ISSN : 0974 - 7435 Volume 10 Issue 2

BioTechnology
An Indian Journal

FULL PAPER

BTAIJ, 10(2), 2014 [049-054]

Research on mechanical model-based bat texture and batting point affect maximum ball speed effect

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ABSTRACT

By utilizing dynamics and physics principles, establish momentum conservation model and maximum ball speed model make calculation on bat impacting problems, and find out best batting point. Through analysis of best batting point influence factors, it establishes maximum ball speed effect model, and utilizes restoration coefficient and quality defining baseball bat texture required physical property. Research achieves that the texture of iron birch which grows in greater part of China is a relative ideal metal baseball bat alternative. Model applies theoretical mechanics abstract analysis of ball and bat impacting problems, used model is easily understood, impressive and helpful for promoting.

KEYWORDS

Baseball texture;
Momentum conservation;
Best batting point;
Maximum ball speed effect.

INTRODUCTION

Baseball bat selection actually has direction connections with batting levels' merits, especially for foreign professional baseball players, selection of baseball bat should according to personal physical conditions, local weather dry and wet status as well as pitcher pitching speed, personal swinging speed, baseball bat light or heavy hand feeling and other conditions, it must choose carefully and pay particular attention to it. While higher competitive levels league matches have also clear requests on baseball bat. So that has certain restriction on baseball bat textures choosing. Why major league baseball prohibits using metal bat while only allow to use woodiness bat. Top baseball competitions all make restriction on baseball bat textures, however presently most of articles just discuss why they have such restrictions, not providing alternative textures. In the following, it establishes model to carry out analysis and discussion.

BAT BATTING MODEL ESTABLISHMENT

In order to make problem discussion convenient and get a relative exact data, we regard baseball bat as rigid body, and take specification of 31 inch that 1.03 m length adults baseball bat as research object, finally we get that under ball as rigid body circumstance, batting point distance from mass center and ball reverse speed, through analyzing, when mass center and batting point distance $r = 0.6879m$, baseball reverse speed can reach the maximum as $46.9938m/s$, which is traditional baseball bat reverse speed maximum best batting point.

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Of course, it is just theoretical best batting point, in practical operation, it should accord people's hand feelings, daily training and other series factors, therefore, the conclusion is just for referencing, which can regard as standard motion guiding point when training.

Best batting point

When selects baseball bat, it has to give priority to best batting point, it has great and direct effects on batting quality and levels, it can also play decisive roles in baseball bat texture selecting. In the following, it first carries out model analysis of best batting point.

Calculation model is as Figure 1, then according to theorem of moment of momentum, it has:

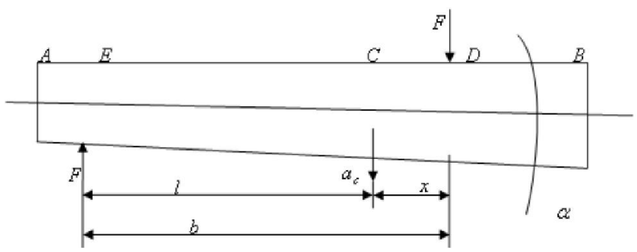

Figure 1 : Bat calculation model

$$(J_c + ml^2)\alpha = F(l + x) \quad (1)$$

$$\alpha = \frac{F(l + x)}{J_c + ml^2} \quad (2)$$

In formula: J_c is baseball mass center point rotational inertia $Kg.m^2$; l is hand grip point E and mass center C distance m; x is impacting point D and mass center C point distance m; α is bat revolving angular accelerate speed rad / s^2; F is baseball acting force on baseball bat[1].

$$a_c = l\alpha = l\frac{(l + x)F}{J_c + ml^2} \quad (3)$$

In formula a_c is mass center C point accelerated speed m / s^2, then according to mass center movement theorem:

$$F - F_1 = ma_c = ml\frac{(l + x)F}{J_c + ml^2} \quad (4)$$

$$F_1 = F - ma_c = \frac{F}{J_c + ml^2}(J_c - mlx) \quad (5)$$

In formula, F_1 is impacting moment hands to baseball bat acting force N, when impacting point reaches best position, let $F_1 = 0$ impacting moment hands to baseball bat acting force arrive at minimum as 0, then hands would not feel impulse, $F_1 = 0$ from formula(3) it can get[2]:

$$x = \frac{J_c}{ml} \quad (6)$$

Among them:

$$b = l + x = \frac{J_E}{ml} \quad (7)$$

From rotational inertia formula, it has:

$$J_E = J_c + ml^2 \quad (8)$$

In formula, b is hands grip point E reaches best batting point D distance m, J_E is bat to hands grip point E rotational inertia $Kg.m^2$, therefore meet formula (5) point D is impacting center point, point is best impacting point, due to bat surface is a revolution surface sector, so best batting position in space is a circle; from formula (4) it is clear that the bigger is l, the smaller x value would be, which is grip position distance from mass center becomes further, it gets closer topoint, best batting point would get closer to mass center[3].

