Creative design of the elliptical stepper with a pace-correction function

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Abstract

A prototype elliptical stepper has been made that possesses both the functions of bodybuilding and pace correction. This paper's creative conception is to make the elliptical stepper available not only for indoor exercise use, but also for correcting an unbalanced gait. This is achieved by adjusting the footplate according to whether the user's pace is splaying inwards or outwards. The Contradiction Matrix and the 40 principles of inventive problem solving were used-- the parameter to be improved is chosen as the 33rd parameter (convenience of use), the parameter that must not be deteriorated is the 6th parameter (area of non-moving object). The matrix shows the most common solution is increasing the system dynamicity. It further puts forward the creative conception of the elliptical stepper with a pace-correction function.

Keywords: TRIZ, contradictory, elliptical stepper, pace-correction

I. Preface

As shown in Figure 1 [1], the elliptical stepper makes use of the theory that when humans are mobile (walking), the motion trail of their anklebone is similar to that of an ellipse. Via the link mechanism the footplate's motion trail can be made quite similar to a walking motion. It is unnecessary for the feet to leave the footplate, and the knee joint will not be harmed. Therefore, the elliptical stepper is a sports equipment for both young and old, for it possesses various functions such as body building, weight loss, and promoting strong heart and lungs [2].

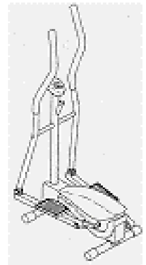

Figure 1 The elliptical stepper [1]

There are a lot of patents on the elliptical stepper. Among which, Chen [1] proposes an elliptical stepper structure that uses a guide rail on the frame to allow the sliding of the U-shaped slider and at the same time improve the structural design for a more smooth and sturdy elliptical stepper. In order to solve the stepper's storage problem (i.e. taking up too much space when not in use as it can not be packed or folded), Luo [3] designed a folding elliptical stepper. This drastically reduces the stepper's bulk and the space that it covers, and it is easy to stow and carry. Luo and Liao [4] designed an elliptical stepper that is adjustable to accommodate the users of different heights. This remedies the problem of legs being overstretched and the inability to gain sufficient momentum, due to the swinging motion being either too long or too short. The user no longer has to settle with the fixed swinging motion and endure muscle strains caused by bad posture. Kuo [5] proposes an elliptical stepper with a motion trace length adjustment function to allow for the training or rehabilitation of users with different stride lengths. Kuo [6] also proposes an improvement to the elliptical stepper that rapidly adjusts the length of the elliptical trainer motion trace to effectively lessen the supporting load of the left and right rockers for a safer and more stable center of mass. Lee [7] has integrated stepping and elliptical rotating exercise with a movable pin folding structure to create a fitness equipment with both stepping and elliptical rotating exercise functions that also folds quickly and saves space. Kuo [8] proposes shrinking the overall assembly width for an elliptical motion trace stepping system with elevated cycling route. Liu et al [9] has proposed a seven links and eight joints mechanism with two-degree of freedom. This mechanism has specially joined a main crank bar and a sub crank bar to form the crank bar. An electronic retractable mechanism and a control circuit have been installed between the main and sub crank bars to control the length of the crank based on the user's needs. The maximum distance between the two front and back pedals change automatically to match the user's stature or exercise speed. The benefits of exercise can be effectively achieved from this ergonomical design.

Until now no patents or research literature have been found about a pace-correction elliptical stepper. All elliptical steppers now sold on the market are equipped with an immovable footplate. Since everyone's pace is to some extent splaying outwards, these elliptical steppers will cause slight inconveniences. Those people that are suffering from serious inward or outward splaying paces will lean in at a certain angle inwards or outwards when they are stepping, thus affecting their walking gait. In medicine the inward or outward splaying pace can be corrected by wearing a corrective belt or via surgery treatment [10, 11]. However, due to various factors, the after-treatment recovery procedures are not always maintained, thus greatly reducing the curing effect. This paper intends to design the elliptical stepper's footplate into one that can cooperate with the user. This is achieved by adjusting the angle of inward or outward splaying pace, combining the function of body building with that of pace-correction and turning the elliptical stepper into an apparatus that posses both of these functions.

