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Dynamics characteristics study of pole vault based on energy analysis

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ABSTRACT

Pole vault belongs to the more complex technique and more difficult sport in track and field events; it is jumping movement that carries vaulting pole devices. Many predecessors take athletes as research object too much in previous studies. But the movement as a whole is a system, and only study part of it has some limitations. So this article starts from the athlete's gripping pole height, the run-up speed and deformation degree of the pole, carries through energy analysis on athletes and vaulting pole system, analyzes the dynamic characteristics of the athletes in the system through energy conversion law, aims at discriminate the pros and cons of present technological action, and provide a theoretical basis for technological improvements. The analysis results show that the athlete's height, run-up speed, gripping pole height, vacated height and material properties of the vaulting pole determines the results of the movement.

KEYWORDS

Vaulting pole;
Conservation of energy;
Run-up speed;
Grip pole height.

INTRODUCTION

In present all kinds of sports; pole vault is a sport that athletes acquire speed through holding pole run-up and plugging whole takeoff. In addition, through the stored energy of vaulting pole, it then passes the energy stored by the pole to athletes to send him over the cross-bar. The movement is very difficult. But through the improvement of material and technique, the results of pole vault have developed from 3.05 meters of a hundred years ago to 6.15 meters now. This shows that the development speed of this sport is very quick.

On the basis of the previous research, this paper uses energy analysis method to analyze and study the dynamic characteristics of the pole vault, proposes reason and method of improvements in accordance with performance reasons of dynamics characteristics, aims to provide a theoretical foundation for this sport and expects scores of new high.

SYSTEM MODEL

In the pole vault, athlete's vacated height determines the quality of his performance. The vacated height is associated with the run-up speed of the athletes and the bending pole related technique. More specifically the vacated height is related to the role of athletes and vaulting pole system. Whether the pole vault technique is good or bad has a direct impact on the development direction of this system. From the timing sequence, the

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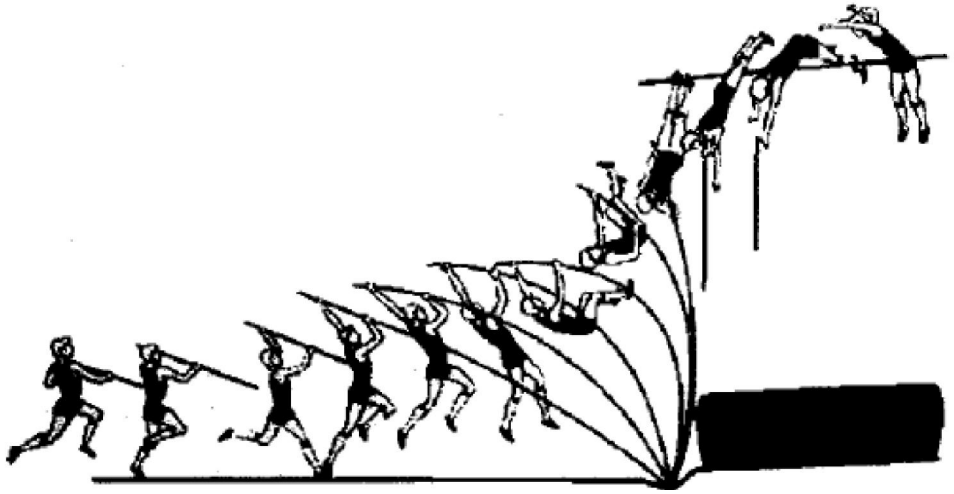

Figure 1 : Schematic diagram of pole vault

system needs to go through the technical process, as shown in Figure 1.

System energy conversion process of pole vault

When athletes finish run-up, the takeoff initial velocity obtained is supposed to be v_1 in the direction of horizontally forward. In addition assume the distance from the body center of gravity to the ground is h; the distance from the body center of gravity to the end of the vaulting pole is l_0 (the height of the grip pole). Body mass is indicated by m. When the athletes finish pole thrust, the instant speed leaving the ground is v_2. The distance between body center of gravity and the end of vaulting pole is d. Figure 2 shows this process.

When athletes is carrying through action ‘$, the kinetic energy that athletes have is denoted by E_{k1}, gravitational potential energy that athletes have is denoted by W_1, elastic potential energy that vaulting pole has is denoted by E_{T1}, the total energy of the system is E_1, their expression is shown in formula (1):

