МАТЕМАТИЧНІ МЕТОДИ В СУСПІЛЬНИХ І ГУМАНІТАРНИХ НАУКАХ

DOI:
UDC 004.942
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MATHEMATICAL MODELING AND COMPARISON OF THE DYNAMICS OF STRIKES ON TWO TYPES OF VESTS FOR MARTIAL ARTS

In this paper, the authors proposed a model of a vest for martial arts with air inside. It is known that airless vests are usually used in sports, inside of which a semi-solid material, such as paralon, is placed. These types of vests are not very practical for the athlete, because the strikes and kicks of any force, when using this type of vest, are felt very strongly. Therefore, we decided to offer our model of a protective vest for martial arts, which in our opinion will reduce the number of injuries in martial arts, as well as improve the training process. Therefore, the purpose of our work we have chosen is to create a mathematical model that describes the physical processes occurred during the impact in a protective vest with air inside. And a comparison of these processes with the processes that occur in a usual protective airless vest is made. Based on the comparison of the results of mathematical modeling of the dynamics of impacts in the vests of two different types, it was concluded that the proposed model of the vest distributes the impact energy twice as well as the usual airless analogue. Due to the air inside, the energy from the impact is transmitted by particles to a larger volume in the vest, which reduces the load on the impact site and avoids injuries. Therefore, the proposed model of the vest can be recommended for use in various types of martial arts as a more effective analogue of the usual vest.
Keywords*: mathematical modeling, dynamics of the strike, martial arts vest, Hooke's law.*

У даній роботі автори запропонували модель жилету для єдиноборств з повітрям у середині. Відомо, що зазвичай у спорті використовуються безповітряні моделі жилетів у середині яких розміщується напівтвердий матеріал, наприклад, такий як паралон. Такі види жилетів є не дуже практичними для спортсмена, бо удари будь-якої сили, при використанні цього виду жилета, відчуваються дуже сильно. Тому ми вирішили запропонувати свою модель захисного жилету для єдиноборств, яка на наш погляд зменшить кількість травм у єдиноборствах, а також покращить процес тренувань в цілому. Тому метою нашої роботи ми обрали створення математичної моделі, яка описує фізичні процеси, що відбуваються під час удару у захисному жилеті з повітрям усередині. Та порівняння цих процесів із процесами, які відбуваються у звичайному захисному безповітряному жилеті. На основі порівняння результатів математичного моделювання динаміки ударів у жилети двох різних видів був зроблений висновок, що запропонована модель жилету у два рази краще розподіляє енергію удару ніж звичайний безповітряний аналог. Завдяки повітрю у середині енергія від удару передається частинками по більшому об'єму у жилеті, а отже це знижує навантаження на місце удару і дозволяє уникати травм. Отже, запропоновану модель жилету можна рекомендувати для використання у різних видах єдиноборств як більш ефективний аналог звичайного жилету.
Ключові слова*: математичне моделювання, динаміка удару, жилет для єдиноборств, закон Гука.*

Problem's Formulation

Protective equipment is widely used in various styles of martial arts. These include: shin protection, helmet, hand protection, shockproof vest and others. However, these protective equipment can not be called completely perfect, because even with them, athletes are injured. Therefore, protection of the athlete need improvement. For example, vests that are made to protect the human body, are made entirely of solid material, such as a thick layer of foam. But this model of protection does not allow to distribute the energy produced during the strike over the entire surface of the body. So the strike falls on a separate part of the body, where the athlete was hit. In our work, we proposed another model of protective vest, which allows to distribute the energy from the strike on the entire body, and thus reduce pain and injury. The main idea of our protective vest is that there is an air layer inside. As a result, during the impact, the energy is distributed evenly throughout the body.

