ISSN : 0974 - 7435 Volume 10 Issue 5

BioTechnology
An Indian Journal

FULL PAPER

BTAIJ, 10(5), 2014 [1226-1230]

Dynamics principle-based analysis and teaching on basketball shooting act

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ABSTRACT

The paper firstly makes research on kinematical equation after basketball shooting and gets that basketball flight distance and ball initial speed are in direct proportion, and ball flight distance will change as athlete release angle changes, when player shooting release angle is 45°, ball flight distance is the farthest. Subsequently analyze athlete shooting instant arms dynamics principle; it gets shooting moment each joint speed relations. And then from Lagrange equation, it establishes constraint particle dynamics equation, solves basketball momentum is up to athlete shooting instant wrist joint momentum, and gets when basketball player shoots, player's release angle should let arms and horizontal line included angle to remain around 45°-50°, when ball is about to enter into rim, its included angle with horizontal line should be 50°-55° that is most proper. Now, player's right shoulder joint and horizontal line instantaneous angle is 142°.

KEYWORDS

Kinematic principle;
Rotational inertia;
Basketball shooting;
Dynamical equation;
Physiology and anatomy.

INTRODUCTION

Basketball is one of the earliest American competitive events, it is originated from 1890s that was created by a young teacher in Field at that time and he was James Naismith. And inspiration that he created basketball was from local children favorite activity that shot the ball into peach basket, while subsequently he compiled basketball such sports event, which solved students in school couldn't take outside training in cold winter such difficulty at that time. In the beginning basketball stipulated one team appeared five people in field, recorded basketball shot into rim as one score, and at that time rim was the one with bottom closed, every time shooting, they should take ball out by ladder, subsequently it improved bamboo rim with bottom closed as live bottom iron rim. In 1892, it regulated that holding ball running was not allowed in the field, and rude acts also forbidden as well as others thirteen rules, while till 1893, basketball then added backboard and net, and it was introduced to China in 1910.

Basketball as a kind of team competitive event, mainly scoring ways is roughly divided into three kinds, shooting, layup and dunk. Shooting is player's uppermost scoring way in the field, and shooting has very high requirements on player's technique and team tactics; layup is favorite shot way by most players, because layup hit rate is very high and layup act is full of artistic feelings; and dunk is the biggest defensive difficulty shot way, it is up to player holds ball and jumps, then directly dunks it into rim. With technological progress, basketball has also been rapidly developed, nowadays players' heights are becoming higher and higher, basketball technique is also improving, which lets player attack and defense technique to be also constantly improved. The paper will research on basketball shooting act, analyzes its techniques and finds out correct shooting postures.

MODEL ESTABLISHMENT AND SOLUTION

Kinematics analysis when basketball is shot

After basketball player shooting basketball, the basketball will make parabolic motion in the air under gravity effects, by kinematical principle, it is clear that when the ball makes parabolic motions, it will have a initial horizontal speed $V_0 \cos\alpha$, and ball horizontal direction can be regarded to make constant motion, vertical direction initial speed is $V_0 \sin\alpha$, and regard it makes upcast motions. Therefore basketball kinematical equation is: $X = V_0 \cos\alpha t$

$H - H_0 = V_0 \sin\alpha t - gt^2/2$

V_0, α are respectively basketball initial speed and angle after player shooting the ball, rim height is H, release height is H_0, basketball flight journey is using X to express. Combine with above formula; it can get basketball flight journey and initial speed as well as release angle and other factors relationship as $X = [V_0^2 \sin\alpha \cos\alpha + V_0 \cos\alpha \sqrt{V_0^2 \sin^2\alpha - 2g(H - H_0)}]/g$

According to above formula, it can get that basketball flight distance will increase with initial speed V_0 increases, and it can get basketball shot moment different release angles and flight journey relations, as Figure 1 show.

By above Figure 1, it is clear that when ball initial speed is defined, ball flight distance will change with player release angle changes, and when player shooting release angle is 45°, ball flight distance is the farthest.

Basketball player shooting moment dynamics analysis

Now it can regard basketball player shooting used arms big arm and small arm as two rigid bodies with different volumes, and establish T, T_1 and T_3 points into three freedom degree model, as Figure 2 show.

