Study on the Application of Continuous Variable Transmission [CVT] Technology to Manual Transmission Three-Wheeler

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***Abstract*—Automobile engineers are concerned about the parameters which are performance, efficiencies, safety, comfortability, budget, and environmental friendliness while designing a new vehicle. Currently, vehicles with automatic transmissions are getting more prominence over ones with manual transmissions in the case of newly designed vehicles. In this research aim is to convert a manual transmission vehicle to an automatic transmission. Therefore, a 4-stroke 205cc three-wheeler with a manual transmission is converted into an automatic transmission system by using rubber V-belt CVT technology. The significant benefits and drawbacks were analyzed to select Belt CVT technology for this approach. The power transmission starts from the flywheel to the Primary pulley of the CVT via a chain drive mechanism. while a secondary pulley of the CVT is directly connected to the differential gear setup. Both the primary pulley and secondary pulley are connected by a Rubber V-belt for power transmission. The physically developed model of the research has achieved a maximum speed of 24kmph while experiencing troubles under off-road conditions with high fuel consumption. The reason for such low speeds was addressed as the impact of the weight of the rollers in the pullies. The reverse drive remained unchanged. Simultaneously it has resulted in comfortable driving, less fatigue, ease of driving, and suitability for disabled individuals. A future direction has been highlighted with the application of center springs of the secondary pulley and weight reduction of the roller weights.**

Keywords*—CVT Technology, Automatic Transmission, Three-wheeler, Chain drive mechanism, Rubber V-belt

I. INTRODUCTION

In Asian and African countries millions of three-wheelers are used as taxi services. Three-wheelers are popular among low-income groups due to the lowest selling price [1]. Normally, the 4-stroke three-wheeler comes with a manual transmission system with 4 forward gears and 1 reverse gear. However, an automatic transmission three-wheeler is not yet commercially popular in the market. In the automatic transmission, there is more comfort during driving situations as it can provide a smooth driving experience and can minimize day-to-day driving difficulties in hills, traffic, or instances where rapid gear shifting is required [2].

Automatic transmission vehicles are very popular in the present market due to their faster gear changing, lack of manual shift gears, improved drivability, and overall efficiency. According to the researchers, three-wheelers run around 40- 60km per day in urban towns [3, 14]. Due to the heavy traffic, driving a manual transmission vehicle is quite strenuous for the driver (especially for taxi three-wheeler drivers). Additionally, an automatic transmission three-wheeler could be handled by disabled individuals also, as reduced, and simplified driver input requirements compared to a conventional system. Though more than 4.5 million three-wheelers with manual transmission are in use, more researchers focus on conventional vehicle re-design and further development to gain more benefits [4]. Environment pollution by emissions, higher fuel consumption, and lower efficiency are remarked as the drawbacks of conventional vehicles. And, in automatic transmission, it is not required to perform any action to shift to the next gear. It is easy to step on the accelerator pedal and drive. braking is enough to control the speed of the vehicle. However, in manual transmission vehicles, driving is dependent on the driver's ability to drive the vehicle by engaging and disengaging the clutch with the help of the driver's foot. According to those inputs, the gear ratio would be changed. Hence, the driver needs good practice and knowledge to handle these clutch, brake, and accelerator pedals for a comfortable ride. Next, there are a few key performance indicators available for automatic transmission systems to compare with manual transmissions, namely, fuel economy, durability, performance, and control. [5]

The CVT transmission system is an outstanding technology for an automatic transmission vehicle. Lightweight components, infinity gear ratios, quick gear changes, ease of driving, low cost of production, simple configuration, and less regular services are the key benefits of the CVT system. Metal belt CVT and rubber belt CVT systems are the most popular and usable technologies which have energy efficiency ranges from 90 to 97 percent. Drive pulley, driven pulley, and belt drive are the major components of the rubber V-belt type CVT system [6, 13].

