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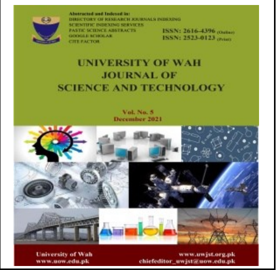

Steering Mechanism for an IC engine powered tracked firefighting UGV

Muhammad Mohsin Dar, Dr. Nasir Rahman, and Dr. Rizwan Alim Mufti

***Abstract*— Rescue and hazard management operations are susceptible to damages related to workers, working inside the installation in addition to workers part of a rescue and disaster management team. In order to minimize this damage, it is needed to incorporate robots with telepresence equipment. Unmanned ground vehicles (UGV) with the capability of reaching different layers of urban structures like buildings play a very vital role in minimizing the damage. The designed robot for the said operations has the capability of climbing stairs, ramps etc in addition to maneuvering or navigating without colliding the obstacles, taking sharp right/left turns and pivoting around, carrying and connecting capability with the fire tender in supervisory teleoperated controlled paradigm. The focus of this research is to design, develop and demonstrate a transmission and steering mechanism for an IC engine powered firefighting UGV.**

***Index Terms*— UGV, Fire Fighting Robot, Rescue Robot, Differential Drive, Differential Steering and Engine Based Robot.**

I. INTRODUCTION

WITH the industrial revolution, there is an increased interest towards the field of robotics and automation. The ultimate desire being to make machines do all the work that men do today The functionality of the robots is enhancing as more and more robots are being built to cater for the various needs of mankind.

Different types of robots are being developed day by day depending on the requisite functionality. Robots can be classified into stationary and mobile. Stationery robots perform their functions while remaining at their fixed position. As far as mobile robots are concerned, they move from one location to another to perform the intended task. Considering the three main classifications of ground mobile robots the legged ones offer high maneuverability, but they are very complex in design also the stability of the robot is the major concern in legged robots. Wheeled robots are the simplest robots, but they have limited maneuverability they are suitable for flat grounds. Tracked robots serve as an intermediate between the two they are simple than the legged robots and have better maneuverability on uneven surfaces. They offer maneuverability on uneven surfaces while climbing stairs and obstacles. Xingguang Duan et.al. [1] presented a four-arm robot, which used a combination of wheels, tracks and legged mechanisms for its maneuvering on different surfaces. Nasir Rahman et.al. [2] presented the supervisory semi-autonomous control for the four-arm robot. Z Y Chen et al [3] studied the dynamics of steering of a tracked robot based on track slip and centrifugal force and computes pressure on each side of track and concrete steering offset.

UGVs are used for surveillance and performing dangerous jobs. They can even go to areas that are not in the access of humans as recently a robotic rover was sent to planet Mars. In the event of nuclear accidents, robots are sent to the disaster sites to check for doses and other surveillance functions. Making robots do dangerous jobs reduces the fatality rates due to the accidents occurring during these jobs. Jie Ma et al [4] presented the design and development of a robot for nuclear accidents. S. Ali A. Moosavian et al [5] presented the design of a robot for rescue operations the design featured an expandable geometry which contracts itself to bypass obstacles and expands to climb stairs.

Of major accidents that cause loss of human lives fire is the most common. Other accidents are specific to the type of industry/ building, but fire can occur in any type of industry and even domestic buildings. T. AlHaza et al [6] described the concept of an indoor firefighting robot the subject robot had numerous features such as extinguishing the fire, assisting the trapped people by providing them with masks and other safety-related equipment and

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surveillance of the disaster site. R. Manikandan et al [7] published the design of a small-scale firefighting robot that assists the firefighters. Adeel ur Rehman et al [8] presented the concept of an autonomous robot that can detect the location of fire

The basic motivation behind this research is to reduce the human exposure both for the general public as well as for firefighters, in fire accidents by developing a firefighting UGV.

The subject paper deals with the transmission and steering mechanism of an IC engine powered tracked UGV. The designed UGV is shown in Fig. 1.

