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Design and Fabrication of Pipe Inspection Robot

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Abstract: Piping is very vital equipment in most of the industries. Especially, in oil and natural gas industry pipe and thereby, its inspection and maintenance for its proper working is very important. But inspection of pipe is a difficult task due to various complicated joints and sudden change in its cross-sectional area. Ultrasonic testing is widely used for this purpose and it is a costly affair. But, pipe inspection robot is different in its features and construction. It has very simple, compact, lightweight designed body. It is powered by battery and driven by motor. Rolling mode, screw driving mode, steering mode makes the robot to propel in a pipe precisely and smoothly.

Its light weight make the robot very portable and it can be used by unskilled operator as well. Apart from inspection, the robot is itself a platform for mounting of various sensors to increase its utility as per requirement and can also be used for cleaning of internal surface of a pipe.

Keywords: Ultrasonic testing, rolling mode, screw driving mode, steering mode, battery, motors, sensors.

I. INTRODUCTION

Pipelines are used for the transportation of various fluids in an industry such as water, natural gas etc. But inspection and detection of a flaw is still a difficult task due to various geographical and physical diversities. But, leakage of these fluids may tend to risk to human life and may also leads to fire hazard. Thus, keeping the pipes clean and crack free is very important function for an industry. In-pipe robot is thus the best solution to such issues.

There are various types of in-pipe robot. But, the available verities are complicated and has a lot of problem of friction. Thus the robot designed here is very different from all other types. It has a camera installed in such a way that, it can cover more than a hemisphere, so that an operator can see the defects very easily.

The camera has wifi module, so that it can be operated remotely from smartphones very easily. Lighting is also provided on the body of a robot.

Spring controlled legs helps the robot while navigating through abrupt cross section. Wheels of the front body are attached to wheel holder at an angle which helps the robot for its screw driving mode.

II. LITERATURE SURVEY

A. Adaptable Quad Arm Mechanism

By T. Okada, "to enable the robot to travel in both reduced branch and zero-radius of curvature branch pipes safely without requiring a complicated locomotion strategy, design the wheels to follow the inner configuration of branch pipes by using the normal force between the wheel and the inner wall of pipe. This mechanism is called as the Adaptable Quad Arm Mechanism (AQAM). Using this mechanism, a robot can travel through various branch pipe shapes, simply by changing the direction of rotation of each wheel." [1]

B. Wheel orientation

By M Horodinca, "It is possible to determine α, the angle of travel of the wheels with respect to the x-z plane (plane A). Here, Point A is where the wheel and the inner surface of the pipe meet, plane A is the tangent plane to the inner surface of the pipe at Point A, and Plane B is the extended surface of the wheel. As it is possible to determine the orientation of Plane B by transforming the orientation of x-y plane by the angle μ with respect to the z axis and angle−γ with respect to the transformed y-axis (y′),z″ →, which is the normal vector of Plane B." [2]

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C. Navigation

By Harish J, "One of the strong points of the proposed robot is its ability to travel through various pipe shapes without using a complicated locomotion or control strategies. To make the robot turn into a branched hole, the operator should first orient the robot's body appropriately using the SHM, then rotate wheels 1 and 2 clockwise, and wheels 3 and 4 counter clockwise until wheels 1 and 2 approach the edges of the branch. Next, if the operator rotates four wheels, 2 and 3clockwise and wheels 1 and 4 counter clockwise, the robot will turn into the branch, adapting to its configure. In the case of straight motion in a branch, one can simply continuously operate the wheels of the robot as depicted in, regardless of its orientation. The robot can also successfully navigate elbows by applying different velocities to the wheels." [3]

D. Apparent Diameter

By M. M. Moghaddam, "The diameter of in-pipe robot should be adjusted when it traverses through elbows. Using the geometrical/analytical equations, the minimum required diameter of a resizable cylinder traversing through a curved pipe is calculated, which is a function of the pipeline diameter, curvature radius, curvature angle and length of the robot. The resizable cylinder has only two contact points located at medial longitudinal cross section of the elbow. However, the contact points of the generic in-pipe robot may locate in any other longitudinal sections. Therefore the adjusted diameter is then calculated for all longitudinal cross sections to define the limited area of the elbow."[4]