Most passenger vehicles are manufactured with automated manual transmissions or automatic transmissions, but the major drawback is that brand-new vehicles are more costly than vehicles with conventional manual transmissions. On the other hand, three-wheelers are not commercially popular with the automatic transmission system, the introduction of automatic three-wheelers could create significant impacts on the market, and it will be one of the biggest challenges to the conventional three-wheeler's marketing strategies [2, 15].

Normally three-wheelers are mainly devoted to serving the middle-income group people. The Highest cost accumulation is the major reason for not being popular or not selling the brand-new three-wheeler with the automatic transmission system [8]. However, the conversion of manual vehicles to automatic transmission systems will not be more expensive than the price of a brand-new three-wheeler. Therefore, this research aims to “Develop a three-wheeler with automatic transmission using continuous variable transmission [CVT] technology (replacing the original manual transmission system) to improve the drivability”. introduction of the latest and cost-effective conversion technology, development of a lighter and compact transmission system, improvement of the drivability experience with less fatigue of the driver, improving the fuel efficiency, and providing a safe and comfortable drive for disabled taxi drivers are the objectives of this project.

This paper is based on the 205cc 4-stroke three-wheeler. Based on the user feedback from society, the requirement of a three-wheeler with automatic transmission has been proven. Finally, a rubber V-belt CVT transmission technology was selected mainly to gain 97% energy efficiency through the system [13].

The principle of this conceptual study is based on several strategies. Reducing the weight of the system, applying minimum changes to the original system, the use of already available spare parts as much as possible, and designing a compact frame to utilize space in the engine compartment. Parts from conventional transmission were removed which are useless for CVT and the reverse gear setup was kept as it is because it was connected to the gearbox separately. Instead of fixing a new reverse gear setup, this conventional reverse gear was used. Due to removing unwanted parts from the transmission and adding CVT the transmission balanced the weight of the vehicle without overweighting.

Features of this system include having mechanical spare parts that can be easily replaced when required, and a user-friendly and simple system that can be repaired easily. High-quality materials for custom-made parts and company-verified mechanical spare parts are included while assembling the final system to achieve the lowest operating cost and low maintenance cost with an acceptable level of safety are few to mention [9]. Usually, the CVT system belt needs to be replaced after passing some range of km of the vehicle, which is notified by the manufacturer. Once the driver felt a lack of speed while accelerating than usual, the variator roller weight needed to be replaced. This design is simple, and few mechanical parts are available. Due to this benefit maintenance is periodically occurred. Due to the selection of cost-effective - high-quality spare parts, the operating cost is also low. In conventional transmission systems, clutch cable and reverse cable replacement, clutch plates and pressure plate replacement, lubrication, gear wheel replacement is so on need to be done when required which tends to increase the maintenance and operating cost.

The preliminary stages start from a conceptual design using Computer-aided design software (SolidWorks) and ensuring the product part’s quality and behavior under real-life conditions by using FEA software (ANSYS). Based on the set of calculations, the exact dimensions of required parts and equipment were obtained. After completing the unit and integrating it into the conventional three-wheeler, A series of testing procedures were conducted to ensure the developed concept’s outcomes. A few remarkable conclusions were made based on this modification, in terms of budget and fuel economy whilst describing the driver's comfortability and safety.

II. Methodology

The research was completed within several stages, initially created a plan of methodology as shown in Fig. 1., to minimize the difficulties and to be ready with a quick solution when any possible issues occurred. The work started with a conventional vehicle which had an original manual transmission system. Identification of the parts that are needed to be removed from the system was the starting point. Clutch plates, pressure plates, clutch cable, clutch lever, and manual gearwheel setup [except the reverse gearwheel setup] were identified and removed. At this point, a feasible analysis was done to ensure the required components of the CVT system could be fixed with the available components of the conventional system. For this development, more attention was paid to finding the components and parts that are readily available in the market. However, some parts were identified as they needed to be custom-made according to this concept.

