the minimal amount of biosignal energy:

$$\min_i [E_d] \wedge \max_i [A], \quad i = 1,2,...,n\,, \tag{1}$$

where E_d is the amount of biosignal energy, A stands for the amount of performing work, i = 1, 2,..., n is the number of possible working modes and essential quantity of the energy.

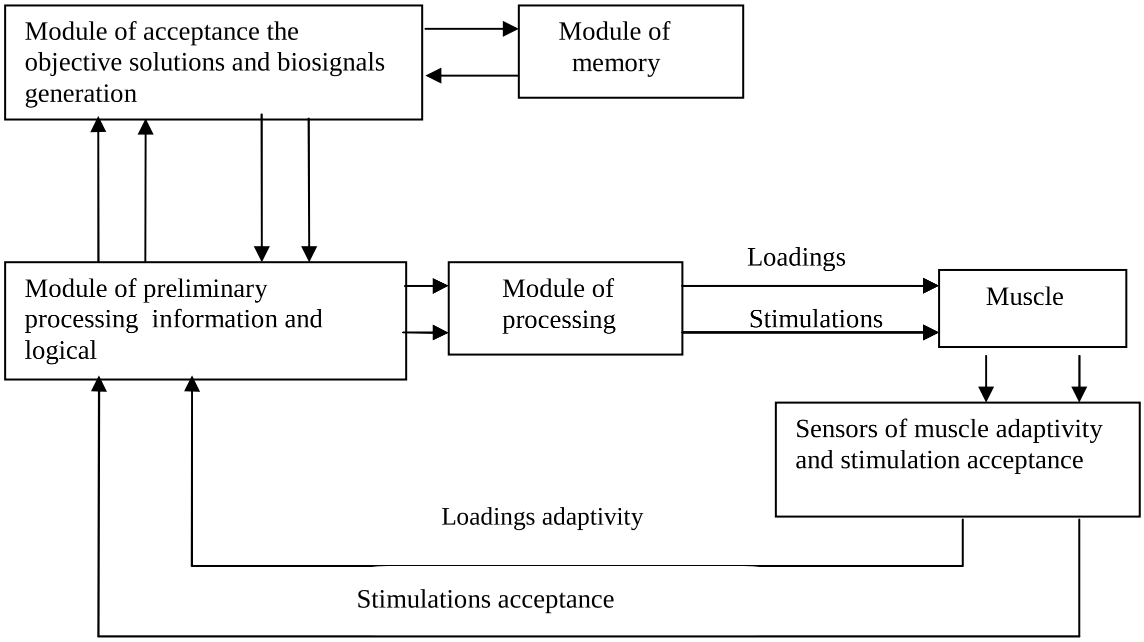

Fig. 1. Muscle‘s adaptive, self stimulation on the resonance frequency working biotronic‘s system

The amount of biosignal energy could be calculated in such a way:

$$E=\int_0^T i(t)u(t)dt=\int_0^T \frac{u(t)^2}{R}dt, \qquad (2)$$

where *i(t)* stands for biosignals current, *mA*; *u(t)* is the value of the biosignal intensity, *mV*; *R* is the impendence of the muscle, *Ω*; *T* stands for the muscle loading duration.

Intake amount of biosignal energy when $E_0 = 0$ necessary for the muscle for performing any work *A* could be expressed:

$$E_d = E - E_0 = \int_0^T \frac{u(t)^2}{R}dt - E_0 = \int_0^T \frac{u(t)^2}{R}dt\,. \qquad (3)$$

Muscule performing work could be different, for example,

$$A = Q \cdot h, \qquad (4)$$

where *Q* is a weight acting to pending muscle, *h* stands for the height of rising weight *Q*.

The muscle from biosignals receives all information. Therefore the biosignal can‘t be a stochastic signal. The information of biosignal could be expressed by the trigonometric row:

$$y = a_0 + \sum_{j=1}^{m} A_j \sin\left(\omega_j t - \varphi_j\right), \quad j = 1,2,...,m\,, \qquad (5)$$

where A_j is an amplitude of *j* component, mV; $\omega_j = j \cdot \omega_1$, ω_1 stands for angular frequency of the lowest harmonic, φ_j is the initial phase of *j* component, *t* is the time, a_0 represents a free member.

