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Design of a Bevel-Disk-Bevel Cam for a 360 Degree Friction Inducing Mechanism in a Snake Robot

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Abstract

Snake robots are versatile in nature by moving on different kinds of surfaces. Frictional forces play a vital role in propelling the snake robot. While moving in cluttered environments, there is a chance for the robot to topple from its initial orientation. Even if it topples, it needs to propel itself and explore the further areas in the toppled position which has different orientation than the initial one. Mechanisms to set right the snake robot to its initial position make it heavier. Hence there is a need for a 360 degree friction inducing mechanism which aids in propelling the snake robot even if it topples from its original position. This friction inducing mechanism is created using a bevel-disk-bevel cam whose design is explained in this paper.

Keywords: Bevel Cam, Bevel-Disk-Bevel Cam, Friction Inducing Mechanism, 360° friction

1. Introduction

Frictional forces play an important role in the motion of the snake robot[1]. A review on snake robot shows that there is a need for designing the robots to move in cluttered environments[2]. While doing so, there is a possibility for the snake robot to topple. Hence there is a need for a 360 degree friction inducing mechanism. It is made possible using bevel and disk cams. Precise motion and ability to dwell easily makes cam a choice for designers. A closed-form modified trapezoidal cam was used and is suitable for multiple dwell and follower application[3]. The influence of the planned interference fit for a conjugate cam mechanism was evaluated[4]. A coordinate measuring machine and a dial indicator can be used to examine the profile of the cam after manufacturing[5]. Bevel gears are used in the joint mechanism of the snake robot. To facilitate the motion, the snake robot is covered with a plastic sheet[6]. This cannot be used in harsh environments and is also a hindrance to attach the sensors over its body to get real time input. A complex friction inducing mechanism using shape memory alloys are used in snake robots to induce friction[7]. The friction anchor module used in the snake robot can be utilized for inducing friction over the ground surface. But when the robot topples, it is impossible for it to induce friction since its orientation changes[8]. This is overcome in the mechanism that is presented in this paper. In a survey about cams, it was noted that the cycloidal displacement of the follower has less complex jerk curves. For a given velocity, the acceleration and jerk curves were plotted. The value of the jerk obtained for cycloidal displacement was found low and the curve appeared less complex[9]. Hence the bevel-disk-bevel cam used in the friction inducing mechanism is designed for cycloidal displacement of the follower.

In our previous work, we used a crank and slider mechanism to induce friction over the ground[10]. But it is suitable only when the snake robot moves on the flat surfaces without toppling. If the snake robot topples, it is impossible for it to propel itself further. Hence in this paper, we introduce the bevel-disk-bevel cam for the fric-

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tion inducing mechanism which makes the snake robot to propel even if it topples.

2. Friction Inducing Mechanism

The friction inducing mechanism is designed in such a way that it can operate in all the angles about the center. This is made possible using a bevel-disk-bevel cam attached in the centre of each segment of the snake robot. The mechanism has spherical faced followers whose ends contain friction material (e.g. rubber). At a particular point of time, the friction is induced in the alternative segments. During the rotation of the cam, the follower rises, dwells and induces friction over the surface it travels. This makes a particular segment of the snake robot stable and pushes or pulls the other segments which are in front or behind it. The two bevel cams induce friction at the top and bottom area of the segment. The disk cam induces friction at the sides of the segment. The regions covered by the cams to induce friction around the cross section of the segment are as shown in Figure 1.

2.1 Parts

2.1.1 Bevel Cam

A bevel cam is used to convert rotary motion into angular linear motion[11]. There are two bevel cams that are mirrored to each other. There is a disk cam in between them. Each bevel cam has four followers around it perpendicular to the cam's surface. This enables the friction to be induced over a wide area on the surface. For one rotation of the cam, each follower rises, dwells and falls four times. This enables the snake robot to propel four steps for each rotation of the cam. The conceptual diagram is as shown in Figure 2 (a)[11]. The bevel cam to be used in the mechanism is as shown in the Figure 2 (b,c).

