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A Propulsion Mechanism of Cleaning Boat Applied For Non-Structural Environments

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Abstract: Based on the existing small rivers' clearing machineries and equipments, a propulsion mechanism of cleaning boat applied for non-structural environments is proposed; The mechanism consists of rubber tires, paddles and displacement tracks; Its movement principle in conventional and non-structural environments are analyzed; Trajectory analysis of rotating shaft and the mass center of the hull were conducted;The maximum height of the stairs that the cleaning boat can traverse is obtained by the establishment of an appropriate coordinate system and functional formulas.

Keywords: Cleaning boat; Non-structural environments; Propulsion mechanism; Trajectory analysis

I. Introduction

Currently, many rural and urban small rivers have the siltation and sediment pollution problems due to many years' disrepair, this lead to the result that many small rivers are considered as natural landfills of all kinds of rubbish and garbage, resulting in wanton growth of aquatic plants. Because of the lack of garbage-collection and disposal system, the garbage of the rural residents were discarded into the rivers, with the result that the retreat of farmland water, industrial waste (oil), sewage and the loss of surface organic,more and more nitrogen and phosphorus flow into the rivers,making small rivers faced the increasingly serious eutrophication. A variety of aquatic plants have the rampant growth, including emergent plants (reeds), floating plants (duckweed, water lettuce, etc.) and submerged plants (bitter grass, etc.), they destructed the natural landscape, influenced the fishery production and caused the secondary pollution of water bodies.The mentioned-above are the pollution status of urban small rivers that encountered,it also indicates that the governance of small rivers is imminent.

There are many types and specifications of cleaning machineries and equipment for small rivers. Fig.1 shows the Conver company's boat in Nether land. Fig.2 is the Dorotea Mekaniska AB company's multifunctional river-cleaning boat named TRUXOR. Firstly, it was used for harvesting plants, after several years technical improvement, this boat have gained the ability of salvaging, grabbing, dredging and so on. Except for this, there are several other oil sewage collection vessels; floating rubbish salvage ships; garbage transportation ships; cleaning boats and dirty-pushing machines. However, these devices are based primarily on wetlands excavators, dredging boats, bucket garbage boats, plant-harvesting boats and other traditional equipment, and most of the devices have the single function and only suitable for operations in water but can not be used for flat lands, slopes, obstacles, ditches and other non-structural environments simultaneously. This paper describes a new propulsion mechanism of cleaning boat applied for non-structural environments.

Fig.1 Conver company's cleaning boat

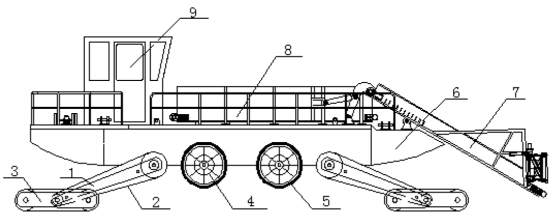
Fig.2 Multifunction boat for cleaning up the weeds

II. Summarization of the propulsion mechanism

Among the existing propulsion mechanism used for boats, wheeled and tracked are the most common[1]The wheeled propulsion has a poor ability to cross the ditches, stairs, and can not be used in the water; The crawler propeller has a strong ability to adapt to the terrains and it is suitable for traveling over rough grounds and also has the characteristics of high efficiency, small loads and compact design, however, it can’t meet the requirements for working under the water. In order to improve the diversity of the cleaning boats, this paper proposes a new propulsion mechanism that used for cleaning boat combined the rubber tires, paddles and displacement tracks.

The mechanism has the characteristics of outstanding ability to adapt to terrains and meet the dual demands for working in water and on the ground, and it is well suited for complex, unknown and unstructured environments.

Rubber tires,paddle wheels, tracked feet, kick mechanism, moving mechanism and the hull are the component units. The cleaning boat’s structure diagram is shown in Fig.3[6].



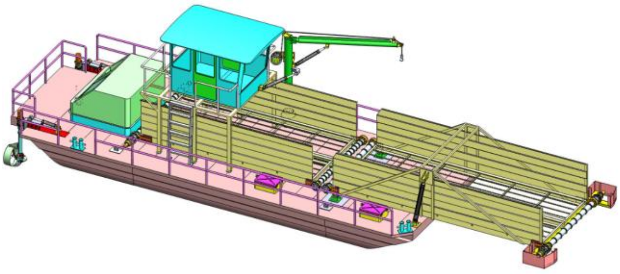


Fig.3 Schematic diagram of the cleaning boat Fig.4 The hull of the cleaning boat

1--kick mechanism; 2--moving mechanism; 3--tracked feet; 4-- paddles; 5--rubber tires; 6--body of the boat; 7--collecting tank;8--storage tank;9--the cab

Fig.4 is the hull that this mechanism applied for.

