

## BIOMECHANICS ASPECTS OF TECHNIQUE OF HIGH JUMP

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**Annotation.** The purpose of work consists in the theoretical ground of optimum biomechanics descriptions in high jumps. A mathematical model is developed for determination of influence on the height of jump: speed and corner of flight of centre-of-mass during pushing away, positions of centre-of-mass body of sportsman in the phases of pushing away and transition through a slat, forces of resistance of air environment, influences of moment of inertia of body. The basic technical run-time errors of sportsman are selected exercises. To biomechanics descriptions, to the step-up effectiveness of high jumps belong: speed of flight of centre-of-mass sportsman (4.2-5.8 meters in a second), corner of flight of centre-of-mass body (50-58 degrees), height of flight of centre-of-mass body (0.85-1.15 meter). Directions of choice of necessary biomechanics descriptions which a sportsman can realize are shown. Offered recommendation on the increase of effectiveness of high jumps.

**Keywords:** biomechanics, trajectory, pose, sportsman, jump, height.

### Introduction.

Selection of optimal parameters, which predetermine successfulness of technical actions, is an important component of a sportsman movements' efficiency increasing. One of leading places in such movements is taken by bio mechanical aspects of technique and the possibility of its simulation on all stages of sportsman's training. The process of simulation, in its turn, demands considering both: general regularities of movement technique's building and sportsman's individual features. Such approach, to a large extent, promotes searching of technique optimal parameters and its realization on certain stages of a sportsman's training.

The works by N.A. Bernstein [3], V.M. Dyachkova [7], V.M. Zatsiorskiy [10], A.N. Laputina [4, 12], G. Dapena [18], P.A. Eisenman [20] are theoretical basis of sport movements bio mechanical regularities researches. The demand for preliminary simulating and further selecting of the most rational bio mechanical parameters of movements is mentioned in the works by V.M. Adashevskiy [1, 2, 28], S.S. Iermakov [8, 28], V.Ye. Chinko [14] et al.

The searching of sportsman jump kinematical and dynamic parameters' optimal combination [15-17], considering the regularities of mechanical energy transmission from link to link [18-20, 27] is of great importance. Such approach permits to successfully influence on the results of sport activity while executing high jumps [21, 25, 26]. With this it is recommended to apply mathematical patterns of movements [5-8, 23, 24], characteristics of sportsman's postures and movements [8].

Sports results of high jumps, to a large extent, are determined by rational bio mechanical characteristics, which a sportsman is able to realize, namely: speed of running, speed of repulsion, takeoff angle of a sportsman's body masses center, position of a sportsman's body masses center in the phases of repulsion and bar over passing.

Alongside with this, some of the above mentioned items concerning high jumps shall be specified.

So, I.V. Lazarev notes, that determination of "fosbury flop" on the stage of sportsmanship formation, revelation of repulsion structure and mechanism, development and application of jump patterns in training is one of urgent problems of running high jumpers training. Kinematical (takeoff height in unsupported phase, speed of running) and dynamic (repulsion impulse by vertical component, average repulsion force by vertical component, force in extremum) indicators effect on improvement of running "fosbury flop" high jumps results to the largest extent [11, 13].

G.A. Zaborskiy thinks that comparison of movements optimum pattern characteristics with really implemented jumper's repulsion movements structure will permit to find out such elements of his technical and speed-strength preparedness, whose correction and development will permit him to form individual optimal jump repulsion technique. [9].

And with that, the demand in researches for simulation of jump patterns for modern conditions of competition activity is still rather acute.

The researches were carried out as per governmental subject M0501 "Development of innovative methods and methods of diagnostics of different qualification and specialization sportsmen's main kinds of preparedness" 2012-2013.

### Purpose, tasks, material and methods.

*The purpose of the work:* theoretical foundation of main rational bio-mechanical characteristics of high jumps and composing of recommendations for improvement of high jumps effectiveness.

*The tasks of the work:*

- analysis of special literature;
- building of pattern for determination of masses center's takeoff speed and angle at repulsion, position of sportsman's body masses center in repulsion and bar over passing phases, air resistance, moment of inertia influence on the height of jump;
- composing of recommendations for improvement of "fosbury flop" high jumps results.