E. Traversing motion Study

By Taiki Nishimura, "The front unit has three arms. Each arm has a pair of passive angled wheels that are extended by coil springs. When the robot passes through a T-branch, it can redirect its front unit for steering. The maximum steering angle range is ±90 degrees. The middle unit has two arms. At the base of each arm, there is a tension spring. When the robot moves forward, the springs fix these wheels in the traveling direction. The rotation of the middle unit causes the arms to rotate in the circumferential direction against the spring tension. The rear unit has three arms with a pair of passive wheels at the tip of each arm. It 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 a coupling and a universal joint. The universal joint is double unit type and can rotate by ±90 degrees. Therefore, even if the robot bends at a right angle, the driving motor can transmit its power to the front unit."[5]

F. Elbow Turning motion Study

By M. Horodinca, "The robot is designed to be able to traverse elbowed and vertical pipes. This is done in the proposed mechanism with the help of rear spring arms. Thus the rear spring arms are not only useful in negotiating obstacle but also help the robot to pass elbows. An adjusting power screw is proposed to adapt the robot with the interior pipe diameter. Furthermore, the adjusting power screw by contracting tracked units can be useful in passing through an elbow. A camera monitors the elbow and the operator contracts the tracked units by driving the power screw motor."[6]

III. METHODOLOGY

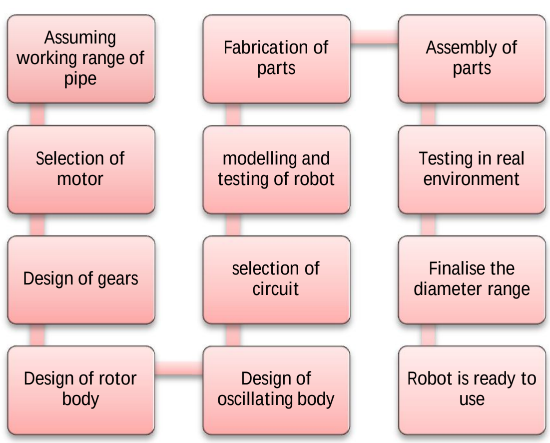

Fig 1. methodology

A. Assuming Pipe Range
The basic and first important step is to decide the range of pipe diameters. By deciding the range we can get an idea of dimension of a body and arms and thereby various components of robot body.

B. Selection Of Motor
After assuming the range the next step is to select the type of motor and the power, speed and torque as per requirement. Based on this the gear design is done.

C. Design of gears
After selecting power and torque requirement the next step is to design a gear. There is a set of internal and one external gear. The external gear is mounted on the shaft of a motor and meshed with the internal gear which is designed in such a way that it is rigidly connected to the rotor, so that the rotor will rotate as per design.

D. Design of rotor body
Body design is most important part of a robot design. Because, it will be the key factor for deciding the operating range of pipeline. Thereby the arm length and type of spring will be decided.

E. Design of oscillating body
After designing the stator and rotor the oscillating body and its integral are designed. This design will be the most difficult and key element of the robot design. Because, the design will decide the angle of oscillation of a robot and thereby its utility is decided.

F. Selection of circuit
The selection of circuit will be governed under the economic criteria and the budget available. Because, there are various circuits available but, they are all costly and programming of these circuit is also difficult. Thus, the most economical and simple circuiting will be chose.

G. Modelling and testing of robot
Modelling and testing of robot is very important as this will tell the designer weather the robot will sustain various forces or not. Similarly, it will give the brief idea of the actual working of a robot.

H. Fabrication and Procurement of Parts
Next fabricate the part by various processes as per requirement. But, some parts like springs and wheels will be procured directly from the market as per design specification mating with the standard parts.

I. Assembly of Parts and Testing
Parts are assembled properly without fail. Then, the testing in real environment and as per the objectives will be done. Try to achieve as much as objective as possible.

J. Finalize the Range
After everything is done give the exact range of operating diameters.

IV. OPERATING MODES

A. Screw Driving Mode
In this mode, the robot can move forward or backward; the movement is powered by the driving motor in the rear unit. The power of the driving motor is transmitted to the coupling, universal joint, and front unit. The front unit with its legs rotates and generates the locomotive force that the robot needs to navigate through pipes using the inclined passive wheels. Simultaneously, the central and rear units act as stators, because they cannot rotate due to the large lateral forces between the wheels and the inner surface of the pipe.

B. *Steering Mode*

This mode is used in T-branches or elbow pipes that have a short radius of curvature. The power is transmitted from the steering motor to spiral mitre gear 2.If the steering motor rotates and the arms of the middle unit maintain their position due to friction, the front unit will steer. The angular velocity of the front unit for steering Ws is calculated by-

Ws = r*Wc*(Zb/Za)

Where, Wc, Za and Zb denote the angular velocity of the steering motor, number of pinion teeth, and number of spur gear teeth, respectively.