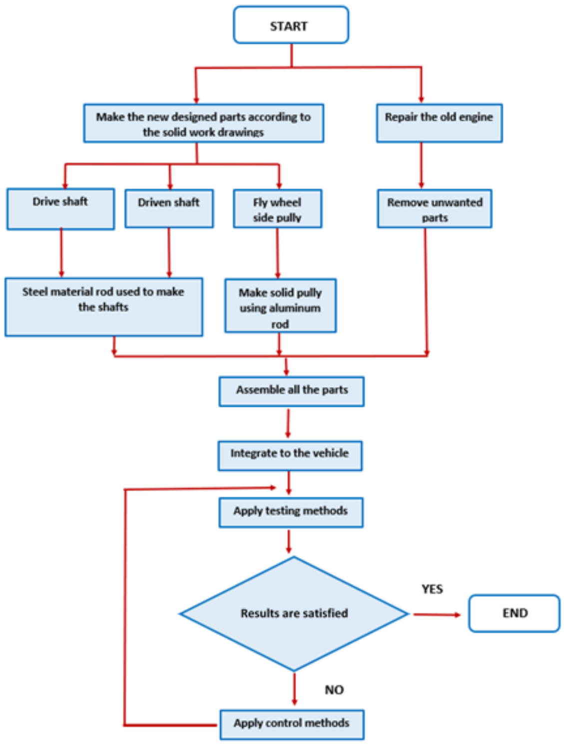


Fig. 1. Progress Flow Chart

Due to the selection made of the conventional vehicle, the engine was repaired to get the optimal working condition of the vehicle. Meanwhile, calculations were done to determine the size of each component of the CVT [9, 17]. There are a few assumptions made for ease of the calculations. In general, a three-wheeler’s odometer shows in the range of 0-80 km/h, a maximum speed is assumed to be 65km/h as an average of a conventional three-wheeler with 3 passengers.

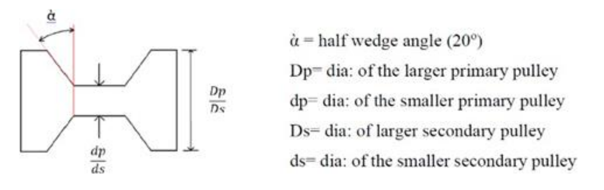
TABLE I. THREE-WHEELER'S SPECIFICATIONS

Description	Value
Maximum torque of the engine	17 Nm
Maximum Power of the engine	7.6 kW
Mass of the empty Vehicle	262.32Kg
Mass of Vehicle with driver	332.32Kg
Mass of Vehicle with driver + 2 Passengers	400Kg
Mass of Vehicle with driver + 3 Passengers	542.32Kg
Maximum r.p.m	5000 r.p.m
Minimum r.p.m	3500 r.p.m
Maximum speed (*V*)	65 km/h
Radius of the tire (front)	0.2m
Radius of the tire (rear)	0.2m
Frontal area	1.5414 m^2
Maximum gradient angle	25°
Density of Air	1.2
Coefficient of drag	0.385
Coefficient of rolling resistant	0.015
Transmission efficiency (ŋ)	0.85

From the data, available as shown in above Tab. 1, a few component calculations were performed. Tab. 2 below summarizes the results of the mathematical calculations performed.

