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Strength Curve Generation of the Biceps Muscles via Electronically Controlled Mechanism

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This study introduces a new concept in the generation of strength curve profiles in resistance training equipments. Rather than of using the conventional spiral off centered cam commonly used in current resistance training equipments, this study focuses on using a DC motor to be controlled by a micro controller to generate the strength curve as well as the resistance in resistance training equipments. Unlike the spiral off centered cam, the method in this study will not be hampered by the limitations imposed by using a mechanical component that usually lack flexibility in these equipments. The concept of this study will be demonstrated in a barbell curl exercise, although the concept can also be applied to other forms of resistance training equipments. With this study, a new and flexible alternative in the generation of strength curve profiles in resistance training equipments can be offered.

1.0 Introduction

It can be observed that in a barbell curl exercise, the resistance felt by the user varies as the movement progress from the starting extended position to the final contracted position. This happens because during a curl, the moment arm of the weight is constantly changing as the movement progress along the axis concentric with the user's elbows (see Fig 1). It can also be noticed that during the starting position of the curl up to the midpoint position, both the length of moment arm and the degree of muscle contraction are increasing along the axis. While from the midpoint thereafter, only the degree of contraction increases while the length of the moment arm decreases. However, it is learned that in order for muscles to grow, it needs to be stimulated in its strongest position, which is in the state of full contraction. But, as what is shown in the figure during the most contracted position, the length of the moment arm is almost zero and it is possible to hold the weight in this position almost indefinitely without any work being done on the muscles in its strongest position. To compensate for the change of strength however in resistance training equipments, manufacturers usually install a mechanical component which is a spiral off centered cam (Fig. 2) to be interposed between the weight stack and the exercising lever. Basically, these components are tasked to offset the length of the moment arm that is being loss due to the rotation along the axis. By using spiral off centered cams, it can be assured that despite the moment arm is almost zero in the muscles strongest position; still, enough work is being done on the muscles. However, defining the proper profile of these components highly depend on the strength curve profile of which particular group of muscles they are intended to train. These muscle groups, more often than not greatly varies among individuals depending on body type, genetic and gender, which results in making these components inferior in flexibility in resistance training equipment. Although there have been other studies that tried to integrate electronics in resistance training equipments like what was done with the Microcontroller-Based Safety Spotter Bench Press Exercise Machine (Dulay, 2006), however, the said study is more concentrated on the safety aspect of the machine rather than of actually generating the resistances.

