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AUTONOMOUS TRANSMISSION CONTROL OF A 2017 YAMAHA GRIZZLY 700 ALL-TERRAIN VEHICLE

Summary. Investigation on a designed and modified standard automatic transmission for a 2017 Yamaha Grizzly All-Terrain Vehicle was carried out to allow it to be controlled remotely and autonomously while maintaining its ability to be manually operated. The vehicle is a part of a project named AutoWeed. This project aims at developing a vehicle which can be used in the Australian outback to control and eradicate weeds. Preliminary tests were conducted on the vehicle to determine the performance parameters required to replace the movement supplied by the operator. Several devices used to achieve this motion were explored. It was concluded that the Motion Dynamics HB-DJ806 - LALI10010 electromechanical linear actuator be used as a proof of concept device for this application. This device is capable of exerting 200 N at 35 mm/seconds. It has a stroke length of 50 mm and was powered by a 12V DC motor, which drew 3 amps at maximum load. Through testing, it was found that the selected actuator did not have enough stroke length to cycle through the five gears on the ATV. This error was rectified allowing the system to function as intended. To achieve a reliable design, however, the Linak LA14 actuator was purchased as a final design as it was stronger, faster and had feedback capabilities. Before procurement, the new actuator was digitally modelled using SolidWorks 2017 and 3D printed to confirm the mounting position and

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method. An ANSYS FEA was conducted on all the custom-made components including the actuator bracket and mounting plate to ensure reliability. The bracket model was manufactured using 3D printing from ABS. It was recommended that for reliability, the bracket should be constructed from a stronger material such as aluminium. The results gained from testing proved that the autonomous transmission system implemented was reliable and repeatable. This was justified as the system achieved a 100% success rate when cycling through gears.

Keywords: autonomous, ANSYS, Finite Element Analysis, transmission

1. INTRODUCTION

Australia's agricultural industry is worth over 100 million AU dollars and is one of the world's largest industries [2, 6]. For centuries, the agricultural industry operated on human power alone, eventually evolving to the utilisation of animals such as horses and donkeys to simplify tasks. For approximately 100 years, the use of tractors dominated the industry. Although larger autonomous vehicles are being developed, there has been very little advancement in the atomisation of smaller vehicles such as all-terrain vehicles (ATV). Honda, the University of Bath, North Carolinas Urban Research University and Harper Adams University, are all institutions, which have developed early design prototypes proving the possibility of manufacturing a fully autonomous and remote-controlled ATV. However, there is no vehicle of this type that is fully developed, functional or commercially available. A fully autonomous all-terrain vehicle would appeal to farmers who want to improve productivity, profitability and reduce the required man time to perform tedious tasks such as spraying weeds.

A team (Auto Weed) at James Cook University have worked on designing an autonomous robotic weed control vehicle. This was performed by converting a 2017 Yamaha Grizzly 700 from its current standard manual operable controls to a fully autonomous system, pictured in Fig. 1.

Fig. 1. 2017 Yamaha Grizzly [26]

The 2017 Yamaha Grizzly 700 associated with this investigation has an automatic 5-gear position gearbox. This design problem requires the determination of a solution to achieve specific gear selection without human interaction.

Weed control has been an interest to farmers according to available literature, since before 1200 A.D [23]. The task of eradicating or controlling the growth and spread of weeds is crucial to farmers due to the need to maintain and service access roads, headlands and drains. Additionally, attending to weed issues will aid in the prevention of produce contamination, which affects the yield of the crops. The reduction of weeds will prevent the amount of nutritional loss to crops, as well as help to prevent pests and diseases spreading as they tend to use the undesired plants as hosts. Furthermore, many weeds strangle cultivated plants as they both compete for light, water and space. This reduces the amount of desired vegetation, even if it is not intentionally farmed, which is used for feeding livestock

2. METHODOLOGY

2.1. Preliminary Research and Design Parameters

This project was initialised by determining the specific parameters associated with the ATV. The plastic covers on the bike were removed revealing the gearbox, the shifter selection lever and the connecting rod. This allowed initial tests to be conducted, quantifying these parameters. Fig. 2 is a photograph of the vehicle with its covers removed.