*The subject of the researches:* a sportsman's bio-mechanical characteristics, which promote improving of high jumps effectiveness.

*The object of the researches:* sportsmen of high qualification- high jumpers.

In solving of the problems special software complex "KIDIM", which was developed at NTU "KPI" department of theoretical mechanics, was used.

**Results of research.**

Sport results of high jumps are determined, mainly, by rational bio-mechanical characteristics, which a sportsman is able to realize, namely: running speed and, consequently, by speed and takeoff angle of sportsman's masses center, by position of the sportsman's masses center in repulsion and bar over passing phases. That is why, the necessity of fulfillment of all above enumerated bio-mechanical parameters in order to obtain maximal results of "fosbury flop" high jumps, is quite evident.

With this it is necessary to proceed from the following preconditions. Jump height is determined, mainly, by bio-mechanical characteristics, which a sportsman is able to realize, namely:

- running speed;
- speed of masses center takeoff at repulsion;
- angle of a sportsman masses center's takeoff at repulsion;
- position of a sportsman's masses center in repulsion and bar over passing phases;

Takeoff speed and angle of sportsman's masses center at repulsion are the main bio-mechanical characteristics of high jumps.

Speed of masses center takeoff at repulsion is a resulting speed, vertical and horizontal components of sportsman's speed of repulsion.

Male sportsmen of high class quality have horizontal running speed 6.5 – 8 mps while resulting speed of masses center takeoff at repulsion is 4.5 – 5.4 mps.

The height of body masses center at repulsion depend on anthropometric parameters and kind of jump. With bar over passing body masses center can be higher than the bar (dumping) or lower (with "fosbury flop" jump), depending on the kind of jump.

The most rational angle of a sportsman masses center's takeoff at repulsion is chosen within 56-59 degrees to horizon considering air resistance force.

With rational combination of these bio-mechanical parameters, "fosbury-flop" jumps results are 2.2 – 2.4 m.

Using the calculated diagram, let us consider the influence of vertical and horizontal speed components and takeoff angle of sportsman body's masses center on repulsion speed and, consequently, on takeoff speed of sportsman body's masses center (fig.1).

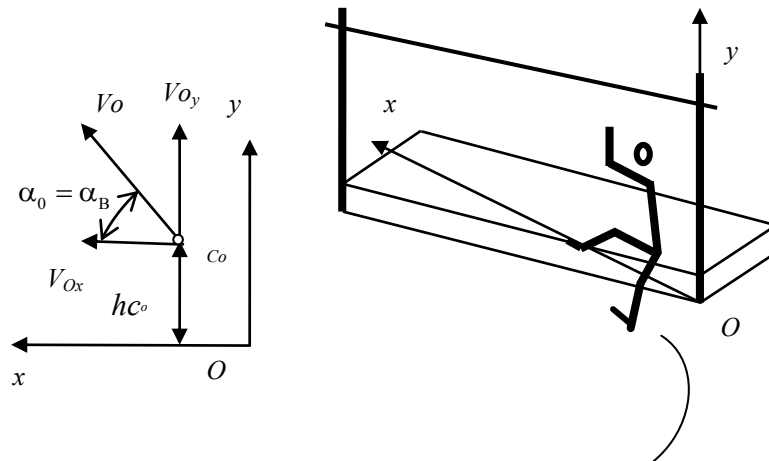


Fig.1. Calculated diagram for determination of repulsion parameters

$$\vec{v}_0 = \vec{v} = \vec{v}_r + \vec{v}_b$$

Here  $V_0$  initial repulsion (takeoff) speed of sportsman body's masses center,

$V_G=V_x$  – horizontal speed of body's running (horizontal component),

$V_B=V_y$  – vertical component of repulsion speed,

$h_{C0}$  - body masses center's height at repulsion,

$\alpha_0=\alpha_B$  – takeoff angle of sportsman's masses center at repulsion,

In projections to Cartesian absolute coordinates system this equation takes the form:

$$v_{0x}=V_G; \quad v_{0y}=V_B; \quad v_x=v_0 \cos \alpha; \quad v_y=v_0 \sin \alpha.$$

