T-SPLIT DRIVE-TRAIN MODULE

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Abstract - *Operational and purposeful drive-train system of a vehicle should do the job of providing driving torque from power source and thus maintaining traction with surface. For effective torque distribution of torque at any road surface, torque vectoring concept is being analyzed, reviewed and tested. We solutions like ABS, Traction Control System, Electronic Stability Control, Limited Slip Differential, these aid vehicle to maintain stability, maneuverability, under-steer and over-steer reduction with respect to wheel spin correction etc. We have presented a framework consisting of mechanical, electric and electronic components, integrating conventional drive-train system, to escalate and efficiently provide torque distribution. Here, we have considered scenarios where torque vectoring is necessary, in support with analytical data to carry out simulations in MATLAB.*

Key Words: Torque vectoring, electric drive-train, servo motors, multi-plate clutch pack.

1.INTRODUCTION

In recent years, all-terrain vehicles (ATV) with hybrid or all electric power units are being accepted for personal, industrial and civil mobility catering private and public transportation, agricultural sector, security and defence, mining, construction and forestry equipment. Challenge to design a drive-train with maximum surface traction, reduce wheel-spin. ATV (All Terrain Vehicles) with high end application such as extreme off road racing can be equipped to enhance driving capabilities of vehicle. The scope here is to increase overall efficiency and effective torque distribution of proposed system. While considering conceptual realm of the project, DFM and DFA can be further analyzed.

2. LITERATURE REVIEW

The Research Gate publications cited a conference paper, namely, **Torque Vectoring Control for Progressive Cornering Performance in AWD Electric Vehicles**. A real-time integrated Torque Vectoring Control function was designed and implemented in an AWD axle-split hybrid vehicle. The front axle had a conventional combustion engine, and two individually controlled electric motors are located at the rear axle. The function aims to enhance the vehicle cornering performance by yaw torque control allocation, at steady-state and transient steering manoeuvre, with different propulsion inputs. Topics that were mainly discussed in this paper were Torque Vectoring, Vehicle Dynamics, Integrated Control, Electric Motors. The published conference paper helped us to get familiar with the concept of torque vectoring, understand performance of a hybrid two-door sports coupe car while cornering and selecting the required electric motor for our drive-train.

In the World Electric Vehicle Journal Vol. 5, we came across a research paper namely, **Torque Vectoring for Electric Vehicles with Individually Controlled Motors: State-of-the-Art and Future Developments**. This paper deals with the description of current and future vehicle technology related to yaw moment control, anti-lock braking and traction control through the employment of effective torque vectoring strategies for electric vehicles. This research paper gave us overview about behaviour of Torque vectoring for electric vehicle with individually controlled motor. The different conditions taking under conditions were, namely, 1) Torque vectoring control in steady-state conditions, 2) Torque vectoring control in transient conditions, 3) Torque vectoring control during emergency manoeuvre, 4) Torque vectoring control in off-road conditions.

A conference paper titled, **A Torque Vectoring Strategy for Improving the Performance of a Rear Wheel Drive Electric Vehicle** was published in Research Gate journal by authors Mr. Andrea Tonoli, Mr. Jyotishman Ghosh and Mr. N. Amiti. The conference paper presented a feedback controller for the torque vectoring control of a rear wheel drive electric vehicle. The main objective of the work presented is to improve the vehicle maneuverability. Distribution of driving/braking torque between left and right wheels allows optimal usage of tire forces which leads to better handling behaviour. The controller performance is evaluated by executing steady state and dynamic manoeuvre on a multi-body vehicle model. The dynamic manoeuvre include numerical simulations around a race track in order to understand the influence of torque vectoring across the complete working range of the tires.

In the 20th International Research/Expert Conference "**Trends in the Development of Machinery and Associated Technology**" a research paper, namely, **TORQUE VECTORING DIFFERENTIAL** is published. A torque vectoring differential is presented in this paper. Torque vectoring function is achieved through an additional assembly comprising of the differential gear set and motor. Since this solution does not use friction components it is efficient and durable. It has two main assemblies: standard open differential which realizes main torque transfer and a torque vectoring assembly which consists of differential gear set with electric motor and provides (adds or subtracts) additional torque

3. DESIGN BASED RESEARCH TOWARDS CONCEPT

Proposed concept is based on an ATV prototype which is manufactured in-house for collegiate undergrad competitions as seen in photo. The shown vehicle is capable driving in heavy off road, rough course with highly strengthened tubular chassis which can take roll over impacts and maintain driver safety from intrusions and impact. The vehicle is capable of maneuverability as it is designed with independent double wishbone, direct actuated suspension system. The drive-train considered here is conventional rear wheel axle, whereon an open differential distributes power to each right and left wheels. Here highly articulable driveshafts with constant velocity joints (CV) transmit torque to driving hubs.