Analysis of recent research and publications

We have analyzed recent research and publications related to the topic of this article, and we can highlight the following authors and the results they obtained. In the article by Saveliev V.N. [1] "Mathematical model of a boxer's blow", which was tested in the laboratory of a company that produces force meters, in the process of long-term experimental and scientific research was created physical and mathematical model of human impact on an elastic target. With this model you can accurately describe and understand the whole process of collision and explain the shape of the shock pulse. Also in another work, [2] Sibirtsev S.K., Chernykh R.M. and Volegov P.S. developed a program that calculates the force of a boxer's blow depending on the type of strike and the level of training of the athlete. Kim D. and David V.T. in his article "Measuring the speed of a boxer's hand" [3] conducted a study of the speed of strikes of boxers men and women depending on the type of strike. Busko K., Staniak Z. and others in the article "The force of punches and kicks among athletes engaged in martial arts, measured using a modified punching bag with a built-in accelerometer" [4] presented the results of tests in which men and women participated women boxers and taekwondo fighters. In these tests, kicks and punches were made in a punching bag with a built-in accelerometer. Based on the results of the experiments, it was concluded that the modified punching bag is a good diagnostic tool for martial arts. Khasanshin I. in the article "Application of an artificial neural network for automation of measurement of kinematic characteristics of strikes in boxing" [5] aimed to study automation of measurement of speed of blows of boxers during "fight with a shadow". The model developed in the article showed a high level of strike recognition, and the authors concluded that the use of an artificial neural network significantly accelerates the collection of data on the kinetic characteristics of boxers strikes and allows to automate this process. In [6] authors perform impact testing with auxetic and conventional foam used in sports equipment. Results of experiments and their comparison gives 3 times smaller forces acting on fixed surface when auxetic foam is used. Also authors present time dependency of acceleration during impact, which shows loads at peaks. In [7,8] authors consider energy absorption level of impact protective pads. In [7] it is built from polyurethane and polyester in multilayer configurations and thickness. Experiments lead authors to recommendation of knitted spacer fabrics as they absorb more impact energy than conventional ones.

Formulation of the study purpose

The aim of our work is to create a mathematical model that describes the physical processes that occur during a strike in a protective vest with air inside. And a comparison of these processes with the processes that occur in a conventional protective airless vest.

Presenting main material

Front view of considered vest is shown at Fig. 1. Along with the usual vest with a solid material (Fig. 2), it is proposed to simulate a strike to the vest with air inside (Fig. 3).

Modeling the dynamics of a fist strike on two types of vests for martial arts is simplified according to the following approximations:

1. The geometry of the vest allows a two-dimensional formulation of the problem.
2. The vest material is elastic and can consist of several layers for both types of vests.
3. Molecules of air inside the proposed vest is modeled by a set of elastic balls of the same radius.
4. During the impact, the body does not move and the vest takes on all the momentum from the fist.

5. The fist and its rectilinear motion are modeled by a rectangle with the corresponding width and speed.

Thus, the particle system consists of three types of elements for the vest with air inside:

1. Air particles that move freely and are affected by repulsive forces.
2. Connected particles of the vest material, which are additionally acted upon by the forces of attraction. These particles can form both chains and bond through several bonds, increasing the hardness of the layers.
3. Static particles of the body, which are used to assess the pressure on it during the strike.

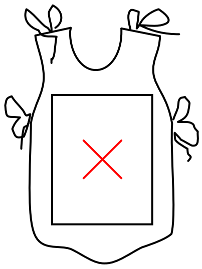

Fig.1. Schematic image of a vest, front view. The rectangle indicates the simulation area. The red cross means the place of strike

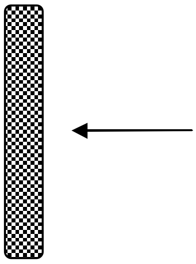

Fig.2. Schematic representation of an ordinary airless vest, side view. The arrow indicates the direction and place of impact

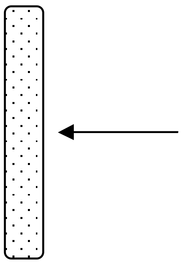

Fig.3. Schematic image of a vest with air inside, side view. The arrow indicates the direction and place of impact

To model a usual airless vest, the particle system consists only of the second and third types of elements from the previous list.