Absolute initial takeoff speed is expressed as follows:

$$v_0 = \sqrt{v_{0x}^2 + v_{0y}^2}$$

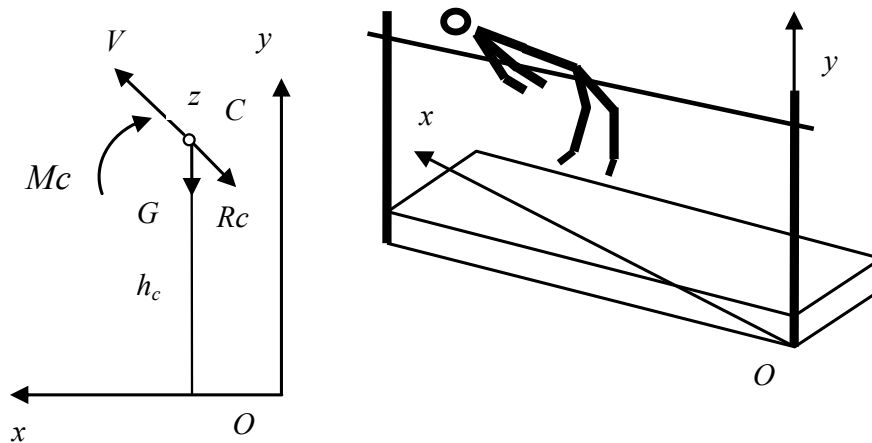


Fig.2. Calculated diagram for determination of rational bio-mechanical parameters in flight phase

G – gravity force, Mc – moment of air resistance forces,  $h_c$  – current height of body masses center, Rc – air resistance force.

Air resistance force Rc for objects, moving in air of  $\rho$  density equals to vector sum  $\vec{R}_c = \vec{R}_n + \vec{R}_r$  of lifting force –  $R_n = 0.5c_n \rho S V^2$  and head resistance force  $R_r = 0.5c_r \rho S V^2$ . During calculation of these forces, non-dimensional coefficients ( $c_n$  and  $c_r$ ) are determined experimentally depending on the shape of a body and its orientation in its environment. Value S (middle) is determined by the value body cross section's projection on the plane, which is perpendicular to the axis of movement, V – is absolute speed of body.

It is known that air density is  $\rho = 1,3 \text{ kg/m}^3$ . It should be noted that body in flight has common free motion. Angle of body turns in anatomical planes change and with it, correspondingly, value S also changes. Determination of variable S middle values and head resistance coefficient  $c_r$  require additional researches, that is why for solution of our task we take their averaged values.

Also, it is possible to determine average values of coefficient ( $\kappa$ ), which is near  $V^2$  – absolute speed of body flight in jump.

Without consideration of lifting force, which has very negligible, we obtain average values of the coefficient.

$$k = 0.5c_r \rho S \quad k = 0-1 \text{ kg/m.}$$

Then  $R_r = R_c = kV^2$ .

Let us consider that sportsman's body moves in one of anatomical planes in flight phase. In our case it is sagittal plane.

Let us compose dynamics equations of plane-parallel motion in projections on co-ordinates axes.

$$m\ddot{x}_c = P_x^e; \quad m\ddot{y}_c = P_y^e; \quad J_z \ddot{\phi} = M_z^e.$$

Here  $m$  – body mass,  $\ddot{x}_c, \ddot{y}_c$  – correspond to projections of masses center acceleration,  $P_x^e, P_y^e$  – projections of external forces, which affect on body, resultant,  $J_z$  – moment of inertia in relation to front axis,  $\ddot{\phi}$  – corresponds to angle acceleration at body turn around front axis,  $M_z^e$  – sum moment of external air resistance forces relating to front axis.