II. Theoretical analysis on the creative design

TRIZ (Theory of the Solution of Inventive Problems) was put forward a former Soviet Union scientist Altshuller, who after studying almost 400,000 patents, deemed that it is possible to turn this theory into a systematic method [12, 13]. In this paper, TRIZ is adopted as the theoretical basis of the elliptical stepper's creative design. First an innovation situation questionnaire (ISQ) analysis will be carried out on the existing holding mechanisms, then establish linkage and formulate problems, state problems that can be improved, find the contradiction nodes, and analyze the parameters to be improved and those not to be deteriorated. It will also aid in finding the creative principles from the contradiction table, and develop the ameliorating conception of the elliptical stepper.

2-1 Innovation situation questionnaire (ISQ) analysis

In this paper the system is named elliptical stepper, with the original mechanism shown in Figure 1 and the mechanism sketch in Figure 2 Such system components as the footplate, rocker link, crank link, and connecting link all belong to substance resources. The kinetic energy produced by the user walking on the stepper belongs to field resources. Use of the elliptical stepper can produce the effects of bodybuilding, weight loss, and promoting strong heart and lungs, which belong to the function resources. The space taken up by the elliptical stepper belongs to the space resources. All these resources may be effectively used to eliminate any defects the system may possess.

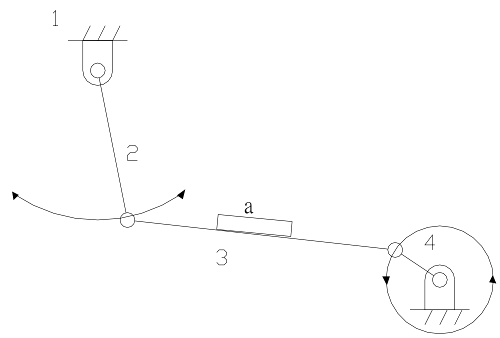

Figure 2. The original mechanism sketch (1 is the frame, 2 is rocker link, 3 is connecting link, 4 is crank link, and a is the footplate).

2-2. Problem formulation (PF)

Problem formulation means applying information collected via ISQ to describe the cause and effect relationship between the system's useful and harmful functions, and also in using such a relationship between each problem to establish the linkage of primary useful and harmful functions. In this paper small brackets will be adopted when including narration on useful functions, the middle bracket plus an underline include harmful functions narration, the ellipse represents useful functions, and the gray oblong represents harmful functions. Taking into account the cause and effect relationship, the line with an arrow will be used to mean that this function will be required for another useful function. The bold line means that this function will cause another harmful function, and a cross black line to mean that this function will eliminate another harmful functions, as shown in Figure 3.

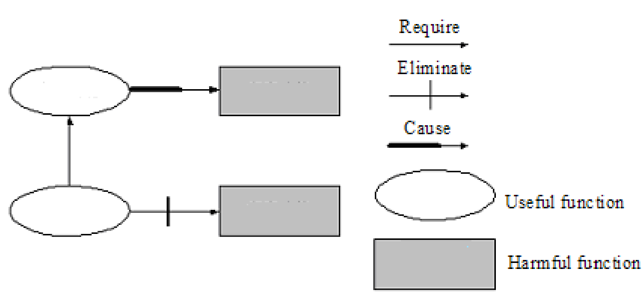

Figure 3. The cause and effect graph

From the ISQ analysis, it can be found that the elliptical stepper's primary useful function is the motion trail produced by the footplate. The primary harmful function is that the footplate cannot match the user's pace and allow the user to adjust bad posture in the movement. This paper starts with the primary useful function to construct the cause and effect linkage of the stepper's related functions, as shown in Figure 4. This system's primary useful function is provided elliptical motion trail (Node 1). In the course of movement, the stepping action is similar to the elliptical motion trail, it eliminates the possibility of training injury caused by shock upon the knee in movement (Node 2). The elliptical motion trail is supplied with the useful stepping on the footbrake function (Node 3), which in turn requires the useful function of the user's movement (Node 4). The immovable footbrake that is currently used causes the harmful function of not being able to adjust incorrect pace (Node 6). This in turn causes the harmful function of inconvenient use (Node 7). It is the user's movement that be required for the useful bodybuilding function (Node 5). It is proved in the cause and effect linkage in Figure 4 that Node 3 requires a useful function, but also causes a harmful function, together forming a technical contradiction node.