Results of harmonic analysis or expressions by trigonometric row (5) are presented in figure 2.

From expressions (1), (3) and (5) we'll get:

$$\min_i\left[E_d\right] = \max_i \left[\int_0^T \frac{1}{R}\left[a_0 + \sum_{j=1}^{m} A_j \sin\left(\omega_j t - \varphi_j\right)dt\right]\right]. \qquad (6)$$

From expression (6) seen that the muscle receives information and at the same time it is stimulated by vibrations of different biosignal frequencies and amplitudes. Therefore it is very important to analyze the relation between the natural frequency of the muscle and biosignal frequencies, and also the influence of this ratio on muscle's maximal work performances.

From vibration theory is known that when the system is affected by the same value of external generating force, the amplitudes of system resonance oscillations are *k* times major than not resonance frequencies, that is:

$$k_l = \frac{A_{rl}}{A_l}, \quad l = 1,2,...,p, \ \text{and} \ k_l > 1, \qquad (7)$$

where A_{rl} is the amplitude of *i* resonance frequency, A_l represents the amplitude of *i* not resonance frequency.

When evaluating the expression (7) the kinetic energy of muscle mass in the way of oscillating by different frequencies must satisfy the inequality:

$$\frac{m\left(\omega_l A_l\right)^2}{2} < \frac{m\left(\omega_l k A_l\right)^2}{2},$$ and when *k*= const,

then

$$m\left(\omega_l A_l\right)^2 < k^2 m\left(\omega_l A_l\right)^2, \ k > 1, \qquad (8)$$

where *m* is the mass of the muscle.

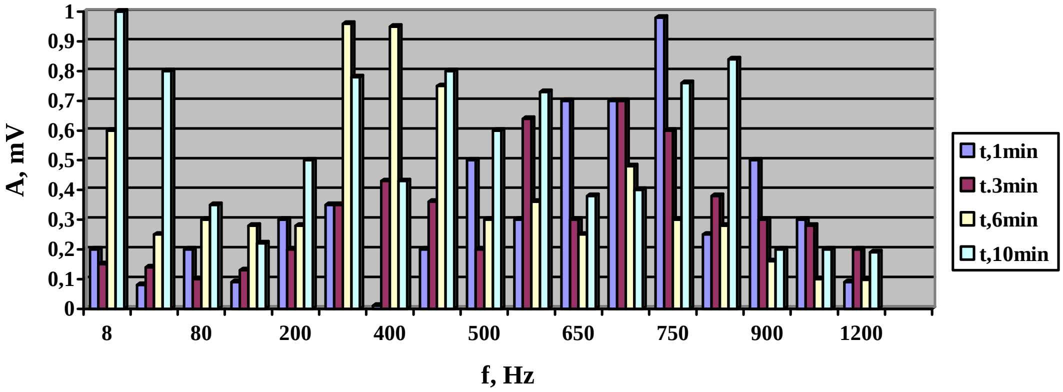

Fig. 2. The results of male harmonic analysis at $F = 18\ N$ and different loading durations

It is seen from expression (8) that the energy of the system oscillating by the same magnitude generating force resonance frequencies is k^2 times bigger than the energy of the system oscillating by non-resonance frequencies. Inequality (8) could be expanded for l system's resonance frequencies:

$$\frac{m}{2}\left[(\omega_1 A_1)^2 + (\omega_2 A_2)^2 + \ldots + (\omega_n A_n)^2\right] <$$
$$< \frac{m}{2}\left[(\omega_{r1} A_{r1})^2 + (\omega_{r2} A_{r2})^2 + \ldots + (\omega_{rp} A_{rp})^2\right]$$

or (9)

$$\sum_{l=1}^{p} (\omega_l A_l)^2 < \sum_{l=1}^{p} (k_l \omega_{rl} A_l)^2.$$

In the partial way as it possible to say that all k_l, $l = 1, 2, \ldots, p$ are equal and are the same k, the expression (9) could be transformed in such a shape:

$$\sum_{l=1}^{p} (\omega_l A_l)^2 < k^2 \sum_{l=1}^{p} (\omega_{rl} A_l)^2. \tag{10}$$

Dependencies (8), (9) and (10) prove that the biotronic system of the muscle satisfies the condition (1) when it works at resonance frequencies.

