385. EVALUATION METHOD OF MUSCLE NON-LINEAR SYSTEM'S ELECTROMECHANICAL EFFICIENCY

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Abstract: Paper presents the method of evaluation of muscle efficiency characteristics. Previously presented criterions of muscle endurance are sustained by varieties of integral values of the muscle elongation and the muscle stiffness in the time–span. The dependency of variations of the muscle biosignal amplitude on loading time represents three extreme points which mark efficiency states of the muscle. The rate indicating muscular reaction to the loading size has been derived. Item, one more rate evaluating the muscular adaptation to a load has been obtained. This rate was expressed as the relation between amplitudes at the extreme points of the curve. According to the presented methodic the muscular efficiency could be explained by its working ranges – *A*, *B* and *C*, by setting bounds between them. Presented muscular stiffness expressions will be used for nonlinear dynamic model of the muscle.

Keywords: muscle efficiency, nonlinear dynamic system of muscle, muscular stiffness, fatigue, simplified methodic

Introduction

Reasons of decline in organism endurance caused by changes in other organism systems and are always concrete e. g. they depend on performing work character, intensity, mode of muscle work and other factors. Mostly, endurance is declining during physical activity due to the fatigue in the CNS, endocrines system, and vegetal systems and in working muscles. The main factor of diminishing in person's physical activity is muscular fatigue. Therefore fatigue phenomenon could be explained as a process in time where encloses some phases of muscle activity state: recoverable, non recoverable and complete fatigue [15]. The coefficient of the separation of these phases is the ability of organism as a whole unit to perform desirable work for example to keep selected work's power as long as possible [14, 15]. Fatigue in a muscle takes place as a result of an intensive activity of this muscle and is reflected by certain changes in its electromyogram (EMG) signal in either the time or frequency domains (Edwards 1981). Changes in muscle force depend on both metabolic fatigue (Green, 1997) and non-metabolic fatigue (Newham et al., 1987).

Varieties of investigations are presented wherein the muscle efficiency is researched by a special methodic or the muscle is tested according appropriate criterions [1–18]. Phases and limits of the fatigue are defined in conformity of these researches' results and also are evaluated reasons of diminished of muscles efficiency. Declining in values of the muscle's efficiency is often performed by reduction in magnitude of its force [1, 6–8]. Strength training increases the muscle mass and maximal muscle strength in young as well as in elderly subjects [4–6]. Increase in maximal strength with training could be the result of neural adaptation, especially at the beginning of the training period, as well as of adaptive changes in the skeletal muscle fibers [5]. The efficiency of human muscle has been measured in the context of walking, rowing and cycling [1, 3, 7, 10]. The efficiency is defined as the ratio of mechanical work output to the total metabolic cost [6, 9].

A lot of studies are made on low frequency fatigue [15]. It was concluded, that after exercises of the maximal intense there was a smaller fatigue of low frequency in the muscles but there was a greater decline in muscle endurance after exercises. This shows that metabolic fatigue caused by performing the exercise of maximal intensity can partially compensate for the decrease in the muscle contraction force at low frequency fatigue but it is detrimental to muscle efficiency [1, 6, 8, 15]. Many physiological studies, methods and techniques are used for clarifying hypothesis of different muscles efficiency stages [2–6]. Localized muscle fatigue has received growing attention in ergonomics [8]. Muscle efficiency evaluation methodic is beneficial for prevention of musculoskeletal disorders in the workplace. While fatigue during sustained static work are been investigated extensively, effects during tasks comprising work–rest cycles are less clear. Work–rest models for static intermittent work have been presented in several reports, but the applicability is often limited to specific conditions [3, 8].

Observing, the efficiency of the muscle could be evaluated by many parameters and methods. Results of research of muscle efficiency are very useful for variety of fields, such as rehabilitation, sport biomechanics, ergonomics and etc., and have wide application.

The purpose of this work is to compound and to present new method for evaluation of muscle efficiency, also to derive muscle stiffness dependency on loading duration. It will be used for nonlinear dynamic model creation.

Methods

For experimental research electromyography system "*Viking Quest*" has been used. Surface and invasive electromiograms (EMG) have been measured [17, 18]. Recoded EMG were transferred through "*E-biol*" interface and processed on PC. Random components of EMG signal were filtered applying special filtering technique. *MATLAB 7.1*software was used for numerical analyses.