C. *Rolling mode*

In this mode, the robot can change the direction of navigation in pipes when it cannot steer, e.g. in straight pipes or in the top part of a "T" in the T-branches. Although the power of the steering motor is also transmitted to the spiral mitre gears in the steering mode, the wall prevents the front unit from steering. Therefore, the entire middle unit rotates around the central axis, driven by the orbiting mitre gear. Simultaneously, the wheels of the middle unit rotate in the circumferential direction as casters. The angular velocity of rolling Wr is equivalent to that of steering Ws.

V. DESIGN OF COMPONENTS

This section shows the design of the sub-assemblies directly

A. *Sub-Assembly1*

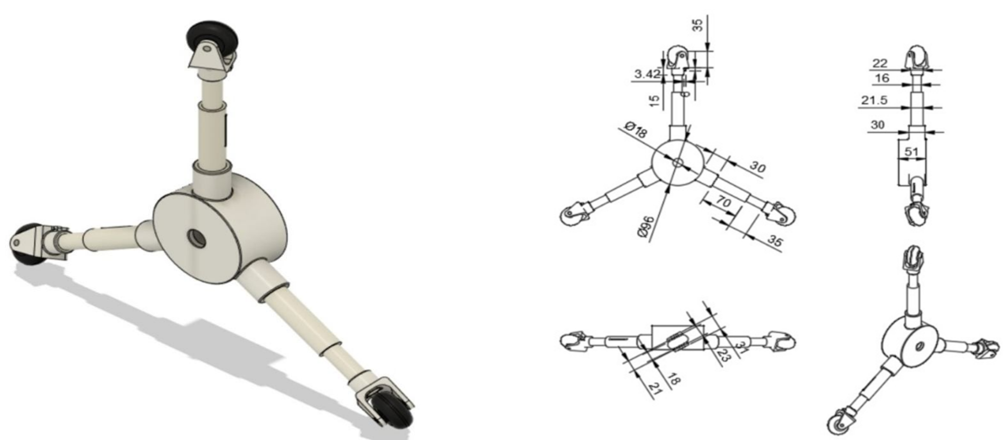

Fig 2. sub-aasembly1

B. *Sub-Assembly2*

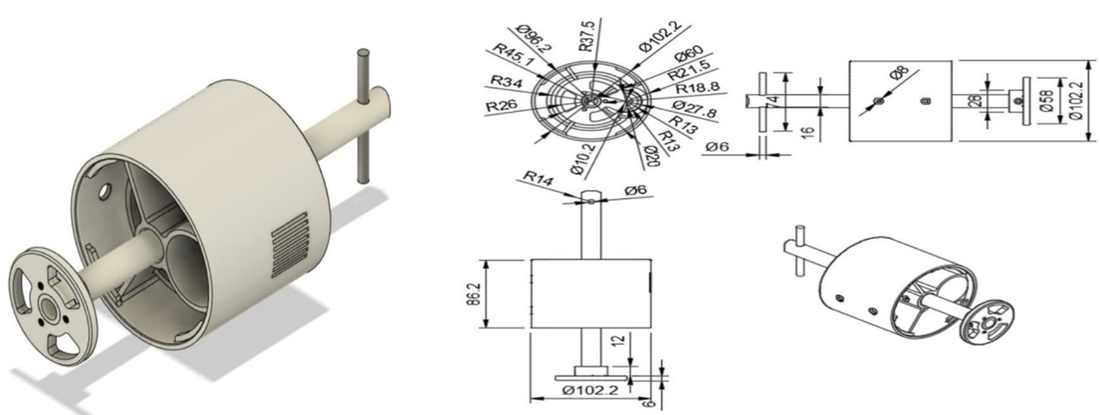

Fig 3. sub-assembly2

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C. Sub-Assembly3

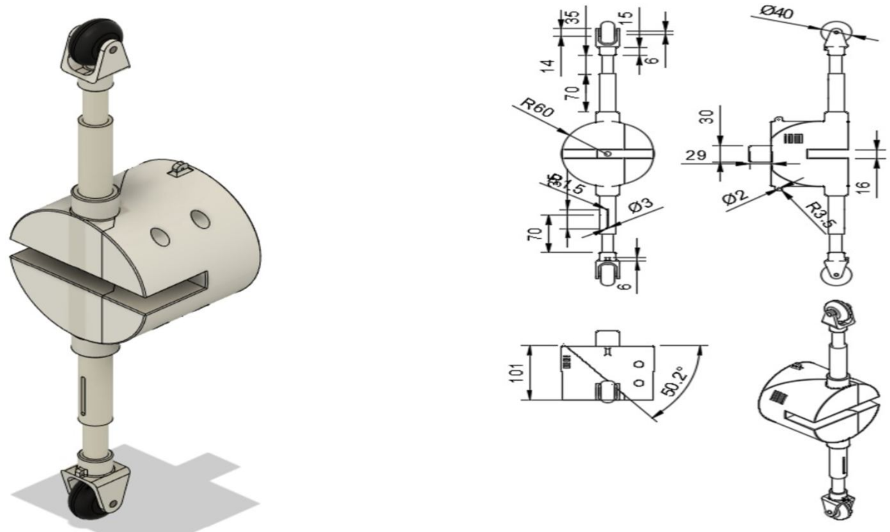

Fig 4. sub-assembly3

D. Sub-Assembly4

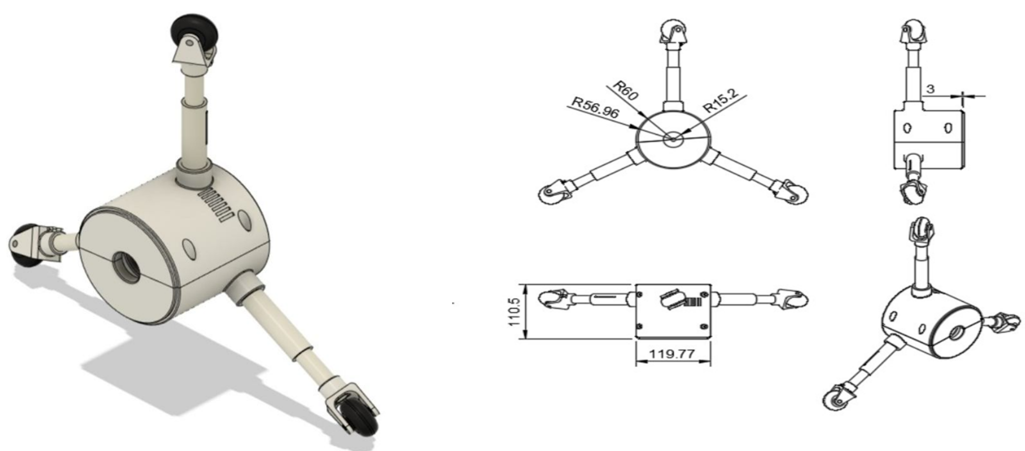

Fig 5. sub-assembly4

Following image shows the complete assembly of the robot-

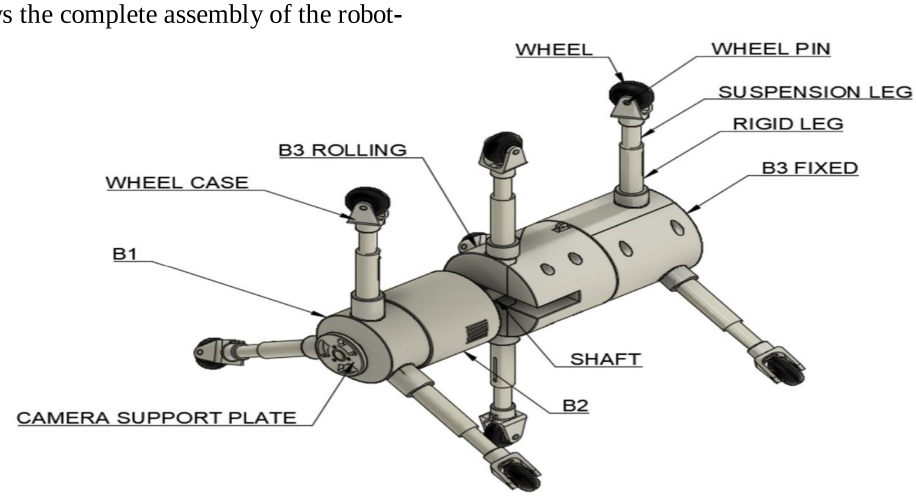

Fig 6. assembly

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VI. EXPERIMENTATION AND ANALYSIS OF WORK