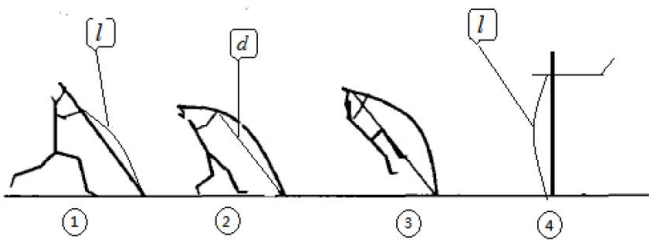

Figure 2 : Schematic diagram of take-off process and cross-over the hurdle process

$$\begin{cases} \mathbf{E_{k1} = \frac{1}{2}mv_1^2} \\ \mathbf{W_1 = mgh} \\ \mathbf{E_{T1} = 0} \\ \mathbf{E_1 = E_{k1} + W_2 + E_{T1}} \end{cases} \quad \textbf{(1)}$$

When athletes is carrying through action a$, the kinetic energy that athletes have is denoted by E_{k2}, gravitational potential energy that athletes have is denoted by W_2, elastic potential energy that vaulting pole has is denoted by E_{T2}, the total energy of the system is E_2, their expression is shown in formula (2):

$$\begin{cases} \mathbf{E_{k2} = \frac{1}{2}mv_2^2} \\ \mathbf{W_2 = mgh} \\ \mathbf{E_{T1} \neq 0} \\ \mathbf{E_2 = E_{k2} + W_2 + E_{T2}} \end{cases} \quad \textbf{(2)}$$

As in the take-off process the ground does not produce torque to the end of the pole and there is great difference between body weight and the pole weight, according to moment of momentum theorem there is quantitative relation of process a$shown in formula (3):

$$\mathbf{mv_1 h = mv_2 d} \quad \textbf{(3)}$$

Substitute formula (3) into formula (2), then we have formula (4):

$$\mathbf{E_2 = \frac{1}{2}m\left(\frac{v_1 h}{d}\right)^2 + mgh + E_{T2}} \quad \textbf{(4)}$$

When there is no energy loss, the elastic potential energy is shown in formula (5):

$$E_{T2} = \frac{1}{2}mv_1^2\left(\frac{d-h}{d}\right)^2 \quad (5)$$

When athletes is carrying through action c$, the kinetic energy that athletes have is zero, elastic potential energy that vaulting pole has is zero, all of them is converted to the athlete's gravitational potential energy. The total energy of the system E_3 is shown in formula (6):

$$E_3 = E_2 = mgl_0 \quad (6)$$

2.2. System energy conversion efficiency of pole vault

As there is energy loss in the process of the pole holding and hole insertion, the elastic potential energy owned by the pole after the jump should satisfy formula (7):

$$E_{T2} < \frac{1}{2}mv_1^2\left(\frac{d-h}{d}\right)^2 \quad (7)$$

Then the poles will also have loss in the process of deformation recovery. Based on the energy recovery coefficient of the material, in the case of athletes technique is standard, the energy recovery coefficient is only associated with the pole material, which is smaller than 1. The conversion relationship between elastic potential energy E_T and the mechanical energy W is shown in formula (8) below:

$$\begin{cases} E_T = W + \Delta E_T \\ W = \lambda E_T \end{cases} \quad (8)$$

In formula (8) ΔE_T stands for the loss of elastic potential energy.

Substitute formula (8) into formula (4) and (6) the elastic potential energy in processa$ can be calculated, as shown in formula (9):

$$E_{T2} = \frac{mg(l-h) - \frac{1}{2}m\left(\frac{v_1 h}{d}\right)^2}{\lambda} \quad (9)$$

The expression of mechanical efficiency in energy conversion process is shown as formula (10):

$$\eta = \frac{2g(l-h) - \left(\frac{v_1 h}{d}\right)^2}{\lambda v_1^2\left(\frac{d-h}{d}\right)^2} \times 100\% \quad (10)$$

The formula (10) shows that, the method to improve the mechanical efficiency is to reduce the value of d and increase the value of v_1. In the operation it is to increase the bending degree of the vaulting pole and increase the final speed of run-up.

The mechanical property of vaulting pole

The continuous development of science and technology makes the material of vaulting constantly change too. The direction of change is: 1) the mass is light; 2) fatigue strength is high; 3) the bending can withstand is large. The vaulting pole used in modern Olympic Games is FRP (fiber reinforce plastic) composite materials that satisfies these conditions.

Suppose the inner diameter of the vaulting pole is D, and the outer wall thickness of vaulting pole is y. Parameterchanges with the length of. The density of the homogeneous vaulting pole is. The expression of the vaulting pole mass is as formula (11). The deformation schematic diagram of homogeneous vaulting pole is shown in Figure 3.