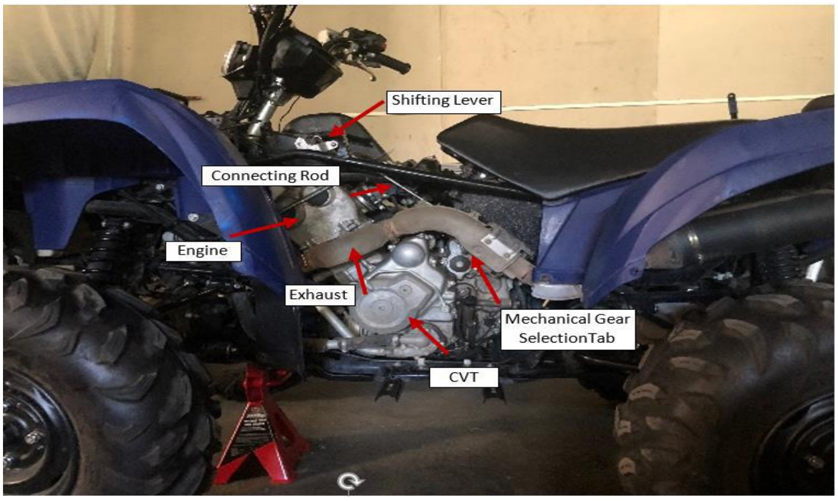

Fig. 2. Exposed Yamaha Grizzly Side

While the plastic covers were detached, the quad bike was operated to heat the vehicle's engine and sub-systems. The maximum temperature recorded was 470°C and was located at the front of the exhaust where the exhaust gases first exit the engine. This was measured using a handheld thermometer gun measuring the emissivity of an object. For comparison, measurements were taken while the bike was cold. Additionally, a spring scale was used to measure the force required to move the connecting rod. It was determined that 353 N was required to initiate the movement of the rod from rest. Once moving, this required force was reduced to 20 N.

The linear movement of the connecting rod was determined to reach a maximum of 47 mm when moving between the extremities (high range through to park). Further to this, using a protractor, the angle of rotation of the mechanical gear selector mechanism located on the outside of the gearbox was 70°. Based on this information, research was conducted to determine the best solution to implement an autonomous transmission system.

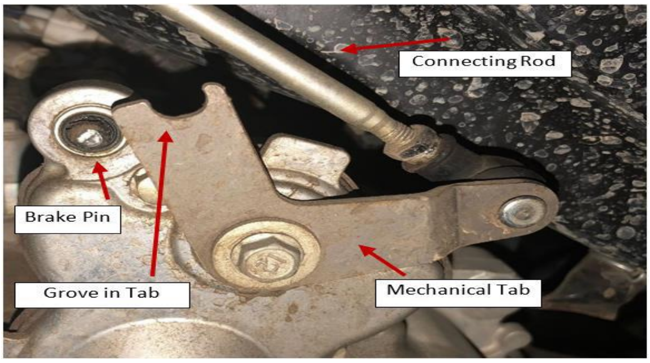

Fig. 3. Mechanical Gear Selector Tab

2.2. Proposed Design Solutions

A gear shifter lever is used to change the positions of the selector forks to vary the position of the gears. The manual force applied to the lever moves the connecting rod and gear selection tab, activating one of five solenoids. This movement is illustrated in Fig. 4. As the solenoid is activated, the internal transmission fluid, which is pressurised, flows through the opened chamber caused by the void left from the solenoid. This applies a force to a specific clutch plate, which allows the desired energy paths to be obtained through the planetary gearset. Attaching a linear actuator to the connecting rod, installing a servomotor or rotating actuator as well as replacing the transmission fluid pump with a computer-controlled fluid velocity device, were all possible avenues that were explored to autonomously achieve transition of the transmission.

Fig. 4. Gear Shifting Motion

It was concluded from the research conducted that it was not economical or viable to replace the fluid pump inside the transmission box. To obtain a pump with the specific geometry, speed and feedback inputs which are necessary for this application would be extremely difficult. Additionally, there would be a significant increase in the essential programming needed to satisfy the predetermined parameters of the current factory pump.

Furthermore, due to the limited available space, high temperatures around the engine and gearbox and need for high levels of precision positioning of the servomotor, it was determined that this solution would not be the best suited for the specific application of autonomising an ATV.

Because of the simplicity of implementation, as well as effectiveness and ability to absorb any small inaccuracies related to distance measurements, it was concluded that the linear actuator was the best solution to modify the standard 2017 Yamaha Grizzly's transmission into a fully autonomous system.

2.3. Actuator Selection

There are many different types of linear actuators which include but are not limited to electromechanical, hydraulic and pneumatic. Through research and discussions with actuator technicians and manufacturers, it was decided that the electromechanical type was the most appropriate for this task. An electromechanical actuator was chosen due to the achievable accuracy of increments, the low cost of procurement, the minimum force needed to move the connecting rod, the benefit of not requiring a pump or compressor as well as the low maintenance needs.

The accuracy of the electromechanical actuator is directly related to the accuracy of the potentiometer, the coarseness of the threaded rod as well as the velocity of the shaft. Accuracy is defined by manufacturers as "the ability of an actuator to achieve a specified position." A standard actuator can obtain an accuracy of ± 1mm provided they are installed correctly. This accuracy is sufficient for this application as there is an additional degree of alignment as the gear selector falls into the desired gearing mesh which contributes to the overall self-alignment of the system. Further to accuracy is repeatability. Repeatability is "the ability for an actuator to achieve a given position time after time or repeatedly." In most applications, the ability to have greater repeatability is more important than the ability to achieve high levels of accuracy [21].