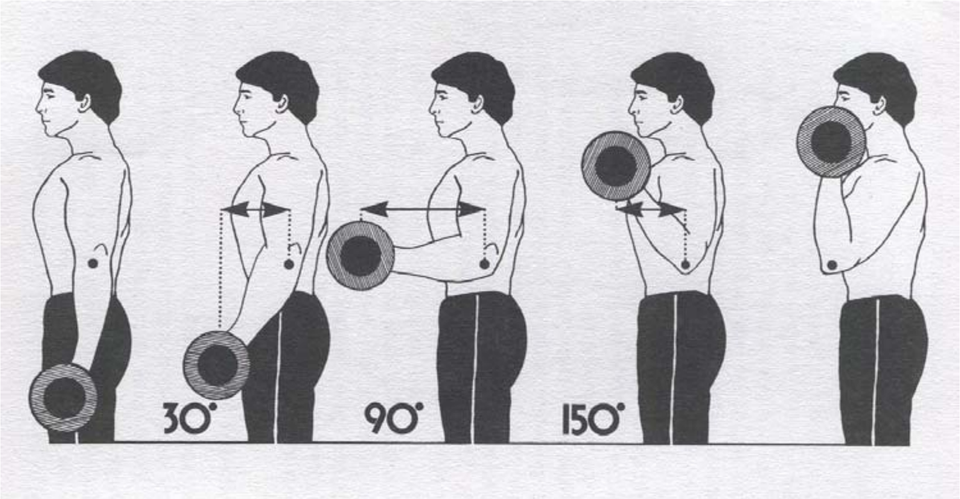

Fig. 1 Progression of the Barbell Curl Exercise

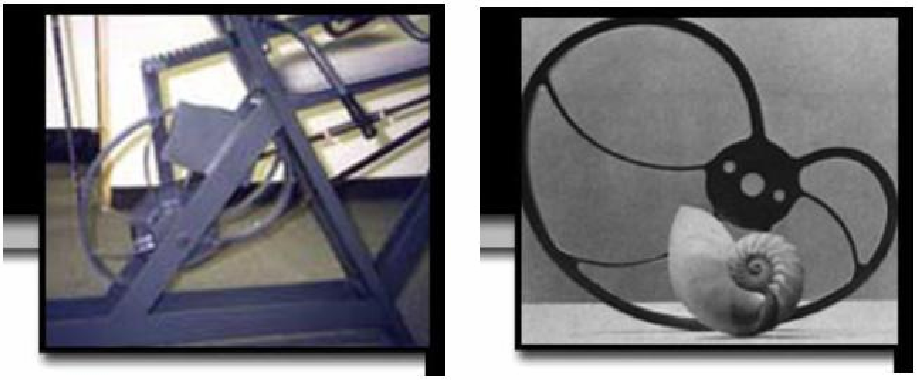

Fig. 2 The Spiral Off Centered Cam, a Mechanical Component

Strength Curve Profile and the Spiral Off Centered Cam

If the degree of elbow flexion from the figure above is graphed against the percentage of muscular contraction of the biceps muscles (see Fig. 3) between the length-tension curve of the biceps muscles (A) and the effective, or actual resistance of a barbell curl (B), it can be seen in the difference (C) that the ideal strength curve of the biceps muscles (A) does not perfectly match the length-tension curve that it should be subjected to. In other words, the shaded area (C) is the apparent difference between ideal resistance (A) and barbell resistance (B) for the biceps muscles.

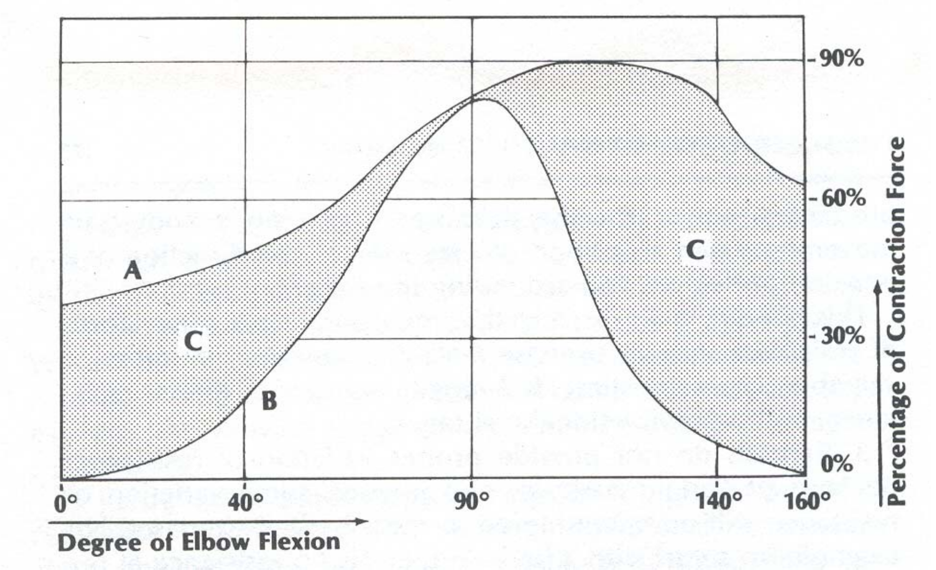

Fig. 3 Strength Curve

Therefore, in order to optimize growth in the human muscles, the resistance applied should exactly match the apparent change in strength of the human muscle. That is, a resistance that at no point over the range of movement would appear to be any heavier or lighter than at any other point. In order to do this however, the resistance needs to be varied along the entire range of motion to compensate for the change of strength of the muscle during contraction. This is the main reason of using spiral off centered cams in resistance training equipments to possibly duplicate the ideal strength curve.

