In Pipe Maneuvering Robot

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Pipelines have become an essential tool to transport raw materials in Industries, Fuel transmission in households, etc. To ensure safe working, there is a need for proper inspection and maintenance of the Pipe. Human Involvement in Inspection and Maintenance of Pipe is Time-consuming and even risky. Therefore, the robot is one of the viable solutions for these tasks. This paper presents a novel design for an in-pipe maneuvering Robot, especially for countering T and L joints in a Pipe. The robot uses a screw drive mechanism and has passive support wheels at the rear. Three continuous tracks with Scott-Russell mechanism is used for providing Extra actuation when passing through joints. Every wheel has a spring attached to push against the wall of the Pipe, and this spring ensures robot adaptability in various diameter pipes. The robot is modelled using SolidWorks 2019. The bond graph method is used for dynamic simulation of the robot to examine the bot's motion while countering the bend, t and l joint. Simulations have been performed in the Adams Software to check various characteristics of the robot inside the bend pipe.

Keywords: In-Pipe Maneuvering robot, Bond Graph,Dynamic Simulation, Screw Drive, Wall Pressed Robot.

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1 Introduction

Several important materials for our daily lives are fluids provided by different industries. Fluids such as oil, gas, chemicals, and water are transported and delivered to final customers using pipes with different characteristics. A common problem for all the industries providing fluid transport and/or delivery is the maintenance of their infrastructure, i.e., pipes. Pipes are subject to many troubles, most of them caused by aging, corrosion, fissures, cracks, or third-party damage. To develop a proper investment plan for pipe maintenance, including rehabilitation, it is necessary to know the pipe's current condition [1].

Therefore, it is necessary for the pipelines to perform scheduled inspection and maintenance. For complicated structure and dangerous environment inside the pipeline, however, in-pipe robots would be a better choice to carry out it than human. Therefore, in-pipe robots have been an attractive research area. In-pipe robots basically are an integrated system including machinery, electric and instrument, which can automatically move along the interior or exterior of small pipe and carry several types of sensors as well as equipment to perform a series of pipe operation under the control of human or computer [2].

In-pipe robots are broadly classified into actively moving robots and passively moving robots. This classification is made on the basis of difference in operating source and controllability of steering mechanism. Active locomotion robots can be further sorted into six categories which are shown in figure 1. Pig type is a classic example of passively moving robots [2].

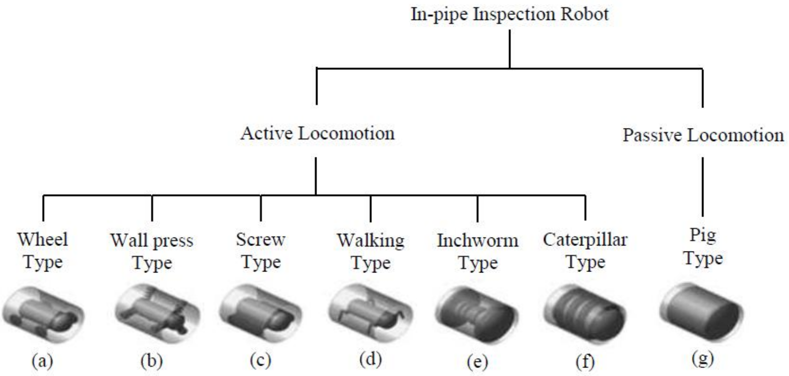

Fig 1. Classification of the In-pipe robot based on the type of locomotion [4]