A. Driving Gear Analysis

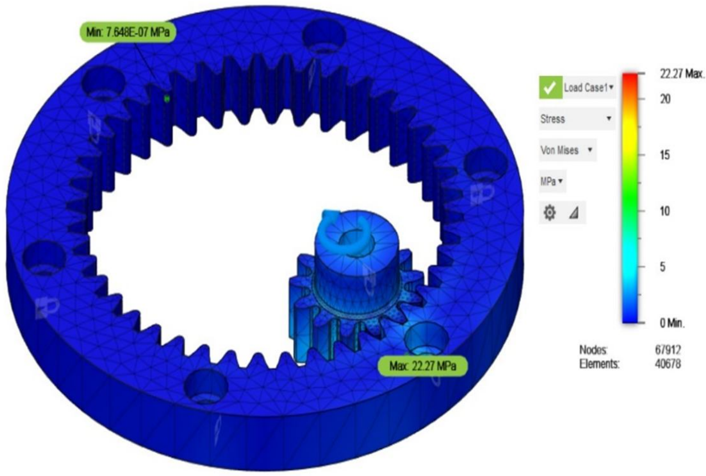

Fig 7. stress analysis of driving gear

B. Rolling Gear Analysis

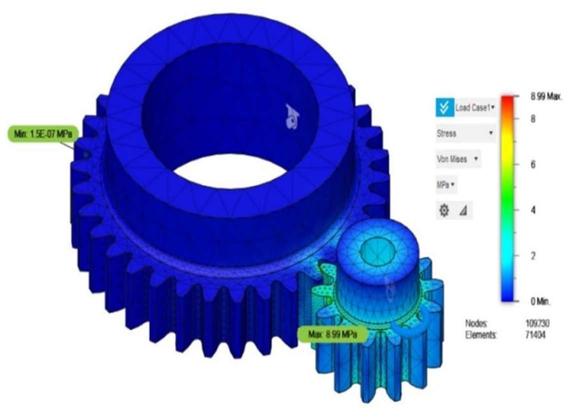

Fig 8. stress analysis of rolling gear

C. Turning Gear Analysis

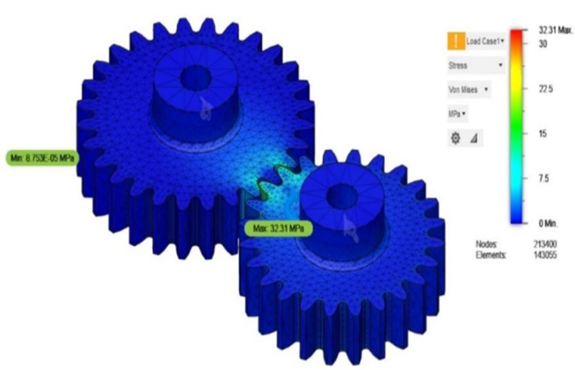

Fig 9. stress analysis of turning gear

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D. Body B1