TABLE II. SUMMARY OF THE CALCULATIONS

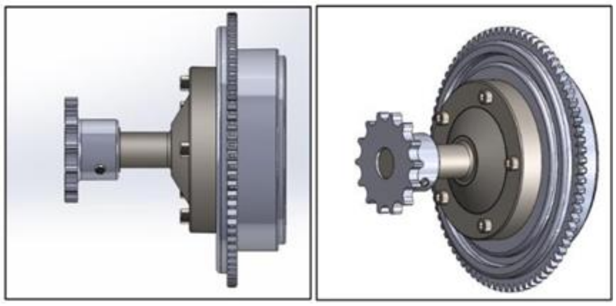
Description	Results
Speed of tire (N), at 65 km/h	861.82 r.p.m
Air resistance (*Fd*)	114.49 N
Rolling resistance (*Fr*)	79.80 N
Gradient Resistance (*FG)*	2048.39 N
Tractive Effort (*TE*)	2242.68 N
Torque	448.53 Nm
Higher gear ratio (Transmission)	5.27
Lower gear ratio (Transmission)	0.45
Higher gear ratio (by CVT)	5.89
Lower gear ratio (by CVT)	0.48
CVT Pulley sizes (as per the Market research)	*Dp* = 107 mm *dp* = 24 mm *Ds* = 141.5 mm *ds* = 52mm
The center-to-center distance of pullies.(to determine the Belt length)	530 mm
Chain drive gear ratio	1.7:1



Fortunately, the available size of the CVT components is matched with the required size for this concept. As shown in Tab. 2, the three-wheeler's engine required a higher gear ratio as given in 5.27 and a lower gear ratio of 0.45 which can be achieved by using this selected size of CVT pullies. This CVT provides 5.89 as a higher gear ratio and 0.48 as a lower gear ratio. That made it easy to advance the concept beyond the prototype model.

After the selection of the required CVT system components was done, the next stage was to design the new components namely, the chain drive shaft, driven shaft, and drive shaft of each pulley. According to the selected part's dimensions and requirements of the system, all the shafts were modeled by using Solid Work Software as shown in Fig. 2., Fig. 3., Fig. 4., and Fig. 5. and the shafts were tested according to Finite Element Analysis by using ANSYS 2022 R1 software as shown in Fig. 6., Fig. 7., Fig. 8. to ensure the physical behavior of the shafts as in real-life conditions.

Fig. 2. Flywheel assembly.



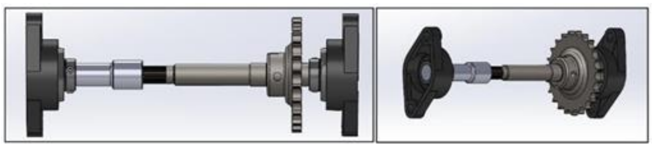


Fig. 3. CVT drive shaft assembly.

Fig. 4. CVT drive shaft – Primary pulley shaft.

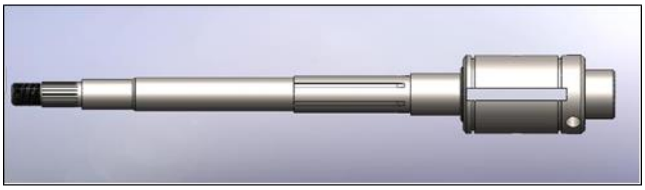


Fig. 5. CVT driven shaft – Secondary pulley shaft.

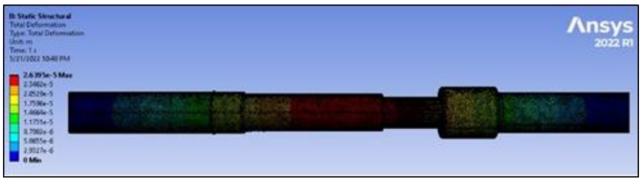


Fig. 6. FEA of CVT drive shaft.

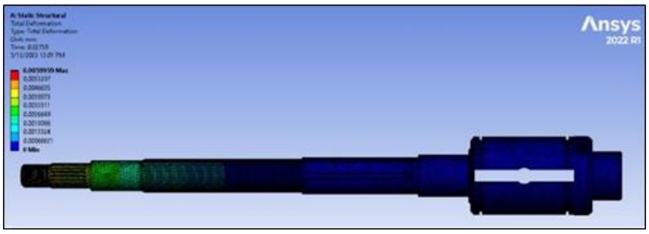


Fig. 7. FEA of CVT driven shaft.

