Investigation of increasing the range of height of user in the elliptical trainer machine using SAM software

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INTRODUCTION

Today's society is prone to high blood pressure, diabetes, osteoporosis, obesity and other diseases due to inactivity and exercise is the only way out of this problem. Elliptical trainer is popular and has many benefits. But the main disadvantages is that it is only designed for people who have an average height of Europeans, so taller or shorter height users face with numerous problems during the elliptical training. The overall aim of this study was to increase elliptical trainer flexibility for use in a wider range of height using the SAM software. Accordingly, we must evaluate elliptical trainer benefits and harms to introduce the best model for Iranians figure. Elliptical trainer (Galaxy 00) is the latest version of this machine on Iran market selected for optimization. The study is an applied field research. The average height of Tehran citizens was considered as indicator of all Iranian population. With regard to research objectives and methods, first images of the sample machine with the measure rod at the length of a meter was prepared and using Auto CAD drawing software, the exact sizes of the rods, hinges, angle bends and other parts of the system were determined. The data are then transferred to the SAM software and the desired model was designed. The main machine has a flywheel to crank radius of 17 cm was proposed to improve the condition of the machine to adjust the radius of the flywheel. This means that values less than 15 cm for shorter individuals and more than 19 cm for taller of the current situation (17 cm) on the flywheel is adjustable. Machine adjustment in the 15, 17, 19 cm radii of the flywheel would lead to the better practice for everyone.
recommended height groups was obtained. Furthermore, the kinematic curves of body parts attached to the mechanism were determined in a variety of sizes of flywheel. Then recommendations for further research work on this topic will be discussed.

**Elliptical Galaxy 00 Measurements:**

It is needed to determine the exact location of bends and joints of the arms and their dimension in careful analysis of Elliptical mechanism. The method used is a combination of photo-scale, meter measurement and using Auto CAD drawing software.

The stages are:

Select the Insert menu and then Image Manager (Figure 1).

![Fig. 1: Image Manager Option selection](image1.png)

Select Attach command in the open window and the desired image file is presented (Figure 2 and 3).

![Fig. 2: Set the Image Manager](image2.png)

![Fig. 3: File selection](image3.png)
By choosing the values of 0 and 0 for x and y, the corner of the image coincides with the origin (Figure 4).

**Fig. 4:** set the origin of the image

The image boundaries are specified in a dynamic window and by determined length of guide line the magnification of image will be determined.

After inserting image into the Auto CAD software, it is required to extract dimensions and angles of the trainer using the scale bar and standard sizing methods from the image. The used tool is Dimension toolbar in Auto CAD software (Figure 7).

**Fig. 7:** Dimension toolbar

First two points are put on both ends of scale bar the using the Point tool, and then use the Aligned Dimension tools measured the length of both ends of bar. At the beginning and end of each desired length arm two points are put using Point tool and again using the Aligned Dimension Software arm’s length is measured at software (Figures 8 and 9).

**Fig. 8:** Point creation command

**Fig. 9:** Dimension toolbar

The actual length of the scale bar and size obtained by the software it is possible to obtain a real length of each arms and bars using a linear fit between the length determined for the arm or bar in the software and the length determined for the reference bar in the software and its comparison with the actual length of the scale bar (100 cm), but the angles are transferred directly and without scale (Figure 10).

Given the length of the arms, bends places, support places and hinges as well as the angles between the detailed maps of Elliptical trainer Auto CAD software is produced (Figure 11).
The main unit has a flywheel to crank radius of 17 cm. In the parameter study and the diameter of the flywheel determination it is necessary to change the curved arm engagement with the flywheel. Therefore, the flywheels with engagement radius of (flywheel center distance from the pin), 15 and 19 cm are considered.

To transform the current state of the trainer to the crank radius of 19 cm, first a circle with the radius of 19 cm to the same center is plotted and other arms are transferred to the primary site (circle circumference of 17 cm) to the new location (circle circumference of 19 cm) through Move command.

Since the flywheel circle is fixed and all parts have been moved to a new location, the crank arm length increases and due to the lack of change in the other arms a new situation will be created for the mechanism (Figure 12).

To change the flywheel 17 to 15, steps like this will be followed.

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**Fig. 11:** Elliptical trainer figures in Auto CAD software environment

**Fig. 12:** change the current state of flywheel to the 19 cm state

**Fig. 13:** Compare flywheel and connected trainer to each of them

Elliptical trainer mechanism modeling in SAM software:
Definitions of basic mechanisms terms:
Structure: a set of lever that does not move by the applied load.
Mechanism: a collection of the levers that moves by the applied load.
Lever: A member that is different in motion than the rest of its neighboring.
Joint: the joint between the neighboring levers.

*An Introduction to SAM Software:*
The Synthesis and Analyses of Mechanism Software is relatively simple software with good features of two-dimensional for modeling and analysis of mechanisms. This software works based on the polar analysis mechanism. Mechanisms consist of a variety of simple, slider, belts; gears, springs and dampers arms are defined in the software. Hinge and roller bases (guided or slip) can be described.