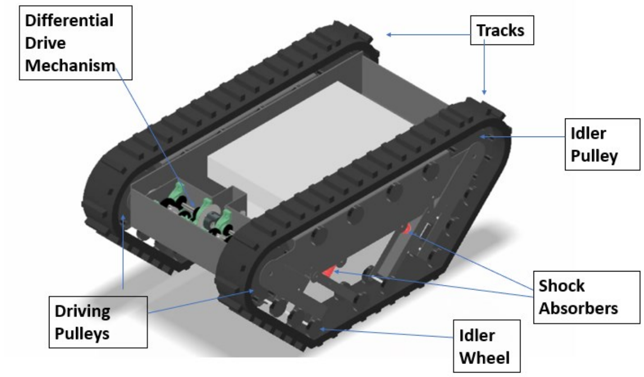

Fig. 1. Tracked Robot Assembly

There are several complexities associated with controlling an engine-powered vehicle when we compare it with an electric motor-powered robot. The first problem is associated with the steering of the tracked vehicle. As tracked vehicle steers based on the relative speed of the two tracks. Jintao Cui et al. [9] presented the design and analysis of a tracked robot that is driven by a single DC motor. The subject robot employed a differential drive mechanism to drive the tracks in this way the number of motors required is reduced The forward and reverse motion of the robot is achieved by changing the direction of the DC motor.

Different mechanisms have been used to convert the single input from the engine to two independent power sources. Of these mechanisms, we have selected the braked differential steering system. This mechanism employs a differential gear set that converts a single power source to two independent shafts. Each output shaft of the differential is connected to a reverse forward gearbox. Separately controlled brake is employed on the output shaft of each gearbox. Brake is engaged to slow down the respective track and the robot turns in the direction of the slower track. The block diagram of the designed mechanism is shown in Fig. 2.

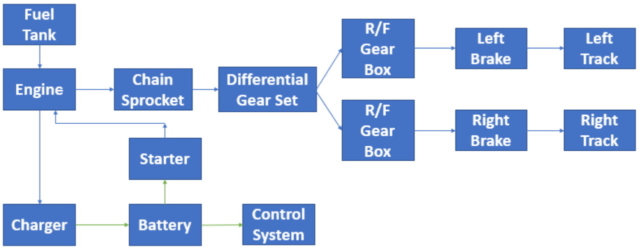

Fig. 2. Block Diagram of Differential Steering Mechanism

II. DESIGN

A. Reverse Forward Mechanism

The design procedure of the reverse forward gearbox started with the selection of a reverse forward mechanism; the mechanism selected was an idler based reverse forward mechanism that employs an idler gear to change the direction of rotation.

An important constraint in this design was that the ratio of two gear sets must be same in both forward and reverse configuration. Since it is needed to shift between the reverse and forward gears so the input and output shafts or the two gear sets should be the same which meant the same centre distance between the two gears and this poses the second constraint. To have the same gear ratio and same centre distance between two sets of gears one having 3 gears and other having 2 gears we changed the module of the two sets. The reverse mechanism which employed two gears was designed using a module of 2.5 and the forward mechanism which employed 3 meshing gears was designed with a module of 2.

B. Gear Shifting Mechanism

As regards the motor-based shifting between the reverse and forward drives is concerned a selector disc was designed which employed spring-loaded pins to engage and disengage from the gears. The smaller gears were coupled with the input shaft and the output shaft was coupled with the selector disc. The selector disc could slide on the output shaft while remaining coupled with it. The driven gears were rotating freely on the output shaft. Whenever power is supplied to the input shaft all the gears start to rotate in their respective directions but the direction of rotation of the output shaft depends on the engagement and disengagement of the selector disc. If the selector disc engaged with the output gear of the forward gear set, the output shaft moves in the forward direction and vice versa. The selector disc consists of 6 spring-loaded pins (3 on each side), these pins are responsible for smooth engaging and disengaging of the gears and selector disc. The gears on the output shaft are provided with slots, as the disc approaches the gear the spring-loaded pins press against the slowly rotating gear, the spring is compressed in this case. And when during rotation the slot, on gear, come in front of the pins the spring extends and the pin enters the slot. As the pin fits in the slot the gear and the selector disc are engaged. The reverse forward gear box assembly is shown in Fig. 3.