Independent motors can be used to control the kick mechanism[1], the mechanism may has a rotation that over 180 degrees with the upper end of the shaft. It is mainly consists of the driving motors, turbine worm reducer, gear reducer and tracks. When the cleaning boat working on rugged environments while leaving the hull tilted, and this time we can independently control the rotation of the four legs swing through the implementation of appropriate control strategies, the hull can be adjusted to a horizontal posture, the principle is based on the parallel mechanism, this feature ensures that the cleaning boat has a better stability and terrain adaptability.

Sync tracks, tracked wheels and crawler feet are the component units of the moving mechanism, the left and right wheel tracks of the cleaning boat are driven by the two motors through the turbine worm reducer and the gear reducer. Using the synchronous belt can ensure the driving wheel and the driven wheel with a same speed. Also, you can take advantage of the different speeds to realize the turning and zero radius of rotation of the cleaning boat.

Both sides of the hull have two rubber tires, convenient for boat has the fast forward on land when there is no cleaning tasks, each rubber tires equipped with a movable webbed paddle[6], providing the power for forward and backward movement while working under the water. The axis of rubber tires and paddles are empty sleeve shafts, their separation and combination are controlled by brakes and clutches. The problem for plant-twining will not occur and the movable webbed paddles has a small turning radius, etc.

III. Working in conventional environments

3.1 Fast forward on flat ground

When the boat conducts the cleaning task at a far destination, requiring a fast forward speed to save time. In this case, the four rubber tires that evenly distributed on both sides of the hull will serve as the propellers, as is shown in Fig.5, the axis of the rubber tires and the movable webbed paddles will separate with each other under the action of the clutches, the rubber tires rotate only to drive the boat generate the forward and backward movements.

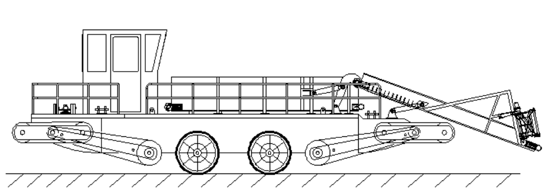


Fig.5 Fast forward on flat ground

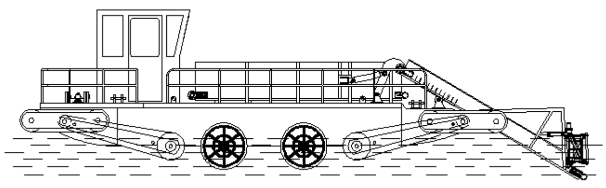


Fig.6 Working in water

3.2 Working in water

When working in water, the four movable webbed paddles that equipped on both sides of the hull will push the boat forward and backward, as is shown in Fig.6. While the paddles rotate at a low speed driven by the motors, the movable plates in and out of the water one by one, generating a reaction force from water then push the boat forward. The webbed plates of paddles connected to the wheel body in an articulated manner, conducting the complex exercises by eccentric structure, the webbed plates can in and out of the water with a suitable angle, eliminating the water-shooting phenomenon when plates into the water and the water-pumping phenomenon when plates out of the water, its eccentric structure improved the efficiency.

IV. Working in unstructured environments

4.1 Typical terrain obstacles

Many terrain obstacles have the similar geometry, in order to facilitate the analysis and presentation of the boat, we simplify the terrain obstacles as slopes, stairs, wetlands and ditches. the geometry characteristic of slopes are gradient and slope direction, gradient is the maximum rate of height, slope direction is the maximum rate of the direction of the area, its boundary line is the turning line that of the bottom and top of the abrupt slope;The geometry characteristic of stairs is the height, its boundary line is the outside line of stairs;The geometry characteristic of ditches are the span and depth, its boundary lines are the edge lines of ditches; The cleaning boat across the barriers means that it uses the moving mechanism to ensure the mass center crossover the boundary line of obstacles, in this process, the circumstance of capsized hull does not occur and without obstruction jamming, the boat should continue to maintain its stability and has the ability to move on.

4.2 Climbing the stairs

When climbing the stairs, its front tracked feet encounter the stairs and a friction that the wall exert to tracked feet makes it generate a flip-up torque and the feet climb along the wall until onto the stairs, the back tracked feet climb onto the stairs in the same way. The process of cleaning boat for climbing the stairs is shown in Fig.7[1].

