Editors Note: The NSCA believes that the strength coach should be aware of the various modes (types) of resistance methods and equipment on the market. Each has its own unique features that set it apart from the competition.

We have invited numerous equipment companies to “toot their own horn” and explain how their product’s training mode achieves a training effect.

This series of articles will help you judge the modes of conditioning and hopefully allow you to make your future purchases based on your strength and conditioning needs.

We would like to extend an open invitation to any equipment company that would wish to contribute to this series.

Thanks to some basic laws of physics, 100 pounds is not always 100 pounds. It is one of those quirks of nature that has kept designers of variable resistance machines busy for a century wrestling with the age-old laws of gravity and acceleration.

When looking at an iron weight, whether in the form of a barbell or a weight stack on a machine, one assumes it always represents a particular resistance. It does, but only when it is at rest. Once in motion, the changes in speed of movement cause the weight to change.

That change can be illustrated by the sensation felt by persons riding an elevator. As the elevator starts to move upward, one begins to feel heavier. When it achieves a constant speed, a feeling of a return to a normal weight is experienced. As it slows to a stop, one feels lighter. A person standing on a scale would have seen that exact change. Even though actual body weight did not change, the force exerted on the scale (floor) did. Much the same thing happens when a barbell is lifted. The force exerted by a barbell on the hands, during an exercise, will vary in the same way. This occurs because the barbell is accelerated just as the elevator accelerates persons riding on it.

The foundation for this phenomenon may have been encountered in a high school or college classroom. Long before man thought of exercise machines, Sir Isaac Newton showed the interrelationship of the variables that make up the force needed to move an object. Newton showed that this force is arrived at by multiplying the mass of the object (mass equals weight divided by 32) times the acceleration (rate of change of speed). \( F = ma \), “F” being the force, “m” mass, and “a” acceleration.

Acceleration changes as the speed of movement changes. To attain greater speeds of movement higher accelerations are necessary. Because of this simple formula, it can be seen that if the mass is high (as it is when using iron weight as a resistance) the forces can change greatly depending upon the speed of movement. It is not unusual, when the person is moving a weight, to have acceleration forces equal to or greater than the actual weight being lifted. For example, a shot putter may exert a force in excess of ten times the weight of the shotput because of the tremendous acceleration necessary to get the distance.

Figure 1 shows how the actual resistance produced by the barbell varies as it is moved during an exercise routine. In the first part of the positive stroke, as the bar leaves the chest, it requires additional force to accelerate it to the desired speed. As the desired speed is approached the acceleration force becomes less until a constant speed is reached. At that point the acceleration, and thus the acceleration force, becomes zero and the resistance drops to that of the barbell’s weight. A few inches from the end of the positive stroke the resistance drops as the barbell slows to a
stop. The negative portion of the stroke is the mirror image of the positive stroke. The resistance drops as the bar accelerates downward to a constant speed. At constant speed the resistance increases to that of the barbell’s weight. As the barbell nears the chest a greater force must be exerted to slow or decelerate the barbell to a stop. The faster the speed of movement the greater the acceleration forces. It can be seen from figure 1 that, although we refer to the barbell as isotonic resistance (that is an unchanging resistance) it is in fact variable in nature.

It is that very phenomenon—the change in the barbell’s resistance as it passes through the stages of an exercise routine—that has posed a challenge to designers of variable resistance equipment since the first such exercise machines were developed in the late 1800’s.

The design of variable resistance machines requires a very tight control of the output resistance throughout the range of movement. Then, the output resistance will conform as close as possible to the strength curve of the individual. The function of the cam in a cam and chain type machine is to do just that, and the cam profile must take into consideration the forces due to acceleration and deceleration (starting and stopping the weight stack) so that it can counteract the effects of inertia and momentum. The previous paragraphs showed that the acceleration forces change as the speed of movement changes. Therefore, a speed of movement must first be determined and the cam profile designed accordingly. For this reason, the manufacturer of high inertia (iron weight resistance) variable resistance machines require strict exercise speeds. Figure 2 shows how the deviation from that speed results in an improper strength curve output. This is also the reason that so much has been done to promote certain speed programs. The manufacturers have committed themselves to the speed for which their equipment was designed.