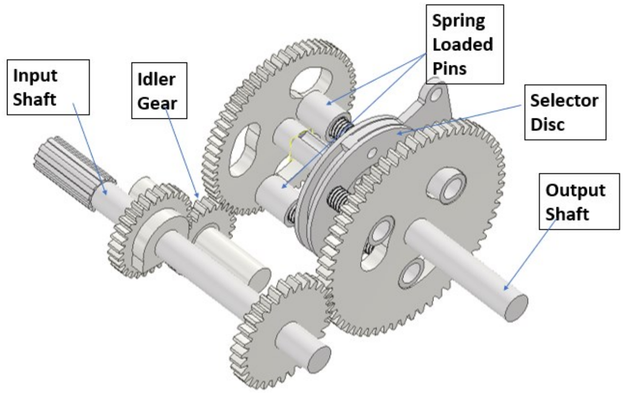

Fig. 3. Reverse Forward Gear Box

We require two of these gearboxes, one for each track, with the input shaft connected of each serving as the output shaft of the differential and the output shaft connected to the respective track pulley and brake. The differential is powered by a sprocket which is driven by an engine through a chain. The differential drive mechanism is shown in Fig. 4.

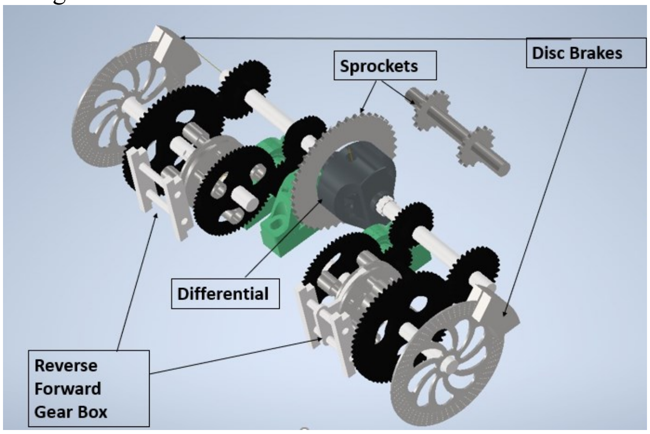

Fig. 4. Differential Drive Mechanism

C. Gear Shifting Algorithm

1. Brakes are applied (engine in neutral position).
2. Selector Disc actuated to move to the respective position.
3. Track Brakes are released as the limit of selector disc is reached.
4. Slowly release the engine brake.
5. Increase throttle as the robot starts to move in respective directions.

III. ANALYSIS

A. Evaluation of Required Torque

First, we calculate the torque requirements of the designed robot while climbing accents, the free body diagram is shown in Fig. 5.

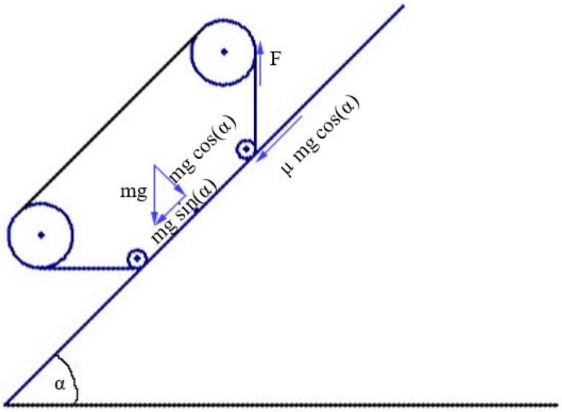

Fig. 5. Free Body Diagram

It is evident from the figure that the robot needs to work against gravity and frictional forces to move with a constant velocity and minimum required force is the equal to the sum of gravitational and frictional force components acting against the direction of motion given by (1).

$$F = \left(\mu\, mg\cos(\alpha) + mg\sin(\alpha)\right) \tag{1}$$

This force is to be overcome by the torque at the pulley so for a pulley radius of 177.8 mm the required torque at the pulley shaft is given by (2).

$$T = 0.1778 \times \left(\mu\, mg\cos(\alpha) + mg\sin(\alpha)\right) \tag{2}$$

For a mass of 150 kg and co efficient of friction between ground and track to be 0.7 (2) was evaluated for a range of angle of inclination from 0 to 90. It is evident from the equation that for small angle of inclination friction component plays a major role while gravitational component dominates at higher angles. The relation between required torque and angle of inclination for the said conditions is shown in Fig. 6.