The main type of mechanism input is angle change curve in terms of time that is applicable in linear, sinusoidal, third-order polynomial, fifth-order polynomial, spline (third-degree polynomial curve smoothly sliced) and other optional inputs through data file. Mechanism positioning at any time of motion will be determined after the mechanism analysis at time interval of input time values based on polar shift values.

Consecutive creation of this situation together creates the mechanism in the form of animation. In addition, it is possible to determine the direction of the curve in the whole cycle of motion for each joint. Moreover, the software can, given the shift values in terms of time in various joints, calculate the components of the displacement, velocity, acceleration and lever force in a motion cycle. Thereby, determining the outcome of these values would be possible (ARTAS SAM 6.1 User’s Manual), moreover, the reference to learn more about this software is recommended.

**Elliptical trainer modeling approach:**

First the mechanism coordinates of nodes on a map prepared in Auto CAD is extracted. Beam Element Create command is used to create any leverage. To create arms, main tool kit can be used to order or select Element option from the Build menu (Figure 14).

![Fig. 14: Coordinates or position of the node can be changed after drawing an arm.](image)

To do this, simply double-click on a node or joint or right-click the node and select Node Properties option, and select Coordinates menu from the window and then insert coordinates specified for the joint in Carthesian (absolute) section (Figure 15).

![Fig. 15: Correct the location coordinates of each arm end](image)

The end of each arm is the beginning of the next arm; as a result to draw a straight chain it is enough to create next arm from the endpoints of each arm.

During this process the whole elliptical trainer can be modeled in the SAM software (Figure 16).
Fig. 16: Elliptical trainer mechanisms in SAM software

The elliptical trainer bars are created by bending tube profile, mechanism of these bars when working is rigid without changes in angle among different parts of a bar. To create unchanged angle among sections of a bar two adjacent bars should be attached to each other in an angle.

To do this in the Elliptical trainer, adjacent arms that of a bending profile are fixed in an angle (Figure 17).

Fig. 17: the means to apply unchanged angle between the two levers

As an example, arms 5 and 6 are bound to each other, and the angle between them (relative angles) never changes. Similarly, the arms 6 and 7 … (Figure 18).

Fig. 18: Elliptical trainer mechanisms after unchanged angle between some arms is applied
Elliptical trainer has 3 fulcrums:
- a fulcrum roller at the end of four bent bar
- a joint fulcrum in the center of the flywheel
- a joint fulcrum in the middle of handles bar

According to the type of fulcrum, the trainer motion is bound in these points (Figure 20).

![Figure 20: Elliptical trainer mechanisms after fulcrum condition is applied](image)

Configuration applied on the model:
To apply input into the flywheel mechanism the lever representative of the flywheel is rotated a full period. For this purpose, Angle Input Motion option is selected from the main menu (Figure 21).

![Figure 21: angle input applied to an arm](image)

Click on the flywheel center (node 11), the window to apply angle input to the node opens (Figure 22).

![Figure 22: Constant speed input (no acceleration) applied to the machine flywheel](image)

After the arms modeling stages done correctly, applied unchanged angle constraints, input and fulcrum condition applied, the Analysis Ready message is shown in the application window (Figure 23).

![Figure 23: Analysis Ready message](image)
Fig. 23: the model is ready to run

Model application and the outputs:
Now, the software model is completed and ready to run.
From the main menu, select Start / Stop Animation (F2) and the model will run (figure 24).

Fig. 24: model application

Fig. 25: Different aspects of the operation of the machine at different moments

Select Start Analysis (F9) from the main menu and select Node Data in the window, then click on the desired node to activate the input and output node or joint window (Figure 26 and 27).

Fig. 26: Start Analysis command selection
Fig. 27: Joint or node selections to obtain the desired output

Information about the horizontal and vertical components of displacement, velocity, acceleration, and the resultant values are selected in the opened window to plot the curves corresponding to the parameters during the simulation of the elliptical motion mechanism (Figure 28 and 29).

Fig. 28: the desired output selection

Fig. 29: the graph of desired outputs in terms of flywheel turnaround time

Again, after Nod Data selection and click on the desired node, go to Patch Display in Nod Properties window (which is related to the input and output nodes) to plot the selected node route in the mechanisms (Figure 30 and 31).
The effect of the flywheel radius on wrist and ankle route curves:
the effect of the radius of the flywheel on the curves generated in the wrist and ankle in models built with the flywheel radius of 15, 17 and 19 cm at constant rotational speed of one revolution per second, the speed of rotation of the flywheel is evaluated.

Flywheel moves in a full circle in full cycle of a motor. Wrist has a swinging one way (back and forth) motion, i.e. The back and the forth motion path matches. Ankle follows an oval route, ankle back and the forth motion are not compatible to each other.

In this section, Elliptical trainer kinematic (movement) is studied in terms of the radius of the flywheel set at 15, 17 and 19 cm. For this purpose, in the same angular velocity input conditions applied to the flywheel (one cycle per second, or 360 degrees in seconds with no acceleration) changes of position, displacement, velocity and acceleration at the end points of the body that are connected to (ie, the wrist and a ankle) the return a flywheel rotations in the starting position is studied.