A wheel type robot shown in figure 1(a) is most preferred type of pipe inspection robot. Advantage of this type of robot is its very simple design. The wall pressed type robot shown in the figure 1(b) gives most tractive force as compared to other types. Due to high tractive force it can climb in vertical pipelines by pressing the wall by whatever mode they employ. In this type, design of robot is decided by the particular application. Figure 1(c) displays screw type (helical drive type) robot which follow the principle of screw. When it travels in the pipeline, it follows the helical path. Figure 1(d) depicts a walking type which is generally called as crawler robot. Advantage of this type of robot is that it can walk on any type of surface. Figure 1(e) shows inchworm type robot, which emulate motion of inchworm. Its movement through pipe is very slow like inchworm but it can be used for very small diameter pipelines. Figure 1(f) illustrates the robot with caterpillars. This type of robot comes up with additional grips than wheel type robot, which helps to reduce the slips inside the pipe. Figure 1(g) displays a pig type of in-pipe inspection robot. In this type fluid pressure is used to drive the robot passively inside the pipeline. Generally, this type of robot is preferred for inspection of large diameter pipelines [3].In this paper we focus on wall pressed screw type robot as wall pressed robot have the advantage of maneuverability in vertical pipes and screw type robot requires less no of actuator as compared with other type of robot. So, this help as solve the problem of robot maneuverability in vertical pipe and T&L joints.

2 Literature Review and Problem Identification

Over the years a lot of work has been done in the field of robotics and In-pipe robot is one of the topics which is very popular among researchers. Some important literature relevant to this paper's work are discussed here.Atul Gargade et al.[4] have presented a screw driven wall pressed wheel type in-pipe inspection robot version 2. This robot can pass easily through horizontal pipes, vertical pipes and couplings of 8 inches and 10 inches diameter. It does not pass through bends and T joints. At Kakogawa et al. [5] have presented a method for designing the arm lengths of a screw drive in-pipe robot with a pathway selection mechanism to pass through bent pipes. This robot can travel across the vertically positioned bent pipes but still it required finding optimal values of arm length to reach to the pipe wall and the upper limit with minimum torque. Muhammad AzriAbdul Wahed and Mohd Rizal Arshad [6] have presented wall pressed wheel type pipe inspection robot which can maneuver through a variable diameter pipe of 150mmto 230mm and able to climb a 30° slope. Atsushi Kakogawa [7] have presented an In-pipe Robot with Under actuated Parallelogram Crawler Modules, which can automatically overcome inner obstacles in the pipes like couplings, scale formations, diameter change, etc. This robot has adaptive diameter of 140 - 226 mm. Yoon-Gu Kim et al. [8] have proposed an in-pipe robot platform applied a modified scissor-lift mechanism controlled by pneumatic cylinder actuators. With adaptability to variable pipe diameters from 600mm to 800mm. Nayak and Pradhan [9] have presented a screw drive wall press in-pipe inspection robot. The robot can maneuver inside a pipe of diameters ranging from 127mm to152mm.Performedkinematic and dynamic analyses to understand the behaviour of proposed model in vertical, inclined and horizontal pipe line with Y or L bends. Initial conceptual prototype of pipe inspection robotis presented. From above literature review it is clear that few researchers have worked on countering T and L joint in vertical pipes with wheeled robot. So, focus of this research is to work on developing a robot which can counter T and L joints in vertical pipes using a wall pressed and screw drive mechanism.

3 Methodology

While designing a mechatronic/Robotic device, it's critical to balance engineering analysis with hardware experimentation in an appropriate way. The problem is that if you don't use a rigorous engineering analysis approach, then that can lead to, for instance, excessive development time. It can take a long time to get something to work. When we do get it to work, it may not work very well. And so, we might not achieve the objectives that we've set for whatever you're trying to build. So, it's important to balance both an engineering analysis process with a hardware experimentation process.

(i) The first step is to study and research literature and solutions available.
(ii) Following that step, short listing the key shortcomings in existing solution.
(iii) Step three is to come up with a goal or set of requirements for our system.
(iv) Step four is to brainstorm and finalize ideas for robot mechanisms.
(v) Step five is to design the robot using a cad software (SolidWorks 2019)

(vi) Step six is to select the components for the robot and model it and run simulation based on the component specification. This step is an iterative process and component specification changes till it achieve system goals.