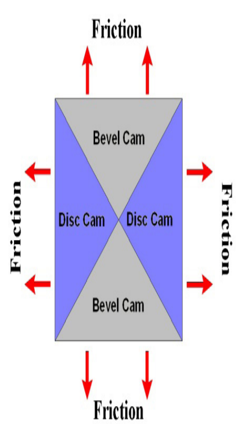


Figure 1. The cross section of the snake robot showing the friction inducing regions by the cams.

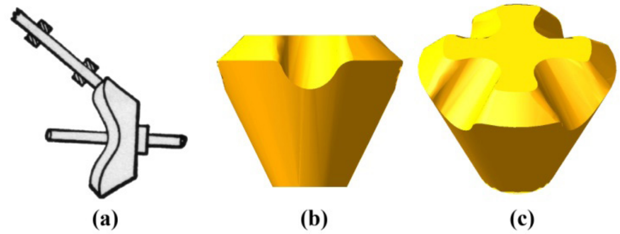


Figure 2. (a) Conceptual bevel cam. (b) Side view of the bevel cam .(c) Isometric view of the bevel cam.

2.1.2 Waist

The disk cam is sandwiched between the two bevel cams. It is used move the followers on the sidewise. This enables the friction to be induced over the sides of the snake robot. The motion of the follower is similar to that of the bevel cam. It is because all the followers of the bevel and disk cam have to rise, dwell and induce friction on the surface at the same period of time. The disk cam used in the mechanism is as shown in Figure 3.

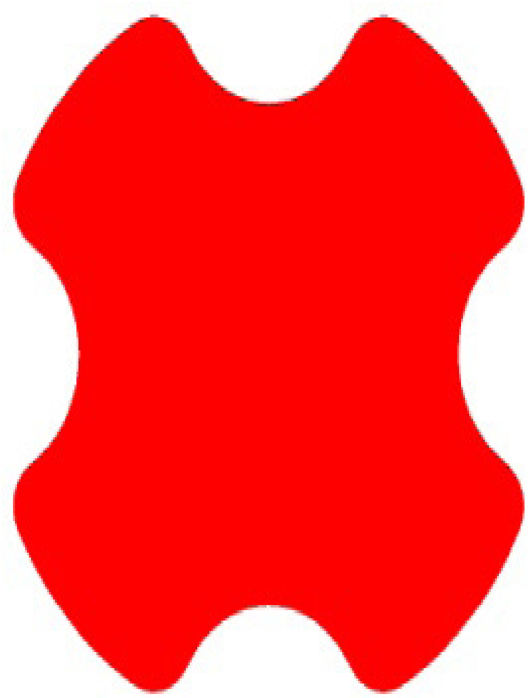


Figure 3. A disk cam used in between the two bevel cams.

2.1.3 Follower

There are four followers for each bevel cam and two followers for the disk cam. These are spherical faced followers. It is chosen because it has reduced surface stresses[12]. The length of the follower depends on the angle of the bevel. This angle depends on the height between the bevel cam surface and the segment surface. One end of the follower has a spherical face and the other end has a friction inducing material. When the follower rises and dwells, the friction is induced on the surface over which the snake robot moves. The conceptual design of the spherical faced follower is as shown in Figure 4 (a)[12]. The follower to be used in the mechanism is as shown in Figure 4 (b).

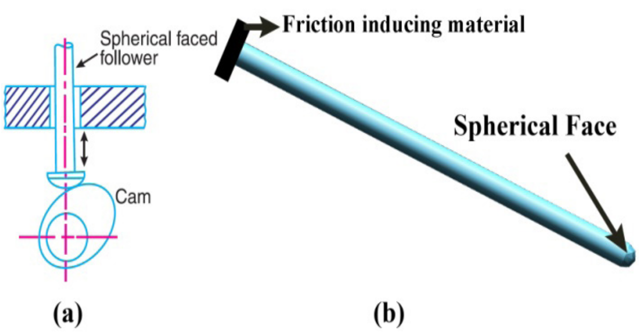


Figure 4. (a) Conceptual spherical faced follower. (b) Spherical faced follower used in the mechanism.