Electromechanical actuators come in a wide range of sizes and shapes, each with its force capabilities. According to Donald Firesmith, to ensure an over-engineered design a factor of safety (FOS) of 2.5 should be used [5]. Because of this, the minimum required force capability of the actuator was determined to be 236 N. Another design condition of the actuator was to have the ability to change between the extremity positions in under 5 seconds (0.01 m/s). Additionally, the resistance to heat, dust, water, vibration and impulse force were likewise considered. Furthermore, the ability to comply with geometric restrictions, the overall cost of the component, the time to receive the product and its availability were all influencing factors when selecting the optimal solution for the project. It was concluded that the best linear electromechanical actuator to use as a prototype and proof of concept was the Motion Dynamics HB-DJ806 - LALI10010. This was based on performance specifications, availability of the item and the total price.

The HB-DJ806 is a small and compact unit, which can easily be mounted on the Yamaha Grizzly without interfering with other standard or additional components on the vehicle. Additionally, because of the actuator's slim geometry, the original plastic covers can be reinstalled to ensure aesthetics are maintained.

The performance parameters of the actuator are; maximum stoke length 50 mm, speed 10.9 mm/s force capability 200 N and a voltage draw 12 volts while drawing a maximum load of 3 amps. The actuator can be fitted with an internal potentiometer to measure the resistance in the actuator and convert the values to a position. This feature, however, endures an additional cost as well as increasing the lead time by 8 weeks as they are made to order.

2.4. Mounting the Actuator

Before procurement, an approximation of the geometries of the HB-DJ806 actuator was replicated using a full-sized 3D printed model, designed using SolidWorks 2017.

Due to the limited geometries supplied by the manufacturer, the plastic printed replica could only be approximately modelled. The supplied dimension for the height, length and width were sufficient to manufacture a replica to determine the exact mounting position, method and location. Once the functioning actuator arrived, correct installation to the vehicle without complications was achieved.

Initially, the method to mount the actuator was to attach the fixed end to the tabs on top of the chassis of the vehicle where the plastic housing for the shifter selector lever was originally situated. It was secured using an M4 bolt and nut attaching it to a rod-end, which is fitted to the mounting tabs of the frame. The intent of the rod-end was to restrict the translational movement of the actuator in all directions while maintaining its ability to rotate freely. The connecting rod was shortened to account for the additional length provided by the actuator and was attached to the shaft end of the actuator via a double acting coupling.

For a robust and reliable system to be developed, a new actuator was required. The device selected for this application was the Linak LA14. This device is capable of withstanding temperatures of 85°C, utilised a 12V DC motor, and could reach speeds of 36 mm/s while maintaining a load level of 300 N drawing 2.6 amps. It also had a stroke length of 130 mm. This device was rated to an IP66 standard, which is suitable for the intended environment (Australian Outback).

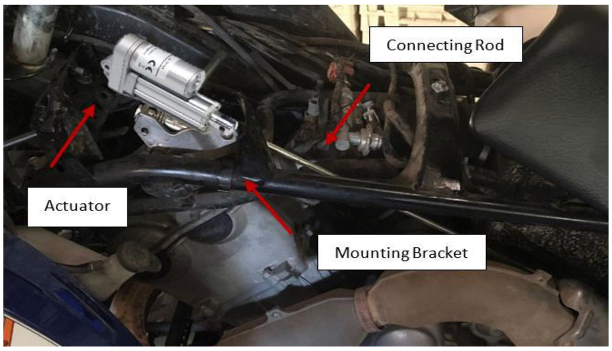

Fig. 5. Proposed Autonomous Transmission Solution

When Yamaha manufactured the vehicle, a safety system was implemented to eliminate the risk of selecting the reverse position while the ATV was moving forward, therefore, removing the possibility of damaging the gears in the transmission box. This safety measure was implemented by inserting a small bar between two groves on the tab on the exterior of the gearbox as seen in Fig. 3. This created a mechanical barrier, which prevents the reverse gear position to be selected without engaging the brake to ensure motion was stopped. As the modification to the transmission system will be controlled electronically via a computer, this error will not arise, therefore, this factory safety measure will be removed to simplify the communication between the autonomous gear and braking systems.

2.5. Gear Selection Board

To select the desired gear position (that is, park or neutral), it is proposed that a 5-button backlit board, similar to Fig. 6, is implemented. By utilising a button board, it will be possible to achieve the aim of operating the vehicle manually, remotely or autonomously. The hardware would remain constant for each case with the variation arising with the method of supplying a signal to the actuator to alter its position, thus, gear position. Additionally, when the vehicle is operated manually, it will allow the driver to select the desired gear without the need to manually cycle through the intermediate positions. More so, as the buttons are backlit, the operator can visually see the current gear position of the vehicle. This is used in conjunction with the standard vehicle's display. These features will contribute to saving time and creating a more accessible design. The board will be positioned on the right-hand side of the vehicle, on the upper wheel arch, in an easy to reach and comfortable position for the operator. The board will be recessed into the plastic body work creating an aesthetically pleasing finish.

