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Design and Development of Drone to Remove Scale in Steam Carrying Pipes

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***ABSTRACT**: Power plants where steam is generated in boilers, because of the temperature difference between outer and inner walls condense steam this leads to the deposition of scales on the inner walls. This could lead to disasters when left unnoticed. Conventionally the scales are removed by dismantling the tubes and then manually removing them using high pressure water jets. This stops the power production in the power plants for several days and also the cost associated is very high. Our novel solution for this problem is to insert a drone with rotary nozzles which could travel through pipes and remove the scale deposition using high pressure water jets also the robot drone will be capable of adapting to different pipe diameters by using suspension system and moves along the bend line pipe.*

***KEYWORDS**- Scale deposition, robot drone, water jet, rotary nozzle, scale removal, adapting to different pipe diameter, moves in bend pipes.*

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I. INTRODUCTION

Pipes are one of the most important components that are being used for the transportation of the raw materials in many industries. They are the integral part of oil and gas industries. Pipelines are used to carry materials like water, crude oil, gases, petroleum and industrial waste.

1.1 SCALE

Hard water is a common quality of water which contains dissolved compounds of calcium and magnesium and, sometimes, other divalent and trivalent metallic elements. The term hardness was originally applied to waters that were hard to wash in, referring to the soap wasting properties of hard water. Hardness prevents soap from lathering by causing the development of an insoluble curdy precipitate in the water; hardness typically causes the build-up of hardness scale (such as seen in cooking pans). Dissolved calcium and magnesium salts are primarily responsible for most scaling in pipes and water heaters and cause numerous problems in laundry, kitchen, and bath. Hardness is usually expressed in grains per gallon (or ppm) as calcium carbonate equivalent.

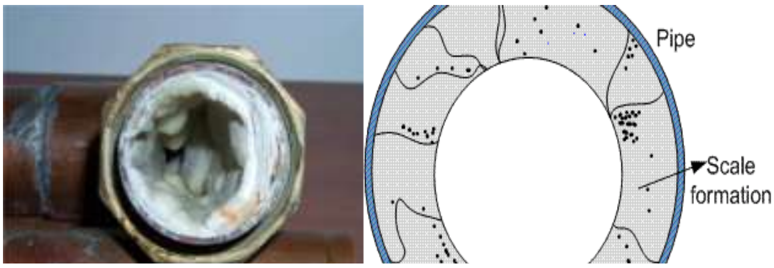

Figure -1 Formation of scale

Due to over usage the pipes will damage very less time.So we have to monitor the pipes continuously and clean the pipes on a regular basis. But inspection and cleaning the pipes is not an easy task it requires a lot of effort and time. In olden days, large size pipes like drainages are cleaned manually by labors. Because of the size of the pipes and shapes involved with them we can’t use men for all occasions. Especially the industrial pipes vary in size from millimeters to meters and contain many types of harmful substances inside the pipe. The shapes are also very complicated, and branches like T-shape, Y-shape, increaser, decrease and elbow are making the locomotion even more difficult. Because of the harmful substances it is necessary to use devices that can do the inspection and cleaning operations in the pipe. In this investigation, a new and a simple solution to remove the scale depositions on the inner walls of the steam carrying tubes is to be designed and tested. The conventional manual water jet scale removal is to be replaced by a more efficient, quick and cheap solution that can clean the inner walls of the tubes by travelling inside steam carrying tubes and using high pressure water jets. Size of system can be automatically adjusted for the requirement of pipe line which are to be cleaned, it can also move along the bends of the pipe line without any hesitation. This process is more efficient than the normal cleaning process and time can be also reduced.

1.2 Methods Of Scale Removal Process

There are two methods are used to remove the scale on the steam pipe line they are:

1. Chemical scale removal process
2. Mechanical scale removal process

1.3 CHEMICAL SCALE REMOVAL PROCESS

This Specification is prepared for chemical cleaning and post-cleaning passivation treatment of carbon steel suction piping of compressors prior to pre-commissioning. This specification covers the chemical cleaning of fabricated and erected carbon steel piping at plant site prior to pre-commissioning by chemical circulation method. The technical procedure is prepared only for carbon steel surfaces. Materials other than carbon steel shall not come in contact with pickling solutions. This procedure is for GT-HRSG plant constructed forming part of the Residue up gradation and MS/HSD Quality Improvement Project for IOCL's Gujarat Refinery in Vadodara. Indian Oil Corporation Limited (IOCL), has appointed Toyo Engineering India Ltd as "Project Management Consultant "(PMC).

1.3.1.LIMITATION OF CHEMICAL SCALE REMOVEL PROCESS

- ✓ Chemically inert materials, e.g., coke deposits cannot be removed.
- ✓ Severely fouled or fully plugged equipment will require mechanical cleaning since the circulation of chemical cleaning liquids would be impossible or so limited as to render the chemical cleaning less effective.
- ✓ Corrosion or equipment damage during chemical cleaning is generally low, but severe damage can occur if improper procedures are applied or unskilled personnel are employed in the application process.

1.4 MECHANICAL SCALE REMOVAL PROCESS

This investigation has been focused on the implemented methodologies on the categorized in-pipe robots for performing in-pipe cleaning and inspection tasks. Moreover, this work has been concentrated on review of various sensors used in robots to perform in-pipes inspection operation for determining flaws/cracks, corrosion affected areas, blocks and coated paint thickness. Various actuators like dc motors, servo motors, pneumatic operated and hydraulic operated are discussed in this review analysis to control the motion of various mechanical components of the robot.

1.5 PROBLEM DEFNITION

Develop a mechanism that continuously removal slugged-pipe System in a single shot. This developed system must be self-propelled and carrying sludge removal mechanism it should be characterized with breaking and recovery arrangement in case of system or functional failure. It serves fluid supply to the system from the external source. The range of the pipes system length and dimensional variation and bend in the pipe system to be considered according so as the size and specification of the device to be finalized

1.6 AIM &SCOPE OF PROJECT

To determine the removal operation of scale by using of drone with high pressure water jet method and calculate the kinematic design and kinematic analysis of robot drone.

Nowadays, the vast majority of the scale removal in power plant is performed manually by qualified operators. The process is subjective and the operators need to face very uncomfortable and even dangerous conditions. Robotic technologies can overcome many of these disadvantages and provide quality scale removal with reduced manpower and effective costs

II. LITERATURE REVIEW

2.1 OVERVIEW

Lot of work has been done on the pipe cleaning robot up to now. Many types of robots had been invented. In this a lot of literature study is done to understand the mechanism of various types of in-pipe robots.

Literature work is also done on various sensors that are used for inspection of in-pipe environment for detecting the flaws in the pipe.

2.2 EXPERIMENTAL INVESTIGATION

Se-gonRoh et al [1] presented a comprehensive work for moving inside underground urban gas pipelines with a miniature differential-drive in-pipe robot, called the Multifunctional Robot for IN-pipe inspection (MRINSPECT) IV. MRINSPECT IV has been developed for the inspection of urban gas pipelines with a nominal 4-in inside diameter. The mechanism for steering with differential-drive wheels, arranged three-dimensionally, allows it to easily adapt to most of the existing configurations of pipelines, as well as providing excellent mobility during navigation.