Bat mass and rotational inertia

(1) Bat mass

Regard bat as cone frustum, its volume is equal to big cone volume minus small cone volume. As Figure 2 shows:

Let mass to be M, upper and lower bottom radius to be r, R, height to be h homogeneous cone frustum rigid body, rigid body density is ρ, through integral, it

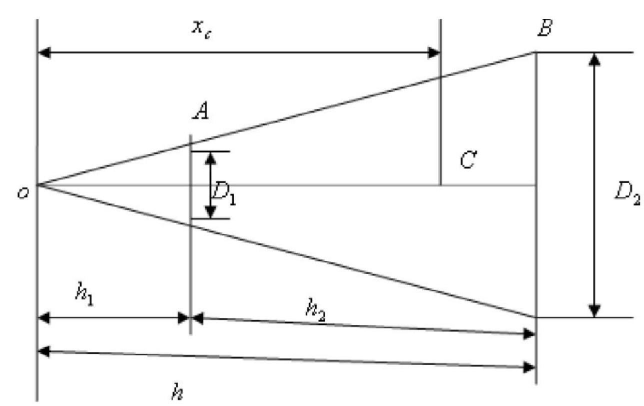

Figure 2 : Bat mass and rotational inertia calculation sketch

solves:

$$\mathbf{M}=\frac{1}{3}\rho\pi\mathbf{h}\left(\mathbf{R}^2+\mathbf{Rr}+\mathbf{r}^2\right) \quad (9)$$

$$\mathbf{J_0}=\frac{3}{10}\mathbf{M}\frac{\mathbf{R}^4+\mathbf{R}^3+\mathbf{R}^2\mathbf{r}^2+\mathbf{Rr}^3+\mathbf{r}^4}{\mathbf{R}^2+\mathbf{Rr}+\mathbf{r}^2} \quad (10)$$

And cone frustum gravity center *G* to radius as *R* lower bottom distance:

$$\mathbf{h}'=\frac{\mathbf{h}}{4}\frac{\mathbf{R}^2+2\mathbf{Rr}+3\mathbf{r}^2}{\mathbf{R}^2+\mathbf{Rr}+\mathbf{r}^2} \quad (11)$$

$$\mathbf{l}=\mathbf{h}-\mathbf{h}'=\frac{3\mathbf{R}^2\mathbf{h}+2\mathbf{Rrh}-\mathbf{r}^2\mathbf{h}}{4(\mathbf{R}^2+\mathbf{Rr}+\mathbf{r}^2)} \quad (12)$$

$$\frac{\mathbf{b}}{\mathbf{h}}=\frac{\mathbf{J_E}}{\mathbf{mlh}}=\frac{\mathbf{ml}^2+\mathbf{J_c}}{\mathbf{mlh}} \quad (13)$$

(2)Hands grip point *E* position influences on best batting point *D*:

Assume that baseball bat smaller end radius *r* is $12.25mm$, bigger end radius *R* is $35mm$, length of bat *h* is $103mm$, woodiness baseball bat proportion, It solves: $M=962.9617g$, $J_c=362761g\cdot mm^2$, $l=593.8043mm\cdot$

Maximum ball speed model

In the following, it tries to make use of extremism problems finding out the point let batted ball reverse speed reach the maximum. After batting, to let ball get bigger speed that is similar to let ball gets maximum power. Due to batting points are different, ball suffered forces are different, besides, ball and racket angular momentum are different, from baseball bat batting baseball process, we can get mass center speed as :

$$\mathbf{u}=\varpi\mathbf{H} \quad (14)$$

Among them, H represents bat mass center to supporting point distance. Batting point speed is:

$$\mathbf{v}=\varpi(\mathbf{H}+\mathbf{r})=\mathbf{u}+\varpi\mathbf{r} \quad (15)$$