Control architecture is designed with reference to analysis, speculation based on observation, driver feedback and experts' advice vehicle with referring '**TORQUE VECTORING DIFFERENTIAL**'.

Wherein, system performs well with an open differential as main torque distributing source; however it does not work at fullest on different surfaces. Main drawback of an open differential is that it distribute power to wheel with limited friction. For instance, vehicle is stuck at slippery clog where a wheel on ground surrounded with mud and other one is in air, ideally in the situation available power should be sent to grounded wheel, but open differential works exactly oppositely.

To find out alternate systems or solutions to tackle the issue, similar systems with torque holding or torque vectoring mechanisms were analyzed such as Limited Slip Diff (LSD), Anti-lock Braking System (ABS), Traction Control Unit, etc.

The platform over which vehicle's driving power is constrained is based on intercollegiate BAJA SAE India (Society of Automotive Engineers) competition. The rule for electric propulsion mentioned by SAE officials is presented along with image of the vehicle from the Team Conquistador (PVG College of Engineering and Technology, Pune),

4. DETAILED DESIGN BASED ON CALCULATION

According to constraints set, input and output parameters, design of sub-assembly components are explained as follows,

1. Power Supply Unit

The electric motor acts as an automatic transmission along with planetary gear set eliminating conventional synchronous-mesh gearbox. Our model's architecture based on limited sourced EV power-train, we had our mechanical output to 6kw (or equivalent 10 hp). For reference, electric motor IPM 200-33-AW01 from Dana TM4 which has peak power capacity of 6kw with 30 Nm of peak torque at 3200 RPM. Capacity and type of chosen electric motor can be altered after prototype analysis and requirement.

2. Final Drive Ratio

Final drive ratio was calculated for buggy so as to climb 35% gradeability and drive with load of 1T. Final drive ratio of 1:12.6 was selected. Please refer to mentioned paper [2. SAE BAJA Drive-train Report] for detailed report on consideration of drive ratios (along with associated competition rules, assumptions and professional reviews).

3. Differential Gearbox

Standard open bevel geared differential with gear ratio of 4.2 is used. Power is divided on each side of the output of the differential. Therefore output torque from the differential is 63Nm.

Planetary gear system will provide 63* 3= 189 Nm where output gear ratio of planetary set. This means torque is equally split between right and left tires.

According to design, as per requirement, when balance happens to be at around 25% and 75% for inner and outer wheels respectively, then 75% torque would be, 63*3*2*0.75= 283.5 Nm for outer wheel 63*3*2*0.25=94.5 Nm for inner wheel.

4. Planetary Gearbox

According to required torque at wheels (570 Nm), the final drive ratio at each wheel will be 570/2=285.

So Gear ratio of the planetary gearbox is 285/60= 4.75.

??. Clutch Pack Unit

A multi plate clutch is composed of a series of friction discs that are connected to a shaft. The friction discs have friction surfaces to increase the coefficient of friction.

Required clamping force on clutch pack is given as follows- 3.14*Pa*d*(D-d)/2 [Referred from 7. V. B Bhandari]

Where outer diameter of friction surface, D= 120mm Inner diameter of friction surface, d=D*0.577 (standard equation for multi plate dry clutch)

Pressure Capacity for graphite material, Pa=500 MPa.

Max torque transmitted to one side of drive train, Mt= 283.5 ..300 Nm (Assuming Safety Factor)

Clamping Force, F= 2760.377 N

No. of friction surfaces, z=4Mt/(mu*F*(Dd) =11.45 ...12 number of friction surfaces.

??. Actuation Unit

The clutch actuation system (mechanism) is the interface between the input shaft from planetary set and the shaft on clutch basket further connecting to driveshaft unit, which allows the control engagement and disengagement of the clutch.