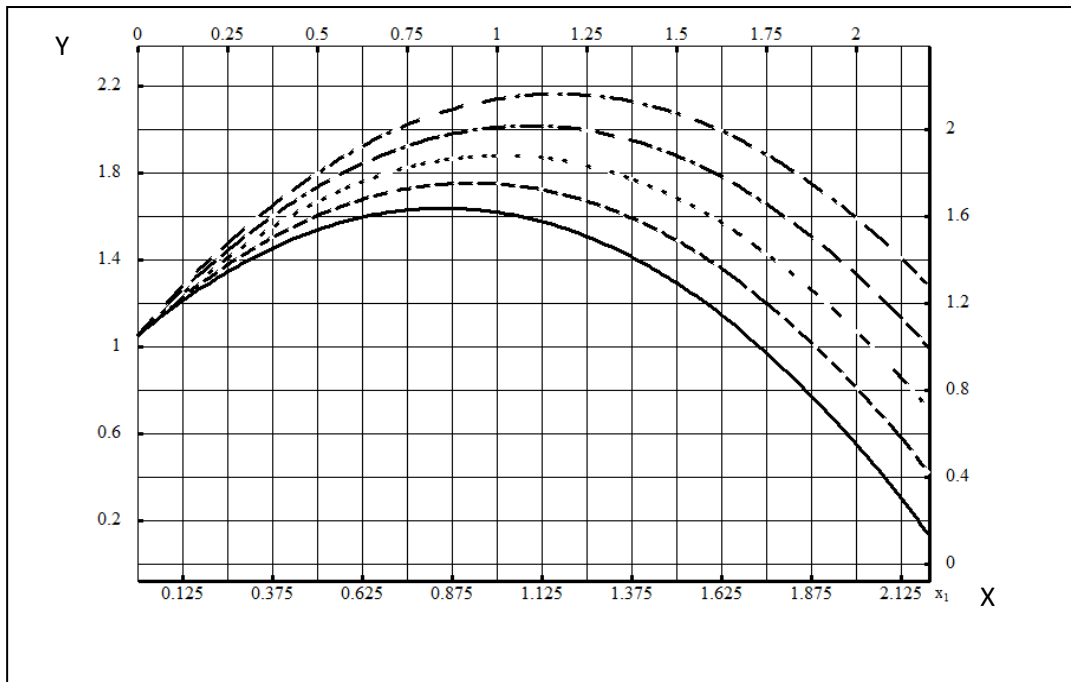
For movement in plane  $xAy$ , equation system can be expressed as follows:

$$\begin{aligned} m\ddot{x} &= -R_{c_x}; & m\ddot{y} &= -G - R_{c_y}; & J_z \ddot{\phi} &= -M_c \\ m\ddot{x} &= -kv^2 \cos \alpha; & m\ddot{y} &= -mg - kv^2 \sin \alpha; & J_z \ddot{\phi} &= -k\phi^2 \\ \cos \alpha &= \dot{x}/v; & \sin \alpha &= \dot{y}/v; & v &= \sqrt{v_x^2 + v_y^2} = \sqrt{\dot{x}^2 + \dot{y}^2} \end{aligned}$$

$\alpha$  – angle between current projections of body masses center speed and speed vector.

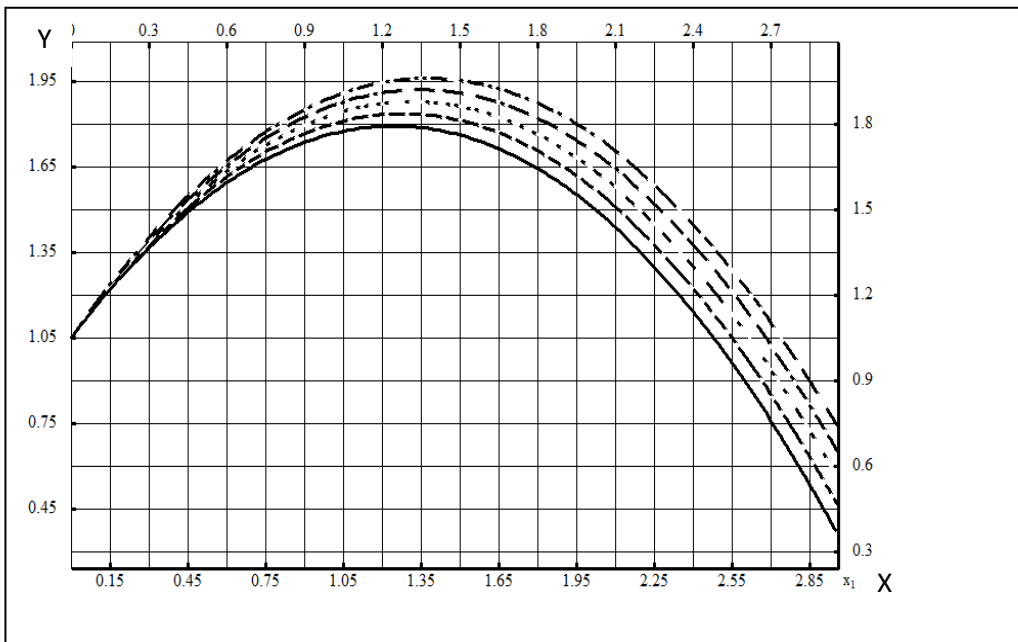
Solution of this task requires integrating of differential equations of motion.