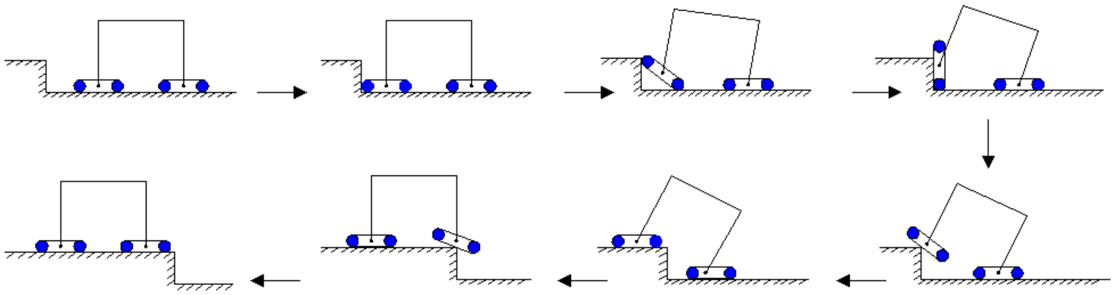


Fig.7 The process of climbing the stairs

4.2.1 Trajectory analysis of mass center for climbing the stairs

In order to facilitate the calculation during the theoretical analysis,we regard the midpoint of the line connecting the centers of the front and rear foot crawler as the center of the rotary axis position

4.2.1.1 Trajectory analysis of rotating shaft

Establish the coordinate system as is shown in Fig.8, H is provided for the vertical height of obstacles,the length of the caterpillar foot is a and h is the height of the distance between the ground and the rotating shaft(diameter of the track foot). (x, y) is the coordinates of rotating shaft A_0, (x_1, y_1), (x_2, y_2) are the coordinates of A_1 and A_2.

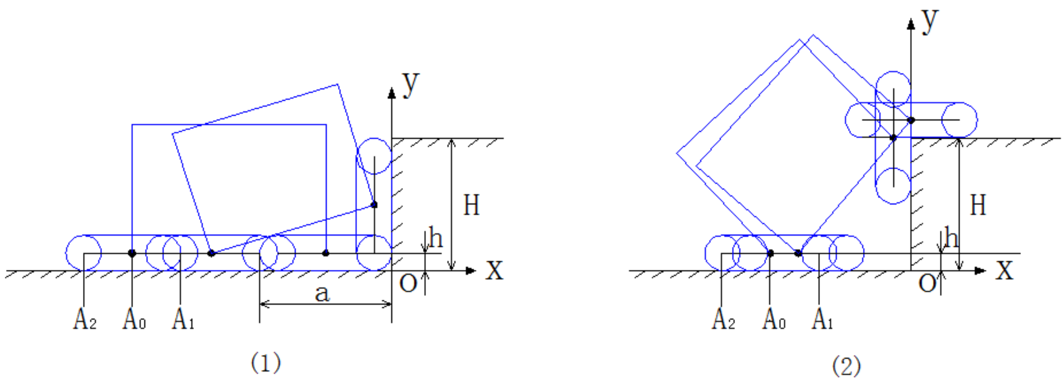


Fig.8 the two conversions of track foot when traversing the obstacles

Throughout the obstacle process, according to the relative positions of the track foot and vertical barriers,the whole process can be divided into the following five stages:

Stage1:The process of the track foot before contacting the vertical wall ,at this point the locus of A_0 is a horizontal line:

$$y = h \quad x \in (-\infty, -\frac{a}{2}) \tag{1}$$

Stage2: The process from the front track foot contact vertical wall to it in full contact with the vertical wall. At this point, the former track wheel A_1 rose along the vertical plane and the back track wheel A_2 forward along the plane. The start and the end positions of the rotary are $(-\frac{a}{2}, h)$ and $(-h, \frac{a}{2})$,because:

$$\begin{cases} (x_2 - x_1)^2 + (y_2 - y_1)^2 = (a - 2h)^2 \\ x = \dfrac{x_1 + x_2}{2} \\ y = \dfrac{y_1 + y_2}{2} \\ x_1 = -h \\ y_2 = h \end{cases} \tag{2}$$