2.0 Conceptual Framework

The resistance training equipment in this study will be particularly adapted for exercising the biceps muscles of the user; and which make use of a DC motor and a micro controller to provide a programmable resistance. The machine includes an exercising lever supported by flange bearings for pivotal movement aligned along the rotational axis of the user's elbow; and is connected to the first of a two stage gear reduction system interposed between the DC motor and the exercising lever to compensate for the desired ratio. A digital data processor and a shaft encoder operatively connected to the DC motor are used for monitoring the position and direction of movement of the exercise lever relative to the DC motor. The resistance that will be produced by the DC motor is dependent upon the profile of the program set at the micro controller; and implemented by amplifying the motor current to produce the corresponding torque to be generated and deployed accordingly upon the desired positions along the range of motion of the exercise lever. The architecture of the system is shown in Fig. 4.

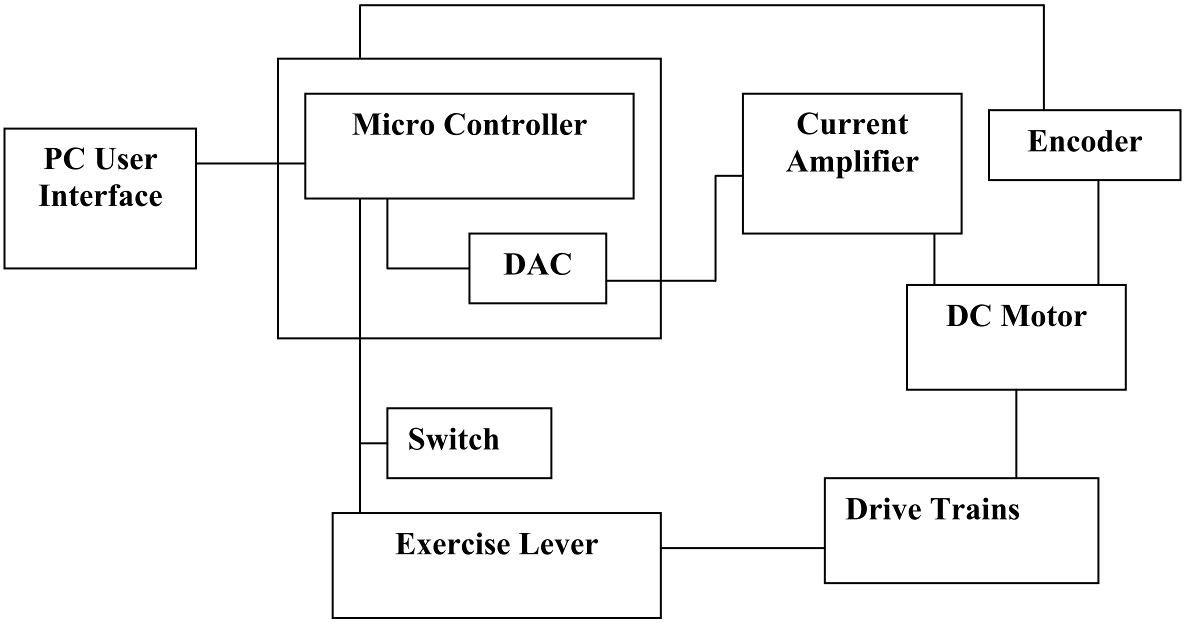

Fig. 4 System Architecture of the Prototype

3.0 Mechanical Design

The mechanical set-up of the system as shown in Fig. 5 composes of three main components, the base, the exercise lever and the drive train. The base supports the user, as well as the exercise lever and the drive trains. It is made up of individual parts created from rectangular tubing and mild steel plates that are welded together. The mild steel