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Volleyball spiking technique influence factors biomechanical model research and application

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ABSTRACT

Volleyball as a sports event of world concerns, and China has also ranked among world volleyball powers, so Chinese people are fonder of volleyball. In order to let Chinese people volleyball level to more effective improve, the paper gets volleyball and athlete hitting instant each joint speed relations by studying on arms dynamics when volleyball players spike. Carry out rotational inertia analysis on them, and get athlete each joint momentum relations, and then use Lagrange equation established constraint particle dynamical equations to solve that volleyball momentum is up to athlete wrist joint momentum when hitting, and get when volleyball player spikes, firstly it should let shoulder joint angle to arrive at minimum value and then let elbow joint and wrist joint angle to arrive at minimum, and arms crooked degree gets bigger, it is more beneficial to speed up wrist joint speed so that let small arm angular speed to be larger than big arm angular speed, let impulse when volleyball is hit to be increased. Therefore, public can pay more attention to arms exercises when take volleyball exercises.

KEYWORDS

Dynamics analysis; Lagrange dynamical equation; Theorem of momentum; Rotational inertia.

INTRODUCTION

In 19th century, basketball and tennis were most popular sports events in America at that time, but people felt that basketball exercise amount was too big while tennis was relative too relaxed by comparing; didn't it mean any neutral sport here? In 1895, one sports staff of Massachusetts had drawn from instincts, he combined basketball and tennis, but due to basketball court was too small, the new playing ball was prone to shot out of bounds, so he changed rules as ball cannot drop in ground before returning in competition, and changed heavier basketball into basketball bladder, though it was light and not easy to control, the trial effects were good. Modern volleyball adopted standard ball has already be revised more than thousand times in all ages, but its specification has no bigger differences with initial used ball. In the beginning, America regulated volleyball participants as six people, after introducing volleyball to Asia, due to Asian population base is larger, and people took more outdoor exercises, field was larger, initial Asian volleyball amount of people entering in the court was regulated as sixteen people, till fifties of 20th century six-person system stipulation appeared in China and formal adopted in the next year.

Volleyball was formal listed as Olympic Games competitive sports event in 1964, after that, volleyball started to rapidly develop, its techniques and tactics and other contents were also constantly perfecting. In the earlier times, tall European athletes were dominant and always the hegemon of volleyball, but after sixties, Japan, China and other Asian countries become famous in the world with changeable and flexible playing, and Cuba with good leaping ability also showed its advantages, subsequently American volleyball techniques were also rapidly advancing, till eighties of 20th century, world volleyball powers were China, Japan, the Soviet Union, Cuba and America. With the swift development of time, modern volleyball tactics and techniques also become more and more perfect, modern volleyball techniques focus on skyer and storm, rapidly and fast changing two techniques to mutual supplement their shortcomings and keep respectively advantages, make comprehensive application; in defensive tactics aspect,it highlights when defending, defensive players should be flexible and changeable and avoid by all means to stick to conventions, creative and have planned organizational defense and counter back. Volleyball motion techniques are quite a lot, for example service, touching ball, attacking hit, passing the net, passing center line and blocking as well as others should have higher professional quality. The paper will make corresponding analysis and researches on a kind of strongest attacking way "spiking" in volleyball.

MODEL ESTABLISHMENT AND SOLUTION

Volleyball spiking motions techniques

When volleyball athletes spike, firstly it steps forward for three times, when athlete steps forward the first step, it must let body orientations to be well adjusted, the step two is well defining self stride, and twist body towards right rear (right hand hits ball), the step three is taking-off, when taking-off, it must find out proper position, after taking-off head is nearly in $20 \sim 30cm$ orientation far from ball and in head top right. Subsequently, straight abdomen and swing arm, body rotates left, align angles to powerfully swing arms. Figures 1, Figure 2 are volleyball athletes spiking rear view and lateral view.