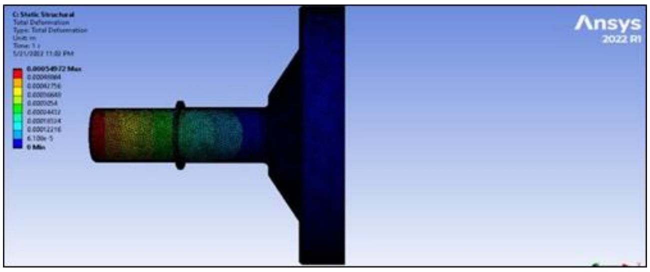


Fig. 8. FEA of Flywheel shaft.

Under Finite element analysis – FEA, Total deformation, elastic strain, and equant stress were analyzed mainly for each shaft. Once the simulation results were highly satisfied, shafts were constructed using AISI 1035 steel as per the design.

In the design stage, A trial-and-error approach has been used for the fixing of components where the appropriate means have been identified. Because of the available resources of the market and space utilization of the engine bay, the chain drive mechanism that can transfer the engine power to CVT was added to the design. In the end, the drive shaft location was changed from the original vehicle design. While the driven shaft is not changed. The chain drive mechanism is fixed on the flywheel as shown in Fig. 2.

II.I Power Transmission

The power flow of the assembled final system can be defined as a driver who can control the acceleration lever (throttle position) which is fixed on the steering handle of the three-wheelers. Then the engine produces power to move the vehicle. As usual, engine power is taken directly from the crankshaft to the flywheel. According to the flywheel rotational speed, the shaft that connects the flywheel will also be rotated. Two sprocket wheels, one from the flywheel's side and the other from CVT's primary pulley side are connected by a chain drive that can transmit the power from the flywheel shaft to CVT's primary pulley shaft. Hence, CVT gets power from the engine now as shown in below Fig. 9. The primary pulley and secondary pulley of CVT were connected via a rubber V belt. Then finally, power is transmitted from the secondary pulley to a differential unit of the engine.

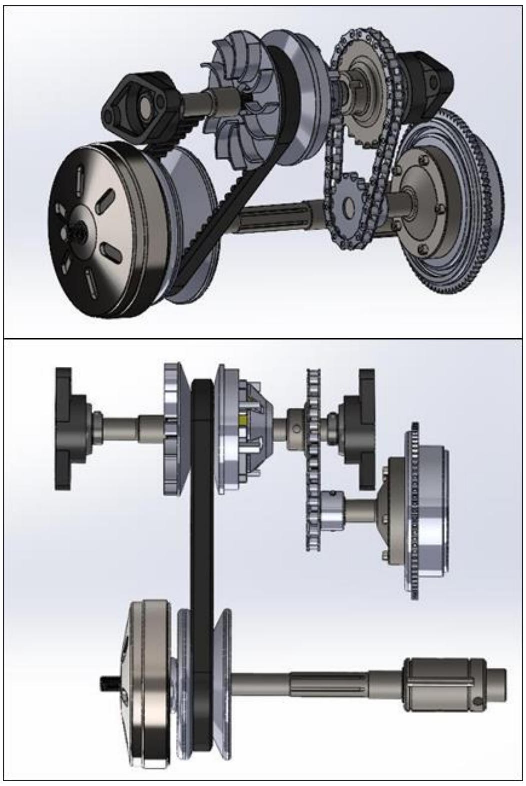


Fig.9. Final 3D design of the concept

The primary pulley of the CVT contains a ram plate, roller weights, variator plate, and front plate. The front plate is fixed while the variator plate can only move. When this shaft is rotating, roller weights will move from the center of the plate outwards. This moment will induce the centrifugal force along the curved surface. When the roller weights are moving, the variator conical plate will move meanwhile the ram plate is in a fixed condition as shown in Fig. 10.