2.1.4 Spring

A spring is attached between the follower and the segment of the snake robot. The spring force is used to make the follower be in contact with the cam. As the cam rotates, the follower rises by compressing the spring. The spring is used to ensure that the follower is always in contact over the cam surface while it is rotating. Even if the snake robot topples, the follower will be in contact with the cam due to the spring force. It is as shown in Figure 5.

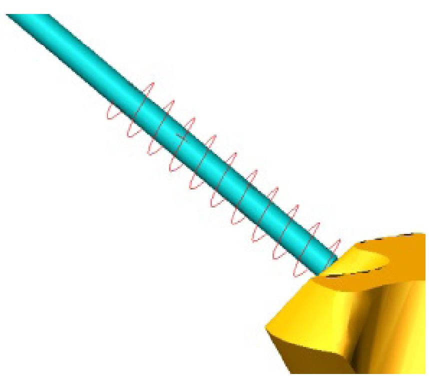


Figure 5. Spring force establishing the contact between the follower and cam.

3. Orientation of the Bevel-Disk-Bevel Cam

There are three cams arranged one over the other. The two bevel cams mirrored to each other sandwich the disk cam. These three cams have a common axis of rotation. This is as shown in Figure 6 (a, b). The followers about the three cams induce friction all around the cross section. But in the initial stage, the followers of the bevel cam at the

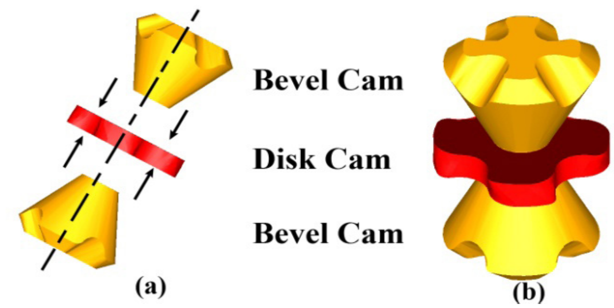


Figure 4. (a) Exploded view of the bevel-disk-bevel cam arrangement. (b) Assembly of the bevel-disk-bevel cam.

bottom induce friction on the ground. If the snake robot topples, the bevel cam comes to the side and the disk cam becomes vertical. The axis of rotation of all the three cams changes from vertical to horizontal. This still enables the snake robot to propel by inducing friction on the ground using the followers of the disk cam. This is as shown in the Figure 7.

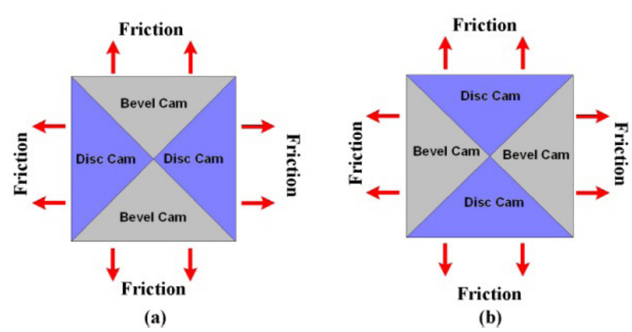


Figure 7. Cross section of (a) Initial position of the snake robot. (b) Position after toppling.

4. SVAJ Equations for the Motion of the Followers

The bevel and disk cams are designed for rise-dwell-fall motion. This happens for every 90° of the rotation of the cam. Therefore this leads to four rise-dwell-fall motion of the follower for every rotation of the cam. The cycloidal displacement of the follower is chosen due to fewer jerks during the motion of the follower. The principal concern of the designer must be acceleration function, and to a lesser extent the jerk function[13]. The required output is obtained during the dwell period where the follower presses the friction material on the ground which provides stability. During this dwell period, the velocity, acceleration and the jerk are zero. Therefore they do not affect the required output.

