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STUDYING THE PHYSICAL LAWS OF MOVING BALL AT THE POWER SERVE IN JUMP

Abstract. ***Purpose***: *to study the dependence of the characteristics of the trajectory of moving ball, which determine the accuracy of the power serve in the jump, from the values of the relevant kinematics variables.* ***Material and Methods***: *analysis of video filming, teacher observations, mathematical methods of processing the results.* ***Results***: *the appropriate experiment, whose data were used to study the physical laws of moving ball, have been proposed and carried out. A detailed analysis of the characteristics of the ball trajectory, depending on the choice of the values of kinematics parameters such as speed, altitude and angle of moving ball relative to the playground at the initial time of performing serve, have been carried out.* ***Conclusions***: *it is shown in particular that the precision of performing serve is substantially depended on the emission angle and the initial velocity of the ball.*

Keywords: *volleyball, trajectory, experiment, coordinates, target, efficiency.*

Introduction. The modern volleyball makes more and more great demands to technical-tactical skill of volleyball players, and also of a level of the development of their physical capacities [6]. The sports technique of the performance of a serve of a ball in volleyball can be considered as a certain system of movements by means of which the corresponding motive problem is solved. The efficiency of this technique is defined by a high coordination of movements of a sportsman, their stability and rationality that allows reaching considerable results in the competitive activity. An important element of an approach to studying of a technique is a detailed consideration of its kinematic structure which includes the determination of duration of various phases, trajectories, speeds and accelerations of flight of a ball, etc. [1–3; 5; 7; 8]. Different types of filming and modern computer technologies are widely applied to this purpose now [3-5].

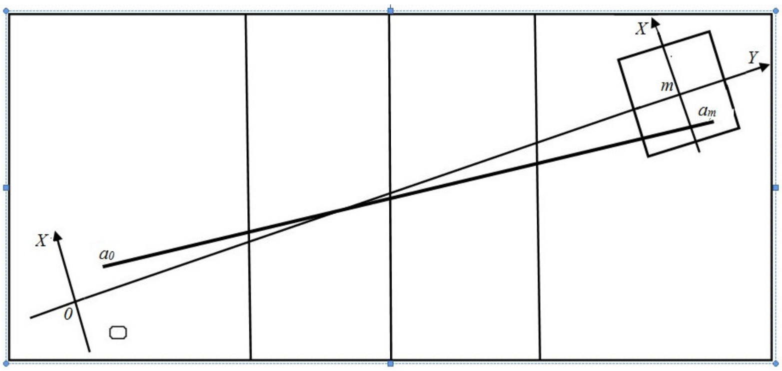
Studying of opportunities of the improvement of accuracy of its performance is of great importance for a solution of the problem of the increase of efficiency of a power serve in a jump. It is necessary to carry out the detailed analysis of various characteristics defining a trajectory of flight of a ball and to study their dependence on the corresponding kinematic variables for receiving the reliable conclusions connected with a problem of the improvement of accuracy of power serve in a jump. For this purpose we offered and made an experiment. Using the obtained data, the sizes were determined in works [3; 5] characterizing the movement of a ball after a serve, and also kinematic variables on which the trajectory of its flight depends. Processing of the received results by means of a method of average sizes is executed, and also the correlation analysis of the corresponding characteristics is carried out.

The objective of the research: studying of the dependence of characteristics of a trajectory of a flight of a ball which determine the accuracy of the performance of a power serve in a jump, from values of the corresponding kinematic variables.

Material and methods of the research: analysis of video filming, pedagogical supervision, mathematical methods of processing of results.

Communication of the research with scientific programs, plans, subjects. The research is executed according to the plan of the research work of the chairs of Olympic and professional sport, the chair of sports and outdoor games of Kharkov state academy of physical culture. The direction of the research corresponds to a subject of the Consolidating plan of the research works in the sphere of physical culture and sport for 2011-2015 in the direction: "The improvement of the educational-training process in sports games" (the number of the state registration is 0111U003126).

Results of the research and their discussion. An important role in the increase of the efficiency of a power serve in a jump is played by the accuracy of its performance in a certain zone of a playground. In this work the technique is offered which is allowing volleyball players to improve a technique of such serve due to the corresponding adjustment of kinematic parameters of its performance for the purpose of an exact hit in a certain zone. We made the experiment for the practical realization of this technique which scheme is submitted in the pic. 1. Details of this experiment are described in works [3; 5].