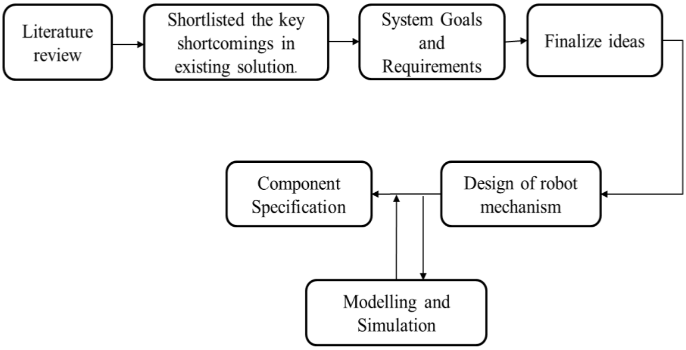

Fig. 2. Methodology

4 Robot Design and Mechanism

Solid-modelling of all robot parts and their assembly is carried out in SolidWorks 2019.

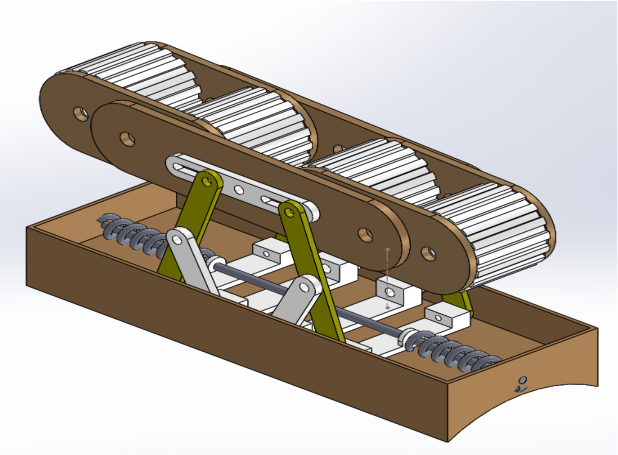

Fig. 3. The Scott-Russell Mechanism with Continuous Track

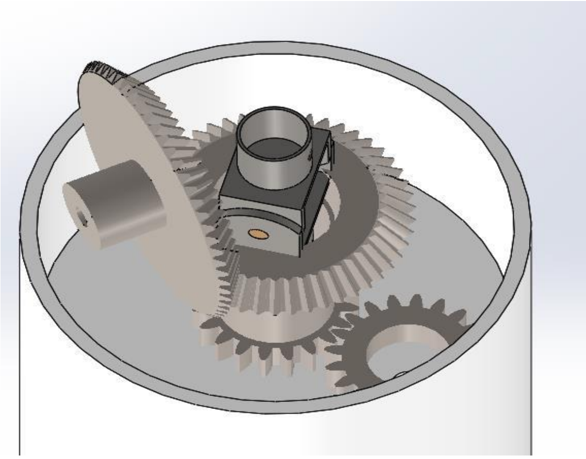

Fig. 4. Gear Assembly for Path Selection

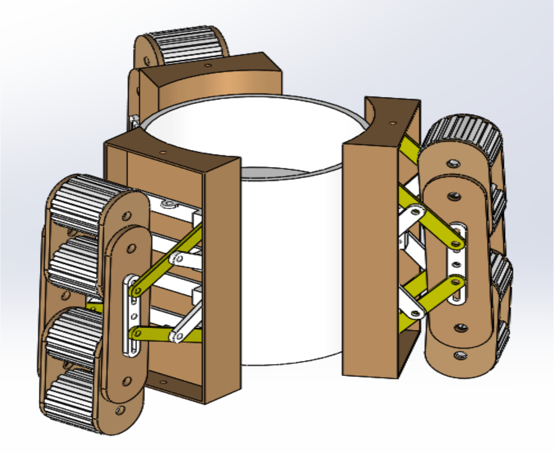

Fig. 5. Rear Unit

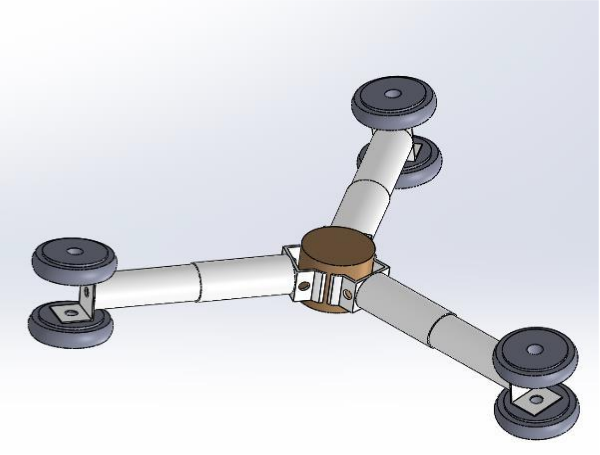

Fig. 6. Front Unit

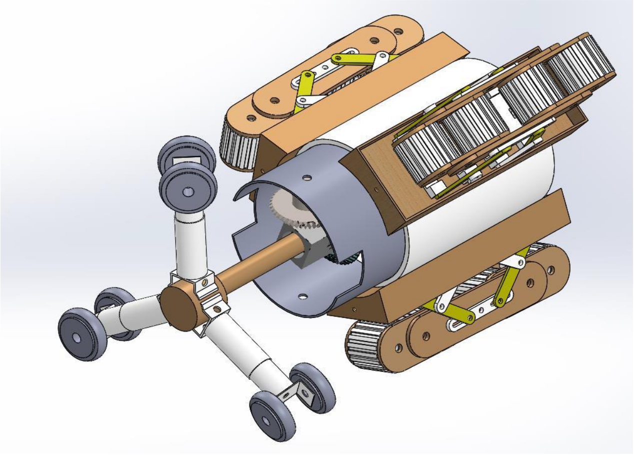

Fig. 7. Complete Assembly of In-Pipe Robot

4.1 Mechanism

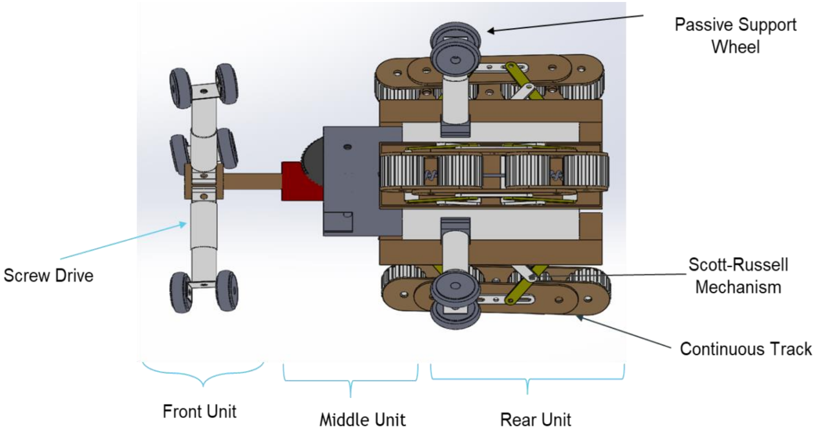

Fig. 8. Different Units of In-Pipe Robot

Each arm is equipped with a pair of wheels tilted at angle, that are supported by springs. Front unit can be redirected for turning when it travels through the T and Elbow Joint. Maximum range of steering angles is±90 degrees. The middle unit consists of all the gear assembly and shaft for transferring power from motor to Front Unit. This gear train consists of two spur gears and two bevel gears from inside this middle spur gear a shaft is coupled with a motor which transfers power to the front unit. And this shaft is then connected to a universal joint and through this universal joint to the front unit. The rear unit has three Continuous tracks attached to the rear unit with Scott-Russell mechanisms and three passive supporting wheels. Rear unit works as a stator in which two dc motors are installed. The screw motion of the front unit is driven by the driving motor. Steering is handled by the steering motor. The driving motor is connected to the central axis of the front unit via coupling and universal joint.