Represents batting point to mass center distance. According to momentum conservation, angular momentum conservation and restitution coefficient, it can get expression:

$$\mathbf{m_1v_1}+\mathbf{m_2u_1}=\mathbf{m_1v_2}+\mathbf{m_2u_2} \quad (16)$$

$$\mathbf{m_1v_1r}+\mathbf{I}\varpi_1=\mathbf{m_1v_2r}+\mathbf{I}\varpi_2 \quad (17)$$

Restitution coefficient is:

$$\mathbf{e}=\frac{\mathbf{u_2}-\mathbf{v_2}}{\mathbf{v_1}-\mathbf{u_1}} \quad (18)$$

It can simply deduce that batting point is not mass center, so we make further optimization of restitution coefficient *e* expression as:

$$\mathbf{e}'=\frac{\mathbf{u_2}+\mathbf{r}\varpi_2-\mathbf{v_2}}{\mathbf{v_1}-\mathbf{u_1}-\mathbf{r}\varpi_1} \quad (19)$$

From (14) to (17), it can get baseball received speed after batting is:

$$\mathbf{v_2}=\frac{\mathbf{J}\varpi_1(1+\mathbf{e})(\mathbf{h}-\mathbf{b})+\mathbf{m_1v_1}(\mathbf{h}-\mathbf{b})^2-\mathbf{e}'\mathbf{v_1J}}{\mathbf{m_1}(\mathbf{h}-\mathbf{b})^2+\mathbf{J}} \quad (20)$$

In above formula m_1, is baseball mass, m_2 is bat mass, v_1 is baseball initial speed, v_2 end speed, u_1 is bat initial speed, u_2 end speed, I is baseball rotational inertia, e' is restitution coefficient, input data into them, it can get schematic diagram as following, as Figure 3 shows:

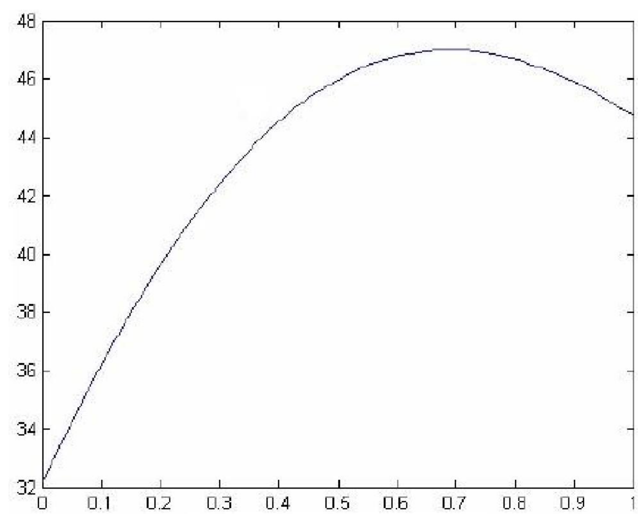

Figure 3 : Woodiness baseball batting point and baseball speed after impacting correlation

BASEBALL BAT TEXTURE INFLUENCES ON TECHNICAL PLAYING

Model analysis of baseball bat texture

By best batting point model calculation, it can get from formula(20) that baseball final speed is related to e' and m_1, while because baseball bat volume is basi-

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cally fixed, which means it has direct relationship with baseball bat ρ, which has relationship with baseball bat density. It gets best batting point and baseball bat texture relationships.

Restitution coefficient is:

$$e = \sum_{i}^{\infty} \frac{4a^2}{\phi_i L^2} \frac{\frac{2\phi_i}{L} \cos \frac{2\phi_i}{L} / \cos \phi_i - \frac{2\phi_i}{L} \cosh \frac{2\phi_i x}{L} / \cosh \phi_i}{1/\cos^2 \phi_i - 1/\cosh^2 \phi_i + 2M/\phi_i^2} \sin \frac{2\phi_i^2 a^2}{L2} t_c \qquad (21)$$

Among them, L is baseball bat length, a is best batting point baseball bat radius, ϕ_i is impacting angle, t_c is impacting angle.

From above formula (21), it is clear when considering restitution coefficient is not a constant but an impacted object mass as well as elastic rod length influences.