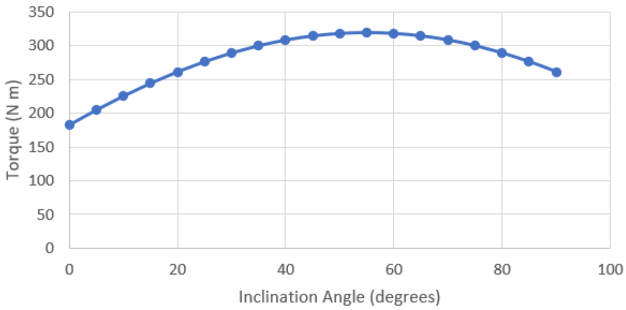

Fig. 6. Required Torque and Inclination Angle

Fig. 6 shows that the maximum torque requirements occur at an angle of inclination of 55 degrees and is equal to 319 Nm.

B. Static Analysis of Reverse Forward Gear Box

Static analysis of the gear train was performed to check if the proposed gear thickness is sufficient to bear the requisite load. Factor of safety of gear set was evaluated by applying quarter of the required torque at the input gear. Contour of factor of safety in reverse configuration is shown Fig. 7 and that of forward configuration in Fig. 8.

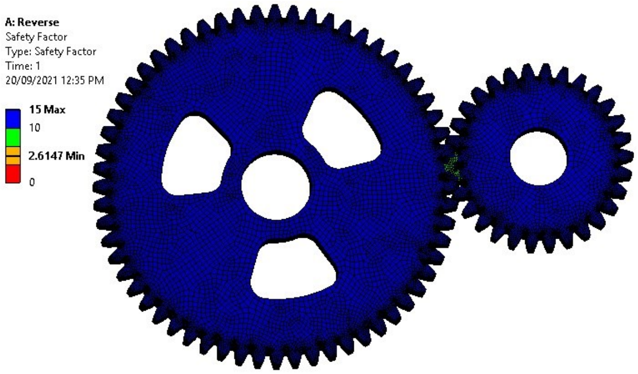

Fig. 7. Static Analysis of gears in Reverse Configuration

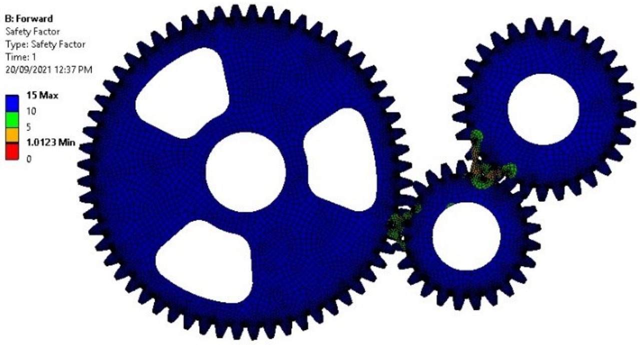

Fig. 8. Static Analysis of Gears in Forward Configuration

After evaluating the gears the next step is the evaluation of pins of selector disc the contour of factor of safety of pin is shown in Fig. 9.

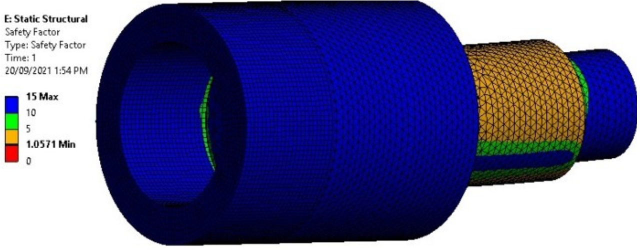

Fig. 9. Static Analysis of Pin

The minimum factor of safety in figure III-3, figure III-4 and figure III-5 is greater than 1 so the design is safe.