plates serve as the joining profile along with rectangular tubing using nuts and bolts to fix the parts together to form the base. The exercise lever on the other hand is the portion of assembly where the user will feel the resistance, also known as engagement portion. Just like the base, it is made up of rectangular tubing that is welded together. It is connected to the base by a shaft that is then fastened both from the base and the component itself using flange bearings to allow pivot. While the handle bar is made from cylindrical tubing that is also fastened by employing flange bearings with the same intention to permit pivot. It is important for this portion of the assembly to have a smooth and fine movement. And using flange bearings ensures just that. It is the function of this component to directly apply resistance to the body part being trained while the movement occurs. The last component of the system is the drive train. They are designed to transmit the resistance from the DC motor to the exercise lever. It is composed of gears and timing belts. As well as keys and pins to lock everything up.

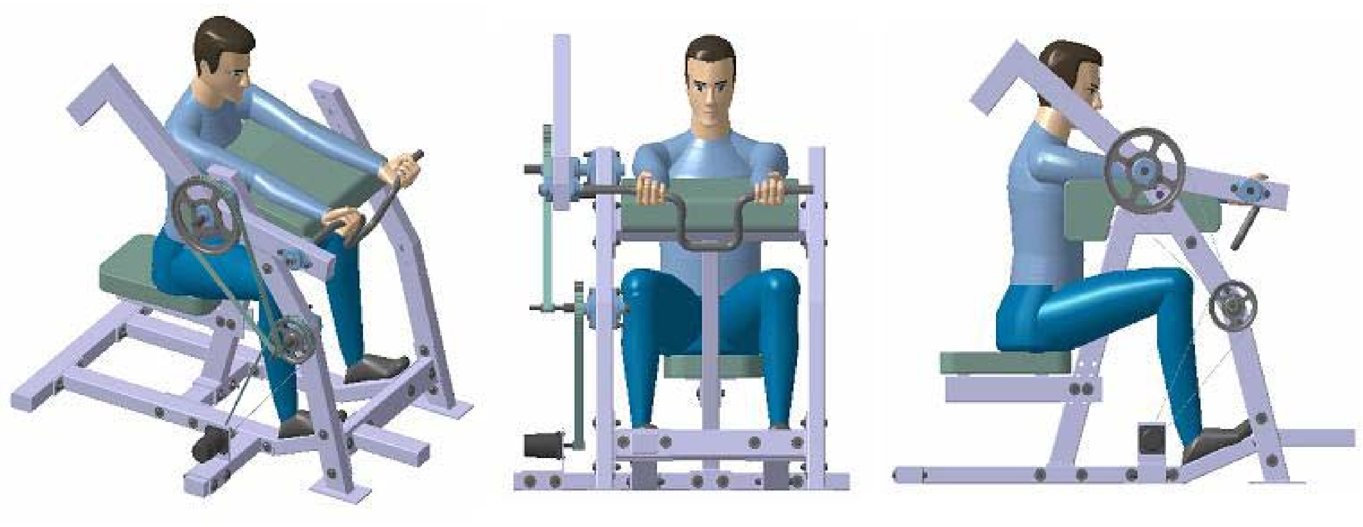

Fig. 5 Mechanical Set-up

4.0 Electronics Design

The diagram of the electronic design used in this study is shown below (Fig. 6). Basically, the resistance on the exercise lever of the prototype needs to be controlled electronically. Since the exercise lever is directly connected to the DC motor via the drive trains, controlling the DC motor therefore is a way to directly control the resistance in the exercise lever.

