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Mechanical Analysis Tai Chi Based on Energy Conversion Mathematical Model

Qingfeng Wang

Institute of Physical Education, Henan Polytechnic University, Jiaozuo 454000, China

Abstract: For the "Yanshougongchui" action process in Tai Chi, this paper conducts energy analysis, explores the biomechanical principles of stiffness and strength launching in Tai Chi, establishes the translational and rotational energy conversion model of human motion, analyzes the rationality of the mechanical model and provides reasonable scientific boxing basis for the majority of Tai Chi enthusiasts, so that the sport can get higher and further development.

Key words: Energy conversion, rotation, mechanical analysis, mathematical model

INTRODUCTION

Tai chi as a martial arts it has been adhering to the principle of adjusting body, adjusting mental and adjusting pranayama in its creation and development process, making it a low-intensity aerobic exercise of harmony between yin and yang, moving to self-cultivation, being quiet to nourish the heart, between moving and motionlessness, training of both body and mind, integration of heaven and human, integration of body and spirit (Tan, 2013). The Americans call it as "Oriental fitness ballet." Every country and every people have a self-evaluation of Tai Chi and the opinions are different. But as a kind of martial arts, tai chi has spread into different genres and is constantly developing; its martial effects and health effects should be superb (Wang and Yang 2013). Tai Chi is a form of human movement, the body has generation and consumption of mechanical energy as long as there is movement, including: translational kinetic energy, rotational kinetic energy and potential energy and conversion between mechanical energy complete through the way of acting. This paper focuses on analyzing the "Yanshougongchui" action, mainly studies its martial effects and body balance effects and describes the mechanics principle of the action by studying (Yang, 2013).

In this study, based on the results of previous studies it uses the energy conversion model, conducts biomechanical analysis on the "Yanshougongchui" action in order to verify the martial principles of tai chi and provides theoretical basis for the development of this sport.

MECHANICAL ANALYSIS AND ILLUSTRATIONS OF ACTION "YANSHOUGONGCHUI"

The practice purpose of tai chi is to exercise their stiffness and strength. Tai chi has different stiffness and strength. Stiffness is a material mechanics presented in the bones, while strength is the translational impact on rotational force during the mechanical motion of the body and it is an external expressive force (Xi, 2011). "Yanshougongchui" has "Left Yanshougongchui" and "Right Yanshougongchui". This paper takes the "Right Yanshougongchui" as the study object. This action is divided into four technical links: knee lifting and leg recovering link, feet wiping and arm joining link, body turning and arm rotating link, step bowing and punch launching link. The following is the decomposed description of the above four links and puts forward some notes (Zhang, 2008).

Knee lifting and leg recovering link: The body rotates slightly to the left, the body center of gravity moves slightly to the left, meanwhile his arms stretch toward both sides, the left hand rotates inside and the center of the palm oblique downward, the right hand rotates outside, the center of the palm turns upward and then control the body to turn right, the whole body center of gravity moves to the left leg, the right foot pedals on the ground, the knee bends and raises, in the process the toes maintain the natural sagging state, then the right arm bends elbow and moves to the front of the abdomen from upward -> left ->downward during the right palm rotating inside and box changing process; finally left arm bend the elbow, rotation in the left palm rotates externally from upward -> right -> downward and moves until his left hand and right hand fits in front of his chest, the left palm puts on the right forearm and the eye looks straight ahead (Zhang, 2010). The action of knee lifting and leg recovering link is shown in Fig. 1.

As Fig. 1 shows, in the knee lifting and leg recovering link process the right palm should lead the strength with little finger, complete the fist holding arm joining and right leg lifting simultaneously; because the entire process is the rising of body center of gravity,
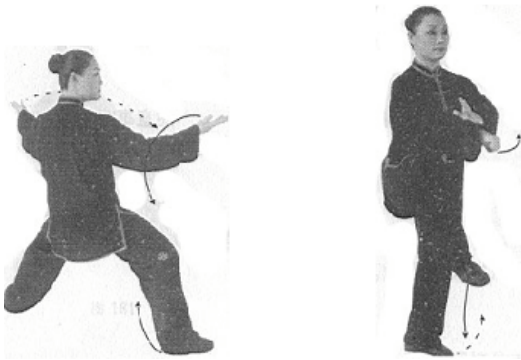
Fig. 1: Knee lifting and leg recovering link

Fig. 2: Left leg and knee bending link

Fig. 3: Body turning and arm rotating link

experience tells us that in the knee lifting and leg recovering link action we should take the inspiratory mode of expiration and inspiration.