The locus of point A_0 at this stage can be obtained :

$$(x+h)^2 + (y-h)^2 = \frac{(a-2h)^2}{4} \tag{3}$$

Stage3:The process of track foot in full contact with the vertical wall. At this point the locus of point A_0 is a vertical line:

$$x = -h \quad y \in (\frac{a}{2}, H) \tag{4}$$

Stage4:The process from the track leaving the vertical wall to it in full contact with the upper plane. At this point, the point A_0 maintain the same distance h from the line of intersection of the two planes,the start and the end positions are $(-h, H)$ and $(0, H+h)$,its trajectory can be determined by the following equation:

$$x^2 + (y-H)^2 = h^2 \tag{5}$$

Stage5:The process of the track in full contact with the upper plane.At this point, the trajectory of point A_0 is a horizontal line:

$$y = H + h \qquad x \in (0, +\infty) \tag{6}$$

The formulas (1) (3) (4) (5) (6) give a complete trajectory of the rotary when the track foot traversing the obstacles. Suppose $H = \frac{3}{2}a = 6h$, then the trajectory of the rotating shaft can be shown in following Fig.9.

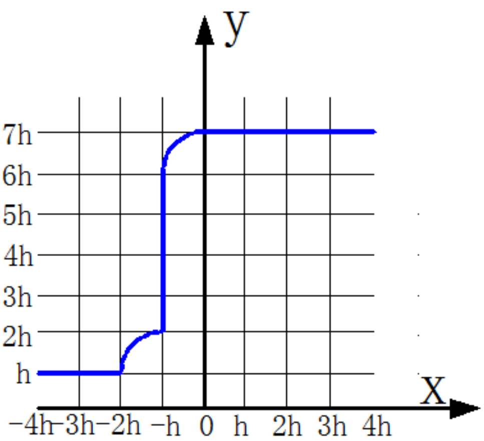


Fig.9 The trajectory curve of the track foot

4.2.1.2 The mass center trajectory analysis of the hull

Firstly, establish the coordinate system, the coordinate system is the same as the track foot movement, it can be shown in Fig.10.

When the hull is during the first conversion process as is shown in (10), At this point the rear tracked foot is the main driver, B is the rotary of the late track foot, its movement and position are the driving force input to a known. $\alpha = \arctan\frac{2h_0}{a_0}$ is the angle between O_1B and AB ,the distance between B and the hull mass center O_1, $O_1B = \sqrt{\frac{1}{4}a_0^{\ 2} + h_0^{\ 2}}$ is determined by the size of the hull structure. The movement and position of the mass center O_1 is determined by the movement and position of B and the calculation of vector $\overrightarrow{OB}$ and $\alpha + \beta$.

When the hull is during the second conversion, as shown in (10), At this point the front tracked foot is the main driver, A_1 is the rotary of the front track foot, its movement and position are the driving force input to a known. $\alpha_1 = \arctan\frac{2h_0}{a_0}$ is the angle between O_2A_1 and A_1B_1, $O_2A_1 = \sqrt{\frac{1}{4}a_0^{\ 2} + h_0^{\ 2}}$ is the distance between A_1 and position mass center O_2 and it is determined by the size of the hull structure. the movement and position of the mass center O_2 is determined by the movement and position of A_1 and the calculation of vector $\overrightarrow{O_2A_1}$ and $\alpha_1 - \beta$.

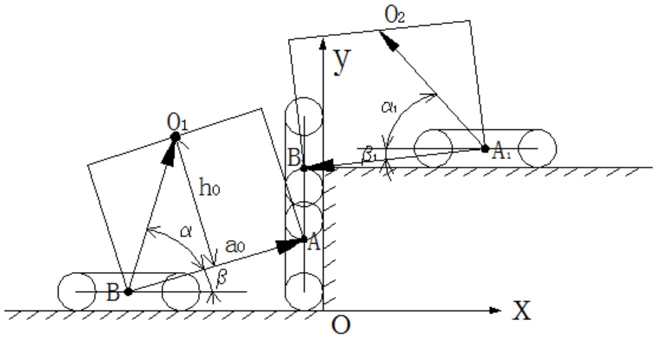


Fig.10 The coordinates of the mass center of the hull

4.2.2 The analysis for climbing the stairs

Establish the schematic diagram of the boat for climbing the stairs as is shown in Fig.11 and conduct the calculation of height that the boat can across.