Fig. 6. Gear Selector Board

2.6. Connectivity to the Main Operating System

The actuator, along with the gear selection board will be connected to the CAMBUS via an Ethernet transfer cable. It will be powered from an auxiliary battery used for the additional accessories. Specific parameters are programmed once the hardware is communicating and responding correctly to the operating system. To complete a gear change, one of the 5-gear position buttons are activated, causing the linear actuator to translate the appropriate distance. This will engage the connecting rod, therefore, the selector plate. As the plate rotates, it activates the solenoids inside the gearbox which are responsible for altering the internal gearing position. Further to this, the ATV transmission programming system will feature an automatic 'park-engage' system when the ATV is started and stopped. This removes the risk of the vehicle rolling away if unattended or if the operator forgets to move the gear position to the park location. Additionally, when changing gears, the system will automatically disconnect the current gear position and the corresponding backlit button transitioning to the new required position, lighting the new button. For extra safety and reliability of the design, the transmission system will be required to communicate with the acceleration system to prevent gear changes unless the ATV is stationary. This will also help to prolong the life of the gearbox as grinding of gears will be eliminated.

2.7. Testing, Modifying and Commissioning

Following the implementation of the proposed solution, the final phase scheduled to be completed to ensure functionality, safety and compliance is testing, modifying and commissioning. The preliminary testing is initialised by varying the actuator's position in a controlled environment before it is connected to the ATV. This is known as a bench test and is the safest and simplest method of testing as it eliminates most of the associated risk. The exact ramped speed, accuracy and repeatability of the system can be tested and modified before it is placed under load when attached to the vehicle.

The secondary testing consists of changing the gearing positioning while the bike is powered down, again eliminating several risks and creating a simpler testing environment. Modifications to the mounting angle, the distance of extension and ramped acceleration speed will all be improved during this stage.

Once this phase of testing has been completed and optimised, the following stage of trials will commence while the bike is suspended and secured off the ground. This is to prevent an incident from occurring if the newly implemented system fails and the bike is unable to be controlled, causing damage and injury to the surrounding equipment and bystanders. In this phase, the purpose is to test and optimise the communication to alternate systems such as the brakes, acceleration, display monitor and the main control system.

2.8. Control System

An Arduino Uno Board was used as it was simple to program and install. This type of microcontroller was used for prototyping as it was simple to program and install.

For the prototype software only, an H-bridge was created using relay boards [27]. An H-bridge changes the polarity on the DC motor within the actuator by changing the flow direction of the current. This alters the direction of motion of the actuator shaft, causing it to extend or retract. Two momentary buttons are attached to the Arduino (Fig. 7), which are used to send a signal to the processor, determining the appropriate combination of relays to be activated/deactivated to achieve the desired movement.

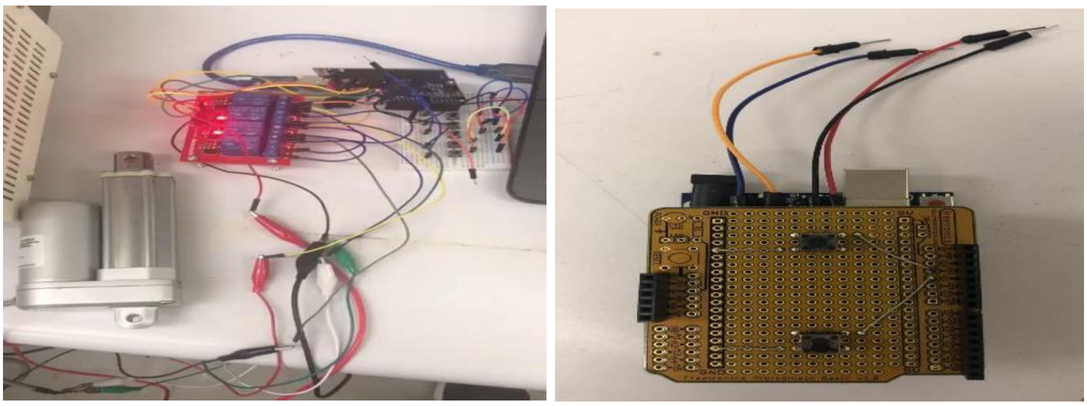

Fig. 7. Hardware (Prototype Proof of Concept and Prototype Testing Device)

3. RESULTS AND DISCUSSION

3.1. Temperature

The temperature of the vehicle components (Gearbox, Exhaust, Heatshield, Dump Pipe, Engine, Frame/Chasis, surrounds) were taken in two trials as shown in Tab. 1. It was observed that temperatures around the gearbox and the engine were around 100^{o}C.