The offensive and defensive strategy of knee lifting and leg recovering link is to take the advantage to turn left when the opponent hold his left wrist; the left hand moves to the left and make force from a borrowed force in order to change the opponent's state of motion and the stability of the center of gravity and break the opponent's attack means.

Feet wiping and arm joining link: When the left leg bends the knee, the right foot steps and shakes on the ground at the same time and then the left foot shovels out to the left front meanwhile when the left leg bents the knee and lifts, then control the body center of gravity move slightly to the left, during the above action course the left leg should bent the knee and the left feet should be at ease. With the action of the left leg bending the knee and left foot stepping on the ground, control the body center of gravity decrease to make the body's upper body move slightly right, the action is accomplished with the two swivel arms continue to strength joining over his chest, the requirement on eyes is looking straightly in the right palm, the action of feet wiping and arm joining link is shown in Fig. 2.

As Fig.2 shows, in the left leg and knee bending link process, we should pay attention to the simultaneity of step and fist rubbing, both hands should do the opposite twine action in the process of opening his arms, both hands should do the suitable twine action in the process of fist holding and arm joining; as in the left leg and knee bending link process, the body center of gravity moves downward, we should take the expiratory mode of expiration and inspiration.

The offensive and defensive strategy of feet wiping and arm joining link is that when the opponent attacks, his

left hand can catch the opponent's left wrist from the inside -> upward -> front and inversely twine the opposite side outside and then lead the opponent to the left in order to destruct the balance of the opponent's body and find the opponent's flaws.

Body turning and arm rotating link: When the body rotates right and controls the body's center of gravity move to the left, the left hand rotates a little to the outside and the right hand rotates slightly inward and then the both hands separate along the arc of the left upward and right downward, the center of the left palm is outward and the center of the right palm is outward at the same time; the body moves slightly to the left and the center of gravity shifts to the right, then the right arm bends the elbow and left fist rotates outside until close to the chest in upward -> left -> downward direction, the fist eye is outward. Finally left arm bend the elbow, left hand rotates externally to the right -> down -> Left, slide along an arc in front of the left shoulder, control palms upward, thumb and forefinger straight and rest three fingers bend naturally, the requirement of eyes is visually contacting the left hand, the action of body turning and arm rotating link is shown in Fig. 3.

As Fig. 3 shows, in the body turning and arm rotating link process, both hands should do twine action when

holding the fist and joining the arm, in order to achieve the purpose of accumulating strength; as in the body turning and arm rotating link process the body center of gravity is in a downward and strength accumulating process, we should take the inspiratory mode of expiration and inspiration. The offensive and defensive strategy of body turning and arm rotating is subduing the activity with serenity and coming into play.

Step bowing and punch launching link: The body rotates slightly to the right and then rapidly rotates to the left, in this process the body center of gravity quickly moves left into a step bowing state, the right leg bends slightly meanwhile the left hand rapidly contracts to the left rib it requires the center of the palm lightly against the left rib and the right fist accumulates energy with the twist, then the right fist rotates inside and issues with top speed toward the front right through his left arm, the vertical height of right fist flushes with the shoulder and the right arm is in slightly bending state and fully downward, the requirement of eyes is visually contacting the right fist, the action of step bowing and punch launching link is shown in Fig. 4.

As Fig. 4 shows, in the step bowing and punch launching process we should pay attention to force on the boxing face left elbow retreat initiatively, use lumbar to issue spiral shaking force; because the link is a forcing process, we should take the expiratory mode of expiration and inspiration.

The offensive and defensive strategy of step bowing and punch launching link is that when the opponent advances to attack, their left foot should move toward the left front of the opponent and step down near to the front side outside the opponent's right foot and then bow the knee forward, at the same time the right hand makes a fist and impact to the opponent's left rib by the twine action in reverse.