The acceleration which is a higher derivative is chosen to start drawing the SVAJ diagram. The equation for a sine wave is[13],

$A = C \sin(2\pi\Theta/\beta)$, where C defines the amplitude of the sine wave

By integrating and simplifying the acceleration equation, we get the velocity as[13],

$V = (h/\beta)\,[1 - \cos(2\pi\Theta/\beta)]$

Integrating again, we get the displacement as[13],

$S = h\,[(\Theta/\beta) - (1/2\pi)\,(\sin(2\pi\Theta/\beta)]$

Simplifying and substituting the value of C in acceleration[13],

$A = (2\pi h/\beta^2)\,\sin(2\pi\Theta/\beta)$

The jerk expression is obtained by differentiating the acceleration with respect to Θ[13],

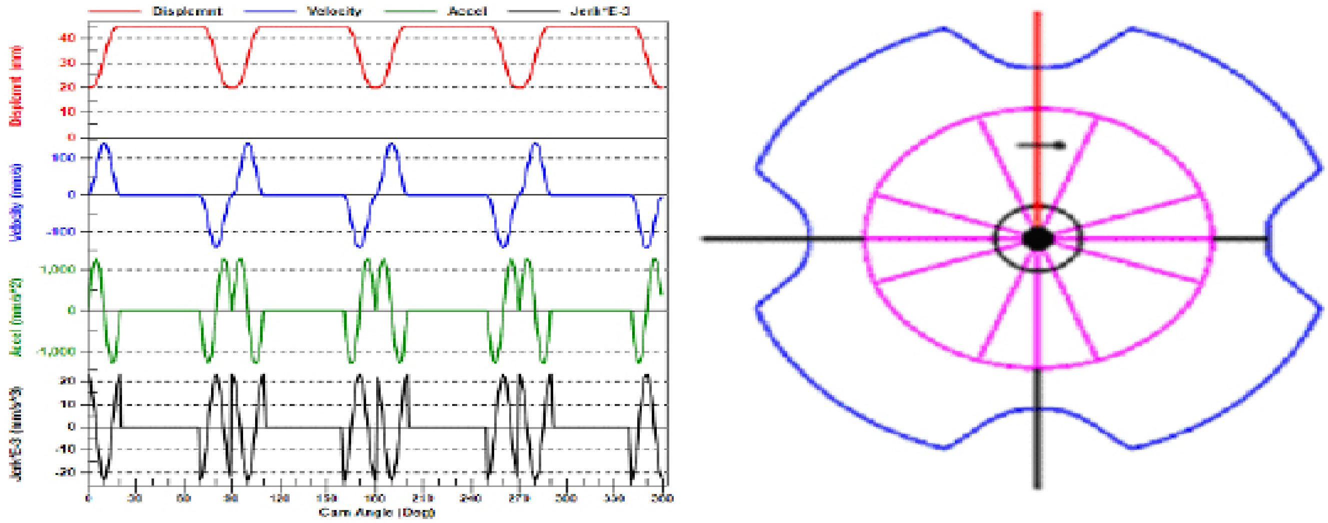
$J = (4\pi^2 h/\beta^3)\,\cos(2\pi\Theta/\beta)$

5. A Case Study

A bevel-disk-bevel cam is designed using the data in Table 1. The SVAJ diagram is drawn for these values. The cam profile is drawn for both the bevel and disk cam. The SVAJ diagram and cam profile are same for both the bevel and disk cams since follower motion is the same for these two cases.