Tab. 1

Temperature

Component	Cold - Temperature (°C)	Hot Trial 1 – Temperature (°C)	Hot Trial 2 – Temperature (°C)
Gearbox	24	76	85
Exhaust	23	198	183
Heatshield	23	60	75
Dump Pipe	23	470	455
Engine	23	87	100
Frame/Chassis	24	43	45
Surrounds	24	50	55

3.2. ANSYS FEA on Custom Made products

The ANSYS FEA analysis was performed to determine if the design would achieve infinite life criteria and perform correctly for the intended purpose. The following table contains the summarised results from the analysis.

Tab. 2

ANSYS FEA result

	Component	Maximum Deformation	Maximum Stress	Maximum Strain	Life	Safety Factor
Bracket	**Original**	0.21121	3.183	0.002923	7.331e5	0.9739
	Final	0.005497	12.768	6.9473e-5	1e6	1.35
Mounting Plate	**Original**	0.05748	54.479	-	1e6	1.5823
	Final	0.06902	20.727	-	1e6	4.1589

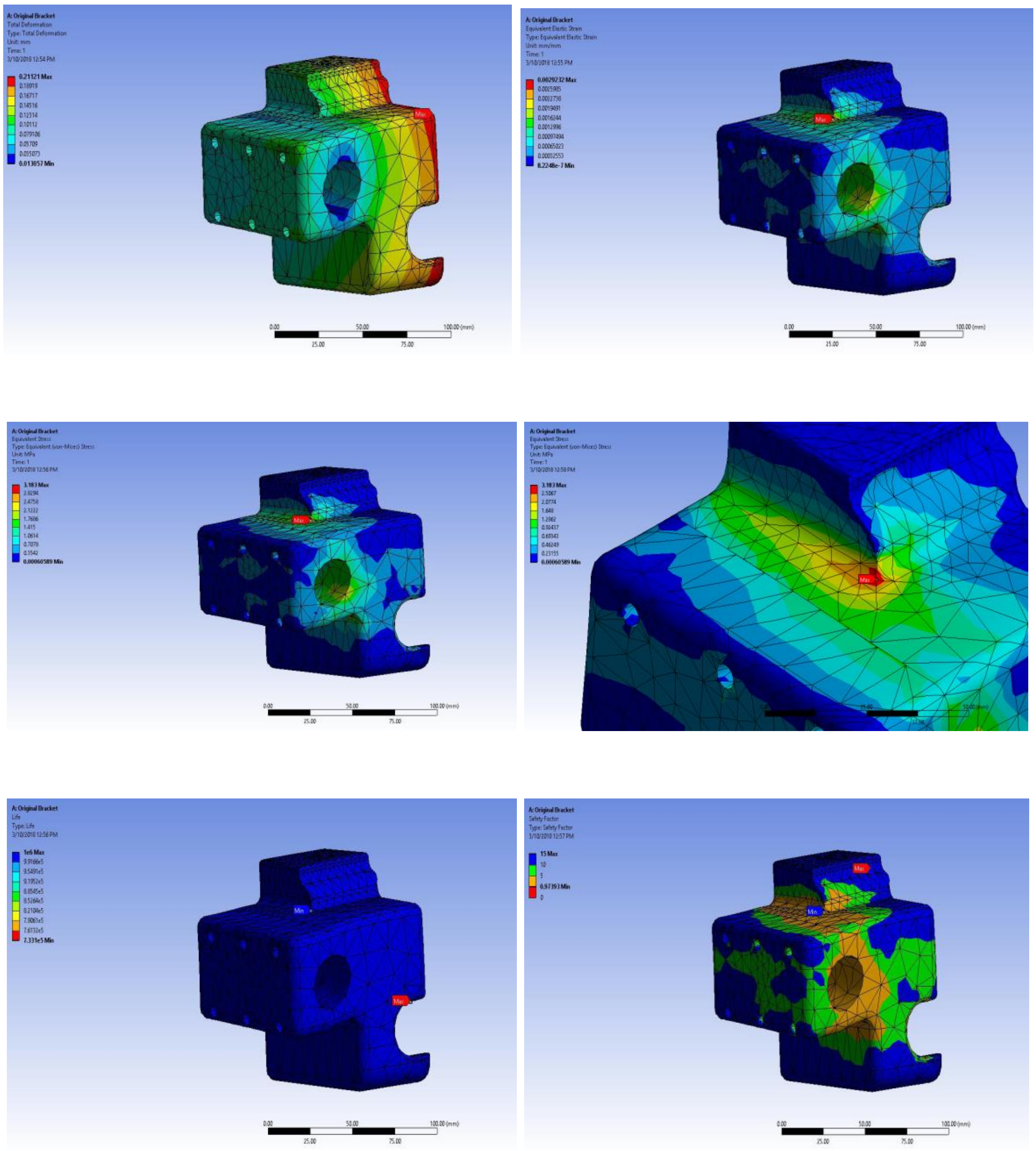

Fig. 8. Original Bracket (Deformation, Strain, Stress, Stress (Zoomed), Life and Safety Factor)