Main research have been made on the thumb‘s short abductor muscle (*m. abductor policis brevis*). For comparing measurement results brachioradialis muscle (*m. brachioradialis*), which lies in the lateral said of forearm, has been studied. For experimental investigations and for ensuring of their accuracy, twenty health people have been invited: ten females (from 24 to 30 years) and ten males (from 28 till 60 years). The investigation has been focused on five load groups: from 8 N to 24 N. The muscle has been subjected to loading with different duration times from 5 up to 6 min and sometimes even up to 10 min. EMG measurement has been followed by a break lasting till complete relaxation of the muscle and becoming ready for the next measurement stage.

Muscle efficiency relations were formulated by evaluating energy of biosignal and elongation of the muscle in female and male groups. Working criterions were defined [17, 18].

Supposedly, both evaluating the criterion of muscle endurance by biosignal energy and by muscle elongation, it displays two main rates of muscle endurance such as time of effective muscle work and reserve of muscle capacity under appropriate loads. Variations of criterions of muscle endurance in loading time disclose stages of muscle state and behavior: the stage as it works effectively and when it gets into fatigue [17, 18].

Analysis and Results

In the literature [17, 18] presented criterions of muscle endurance are sustained by varieties of integral values of the muscle elongation and muscle stiffness in the time–span and analytically expressed in such a way:

$$D_{k_p} = \frac{1}{\frac{\partial x(F,P,t)}{\partial t}} \text{ or } D_{k_s} = \frac{1}{\frac{\partial k(F,P,t)}{\partial t}}, \tag{1}$$

when $x(F,P,t) = \frac{1}{F}\int \frac{U^2(F,P,t)}{R}$ and

$$k(F,P,t) = \frac{F}{x(F,P,t)} = \frac{F^2}{\int \frac{U^2(F,P,t)}{R}}. \tag{2}$$

Where $x(F, P, t)$ is the muscle elongation, $k(F, P, t)$ represents the stiffness of the muscle subjected to the size of the muscle's load F, the pathology P, the muscle loading duration t . U stands for the amplitude of muscle biosignal and R represents impedance of the muscle.

The expression (2) shows the function of the dependency (Fig. 1.) of the amplitude of muscle on the muscle loading F, the pathology state P and the loading duration t, which is under the integral sign and also squired. If evaluating that the squired rising do not reduces the clarity of functional variations, so the integral will eliminates some small changes in muscles biosignal parameters. Therefore, muscle efficiency criterions described by the expression (1) in some cases could be not very precise, especially evaluating abilities to applied loadings of sportsman or workman. The new parameter of the muscular efficiency has been derived by using the criterion of an inverse proportion of biosignal amplitudes dependency on the loading size and duration:

$$\overline{D}_{k_F} = \frac{1}{\frac{\partial U(F,P,t)}{\partial t}}. \tag{3}$$

Similarly will be estimated the abilities of sportsman or other person to adapt to applied tasks. The graphical interpretation of calculating results according the expression (3) is presented in the figure 2. In the figure 1 presented the dependency of variations of the muscle biosignal amplitude on loading time shows three extreme points signed as 1, 2 and 3 which marks efficiency states of the muscle. These points also reflect in figure 2. The first point indicates the state when the muscle biosignal amplitude reaches the maximal its value that is mean that the muscle was a little more strained with the loading. Further the amplitude of muscle biosignal gradually declines and when the point "2" displays the end of muscle's adaptation to applied load process.