4.1.1 Scott-Russell Mechanism

In the rear unit of the in-pipe robot, the three arms are composed of a continuous track. To make the robot adjustable to inner pipe diameter we have added a Scott-Russell Mechanism. This mechanism will help to adjust the overall diameter of the robot according to requirements. It has components like a slider and a spring. The spring will help to retain the original diameter and the spring will also provide the required normal reaction to hold the robot inside the pipe within side the secondary actuation mode, to alternate the adaptive diameter, every crawler module is attached to a principal base unit via passive Scott-Russell Mechanism Fig. 10.

This straight-line motion is shown in Fig. 9. The mechanism is essentially the same as that of the reciprocating engine. The crank OC is equal in length to the connecting rod CP and P is constrained to move along a straight path by a crosshead and guide bars. The connecting rod is extended to Q, such that CQ = CP, and it is easily seen that Q then moves along a straight path normal to OP. [10]

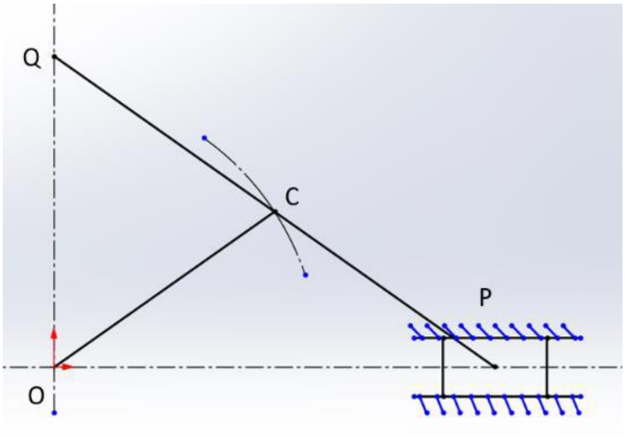

Fig. 9. Scott-Russell Mechanism

Each continuous track is radially assembled with an interval of 120◦. A slider action alongside the horizontal shaft is passively driven via the means of a spring. As formerly mentioned, the spring pressure and gravity push the arm down at the same time as in riding mode. The cease of the hyperlink is ready on the centre a part of the crawler (Joint A and B) due to the fact there may be no area someplace else because of the presence of the front and rear arms. Due to their geometric nature, Joints A and B can most effectively flow vertically. Hence in theory, the crawler module cannot have a relative perspective to the principal base unit due to the fact the gap among Joint A and B is constant. However, as depicted in Fig. 10the positions of those joints can pass independently due to the fact every linkage has a certain axial interspace. Without this effect, the crawler is kept parallel to the pipe even if transforming, which isn't always possible for adaptive movement.

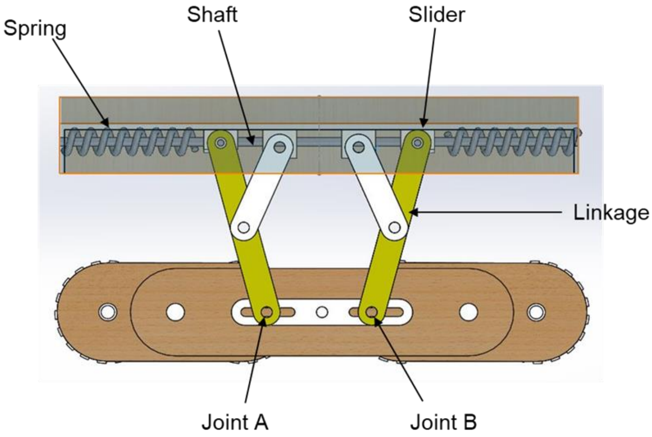

Fig. 10. A Scott-Russell Mechanism used to change the diameter of the robot

4.2 The different modes of maneuvering

The robot has 4 modes of locomotion – screw driving, steering, rolling and Secondary Actuation mode – which permit it to navigate through T-branches. These modes are actuated by means of a differential mechanism.