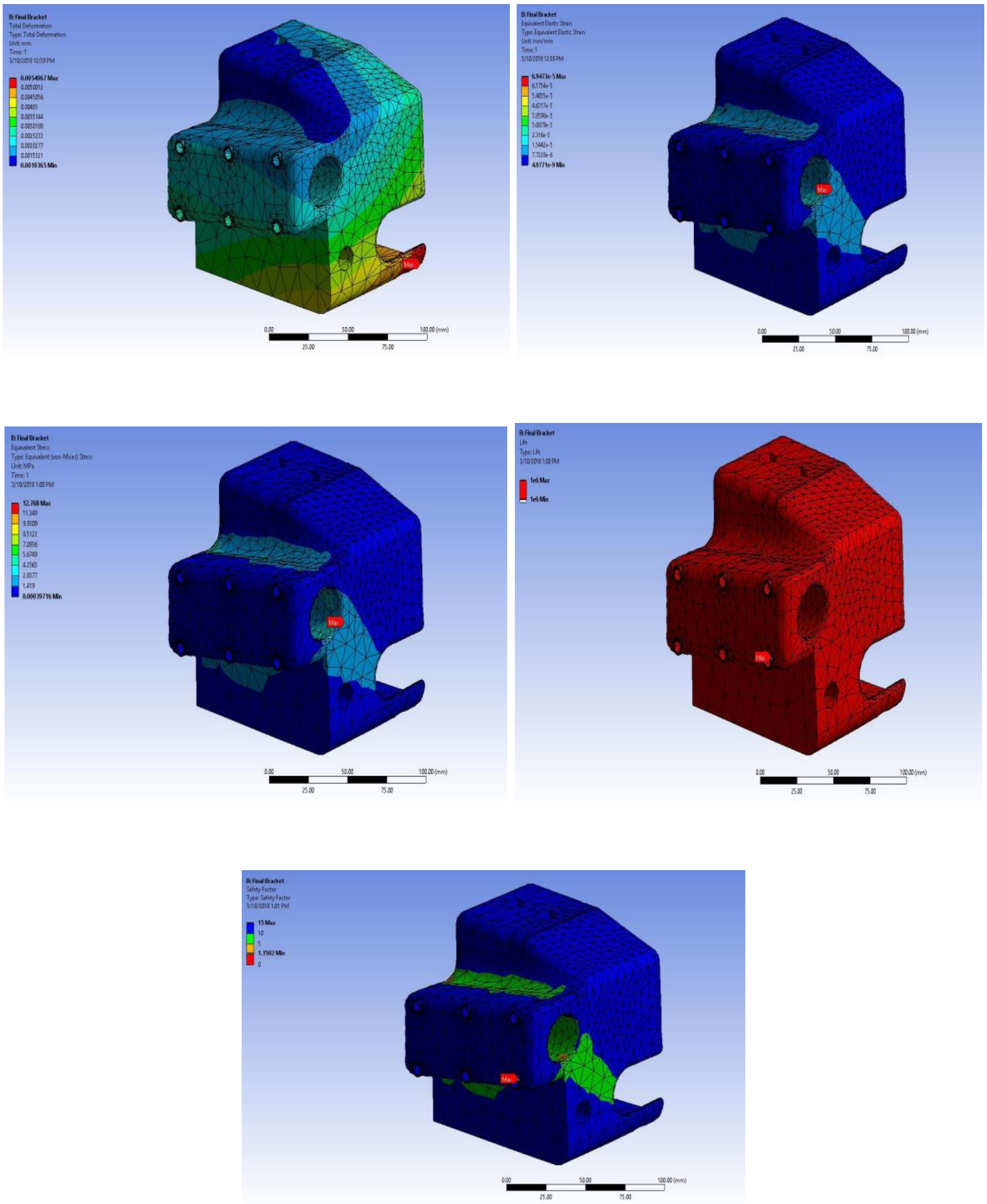

Fig. 9. Original Bracket (Deformation, Strain, Stress, Life and Safety Factor)