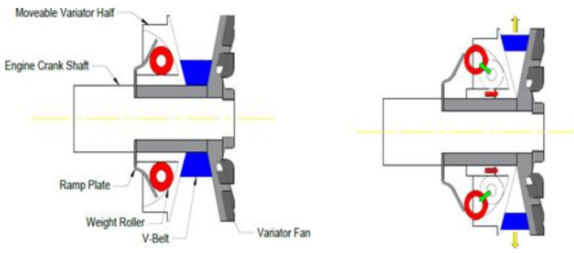


Fig. 10. The behavior of the Roller weights

The belt drive will be under friction to rotate both pullies. The secondary pulley which is consisting of the clutch bell housing, outer and inner conical plates, center spring, centrifugal clutch assembly, etc. One of these plates is fixed and another one is capable of moving. The clutch assembly consists of weighted arms which are connected to the secondary pulley. When the speed is over the ideal speed, or in other words, when sufficient speed is reached, this weighted arm will swing outward causing the centrifugal force. Weighted arms consist of friction pads that are engaged with the clutch bell housing. Thus, the clutch bell housing will get the speed of the system to rotate. At the end, the secondary pulley will transmit the power to the wheel through the final gear setup of the transmission system.

This system should fix the chassis of the three-wheeler. In a three-wheeler, the engine is located at the rear side. The frame was made by using iron metal plates (8mm thickness) and mild steel square rods (thickness 6mm). This frame needs to only hold the primary pulley assembly. Therefore, the use of steel plates and rods is a compact way to reduce the weight of the system.

The final stage of designing is the testing procedure. The CVT system is absent with a neutral gear which is only available with the manual transmission system. Once the vehicle completely stops and brakes are applied, in this situation only the CVT system can activate the neutral gear. When starting the vehicle, press the brake pedal and accelerator gently and start it by twisting the ignition key or pressing the start button. Once the engine is started, release the pressure on the brake pedal slowly meanwhile increasing the acceleration. Normally CVT system is not functioning when the engine is starting which is about the ideal speed of the vehicle, the speed of the CVT system is dependent on the acceleration level. Anyhow, at any time like traffic modes neutral gear requirement arises by applying brakes that can be achieved. But when thinking about the neutral gear requirement beyond this point, emission testing occurs. The engine emission tests needed to be done by accelerating the vehicle up to some RPM level. This traditional three-wheeler can be tested by having the vehicle in a neutral gear position, but in the CVT system due to the absence of a neutral gear that could not be carried out. If it is needed to be added to this system, that would require fixing a separate gearbox with the CVT. To keep the design simple and compact this idea was not considered. Anyhow, to solve this drawback of this concept, one suggestion has been elaborated here. As shown in Fig. 11., the three-wheeler's engine and transmission system will automatically be in the neutral position when lifting one rear wheel from the ground at the same time the other two wheels should be on the ground. Finally, the three-wheeler was in the neutral position and able to conduct the emission test. Driver normally keeps vehicle jack while driving for any unexpected or instant repairing purposes.

Fig. 11. Tire lifted to get the neutral condition.

II.II Test the System

One of the major factors affecting the CVT system is gear transmission efficiency which can be defined by CVT pulley diameter's changing capacities. The changing of the gears automatically is done by the diameter variation of each pulley [8, 17].

To ensure the pulley's diameter variation, one technique was elaborated. Firstly, dismantling the CVT primary pulley assembled from the holding frame. By using a marker pen, an Ink mark was drawn on the variator plate surface as a visible line that can be easily erased. The displacement in full acceleration is measured depending on the weight of the roller and the rpm of the engine. As shown in Fig. 12., after the full acceleration was completed, the ink line was erased up to this level. This test was used to determine the belt rising level at high acceleration.

Fig. 12. Ink mark to determine the belt rising level

To conclude the value of this research to the market, a survey-based study has been carried out to identify further improvements and suggestions for the developed mechanism from the end users.