The presented condition must be satisfied as the muscle performing the permanence work in the time:

$$\frac{m}{2}\left[(\omega_1 A_1)^2 + (\omega_2 A_2)^2 + \ldots + (\omega_n A_n)^2\right] = const,$$

when $t \to T$ (11)

The condition (11) is important, because in the work [7] was noticed that the natural frequency of the muscle is decreasing at the longer loading, e. g. $\omega_{rl} \neq const$ and it declines according nonlinear dependency (fig. 3). In such a way, the amplitudes of the natural frequency of muscle amplitudes A_l, $l = 1, 2, \ldots, p$, must increase for the satisfaction of the condition $\omega_l A_l = const$, because at the same time the condition (1) will be satisfied too. If least one $\omega_l A_l \neq const$, when $l = 1, 2, \ldots, p$, so the component of biotronic system mass's oscillations will not be optimal and more biosignal energy will be needed for performing the permanence work.

Results of experimental research

From the harmonic analysis made on biosignals of the thumbs short abductor muscle abductor (m. abductor pollicis breivis), then the spectrum changes in loading duration and as $F = 18N$ (fig. 2) was noticed that values of spectral low frequencies are diminishing at the longer loading duration (fig. 4), and the amplitudes are growing (fig. 5 and 6). Analyzing presented in the figure 4 changes of the frequency range from 520 to 175 Hz in the loading duration according its upper surrounding line, the refraction at the 7th loading minute is clearly seen. After this time the generation and stimulation frequencies are decreasing. The similar point of the refraction or rising oscillating amplitude could be noted near the 7th minute in figures 5 and 6. Item, in the figures 4 and 5 the „Top" marks the upper margin of maximal frequencies range and „B" represents the lower margin of minimal frequencies. Explained graphical values reflected in figures 3 and 6 must be compared with ones of the „B" and 8 – 10 Hz frequency range.

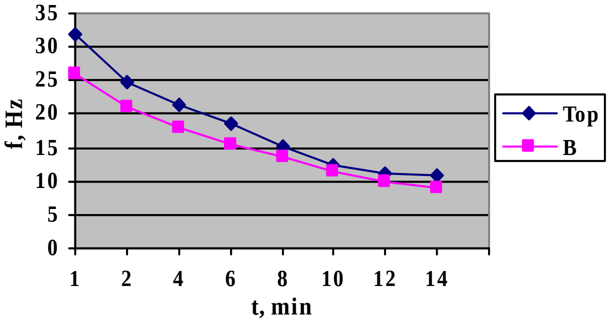

Fig. 3. Variation of calculated muscle's frequencies in time-span at F=18 N, [7]

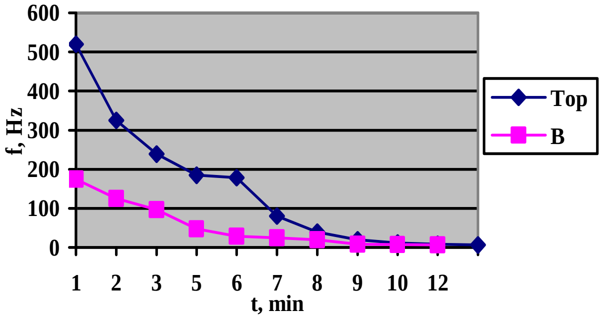

Fig. 4. Variations of different frequencies of male muscle biosignals in time, at F=18 N

From the comparison of last-mentioned experimental research results is seen that the lowest frequencies are diminishing as the muscle is longer loaded and the amount of their components approximately decrease. Comparing the results presented in figures 4 and 3, especially at the way of „B“, we see that their variations' regularities are very similar and the same alike their values of their frequentative characteristics. Consequently, it could be supposed that frequencies of biosignals are following varieties of the muscle natural frequency and are receiving information trough the „sensors of muscle adaptivity and stimulation acceptance“ then transferring it to the „Module of preliminary processing information and logical“. This last module is making the decisions for the further performances and if it is possible is transfering the same information to „Module of acceptance the objectives solutions...“ In the last-mentioned module, the biosignals and other possible commands, which must guarantee the condition, are generating, that is mean, that the amplitudes of lower frequencies are expending and the generated biosignal and other information through „Module of preliminary processing information and logical“ and „Module of processing“ is transfering to the main part „Muscle“.