Table 1. Segment data for the bevel and disk cam

	Angles			Cam Contour		Position of follower(mm)	
Segment	Beta	Start	End	Motion	Displacement	Start	End
1	20	0	20	Rise	Cycloidal	20	45
2	50	20	70	Dwell	Dwell	45	45
3	20	70	90	Fall	Cycloidal	45	20
4	20	90	110	Rise	Cycloidal	20	45
5	50	110	160	Dwell	Dwell	45	45
6	20	160	180	Fall	Cycloidal	45	20
7	20	180	200	Rise	Cycloidal	20	45
8	50	200	250	Dwell	Dwell	45	45
9	20	250	270	Fall	Cycloidal	45	20
10	20	270	290	Rise	Cycloidal	20	45
11	50	290	340	Dwell	Dwell	45	45
12	20	340	360	Fall	Cycloidal	45	20



(a) (b)

Figure 8. (a) SVAJ diagram of the follower for the values taken in case study. (b) Profile of the bevel and disk cam.

Based on the conditions in the table, the values of SVAJ were calculated. They are plotted against the cam angle. This is shown in Figure 8 (a). It is observed that during the dwell period, the velocity, acceleration and the jerk are zero. This therefore makes the follower to give a continuous contact on the ground thereby enabling a steady frictional force over it. The cam profile for the bevel and disk cam is as shown in Figure 8 (b). It is drawn based the values in the Table 1. It is observed that there is a smooth contour.

6. Bevel Cam Design

The geometric representation of the bevel cam in the segment of the snake robot is as shown in the Figure 9. The angle of the bevel (α) decides the length of the follower (F_L). The thickness of the cross section is represented by the letter "L". There are three right angled triangles namely i, ii, iii. The length of the follower is calculated based on the height of the segment from the bevel cam (h) and the horizontal distance (l) where the friction has to be induced on the ground.

The length of the follower is given by,

$F_L = (l^2 + h^2)^{1/2}$

The angle of inclination of the follower is given by,

$\tan \alpha = (l/h)$

By geometry, it is found that the angle of inclination (α) of the follower is equal to the bevel angle. The angle of bevel in terms of the height of the bevel and the diameter of the bevel cam is given as,

$\tan \alpha = [2a / (D-d)]$

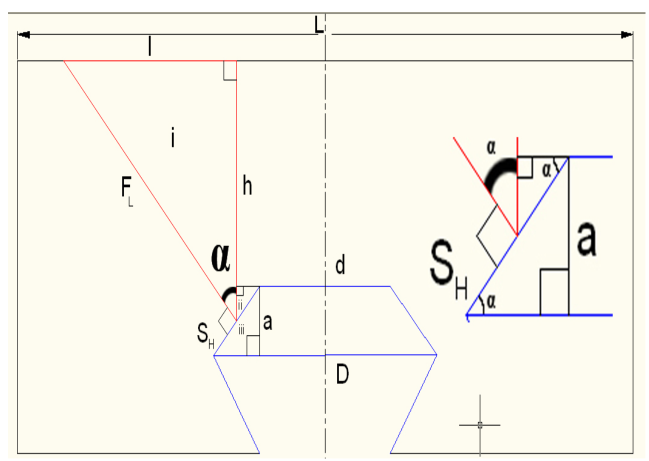


Figure 9. The geometry of the cross section of the snake robot with the bevel cam.

The follower has to touch the bevel cam at the midpoint of the slant height (S_H) of the bevel. The equation to find out midpoint is given by,

$$S_H = [1/2] * [a^2 + \{(D\text{-}d)^2/4\}]^{1/2}$$

7. Results of Simulation

Based on the values in the table, the bevel-disk-bevel cam was designed and simulated using MSC Adams. It is found that the followers move according the values given in the case study. The required periodic rise-dwell-fall of the follower is observed. The friction is induced on the ground when the follower is in the dwell position. It is as shown in Figure 10 (a). As the cam rotates, the follower falls in and the friction is not induced on the ground. It is as shown in Figure 10 (b).

