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Fabrication and Analysis Pneumatic Quadruped Robot

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Abstract—Pneumatic quadruped robot is a research project with wide variety of applications. It is a remarkable mechanical machine, category to few competitors to date. There are only limited places on earth where an existing wheeled and tracked vehicles can go, but a machine with legs can go everywhere on land. This quadruped machine can go on muddy, wet, rocky, steep and snowy terrain region.

It has sophisticated computing power and pneumatic actuators. It has integrated sensors. It can carry heavy payloads and can manoeuvred in rough terrain regions. It can be used to pick and place objects without changing orientation by three degrees of freedom Robotic arm using encoder motors mounted on it.

The height, width and length of the pneumatic quadruped robot are 0.8m, 0.6m and 1m respectively and a total of 12 pistons is being used for controlling the locomotion of the robot. The weight of the robot is 40Kgs approximately.

We are currently working to expand the Pneumatic quadruped robot's rough terrain mobility by analysing its structure, testing and research.

Key words: Quadruped machine, Pneumatic, actuators, Sensors, Robotic arm, Pistons.

I. INTRODUCTION

Technology plays a great role in our lives as every area of education and professional life require the use of advanced technology. One of the examples of advanced technology is the use of robotics. This new form of technology showed the world how advanced technology can help the people to perform their duties by artificial bodies which are used commercially, domestically and militarily.

This project reports of advancement in robotics in which we are exploring the application recently developed technologies to solve important problems faced in various sectors. To solve these problems, we are developing pneumatic quadruped robot for manoeuvring in rough and rugged terrains too difficult for existing vehicles.

Figure 1: Robotic Dog manoeuvring rough terrain.

II. BASIS

Over the past years we have started our research in quadruped robot. And got inspired by Big Dog 2004, Raibert 1986 legged robots that balance.

Based on our research on various actuators like motors, pneumatics, hydraulics and IC engines, pneumatics was chosen as it has many advantages. In comparison to electrical actuators, pneumatics deliver more power per unit cost and per unit weight.

In terms of simplicity, pneumatics turns out to be best option as there are minimum components involved. Along with simplicity, the pneumatics piston are quite precise. Pneumatics actuators avoid using hazardous materials. They meet explosions protection and machine safety requirements, as they create no magnetic interference due to lack of motors.

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III. DEVELOPMENT

Pneumatic quadruped robot is under development in MJCET college in Robocon Lab with funding from colleges research and development cell.

The development of this project is based on three major Methodologies:

- Design
- Analysis
- Fabrication

1. Design

The project modelling was carried out in solid works 2016 software , through which the complete structure of the bot was designed and modified , different were tested for making the structure.

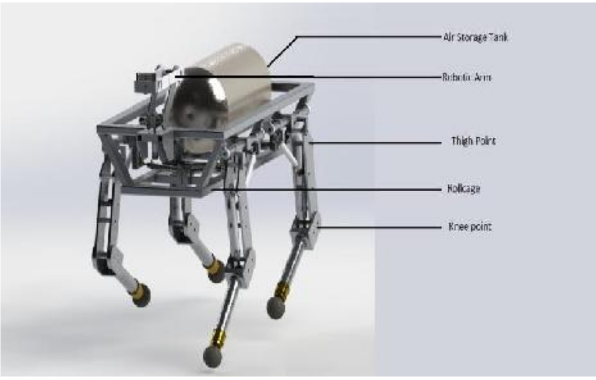

Figure 2: Anatomy of Robotic Dog

Aluminium was chosen as it has as it high strength to weight ratio for given price

The body of the bot consists of 4 legs actuated with 12 pistons, each leg is operated by 3 pistons . 2 for linear and 1 for side motion.

It has one robotic arm mounted on it for picking and placing object without changing its orientation.

It has built in space for loading the bore and stroke length of the piston is based on the force acting on it the total weight of the bot is around 40 kg s according to the design and another 20m kg payload.

The weight acting on each piston would be 15 kg s so according we choose a piston with 20 mm bore and 100mm stroke operating at 10 bar pressure.