Pic. 1. The scheme of the executed experiment
(a rectangle is near the beginning of coordinates – a video camera projection to a platform)

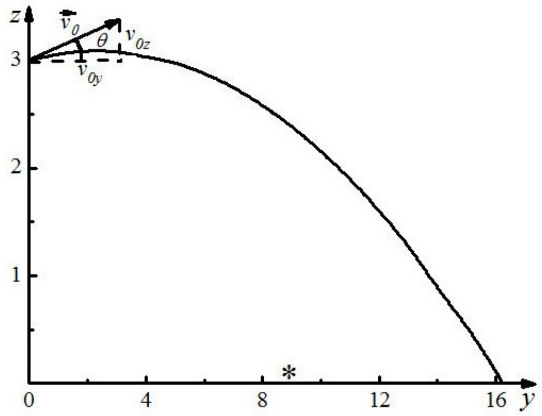
The volleyball court is represented in the pic. 1 on which the system of reference *XY* chosen by us is presented the fixation by means of vertical shooting by a high-speed video camera of coordinates of a projection of the center of gravity of a ball both at an initial time point a_0, and in a place of its landing a_m on a platform. The straight line piece which connects the points a_0 and a_m, is the line of crossing of the plane in which the corresponding trajectory of flight of a ball passes in each separate serve, with the playground plane. This line characterizes the direction of the flight of a ball after the performance of a serve, and the size of a piece of a_0a_m defines a range of its flight.

The initial speed v_0 of a flight of a ball, and also initial coordinates of the corresponding projection of a ball to a playground were defined by us when processing frames of video filming of the existential evolution of its flight by means of the software Dartfish [3; 5].

As a result of carrying out the experiment we obtained the data on the performance of 55 power serves in a jump in the form of the corresponding coordinates in the system of reference *XY*. In this work regularities of behavior of trajectories of the movement of a ball with the use of the obtained data are investigated in details. As an example we will give results of such analysis below, using the relevant data for the serve chosen by us in a series of attempts executed by the volleyball player who showed the best result. We will note that only as a result of the performance of this serve, the ball got precisely to a target [5]. We will assume for the descriptive reasons that the point a_0 (pic. 1) corresponds to a blow place on a ball by the player when performing the serve, and a_m point – to a ball landing place. At the solution of the specified task we will choose a reference system in which the axis z is perpendicular the platform planes from the beginning of coordinates in the point a_0, and the axis y is directed along the line a_0a_m.

As a result of the serve the center of gravity of a ball receives an initial impulse $\vec{p}_0 = m\vec{v}_0$, where m – the mass of a ball. The movement of a ball happens in the vertical plane zy in which there are vectors $\vec{v}_0$ and $\vec{P} = m\vec{g}$ (ball gravity, $\vec{g}$ – acceleration of gravity).

Further we won't consider a ball as a spatial object, and consider the air resistance. We will note that the accounting of these effects significantly won't affect regularities of the movement of a ball, however can introduce some amendments in numerical estimates of characteristics of a trajectory of its flight. In the case under consideration for the solution of the equations of the movement of a ball it is possible to receive analytical expressions which simplify carrying out the further analysis.



Pic. 2. A trajectory of a flight of a ball (an asterisk – a grid arrangement on a playground)

In the initial time point ($t=0$) coordinate of the ball $y_0=0$, and $z_0=h_0$, where h_0 – a ball height over the platform level at the time of a blow to it. An acceleration of a ball in any point of a flight is equal $\vec{g}$. In the case under consideration, the determined by us initial speed of flight of the ball is v_0=17,48 m/s. The blow to a ball was executed by the player at height h_0=3 m.

Vector projections $\vec{v}_0$ on axes of coordinates z and y are equal respectively $v_{0z} = v_0 \sin\theta$, and $v_{0y} = v_0 \cos\theta$, where θ – the angle of a ball departure formed by a vector $\vec{v}_0$ and an axis y. As the vector projection $\vec{g}$ on an axis y is equal to zero, a flight of a ball along this axis is uniform with a constant speed v_{0y}. The movement of a ball along an axis z is variable with the acceleration g and the initial speed v_{0z} (the projection $\vec{g}$ to this axis is equal to g).

The equation of a trajectory of a flight of a ball can be written down in the following look:

$$z = h^* - (y - y^*)^2 g/2v_0^{\,2}\cos^2\theta, \quad (1)$$

The curve described by the received equation is the parabola turned by top up and passing through a point with coordinates $u=0$, $z=h_0$. It should be noted that in a real situation the air resistance which increases in proportion to a ball speed square, can distort a trajectory of its movement a little and affect, in particular, a flying range.