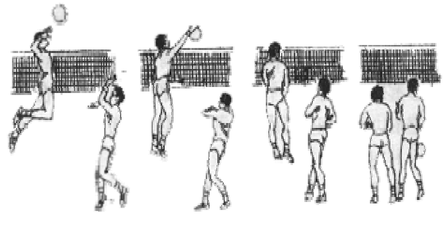

Figure 1 : Volleyball athletes spiking rear schematic view

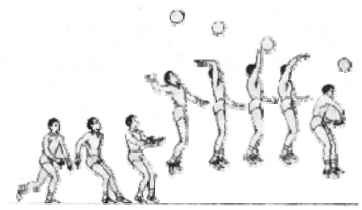

Figure 2 : Volleyball athletes spiking side schematic view

Volleyball athletes spiking dynamical analysis

Now regard volleyball player spiking used arms' bigger and smaller arms as two different volumes rigid body, and establish shoulder joint, elbow joint and wrist joint into three freedom degree models, as Figure 3 shows.

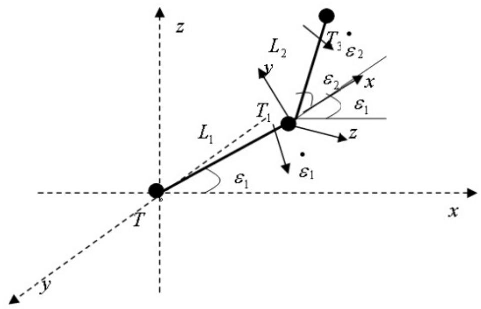

Figure 3 : Volleyball athlete spiking arm freedom degree schematics diagram

Set volleyball player shoulder joint, elbow joint and wrist joint are respectively T , T_1 and T_3 points, big arm and small arm lengths are respectively L_1, L_2 , big arm and small arm anatomical angles are $\varepsilon_1, \varepsilon_2$. Among them, T point and T_1 point trivector is $\dot{\gamma}_1, \dot{\gamma}_2$,which is volleyball player spiking arms big arm and small arm angular speed with respect to reference system of earth, T_1 point speed is $\dot{\varepsilon}_2$,its size is : $\dot{\varepsilon}_2 = \dot{\gamma}_2 - \dot{\gamma}_1$.

When volleyball player is spiking, volleyball hit speed and momentum are up to wrist hitting volleyball instantaneous speed, while spiking arms big arm and small arm angular speed as well as T_1 angular speed can affect T_3 angular speed. Due to T_1 in circulation motion process drives L_2 to make translation and rotation in relative coordinate system $T_1 - xyz$. So T_3 speed is correlated to its relative speed and T_1 speed,that is : $\vec{C}(\vec{T}_1)_G = \dot{\varepsilon}_1 \times \vec{R}_1 = \dot{\varepsilon}_1 \times \vec{R}_1, C(\vec{T}_3)_L = \dot{\varepsilon}_2 \times \vec{R}_2$.

$\vec{C}(\vec{T}_1)_G$ is T_1 speed vector in reference system, $C(\vec{T}_3)_L$ is T_3 point relative to T_1 point speed. $\dot{\varepsilon}_1, \dot{\varepsilon}_2$ are respective T and T_1 angular speed, $\vec{R}_1$ is T to T_1 position vector, $\vec{R}_2$ is T_1 to T_3 position vector.

To solve T_3 relative to reference system speed $\dot{T}_{3\,G} = \vec{C}(\vec{T}_3)_G$, it should first solve L_1 and L_2 partial motions to T_1 impact, according to vector theorem, it gets: $\dot{T}_{3\,G} = \dot{\varepsilon}_1 \times \vec{R}_1 + \dot{\varepsilon}_2 \times \vec{R}_2 + \dot{\varepsilon}_1 \times \vec{R}_2$,

$\dot{T}_{3\,G} = \dot{\varepsilon}_1 (\vec{R}_1 + \vec{R}_2) + \dot{\varepsilon}_2 \times \vec{R}_2$

Simplify and get: $\dot{T}_{3\,G} = \vec{T}_{3\,G} \times \dot{\varepsilon}_1 + \dot{\varepsilon}_2 \times \vec{R}_2$

T point lets T_1 point to generate speed as $\vec{T}_{3G} \times \dot{\varepsilon}_1, \dot{\varepsilon}_2 \times \vec{R}_2$ is generated speed that T_1 point leads to T_3 point, $\dot{T}_{3G}$ is T_3 point position vector in reference system.