C. Evaluation of Torque Ratio of Designed Mechanism

Dynamic simulation environment of Autodesk Inventor was used to evaluate the torque ratio of the designed mechanism. The output shafts of the two gearboxes were coupled to gears of the reverse configuration of each gearbox. An imposed motion of 0 m/s was applied at the two output shafts and a toque of 62.1 N.m was applied at the input shaft. The torque evaluated at each output shaft was 181.86 N.m as shown in Fig. 10. In order to evaluate the ratio in forward configuration, the output shaft was coupled with gear in forward configuration and the same motion was imposed the output torque was identical to that evaluated in reverse configuration.

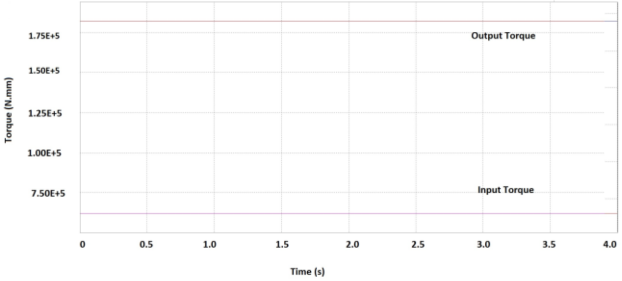

Fig. 10. Plot of Input and Output Torque

D. Dynamic Analysis of Gear Shifting Mechanism.

Dynamic simulation of gear shifting mechanism was carried out using Autodesk Inventor. Constant velocity was imposed at the input shaft velocity profile as shown in Fig. 11. Selector disc was imposed with a position profile shown in Fig. 12. The output of the simulation is shown in Fig. 13.

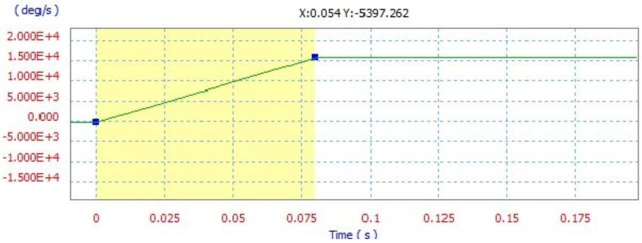

Fig. 11. Input Velocity Profile

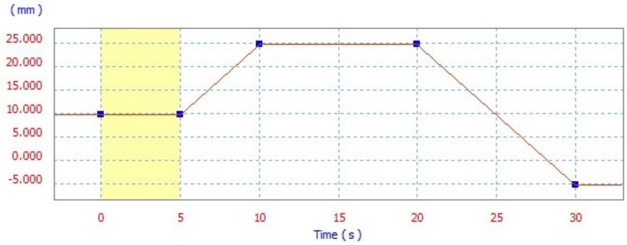

Fig. 12. Position Profile of Selector Disc

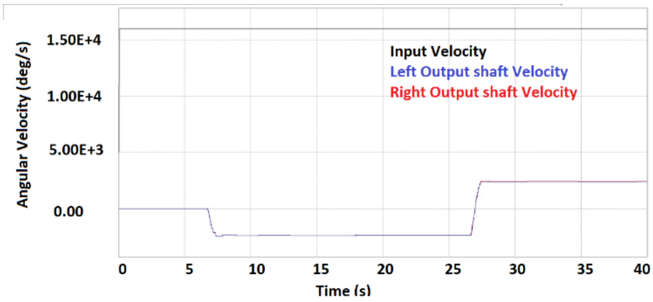

Fig. 13. Output Velocity Profile

Fig. 13 shows the velocity profile of the input and output shafts. Input velocity ramps from 0 to 16000 degrees/sec in .08 seconds and then remains constant at 16000 deg/sec. Velocities of the two output shafts is zero at the start since the selector disc is in neutral position at around 7 seconds the selector discs approach the gears in reverse configuration and velocity of the output shafts starts to increase in the negative direction then it becomes constant.

Then at 20 seconds, the selector discs start to move towards the gear in forward configuration thus starts to disengage from gears in reverse configuration. After disengagement, the output velocity remains constant due to inertia until the selector disc approaches the gears in forward configuration then the velocity of the output shaft approaches zero and thereafter increases in the positive direction as the selector disc engages. Afterwards the velocity remains constant until the end of the simulation.