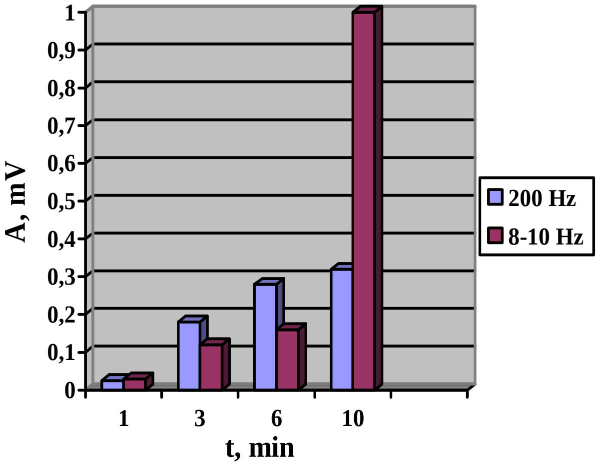

Fig. 5. Variations of amplitudes of male muscle biosignals in time, at different frequencies and at F=18 N

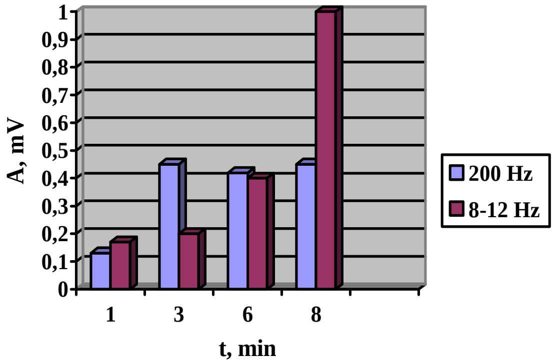

Fig. 6. Variations of amplitudes of female muscle biosignals in time, at different frequencies and at F=18 N

Sometimes the cardinal decisions are made, for example even the subject handles the weight and felt the hand tired, so receives the command to change the hand and so on. If the modulus „Sensors of muscle adaptivity and stimulation acceptance“ do not registering any changes in muscle work, the biotronic system (fig.1) will work the same without any changes and the „Module of processing“ closes the cycle. Therefore in the figure 1 presented simplified scheme of the muscle biotronic system explains its work and main processes.

Figure 7 represents the variation of maximal frequencies of muscle biosignal. It is seen that the maximal frequencies of spectrum increase with longer muscle loading and asymptotically approaches to appropriate size. Although last-mentioned biosignal frequencies amplitude is not large the energy of biosignal is big enough, because of intense frequency. So the analysis of experimental research results has proved the conclusion that the biotronic system of the muscle is the self stimulated, adaptive and works in resonance frequencies. The characteristic indication of this system is appearance than the muscle is loaded for longer the amplitudes of low frequencies of biosignals stimulating increasing and exactly from this moment the person starts to feel tiredness and pain.

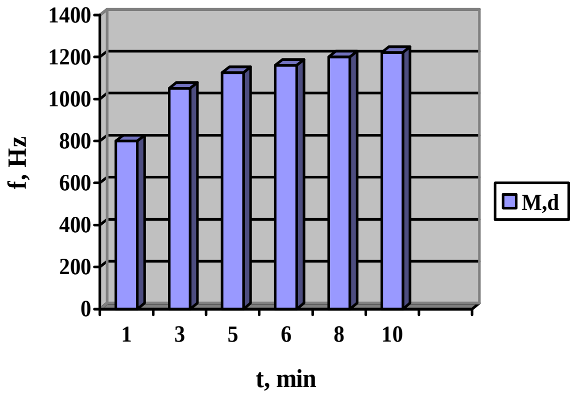

Fig. 7. Variations of maximal frequencies of male muscle biosignals in time, at F=18 N

Conclusions

After observing analytical and experimental research results there were formulated the following conclusions:

1. The muscle is the part of the complicated biotronic system and its endurance characteristics could be explored only analyzing the whole system.
2. The biotronic system of the muscle supports energetic stability when it performs work.
3. With the diminishing of values of natural frequencies of the muscular system, values of biosignal amplitudes are enlarging.
4. The biotronic system of the muscle works in the resonance mode and is adaptive and self simulative.
5. With the muscle longer loading, the amplitudes of components of low frequencies become very large and the person starts to feel tiredness and pain.

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