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Research on biomechanics based bat texture affects athlete injury

Zhiyuan Liu

Department of Physical Education, Jilin Agriculture Science And Technology College, Jilin, (CHINA)

ABSTRACT

Baseball is a worldwide sports event; its high ornamental and competitiveness charm the people. And baseball game is also a game relies on apparatus, therefore bat some physical properties will have great effects on batters' abilities. This paper targeted market two kinds of textures (all-wood and all aluminum) bats hitting effects, it makes deeply research from the two aspects. By deeply researching and analysis of bat hitting process and establishing physical model, it gets bat maximum delivery speed expression, therefore it gets aluminum bat maximum delivery speed is obviously larger than wood bat. Aluminum bat speed change curve is more smoothly than wood bat, which means hitting point position influences on hitting speed is not obvious so that cannot reflect batters' levels. By establishing bat elastic beam model, through analyzing, it gets wood bat and aluminum bat force status.

KEYWORDS

Maximum delivery speed;
Elastic beam model;
Bat force;
Sports injury.

INTRODUCTION

Due to baseball is a kind of sports game combining with apparatus, bat qualities affect batters' performance to greatly extent. In general, bat divides into two kinds that are respectively made of wood (generally is ash) or metal (generally is aluminum). It is well-known that aluminum bat has best elasticity and will not crack, when swinging, only with enough strength it normally can play ball higher and further, while wood bat is prone to crack, it had appeared wood bat cracked and flied to bleachers and hit a female audience in major league baseball, which caused personal injury. For beginners and high school competitions, it can use aluminum bat, so that is very easy to generate sense of achievement; but major league baseball prohibits using metal bat, because competitive sports principle is improving performance by its own techniques improvement rather than apparatus properties improvement.

This paper, from delivery maximum speed and bat acting force on hand these two aspects, it respectively makes quality analysis of wood bat and aluminum bat.

BAT HITTING MODEL ESTABLISHMENT AND ANALYSIS

Consulting information, it gets bat each physical property as following TABLE 1:

Analyze from the perspective of maximum delivery speed

In order to convenient for model calculating, it simplifies the model as Figure 1 showed circular table, from

TABLE 1 : Bat each physical quality value

Property	Wood bat	Aluminum bat
Mass	0.142 kg	
Length	1.05m	1.05m
Density	$0.7kg/m^3$	$25kg/m^3$
Structure	Solid	Hollow(thickness 2.5cm)
Restitution coefficient e	0.25	0.4
Elastic coefficient		
v_1	-40 m/s	-40 m/s
u_1	16 m/s	16 m/s
ω_1	34 rad/s	34 rad/s

which E is hand griping bat position, C is bat mass center, D is bat and ball contact point.

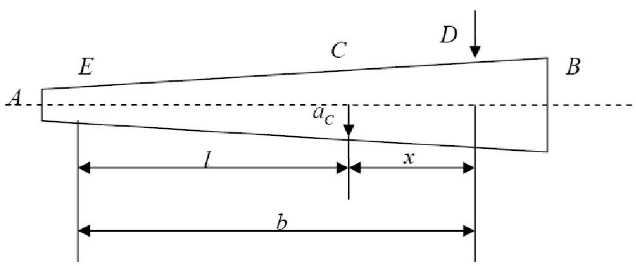

Figure 1 : Bat simplified model

Due to hitting instantaneous, bat rotates around E point, angular speed is ω, mass speed is $u = \omega \times l$, hitting point speed is $v = \omega(l+x)$, according to momentum conservation and angular momentum conservation as well as restitution coefficient expression, it has:

$$m_1v_1 + m_2u_1 = m_1v_2 + m_2u_2 \quad (1)$$

$$m_1v_1x + J\omega_1 = m_1v_2x + J\omega_2 \quad (2)$$

$$e = \frac{u_2 - v_2}{v_1 - u_1}$$

Because hitting point is not mass center, we improve restitution coefficient expression as:

$$e = \frac{u_2 - x\omega_2 - v_2}{v_1 - u_1 - x\omega_1} \quad (3)$$

By (1), (2), (3), it can get ball speed expression after hitting, as following:

In order to solve bat mass center and rotational inertia, extend above bat model to cone, as Figure 2 show, and then bat volume is equal to big cone volume minus small cone volume.

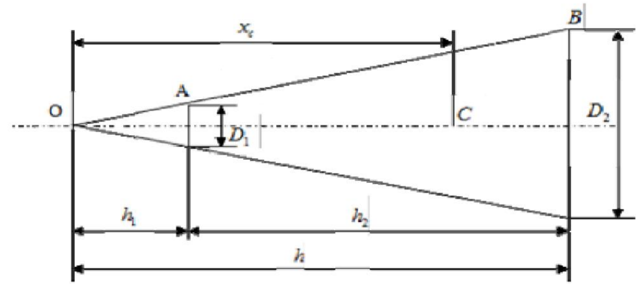

Figure 2 : Calculate bat inertia moment simplified model

Among them: $h = \frac{R_2}{R_2 - R_1}h_2 \;\; h_1 = \frac{R_1}{R_2 - R_1}h_2$

$$V = \frac{\pi}{3}R_2^2h - \frac{\pi}{3}R_1^2h_1 = \frac{\pi}{3}\frac{h_2}{R_2 - R_1}\left(R_2^3 - R_1^3\right) \quad (4)$$