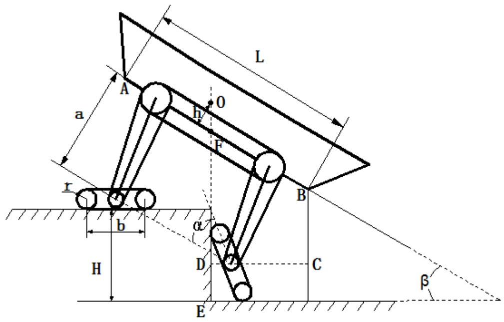


Fig.11 Schematic diagram of climbing the stairs

L--length of the boat; a--length of legs; b--the center distance of track wheels;H--the height of stairs; r--the wheel radius; h--distance between the mass center and chassis; α --the maximum displacement angle of tracks; β--the dip angle of the boat

Analyze the climbing process combined with the schematic diagram, we can get the following formulas:

$$L\sin\beta + a\cos\beta + \frac{b}{2}\sin(\alpha+\beta) + r = H + r + a\cos\beta$$

That is

$$H = L\sin\beta + \frac{b}{2}\sin(\alpha+\beta) \tag{7}$$

because:

$$CD = a\sin\beta + \frac{b}{2}\cos(\alpha+\beta) + r \tag{8}$$

and

$$CD = \frac{L}{2}\cos\beta - h\sin\beta \tag{9}$$

combine (2)with(3),we can get that:

$$\frac{L}{2}\cos\beta - (a+h)\sin\beta - \frac{b}{2}\cos(\alpha+\beta) - r = 0 \tag{10}$$

In addition, the undersurface of the cleaning boat should not touch the stairs. $H < EF$, that is:

$$H < \frac{b}{2}\sin(\alpha+\beta) + a\cos\beta + r + (\frac{L}{2} - h\tan\beta)\sin\beta \tag{11}$$

Theoretically, when the dip angle is large, the case that $\alpha+\beta > 90^o$ will occur, in fact this situation is not the case, because when $\alpha+\beta = 90^o$, the tracked feet are in full contact with the surface of the stairs and it will not turnover to more than 90^o, so when $\alpha+\beta > 90^o$,we should regard it as $\alpha+\beta = 90^o$. Generally, in order to make the front feet have a full contact with the stairs, we should take a larger value for α, substantially greater than 60^o, and at this time, as long as $\beta > 30^o$, $\alpha+\beta$ will be more than 90^o.Typically, the limiting case is $\beta > 30^o$, so in formulas (1)(3)(5) we can according to $\alpha+\beta > 90^o$ to calculate. In this way, (1)(3)(5) can be rewritten as:

$$\begin{cases} H = L\sin\beta + \frac{b}{2} \\ \cos\beta\frac{L}{2} - (a+h)\sin\beta - r = 0 \\ H < \frac{b}{2} + a\cos\beta + r + (\frac{L}{2} - h\tan\beta)\sin\beta \end{cases} \tag{12}$$

Additionally, no interference of the baseboard should be verified under the condition of H,we can take a reference of Fig.8(2) to verify this phenomenon. Suppose the dip angle is θ, then,

$$\begin{cases} L\sin\theta = H \\ r + \frac{a}{\cos\theta} > H \end{cases} \tag{13}$$

Eliminate θ,we can get an inequality;

$$\frac{a}{\sqrt{1-\frac{H^2}{L^2}}} + r > H \tag{14}$$

By the equations(4) and the inequality(5) ,we can obtain the maximum height for climbing stairs that meet the requirements. This question can be viewed as a constrained optimization .The independent variables are β, L, a, b, r, of which L, a, b, r can be specified one or more or a given range.

The objective function:

$$H = -(L\sin\beta + \frac{b}{2}) \tag{15}$$

The equality constraints:

$$\frac{L}{2}\cos\beta - (a+h)\sin\beta - r = 0 \tag{16}$$

The inequality constraints:

$$\begin{cases} a\cos\beta - b + r + (-\frac{L}{2} - h\tan\beta)\sin\beta < 0 \\ -L\sin\beta - \frac{b}{2} - \frac{a}{\sqrt{1-\frac{H^2}{L^2}}} - r < 0 \end{cases} \tag{17}$$

Based on the appropriate optimization method , we can get the maximum height of H .

4.3 Analysis for climbing the slopes

The cleaning boat rely on the tracked feet to generate a driving force when climbing the slopes, as we can see in Fig.12.