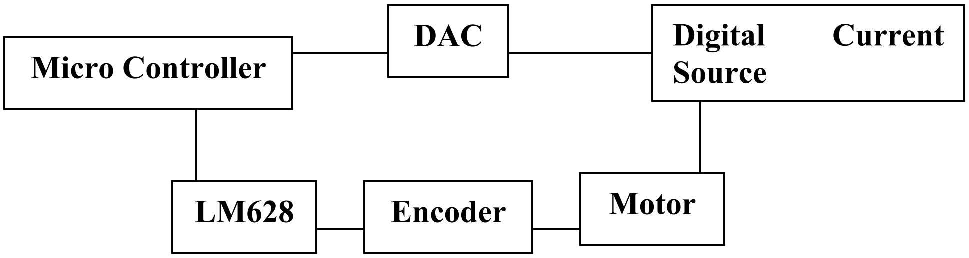

Fig. 6 Electronics Design

The diagram shows the necessary components needed to control the DC motor. The main component that will control the DC motor is the Digital Current Source. However, in order to control the current source digitally, a digital to analog converter (DAC) need to be employed to directly control the current source. Accordingly, the DAC is connected to the micro controller, which supplies the number of counts the DAC is sending the current source. The micro controller on the other hand is operatively connected to the LM628, which is used to monitor the position of the optical shaft encoder relative to the position of the DC motor.

Digital Current Source

In controlling DC motor with this kind of application, controlling the current would seem to be the most effective since it is proportional to the output power. Therefore, a digital current source was employed in controlling the resistance that will be generated by the motor.

The circuit shown in Fig. 7 provides an output current proportional to the input voltage. Current drive is sometimes preferred for servomotors because it aids in stabilizing servo loops by reducing phase lag caused by motor inductance. In applications requiring high output resistance, such as operational power supplies running in the current mode, matching of the feedback resistors to 0.01 percent or better is required. Alternately, an adjustable resistor, R3, can be used for trimming. Offsetting R3 from its optimum value will give decreasing positive or negative output resistances.

The current source input is actually differential. It can be driven as shown, or from the bottom of R3 to obtain the opposite output sense. Both inputs should be connected to a low source impedance like ground or an op amp output. Otherwise, the source resistance will imbalance the feedback, changing output resistance. Alternately, an input can be driven by a known source resistance, like a voltage divider, if this resistance is made part of the feedback network.

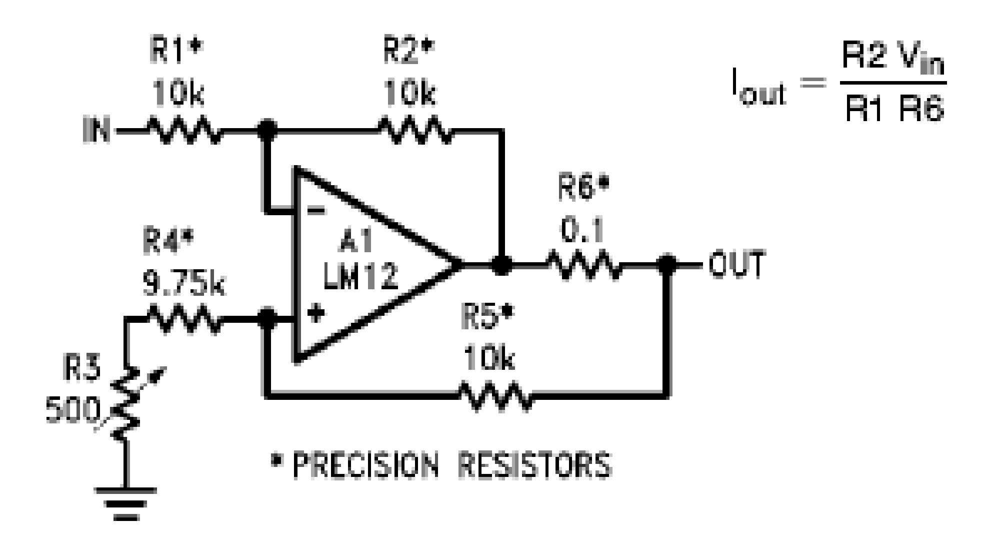

Fig. 7 Electronics Design

5.0 Software Design

The software in this study was done through micro controller programming (Fig. 8). Basically, the micro controller accepts input values from a look up table of the desired profile to be deployed coming from the PC User Interface. These values are then passed through by the micro controller to the Digital Analog Converter (DAC) which from there, data is passed on to the Current Amplifier to eventually control the resistance of the motor. In the same manner, a shaft encoder is operatively connected to the micro controller to ensure that the Current Amplifier is deploying proper resistances upon the entire range of motion.