Bat mass is:

$$m_2 = \rho V \quad (5)$$

In formula (5): ρ is bat density, V is bat volume. Mass center coordinate formula is (6):

$$x_C = \frac{\int xdm}{m} = \frac{3}{4} \bullet \frac{R_2^4 - R_1^4}{R_2^3 - R_1^3} \bullet \frac{h_2}{R_2 - R_1} \quad (6)$$

$$l = x_C - \frac{R_1h_2}{R_2 - R_1} \quad (7)$$

While because $J = \int x^2dm$ big cone inertia moment is:

$$J_{C2} = \frac{3}{80}\rho\left(\frac{\pi}{3}\frac{R_2^3h_2}{R_2 - R_1}\right)\left(4R_2^2 + h_2^2\right) + \rho\left(\frac{\pi}{3}\frac{R_2^3h_2}{R_2 - R_1}\right)\left(\frac{3}{4}\frac{R_2h_2}{R_2 - R_2} - x_C\right)^2 \quad (8)$$

Small cone inertia moment is:

$$J_{C2} = \frac{3}{80}\rho\left(\frac{\pi}{3}\frac{R_2^3h_2}{R_2 - R_1}\right)\left[4R_1^2 + \left(\frac{R_1h_2}{R_2 - R_1}\right)^2\right] + \rho\left(\frac{\pi}{3}\frac{R_2^3h_2}{R_2 - R_1}\right)\left(\frac{3}{4}\frac{R_1h_2}{R_2 - R_2} x_C\right)^2 \quad (9)$$

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Mass center inertia moment is:

$$J_C = J_{C2} - J_{C1} \quad \textbf{(10)}$$

E point inertia moment is $J_E = J_C + ml^2$.

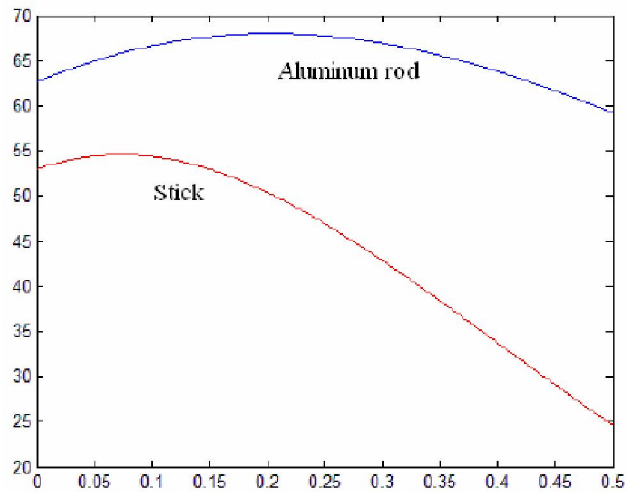

Figure 3 : Wood bat and aluminum bat speed and best hitting point relationship

Collecting information, it is clear that small radius R_1 is 12.55mm, big radius R_2 is35mm, input (1)-(10) into speed v_2 following hitting point to mass center distance x changing figure as Figure 3. Therefore it gets two textures' bat speed and hitting point relationships as Figure 3.

From Figure 3, it is clear when aluminum bat in x=0.204, speed arrives at maximum value 68m/s. Aluminum bat hitting speed is obvious larger than wood bat. And aluminum bat change curve is more smoothly than wood bat. Even aluminum bat minimum hitting speed is larger than wood bat maximum hitting speed. That brings into obvious unfairness to game. Aluminum bat curve changes is smooth, which indicates hitting point position has no big effects on hitting speed, while a very important factor that decides hitting position is athlete level. It shows that using aluminum bat is difficult to reflect athlete level. And wood bat curve changes are larger, which indicates athlete levels can obvious affect hitting speed, which conforms to competition significance. To sum up, game is required to use wood bat and prohibit using aluminum bat.

Analyze from bat to hand acting force

According to moment of momentum theorem, it has:

$$\left(J_C + ml^2\right)\alpha = \left(1+x\right)Q \quad \alpha = \frac{\left(1+x\right)Q}{J_C + ml^2}$$

In formula, J_C is bat to mass center rotational inertia, l is hands grip point E to mass center C distance, x is colliding point D to mass center C distance, α is bat rotational angular accelerated speed, Q is ball to bat colliding force, and then:

$$a_C = l\alpha = l\frac{\left(1+x\right)Q}{J_C + ml^2} \quad \textbf{(11)}$$

In formula (11), a_C is mass center C accelerated speed. According to theorem of motion of mass center:

$$Q - F = ma_C \quad Q - F = \frac{m\left(1+x\right)Ql}{J_C + ml^2}$$

$$F = Q - \frac{m(1+x)Ql}{J_C + ml^2} = \frac{1}{J_C + ml^2}\left(J_C - mxl\right)Q \quad \textbf{(12)}$$

In formula (12): F is colliding moment hand to bat colliding force.