Let us regard influence of sportsman body masses center's speed and angle, sportsman body masses center's position in repulsion phases, moment of inertia in regard to the front axis, considering air resistance forces.



$\cdots$   $V_0=5.8\text{mps}$ ;  $-\cdot-$   $V_0=5.4\text{mps}$ ;  $\cdots$   $V_0=5.0\text{mps}$ ;  $--$   $V_0=4.6\text{mps}$ ;  $---$   $V_0=4.2\text{mps}$ .

Fig.3. Characteristic curves of masses center trajectory for different values of takeoff initial speed



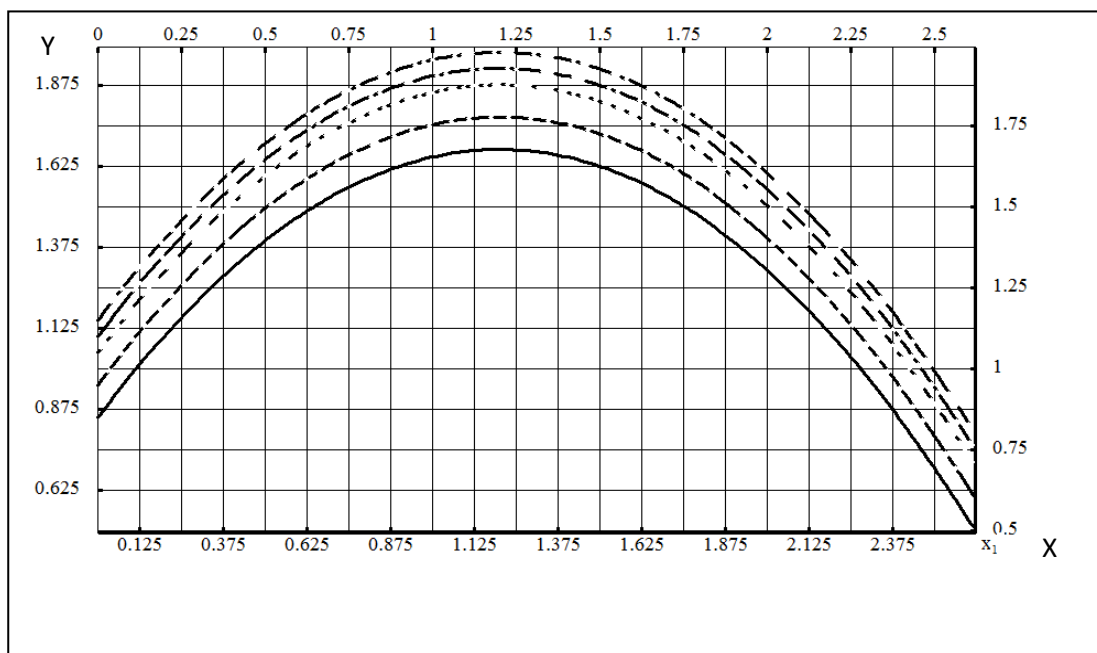
$\cdots$   $\alpha_0=58^\circ$ ;  $-\cdot-$   $\alpha_0=56^\circ$ ;  $\cdots$   $\alpha_0=54^\circ$ ;  $--$   $\alpha_0=52^\circ$ ;  $---$   $\alpha_0=50^\circ$ .