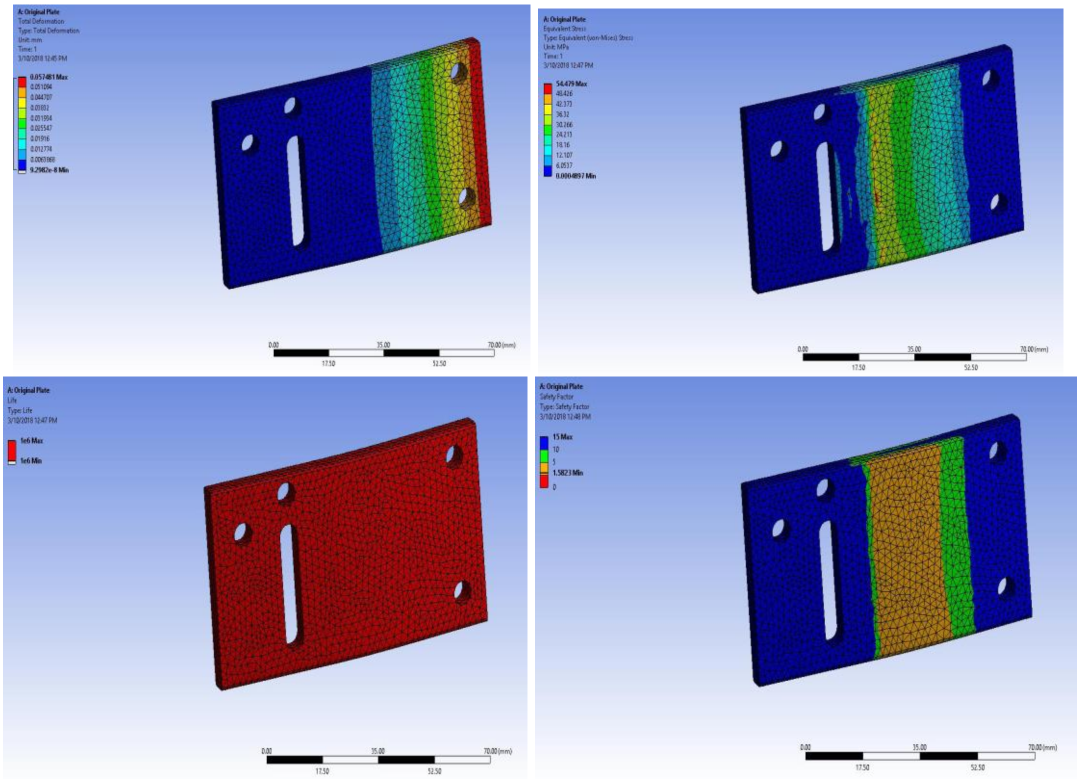

Fig. 10. Original mounting plate (Deformation, Stress, Life and Safety Factor)

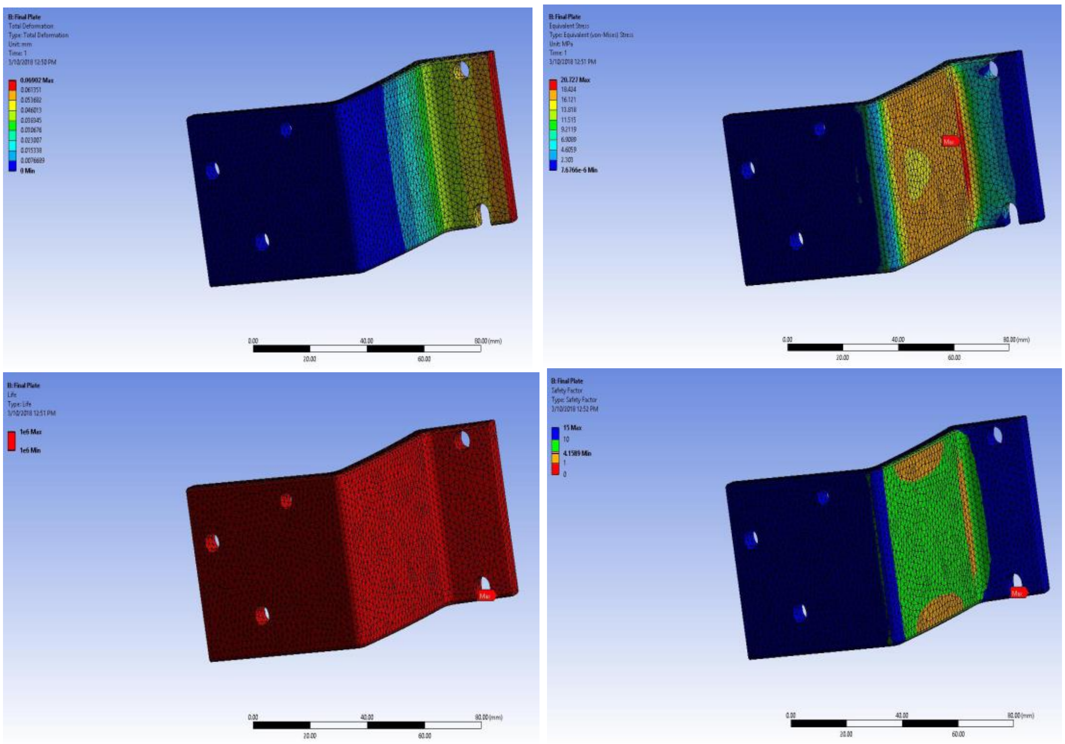

Fig. 11. Final Mounting Plate (Deflection, Stress, Life, Safety Factor)