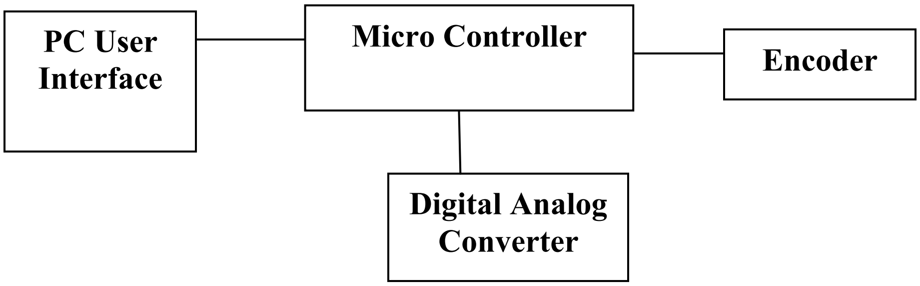

Fig. 8 Software Design

6.0 Experiments and Results

The experimental system was set up with the prototype along with a digital weighing scale. The digital weighing scale was placed beneath the counterweight of the exercise lever at the opposite end. From the pivot axis up to the midpoint of the counterweight, the distance is 20. 5 inches, from the pivot to the handle is 13 inches. Figure 9 demonstrates the system described. Two experiments were performed using this system, one involving current-force and the other confirmatory experiment on DAC-force.

Current-Weight Curve (Initial)

The first experiment done was finding if an increase of current (I) in the motor would also be proportional to the force (kg) that will be exerted. In conducting the experiment, a VOM was set series between the motor and the current supply to monitor the change in current. And the digital weighing scale was used to measure the equivalent force exerted by the motor in a given amount of current.