4.2.1 Screw-driving mode

In this mode, the front unit of the robot rotates clockwise and anticlockwise which helps the robot to maneuvering forward and backward respectively. The front unit is actuated using screw drive motor located at the rear unit. The power from the rear unit is transferred to the front unit via the help of universal joint.

4.2.2 Steering mode

This mode is used when robot encounters a T-branches or elbows. Here, the power is transferred using the steering motor located in the rear unit with help of two spur gear and two bevel gear as shown in the fig. 4.

4.2.3 Rolling mode

In this mode, the robot rotates it middle unit about itsaxiallength when its not able to steer its front unit along direction of the bend, it rotates the middle unit

4.4.4 Secondary Actuation Mode

This mode is used at T -branches or elbows when the front unit loses the contact the inner diameter of the pipe. Here, the continuous track in the rear unit helps the bot to maneuver through the joints.

5 Robot Specifications and Mechanical Design Calculation

Table 1. Robot Specifications

Axial length	430 mm
Max and min diameters	380 mm to 300 mm
Wheel diameter	54 mm
Total weight	3.7 kg
Angle of the wheel	10°
Max velocity	165.93 mm/sec
Spur Gear Ratio	1:1
Bevel Gear Ratio	1:2

Table 2. Deign Parameters and Calculation

Sr. No.	Parameter to Design	Parameters Considered for Design	Designed Parameters
1.	Linear velocity of robot	Helix angle, $\alpha = 10^\circ$ Diameter of Pipe, $D = 360$ mm	$V_H = 942$ mm/sec, $V_L = 165.93$ mm/sec

2.	Speed of motor	Helical Velocity, V_H = 942 mm/sec Radius of wheel, r = 26.86 mm	Motor speed, N = 50 rpm
3.	Spring force & Spring stiffness	Mass of robot considered for design, m = 4 kg Coefficient of friction, μ_s = 0.3 Minimum compression of spring, δ_{min} = 20 mm	Springforce, $[F_S]_{min}$= 60 N Spring Stiffness, k = 3 N/mm
4.	Spring wirediameter	Stiffness of Spring, k = 3 N/mm Outer diameter, D_o = 16 mm Free length, L_f = 60 mm	Spring wirediameter, d = 2.1 mm
5.	Power required	Weight of robot = 40 N Frictional force = 54 N Linear velocity = 165.93 mm/sec	Power required, $P_{required} > 15.6$ watt
6.	Design of motor shaft	Shear stress, τ_{max} = 90 N/mm^2 Power, P = 15.6 watt	Motor shaftdiameter, d = 7 mm

For this robot, pipe radius is 180mm, spring constant 3 N/mm, the mass of the robot is 4 kg, Acceleration due to gravity is 9.8 m/s^2 and After calculation, we have got the linear speed and Helical speed of robot in the curve pipe as 165mm/sec and 942 mm/sec respectively. and the power required to drive the motor is more than 15.6 watts.

6 Result and Discussion

A simulation platform along with the bodily prototype of the robot and the pipe surroundings is constructed in the ADAMS software. On the platform, the robot complies with the transmission relationship provided in phase four through the joint constraints. Contact constraints are implemented among the rollers of the robot and the pipe. In the simulations, the angular pace of Motor is the single input. Some parameters of the robot in the dynamic simulation platform are indexed in Table 1. Two groups of simulations are implemented. One group is the verification check of the characteristics for the proposed robot in diverse pipes; the alternative group is the simulation to study the variation in the arm lengths when the robot passes through bent pipe. The robot is designed for straight pipe and curved pipes with numerous curvature radius. D, R, denote the pipe diameter, radius of curvature. The gravity is in the direction of the Y-axis. In the simulations, different parameters of pipes have been tested to fully verify the validity of the proposed robot. Several simulations are realized to observe the motion abilities of the robot in pipes with varied steering angles, varied curvature radius and different pipe inclining angles.