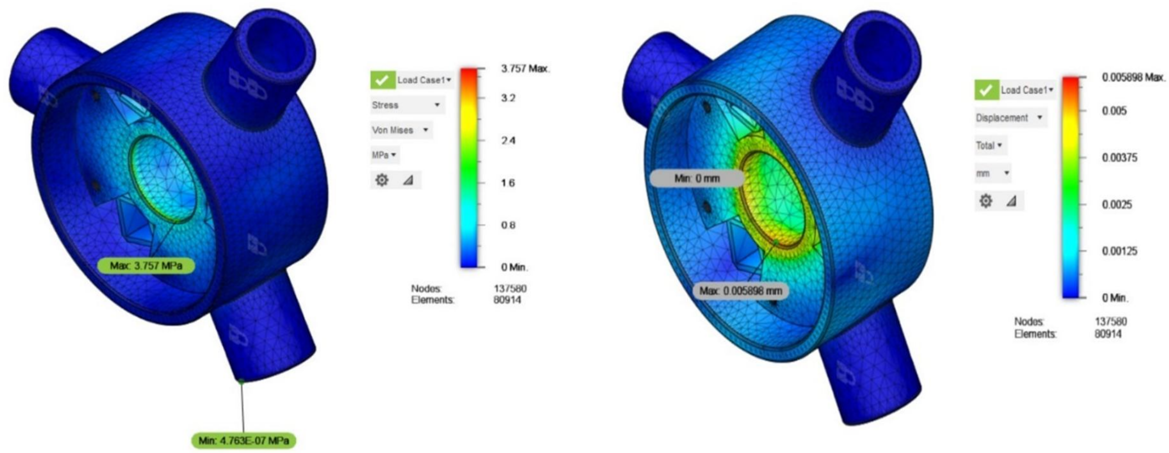

Fig 10. stress and displacement analysis of body b1

E. Body B2

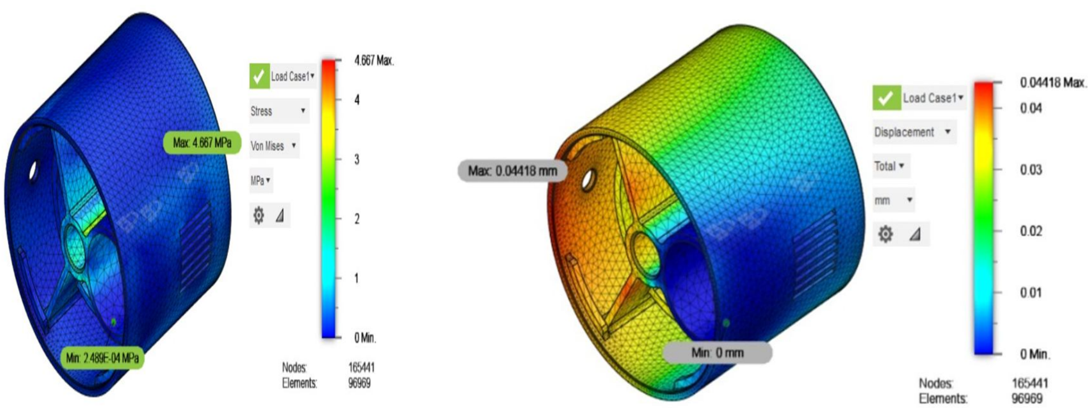

Fig 11. stress and displacement analysis of body b2

F. Body B3(Rolling)

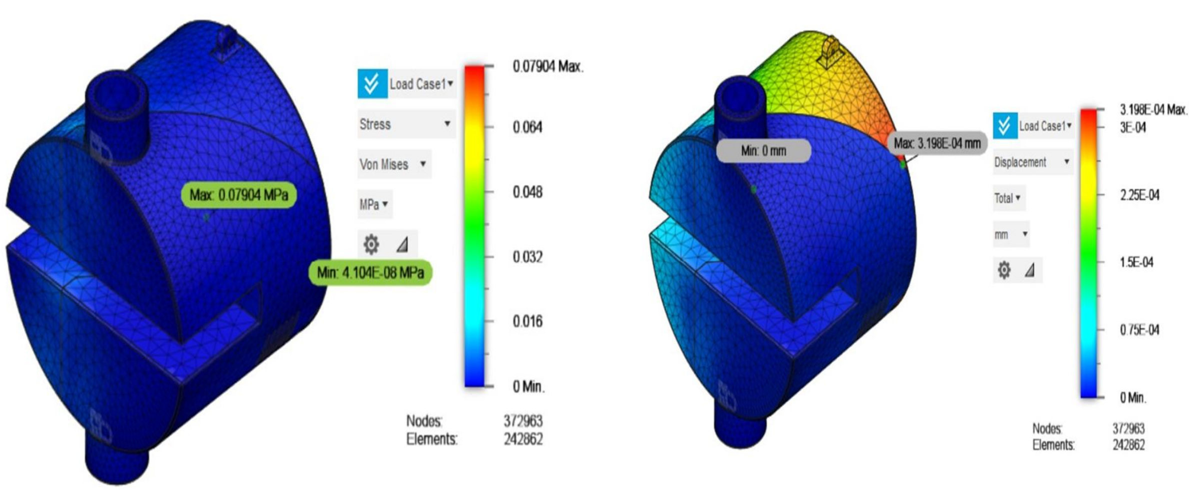

Fig12. stress and displacement analysis of body b3(rolling)