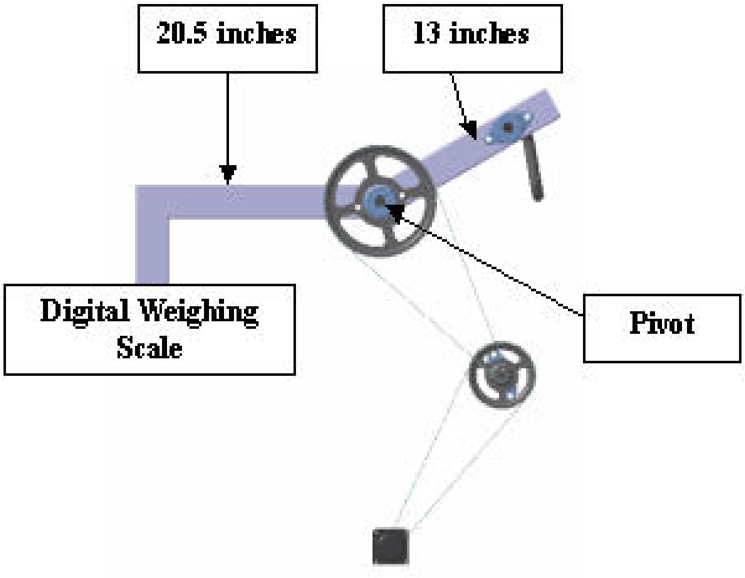

Fig. 9 Experimental Set-Up

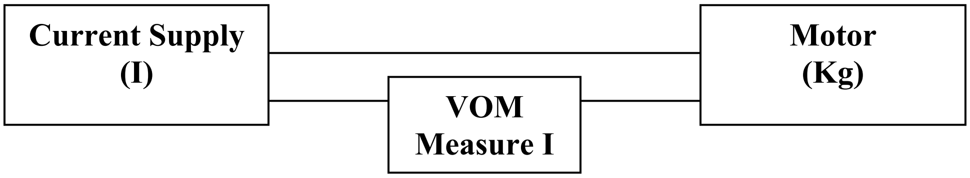

Fig. 10 Current-Force Block Diagram

Table 1 shows the result of this experiment. The resultant graph is shown in Figure 11. Therefore, based from the graph, the increase in current is directly proportional to the increase in weight.

Table 1: Experimental results for Current-Force

Current (I)	Weight (Kg)	Torque (Kg • 2.2 lb • 20.5 in)	Equivalent in Exercise Lever (lb)
3.5	2.46	110.946	8.53
4.5	2.66	119.966	9.23
5.5	3.24	146.124	11.24
6.5	4.07	183.557	14.12
7.5	4.65	209.715	16.13
8.5	5.20	234.520	18.04
9.5	5.87	264.737	20.36

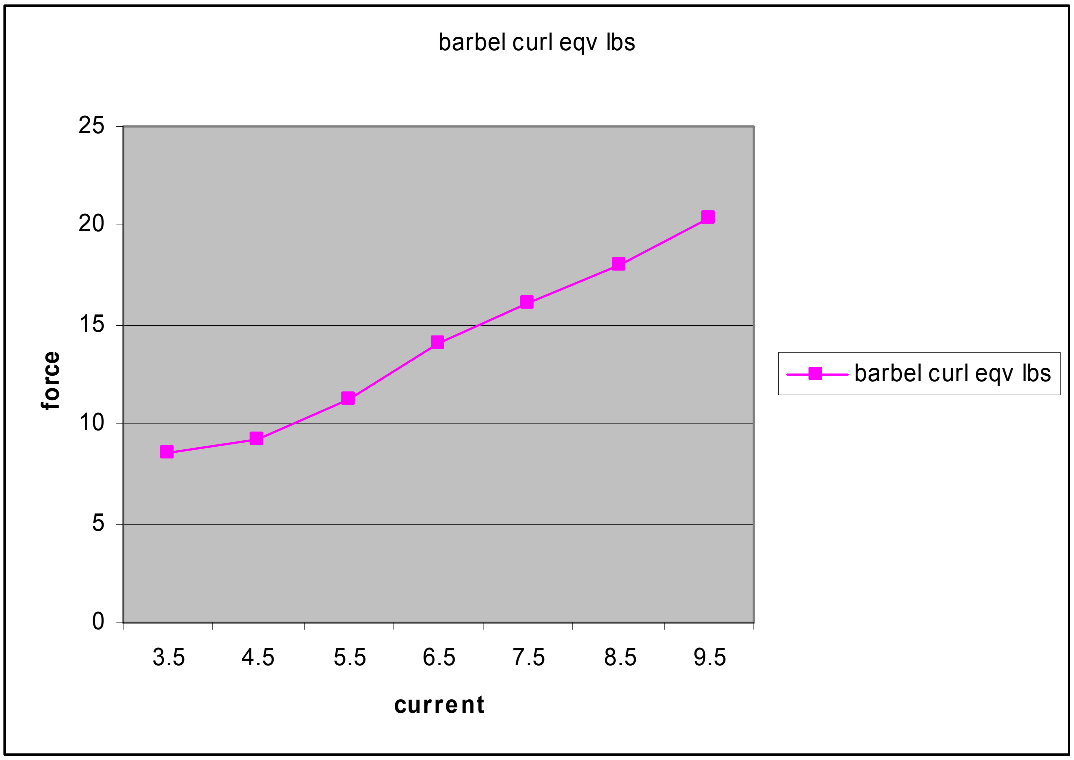

Fig. 11 Current-Force Graph

DAC count-Force

With the data from the first experiment confirming that the increase in current is directly proportional to the increase in weight, therefore, a capability to control the current definitely controls the resistance. One way of controlling current however is by employing a DAC connected before the Current Amplifier Source.