In the first simulation, we have studied the velocity of the robot in the curved pipe; we have studied these characteristics of robots in curved pipes of different radius. In our case we have taken the bend radius as 500mm, 550 mm, 600mm respectively.

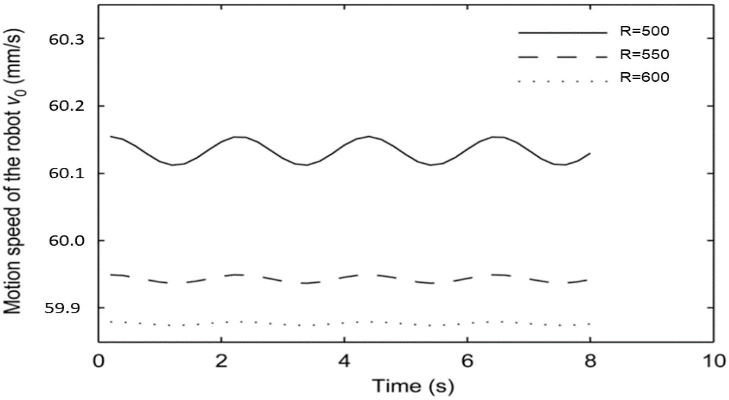

Fig. 11. Motion Speed of Robot vs Time(s) graph

In the second Simulation we have studied the variation in Arm length of robot in Curved pipe of radius 180 mm.

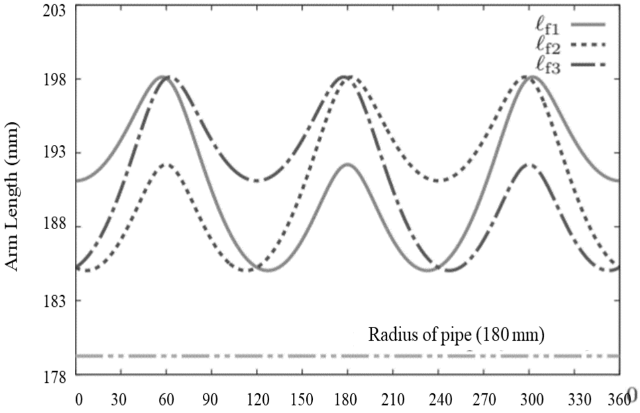

Fig. 12. Arm Length vs Angular Displacement graph

7 Conclusion

A model for a screw-drive in-pipe robot's fundamental helical motion in a curved pipe has been provided. To suit the egg-shaped curve in this model, the length of the elastic driving arms must be modified passively. This indicates that the rigidity of the elastic driving arms is critical and must be properly engineered. It gets simpler to ascend vertical straight pipes if the spring stiffness is high without stumbling. In curved pipes, however, a larger motor torque is required. Compress or expand the springs repeatedly by rotating in a non-precise circle. Furthermore, the friction force plays a significant part in allowing the robot to pass. via the pipes, both straight or curved. As a result, while building a screw-drive in-pipe, keep this in mind. First and foremost, the material of the pipes should be evaluated. Following that, the needed spring stiffness to prevent slippage and the required motor torque must be calculated. More passive motion behaviors may be necessary for the robot to go from a horizontal pipe to a vertical pipe, passing through not just one form of curved pipe, such as an elbow pipe, but also T-branch and pipes with variable diameters. This might be accomplished by employing a unique mechanism with only one motor or by expanding our suggested mechanism with more motors. Although the robot with one degree of freedom can solve many problems, there are still numerous obstacles to overcome in order to reach great adaptability.

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