For the topic, since to a professional baseball batter, his hand feeling has already fixed. For bat length, mass, it has its own standard. Therefore when baseball bat textures are different, only elastic coefficient is the unique variable. While since elastic coefficient can also be expressed by Yung Modulus. Through consulting data, it is known that woodiness Yung Modulus is $11GPa$, alloy Yung Modulus is $190GPa$ Given alloy baseball bat mass and woodiness baseball bat mass are the same, then:

$$v_{2\text{wood}} / v_{2\text{alloy}} = \frac{21.81 m/s}{49.87\, m/s} \approx 0.4373 m/s \qquad (22)$$

Alloy, woodiness baseball bat batting point and baseball speed after impacting as Figure 4 shows:

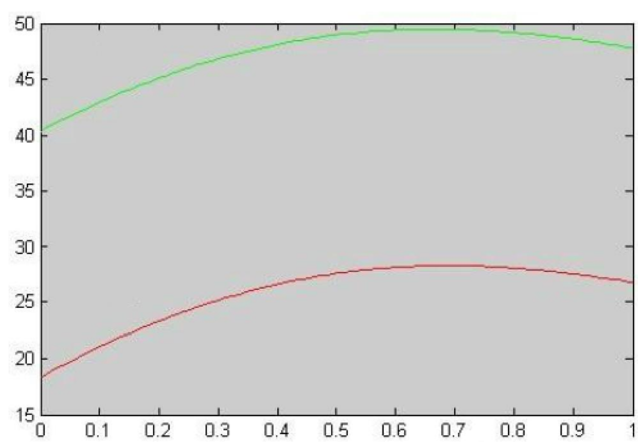

Figure 4 : Alloy, woodiness baseball bat batting point and baseball speed after impacting relationships comparison

From Figure 4, it can intuitive analyze on the same case maximum speed playing by alloy baseball bat is 2.29 times of that playing by woodiness baseball bat. It seriously effects on competition levels, so that it will not indicate athlete batting skills, and violates "higher, faster, stronger" sports competition spirits, and will cause sports misunderstanding "equipment competition", therefore major league baseball game prohibits using metal texture baseball bat.

Baseball bat texture selection analysis

From above context, it is clear since major league baseball prohibits using metal texture baseball bat, to get good competition results, whether it can find a baseball bat not with metal texture but can possess metal texture property as producing "maximum ball speed effect" when batting baseball. In the following, we make simple list and comparison of several kinds of baseball bat common textures, as TABLE 1 shows.

Data in TABLE 1 most are approximate numbers, but it can provide certain reference values. We can analyze from it that metal woodiness texture alternatives are iron birch, Australian ash, American maple, Russian ash wood, bamboo. Then we compare their merits from economic perspective, available supply of "maximum ball speed effect" as well as hand feeling after people using. As TABLE 2 shows:

From TABLE 2 data, it is clear that due to Australian ash, American maple, Russian ash wood all are imported, price are relative expensive, while most part

TABLE 1 : Baseball bat several kinds of common textures physical properties comparison

Material	Density g/cm^3	Yung Modulus $(E)/GPa$ (approximate number)
Oak (represents general wood)	0.45-0.7	11
Metallic aluminum	2.7	69
Carbon fiber reinforced plastic (one-way, particle surface)	0.66	150
Alloy and steel	7.87	190-210
Iron birch	0.723	190
Australian ash	0.65	10-12
American maple	0.74	10-12
Russian ash wood	0.67g	10-12
Bamboo	1.49	10-12

TABLE 2 : Several kinds of baseball bat textures properties comparison

Material	Price ($Yuan/m^3$)	Maximum ball speed m/s	Hand feeling
Iron birch	200	37.13	similar to metal baseball bat
Australian ash	350	23.73	normal
American maple	6000	24.21	normal
Russian ash wood	4700	24.33	normal
Bamboo	150	21.81	Good elastic, worst hand feeling

has already used as baseball bat textures for many years, while bamboo hand feeling is too bad. To sum up, through comparing, we get the relative ideal metal alternative wood texture is iron birch. While its texture is very superior, is adapted to make plan and ship as well as other high strength plywood, is a very important military material: wood air-dry volume-weight $0.723 g/cm^3$, bending strength $1304 kg/cm^2$, end hardness $824 kg/cm^2$. Iron birch wood hardness is one time harder than normal steel, three times than oak, is world hardest wood, people use it as alternative of metal. Former Soviet Union had ever used iron birch making grounder, bearing for speedboat. Iron birch has also some marvelous properties, due to its texture is extremely compact, it will soon sink once be put into water. And iron birch hardness is twice of steel.