It has 2 pistons for linear motion one for hip joint another for knee joint, the third piston is mounted on the roll cage and the piston road is connected to the leg assembly orthogonal as the piston actuates the leg moves side ways , which is helpful when the bot begins to loose balance or for stabilizing itself in rough terrain. The pneumatic piston are controlled by double solenoid which can stop the piston at any desired point the maximum radial distance for linear thigh moment is 136 degrees.

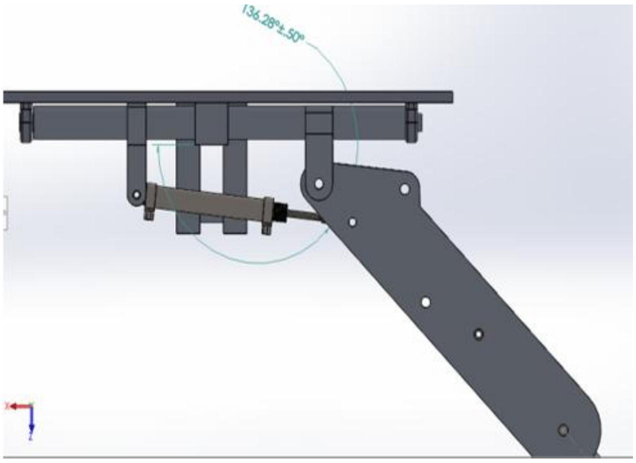

Figure 3: Range of actuation of Thigh piston.

And for the knee movement is from 120 to 310 degrees.

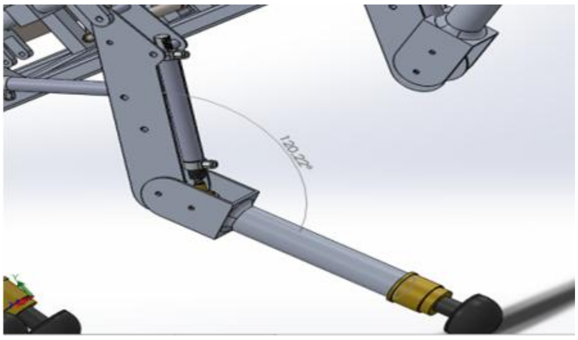

Figure 4: Range of actuation of Knee piston.

The storage tank is cylindrical in shape as it is the perfect balance of cuboidal and spherical pressure vessels for storing optimal volume of air and provides a good centre of mass for the given design as shown in the design below.

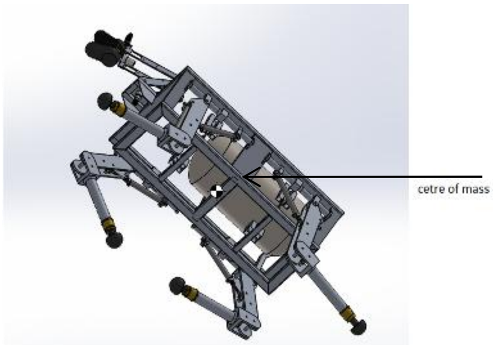

Figure 5: Location of center of mass with respect to body.

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The storage tank is made up of 5mm 201 stainless steel, and is used to store 30 lit res of air up to 10 bar of pressure and has a factor of safety 3.462 according to our analysis.

Experimental model

The prototype was built to study the complications and problems faced during the actual working, this design had 2 legs at the rear, and the front was fixed with dummy wheels the sequence of legs was studied and different patterns and combinations of leg movement were tested this was done to reduce the complexity during the initial tests.

Figure 6: Initial prototype under test.

Now to further improve on the prototype and to better understand the movements, all the 4 legs were added and tested, the bot was able to move but the movement was not so steady.

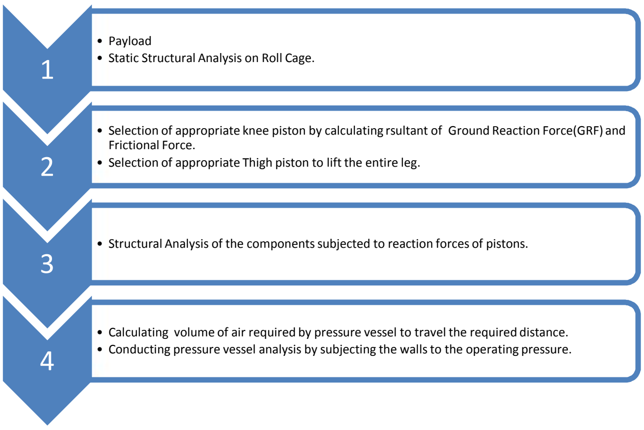
Figure 7: Developed prototype under test.