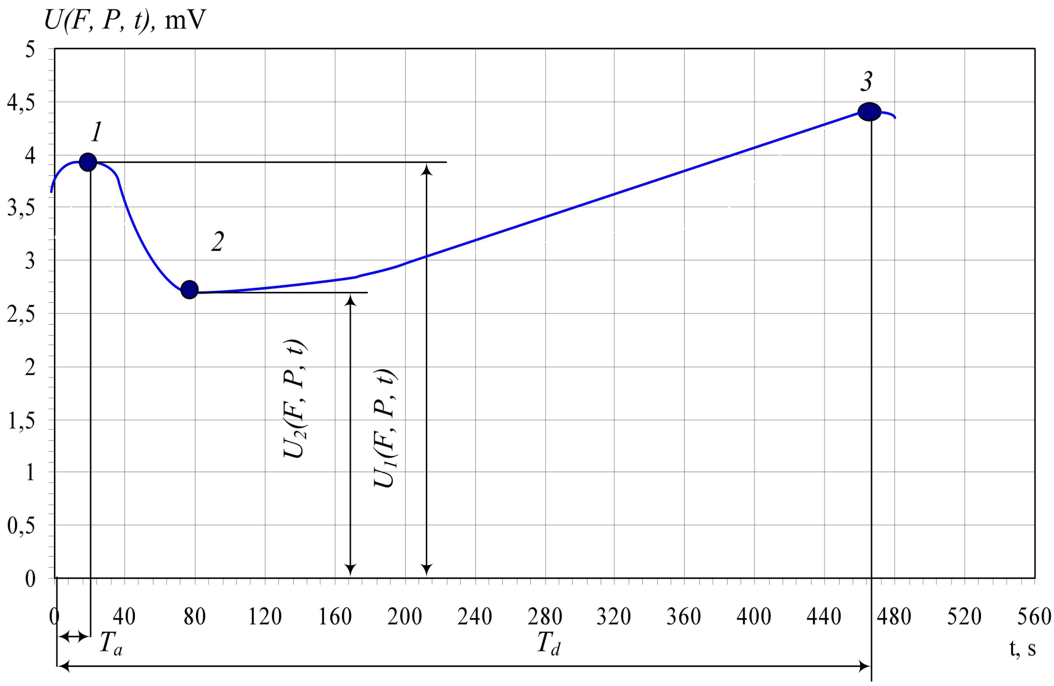

Fig. 1. The dependency of biosignal amplitude on loading size *F* and duration *t*

In the time interval between points "2" and "3" the amplitude of the muscle biosignal progressively enlarges with the longer muscle loading. And finally coming up to the limit of the point "3" the muscle gets into fatigue.

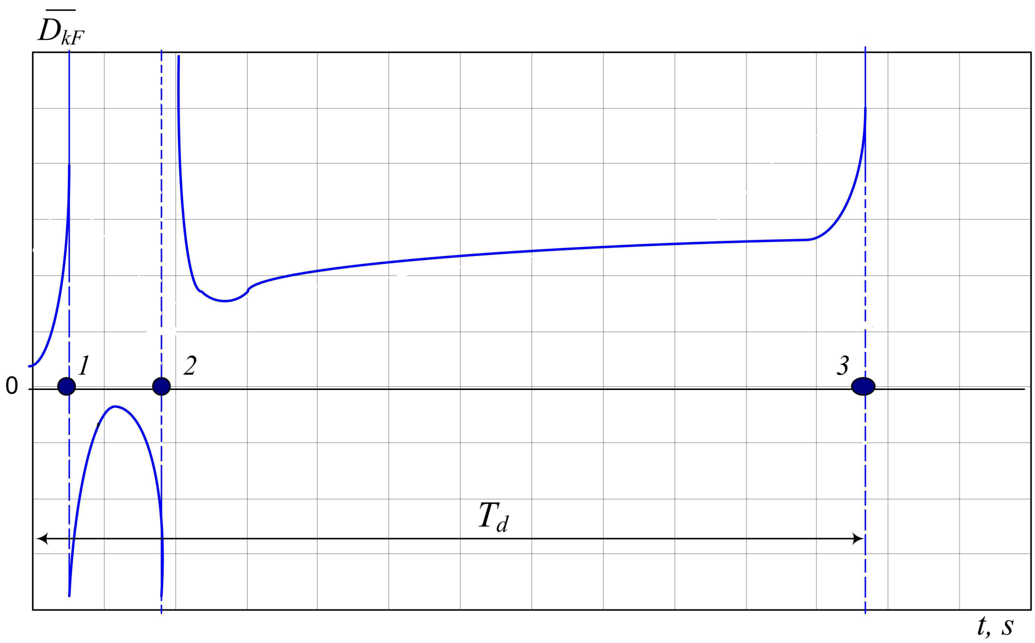

Fig. 2. The dependency of the criterion of muscle efficiency in loading duration *t*

Offered criterion of evaluation of person efficiency abilities could be used in the assessment of sportsman and workers to appropriate working tasks. If in the papers [17, 18] presented criterions would be used, the point "2" in the presented curve (Fig. 2) will be eliminated, because of made calculations. Secondly, operating with extreme points in the curve of muscular efficiency criterion variation, using simplified methodic, persons relevance to applied him loads could be evaluated. The ratio of the amplitude of muscle biosignal in the extreme point "1" and the one at point "2" shows the sensibility of muscular reaction to a loading size. This ratio could be expressed in such a form:

$$I_{1,2} = \frac{U_1(F,P,t\ )}{U_2(F,P,t\ )}, \qquad (4)$$

where $U_1(F, P, t)$ is the amplitude of muscle biosignal in the first extreme point, $U_2(F, P, t)$ represents the amplitude of the muscle biosignal at the point "2".