The kinematic characteristics (location and velocity) of an individual particle i in space are determined by the radius vector and its time derivative:

$$\vec{r}_i = \overline{(x_i, y_i)}, \quad \vec{v}_i = \dot{\vec{r}}_i, \tag{1}$$

where r_i is the radius vector, v_i is the velocity of the particle.

The set of particles has dynamics according to Newton's second law [9]:

$$\vec{a}_i = \frac{\vec{F}_i}{m_i}; \tag{2}$$

$$\vec{F}_i = \sum_{i \neq j} f\, \vec{d}_{ij}; \tag{3}$$

$$\vec{d}_{ij} = \vec{r}_j - \vec{r}_i; \tag{4}$$

$$f = \begin{cases} 0, & \left\| \vec{d}_{ij} \right\| \geq d_r \\ k, & \left\| \vec{d}_{ij} \right\| < d_r \end{cases}, \qquad (5)$$

where F_i and k are the conservative force and the coefficient of attraction / repulsion, d_r is the distance from the radius vector of the particle at which the forces of interaction are equal to zero. The coefficient f also depends on the type of particle — for the connected particles of the vest material it is always equal to the coefficient of elasticity k.

The computer implementation of the mathematical model allows you to choose the initial geometry of the vest, including the number and stiffness of the layers, the duration of the blow and the width of the fist, as well as the number of particles. In the case of a large number of particles, it is necessary to use special algorithms for searching for neighboring particles, otherwise the calculation speed will decrease quadratically relative to the number of particles.

The coefficient of elasticity should be chosen high enough to minimize the side effect of penetration of some particles through others — especially through the particles of the vest and body.

The numerical experiment was performed with 500 particles. The duration of the blow is 0.5 seconds.

Fig. 4 shows the dependence of the maximum value of the force on the horizontal position on the vest. As theoretically assumed, the highest values of force are located in the center. The graph shows the beneficial effect of air use — free particles better redistribute impact energy — the maximum force is almost halved. This result is one of the factors in the use of airbags in cars. The obtained values of force correspond to the values obtained in other studies from the bibliography.

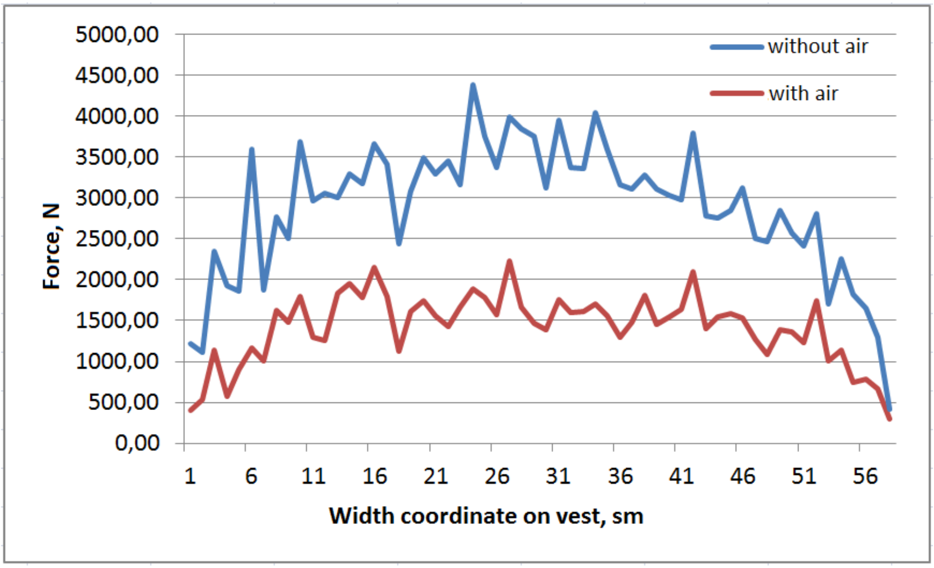

Fig. 4. Calculated maximum forces acting on different parts of the vest during the impact (less — better)

For better impact analysis, the deformation of the vest was calculated (Fig. 5). It is expected that the air vest deforms more — it has less rigidity.