Balaguer. C et al [2] Revealed that wheeled type in-pipe robots is very simple in design. They will appear just like a regular robot. They can only use for pipes with horizontal sections. The main problem with this type of robots is that they can't give enough support to the robot structure while the robot is in motion inside the pipe line. Enough support can be provided to the body by maintaining more wheel track. It represents a typical wheeled type in-pipe robot for inspection purpose.

Li. Z et al [3] envisages that wall pressed typeis very useful for the locomotion in the vertical pipes. This type of robot contains flexible links that can provide sufficient amount of force which will help the body to move in vertical pipes without slipping. It represents a typical wall pressed type in-pipe robot for inspection & cleaning purpose.

Landsberger [4]Itis rarely used in the industries due to its mechanical complexity. Its design is very sophisticated so it can't be used in all the time unless the situation demands. It represents a typical walking type in-pipe robot for inspection & cleaning purpose

Virgala. I et al [5] envisages Inchworm type in-pipe robots are very rarely used for pipes with long distances. They are preferred using the pipes with small diameters of range in millimeters. It represents a typical inchworm type in-pipe robot for inspection & cleaning purpose.

Canavese et al [6,7]It is very famous for inspecting pipes with large diameters. It is one of the most commonly used pipe cleaning robot when there is a good amount of flow in the pipeline. By making small changes like adding a propeller, the motion of the robot can be controlled.

AtulGargade et al [8] revealed Modelling and Analysis of Pipe Inspection Robotare used to remove human being from laborious and dangerous work. It consists of a fore leg system, a rear leg system and a body. The fore and rear leg systems are constructed by using three worm gear system that are arranged at an angle of 120 degrees with respect to each other to operate inside a pipe of different diameters.

T. Tamilarasia et al [9]Revealed design and Development of Pipeline Cleaning Robotdeveloped an autonomous robot which travels inside the pipeline and cleans it & it makes the cleaning process faster and also it can cover even small areas which are in accessible by humans. The only limitation with this system is, we have to insert the machine into the pipe and start it and take it out after cleaning at the finish point. Also to clean the robot regularly for achieving long life of the robot.

The Versatrax series robot [10] provides wide range of applications, including inspecting many miles of a sewer pipe, searching for survivors after a natural disaster, removing dangerous materials safely, completing assigned task in hazardous environments, etc. The Versatrax robot is applicable either in various diameters of round pipe or flat surface operation. The main camera can be lowered to carry out the navigation in tight spaces or can be raised upright to gain a 360-degree viewing. High output LED lights are mounted on both front and rear of the robot to provide high visibility in low light environments.

2.3 SUMMARY

From the literature survey it is evidence that very less work has been reported on pipe cleaning robot and automatic adjustment are done, based on that cleaning robot with individual motor propulsion system and automatic adjustment of size reduction are done. Hence the experimentation is done on above said combination process of pipe cleaning and automatic size adjustment system are done for the range of 180mm to 250mm diameter pipe.

2.4 OBJECTIVE OF PROPOSED WORK

- ✓ The Vehicle system concept is development on Driving system, Breaking system and Size reduction system.
- ✓ The Structural design and functional analysis of the drone are design by 3D modelling.
- ✓ Failure modes and kinematic data (design and analysis) are also calculated.

Consideration of failure modes of drone are based on the matrix diagram and Pugh chart table.

III. EXPERIMENTAL PROCEDURE AND METHODOLOGY

The existing way of scale removal process like mechanical method, chemical method is tedious and the time taking process. Hence there is a need to overcome the above issues the proposed method introduces the robot which is an automatic or semi-automatic way of scale removal technique to improve the cleaning efficiency.

3.1 FUNCTIONAL LAYOUT OF ROBOT PROCESS

The Relationship between the various components and their functions have been represented in the below functional layout (FIG 2). Its helps in understanding the different elements and their attributes for designing a new drone.

Figure 2: Functional Chart

3.2 DRONE DESIGNPROCESS

There are following phases which need to be considered while designing a drone:

A) ProblemDescription

The first thing in designing a drone is identification of the purpose for which it has to be built along with specifying requirements. In this case, the task is to provide access to confined inaccessible and hazardous places inside the power plant duct system. It implies that there should be an environment sensing and real time reporting system on board on the drone along with on board power supply for movement, sensing and transmission system. It should be compact in size and low weight as it has to move in various ducts and narrow cavities in plant

B) ProposedDesign

In this phase, it is required to specify details that the proposed design should have. The proposed design should have following details:

- ✓ How the drone will move in theenvironment?
- ✓ What are its power requirements?
- ✓ What type of sensors is used?
- ✓ How it is controlled?

C) Drone Fabrication

It is proposed to use CAD for designing mechanical designs of drone. It is designed to move forward, right, left and reverse direction. The controller, Nozzle and Water jet cleaner are attached to the robotic front are processed locally.

D) Robot Programming

Following the fabrication stage, it is required to program the microcontroller in ‘C’ language. The programming also involves the design of interface.

E) Control Logic

The main function of microcontroller is to control the movement of drone in all directions. For making it to move in a particular direction, the 'ON' logic will be given to the wheels that push the carrier to move in that specific direction.

F) Power Scheme

The drone would be operated by using carrier mounted two rechargeable batteries. Two 6 V batteries are connected in series to supply 12 V to DC motors driving the wheels. 12V supply is converted to 5V (for circuitry) voltage regulator.

G) Operator Control

Remote operation enables an operator to sense and manipulate an object from remote locations. This is an essentially useful feature where the operator has to work around in hostile environments or confined spaces where human access is difficult or not possible. The control strategy of the proposed drone is based on the theme that the operator will operate and control it remotely. There would be a GUI, providing interface between the robot, and the human operator. Thus, the operator will act as a supervisor, and will give instructions to the drone by using the user interface.

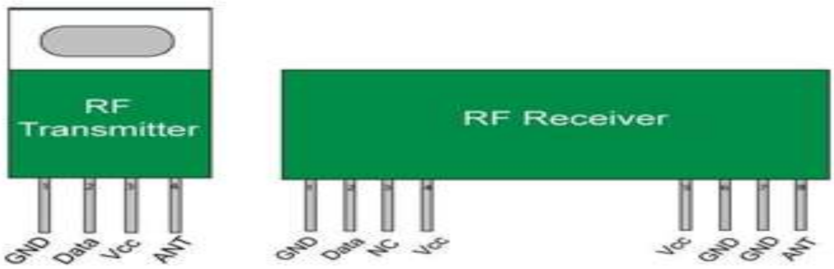

Figure 3:Operator control

E) Testing

Testing is the most crucial phase. A mock up would be developed to test drone before deployment.