Fig.4. Characteristic curves of masses center trajectories for different values of takeoff angles

Results of calculations on mathematical models and obtained characteristic curves show:

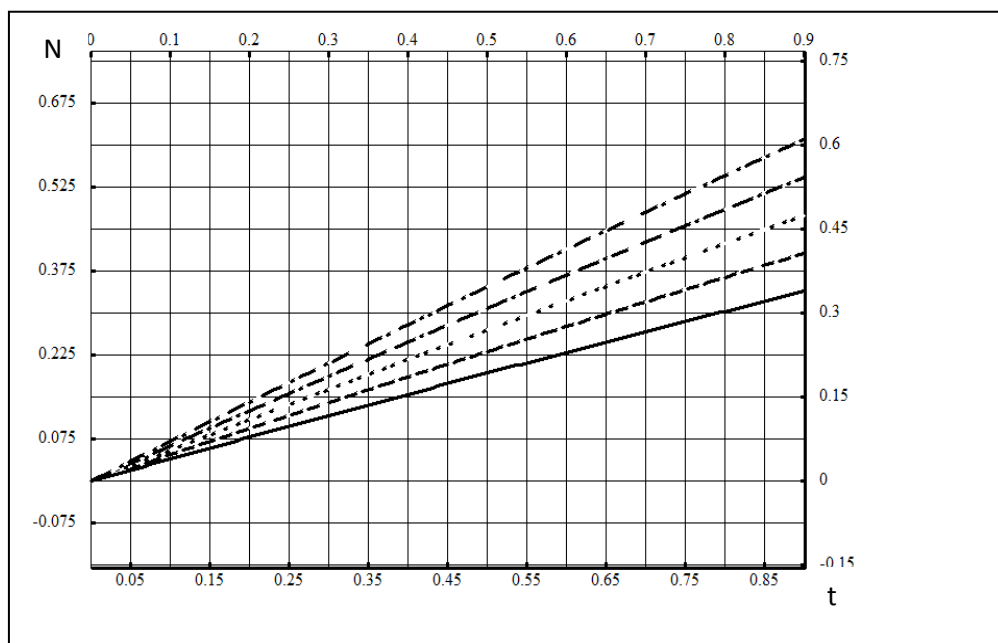
- different values of body's moments of inertia, relating to front axis, in flight change angle speed value and, consequently, values of turns quantity  $N$ , that, with rational postures, can promote quicker rotation around front axis when over passing bar;
- for actual speeds of sportsman's body flight, air resistance force for different middles affects negligibly on changing of result;
- for reaching high results it is necessary to increase horizontal running speed and, as a result, initial takeoff speed, takeoff angle of body masses center, body masses center height at repulsion with their rational combination.

The obtained calculated bio-mechanical characteristics of high jump are the models and in practice they will be a little different.



— ·  $h_{c0}=1.15\text{m}$ ; - - ·  $h_{c0}=1.10\text{m}$ ; ····  $h_{c0}=1.05\text{m}$ ; - -  $h_{c0}=0.95\text{m}$ ; —  $h_{c0}=0.85\text{m}$ .

Fig. 5. Characteristic curves of masses center trajectory for different body masses center height values



— ·  $I_c=5\text{kgpm}^2$ ; - - ·  $I_c=9\text{kgpm}^2$ ; ····  $I_c=13\text{kgpm}^2$ ; - -  $I_c=17\text{kgpm}^2$ ; —  $I_c=21\text{kgpm}^2$ .

Fig 6. Characteristic curves of quantity of turns for different moments of inertia relating to front axis