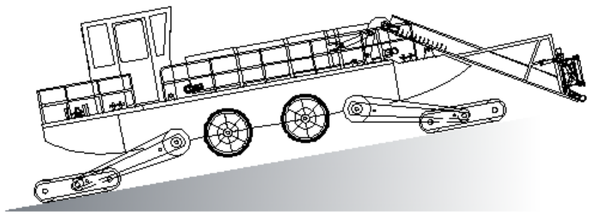


Fig.12 Schematic diagram of climbing the slopes

When climbing the slopes, it can be divided into two cases: one is the boat climbing the slopes that the hull parallel to the slopes, another is the boat climbing the slopes at a certain azimuth.

4.3.1 Climbing the slopes at a inclination θ

When the boat climbing the slopes in a way that the hull facing the slopes as is shown in Fig.13, wherein R is the resultant of positive pressure that perpendicular to the contact surface and the friction of the contact surface.The climbing resistance under the conditions to ensure the decline does not occur $(\theta < \varphi_m)$ is:

$$F_S = G \sin\theta \tag{18}$$

This is the resistance produced due to the component of gravity. φ_m is the maximum angle of slopes to ensure that the ship does not fall.

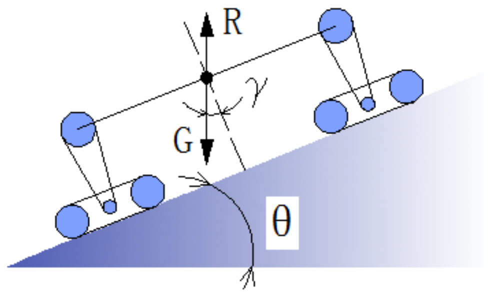


Fig.13 Climbing the slopes at an inclination θ

4.3.2 The analysis for climbing at the azimuth γ

When the boat crawling on a slant at a certain azimuth as is shown in Fig.14, at this time the climbing resistance the hull suffered is:

$$F_s = G \sin\theta \cos\gamma \tag{19}$$

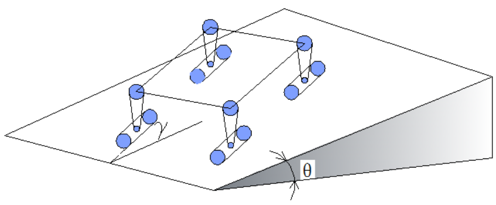


Fig.14 Climbing the slant at a azimuth γ

4.4 Analysis of traversing the ditches

The movement of crossing the ditches is achieved by the tracked feet, as is shown in Fig.15. As is well known to all,wheeled locomotion offers some disadvantages, especially in case of omnidirectional vehicles using spherical or Swedish wheels, in rough, loose terrain, due to the increasing rolling friction which causes power inefficiencies; furthermore vehicles using wheels are just able to cross gaps that are smaller as the diameter of the vehicles wheels. In tracked locomotion vehicles using tracks like a tank. A tracked vehicle is steered by moving the tracks with different speed in the same direction or in opposite direction.

The use of tracks offers a much larger area of ground contact, so the vehicles traction on loose surface is much better than the traction of wheels, furthermore the vehicle is able to drive through rougher terrain than wheeled vehicles are (it is for example able to cross larger gaps). Due to the large contact patches, tracked vehicles usually change their direction by skidding, where a large part of the vehicle slides against the ground.

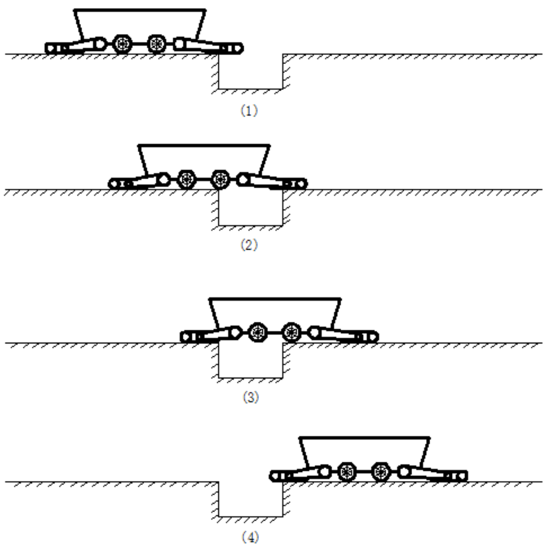


Fig.15 The process of crossing the ditches

V. Conclusion

A propulsion mechanism of cleaning boat applied for non-structural environments is proposed and the moving principles in different environments are analyzed; Trajectory analysis of rotating shaft and the mass center of the hull have been done;The critical conditions (maximum height)for climbing the stairs is obtained;The research has certain significant theoretical and practical values.

VI. Acknowlgement

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