F) Evaluation

Evaluation includes testing and verifying the design specifications by the client or user. It is planned to use it by clients at auxiliary building areas outside the power plants first, and then in the actual field areas

3.3 MODULAR DESIGN OF THE CLEANING SYSTEM

The proposed model for the cleaning process has to be done by the design procedure.

3.4 MODULE 1- PROPELLER TYPE

A propeller is a type of fan that transmits power by converting rotational motion into thrust. Different propulsion systems develop thrust in different ways, but all thrust is generated through some application of Newton's third law of motion. For every action there is an equal and opposite reaction. In any propulsion system, a working fluid is accelerated by the system and the reaction to this acceleration produces a force on the system. A general derivation of the thrust equation shows that the amount of thrust generated depends on the mass flow and the change in velocity through propulsion system.

3.4.1 PROPELLER DESIGN

Figure – 4 Propeller Drive

3.4.2 FAILURE MODE OF PROPELLER SYSTEM

- ✓ It is expensive system.
- ✓ It has lesser efficiency compare to other systems.
- ✓ It is complex system due to more equipment.
- ✓ It has low breaking effect.
- ✓ Recovery is complicated.
- ✓ Size of the system is to be adjusted for each pipe diameter

3.5 METHOD 2 - NOZZLE PROPELLSION TYPE

A propelling nozzle converts a gas turbine or water generator into a jet engine. Energy available in the turbine exhaust is converted into a high speed propelling jet by the nozzle. Propelling nozzles accelerate the available fluid to subsonic, transonic, or supersonic velocities depending on the power setting of the engine, their internal shape and the pressures at entry to nozzle and exit from the nozzle. The internal shape may be convergent or convergent-divergent (C-D). C-D nozzles can accelerate the jet to supersonic velocities within the divergent section, whereas a convergent nozzle cannot accelerate the jet beyond sonic speed.Propelling nozzles may have a fixed geometry, or they may have variable geometry to give different exit areas to control the operation. Nozzles for supersonic flight speeds, at which high nozzle pressure ratios are generated, also have variable area divergent sections.

3.5.1 NOZZLE DESIGN

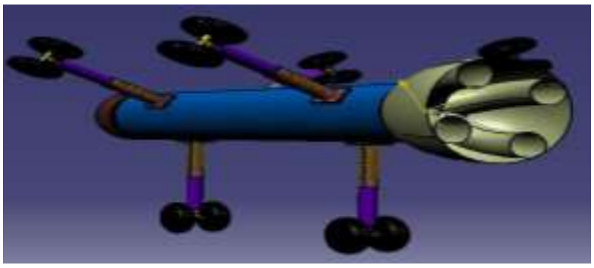

Figure: 5 Nozzle Drive

3.5.2 FAILURE MODES NOZZLE SYSTEM

- ✓ It is expensive system.
- ✓ It is complex system due to more equipment's.
- ✓ It has low breaking effect.
- ✓ Water usage is higher than other methods.
- ✓ Recovery is complicated.
- ✓ Turning on the pipe line system will be complicated.
- ✓ Need of high pressure control valves.

3.6 MODULE 3 - INDVIDUAL MOTORIZED PROPELSION TYPE

Electric propulsion is a technology aimed at achieving thrust with high exhaust velocities, which results in a reduction in the amount of propellant required for a given space mission or application compared to other conventional propulsion methods. Reduced propellant mass can significantly decrease the launch mass of a spacecraft or satellite, leading to lower costs from the use of smaller launch vehicles to deliver a desired mass into a given orbit or to a deep-space target.

3.6.1 MOTORIZED DESIGN

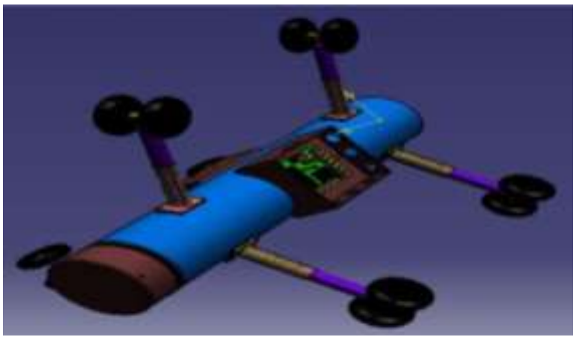

Figure – 6 Motorized Drive

3.6.2.1 CHARATERSTICE OF MOTORIZED SYSTEM

- ✓ Propulsion system can be controlled easily by using of Ac electrical drive or Dc electrical drive control system.
- ✓ It has High breaking effect by using of separate motor for individual wheel.
- ✓ It is simple system due to Less equipment.
- ✓ No Need of high pressure control valves and high expensive system.
- ✓ Turning on the pipe line system will be simple.
- ✓ Recovery will be less complicated

3.7 DESIGN FUNCTIONAL MATRIX

Figure: 7 Functional matrix

3.8 MATRIX DIAGRAM

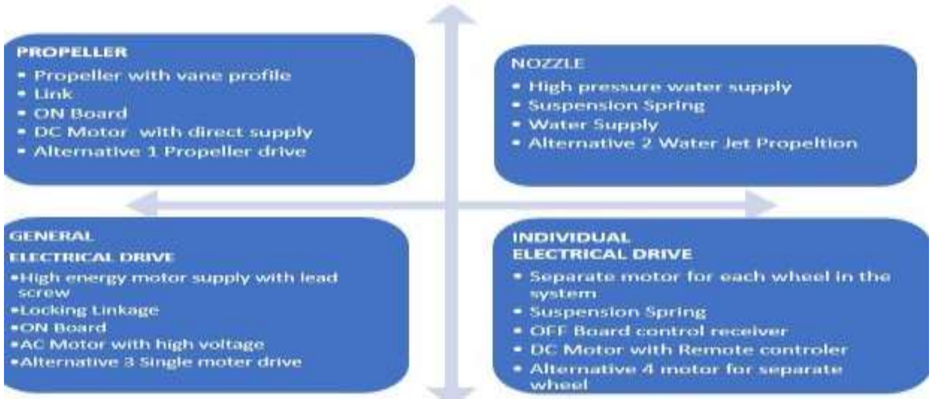

Figure – 8 Matrix diagram

3.9 PUGH CHART

Table 1:Pugh chart

METHODS	CONFIGRATION							
	Rating Scale (0 to 10)	Propulsion system	Recovery of System During Failure	Breaking	Maintenance	Automatic Size Reduction	Sum of positive #s	Average
WALKING TYPE	0 to 10	05	0	07	03	05	04	X
WHEEL TYPE	0 to 10	05	0	03	04	03	03	X X
CATTERPILLER TYPE	0 to 10	07	03	05	04	06	05	✓
WORM TYPE	0 to 10	0	0	03	06	02	02	X X
WALL PRESSED TYPE	0 to 10	03	06	03	04	05	05	✓
INCH TYPE	0 to 10	03	04	06	04	05	05	✓
PIG TYPE	0 to 10	05	04	060	06	0	03	✓
PROPELLER	0 to 10	06	05	06	07	05	06	✓
NOZZLE	0 to 10	0	02	05	05	07	04	X
INDVIDUAL MOTERIZED	0 to 10	06	04	06	07	08	08	✓✓

(Notes: X-Complicated, X X-Difficulty, ✓- Average, ✓✓-Better)

In this chart previous method are configured and compare with new method design, by this Pugh chart propulsion system, recovery of system during, breaking, cleaning efficient, automatic size reduction are considering in the chart

3.9.1 SELECTION OF METHODS

From the above chart we are decided to use the Method 3 system or Individual Motorized system for cleaning the pipe line. Because compares with all the previous method based on that comparison Electric type propulsion system is better than other method. In this method propulsion is average, Recovery system is complicated, Automatic size during the operation is better and Cleaning is more effective than other methods.