G. Wheel Case

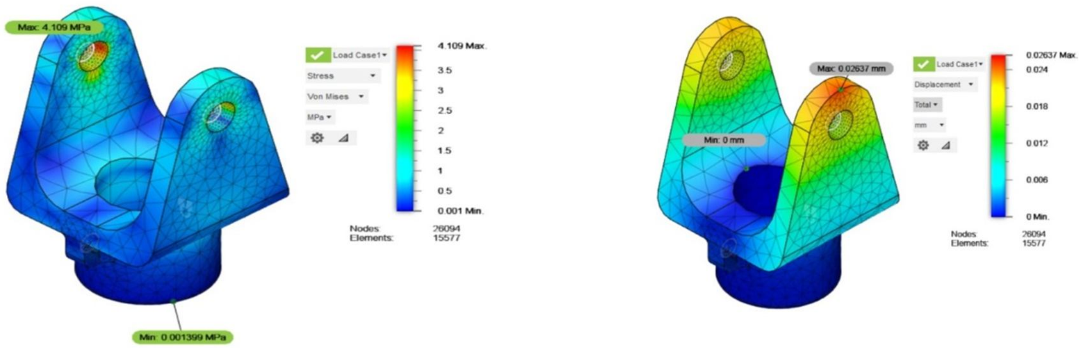

Fig 13. stress and displacement analysis of wheel case

All the study reports are uploaded to the link given below-
https://drive.google.com/folderview?id=1MljEE3m06Nlela8_kUF3AbvxWK-ZfKBa

VII. FABRICATED AND BOUGHT-OUT ITEMS

As per the design of the Pipe Inspection Robot, the system consists of the following bought-out items,

- *A.* 12 Volt Lead-Acid Battery
- *B.* 12 Volt, 33 RPM, 16000 N-mm, DC Motor
- *C.* 12 Volt, 10 RPM, 20000 N-mm, DC Motor
- *D.* WiFi Smartnet Pan-tilt Camera (2MP)
- *E.* 12 Core, Flat Cable
- *F.* 8 Compression Springs
- *G.* 560 Ohms Resistors
- *H.* 8 Alanki Bolt (M6)
- *I.* 6 Alanki Bolt (M3)
- *J.* 6 White LEDs
- *K.* Hollow Steel Pipe (2feet and 16mm Dia)
- *L.* PVC Pipe of Schedule 40 (I/D-3/4 inches)
- *M.* Rubber Wheels (Dia-40mm)

Following list will give the information of fabricated parts-
1) Driving Pinion- T=13, Module= 1.5mm, Pressure Angle= 20degrees
2) Driving Gear- T=42, Module= 1.5mm, Pressure Angle= 20degrees
3) Turning pinion- T=24, Module= 1.5mm, Pressure Angle= 20 degrees
4) Turning Gear- T=28, Module= 1.5mm, Pressure Angle= 20degrees
5) Rolling Pinion- T=13, Module= 1.5mm, Pressure Angle= 20degrees
6) Rolling Gear- T=34, Module= 1.5mm, Pressure Angle= 20degrees
7) Body B1
8) Body B2
9) Body B3-Fixed
10) Body B3-Rolling
11) Camera Support Plate
12) Wheel Case
13) Pins

VIII. EXPEXTED RESULTS

A. Robot should navigate through the elbows in all the situations.
B. While navigating through the vertical pipeline, the robot should overcome the force due to its self-weight and force of friction.
C. All the area ahead of the camera should be visible on the screen of mobile by means of illumination.
D. As the wiring is done accurately and precisely, there should not be any problem of wire interference in the path of the robot.
E. While negotiating turns the middle unit should be firm and stable.

IX. SCOPE FOR FUTURE MODIFICATION

A. Piping industries

Piping is very important and vital equipment in a most of the industries like oil and natural gas industries. Thus, inspection and maintenance of the pipe is very important and costly affair. Detection of a crack is very important before happening of any undesired situations like fire or leakage of gas in these industries. The pipes are bolted to each other forming a long series pipeline.
Thus the robot will play a vital role, in these industries. The cost of inspection will also be reduced. As well as, the quality of inspection will be improved by using wide angle and more X cameras. Due to oscillating rotor the robot can navigate through cross or T-sections etc.

B. Circuit design

Nowadays various circuits are available for controller wiz; microcontroller based circuits, iot based circuits, dynamo based circuits etc. Thus, in future various such modification can be done in a design of circuits and get the desired output.

C. Cleaning of pipes

If modification in the design is done by providing brushes on the periphery or by providing extra arms carrying brushes for cleaning purpose along with its controller, then the robot will also be capable of cleaning of the pipelines with ease.

D. Application of Sensors

If sensors which will predict the nature of the crack along with its complete analysis will be used, the robot will become very highly detailed instrument in every piping sector.