In order to more clearly describe T 、T_1 and T_3 points speed relations, for Figure 3 model T and T_1 point angle as well as T_3 point position relations, it writes as : $\begin{cases} x_p = R_1 \cos\varepsilon_1 + R_2 \cos(\varepsilon_1 + \varepsilon_2) \\ y_p = R_1 \sin\varepsilon_1 + R_2 \sin(\varepsilon_1 + \varepsilon_2) \\ z_p = R_1 \cos\varepsilon_1 + R_2 \sin(\varepsilon_1 + \varepsilon_2) \end{cases}$

Then make differential with T point and T_1 point angle,relation with T_3 point position vector can be derived from above formula and get :

$$\begin{cases} dX = \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} d\varepsilon_1 + \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} d\varepsilon_2 \\ dY = \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} + \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} d\varepsilon_2 \\ dZ = \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} + \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} d\varepsilon_2 \end{cases}$$

Convert above formula into matrix form as:

$$\begin{pmatrix} dX \\ dY \\ dZ \end{pmatrix} = \begin{pmatrix} \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} & \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} \\ \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} & \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} \\ \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} & \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} \end{pmatrix} \begin{pmatrix} d\varepsilon_1 \\ d\varepsilon_2 \end{pmatrix}$$

By matrix property and vector product method, write above formula as: $d\vec{T}_{3G} = \vec{Y}\, d\vec{\varepsilon}$, from which $\vec{Y}$ is:

$$\vec{Y} = \begin{pmatrix} \dfrac{\partial X}{\partial \varepsilon_1} & \dfrac{\partial X}{\partial \varepsilon_2} \\ \dfrac{\partial Y}{\partial \varepsilon_1} & \dfrac{\partial Y}{\partial \varepsilon_2} \\ \dfrac{\partial Z}{\partial \varepsilon_1} & \dfrac{\partial Z}{\partial \varepsilon_2} \end{pmatrix}$$

$\vec{Y}$ is differential relation between current structure node angular displacement and T_3 point infinitesimal displacement. Input matrix relationship into above formula and can get:

$$\frac{d\vec{T}_{3G}}{dt} = \vec{Y}\frac{d\vec{\varepsilon}}{dt} \text{ or as } \vec{T}_{3G} = \vec{Y}[\dot{\varepsilon}_1, \dot{\varepsilon}_2]^T$$

Input it into T_3 point relative speed computational formula and can get:

$$\dot{O}_G = \begin{pmatrix} \dfrac{\partial X}{\partial \varepsilon_1} & \dfrac{\partial X}{\partial \varepsilon_2} \\ \dfrac{\partial Y}{\partial \varepsilon_1} & \dfrac{\partial Y}{\partial \varepsilon_2} \\ \dfrac{\partial Z}{\partial \varepsilon_1} & \dfrac{\partial Z}{\partial \varepsilon_2} \end{pmatrix} [\vec{\varepsilon}_1, \vec{\varepsilon}_2]^T \dot{\varepsilon}_1 + \dot{\varepsilon}_2 \times \vec{R}_2$$

According to rotational inertia theorem, it can get volleyball player overall rotational inertia should be: $P = \Sigma M_i H_i^2$

Among them, M_i is human body each particle mass, H is player each particle to axis length, due to human body is continuous distributed rigid body, it has: $P = \iiint_v H^2 dm = \iiint_v H^2 \rho dV$

ρ is human body density. In spiking Volleyball player used arms rotational tensor $\overset{\leftrightarrow}{Y}_c$ is: $\overset{\leftrightarrow}{Y}_c = \iiint_v \rho(H^2 \overset{\leftrightarrow}{E} - \vec{H}\vec{H})dV$