??. Actuation Drive Assembly

An electric servo motor provides torque to an gear arrangement wherein, force is applied on actuation assembly to carry out clutch engagement(full, semi and auto) and disengagement. Power is transferred from servo motors through a single stage constant mesh gearbox which acts as an torque multiplier providing sufficient clamping force for effective clutch actuation (please refer to 5th point for clamping force calculation).

??. Servo Control Module

An algorithm has to be set up for control of servo motors [5*]. These were designed on the basis of vehicle dynamics parameters explained further.

Factors such as weight transfer, relative tire slip, wheel RPM, yaw and moment play crucial part that affects torque transfer at cornering situations. To get real time values of weight transfer, LVDT and strain gauge sensors can be used.

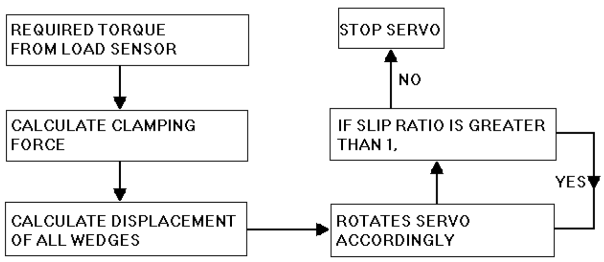
LVDT (Linear Variable Differential Transistors) are mounted on suspension struts to that vary resistance values with changing strut displacement while in operation. Attached sub-circuits send displacement values (in mm) to control unit.

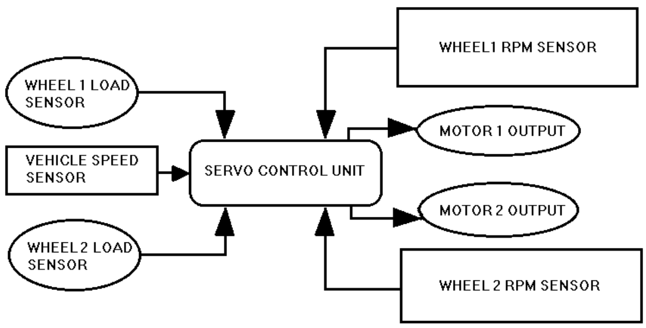
Strain gauges measure strain caused on vehicle body due to cornering, roll over, bump in track etc. These can be used in the system as alternative to LVDT or for calibration for switching between manual and automatic operation.

Lastly, wheel speed sensors (IR or hall effect based) are to be used to get tire slip ratio. If one wheel spins more than others, possibly it has lost traction due to surface undulation (like mud, icy patch, dirt). In such condition, torque requirement of that wheel is more for extraction of vehicle.

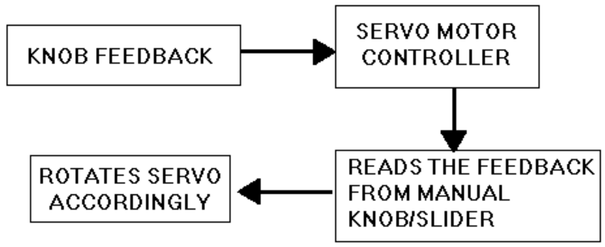
Following are flowcharts presenting algorithms to followed by servo control unit and components associated with it.