Then through comparing its "maximum ball speed effect" with that of alloy, woodiness baseball bat, input them into formula (20), it gets these kinds of different textures' maximum ball speed as Figure 5 shows:

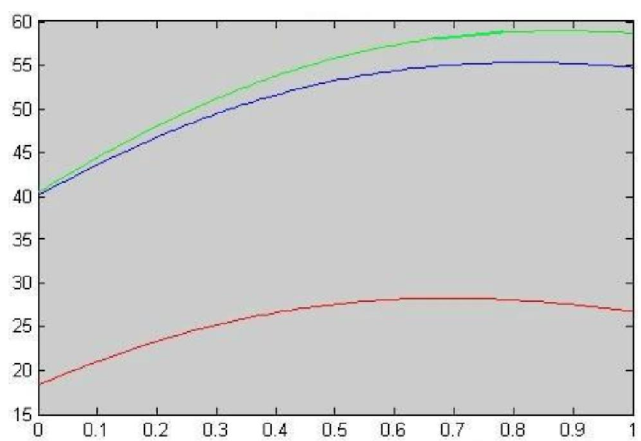

Figure 5 : Several kinds of different textures' baseball bat maximum ball speed comparison

We can see that iron birch "maximum ball speed effect" approximates to alloy, it can approximately replace metal baseball bat.

Iron birch and metal bat comparison

After all, iron birch is wood, its density is quite smaller than metal. Subsequently, through maximum stress model, compare the two differences.

$$\sigma_{d1} = K_d \sigma_{st} = \frac{Qb}{W}\left(\frac{1}{1+m_e/m_1}\right)\sqrt{\frac{v^2}{g}\frac{3E_1 I_z}{Qb^3}} \quad (23)$$

In formula, σ_{d1} is iron birch bat maximum impulsive stress MPa, E_1 is iron birch Yung Modulus GPa.

When adopts aluminum rod:

$$\sigma_{d1} = K_d \sigma_{st} = \frac{Qb}{W}\left(\frac{1}{1+m_e/m_1}\right)\sqrt{\frac{v^2}{g}\frac{3E_1 I_z}{Qb^3}} \quad (24)$$

In formula σ_{d2} is metal bat maximum impulsive stress MPa, E_2 is metal bat Yung Modulus GPa [6].

$$\frac{\sigma_{d2}}{\sigma_{d1}} = \sqrt{\frac{E_2}{E_1}} \quad (25)$$

Among them, iron birch baseball bat $E_1 = 190GPa$, alloy bat $E_2 = 210GPa$, then:

$$\frac{\sigma_{d2}}{\sigma_{d1}} = \sqrt{\frac{E_2}{E_1}} = 1.1053 \quad (26)$$

Alloy baseball bat maximum impulsive stress is 1.1053 times of that from iron birch baseball bat, when iron birch baseball bat maximum impulsive stress is $\sigma_{d1} = 10MPa$, aluminum rod maximum impulsive stress is $\sigma_{d2} = 11.053MPa$. By comparing, the two differences are not great; it is fit for children or beginners.

While because, $\rho_{\text{alloy}} > \rho_{\text{Iron banyan tree}}$, when same mass different textures baseball bats, from which alloy baseball bat will be hollow, while iron birch baseball bat will be solid, then in elastic, it will be slight inferior to alloy baseball bat.

In conclusion, it gets, for alternative of alloy baseball bat, it can choose iron birch as reference, which not only meets premise of league constraints, but also can improve performance, double benefit.

CONCLUSIONS

Through using mechanical model that is momentum conservation theorem and others, it carried out respectively researching and discussion on baseball bat batting point and textures. Made abstract simplifying the bat shape, let research objects easier to describe and modeling: Used theoretical mechanics, physics and so on multiple theory to implement abstract analyze ball-bat impacting problems: Applied model is easily understood, impressive, helpful for promoting, which could promote to billiards movement analysis, golf club improvement and so on series of sports events that would applied mechanical analysis and has ball speed analyses.

For xylotomy, investigation is not deep enough, acknowledge of material is also not mature enough, the recommended material is also theoretical one, it cannot well reflect objective fact that needs to be tested by time. Therefore in future work, it can carry out further researching and investigation on above aspects, get better results.

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