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Baseball best batting point to batting efficiency optimization model analysis based on rigid body dynamics

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ABSTRACT

Baseball is a kind of collective, highly confrontational ball sports event that main characterized as playing ball by bat. It is widely developing in the world with great influences, which is honored as "competitiveness and intelligence combination". Baseball players divides into attack, defense the two parties, using bat and gloves, they play game in a fan-shaped baseball field. In game, two parties alternate attacking, when attacker successfully runs back to home base, he can get 1 score. Highest score team in nine innings wins the game. To get high score, besides relying on athlete himself technique and physical quality, it should also find out baseball bat batting best position achieved high score. This paper, with regard to batting best position, it makes systematically analysis in theory and experiments. It includes applying momentum conservation law, angular momentum conservation law and restitution coefficient, optimal solution, establishes rigid body dynamical model to research on baseball batting process, and by impact center concept, it solves baseball bat batting best position.

KEYWORDS

Best batting point;
Restitution coefficient;
Dynamical model;
Optimal solution.

PREFACE

Baseball as world one kind of extreme high appreciation sport, its speed and strength beauty charms the people. Baseball is a kind of collective, highly confrontational ball sports event that main characterized as playing ball by bat, is honored as "competitiveness and intelligence combination", is a kind of collective sports event that combines intelligence and courage, interest and cooperation into one. It combines activity and stillness with clear division. During players, it focuses on individual intelligence and capability, and also should pay attention to strategy and tactics, and make mutual cooperation. There is precise division and clearly responsibilities among members, they also should take the initiative to cooperate and services with each other; to take overall situation into account if it is necessary, individuals should be willing to make self-sacrifice. In baseball, everyone has an opportunity of being a master, and it requires oneself positioning and his judgment on the overall situation. Baseball players divides into attack, defense the two parties, using bat and gloves, they play game in a fan-shaped baseball field. In game, two parties alternate attacking, when attacker successfully runs back to home base, he can get 1 score. Highest score team in nine innings wins the game. In game,

FULL PAPER

batting, base running and sliding as well as others are main ways to get scores.

Now, baseball also attracts much more peoples' attentions, so to players, how to bat can play more home run and get high scores so that win the game also becomes more and more important, except for athlete himself technologies, his successful external factors such as where is baseball bat best batting point so that correct bat baseball to get scores, people generally think the best batting point is bat end, and then with regard to the problem where on earth baseball best position is, we will further discuss it on the paper.

PROBLEMS ANALYSIS

By far, international general significance about baseball best batting point has 8 kinds of definitions, analyze through physical perspective, we can conclude into one point that is ball received largest flight speed after batting. To get largest speed, accelerated speed should arrive at maximum value that acting force to be maximum, simple analyze can get that maximum torque does not represent force is the maximum one. We can draw geometric schematic diagram (refer to Figure 1) according to bat external features, make the abstract concrete, and do quantitative analysis of it. Then combine with batting ways, establish rigid body dynamical model, it can solve ball flying away bat instantaneous speed expression. And further solve best batting point. Assume that baseball bat with even texture, baseball to bat batting ability within bat tolerance, ball does not make self rotation in flying process, baseball flying speed direction is vertical to baseball bat surface slice, researched baseball and bat size, mass, shape and specification are the same, during the whole process, it ignores air resistance, neglects bat and ball friction force, idealize people difference, it is thought that people playing way and strength are the same.