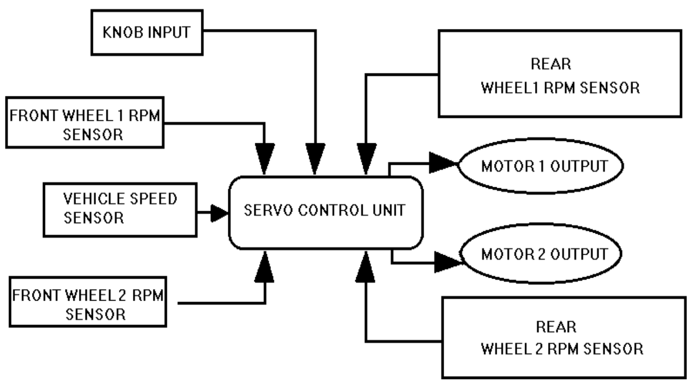
I?? Auto Operation





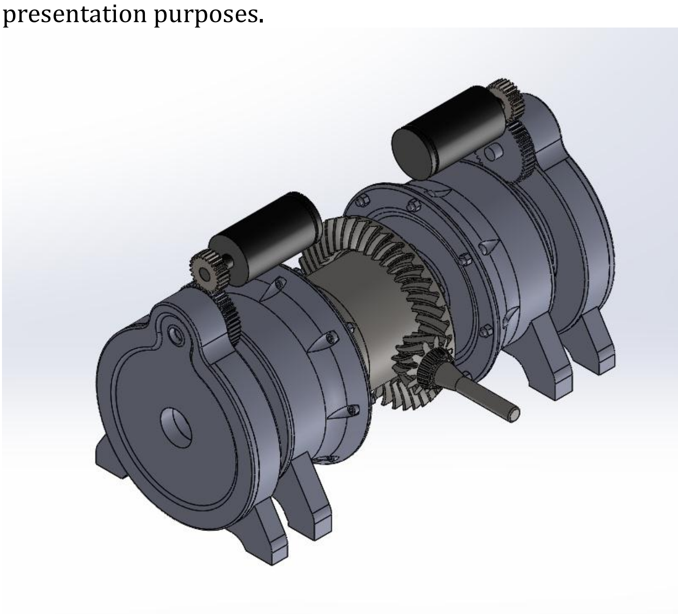
II?? Manual Operation





5. COMPUTER AIDED DESIGN

Design on Solidworks package was carried out for presentation purposes.



6. VALIDATION PRIOR PROCESSING

Design modeling and simulation are especially valuable for testing conditions that might be difficult to reproduce with hardware prototypes alone, especially in the early phase of the design process when hardware may not be available. Iterating between modeling and simulation can improve the quality of the system design early, thereby reducing the number of errors found later in the design process.

Common representations for system models include block diagrams, schematics, and state diagrams. Using these representations one can model mechatronic systems, control software, signal processing algorithms, and communications systems. A physical model was designed in MATLAB SIMULINK.

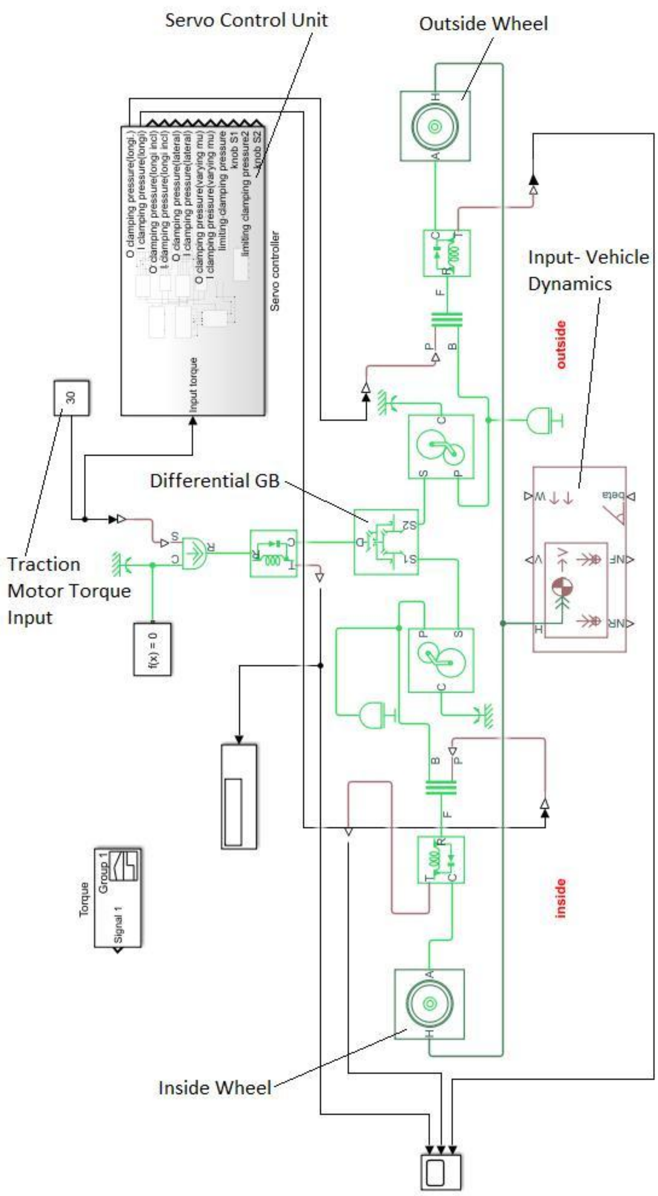
Physical modelling helps to simulate the system which consists of real physical components. It employ a physical network approach. SIMSCAPE components were used to design the Drive-train system. The system consists of a Traction Motor, Open Differential, Planetary Gear, Clutch pack and Wheels.