Volleyball player body any point O vector expression is $\vec{H} = H_1 \vec{E}_1 + H_2 \vec{E}_2 + H_3 \vec{E}_3$, $\vec{H}\vec{H}$ is product of two vectors; Unit tensor is: $\overset{\leftrightarrow}{E} = \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \end{bmatrix}$

unit orthogonal curve frame is : $(C; \vec{E}_1, \vec{E}_2, \vec{E}_3)$ 。

Volleyball player spiking instant arms resultant moment vector is $\Sigma \vec{k}_c$, $\vec{\beta}$ is athlete angular speed vector in inertial motion system, angular speed vector is $\vec{\omega}$, so volleyball athletes spiking instant arms rotational tensor moment equation is: $\Sigma \vec{k}_c = \overset{\leftrightarrow}{Y}_c \bullet \vec{\beta} + \vec{\omega} \times \overset{\leftrightarrow}{Y}_c \bullet \vec{\beta}$

Player arms moment equation in each coordinate axis direction is projection from original moment equation to three-position coordinate system, so player spiking instant arms rotation generated resultant moment T_1 is: $T_1 = \eta_1 \bullet J_1$

η_1 is spiking arms angular accelerated speed, J_1 is arms rotational inertia. And: $J_1 = \frac{m_1 j_1^2}{2}$

j_1 is big arm radius, m_1 is big arm mass, big arm angular accelerated speed η_1 is: $\eta_1 = \frac{dw_1}{dt} = \frac{d^2\beta_1}{dt^2}$

And then small arm angular accelerated speed η_2 is: $\eta_2 = \frac{dw_2}{dt} + \frac{dw_1}{dt} = \frac{d^2\beta_2}{dt^2} + \frac{d^2\beta_1}{dt^2}$

Then by Lagrange equations, establish constraint particle dynamical equation,define Lagrange function U as difference between system kinetic energy J and potential energy Q : $U = J - Q$

System dynamical equation is: $F_i = \frac{d}{dt}\left(\frac{\partial U}{\partial \dot{q}_i} - \frac{\partial U}{\partial q_i}\right) \quad i = 1,2,\ldots,n$

In above formula $\dot{q}_i$ is particle corresponding speed, q_i is particle dynamic energy and potential energy coordinate, F_i is the i coordinate acted force,big arm and small arm as well as coordinate axis included angle are respectively $\varepsilon_1, \varepsilon_2$, lengths are respectively L_1, L_2,big arm and small arm gravity center position distances with T point center and T_1 are respectively q_1, q_2,thereupon it is clear that big arm gravity center coordinate (X_1, Y_1) is:

$$\begin{cases} X_1 = p_1 \sin\varepsilon_1 \quad Y_1 = p_1 \cos\varepsilon_1 \\ X_2 = L_1 \sin\varepsilon_1 + p_2 \sin(\varepsilon_1 + \varepsilon_2) \quad Y_2 = -L_1 \cos\varepsilon_1 - p_2 \cos(\varepsilon_1 + \varepsilon_2) \end{cases}$$

Similarly,small arm gravity center coordinate (X_2, Y_2) can also be solved. System kinetic energy E_k and system potential energy E_p expression is:

$$\begin{cases} E_k = E_{k1} + E_{k2}, E_{k1} = \frac{1}{2} m_1 p_1^2 \varepsilon_1^2 \\ E_{k2} = \frac{1}{2} m_2 L_1^2 \varepsilon_1^2 + \frac{1}{2} m_2 p_2^2 (\varepsilon_1 + \varepsilon_2)^2 + m_2 L_2 p_2 \left(\varepsilon_{01}^2 + \varepsilon_1 \varepsilon_2\right) \cos \varepsilon_2 \\ E_p = E_{p1} + E_{p2}, E_{p1} = \frac{1}{2} m_1 g p_1 (1 - \cos \varepsilon_1) \\ E_{p2} = m_2 g p_2 [1 - \cos(\varepsilon_1 + \varepsilon_2)] + m_2 g L_1 (1 - \cos \varepsilon_1) \end{cases}$$