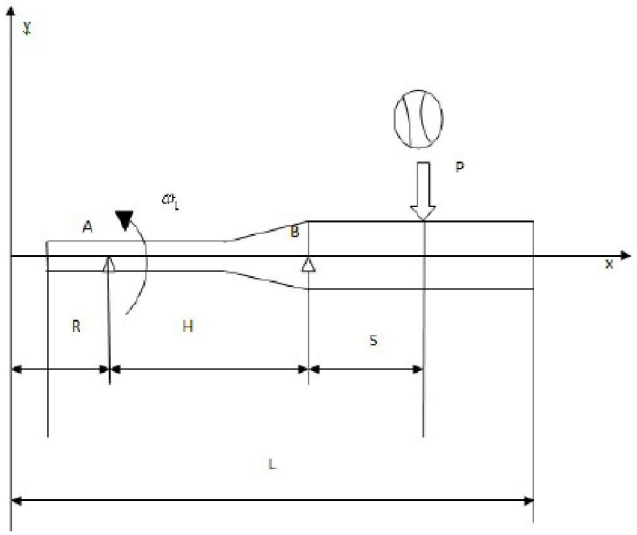

Figure 1 : Baseball section schematic diagram

When rigid body makes rotation around the fixed point under external force, it will generate larger additional force in support point, the force tends to harmful in practical applications. But when external force acting on rigid body some special positions, rigid body arrives at dynamic balance, the additional force can eliminate. At that time, the rotational support point is called free rotation point, even it cancels constraints, rigid body will still rotate around the point, such external force special acting position is rigid body batting center. For bat best batting point research, by physical analysis, we know that so-called best batting point is maximum speed that achieves when ball flies away from bat. When speed is largest that accelerated speed is largest, that is to say, acting force is the largest, regard ball, bat as rigid body, it can regard "ball-bat" as a system, and take it as research objects and make analysis by establishing typical mechanical model, utilize "momentum conservation law", "angular momentum conservation law" and " restitution coefficient" to research batting position and ball departing speed relationship, which can get that maximum torque does not represent maximum acting force.

RIGID BODY DYNAMICAL MODEL ESTABLISHMENT AND SOLUTION

Due to collision instantaneous, ball and bat acting force is far larger than its own gravity and hand support force. So, take ball-bat system as research objects, and then it can get y axis direction momentum conservation: $m_1v_1 + m_2u_2 = m_1v_2 + m_2u_2$

Given baseball angular speeds are respectively ω_1, ω_2, then: $u_1 = \omega_1(R+H), u_2 = \omega_2(R+H)$.

Restitution coefficient e is collision contact point relative approximate speed divides relative far speed that is:

FULL PAPER

$$e = \frac{v_2 - \omega_2(S+R+H)}{-v_1 + \omega_1(S+R+H)} \quad (1)$$

Take body gravity center as axis, establish ball-bat angular momentum conservation equation, the equation takes bat mass center as axis, ball-bat system has no exterior torque, therefore angular momentum conserves, that is:

$$m_1 v_1 (S+R+H) + J\omega_1 = m_1 v_2 (S+R+H) + J\omega_2 \quad (2)$$

Thereupon after colliding ball speed expression is:

$$v_2 = \frac{J\omega_1(1+e)(S+R+H) + m_1 v_1 (S+R+H)^2 - e v_1 J}{m_1(S+R+H)^2 + J} \quad (3)$$

From which slim stick rotational inertia J can be approximately solved:

$$J = \frac{m_2 l^2}{3} \quad (4)$$

It solves when speed arrives at maximum, best batting position is 70m far from baseball handle.

In the following, it uses another method to verify it:

Batter batting process can be regarded as a rigid body rotates around fixed axis and particle collision process in plane, as Figure 2 show, so that establish a collision model. Because bat has mass symmetry plane, baseball mass center CM, is surely in the bat symmetry axis. In the moment bat and ball collide, ball gives bat a colliding impulse I effect, it transfers to batters' arms through bat, solve arm anti-collision impulse I_{ox} and I_{oy}, as Figure 3 show.

Take oy axis through mass center CM, , x axis is vertical to y axis, by impulse theorem, it gets

$$Mv'_{cx} - Mv_{cx} = I_x + I_{ox}$$

$$Mv'_{cy} - Mv_{cy} = I_y + I_{oy}$$

In above formula, M is baseball mass, v_{cx}, v'_{cx} and v_{cy}, v'_{cy} respectively represent before and after colliding mass center speed along x, y axis directions projection. If hand positions are fixed without play, then it has

$$v_{cy} = v'_{cy} = 0$$

So:

$$I_{ox} = M(v'_{cx} - v_{cx}) - I_x \quad (5)$$

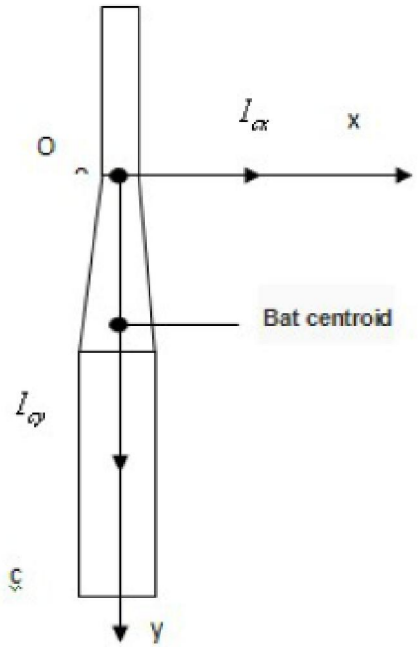

Figure 2 : Collision model figure

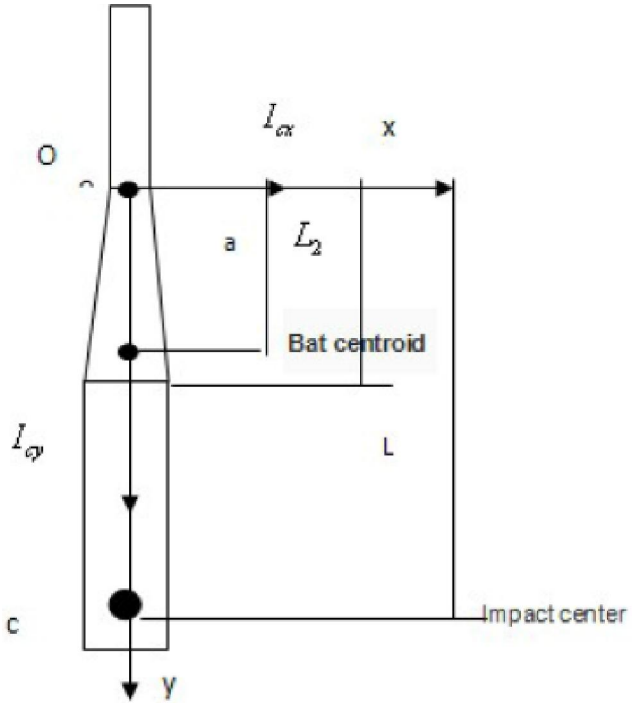

Figure 3 : Collision impulse vertical to y axis

$$I_{oy} = -I_y \quad (6)$$

When ball batting in the collision center, our hands will not get recoil force. When batting point is far from collision center, it will have net force on our hands, in this case it will let hands that grip the racket get injured. Therefore, when $I_{oy} = 0, I_{ox} = 0$, it is the optimal.

Analyze formula (5)(6),it gets:

$$\begin{cases} I_y = 0 \\ I_x = M(v'_{cx} - v_{cx}) \end{cases}$$

By formula(5), it gets that if it is required that external colliding impulse vertical to y axis, then I must be vertical to OC, as Figure (6) show.

By formula (6), it gets that mass center to O distance is a, L_{z2}, L_{z1} are baseball in the beginning and ending of collision moment to oc axis momentum moment.

Given ω_1 and ω_2 are respectively instantaneous angular speed, J is baseball rotational inertia, it gets:

$$I_x = Ma(\omega_2 - \omega_1) \quad (7)$$

According to impulsive momentum theorem:

$$L_{z2} - L_{z1} = \sum_{i=1}^{n} M(I_i^{(e)})$$

Angular speed transformation is:

$$\omega_2 - \omega_1 = \frac{\sum_{i=1}^{n} M(I_i^{(e)})}{J}$$

Input into formula (7), it gets:

$$ML_2 \frac{IL}{J} = I$$

In formula, L is O to colliding point distance, then is K optimal collision point, when ball batting to K point, O net profit be minimum, it solves:

$$L = \frac{J}{Ma}$$

Given baseball density to be ρ, decompose baseball into three parts, respectively solve bat to support point rotational inertia:

$$J_1 = \frac{\rho\pi r^2 L_1^3}{3}$$

$$J_2 = \frac{\rho\pi L_2^3}{30}(r^2 + 3Rr + 6R^2)$$

$$J_3 = \frac{\rho\pi R^3}{3}\left[(L_2 + L_3)^3 - L_2^3\right]$$

Finally it gets bat entirety to support point rotational inertia:

$$J = J_1 + J_2 + J_3$$

$$J = \rho\pi r^2 \frac{10L_1^3 + L_2^3}{30} + \frac{5(L_2 + L_3)^3}{15}\rho\pi R^2 + \frac{\rho\pi RrL_2^3}{10}$$

It solves baseball mass is :

$$M = \pi\rho\left[L_1 r^2 + L_3 R^2 + \frac{1}{3}L_2(R^2 + Rr + r^2)\right]$$

Input J and M into (4), it gets L. By calculation, it is clear that best batting point is nearly 30cm distance from bat end.

CONCLUSIONS

The paper established model is correct and reasonable, it improves established model quality; Model principle is simple and clear, easy to understand and flexible using; established model is well-considered; it has closely connection with actual status. The model correctly shows best batting point position, but on the premise of ideal model, best batting point will have different changes due to bat texture changes, so when making qualitative analysis of best batting point, taking friction force and other resistance, it will let the model become more persuasive.

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