Wherewith the sensibility value $I_{1,2}$ is bigger, it displays the subject's inadaptability to applied strain. The value of the ratio $I_{1,2}$ for trained and healthy person must be approximately lower then $I_{1,2} < 1{,}5$, and for not trained subject, especially with pathology, the value of $I_{1,2}$ could exceed 2, that is $I_{1,2} < 2$.

Other characteristic of muscle adaptability to applied strain could be approximately calculated as the ratio of amplitudes in the extreme points:

$$I_{0,1} = \frac{U_1(F,P,t)}{U_0(F,P,t)}, \qquad (5)$$

where $U_0(F, P, t)$ is the amplitude of muscle biosignal at initial moment of loading, when the muscle is just strained and $0 < t < 5$ s.

Graphically presented nomograms (Fig. 3, Fig. 4, Fig. 5, Fig. 6) could be used for preliminary assessment of sportsman and workers to applied strain. The assessment has these explained stages. First, if the values of subject assessing ratios $I_{1,2}$ and $I_{0,1}$ are in the green regions "*A*" and "*A_1*", he can perform applied tasks and ratios' values approach to 1, it means that the assessing person is ready to perform selected works and also to reach the better results.

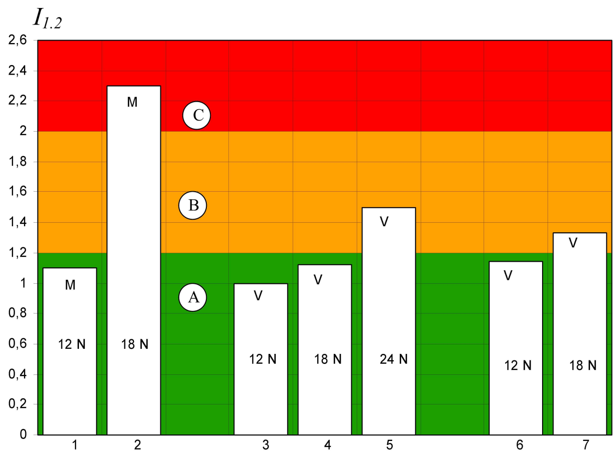

Fig. 3. Variations of values of the ratios $I_{1,2}$ of thumbs muscle's biosignal amplitudes at different loadings: M – female group, V– male group, *A*, *B* and *C* stands for muscle efficiency states

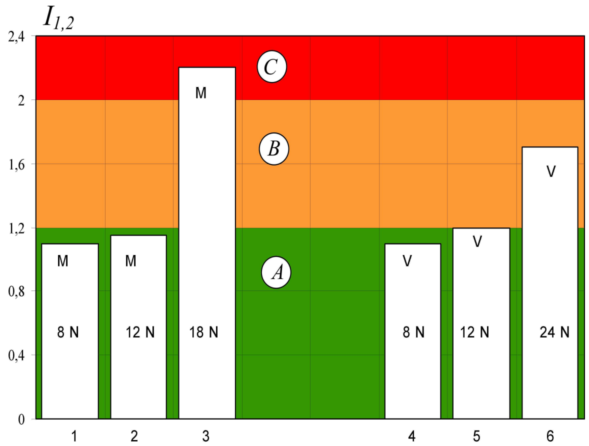

Fig. 4. Variations of values of the ratios $I_{1,2}$ of brachioradialis muscle's biosignal amplitudes at different loadings: M – female group, V– male group, *A*, *B* and *C* stands for muscle efficiency states