E. Domestic applications

Pipes are also used in domestic households and co-operative apartments. If the pipe diameter is in the range of robot, then robot will be used in such cases. This will used to find out the problem of choking of pipeline, which is one of the most recurring problem and causes trouble to the people living the apartment.

X. CONCLUSION

Thus we concluded that, the Pipe Inspection Robot is very useful tool for piping industries and as per requirement the robot dimensions can easily be changed and thus can be widely used. It has excellent future scope if it is atomized with the sensors. It is cost effective tool and will give 100% satisfaction to the user. Due to ability of camera to move freely, the robot is very effective in complex pipings as well.

XI. ACKNOWLEDGEMENT

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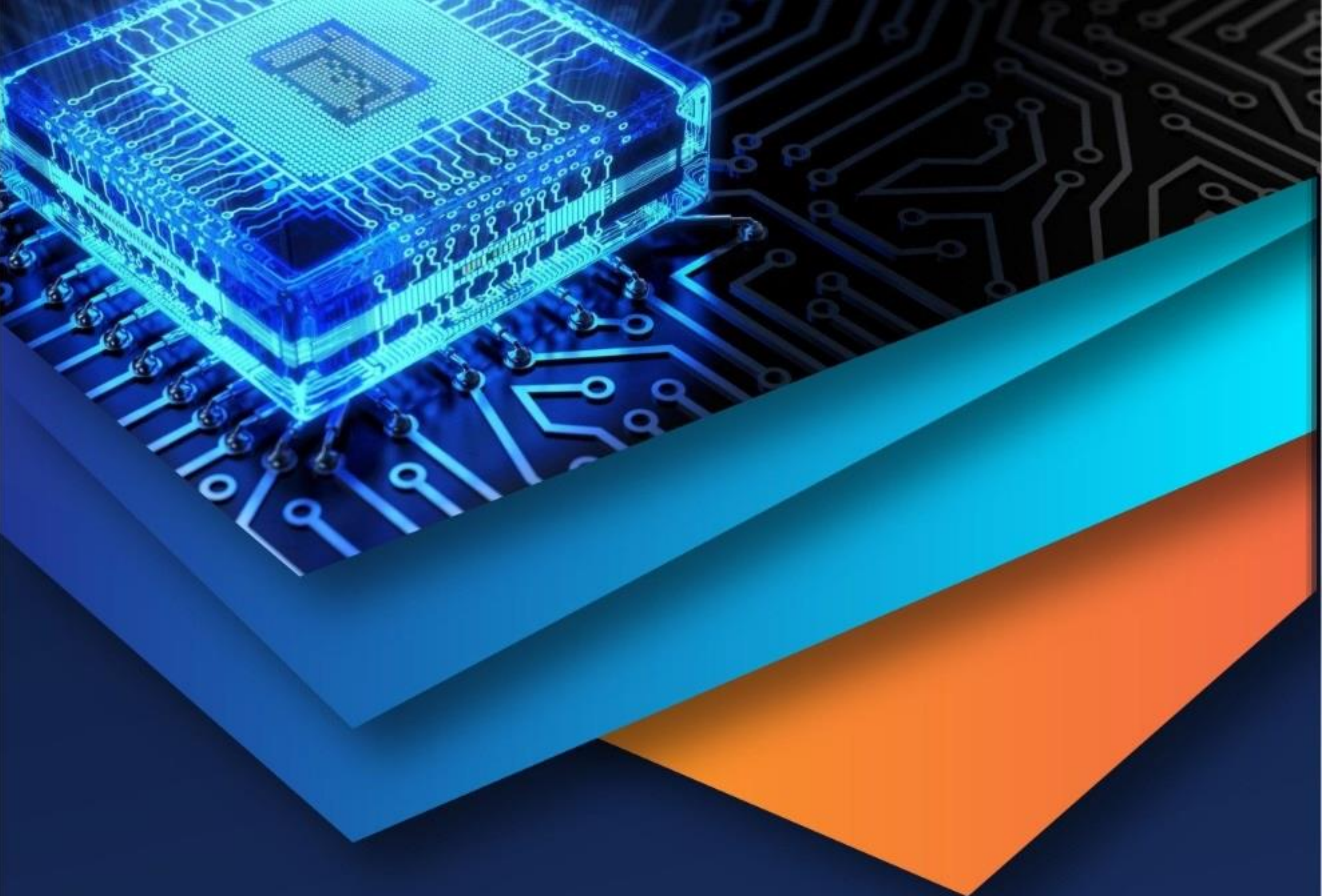

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