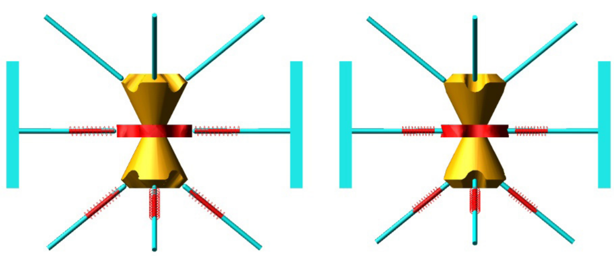


Figure 10. The bevel-disk-bevel cam with follower in (a) dwell position (b) fall-rise position.

8. Implementing the Friction Inducing Mechanism in the Snake Robot

The snake robot consists of three segments. There is a joint mechanism in between the segments. This joint mechanism aids in propelling the snake robot. The friction inducing mechanism is present in the middle of each segment. Initially the followers are in the fall position. When the snake robot starts to move, the friction is induced in the second segment. The joint mechanisms are actuated which propels the first and the third segment. Then the cam rotates which induces friction in the first and third segment. Hence the first and the third segment become stable. The friction induced in the second segment is removed due to the rotation of the cam. Therefore the second segment is free to move. The joint mechanisms are actuated and the second segment moves forward. Thus the snake robot has moved a step forward. Even if the snake robot topples, the robot can propel itself since the friction inducing mechanism is activated on all the surfaces of the snake robot. The initial and toppled positions of the snake robot with the friction inducing mechanism are as shown in Figure 11 (a, b, c, d).

9. Conclusions

In this paper we have created a mechanism for the snake robot which is used to induce friction at all points on the

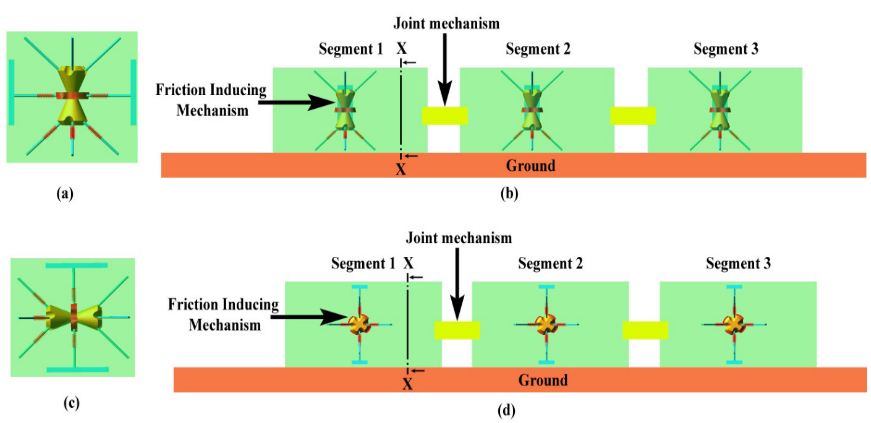


Figure 11. (a) Cross section (X-X) of the mechanism at initial position; (b) The initial position of the snake robot with the friction inducing mechanism at the center of each segment; (c) Cross section (X-X) of the mechanism at toppled position; (d) The toppled view of the snake robot with the friction inducing mechanism at the center of each segment.

surface. This enables the snake robot to propel even if it topples. The bevel-disk-bevel cam arrangement with the followers about it is used to induce friction about 360° around the snake robot. During the dwell period, the desired output is obtained to induce the friction on the ground. The SVAJ diagram shows that there are no jerks in the dwell period. Therefore it can induce friction continuously during the dwell period. The snake robot with the friction inducing mechanism was simulated. The snake robot was able to move even when it was toppled. This friction inducing mechanism can be used by the snake robot while travelling through pipes. The mechanism can also be used for snake robots with circular cross section. It can be done by modifying the shape of the follower.

10. Acknowledgements

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Appendix

Nomenclature

Θ = camshaft angle, degrees or radians.

β = total angle of the segment, rise, fall or dwell, degrees or radians.

h = total lift (rise or fall) of any one segment, length units.

S = follower displacement, length units.

V = follower velocity, length/sec.

A = follower acceleration, length/sec^2.

J = follower jerk, length/sec^3.