To sum up: In the process of completing the "Right Yanshougongchui" action, the key points are: Land stomping, waist turning, lumbar hitting and arm rotating; in this process the force should reach on boxing face, left

elbow actively retreat backward, use lumbar to issue spiral shaking force, in order to achieve the effect of strength accumulating as bow bending and strength delivering as arrow shooting, focus on strength delivering, first accumulating and then delivering and seeking straight in bending.

ANALYSIS OF ENERGY CONVERSION MODEL

Translational energy conversion model: During the human body's exercise process, the body shape and the motion state changes of each link include the center of gravity moving and body structure's deformation conditions. In this process, the bodies' own mechanical energy has two aspects of changes, one is the change of the gravitational potential energy and the second is the change of elastic potential energy. In the "Right Yanshougongchui" action process it includes the movement of the body center of gravity and the body shape's force building process. The action of Tai chi in the routine is very slow and only in the martial process it will have instant mutations. So this study assumes that the kinetic energy change is zero during the routine "Yanshougongchui" exercise process, there are only energy conversion between the body's internal energy and two kinds of mechanical energy (the gravitational potential energy and elastic potential energy).

Assuming a certain part of the body is the cylinder, the shape changing process of the initial state, the deformation state and the recovery state is a cylinder state model as shown in Fig. 5.

Model assumptions and symbol descriptions: The model in the course of action is an elastic cylinder, elasticity coefficient is k, the cylinder mass is m, he initial radius and the radius after recovery of the cylinder in Fig. 5 are both r, when the deformation is the maximum the radius is R, the position change amount of the center of gravity is x_1, the maximum deformation in the vertical direction is x_2, the internal energy of the human body can be
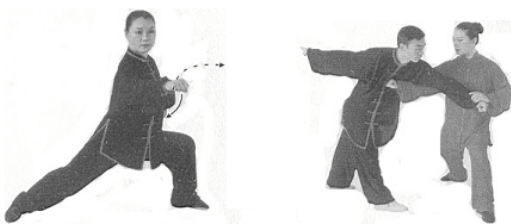

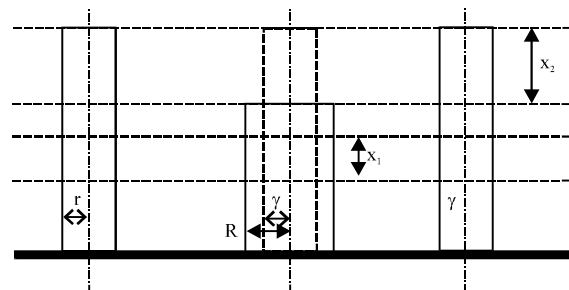Fig. 4: Step bowing and punch launching link

Fig. 5: Cylinder state model

represented by E, the variation of gravitational potential energy can be represented by ΔE_g, the variation of elastic potential energy can be represented by ΔE_t, the energy equation of the object's initial state is in the Eq. 1 below:

$$\Delta E = \Delta E_g = \Delta E_t = \Delta E_g + \Delta E_t = 0 \qquad (1)$$

When the object has the maximum deformation state, the energy equation is shown in the Eq. 2 below:

$$\begin{cases} E = \Delta E_g + \Delta E_t \\ \Delta E_g = mgx_1 \\ \Delta E_t = -\dfrac{1}{2}k\left[(2R-2r)^2 + x_2^2\right] \end{cases} \qquad (2)$$

The energy equation of the objects' reconversion process is in Eq. 3:

$$\begin{cases} E = \Delta E_g + \Delta E_t \\ \Delta E_g = -mgx_1 \\ \Delta E_t = \dfrac{1}{2}k\left[(2R-2r)^2 + x_2^2\right] \end{cases} \qquad (3)$$

To sum up: the changes in gravitational potential energy are only relevant with m and x_1. When the body center of gravity changes greater in the vertical direction, the gravitational potential energy changes greater, the more internal energy consumed when the body restitutes to the original state when the body's deformation is larger, the body consumes smaller internal energy when it restitutes to the original state; combination of the two will appear a shift in the relationship. But the relationship between the deformation and vertical position changes of the center of gravity and the energy are not consistent. The former one is a in quadratic relationship and the latter one is in a linear relationship (Zhang and Yue, 2013). That is in order to be able to consume less internal energy of the human body, the squat is a must. When a person's body mass is smaller, the elasticity coefficient is greater, you can better express the energy of "Yanshougongchui".