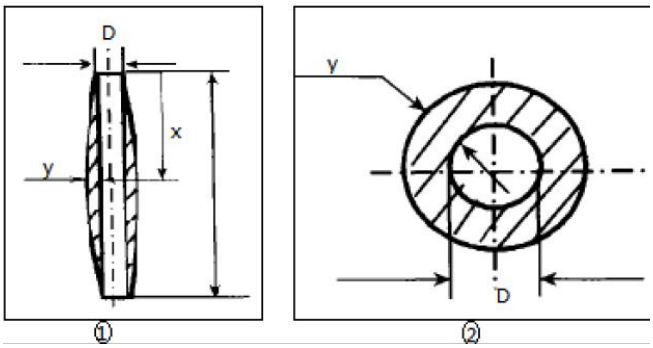

Figure 3 : Deformation schematic diagram of homogeneous pole

In Figure 3 '$is a front view, a$ is a sectional view.

$$M = D\rho\pi\int_0^l y(x)dx \quad (11)$$

When the pole receives the axial force, the pole can bend freely. Because the pole is homogeneous and elastic, the curved shape should be circular arc, and the radius of curvature is the radius of the circular arc. The deformation of the pole is not endless change. When it is subjected to a critical force, the material will produce the initial deformation, and satisfies formula (12):

$$F_{min} = \frac{\pi^3 ED^4}{l^2} \quad (12)$$

In formula (12) is the young modulus, and is the length of the pole. The formula (12) shows that in order

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to make vaulting pole produce the initial deformation it need to add a large force. If the momentum that athletes produced is less than the initial value to make the pole bend, the effect of the vaulting pole and the rigid pole is the same, and this will increase the energy loss when thrusting the pole. If add initial deformation in the process of pole vaulting, then can be greatly reduced. The cross section of vault pole used in Olympics is oval. When plugging the hole make the long axis parallel to the ground can easily reach this and achieve a minimum energy loss.

Other factors of pole vault system

Since the mass of the pole is relatively very small to the mass of the athlete, according to formula (1)-(6) athlete's final pole vault resultcan be approximately expressed as the form of formula (13):

$$H = \frac{v_1^2}{2g} + \frac{E_1 - E_{k1} - W - \Delta E_T}{mg} + l_0 \quad (13)$$

Seen from this that the larger the athlete's mass is, the smallerbecomes; the smaller grip pole height is, the smallerbecomes. From experience the relationship between grip pole height and athlete's height is shown in formula (14):

$$(2H_0) \le l_0 \le (2H_0 + 20cm) \quad (14)$$

Formula (13) and (14) shows that the performance of athletes is not only related to athlete's mass but also to lifter arm's height of athletes; one with high height can achieve relatively better results.

To sum up: the kinetic parameters, speed and height in pole system are fundamental factors to reflect the results. In the course of movement, reduce the loss of effective speed. Through the system internal force role make the initial velocity (also known as initial kinetic energy) when take-off convert into the elastic potential energy of the elastic pole with maximum extent. Then deliver it to the human body through the vaulting pole and transform it into gravitational potential energy of the athletes. In the transformation process, there is the energy loss. In order to increase the takeoff speed, one can increase the shape variables of the vaulting pole and increase the final speed of the run-up, which can effectively improve the take-off speed and mechanical efficiency. For the material properties of the elastic pole, we should follow the characteristics. When athlete is plugging the hole, he should make the long axis parallel to the ground, which helps reduce mechanical energy loss, and helps to increase the mechanical efficiency and athletic performance. Athletes' performance to some extent is related to the gripping pole height, the personal height and individual weight. The higher the height is, the higher the standard gripping pole height becomes and the better personal achievement is. The lighter the athlete's weight is, the better personal achievement becomes.

CONCLUSIONS AND SUGGESTIONS

Conclusions

1 This paper uses energy analysis method to observe kinetic parameters in the motor process of pole vault, which well reflects this sport;
2 Increasing the final velocity of run-up contributes to the take-off speed, which is of great help for athletes performance;
3 During the take-off process, one should try to increase the shape variables of the vaulting pole, which will help save the useful mechanical energy, and plays a good role in improving the mechanical efficiency;
4 Increase the height of the pole gripping can improve athletic performance;
5 The cross-sectional shape of the pole is designed into an oval shape, which helps to reduce the initial deformation force of the elastic pole, make the pole quickly produce deformation, and reduce the mechanical energy loss from the ground impulse;
6 Players' height problem largely determines the athlete's standard height of gripping pole. The standard height of gripping pole also increases with the increase of lifter arm height. Increase standard height of gripping pole helps improve athletic performance;
7 The athlete's personal body weight also determine the results of the movement on the one hand, and achievements increases with the decrease of weights;
8 The energy analysis method well analyzed the system model composed of athletes and vaulting pole; the scientific formulation of kinematic parameters reflects the technical feasibility of the movement.

Suggestions

1 We should develop new materials to make the ma-

terial properties develop toward the direction of lighter mass, larger fatigue degree, greater bending degree, contributing to the record refresh of pole vault;

2 In the training process athletes should focus on the study of the theory knowledge, and constantly confirm the theory in practice. For new discoveries one should test positively, and contribute to the future technological innovations;

3 As for the system energy analysis, it can be applied to other sports movement, such as table tennis.

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