

Physics Behind the Martial Arts

Part Two

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Topics

Center of Mass

Momentum

Impulse

Work

Energy

Power

Note: I would recommend that the physics articles be read in order listed as I define terms in earlier physics articles that are assumed in the later physics articles.

Introduction

Martial Arts can be thought of as applied physics to the body for defense or offense against an opponent. In Martial Arts you are applying forces against an opponent and leverage against the body structure. In defense, you would be blocking or immobilizing an opponent. In offense, you would striking or applying joint locks to an opponent. Of course there is overlap, like the old saying that “a good offense is a good defense.”

Physics is the branch of science concerned with the nature and properties of matter and energy. The subject matter of physics, distinguished from that of chemistry and biology, includes mechanics, heat, light and other radiation, sound, electricity, magnetism, and the structure of atoms. For Martial Arts, we will be looking at the mechanical part of physics.

In these physics articles, I have tried to explain some of the basic concepts of physics, including a definition of a physics concept and an everyday example. Hope-

fully I also related the physics concept to some Martial Arts examples and applications.

I hope you won't get uptight with the word "physics." You do not have to follow each concept in detail, unless you wish. You do not have to understand it all. You do not have to read every word at one sitting. Take a quick look. Look at just one concept. Look at the everyday examples. Look at the results of calculations and numbers, not the calculations themselves. Think about how the martial art examples are similar to the everyday examples. This will still allow you to get a feel of the overall concepts. Hopefully, an understanding of the basic concepts of physics will give you a more in-depth understanding of, and how to better apply, your martial art training.

Happy reading.

Center of Mass

The center of mass of a body is the average position of mass, or the single point associated with a body where all its mass can be considered to be concentrated. It is that point from which it can be suspended in any orientation without tending to rotate. On a person, this is where you can lift that person with one hand.

The average position of weight, or the single point associated with a body where the force of gravity can be considered to act is called the center of gravity. The weight of a body can be considered as a downward force acting on its center of gravity.

In a uniform gravity field, the center of gravity is usually at the same point as the center of mass.

This is the point where an object could be balanced, if on a pivot.

This is also the point that if a force is applied to an object, through this point, the object will not rotate, but only move in a straight line. This point is in the vertical

center of the human body and about the hip area. If you wish to move a person off of you, you need to push near their center of mass. If you apply a rotation force to a person, they will tend to rotate about their center of mass.

Momentum

The **linear momentum** of a body is the product of its mass and velocity.

$$\text{Linear momentum} = \text{mass} \bullet \text{velocity}$$

Linear momentum is a vector quantity whose direction is that of the body's velocity.

The greater the momentum of a body, the greater its tendency to continue in motion. Thus a baseball hit by a bat (large velocity) is harder to stop (take away the momentum) than a baseball thrown by hand (small velocity), and an iron shot (large mass) is harder to stop than a baseball (small mass) of the same velocity.

Think about which you could stop. A baseball moving at a speed of 100 mi/hr or a car moving at the same speed of 100 mi/hr. The car, having so much more mass, would have a much greater momentum and hence be much harder to stop.

Momentum can also be transferred from one person to another. We could talk about exerting a force and accelerating an object to a velocity, but we can just look at it as transferring momentum. sometimes this is easier.

A large momentum could be a fist (small mass) at a high velocity. However it could be a smaller velocity with the fist backed up by your whole body in the punch (large mass).

An example of the first case could be a jab with the fist at a high velocity.

An example of the second case could be a hook with the whole body behind the punch.

Impulse

Impulse is the force applied to an object times the amount of time the force is applied. If you apply a force to an object, the object will change its speed, Hence it will change its momentum. Therefore, impulse is also equal to change in momentum.

$$\text{Impulse} = \text{Force} \cdot \text{time interval} = \text{mass} \cdot \text{change in velocity}$$

Work

Whenever a force affects the motion of a body, the body undergoes a displacement while the force acts on it. The product of the force and the component of the displacement of the body in the direction of the force is called the work (W), done by the force on the body. Work, as defined by Physicist, is a very narrow and precise definition. Work is force applied in the direction of movement times the distance moved.

$$\text{Work} = \text{Force} \cdot \text{distance}$$

In the metric system the unit of work is the Joule (J) and in the British system it is the foot-pound (ft • lb).

Note that if there is no movement, there is no work done.

Work would be done to a nail by applying a force to it, and driving it a distance into a wall.

Note that when you do work, you create energy. Also when you use energy, you do work.

Energy

The ability to do work. The metric unit for energy is the Joule (J).