When Low Inertia Variable Resistance was introduced in 1978 few understood or appreciated what it meant. In short, it was the creation of an alternate resistance which was capable of producing substantially high resistances with very little inertia (moving mass or weight) and without a dependence upon gravity. The elimination of the iron weight significantly reduces the mass, m, in the formula \( f = ma \). Therefore, \( f \) (the force due to acceleration) is virtually eliminated. This leaves only the pure variable resistant force which the user must work against. The substantial reduction of the acceleration forces and the elimination of the dependence on gravity allows the variable resistance strength curve to remain consistent over a wide range of exercising speeds.

The information presented thus far may raise a question about the speed of exercise. Four years ago everyone read that fast speed of movement during an exercise jerked the muscles violently and produced nothing but injuries. This statement is true in that injuries were produced, but the blame was put on the wrong element. Speed appeared to be the cause only because the proper equipment had not been developed at that time. It is like saying that jumping from an airplane produces nothing but injuries because the only equipment available at that time was an umbrella.

The CAM II system developed by Keiser Sports Health Equipment is the forerunner in this new breed of variable resistance machines. Pressurizing pneumatic cylinders with com-

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pressed air creates the alternative resistance spoken of earlier. The CAM II system is comprised of a series of specialized machines, each specifically designed to exercise a specific body part. An air compressor supplies air pressure to each machine just as a generator supplies electricity to lights. A pressure regulator located on each machine is controlled by the user to select the exact air pressure supplied to the pneumatic cylinders.

The air pressure acting on the face of the piston in the cylinder forces the cylinder rod to extend. One hundred pounds per square inch of air pressure applied against a 2½ inch diameter piston (area = 4.91 square inches) will create a force of 491 pounds.

The only moving mass (inertia) involved in this system is the piston and rod, approximately three pounds. This is a significant reduction when compared to 491 pounds of moving mass in an equivalent iron weight stack. The reduction of moving mass by 164 times substantially lowers the acceleration forces. This enables a strength curve to be programmed into the machines and have that curve remain consistent over a wide range of speeds. Automatic closing of a valve as the arm leaves the starting position traps the air in the cylinder and further compresses it. While moving through the positive stroke (or concentric contraction) this allows for the storage of the energy expended on

Figure 2. Three curves showing the changes in resistance at the handle for a typical high inertia variable resistance chest press. The resistance at the handle is represented by the solid line curve. The broken line curve represents the desired strength curve for the chest press exercise. Fig. 2a represents the resistance forces when the speed of movement is much less than the manufacturers required speed. Fig. 2b represents the resistance forces when the speed of movement equals the required speed. Fig. 2c represents the resistance forces when the speed of movement is much higher than the required speed.
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that positive stroke so that it can be delivered back on the negative stroke (or eccentric contraction). This, in turn, provides an eccentric contraction equal to the concentric contraction, which is impossible with a high inertia system except at extremely slow speeds. Also, as the air is further compressed in the cylinder its pressure increases, thus increasing the force output on the cylinder. This, plus the changes in leverage by the linkages, is how the variable resistance curve is programmed, eliminating the use of cams and chains. This is the exact method by which the human body varies its forces. The contractive effort of the muscle changes as it shortens, and the muscular leverage changes as the joint passes through its range of movement.

Strength has always been the measurement of an athlete’s ability to perform. Yet in actual performance the athlete will probably never use maximum strength. In almost all cases speed or a combination of strength and speed (power) will produce greater results than strength alone. Soon, talk will center around the most powerful line in football, not the strongest.

Low inertia variable resistance equipment opens up dimensions in training that were never before possible with existing equipment. This affords strength coaches the opportunity and the challenge to explore these dimensions.

Figure 2c. Resistance Curve

- **Positive Stroke**: High initial resistance due to high acceleration forces.
- **Negative Stroke**: High forces required to slow weights to a stop as handle approaches chest.
- **Large loss of resistance due to rapid slowing (deceleration) of iron weights as arms straighten.**
- **Loss of resistance because weights must start accelerating downward (falling).**

Figure 3. The broken line represents the desired strength curve. The solid line represents the resistance output of a low inertia variable resistance machine. The slight deviations from the desired curve at the beginning and end of the positive and negative stroke would occur only at very high speeds due to the inertia in the handles and linkage.

DISTANCE TRAVELED

HANDLE AT CHEST

ARMs FULLY EXTENDED

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