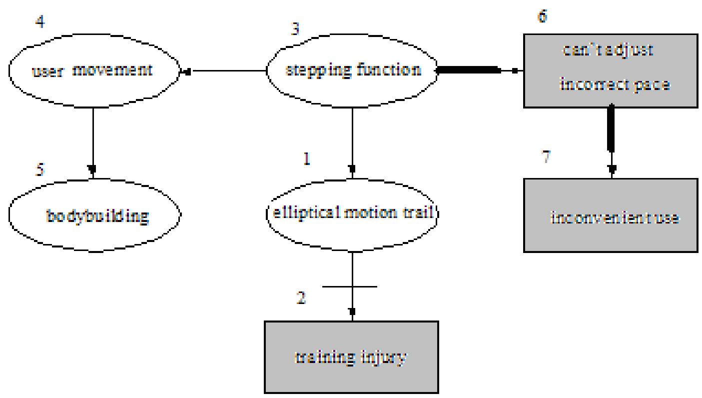

Figure 4. The cause and effect linkage

An additional problem statement for each node can be expressed as either a benefit from a harmful function, an enhancement to a useful function, or the resolution of a contradiction [12, p.53]. List all the ameliorable formulation statements of each node and its nearby nodes in the linkage, and then we can see that every statement can be used when carrying out creative design. In this text the design will be undertaken by means of finding a way to resolve contradiction. The formulation statement of the contradiction node 3 in Figure 4 is: finding a contradiction that can resolve (the footplate's stepping motion) while requiring (the user's movement) but will not cause [people suffering from inward or outward splaying are unable to make adjustments]. This paper carries out the creative design of elliptical stepping mechanism by looking at the improvement of this contradiction.

2-3 Contradiction table

The contradiction table in TRIZ theory contains 39 design parameters and 40 generic principles in solving the contradictions. The parameters to be improved and those not to deteriorate in each contradiction node produced by the problem formulation are put into the contradiction table, which lists the analogous creative principles that have most frequently been used to solve the contradiction problem. In turn the analogous creative principle solves the contradiction problem. As the contradiction statement of Node 3 in Figure 4 is concerned, under the useful stepping function, the function to be improved is that of adjusting the footplate. This is according to the needs of people suffering from inward and outward splaying paces. The function that is not to be deteriorated is that of providing the user's movement. Using the 39 design parameters listed by Altshuller, we interpret the parameter to be improved as the 33rd parameter (the convenience of use) and the parameter not to deteriorate as the 6th parameter (area of non-moving object). Put these two parameters into the contradiction table, the 4 generic principles (dynamicity of principle 15, partial or overdone action of principle 16, mechanical vibration of principle 18, inert environment of principle 39) that can solve the problem are found at the intersection of the "row" of the parameters to be improved and the "column" of the parameters not to be deteriorated, as shown in Figure 5.

Undesired Result / Feature to Change		1	...	6	...	39
		Weight of moving object	...	Area of non-moving object	...	Productivity
1	Weight of moving object					
...	...					
33	Convenience of use			18,16, 15,39		
...	...					
39	Productivity					

Figure 5 The contradiction table

III. Problem-solving plan

3-1 Theoretical analysis

In this paper principle 15 (dynamicity) is applied to carrying out creative design conception of the elliptical stepper. Principle 15 has three explanations: (1) make characteristics of an object or outside environment automatically adjust for optimal performance at each stage of operation, (2) divide an object into elements able to change position relative to each other, (3) if an object is immovable, make it movable or interchangeable. The paper is looking at the stepper's footplate being able to be adjusted according to the user's pace, which means to make an immovable object move. Therefore, the third explanation of principle 15 will be adopted to solve this problem. Figure 6 shows solution example that is found via TechOptimizer™ (computer-aided creative design software). Many other examples can be found in the TRIZ Journal (14).