Due to consider that hand grip point displacement basically not change that the position is basic fixed, ball to bat impact force can be solved by mechanics of materials. That is: simplify bat into elastic beam model as Figure 4.

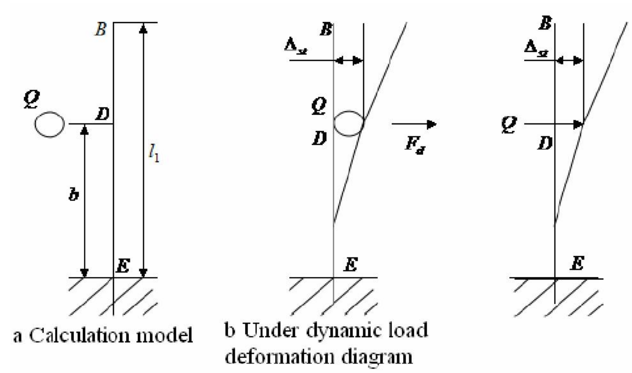

Figure 4 : Bat elastic beam model simplified diagram

Figure 4-a is calculation model, Figure 4-b is under dynamic load deformation Figure, Figure 4-c is under static load deformation figure; then, according to mechanics of materials knowledge:

$$\Delta_{st} = \frac{Qb^3}{3EI_z} \quad \textbf{(13)}$$

$$K_d = 1 + \sqrt{1 + \left(\frac{1}{1 + m_e / m_1}\right)^2 \frac{v^2}{g\Delta_{st}}} \quad \textbf{(14)}$$

In formula (13) (14) : Δ_{st} is static deviation, E is bat Young modulus, I_z is beam cross section to neural axis inertial moment, K_d is dynamic load coefficient, m_e is bat equivalent mass, $m_e = 33m_2 / 140$, m_1 is ball mass, v is colliding moment ball speed.

When ball speed is larger, dynamic load coefficient can be simplified into:

$$K_d = \sqrt{1 + \left(\frac{1}{1 + m_e / m_1}\right)^2 \frac{v^2}{g\Delta_{st}}} \quad \sigma_{st} = \frac{Qb}{W}$$

In formula: W is bend section modulus

$$\sigma_d = K_d \sigma_{st} = \frac{Qb}{W} \left(\frac{1}{1 + m_e / m_1}\right) \sqrt{\frac{v^2}{g\Delta_{st}}}$$

$$F_d = K_d Q \quad \textbf{(15)}$$

In formula (15), σ_{st} is maximum impact force, F_d is ball impacting bat moment dynamic load.

Simultaneous formula (12) to (15), it gets opponents' impact force as well as hitting point to mass center distance figure as Figure 5.

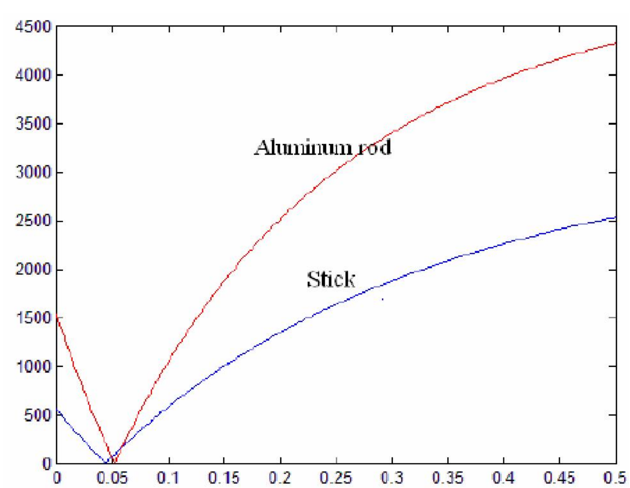

Figure 5 : Bat to hand acting force change diagram

From Figure 5, it is clear that in the position that x=0.05, bat to hand acting force is zero. But, with hitting position changes, aluminum bat to hand acting force obviously changes, the highest can arrive at more than 4000N, which brings into extremely big security risks to baseball players, if it deviates reasonable hitting regions, it will cause injury to athletes, therefore, game should prohibit using aluminum bat.

CONCLUSIONS

From the research, it is clear when aluminum bat in x=0.204, speed arrives at maximum 68m/s. Aluminum bat hitting speed obvious is larger than wood bat. And aluminum bat change curve is more smoothly than wood bat. Even aluminum bat minimum hitting speed is larger than wood bat maximum hitting speed. Aluminum bat curve change is smooth, which indicates hitting point position has no big effects on hitting speed, and one very important factor that decides hitting position is athlete level. It shows using aluminum bat is very difficult to reflect athlete level. And wood bat curve change is larger, it indicates that athlete levels can obviously effect on hitting speed, which conforms to competition significance.

By research, we can get following conclusions: aluminum bat maximum delivery speed is obvious larger than wood bat. And aluminum bat speed change curve is more smoothly than wood bat, which means that hitting point position has no obvious effects on hitting speed. With hitting position changes, aluminum bat to hand acting force obvious changes, it has great injury on batters' body, and to wood bat, force change is relative gently.

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