SIMSCAPE diagrams mimic the physical system layout. If physical components can be connected, their models can be connected, too. The Physical Network approach, with its Through and Across variables and non-directional physical connections, automatically resolves all the traditional issues with variables, directionality and so on. An energy flow is characterized by its variables. Each energy flow is associated with two variables, one 'through' and one 'cross'.The number of connection ports for each element is determined by the number of energy flows it exchanges with other elements in the system, and depends on the level of idealization.

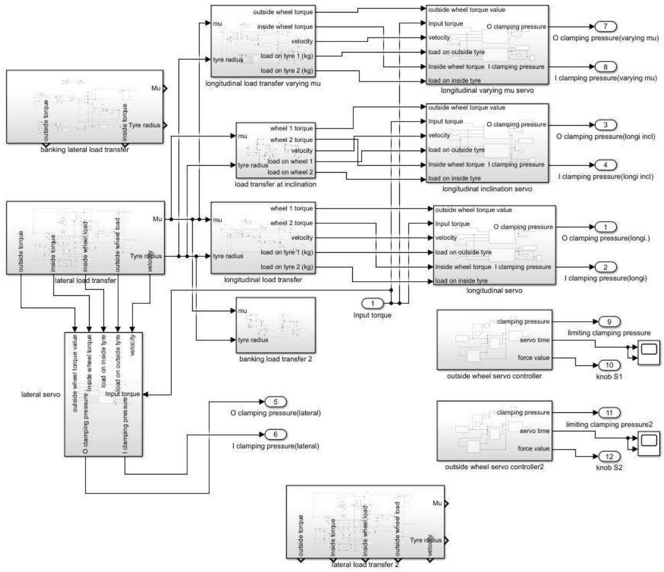
The model was simulated in various situation where the friction coefficient, vehicle speed, cornering radius, road gradient etc was variable.

To vary the torque, Servo Motor was used to actuate the clutch, and data was collected such as servo actuation time, torque on each wheel, load transfer, wheel speed etc. A Servo Motor Controller was designed to reduce the actuation time of Servo Motor. It is designed to actuate according to the load, wheel slip, slip ratio, angular velocity and linear velocity of the vehicle.

Thus improving the traction. It was necessary to reduce actuate time to make the system more robust and reliable. The Servo Motor Controller collects all the data from the vehicle and calculates how much the clutch needs to transfer torque. Complete schematic architecture of MATLAB model is shown below.



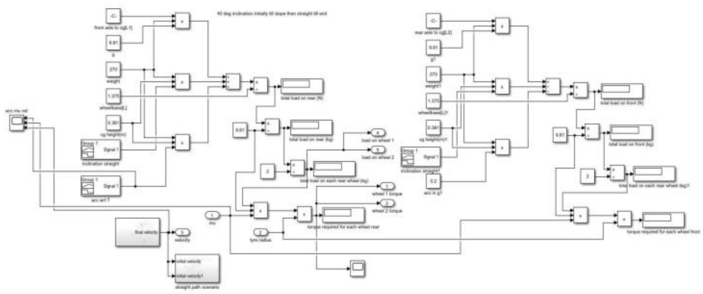
Schematic Diagram of Complete Unit



Schematic Diagram of Servo Control Unit

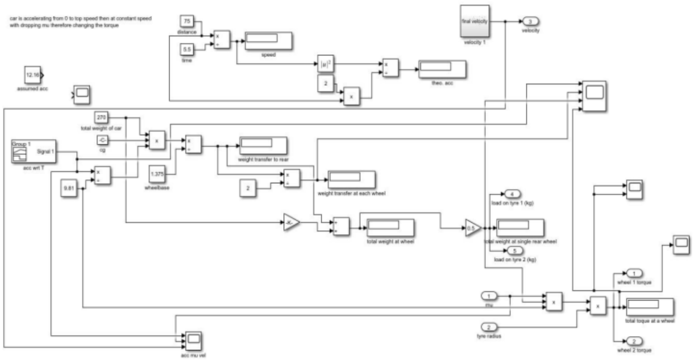
1. Scenario 1- Load transfer at Inclination