3.10 MOTORIZED PROPELSION SYSTEM

Electric propulsion is a technology aimed at achieving thrust with high exhaust velocities, which results in a reduction in the amount of propellant required for a given space mission or application compared to other conventional propulsion methods. Reduced propellant mass can significantly decrease the launch mass of a spacecraft or satellite, leading to lower costs from the use of smaller launch vehicles to deliver a desired mass into a given orbit or to a deep-space target

3.10.1 DESIGN

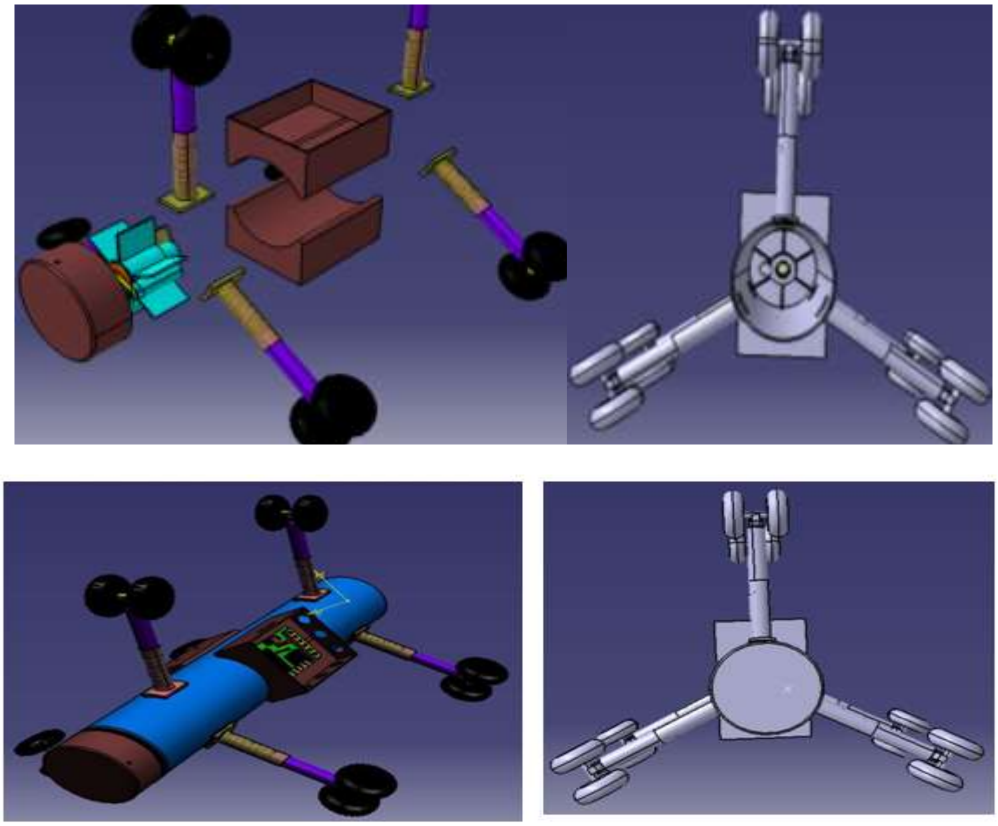

Figure 9 Interior design, Back view design, Exterior design, Front View design

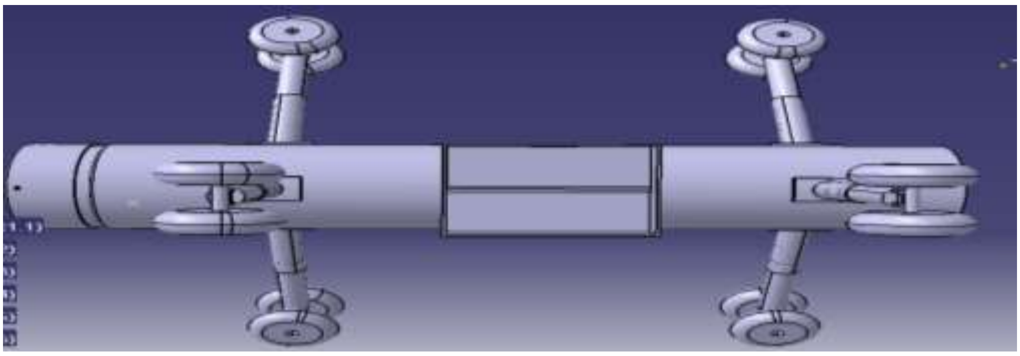

Figure 10: Top View design

3.10.2 CONTROLLER

Controller is the major component in any control circuit. It is like brain of the body. The main concern in design is to provide a very simple controller. There are many types of controllers in the market but according to our need it should be compatible to all the components. When we are going to write the code for controlling the robot, it supposed to be easy. Hence decided to use the arduino mega 2560 controller for the in-pipe robot.

The control is very being to handle. There are predefined slots for power supply, PWM, etc. so it will be very easy for us to make connection with the remaining components. The size of the controller is also very small and it can easily accommodate large number of devices. Coming to the coding part, it is open source to everyone. One can go through the site and can get the code. What we have to do is to make modification in the code according to our needs

3.10.3 DC MOTOR

The motor is one of the major components in the control circuit. It is used to provide both transmission and cleaning. For performing the tasks, it has to provide high amount torque. Since we require very high torque there is need to use a geared motor with low RPM. For this we are using a 400 RPM geared motor. The motor is tested and is giving very good amount of torque. It can able provide cleaning and transmission.

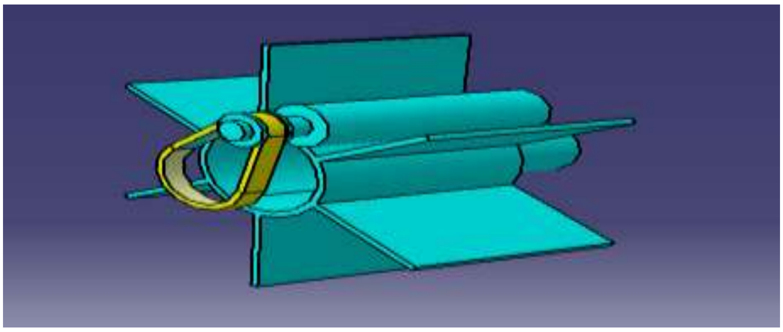

Figure 11: Dc-Drive motor

3.10.4 MOTOR DRIVE

Motor driver play a prominent role in controlling the DC motor. The motor driver helps in changing the direction of rotation of the DC motor. The driver is going to receive the signals from controller. According to control signal the driver is going to change direction of rotation. There will be H-Bridge in the motor driver which is making the task possible. The working principle of the H-bridge is very simple. The construction is showed below. The direction of rotation of the motor depends on the flow of current in the motor. The motor driver is the main component that changes the flow of current according to the control signal.