Fig. 12 DAC-Force Block Diagram

In this second experiment, the set up being the same as that of the first experiment, but this time however, what will be measured is the DAC values against its corresponding weight. With an increment of 32 DAC counts per division, the equivalent resistances are as follows:

Table 2: Experimental results for DAC-Force

DAC counts	Weight (Kg)	Torque (Kg • 2.2 lb • 20.5 in)	Equivalent in Exercise Lever (lb)
32	1.01	45.551	3.50
64	1.33	59.983	4.61
96	2.25	101.475	7.80
128	3.23	145.673	11.20
160	3.90	175.89	13.53
192	4.60	207.46	15.96
224	5.08	229.108	17.63
256	5.60	252.56	19.43

The graph would show direct proportionality.

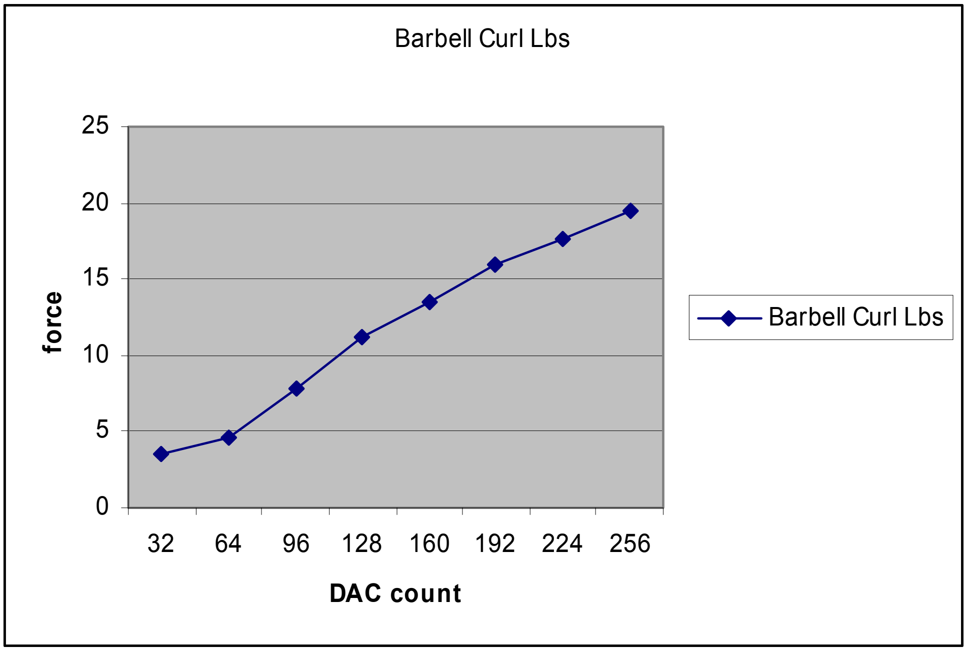

Fig. 13 DAC-Force Graph

7.0 Conclusion

Based from the results conducted in the first and second experiment, it can be seen that an increase in current is directly proportional to the generated resistance of the DC motor. Also, the DAC values that control the current source amplifier is likewise directly proportional to the increase in resistance. Therefore, the desired strength curve profile can then be programmed by having a corresponding look up table with a range of possible DAC values along with its equivalent resistances. As a result, by employing this concept for future resistance training equipments, then it would be possible for the elimination of the mechanical component spiral off-centered cam in resistance training equipments. Furthermore, it would also be possible for a single resistance training equipment to have a wide range of possible strength curves profiles by just simply altering the values in the look up table.

8.0 Acknowledgements

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