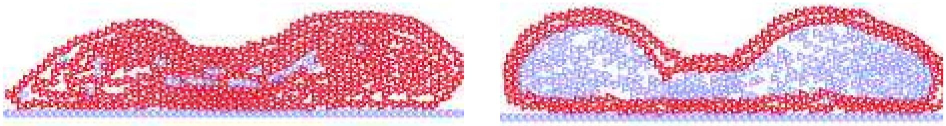

Fig. 5. Calculated deformation of two types of vest during impact (left — usual vest, right — vest with air inside, which is offered for use)

Conclusions

Based on the obtained results of mathematical modeling of the dynamics of strikes in vests of two different types, it is concluded that the proposed model of vest with air inside distributes impact energy twice as well as the usual airless analogue. Due to the air inside, the energy from the impact is transmitted by particles in a larger volume in the vest, and thus reduces the load on the impact site. Therefore, the proposed model of the vest can be recommended for use in various types of martial arts as a more effective analogue of the usual vest. In the future, it is possible to improve the mathematical model using symmetry with respect to the point of impact, if it occurs in the center of the vest, which will significantly reduce the computation time on the computer and increase adequacy. Also, to better match the mathematical model of reality, it will be useful to develop a three-dimensional model of the vest.

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ТА ПОРІВНЯННЯ ДИНАМІКИ УДАРІВ ПО ДВОХ ВИДАХ ЖИЛЕТІВ ДЛЯ ЄДИНОБОРСТВ

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Реферат

У різних стилях бойових мистецтв широко використовуються захисні засоби. Серед них можна перелічити такі як: захист для голені, шолом, захист кисті руки, протиударний жилет та інші. Однак ці засоби не можна назвати повністю досконалими, тому що навіть з ними спорт-

смени отримують травми. Отже засоби захисту спортсмена потребують удосконалення. Наприклад, жилети які виробляють для захисту від ударів у корпус людини, виробляють повність із твердого матеріалу, наприклад, товстий підшарок із паралону. Але така модель захисту не дозволяє розподілити енергію, яка виробляється під час удару по всій поверхні корпусу. Тобто удар приходиться на якусь окрему ділянку корпусу, куди вдарили спортсмена. В нашій роботі ми запропонували іншу модель захисного жилету, яка дозволяє розподілити енергію від удару на весь корпус, а отже зменшити больові відчуття і травми під час бою. Основна ідея нашого захисного жилету полягає у тому, що всередині нього існує повітряний прошарок. У результаті цього під час удару енергія розподіляється рівномірно по всьому корпусу.

Метою роботи є створення математичної моделі, яка описує фізичні процеси, що відбуваються під час удару в захисний жилет з повітрям всередині.

Завдання роботи: порівняти ці процеси з процесами, що відбуваються у звичайному захисному безповітряному жилеті.

На основі отриманих результатів математичного моделювання динаміки ударів у жилетах двох різних типів, робиться висновок, що запропонована модель жилету з повітрям всередині розподіляє енергію вдвічі краще, ніж звичайний безповітряний аналог. Завдяки повітрю всередині, енергія від удару передається частинками у більшому об'єм у жилеті, і таким чином зменшується навантаження на місце удару. Тому запропонована модель жилета може бути рекомендована для використання в різних видах єдиноборств як більш ефективний аналог звичайного жилета.

У майбутньому можна вдосконалити математичну модель, використовуючи симетрію щодо точки удару, якщо вона відбувається в центрі жилета, що значно скоротить час обчислень на комп'ютері та збільшить адекватність. Крім того, аби математична модель краще відповідала дійсності, буде корисно розробити тривимірну модель жилета.

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