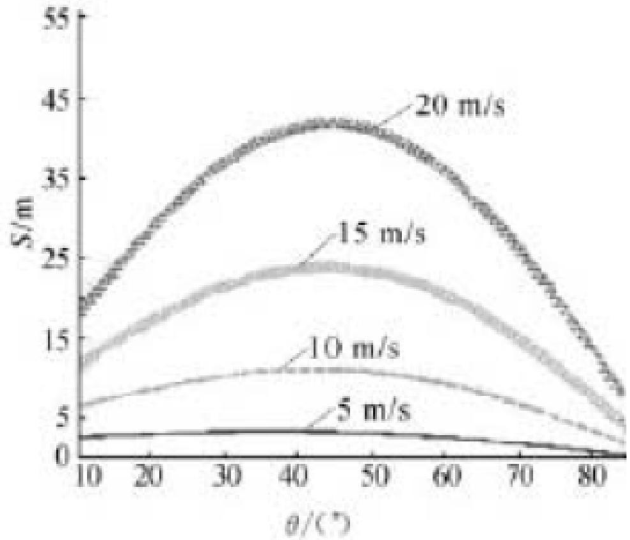

Figure 1 : Basketball initial angle changing curve

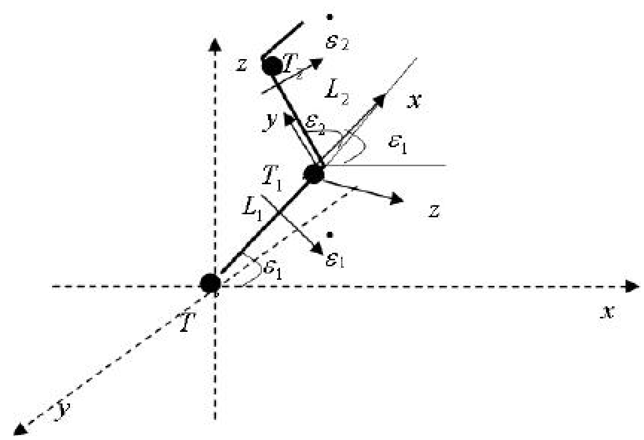

Figure 2 : Basketball player shooting arms freedom degree schematic figure

T, T_1 and T_3 points are respectively basketball player shoulder joint, elbow joint and wrist joint, big arm and small arm anatomical angles are $\varepsilon_1, \varepsilon_2$, L_1, L_2 are lengths of arms. Set that T point and T_1 point trivector is $\dot{\lambda}_1, \dot{\lambda}_2$, which is basketball player shooting arms big arm and small arm actual angular speed, $\dot{\varepsilon}_2$ is T_1 point speed, that: $\dot{\varepsilon}_2 = \dot{\lambda}_2 - \dot{\lambda}_1$.

When basketball player is shooting, basketball shooting initial speed has relations with wrist shooting moment instantaneous speed, and T_3 angular speed is affected by shooting arms big arm and small arm angular speed as well as T_1 angular speed. So T_3 speed is

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correlated to its relative speed and T_1 speed, expression is: $\vec{V}(\vec{T}_1)_G = \dot{\varepsilon}_1 \times \vec{D}_1 = \dot{\varepsilon}_1 \times \vec{D}_1$, $V(\vec{T}_3)_L = \dot{\varepsilon}_2 \times \vec{D}_2$.

$\vec{V}(\vec{T}_1)_G$ is T_1 actual speed vector, $V(\vec{T}_3)_L$ is T_3 point relative to T_1 point speed, $\vec{D}_1$ is T to T_1 position vector, $\vec{D}_2$ is T_1 to T_3 position vector. According to vector theorem, it solves L_1 and L_2 partial motions to T_1 impact:

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

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

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

For Figure 2 model T and T_1 point angle as well as T_3 point position relations, it decomposes and writes as:

$$\begin{cases} x_p = D_1 \cos\varepsilon_1 + D_2 \cos(\varepsilon_1 + \varepsilon_2) \\ y_p = D_1 \sin\varepsilon_1 + D_2 \sin(\varepsilon_1 + \varepsilon_2) \\ z_p = D_1 \cos\varepsilon_1 + D_2 \sin(\varepsilon_1 + \varepsilon_2) \end{cases}$$

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 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: $d\vec{T}_{3G} = \vec{W}\, d\vec{\varepsilon}$, from which $\vec{W}$ is:

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

$\vec{W}$ is differential relation between current structure node angular displacement and T_3 point infinitesimal displacement. Input matrix relationship into above formula and can get: $\dfrac{d\vec{T}_{3G}}{dt} = \vec{W}\dfrac{d\vec{\varepsilon}}{dt}$ or as $\vec{T}_{3G} = \vec{W}[\dot{\varepsilon}_1, \dot{\varepsilon}_2]^T$

Input it into T_3 point relative speed computational formula and can get: $\dot{T}_G = \begin{pmatrix} \dfrac{\partial X}{\partial\varepsilon_1} & \dfrac{\partial X}{\partial\varepsilon_2} \\ \dfrac{\partial Y}{\partial\varepsilon_1} & \dfrac{\partial Y}{\partial\varepsilon_2} \\ \dfrac{\partial Z}{\partial\varepsilon_1} & \dfrac{\partial Z}{\partial\varepsilon_2} \end{pmatrix} [\vec{\varepsilon}_1, \vec{\varepsilon}_2]^T \dot{\varepsilon}_1 + \dot{\varepsilon}_2 \times \vec{D}_2$

Basketball player shooting moment rotational inertial analysis and teaching

Basketball player shooting moment act is as Figure 3 show.

Due to player shooting moment, arms are rotating, according to rotational inertia theorem, it can get basketball player overall rotational inertia should be: $P = \Sigma m_i r_i^2$

Among them, m_i is human body each particle mass, r is player each particle to axis length, human body continuous function is: $P = \iiint_v r^2 dm = \iiint_v r^2 \rho dV$

Therefore basketball player shooting moment arms rotational tensor $\overleftrightarrow{R_c}$ is: $\overleftrightarrow{R_c} = \iiint_v \rho(r^2 \overleftrightarrow{E} - \vec{r}\vec{r})dV$

Basketball player body any point O vector expression is $\vec{r} = r_1\vec{E}_1 + r_1\vec{E}_2 + r_3\vec{E}_3$, $\vec{r}\vec{r}$ is product of two vectors; unit tensor is: $\overleftrightarrow{E} = \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \end{bmatrix}$, unit orthogonal curve frame is $(V; \vec{E}_1, \vec{E}_2, \vec{E}_3)$.

Figure 3 : Basketball player shooting arms schematic diagram

Basketball player shooting instant arms resultant moment vector $\sum \vec{y}_c$ is: $\sum \vec{y}_c = \overleftrightarrow{R_c} \bullet \vec{\chi} + \vec{\omega} \times \overleftrightarrow{R_c} \bullet \vec{\chi}$

Player arms moment equation in each coordinate axis direction is projection from original moment equation to three-position coordinate system, so player shooting instant arms rotation generated resultant moment T_1 is: $T_1 = \phi_1 \bullet I_1$

ϕ_1 is shooting arms angular accelerated speed, I_1 is arms rotational inertia. And: $I_1 = \frac{m_1 i_1^{\,2}}{2}$

Big arm angular accelerated speed ϕ_1 is: $\phi_1 = \frac{dw_1}{dt} = \frac{d^2\chi_1}{dt^2}$

And small arm angular accelerated speed ϕ_2 is: $\phi_2 = \frac{dw_2}{dt} + \frac{dw_1}{dt} = \frac{d^2\chi_2}{dt^2} + \frac{d^2\chi_1}{dt^2}$

Then by Lagrange equations, establish constraint particle dynamical equation that: $D = H - P$

D is system kinetic energy H and potential energy P difference, system dynamical equation is: $F_i = \frac{d}{dt}\left(\frac{\partial D}{\partial \dot{p}_i} - \frac{\partial D}{\partial p_i}\right) \quad i = 1, 2, \cdots, n$

In formula, $\dot{p}_i$ is particle corresponding speed, p_i is particle kinetic energy and potential energy coordinate, F_i is the i coordinate acting 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:

$$\begin{cases} X_1 = q_1 \sin\varepsilon_1 \quad Y_1 = q_1 \cos\varepsilon_1 \\ X_2 = q_1 \sin\varepsilon_1 + q_2 \sin(\varepsilon_1 + \varepsilon_2) \quad Y_2 = -q_1 \cos\varepsilon_1 - q_2 \cos(\varepsilon_1 + \varepsilon_2) \end{cases}$$