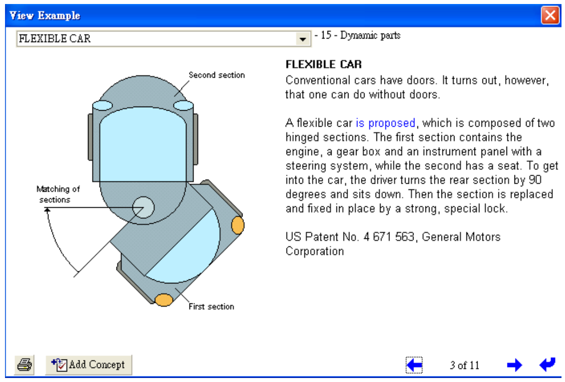

Figure 6 Solution example (via TechOptimizer)

In the course of creative design, this paper attempts to conceive solution plans by following the dynamicity of principle 15, making it possible for the footplate to make corrective angle adjustments according to inward and outward paces. It prevents the user's pace defects causing a mismatch of the elliptical stepper's footplate from occurring. It also renders the sufferers of inward and outward pace to restore their normal walking pace and further return to their graceful gait. After repeated analyses and much revision, finally the running of a flywheel is adopted as the input terminal to make the footplate offset, and the expansion link to connect the elliptical trail stepper's footplate. Since the expansion link possesses the length adjustment function, the function of adjusting the footplate's offsetting angle will be realized. This will then enable sufferers of inward and outward splaying pace to use this elliptical trail stepper conveniently and obtain the efficacy of pace correction.

3-2 The operation of creative mechanism

In order to integrate the corrective function into sport equipment, and to correct the pace in the course of movement, this paper, taking the elliptical stepper as the original mechanism (Figure 1), adds to it a spherical four-bar linkage and equips it with the pace correction function. Thus making it possible to realize the effect of exercising and building the body via simple stepping actions. The creative mechanism sketch of the elliptical stepper is shown in Figure 7; the pace correction mechanism (spherical four-bar linkage) sketch is shown in Figure 8; the normal pace mechanism sketch is shown in Figure 9; the outward splaying pace mechanism sketch is shown in Figure 10; the inward splaying pace mechanism sketch is shown in Figure 11.

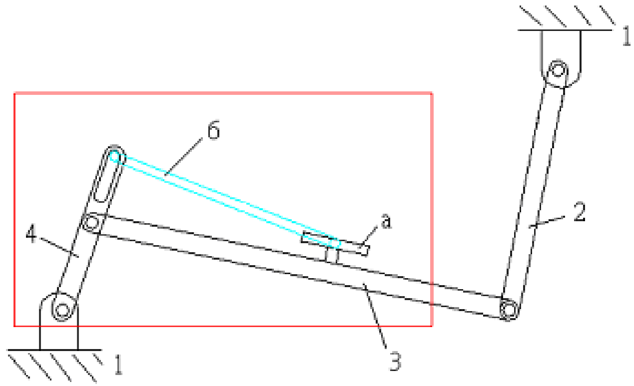

Figure 7 Elliptical stepper creative mechanism sketch. 1 is the frame, 2 is rocker link, 3 is connecting link, 4 is crank link, 5 is interlocking link 2, 6 is expansion link which length can be adjusted, a (link 7) is the movable footplate, b is a screw device used for changing the length of expansion link 6, c and d are ball joints, and e is a turning joint.