E. Dynamic Analysis of Braked Differential Steering

The next step is the dynamic simulation of braked differential steering mechanism it employs the same model as used in the last section the difference is that two disc brakes are added to the model and 3d contact joints are established between the brake pads and the discs.

Fig. 14 represents the position profile of the selector disc. The selector disc remained in the neutral position for the first second and then it started to displace to engage with the gear in forward configuration. The input velocity profile is the same as in the last section.

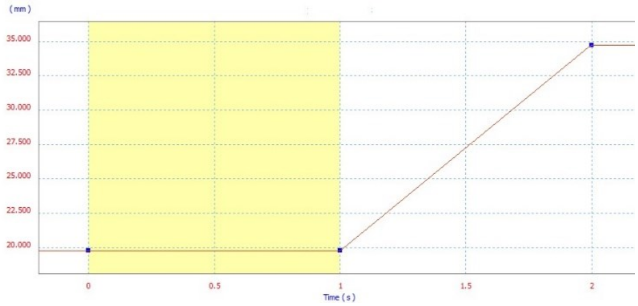

Fig. 14. Position Profile of Selector Disc

Fig. 15 represents the profile of applied force on the left brake pad. A force of 25 N was applied on the left brake pad at 3.9 seconds and force was removed at 4.6 seconds.

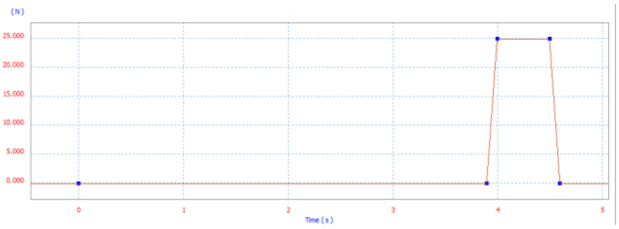

Fig. 15. Force on Left Brake Pad

Figure 16 represents the profile of the applied force on the right brake pad. A force of 25 N was applied on the right brake pad at 6.5 seconds and force was removed at 7.2 seconds.

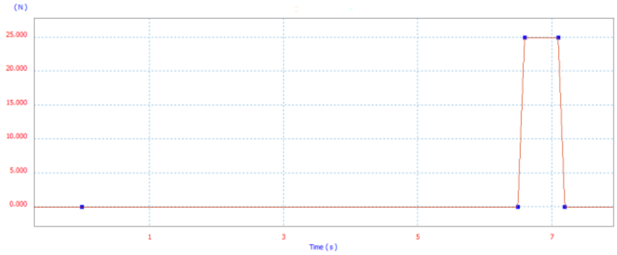

Fig. 16. Force on Right Brake Pad

Fig. 17 shows the output of dynamic analysis. Graph shows that at the start the velocities of the two output shafts is zero and then as the selector disc is engaged the velocities of the two shafts become equal and then as then braking force is applied on the left brake pad the velocity of the left brake pad is decreased and velocity of right brake pad is increased. Then as the force is applied on the second brake pad the velocity of the right pulley is decreased and that of left pulley is increased.

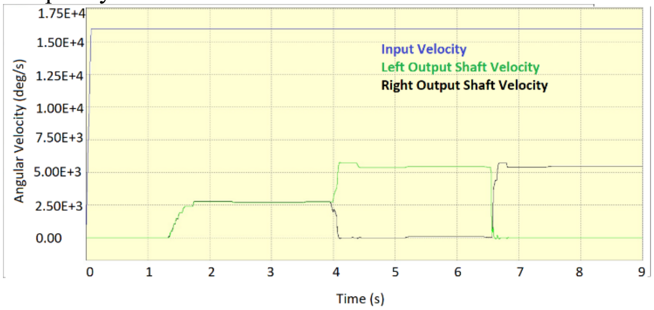

Fig. 17. Output Velocity Profiles

IV. CONCLUSION

From the results it is evident that the mechanism performs the intended function. Engine powered robot with the said transmission will be able to steer left/right, maneuver in both forward and reverse directions and will be able to pivot on its own axis. Due to the smooth shifting between reverse and forward configuration the whole transmission can be controlled remotely using motors, two of which will control the position of selector disc, 2 motors/ actuators will control the brakes, 1 motor will control the throttle and 1 motor will control the main engine brake.

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