Kinematic study of a trainer in different configurations:
Kinematic study of a trainer configuration at 15 cm:

Fig. 30: Adjustment to display route followed by a joint in a motor cycle

Fig. 31: Show routs created by the flywheel and the position of wrists and ankles on the trainer

Fig. 35: Wrist position components graph in terms of required time for a complete cycle of movement within the 15 cm flywheel
Discussion and conclusion:

Physical and mental health are linked and the loss of one causes failure of another, in other words, ergonomics standards and physical health are in close contact with each other in need of simultaneously design processes.

Among the machine for in-situ and home exercises, elliptical is the most appropriate exercises. Given the considerable differences in physically different people the machine needs to be adjusted with the physical conditions of each individual practitioner. Therefore, uncommon force is not applied to joints; movement is not performed less or more than common and on the other hand leads to trainings tailored to the individual’s upper and lower extremities. The elliptical trainer machine Galaxy00 of the front flywheel was selected for the study.

Flywheel is a key part of the elliptical machine. As was discussed current state of trainer is designed for the average height; furthermore, it was shown that a tall or a short person practice is unsuitable to the current machine. To improve the condition of the machine the radius adjustment of the flywheel (junction of the recurve lever) was proposed. This means that lower values (15 cm) and more (19 cm) than of the current situation (17 cm) on the flywheel is adjustable.

According to the motion curves generated by the wrist and ankle, adjust the radii of the flywheel on 15, 17, 19 cm would be suitable for practicing by the short, medium and tall height individuals.

In addition, the change position, displacement, components and the resultant velocity and the resultant acceleration graphs of component parts of the machine associated with individual’s wrist and ankle were extracted. When a tall person practices with a machine that is small in flywheel diameter, to protect peace and create an ergonomic situation, takes curved position (hunched). It has a spiritual root. Adopting such a state puts mental and physical health conditions at risk, because the knee is bent too much that increases in amplitude of the part of the body and puts the person health at risk.

When a short person practices with a flywheel machine that is configured on cm17 radius, due to the relatively larger size of machine compared to the physical state it is necessary to bent forward to adapt his body to the trainer. However, the persons’ hand is at a lower range than his ankle during the practice, so the physical exercise and metabolism are not in good proportion. On the other hand, practicing successive cycles requires the person hand reaches to the end of the handle course and then moves in the opposite direction. The simulated image is compared with the ideal form for a small body form reveals that the wrist should stand more lower compared to the ideal standard, and yet puts mental and physical health of a person in danger.

Figures 59 and 60 illustrate the comparison between a short height training condition and tall height training with an elliptical flywheel radius of 17 cm that is suitable for a range of the average height.

It is possible to change and adapt crank radius and pin of the arm attached to the flywheel under the proposed condition, so:

The current status of the machine (flywheel with a radius cm17) is appropriate to maintain an ergonomic and health with average physical condition.

A short height individual, to better utilize the machine, should adjust flywheel in less than average (flywheel with a radius 15 cm).

A tall height individual, to better utilize the machine, should adjust flywheel in more than average (flywheel with a radius 19 cm).

Table 1 summarizes the results obtained for the range of motion of the wrist and ankle on the various flywheel radii and height ranges of short, medium and tall

<table>
<thead>
<tr>
<th>Flywheel radius (cm)</th>
<th>Handle horizontal motion range</th>
<th>Handle vertical motion range</th>
<th>Pedal horizontal motion range</th>
<th>Pedal vertical motion range</th>
<th>Height range suitable for the flywheel radius of (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>0 (+320)</td>
<td>0 (-19)</td>
<td>0 (-279)</td>
<td>0 (+73)</td>
<td>10 - 160</td>
</tr>
<tr>
<td>170</td>
<td>0 (+366)</td>
<td>0 (-156)</td>
<td>0 (-322)</td>
<td>0 (+77)</td>
<td>160 - 180</td>
</tr>
<tr>
<td>190</td>
<td>0 (-26)</td>
<td>0 (-198)</td>
<td>0 (-37)</td>
<td>0 (+88)</td>
<td>180 - 200</td>
</tr>
</tbody>
</table>

Suggestions:

Iranian manufacturers of sports equipment instead of copying the foreign design try the indigenization of the elliptical trainer for Iranian population, therefore their sales will increase.

Municipal agencies optimize or collect devices in the parks to prevent damage to civilians.

Relevant organizations, such as the Physical Education Department and the municipality can allocate a budget to design models optimized and secured for the Iranians and help engineers demonstrate their abilities.

PEO suggest for different regions of the different body figures, trainer optimized and localized accordingly.

Recommendations for future research:

As Guidance for researchers who wish to study in this field, the following topics are recommended:
Study the users' attitude toward elliptical and its effects as experimental and field data.
Analysis of the back flywheel elliptical trainer compared with the front flywheel elliptical trainer
Evaluation and optimization of the transverse trainer for different height groups
A dynamic model of the body part in the SAM software
Body analysis and modeling on the elliptical

REFERENCES