2. Analysis

Structural Analysis was performed in SOLIDWORKS Simulation to:

- Evaluate factor of safety of the various components subjected to various stresses.
- To develop several iterations of the same component. However, only the final iterations will be explained .
- To increase overall efficiency of design by weight reduction, design optimization, etc.

Systematically, the analysis was performed in the following stages:



1. <u>PAYLOAD AND STRUCTURAL ANALYSIS OF ROLL CAGE</u>

It was decided beforehand that the payload of the robotic dog would be around **20kg.** Additionally, the roll cage would be subjected to the weights of the **Robotic Arm(3.072kg)** and the **Pressure vessel(10.361kg).** The mode of Analysis was Static Structural as the robotic dog would be subjected to bending stresses.. Since the roll cage was designed using the Weldments Feature, the roll cage was first converted to IGES format.

The material selected was Aluminium 6061-Alloy for reasons mentioned in the design study. The roll cage was in contact with the ground through the bearings that held the leg assemblies and therefore the fixtures were assigned to these parts. The weights of Robotic Arm and Pressure vessel were imported from their respective files at their respective positions on the roll cage. The payload was uniformly distributed all over. The following results were generated:

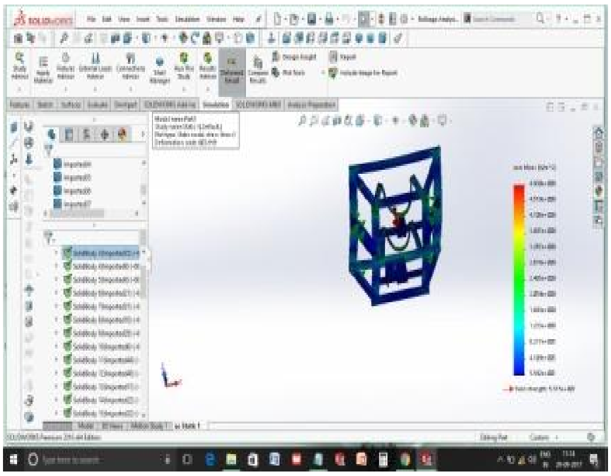


Figure 8: Displacements incurred due to Payload and other components.

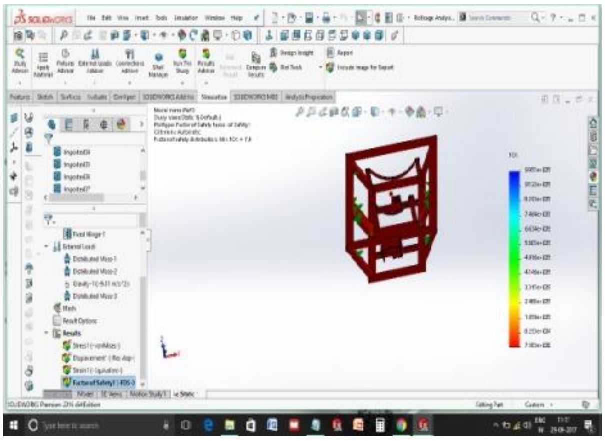


Figure 9: Factor of Safety of Roll Cage when subjected to bending loads; namely, Payload, Pressure vessel and Robotic Arm.

As seen in the results, the maximum stresses(2.87-e6) and displacements(8.518-e-2) are incurred at the pressure vessel mountings. Secondly, the robotic arm mounting and the central links surrounding the pressure vessel are subjected to high bending stresses. The maximum Von Mises Stress is much lesser than the Yield Strength which gives us a Factor of Safety=7.383. Hence, the design is safe.