In mechanics, there are two types of energy, kinetic energy and potential energy. By the way, non-mechanical energies could be sound, electrical, heat, or radioactive.

Kinetic Energy

The Greek word for motion is kinetic. Therefore Kinetic Energy is the ability to do work by the virtue of being in motion.

Kinetic energy, KE, of an object is energy due to both of the mass and velocity (speed) of that object.

$$KE = 0.5 \cdot \text{mass} \cdot \text{velocity} \cdot \text{velocity}$$

$$KE = 0.5 \cdot \text{mass} \cdot \text{velocity squared}$$

Note that velocity is used twice in this equation and mass is used only once.

A bowling-ball, moving along the floor, can hit a nail and drive it into the wall, and thus do work. A low mass object, like a balloon would not drive the nail into the wall. A bowling-ball, not moving, or moving very slow, would not drive the nail into the wall.

A punch throw at an opponent has both mass of your fist and velocity. Hence it has kinetic energy. When the punch hits your opponent, that energy can be delivered to your opponent. The typical fist has 0.61% (0.56%) of the male (female) body mass.

In the case of kinetic energy, mass is a factor, but its the square of the object's speed that is a factor. If you triple the object's mass, you triple its kinetic energy, but if you triple its speed, your increase its kinetic energy by a factor of nine times, not just three.

Hence, speed is more important than mass, and a person will want to maximize speed in a strike. In a hand strike, the maximum speed is not at the end of the

strike (since the hand has to stop and retract) but about 4/5 of the way out. This is why instructors tell you to try to terminate the punch about a fists length inside your opponent. this will help insure that you are at your maximum speed when you make contact with your opponent.

Note that a typical punch generates about 20 - 50 Joules of mechanical energy and a force of 500 Newtons.

The typical front punch has a maximum speed between 6 m/s and 10 m/s. The typical front kick has a speed between 10 m/s and 15 m/s. The typical mass of the leg can be up to 20% the mass of the body, while the mass of the arm is only 10%. Both from the large mass of the leg compared to the arm and the faster speed of the foot, the energy delivered by the kick is three to six times the energy delivered by a straight punch.

The effective mass of the arm can be increased by stepping forward into the punch. However, this is at the expense of your stability and balance. Hence, increasing the speed of your punch is usually a better way to generate more energy for your punch.

Potential Energy

Potential energy, PE, of an object is energy due to height of an object above the earth. It involves the object's mass, m, height above the earth, h, and the acceleration of gravity of the earth, g.

$$PE = m \cdot g \cdot h$$

A ball, let go above a nail, can fall, hit the nail, and drive it into the floor, and thus do work.

Dropping down on an opponent with your knees would be an example of using your potential energy of your body above your opponent. Note the the more mass you have the more potential energy you have.

It is easier to hit a person when you are mounted on him and can then utilize the potential energy advantage, than it is to hit a person who is mounted on you.

If sparing, you usually need to conserve your energy. Remember to be quick, not fast. That is, move smoothly and without hesitation, instead of moving with jerks, or needing to move fast because you are out of position. Keeping your body at the same height is also important for conserving energy. Every up-and-down movement by only 20 cm (7.8 inches) uses almost as much energy as a punch thrown at a speed of 7 m/s.

Power

The time rate at which work is done is called power. (i.e. Power is the amount of work done per unit time.)

It is a measure of how fast you exert your energy.

$$\text{Power} = \text{energy} / \text{time} = \text{work} / \text{time}$$

The metric unit is the watt (W). The units of the Watt = Joules / second and in the British system it is the ft-lb/s.

One horsepower is equal to 746 W or 550 ft-lb/s. The definition of horse power comes from experiment. A typical English horse could pull a 550 lb. sled a distance of one foot in a time of one second.

Suppose you go up ten flights of stairs. Since you have lifted your body mass up the ten stories, you have done a certain amount of work and thereby increased your potential energy. Now, this is true if you walk up the stairs or run up them. However, the power used is greater if you run up the stairs since you took less time. Note that you also will feel much more tired if you run.

By the way, our electric power company does not care how fast you use their energy (e.g. the power), but only how much energy is used. Hence you pay for energy

not power. Our electricity cost less than 10 cents for 3,000,000 J of energy. A 100 Watt light bulb uses 100 Joules each second. This is less than 10 cents in 24 hours.

The power of a strike is how fast we can deliver energy to the target. due to the inertia of your opponent, a high power strike allows more energy to be delivered to a relatively stationary target. a low power strike will tend to push your opponent backwards.