By Lagrange system dynamical equation, it obtained T point and T_1 moment M_h and M_k is:

$$\begin{bmatrix} M_h \\ M_k \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} + \begin{bmatrix} B_{111} & B_{122} \\ B_{211} & B_{222} \end{bmatrix} \begin{bmatrix} \varepsilon_1^2 \\ \varepsilon_2^2 \end{bmatrix} + \begin{bmatrix} B_{112} & D_{121} \\ B_{212} & D_{221} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \varepsilon_2 \\ \varepsilon_2 \varepsilon_1 \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}$$

In above formula B_{ijk} is:

$$\begin{bmatrix} B_{111} = 0 \quad B_{222} = 0 \quad B_{121} = 0 \quad B_{22} = m_2 p_2^2 \\ B_{11} = m_1 p_1^2 + m_2 p_2^2 + m_2 L_1^2 + 2 m_2 L_1 p_2 \cos \varepsilon_2 \\ B_1 = (m_1 p_1 + m_2 L_1) g \sin \varepsilon_1 + m_2 p_2 g \sin(\varepsilon_1 + \varepsilon_2) \\ B_{12} = m_2 p_2^2 + m_2 L_1 p_2 \cos \varepsilon_2 \quad B_{21} = m_2 p_2^2 + m_1 L_1 p_2 \cos \varepsilon_2 \\ B_{122} = -m_2 L_1 p_2 \sin \varepsilon_2 \quad B_{211} = m_2 L_1 p_2 \sin \varepsilon_2 \\ B_{112} = -2 m_2 L_1 p_2 \sin \varepsilon_2 \quad B_{212} = B_{122} + B_{211} \quad B_2 = m_2 p_2 g \sin(\varepsilon_1 + \varepsilon_2) \end{bmatrix}$$

By above analysis, it is clear that volleyball momentum is up to wrist spiking instant momentum, so when volleyball player is spiking, in order to let volleyball get maximum momentum, it should increase swinging arms force, so when $\varepsilon_1, \varepsilon_2$ meet $38° < \varepsilon^1 + \varepsilon^2 < 95°, 0 < \dot{\varepsilon}_1 < \dot{\varepsilon}_2, T_3$ point speed then can get maximum value in sagittal plane. And with $\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$ increase, when volleyball player is spiking, L_1 and L_2 anatomic angle changing rate arrives at maximum in unit time, and during the period L_2 anatomic angle changing rate is bigger than L_1 angle changing rate. The principle is that in the instant of spiking arms out of hitting instant, L_1 and L_2 included angle is almost $180°$, force will be transferred along L_1 axis to L_2,but due to L_1 and L_2 are connected that causes force loss during transmission process, therefore L_2 angular speed bigger than L_1 angular speed is more beneficial to T_1 point acceleration. And according to player spiking instant arms dynamical analysis result,it can get when volleyball player spikes, it should let T point angle to first arrive at minimum value and then let T_1 and T_3 point angles to arrive at minimum, and arms crooked degree gets bigger than it will be more beneficial to speed up T_3 point speed,and further let L_2 angular speed to be larger than L_1 angular speed, which let volleyball hit impulse to be increased.

CONCLUSION

The paper gets volleyball and athletes hitting instant each joint speed relations by arms dynamical analysis when volleyball player is spiking. Carry out rotational inertia analysis on them, and get athlete each joint momentum relations, and then use Lagrange equation established constraint particle dynamical equations to solve that volleyball momentum is up to athlete wrist joint momentum when hitting, and get when volleyball player spikes, firstly it should let shoulder joint angle to arrive at minimum value and then let elbow joint and wrist joint angle to arrive at minimum, and arms crooked degree gets bigger, it is more beneficial to speed up wrist joint speed so that let small arm angular speed to be larger than big arm angular speed, let impulse to be increased when volleyball is hit.

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