When vehicle is driven on a 40degree slope. At end of the slope, vehicle is driven continuously in straight line motion till end of the road. Scenario block-set shown below



2. Scenario 2- Longitudinal Load Transfer

Vehicle when accelerates from rest to its top speed, case is considered. Further, it continues at top speed, where thee torque requirement for that instance is reduced. Scenario block-set shown below

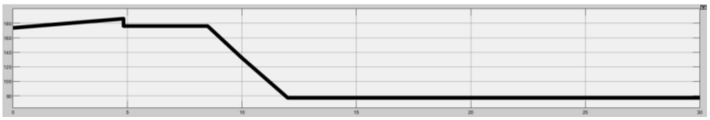


7. VALIDATION RESULTS

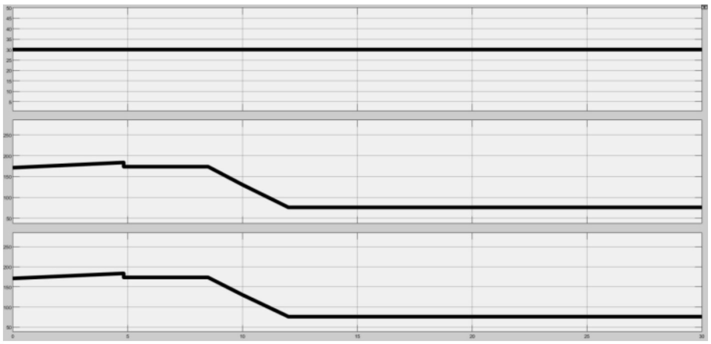
The results were formulated according to cases considered in above section. Individual scopes are explained, which states varying speed, torque requirements and coefficient of friction in tires respectively in theoretical cases. These cases are formulated on proposed drive train block set. The data obtained by both systems is presented according to each scenario.

I) Inclined Motion Scenario

The buggy is initially at the start of inclination. The vehicle accelerates constantly till the inclination ends and then runs at the final speed till the end of simulation. After the inclination, the mu changes and remains constant till the end of simulation. Scopes for required torque, obtained torque, acceleration- velocity with changing mu and time taken for servo [Fig. 61] are shown below respectively.



Scope: required Torque curve of rear wheel1 and rear wheel2. Since equal load is transferred at rear, the torque curve is same for both wheels



Scope: Obtained Torque curve at wheel 1 and wheel 2 [window 1: input torque, window 2: wheel 1 torque, window 3: wheel 2 torque]

Scope: window 1 window 2 window 3 shows acceleration mu & velocity respectively

II) Circular Motion Scenario (For Longitudinal Load Transfer)

The buggy is moving at a constant lateral acceleration on a skid-pad. After a lap the vehicle goes straight till the end of simulation with highest corner exit speed. Scopes for required torque [Fig. 62], obtained torque [Fig. 63] and accl velocity with changing mu [Fig. 64] are shown below respectively

Scope: required Torque curve of rear inside wheel and rear outside wheel [window 1: inside wheel, window 2: outside wheel]

Scope: obtained torque curve of rear inside wheel and rear outside wheel [window 1: input torque, window 2:outside wheel, window 3: inside wheel]

Scope: window 1 window 2 window 3 shows acceleration mu & velocity respectively

8. CONCLUSION

The results obtained from the physical model have minimal errors as the model uses all real time parameters.

As there are various types of losses (thermal, slip, meshing losses or backlash etc) in the clutch, gears and shaft, there is a drop in the desired and actual torque values.

Due to the rise time in holding torque of the servo, there is a lag in time, which delays the actuation of clutch.

Taking a dive into comparison made earlier with similar systems such as LSD, ABS, Traction Control (TCS), ESC etc, the proposed system can be presented as an optimum solution to problems encountered for extremely tractive, greatly handled and efficient automobile drive for AT vehicle sector.

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