In the equation (1) a maximum height of a flight of a ball h^* (a top of parabola) is defined by expression $h^* = h_0 + v_0^{\,2}\sin^2\theta/2g$ over the level of a platform, thus the coordinate y of its top is defined by a formula $y^* = v_0^2 \sin 2\theta/2g$. The distance L from the beginning of coordinates to a place of falling of a ball on a platform a_m (a flying range) corresponds to value $z=0$. A departure angle θ at which the ball hits the point L, is possible to define from the following equation:

$$(1 + tg^2\theta)\,gL^2/2v_0^{\,2} - Ltg\theta - h_0 = 0, \quad (2)$$

As the angle θ wasn't measured in the experiment, we will find him, previously having defined a flying range of a ball L (16,22 m), using the results of our measurements of coordinates of a departure of a ball given above after a serve and a place of its falling. From a quadratic equation (2), using values of the parameters stated above, we will define an angle θ which makes 4,45°. The maximum height of a flight of a ball after the performance of a serve h^*=3,093 m is reached at the distance y^*=2,42 m from the beginning of coordinates in the chosen reference system. Thus the ball flies by over a grid at the height of 2,46 m from the platform level.

Apparently from the equation (1), characteristics of a trajectory of a flight of a ball at a power serve in a jump depend on three parameters: θ, v_0, h_0. It is of interest to investigate a behavior of a trajectory of a flight of a ball depending on the change of each of the listed parameters. For this purpose the corresponding calculations were carried out in the same plane zy which is represented in the pic. 2. The results of various options of calculations in which we fixed values of two chosen parameters are given below, and the value of the third varied in some limits.

For options in which values of parameters $h0=3$ m, v_0=17,48 m·s^{-1}were fixed, and values of the angle θ were changed by us in some limits, the following results were received. So, at $\theta = 9^o$ a flying range of a ball L considerably increased and reached 19,14 m, having exceeded the distance from the purpose more than on 2 m. In this case the ball landed behind the front line of a platform. At a choice of a value of the angle θ is equal 6^o *m* L=17,22, i.e. a ball gets to platform limits, but considerably exceeds the distance to the purpose. At the insignificant reduction of the angle θ in comparison with its value 4,45^o the ball gets to a grid after a serve.

The dependence of a flying range of a ball on value of the initial speed v_0 it was investigated by us at the fixed h_0=3 m and the angle θ = 4,45^o and various values v^0. For the option of calculations with v^0 is equal 20 m · s^{-1} and 16,5 m ·s^{-1} about flying range of a ball made 18,94 m and 15,19 m respectively. In the first case the ball departs out of platform limits, and in the second – gets to a grid.

Table 1

Characteristics of trajectories of a flight of a ball depending on a choice of values of kinematic variables

№	θ gr	v_0 m/s	h_0 m	L m	h^* m	y^* m	Δh m
1	9,00	17,48	3,00	19,14	3,38	4,82	0,70
2	6,00	17,48	3,00	17,22	3,17	3,24	0,26
3	4,45	17,48	3,00	16,22	3,09	2,42	0,03
4	4,45	20,00	3,00	18,94	3,12	3,16	0,32
5	4,45	16,50	3,00	15,19	3,08	2,15	–
6	4,45	17,48	3,15	16,58	3,24	2,42	0,18
7	4,45	17,48	2,90	16,02	2,99	2,42	–

In the third option of calculations the dependence of characteristics of a trajectory of a ball on value of height h_0 was calculated by us at the fixed values θ = 4,45^o and v_0=17,48 m/s. At the chosen h_0 values which are equal 3,15 m and 2,9 m the flying range of a ball made 16,58 m and 16,02 m respectively. As a result in the first case the ball hit the specified mark, and in the second – the ball got to a grid.

Some characteristics of trajectories of the movement of a ball for the options considered above are presented in the tab. 1 (Δh – a distance of the center of gravity of a ball to the upper angle of a grid over a place of its flight). The given values Δh are the simplified estimates of these sizes in which the ball sizes weren't considered.

Conclusions. In work with the use of the data on a power serve in a jump received in the experiment offered by the author some characteristics of trajectories of a flight of a ball depending on values of kinematic variables are calculated. It is shown that the most essential dependence of a flying range of a ball to the chosen target, and, therefore, and the accuracy of the performance of a serve is observed from a departure angle θ and a ball speed v_0.

Prospects of further researches. For receiving more reliable and valid conclusions by results of the offered experiment it is necessary to investigate also other characteristics determining the accuracy of a power serve in a jump with the use of bigger volume of data on their performance. On the basis of such analysis is to develop the corresponding practical recommendations for the increase of accuracy of a serve.

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