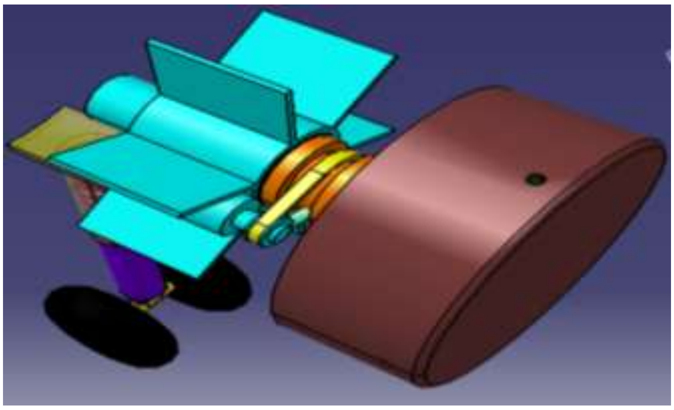

Figure 12 Motor drive

3.10.5 PULLEY

A pulley is a wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable or belt, or transfer of power between the shaft and cable or belt. In the case of a pulley supported by a frame or shell that does not transfer power to a shaft, but is used to guide the cable or exert a force, the supporting shell is called a block, and the pulley may be called a sheave.

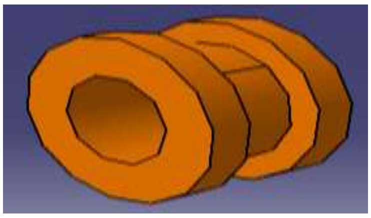

Figure 13 Pulley

3.10.6 POTENTIOMETER

Speed is another important parameter in the in-pipe robot. The speed has to be controlled in order to achieve better cleaning and locomotion. It depends on the speed of rotation of the DC motor. So we have to control the speed of the motor in order to control the speed of robot transmission and cleaning. To control the speed, we are using the potentiometer in our control circuit. The potentiometer is going to vary the resistance in the circuit. When there is change in resistance, according to that the amount of voltage or current changes. Depending upon the amount of current flow in the motor the speed of rotation will vary

3.10.7 SUSPENSION SYSTEM

Figure 14 Suspension system & spring indexing

Suspension is the system of tires, tire air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems must support both road holding/handling and ride quality, which are at odds with each other. The tuning of suspensions involves finding the right compromise.

It is important for the suspension to keep the road wheel in contact with the road surface as much as possible, because all the road or ground forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear.

3.10.8 WHEELS

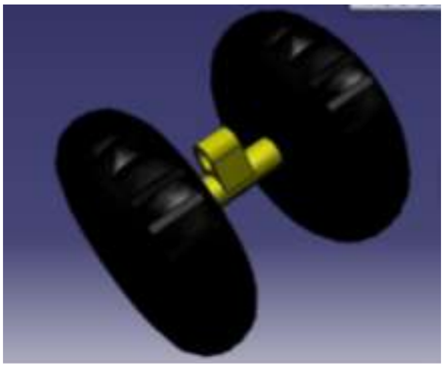

Figure 15 Wheels

Six wheels are required, two for each arm to support the drone. The wheels where machined from a Nylon shaft of 70mm Outer diameter. The wheels are 12mm thick and are strong enough to support the entire drone.

3.10.9 TUBECASING

The tube is also made of stainless steel grade 304 for its corrosion resistance property. The thickness is 3mm for its entire 400mm length. Three smaller links are used to fasten each of the three arms with this tube.

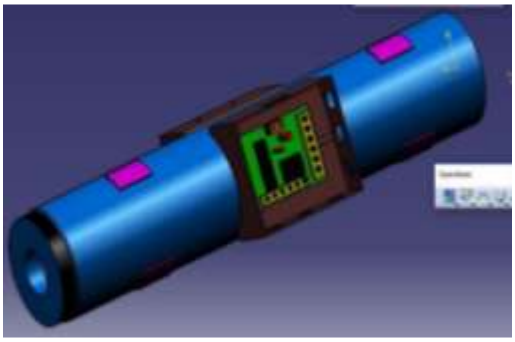

Figure 16 Tube casing

3.10.10 ELECTRICAL DRIVING PULLEY

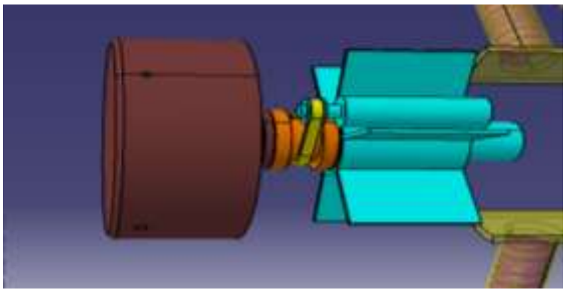

Figure-17 Electric driving belt and pulley

A belt is a loop of flexible material used to link two or more rotating shafts mechanically, most often parallel. Belts may be used as a source of motion, to transmit power efficiently or to track relativemovement. Belts are looped over pulleys and may have a twist between the pulleys, and the shafts need not be parallel.

3.10 SUMILATION

The act of simulating requires that a model to be developed, this model represents the key characteristics, behaviours and functions of the selected physical or abstract system or process. The model of the design represents the system itself, whereas the simulation of design represents the operation of the system itself. So that the developed design models are converted into 3D video simulation by using CATIA V5 and it clearly represents the detail of interior functions of the robot, it also defines Rendering service of approximations and assumptions to the model drone system.