Analysis of rotational energy conversion model: In the process of "Yanshougongchui" action, the body appears rotation. In Tai Chi the energy generated by rotation is a major source of its momentum, since the rotation and stretching process of the muscles includes rotation the ups and downs opening and closing of the bones. In this article we assume the rotation part of the body is a resilient rigid cylinder, the rotation state and the force conditions are shown in Fig. 6.
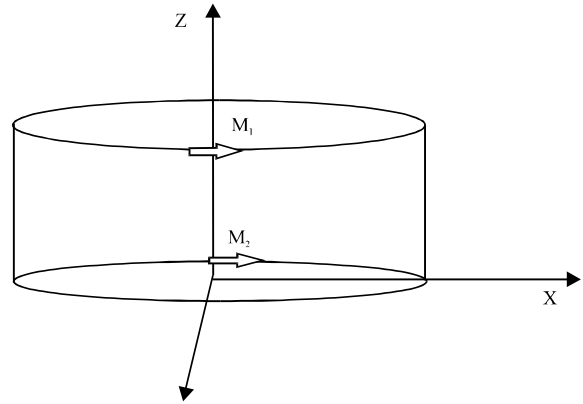

Fig.6. The state model of rotational force

Model assumptions and symbol descriptions: The upper and lower two surfaces of the elastic rigid cylinder receives two torques in opposite direction, the torque size of the upper surface is M_1, the torque size of the lower surface is M_2. According to the right-hand rule: the direction of M_1 is vertical upward, the direction of is vertical downward and there is no deformation in the longitudinal direction of the model, deformation occurs only in the lateral direction. As shown in Fig. 6 the energy stored by the model is represented by E, the energy stored per unit volume of the model is presented by e, then the stored energy when the motion model is in twisted state is in the Eq. 4:

$$E = \iiint_\Omega e\,d\Omega \qquad (4)$$

In equation 4 Ω represents the cylinder volume of an elastic rigid body.

Since the model does not flex, each cross section of the cylinder only suffers shear stress and because the object is in equilibrium it satisfies the Eq. 5:

$$\delta x + \delta x + \delta z + \tau xy = 0 \qquad (5)$$

Substitute the equation 5 into balance equation and then obtain the Eq. 6:

$$\begin{cases} \dfrac{\partial \delta x}{\partial x} + \dfrac{\partial \tau yz}{\partial y} + \dfrac{\partial \tau zx}{\partial z} + x = 0 \\ \dfrac{\partial \tau xy}{\partial x} + \dfrac{\partial \delta y}{\partial y} + \dfrac{\partial \tau xy}{\partial z} + y = 0 \\ \dfrac{\partial \tau xz}{\partial x} + \dfrac{\partial \tau yz}{\partial y} + \dfrac{\partial \delta z}{\partial z} + z = 0 \end{cases} \qquad (6)$$

By the equation 6 we can obtain the Eq. 7:

$$\dfrac{\partial \tau xz}{\partial x} = -\dfrac{\partial \tau yz}{\partial y} \qquad (7)$$

According to theory of differential equations, there must be a function φ (x. y, z) satisfying the Eq. 8:

$$d\varphi(x,y) = -\tau yzdx + \tau xczdy \qquad (8)$$

Combining equations 5 and 8 the strain energy equation of unit volume can be obtained, as shown in equation 9:

$$E = \iiint_\Omega \frac{1}{2}\left(\tau_{yz}v_{yz} + \tau_{zx}v_{zx}\right)d\Omega \qquad (9)$$

In equation 9, v_{yz}, v_{zx}, respectively means the torque size relative to yz and zx.

CONCLUSION

In summary, the rotational energy is related with the deformation volume and rotation dynamics of the motion model. When the effective rotation volume of the rotation dynamics and the model becomes large, the more energy of the model is stored. The use of translational energy conversion model and rotational energy conversion model well explains the stiffness and strength of the "Yanshougongchui" action. In the Tai chi training and teaching process, we should not only pay attention to the body shaping and skills but also study from theoretical aspect, thus this sport can have better development.

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