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

$$\begin{cases} E_k = E_{k1} + E_{k2}, E_{k1} = \frac{1}{2} m_1 q_1^2 \varepsilon_1^2 \\ E_{k2} = \frac{1}{2} m_2 L_1^2 \varepsilon_1^2 + \frac{1}{2} m_2 q_2^2 (\varepsilon_1 + \varepsilon_2)^2 + m_2 L_2 q_2 \left(\varepsilon_{01}^2 + \varepsilon_1 \varepsilon_2\right) \cos\varepsilon_2 \\ E_p = E_{p1} + E_{p2}, E_{p1} = \frac{1}{2} m_1 g q_1 (1 - \cos\varepsilon_1) \\ E_{p2} = m_2 g q_2 [1 - \cos(\varepsilon_1 + \varepsilon_2)] + m_2 g L_1 (1 - \cos\varepsilon_1) \end{cases}$$

Therefore T point and T_1 moment M_h and M_k is:

$$\begin{bmatrix} M_h \\ M_k \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} + \begin{bmatrix} A_{111} & A_{122} \\ A_{211} & A_{222} \end{bmatrix} \begin{bmatrix} \varepsilon_1^2 \\ \varepsilon_2^2 \end{bmatrix} + \begin{bmatrix} A_{112} & A_{121} \\ A_{212} & A_{221} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \varepsilon_2 \\ \varepsilon_2 \varepsilon_1 \end{bmatrix} + \begin{bmatrix} A_1 \\ A_2 \end{bmatrix}$$

In above formula B_{ijk} is:

$$\begin{bmatrix} A_{111} = 0 \quad A_{222} = 0 \quad A_{121} = 0 \quad A_{22} = m_2 q_2^2 \\ A_{11} = m_1 q_1^2 + m_2 q_2^2 + m_2 L_1^2 + 2 m_2 L_1 q_2 \cos\varepsilon_2 \\ A_1 = (m_1 q_1 + m_2 L_1) g \sin\varepsilon_1 + m_2 q_2 g \sin(\varepsilon_1 + \varepsilon_2) \\ A_{12} = m_2 q_2^2 + m_2 L_1 q_2 \cos\varepsilon_2 \quad A_{21} = m_2 q_2^2 + m_1 L_1 q_2 \cos\varepsilon_2 \\ A_{122} = -m_2 L_1 q_2 \sin\varepsilon_2 \quad A_{211} = m_2 L_1 q_2 \sin\varepsilon_2 \\ A_{112} = -2 m_2 L_1 q_2 \sin\varepsilon_2 \quad A_{212} = A_{122} + A_{211} \quad A_2 = m_2 q_2 g \sin(\varepsilon_1 + \varepsilon_2) \end{bmatrix}$$

By above analysis, it is clear that basketball momentum is up to wrist shooting instant momentum, so when basketball player in shooting teaching, in order to let basketball get maximum momentum, it should let player increase swinging arms force, so when $\varepsilon_1, \varepsilon_2$ meet $45^\circ < \varepsilon^1 + \varepsilon^2 < 90^\circ$, $0 < \dot{\varepsilon}_1 < \dot{\varepsilon}_2$, and increase with $\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$, when basketball player is shooting,

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. Because in the instant of shooting arms shooting, force will be transferred along L_1 axis to L_2, which 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 shooting instant arms dynamical analysis result, it can get when basketball player shoots, player release angle should let arms and horizontal line included angle to be remained around $45^\circ \sim 50^\circ$, when ball is about to enter into rim, its included angle with horizontal line should be $50^\circ \sim 55^\circ$. Now, player's right shoulder joint and horizontal line instantaneous angle is 142°.

CONCLUSION

The paper firstly makes research on kinematical equation after basketball shooting and gets that basketball flight distance and ball initial speed are in direct proportion, and ball flight distance will change as athlete release angle changes, when player shooting release angle is 45°, ball flight distance is the farthest. Subsequently analyze athlete shooting instant arms dynamics principle; it gets shooting moment each joint speed relations. Make analysis of its rotational inertia and get player each node momentum relations, then from Lagrange equation, it establishes constraint particle dynamics equation, solves basketball momentum is up to athlete shooting instant wrist joint momentum, and gets when basketball player shoots, player's release angle should let arms and horizontal line included angle to remain around $45^\circ \sim 50^\circ$, when ball is about to enter into rim, its included angle with horizontal line should be $50^\circ \sim 55^\circ$. Now, player's right shoulder joint and horizontal line instantaneous angle is 142°. These results provide good guiding for basketball teaching and training.

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