III. Results and Discussion

To compare the features, both systems were subjected to similar experiments. The newly developed automatic transmission three-wheeler and conventional transmission three-wheeler were driven on a selected road. When the vehicle runs in a flat road condition it reaches 24 km/h with two passengers on board at the high speed of the three-wheeler in flat road, right this time the accelerator is also pressed at its highest level to provide full throttle to the engine. The driving experience was found to be smooth and unnecessary vibration or noises were not observed. Vehicle sound is also normal as in the case of a conventional three-wheeler. The gear changing is done smoothly without any fluctuations, delays, unnecessary vibrations, or shocks.

Under hilly road conditions, the vehicle reached 14 km/h as a top high speed with two passengers while 18 km/h was its top speed without passengers and goods. Right this time, Testing was done by providing full-throttle conditions. When the road traffic situations, a three-wheeler can keep the engine running in idle whilst the three-wheeler is stopped, also, when it is required to drive immediately, smooth acceleration was observed. The CVT was able to change speed and torque by itself smoothly when the driver provided inputs or commands for acceleration and brake. The pickup speed of the CVT system is at a satisfactory level as it was able to reach the highest of 24km/h speed in 13 seconds by providing the full throttle and this system can keep the vehicle in idle condition by providing low throttle same as in the case of the neutral position of the original manual transmission system.

Once the engine is started that engine power will not force to move the vehicle if the vehicle is parked on a flat surface which is like a conventional manual transmission three-wheeler under neutral gear. But when starting the engine, the driver needs to apply brake until the engine gets started. Once the acceleration is gradually increased by the driver which causes the vehicle to start, then move.

This developed CVT three-wheeler is also able to reverse the vehicle as in the case of a manual transmission-based system. Reversing speed also reached up to 22 km/h. No excessive vibrations, no shocks, no unwanted noises, or delays occurred when trying to reverse the vehicle. The torque and speed changes were also smooth while reversing as well. In this vehicle, a conventional reverse gear setup was used without any changes which comes as separate from the manual transmission.

The driving comfort of the developed system is a different experience for passengers when compared with manual transmission three-wheelers. Driving is also easier than manual transmission, no effort needs to be made to change the gears, and it would automatically change as per the driver's requirements when depressing the acceleration pedals. CVT provides infinity gear ratios.

In terms of fuel consumption, this three-wheeler with the original transmission system (before changing to CVT transmission) worked at 30 km per 1L of petrol. After changing this from a manual to an automatic system, it was tested to be at 22 km per 1L. But fuel consumption was higher than with the original transmission system in an unexpected way.

To realize the reasons behind low speed and high fuel consumption, some techniques were incorporated. The primary pulley's major components are the set of six flyweights and the moveable sheaves as shown in fig.10. When the engine speed is gradually increasing, the six flyweights (rollers) tend to swing and generate a force that works on the ram plate of the primary pulley, reducing the gap between the ram plate and the variator. As the contact ratio of the belt rises in the primary shaft, the gear ratio rises as well. More force will be delivered to the ram plate of the primary pulley in CVT by producing a heavier roller, pulling the rear pulley forward more quickly. If the roller weights are heavy, the gear will be required to act at a high speed. As the mass of the roller rises, so does the centrifugal force in the primary shaft, which transmits power and torque through the belt.