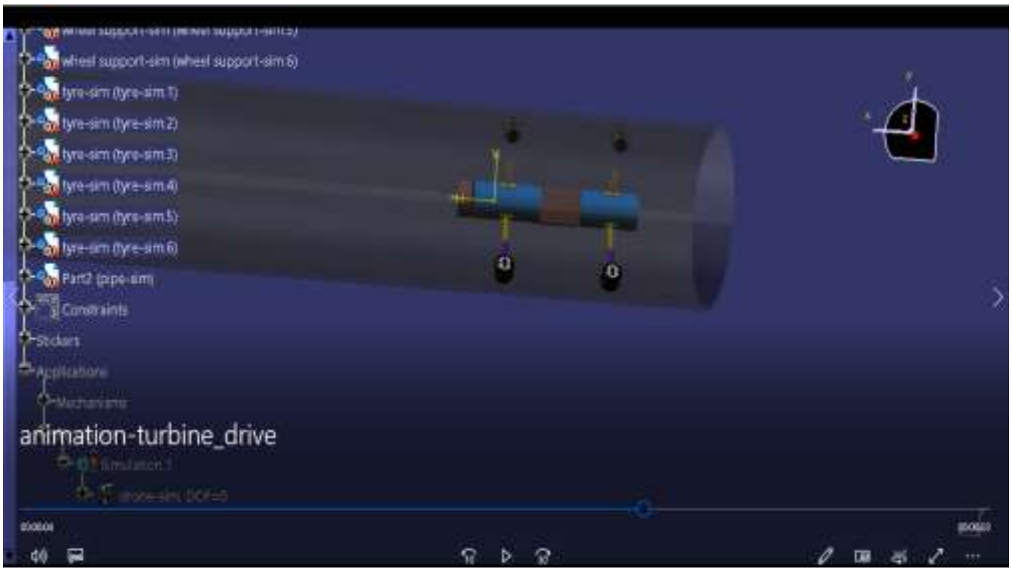

Figure 18 simulation at various stages

IV. KINEMATIC DESIGN AND ANALYSIS

4.1 PARAMETER OF DRONE

For designing the drone, the average parameter is required to calculate the specification and actual dimension. This parameter is considering from above 3D design module. The specified parameters are given below.

Table – 4.1 Parameter table

S.no	PARAMETER	VALUES
1	Length (3/4 of max dia of pipe)	187.5mm
2	Diameter (max)	250mm
3	Diameter (min)	180mm
4	Weight	2000g
5	Power supply	12v
6	Speed	400 rpm
7	Wheels	6 cm Diameter
8	Body frame work	SS Plate

4.2 KINEMATIC DESIGN

A. Size reduction

In this design the drone can able to adjust automatically for the requirement of size reduction. The drone system is consisting of pipe chasing, suspension system, and arm wheel. Pipe chasing is connected to the suspension system and arm wheel. Suspension system and arm wheel are placed on 120° to each other. It helps to carry the weight on the central axis and also has dynamic breaking. By maintaining the weight on the central axis reactive force and breaking system force are calculated.For this auto reduction process the mono suspension system is used. By using the mono suspension system, the drone can easily move along the various dimension in pipe without any emulation. From the above diagram the outer diameter is refereed larger diameter and the inner diameter is known as smaller diameter. During the size reduction the suspension system will reduces length of the arm wheel and it is compressed along with requirement size, move on the adjusting dimension of the pipe. Torque are produced on the wheel by using of individual motorized system, to move the vehicle in forward direction. This motor is connected to every wheel on the system to produce high torque. By using the torque, the drag force of drone can be calculated.

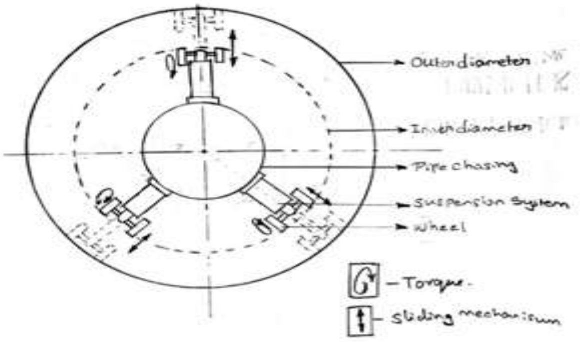

Figure 19 Size reduction

B. Bending in pipeline

In the pipe cleaning system one of the major difficulty of design is bending in pipeline. For that in this system is consist of mono suspension system for every side of wheel. This system helps to move the drone on the bend pipe-line without any haste. In the pipe bending process bend radius, setback length, bend allowance and mold point are considered and calculated. From the fig 20 bending process expounded which is based on sizing and suspension system. Bend allowance is extensive of all the consideration. In the bend allowance the average range of the pipe chasing being calculated. The minimum average of the pipe chasing is based on half ½ of the pipe line diameter and the maximum average of pipe chasing is based on three by fourth ¾ of the pipe line dimension. Due to this average of pipe chasing of the drone the bending in pipe line will become evident.

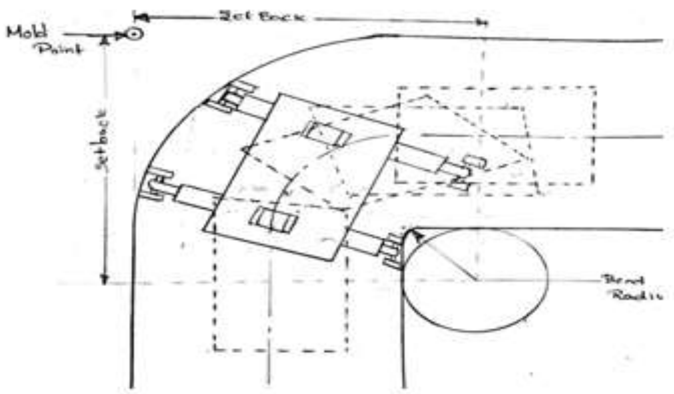

Figure 20 Bending in pipe

4.3 KINEMATIC ANALYSIS

4.3.1 Free Body Diagram

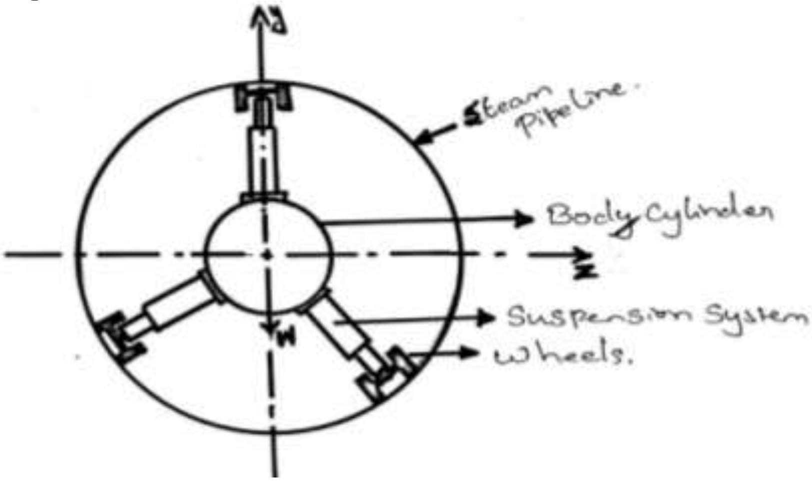

Figure 21 Free body diagram

Free body diagram is about the calculating the relevant force of the robot design system and also calculating the design aspects of drone.