2. SELECTION OF APPROPRIATE PISTONS BY DETERMINATION OF THE FORCES INCURRED BY THE PISTONS.

The knee pistons are subjected to maximum amount of forces, namely, Ground Reaction Force(GRF) F_z and the Frictional forces(F_y)(See Fig.10). According to the leg sequence, two diagonally opposite pistons are subjected to the resultant of these forces at a time. Additionally a third force F_X(Anteroposterior Force). But this force will be neglected in the following study.

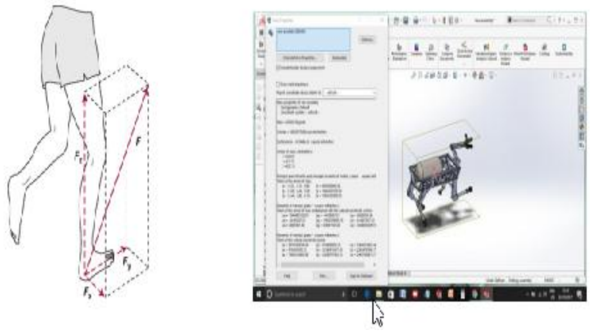


Figure 10: Forces exerted on legs during motion.

The total weight of the entire bot excluding the pistons that would carry this load is approximately 50kg which is approximately 490.5N. This load would be equally bore by the two pistons in the form of Ground Reaction Force. additionally the frictional force would be approximately 187N if the *coefficient of friction is 0.75 on muddy terrain(Cite Source).* This gives us a resultant of 311.7N. At 10 bar operating pressure, the require bore diameter would be 22.47mm. Finally after exploring the market; we found a pneumatic cylinder from JANATICS that satisfied our requirement: **Model#A510250100O.** It has a Bore Dia. of 25mm and a stroke length of 100mm with a maximum operating pressure of 10bar.

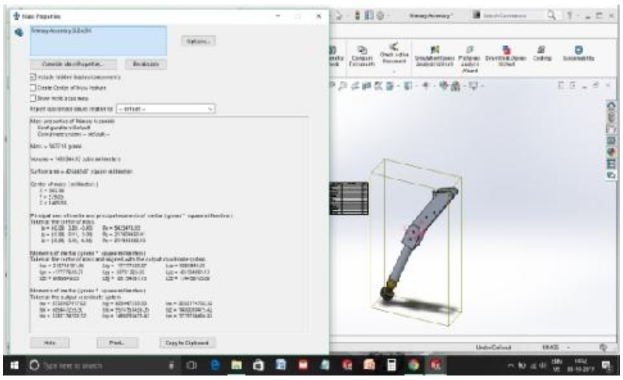


Figure 11: Mass of Leg Assembly. On the right, the Moments of Inertia are listed out.

Next, an optimum piston(Thigh piston)to lift the sub assembly was required. This involved various components as shown in below image which had a total mass of 3.827kg which is about 37.54N. At 10 bar operating pressure, a bore diameter of approximately 8mm was required. The piston used to satisfy this requirement was Model#A510120100O from Jana-tics which has a Bore Dia. of 12mm and a stroke length of 100mm with a maximum operating pressure of 10bar.

3. STRUCTURAL ANALYSIS OF ROD SUBJECTED TO REACTION FORCE OF THIGH PISTON

A special rod has been designed on which the entire leg sub assembly is mounted. This rod is hinged at two bearings and is actuated by the third piston which is required to stabilize the robotic dog i.e used to counter the *Anteroposterior force*(F_x) which was discussed earlier. This rod is subjected to reaction forces of thigh piston equal to 37.54N along the length of the piston. After a Structural analysis with input values as mentioned above, the following results were generated:

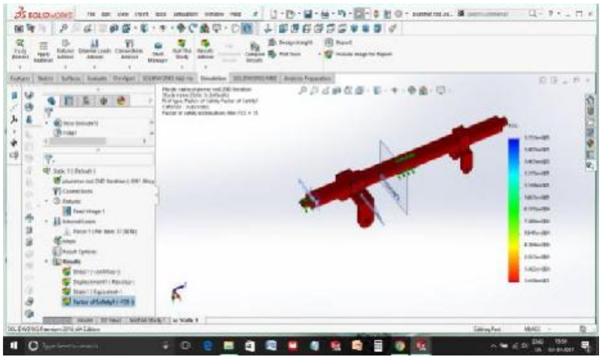


Figure 12: Factor of Safety of the Rod subjected to reaction forces of thigh piston.