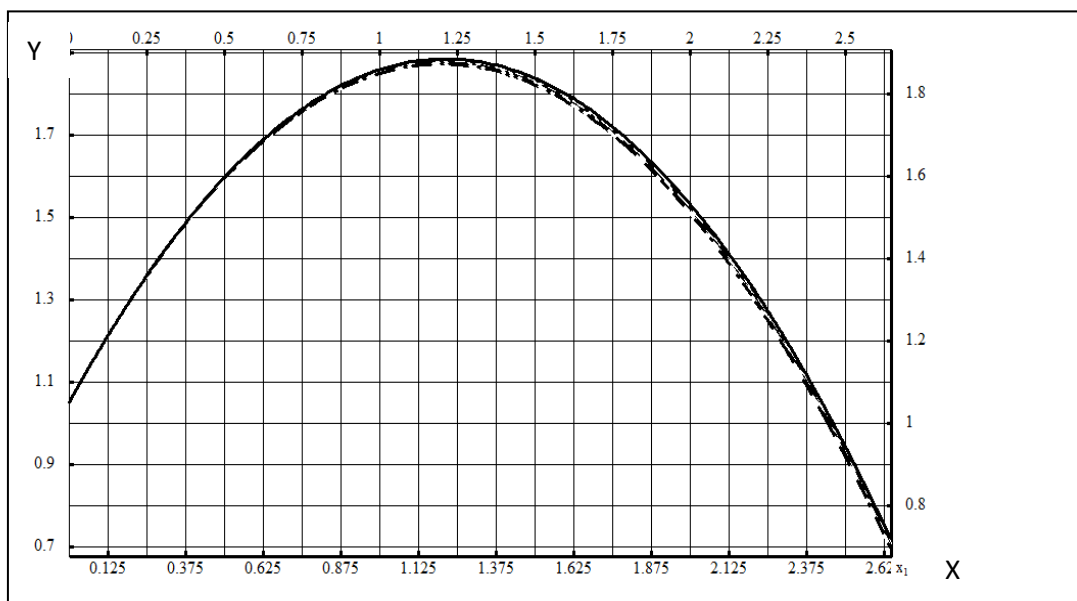
In researches of I.V. Lazarev the main indicators, which influences, to the largest extent, on improvement of running “fosbury flop” high jumps results [11]:

A) kinematical indicators:

- takeoff height in unsupported phase of jump 0,74 - 0,98m;
- running speed 0,55mps;

B) dynamic indicators:

- repulsion impulse by vertical component 0,67 - 0,73;
- average repulsion force by vertical component 0,70 - 0,85;
- force in extremum 0,62 - 0,84.



--- k=1kgpm; - · - k=0.75 kgpm; ···· k=0.5 kgpm; --- k=0.25 kgpm; — k=0 kgpm.

Fig. 7. Characteristic curves of masses center trajectory for different values of air resistance forces

Besides, it was established that the peculiarities of inner individual structure formation of qualified jumpers' technique are characterized, with increasing of sport results, by purposeful change of running speed, angle of leg position for repulsion, body's general masses center (g.m.c.) vertical movement way, body's g. m. c. takeoff angle. At repulsion it is necessary to pay special attention to foot position on rest with following, but not simultaneous, acceleration of waving links. Positioning of leg for repulsion shall be executed by active running movement from hip. Jumper shall carry out positioning of leg on full foot, with it the foot shall be located along the line of the running last step [11, 12].

G.A. Zaborskiy in his work stated that approaching of actual repulsion movement characteristics to theoretically optimal values is reached with increasing of masses center's angle of pitch above rest at starting the repulsion in condition of constant running speed. With this the portion of a sportsman's brake actions reduces in repulsion, while accelerated waving actions of body links, directly in repulsion phase, are activated due to the transfer of these movements' portion from buffering phase to the phase of repulsion [9].

### Summary

Analysis of special literature showed that for ensuring of high jump's good result it is necessary to consider a number of many interconnected factors, which ensure maximal body flight height.

In general, high jumps sport results are determined by bio-mechanical characteristics, which a sportsman is able to realize, namely: running speed, sportsman body masses center's takeoff speed and angle, repulsion height of a sportsman's body masses center.

The following ranges of bio-mechanical characteristics increase the effectiveness of high jumps:

- sportsman's masses center's takeoff speed– 4.2-5.8 m. p. s:
- sportsman's masses center's takeoff angle–  $50^{\circ}$  - $58^{\circ}$ ;
- sportsman's masses center's takeoff height – 0.85- 1.15m.

It has been established that for achieving of high results it is necessary to increase horizontal running speed and, as a sequence, initial takeoff speed, body masses center's takeoff angle, body masses center's takeoff height at repulsion with their rational combination.

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