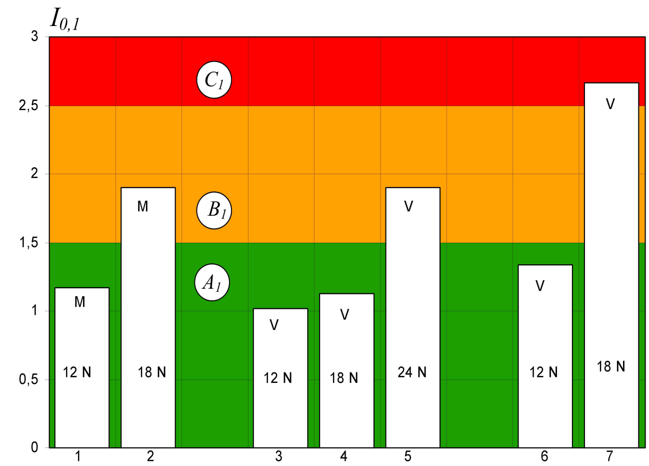

Fig. 5. Variations of values of the ratios $I_{1,0}$ of thumbs muscle's biosignal amplitudes at different loadings: M – female group, V– male group, A_1, B_1 and C_1 stands for muscle efficiency states

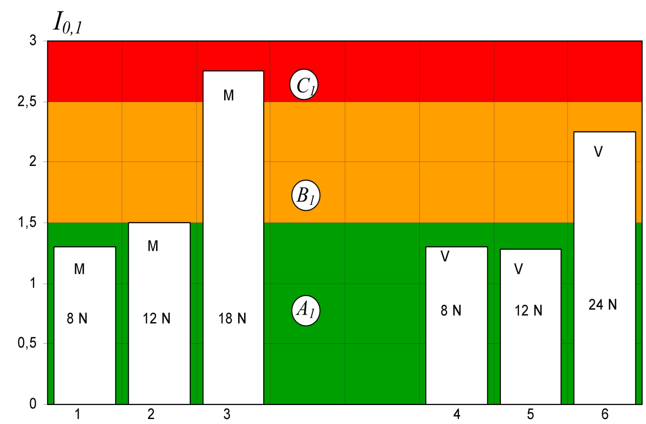

Fig. 6. Variations of values of the ratios $I_{0,1}$ of brachioradialis muscle's biosignal amplitudes at different loadings: M – female group, V– male group, A_1, B_2 and C_3 stands for muscle efficiency states

Secondly, when the values of ratios are in the orange regions "B" and "B_1" two ways are possible: a – when the applied load for the person is too big and better results could be reached only after more trainings and b – when the person has some sort pathology. In both cases a and b the person must to consult a doctor and to clarify the state of health.

Thirdly, as assessing persons values of ratios get into red zone "C" and "C_1" it is clear that he can't keep applied load or work and usually feels pain. In this stage also two ways are possible a – when applied load is too big and the person can't do tasks or b – there is the clear pathology. In both cases the person also must to consult a doctor and to clarify the state of health.

Described simplified method of a subject adaptation to strains could be used studying the decrease of amplitudes of muscles oscillations in the adaptation period. For more precise results the criterion expressed by formula (3) must be used.

Analyzing result in the presented figures has been noticed the fact that with expanded loads the amplitudes of the muscles biosignal increasing and the same values of the ratio of the amplitudes enlarge. When the muscle biosignal enlarge in q times, it amplitude will be:

$$U(F, P, t) = qU(F, P, t), \tag{6}$$

Consequently the muscle stiffness now could be expressed in such a form:

$$k(F,P,t) = \frac{F^2}{\int \frac{q^2 U^2(F,P,t)}{R}}, \tag{7}$$

In that case, when q = const finally the expression of muscle stiffness could be transformed:

$$k(F,P,t) = q^2 \frac{F^2}{\int \frac{U^2(F,P,t)}{R}}. \tag{8}$$

It is seen from expressions (6) and (8) that if the value of muscle biosignal enlarges q times, the stiffness of the muscle decreases q^2 times. This important conclusion append before mentioned methodic due to the evaluation of persons working abilities. Besides, these conclusions could be applied in the creation of the new nonlinear dynamic muscle model.

Conclusions

Having completed the research and summarized its results the following conclusions can be made:

1. Offered method of evaluating muscle efficiency of a person allows detailed assessing of adaptation to applied strains and estimating following variations in this process.

2. Presented simplified method which allows quick evaluation of working abilities of the person during assessment and protects him from overloads and injuries.

3. Estimated, that when the muscle biosignal enlarges in q times, its stiffness decreases q^2 times. Last mentioned dependency will be used in the nonlinear dynamic model of the muscle and for the research of muscular frequentative characteristics.

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