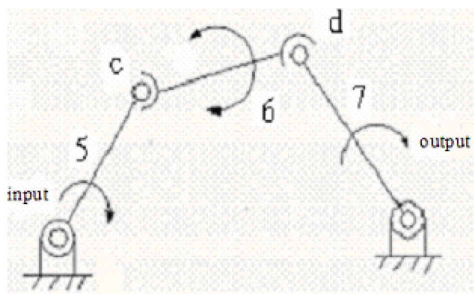

Figure 8 The pace correction mechanism sketch

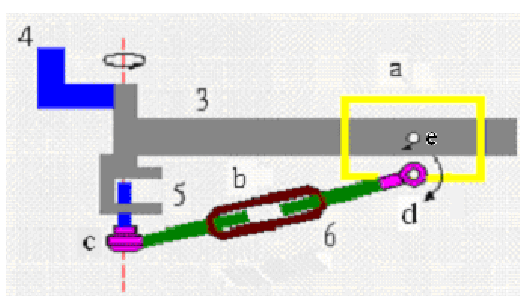

Figure 9 The normal pace mechanism sketch

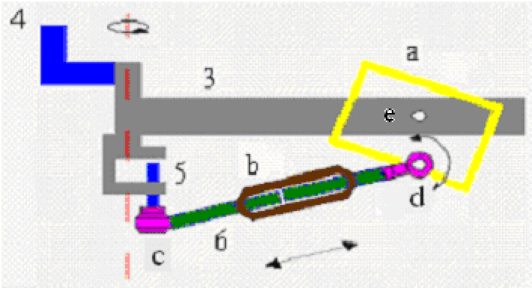

Figure 10 The outward splaying pace mechanism sketch

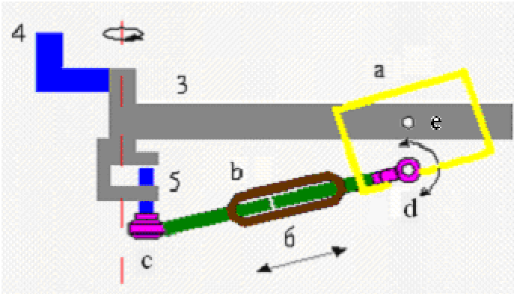

Figure 11 The inward splaying pace mechanism sketch

The operation of adjusting the inward and outward splaying pace via the creative conception design is shown in Figure 12. When the user steps on the footplate, the flywheel (crank link 4) rotates, causing the connecting link 3 to make a stepping action. The rotation center's axis between the crank link and the interlocking link 5 will drive the ball joint c to make a circular motion. By adjusting the offset of the ball joint c, the axis of rotation center and the length of the link 6, the footplate part (link 7) will make the offsetting motion. When the axis center of the ball joint c and the axis of rotation center are on the same axis, the former will make the same rotation with the latter. When there is no displacement on the link 6. Therefore, when stepping movement occurs, the footplate still maintains a normal pace position, able to provide a normal pace for the user. If the axis center of the ball joint c and the axis of rotation center are not on the same axis, the circular motion made by the former will be larger than that made of the latter. This will drive the expansion link to further cause the footplate to make inward or outward offset. If used by persons with different inward and outward splaying paces, the footplate may be changed according to the offset angle of the splaying paces via the distance adjustment between the axis center of ball joint c and the axis of rotation center, thus providing convenience to different users.