Fig. 13. Two types of the Roller weights

In the analysis of speed, the impact of the roller set's weight on the speed of the vehicle was compared. Two different sets of roller weights with diameter variation have been selected as shown in Fig. 13. and compared in case of full throttle position. With higher-weight rollers which weighed 105.54g, the belt drive is raised to 21.5mm out of 41.5mm of the completely higher diameter of the variator pulley while the low-weight roller set which is weighted at 83.70g belt rises to 33.47mm out of 41.5mm of the complete diameter of the pulley. It differed from around 11.97mm distance. By using this procedure, finally realized that the weight of the roller weights is completely corporate to change the gear ratios. But these weight changes rollers weights would not improve the speed of this three-wheeler as well as reduce the fuel consumption. Because these two roller weights did not reach 41.5mm of the complete diameter of the pully to get to the optimum working condition of this CVT system. These roller weights are purchased from different manufacturing companies; thus, each roller weight has a specific RPM value and torque capacity to achieve the optimum condition of CVT. The lower weighted roller set which is 83.7g works with 7000rpm, and the higher weighted roller set which is 105.54g works with 8000rpm. But three-wheel 4 strokes with 205CC engine have 5000rpm as higher rpm than information provided by the manufacturer. However, this developed vehicle has made some differences when compared to the original vehicle conditions. To investigate the exact RPM of the developed system vehicle, an engine tachometer was used. The top RPM was noted as 3139 rpm by providing a full-throttle acceleration. Due to the lack of the vary roller weights in the market, could not find the exact matching roller weight to this development. This is the major reason behind the reduced performance of the system. It tends to cause high fuel consumption, slow speed while riding and made some difficulties in hill climbing also.

If these required gear ratios could be achieved with low acceleration input, then it can be assured that it will improve fuel consumption. This roller set is resistant to rollover completely with 3139 rpm while providing full throttle conditions to drive the vehicle. If the three-wheeler is driving on a flat road surface, low acceleration input is almost enough to drive the conventional vehicle, but this newly designed transmission system, always needs to provide full throttle to drive the vehicle even on the flat road due to available roller weights are not able to work with this 3139rpm. Once the rpm properties of the roller weights are completely matched with the engine rpm, able to manage the throttle conditions as in utilized level. Otherwise, fuel consumption automatically will be higher than manual transmission systems.

The secondary pulley center spring needs to be checked according to this system's required rpm level. The spring, which is used here works for 4000 rpm but still, it provides good performance for 3139 rpm. The effect from the secondary pulley spring is more acceptable than roller weight, as this spring was tested and became satisfied with the performance as expected.

IV. CONCLUSION

Three Wheelers is a compact budget vehicle that comes with a manual transmission system, which is very popular in Sri Lanka. Meanwhile, the automobile industry tends to manufacture automatic drive vehicles with more advanced technologies. Due to various advantages offered by automatic transmission namely, comfortable ride, less effort to handle the vehicle, ease to practice driving for anyone, suitability for disabled people, suitability for urban traffic area driving, etc. This research was aimed towards converting the manual transmission three-wheeler into the automatic transmission three-wheeler. Therefore, the CVT system with a rubber V-belt was selected instead of using another type of technology. This design was based on a compact light design with minimum changes to the original system, to stay within limited space in the engine bay of the three-wheel and low torque vehicle, this rubber V-belt type was selected. The major reason to select the rubber V belt, it is high energy efficient than the metal belt. By utilizing available resources, spare parts, etc. in the market, the design was done. According to the set of mathematical calculations, the parts and equipment were selected. Then all the components as per the design are mounted to the three-wheeler's chassis, and the research's aim and objectives which are defined already are clarified through the experiment tests. According to the collected results, the highest speed of the vehicle can be defined as 24km/h, and it was found to be somewhat difficult to perform a hill climbing drive. The reverse drive was also achieved as similar to the original vehicle without changing the original reverse gear design. The cornering drive also performed without any performance issues with the CVT transmission system due to the unchanged differential part of the conventional vehicle. Therefore, it could be stated that this research became a success, whilst providing comfortable drive, less fatigue for the driver of the vehicle, ease of the drive, suitability for disabled drivers, and lightweight compact design which are included in the objectives also achieved. However, the speed of the vehicle, hill climbing performance, and fuel consumption need to be improved once again by changing the specifications of the roller weights by matching with the engine rpm to enhance the newly developed 4-stroke 205CC three-wheel with the cover of all the equipment to protect them from dust and contaminants.

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