A. Force of water jet to remove scale

Upper Venturimeter Thickness t = 2.2mm

Downstream venturimet Thickness t = 2.0

Venturi throat Thickness t = 2.4

 So that the average thickness = 2mm

Pipe diameter = 250mm

r_1 = 125mm

$A1 = 2\pi r_1^2$

$A_1 = 98174.770mm^2$

For diameter area of scale formation is

$A_2 = 2\pi r_2^2$

$r_2 = (r_1 - t)$

$A_2 = 2\times\pi\times123^2$

$A_2 = 95058.310\ mm^2$

Shear stress $\tau = \frac{F}{A}$

Assume that shear stress of scale formation is 1180 N/m

So, 1180 = F / 95.058

F = 1180 x 95.058

F = 112168.44 N

F = 112.168 KN

B. Drag force

$F_d = 0.5\ c\ \rho\ A\ v^2$

Let take the value,

$\rho = 998.2\ kg/\ m^3$

coefficient = 1.05

Area of pipe = 98.747 m

Velocity = 1.5 m/s

$F = 0.5 \times 1.05 \times 98.747 \times (1.5^2)$

F = 115 .76 KN

C. **Total Reactive Force**

$\sum H = F_1 \cos ø + F_2 \cos ø$

$=19.62 \cos60°+19.62 \cos60°$

$\sum H=0$

$\sum V= -F_1 \sin ø - F_2 \sin ø$

$= -19.62 \sin60° - F\sin60°$

$= -33.98$ N

$R = \sqrt{((\sum H)^2 + (\sum V)^2)}$

$= \sqrt{((0)^2+(-33.98)^2)}$

$= \sqrt{0+1154.6} = \sqrt{+1154.6}$

R =33.9 N

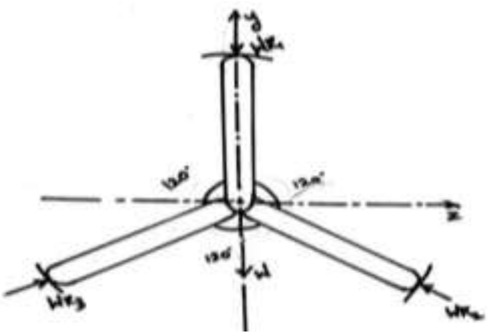

Figure 21 Reactive force diagram

D. Breaking System

BF = M* a* g

M = mass of the vehical (kg)

a_d = decelaration (g units)

g_a = acceleration due to gravity

$a = \frac{(v_{i-} v_f)}{t}$

v_i= initial velocity, v_f = final velocity, t = time

$v_i = \frac{2\pi N}{60}$, N = 400 rpm

V_i = 41.88

a_d= 8.376

g_a= a* g

$a = \frac{f}{m}$ = 5.70 = 5.70 x 9.81 = 55.917

B_f = 2 x 5.70 x 55.917

B_f = 936.72

Therefore the breaking force is larger than the relevant forces
So, that the value is safe for breaking system.

E. Design of Motor Shaft

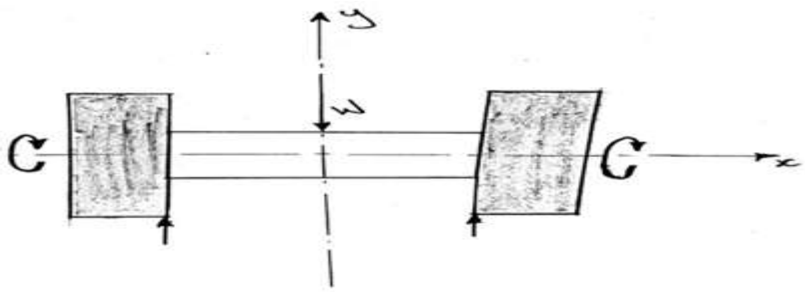

Figure 22 Motor shaft

i. Bending moment

P=2kg =2 x g =19.62N

L=30mm

D=6mm

R_B×30=19.62×15

R_B=9.81N

$R_{A+}R_B$ = 19.62

R_A=19.62-9.81

R_A=9.81N

BM at A=0

BM at C= $R_{A\times}$15

=147.15Nmm

BM at B=9.62

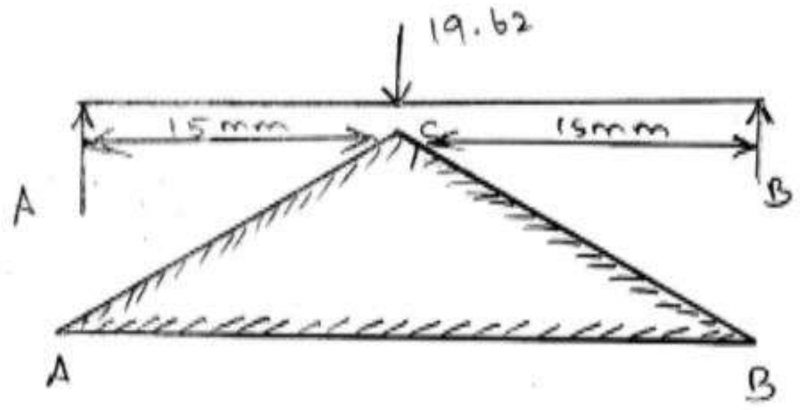

Figure 23 Bending moment diagram

D=6mm, L=30mm, W=19.62N

Max.BM=(W×L)/4=19.62×30/4

M=147.15Nmm

ii. Moment of inertia for solid pipe shaft

$I=3.14/64D^4$

$I=63.58mm^4$

$M/I = \sigma/y$

Y_{max}= D/2 = 6/2= 3mm

$\sigma_{max} = (M / I)\ y_{max}$

= (147.15/63.58) x 3

$\sigma_{max} = 6.943.N/mm^2$

Max shear Stress

$\tau_{max} = 4/3 \times \tau_{avg}$

τ_{avg} = shear force / area of circular section

F = 19.62 N

$= 19.62 / 3.14 \times (3^2)$

$\tau_{avg} = 0.694\ N/mm^2$

$\tau_{max} = 4/3 \times 0.694$

$\tau_{max} = 0.925\ N/mm^2$

iii. Selection of Shaft

Step I: Material selection & Calculation of motor shaftMaterial: C_{45}

We know that diameter of shaft can be calculated by using following formula,

$$d^3 = \frac{16}{\pi \times \tau_{max}} \sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$

where,

$[M_t]$ = twisting moment $[M_t]$ = 0.1574 N-m

$[M_b]$ = bending moment $[M_b]$ = 1.8533 N-m

K_t = torsional factor = 1.5 & K_b = bending stress factor = 2

Now for C_{45} shaft material, σ_{ut} = yield stress = 353 N/mm²

$\tau = 0.5\ \sigma_{ut}$

$\tau = 176.5\ N/mm^2$

Let's take FOS = 1.5

$[\tau_{max}] = \tau/1.5$

$[\tau_{max}] = 176.5/1.5$

$[\tau_{max}]_{design} = 117.6667\ N/mm^2$

$= 117.6667 \times 10^6\ N/m^2$

Diameter of motor shaft is,

$$d^3 = \frac{16}{\pi \times 117.667 \times 10^6} \sqrt{(2 \times 1.8533)^2 + (1.5 \times 0.1574)^2}$$

d = 0.005438 m = 5.438 mm ≈ 6 mm

Select a motor of shaft of 30 mm length and 6 mm diameter.