The maximum Von Mises Stress was much lower than the Yield Strength and maximum displacement was 0.568mm incurred around the piston joint. The Factor of Safety is 14.7. Hence design is highly safe.

4. DESIGN OF PRESSURE VESSEL

The maximum distance requirement for our robotic dog was set at 250-300metres in one go. According to design, one complete cycle of the robotic dog was completed in 8 piston strokes which gives us a displacement of about 362mm. Taking into account the bore diameters of Thigh and Knee pistons(12mm and 25mm respectively) and the stroke length(100mm), the volume covered in one complete stroke is around 0.0002696m^3. This gives us a total of around 0.05m^3.

Thus, the following dimensions were arrived at to accomplishthe task: Internal Dia.=0.148m;Length=0.499 and a thickness of 5mm was arrived at after several iterations that involved change of material and change of thicknesses. The Pressure vessel analysis shown below is of the final iteration which has a thickness if 5mm and the material is AISI 201 Annealed Stainless Steel. The vessel is subjected to 10 bar which is the operating pressure of the pistons. It has Factor of Safety of 3.479 and a maximum displacement of 0.1205mm.

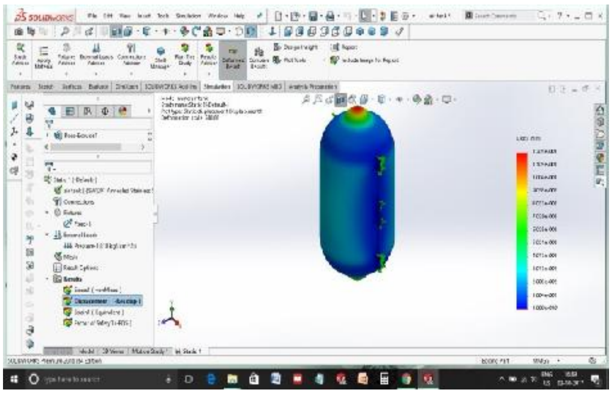


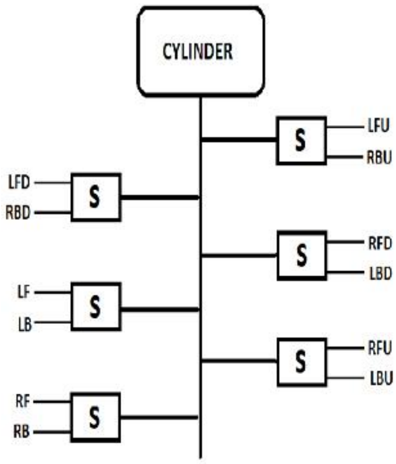
Figure 13: Displacements incurred by pressure vessel due to internal pressure of 10 bar(Operating Pressure).

3. Fabrication

The fabrication of the pneumatic quadruped robot involves the following operations; drilling cutting welding lathe machine operating such as turning facing center drilling etc.

IV. CONTROL

The following are the designations used in pneumatic flow diagram:



S = double solenoid

RFU= the piston at right front up position

RFD= the piston at right front down position

LFU= the piston at left front up position

LFD= piston at left front down position

RBU= the piston at right back up position

RBD= the piston at right back down position

LBU= the piston at left back up position

LBD = the piston at left back down position

RF= the piston at right front orthogonal position

RB= the piston at right back orthogonal position

LF= the piston at left front orthogonal position

LB= the piston at left back orthogonal position

V. FUTURE PLANS

Some of the problems we faced while working with our experimental model are its short range unsteady walking little noisy and sudden jerks.

These problems are addressed in the final modal by storing air at much higher pressure and regulating it to 10 bar to the piston inlet control valves are used to regulate the velocity of entering the pistons which can avoid shocks and reduce noise levels, silencers are attached to solenoids to further reduce the noise, springs are added to dampen the shocks ans improve the smoothness of the smoothness of the bot.

VI. ACKNOWLEDGMENTS

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