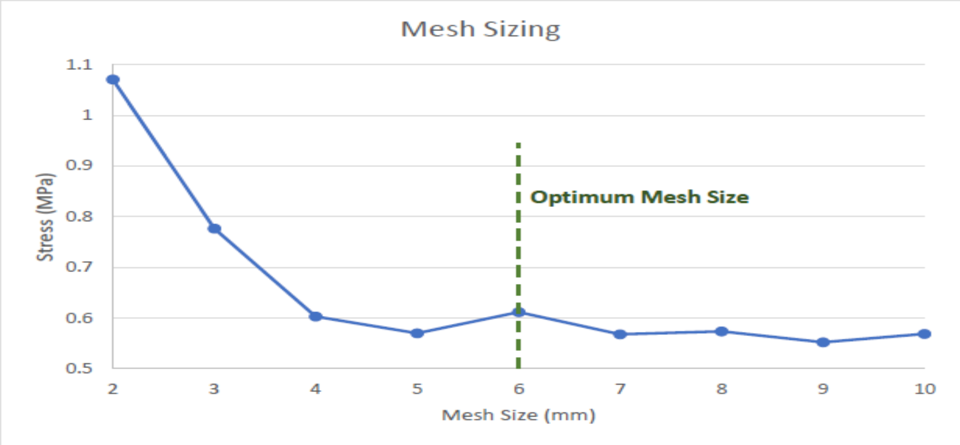

Fig. 12. Mesh Sizing

The mesh size used throughout the analysis was determined by comparing nine different sizes from Fig. 8 to Fig. 11. The results were graphed in Fig. 12. A 6 mm mesh size was selected as it was the most accurate. The stress results remain similar for mesh sizes from 7 mm through to 10 mm. At the 6 mm point, the stress increases before dropping. According to literature, this point is the most optimal for accuracy and computational speed and efficiency [16].

When analysing the bracket in ANSYS, the actuator was fixed by applying a remote displacement, the fixed end only allowing rotation in one direction. The opposite end of the actuator had a remote force applied to the hole in the shaft. The magnitude of this force was set using the component form. The actuator bracket was fixed in place using remote displacement restricting movement in all directions.

When analysing the mounting plates, an additional component was added into the assembly, which was used to apply the force. Originally, the force was applied using a point load, however, it was clear that the result computed was inaccurate and did not replicate the situation investigated.

It was observed that the bracket would not achieve the desired infinite life criteria and would fail. This was confirmed when cracking occurred after the bracket was installed. The bracket was redesigned, reanalysed, and reprinted. Although, the model showed that the new bracket was a suitable design, however, it was limited in its ability to withstand heat, tighten the proof load of the bolts sufficiently as well as oppose the extreme non-intended force due to the physical properties of the plastic it was constructed from. Consequently, it is recommended that for further use of this system, the bracket should be constructed from a stronger material such as aluminium.

4. CONCLUSION

Due to the labour involved with eradicating weeds, there is only a small increase in the profit margin if the crops are treated. This cost could significantly be reduced by using an Autonomous vehicle capable of deploying herbicide. As a result, an autonomous transmission system for a 2017 Yamaha Grizzly All-Terrain Vehicle was developed.

Preliminary tests found that temperatures of around 100°C occurred around the gearbox and the engine. Additionally, the travelled distance between the connecting rod and the gear selection tab was 47 mm, which caused a 70° angle of rotation of the tab. This motion required 7.06 Nm of torque to alter the gears mesh combination. The force to move the tab was originally supplied by the shifter lever and transferred its force through the connecting rod and to the gear selector tab. At this point on the tab, the force required to change gears was 353 N. Using these parameters, an electromechanical linear actuator was chosen as a prototype device to simulate the input motion from the operator of the vehicle. The Motion Dynamics HB-DJ806 - LALI10010 actuator was capable of exerting 200 N at 35 mm/seconds. It had a stroke length of 50 mm and was powered by a 12V DC motor, which drew 3 amps at maximum load.

The actuator was installed, and an electric controller was developed using an Arduino Uno Board to drive the actuator for testing.

The transmission system developed proved the design concept, however, it was concluded that it was not a reliable and robust system, which would achieve infinite life criteria. Subsequently, a larger, stronger and faster actuator was purchased and installed. The new actuator was capable of exerting 300 N at 36 mm/s while drawing 2.5 amps to its 12V DC motor. Before procurement, this new actuator was digitally modelled using SolidWorks 2017 and 3D printed to confirm the mounting position and method. To mount the actuator and restrain its motion, a mounting plate and bracket were manufactured from mild steel and plastic, respectively. The bracket was designed and digitally model then 3D printed and installed. An FEA was conducted on the custom-made components using ANSYS to ensure reliability. The FEA suggested that the bracket would not achieve the desired infinite life criteria and would fail. This was confirmed after cracking occurred following the installation of the bracket. The bracket was redesigned, reanalysed, and reprinted. Although, the model showed that the new bracket was a suitable design, its ability to withstand heat, tighten the proof load of the bolts sufficiently as well as oppose the extreme non-intended force was limited due to the physical properties of the plastic it was constructed from. Accordingly, it is recommended that for further use of this system, the bracket should be constructed from a stronger material such as aluminium.

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