Step II:Checking for bending stress of shaft

Design shear stress is given by formulae,

$$[\sigma_d] = \frac{32\ [M_b]}{\pi d^3}$$

Where,

d = diameter of shaft (mm)

M_b = bending moment (N-mm)

$$[\sigma_d] = \frac{32\ [1.8533 \times 10^6]}{\pi \times 6^3}$$

$[\sigma_d] = 87.4404\ N/mm^2 < 117.6667\ N/mm^2$ …….. hence design is safe.

F. Selection of motor

Let, Total load on robot = 47.5N

∴ Power required to robot to carry weight of 47.5 N with

v = 0.1388 m/s speed is,

P = W × v

= 47.5 × 0.1388

P = 6.593 watts.

∴ In worst case if only one motor is working then it has to give total power.

Power required to two DC motors to drive the robot is,

$P_{required}$ = 2 × 6.593

$P_{required}$ = 13.188 watts

If a motor of 12v & 1 amp current is selected then power provided by two motors is,
$P_{provided}$ = 19.2 watts
here, $P_{provided} > P_{required}$……hence ok.
So, select two DC motors of 12v, 1 amp current & 400rpm each.

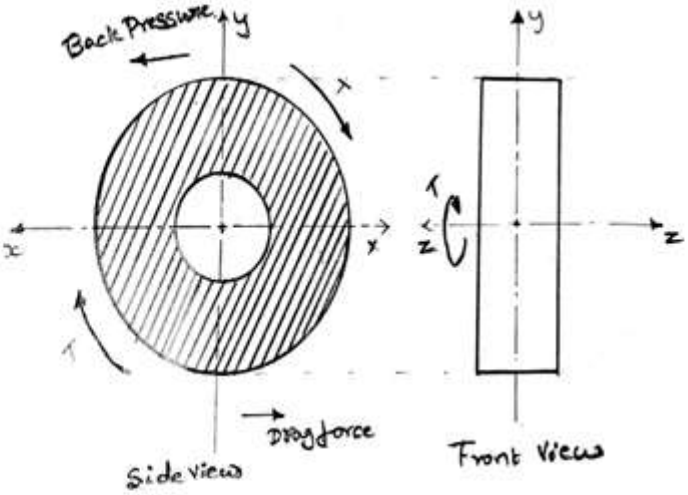

Figure 24 Motor rotation

G. Design of spring

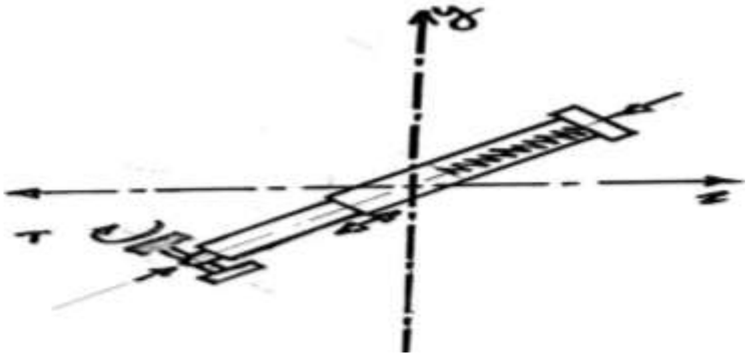

Figure 25 Spring

Step I: Material Selection & Calculation of spring stiffnessMaterial: stainless steel wire for normal corrosion resistance
Type: Ground end
Maximum elongation of spring is given as,

$\delta L = L_2 - L$

$= 98.7368 - 75.4718$

δL = 23.265 mm
Spring force calculation:
In vertical case, total load acting on robot is additional sum of weight of robot and frictional force i.e. 47.5N
we have to design a spring which will hold the load of 47.5N
Design the spring for 40 N force.
Calculation of spring stiffness (K):

$$\text{Spring stiffness} = \frac{\text{Spring force}}{\text{maximum elongation of spring}}$$

$$K = \frac{40}{23.265}$$

K = 1.7193 N/mm

Step II: Spring Proportions
Calculation of spring wire diameter (d):

here, spring wire diameter and mean diameter are unknown.
for (2.10-4.50) mm wire diameter and average service Design stress is,
τ = 48.5 kgf/mm^2
τ = 485 N/mm^2
but, shear stress in spring is given by formulae,
$\tau = \frac{8 \cdot F \cdot D \cdot k}{\pi d^2}$

$$485 = \frac{8x\ 40\ x\ 6\ x\ 1.2525}{\pi d^2}$$

d = 1.2566 mm
But, above calculated „d" is not fitting in (2.10-4.50) mm diameter range.
∴ d = 1.2566 mm is coming in first range i.e. up to 2.10 mm
∴ shear stress up to 2.10 mm diameter is,
τ = 52.7 kgf/mm^2
τ = 527 N/mm^2

τ = 527000000 N/m^2 we know that,

$\tau = \frac{8 \cdot F \cdot D \cdot k}{\pi d^2}$

$$527 = \frac{8x\ 40\ x\ 6\ x\ 1.2525}{\pi d^2}$$

d = 1.4532 mm < 2.10mm …… hence safe.
Pitch or mean diameter of spring,
Spring index C = 6
D = 8.7194 mm
Calculation of no. of turns and angular deflection,
Spring force „F" is given by eq^n, $F = \frac{y\ G\ d^4}{8D^2 i}$
where,
y = axil deflection of spring (mm)
G = Modulus of rigidity (N/mm^2)

G = 81370 N/mm^2

$$40 = \frac{23.265\ x\ 81370\ x\ (1.4532)^4}{8(8.7194)^2 i}$$

i = 39.7999 ≈ 40 turns

for ground end spring type, Solid length = i × d
Free length = i × p where,
p = pitch (mm) Solid length
= 40 × 1.4532
= 57.8341 mm

75.4758 = 40 × p

p = 1.8868 mmF
Angular deflection (θ), $\theta = \frac{16\ F\ D\ L}{\pi\ G\ d^4}$
$= \frac{16\ x\ 40\ x\ 8.7194\ x\ 75.47}{\pi\ x\ 81370\ x\ (1.4532)^4}$
θ = 0.3696 degree

V. RESULT &CONCLUSION

Three various different models for the robot were designed by using the Software CATIA V5, they are
- ✓ PROPELLER TYPE PROPULSION SYSTEM
- ✓ NOZZLE JET PROPULSION SYSTEM
- ✓ INDIVUDUAL MOTORIZED PROPULSION SYSTEM

According to the detailed review process, Pugh Chart given at table No: 3.1 reveals that individual motorized method having dominant features among three methods.
Consequently, individual motorized propulsion type is the feasible one while comparing to other two types. It has more consolation of moving in bend pipes and automatic size reduction.
Using a free body diagram a detailed calculation were computed and all the relevant forces, stress, and design aspects are found and verified.

They are**,**

Breaking Force = 936.72 N
Drag Force = 115.76 KN

Reactive force = 33.9 N

Virtual video has been simulated by using the software CATIA V5, this help in understanding the clear functional view and operation sequence of the proposed model.

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