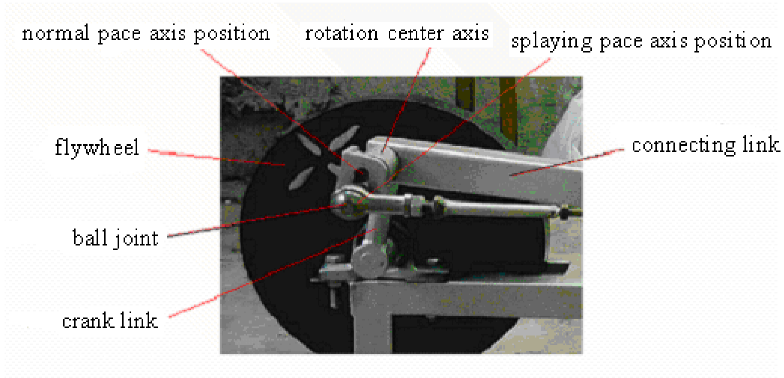

Figure 12 Splaying pace adjusting mechanism

When the stepper is used by people with a normal pace, the position of the axis center of the ball joint c will be adjusted to normal pace axis center position as shown on the left side in Figure 13 and the footplate will be adjusted to the normal pace position by adjusting the link 6 to a proper length, as shown in Figure 13. In this case, when the user is making stepping motions, the elliptical stepper's footplate will remain immovable. When it is used by the people with an inward splaying pace, the position of the axis center of the ball joint c will be adjusted to inward and outward splaying pace axis center position as shown in Figure 14, and the link 6 will be adjusted, by turning the screw device b to lengthen it. As the link 6 is fixed on the lower right side of the footplate, the prolonged link will cause the footplate to offset inward. This allows the user to adjust the angle according to the offset degree he or she requires. After adjustment, when the user makes the stepping motion and when the footplate part is at the lowest point of the stepping movement, the footplate will be in the position of the largest offset angle. When the user gradually raises the footplate position, the footplate's offset angle will also slowly return to the normal pace position. On the contrary, if the stepper is used by a person with an outward splaying pace, the axis center position of the ball joint c should also be adjusted to the inward and outward splaying pace axis center position as shown on the right of Figure 13. By adjusting the expansion link 6, that is, turning the screw device b to shorten it, this shortened link will cause the footplate to offset outwards. Thus making it possible for the user to make angle adjustments according to the offset degree he or she requires. After adjustment, when the user is making the stepping motions and when the footplate part is at the lowest point of the stepping movement, the footplate will be in the position of the largest offset angle. When the user gradually raises the footplate position, the offset angle will also slowly return to the normal pace position with the operation of the user.

Figure 13　Footplate position of normal pace and outward splaying pace

Figure 14　Footplate position of inward splaying pace

When the user is making continuous stepping movements, the angle of his foot will adjust to that of the offset of the footplate. Thus making the feet of the sufferer of inward or outward splaying pace recover to the normal pace position via stepping training. It is advisable for sufferers of inward or outward splaying pace to use this creative elliptical stepper frequently. This is because the inward and outward splaying pace adjustment apparatus in this stepper will help sufferers make the adjustment of offset angle according to their personal need and correction of different degrees, slowly acquainting themselves with a normal walking pace, and realize the effects of pace correction.

IV. Prototype manufacturing

According to dynamic creative design this paper introduces the elliptical stepper, which possesses all the above-mentioned functions in the angle adjustment aspect and is not limited to a certain angle but can be adjusted to any angle according to the inward or outward splaying degree of the user's pace. Prototype of the creative elliptical stepper is shown in Figure 15, the side view of it in Figure 16. This achievement may become the design basis on which the elliptical stepper designer will conceive the amelioration of present mechanisms and become a contribution to the elliptical stepper manufacturing industry.

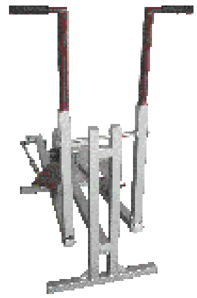

Figure 15 Prototype of the creative elliptical stepper

Figure 16 Side view of the prototype

V. Conclusion

By adopting TRIZ theory, this paper designs and manufactures an elliptical stepper with the correcting function of inward and outward pace. This creative elliptical stepper can not only correct the inward and outward splaying pace, but also has an adjustable footplate offset degree according to the user's need. Compared with the traditional elliptical stepper, this stepper's advantage is that it can correct the inward and outward splaying pace by adjusting the offset degree according to different users and is also very convenient. Since the footplate can swing from right to left and back and forth, it possesses the function of correcting the inward and outward splaying pace and helping sufferers recover their normal walking pace. Even when a user of normal pace is using the elliptical stepper with the pace correction function, he or she will gain the effect of whole-body training. This is much better to the user in body-building than that produced by the traditional elliptical stepper, as the footplate offset in this creative design encourages constant motion around the body's waist.

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