



SIMULATION OF CAR DYNAMICS

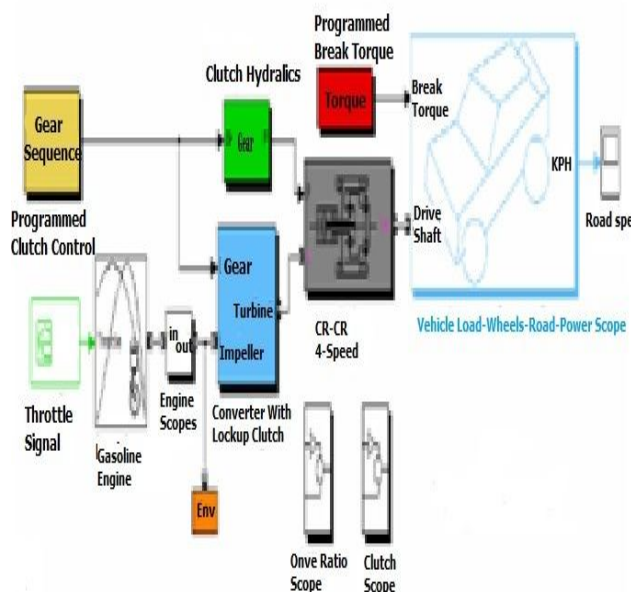
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Abstract- The full car drivetrain simulation of the drive_full_car encompassed in this paper and many key features of SimDriveline™. Here simulation of a gasoline engine car is described. It includes engine and transmission models and a simplified model of the drivetrain-wheel-road coupling. The engine and transmission are coupled with a torque converter. Programmed clutch control steps the transmission through four gears and neutral before a braking torque is applied. The clutch pressure signals are smooth and more realistic than the sharp clutch pressure signals used in the preceding studies. This section explains these features, subsystems, and their relationship and purposes, leading you to actual simulation.

I.INTRODUCTION

Global Structure of Full Car Model Based on CR-CR 4- Speed Transmission.



The main driveline subsystems are

1. Engine
2. Torque converter
3. Transmission

The large subsystem to the right represents the final part of the drivetrain: the vehicle inertia, the wheels, their coupling to the road, and braking. All the other subsystems in the model represent inputs that control the drivetrain or outputs that measure its behavior.

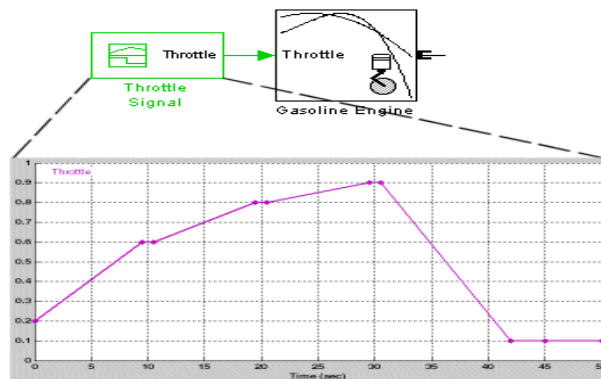
Modeling the Engine

Basically SimDriveline software is developed to modeling the rotational dynamics of drivelines, accepting rotational power from any source that can be modeled in Simulink® and converted to a connection line transferring torque. In most applications, your modeled driveline power and torque sources will represent engines and motors. For the purposes of system modeling, an engine or motor specifies an output torque as a function of driveline speed. However you specify the behavior of the engine or motor, its SimDriveline output is a connector port transferring torque to the rest of the system.

Using an Engine Block from Vehicle Components

The Vehicle Components library contains blocks representing simple engine models. You control these engine models with a Simulink throttle signal. The heart of the engine model is a function that specifies the maximum engine torque possible for each engine speed. The throttle signal controls how much torque, out of this maximum possible, the engine can deliver. The maximum possible torque itself is a function of the engine speed at any instant. . The throttle signal is programmed by a Signal Builder block that specifies a time-depend throttle profile over the course of the simulation

Signal Profile for Engine Throttle



Advanced Methods for Modeling Engines

Some important engine features of the model to consider would be

- Details of mechanical power production, such as air-fuel compression and combustion, or electromagnetic induction.
- Distinguishing steady-state behavior from engine start-up, when the engine speed-engine torque function has not yet reached its maximum possible envelope.
- Additional controls beyond what can be represented by a single throttle signal.

Workspace Variable	Meaning
inPlanetRatio	Gear: input planetary gear ring/sun ratio
outPlanetRatio	Gear: output planetary gear ring/sun ratio
numFricSurf	Clutch: number of surface friction surfaces
effTorqueRadius	Clutch: effective torque radius (m)
peakNormForce	Clutch: peak normal force on friction surfaces (N)
coeffFricTable (matrix)	Clutch: surface friction function (tabulated discrete function)
staticFricPeak	Clutch: static (locking) friction peak factor
velTol	Clutch: clutch velocity locking tolerance (rad/s)

The `drive_full_car` model couples the engine and the transmission through a torque converter subsystem.

A torque converter couples two independent driveline axes in such a way as to transfer angular motion and torque from an input to an output shaft like a clutch. However, unlike a clutch, a torque converter never locks and the output shaft never exactly reaches the speed of the input. So a torque converter does not

step through discrete stages and avoids the motion discontinuities inherent in friction clutches.

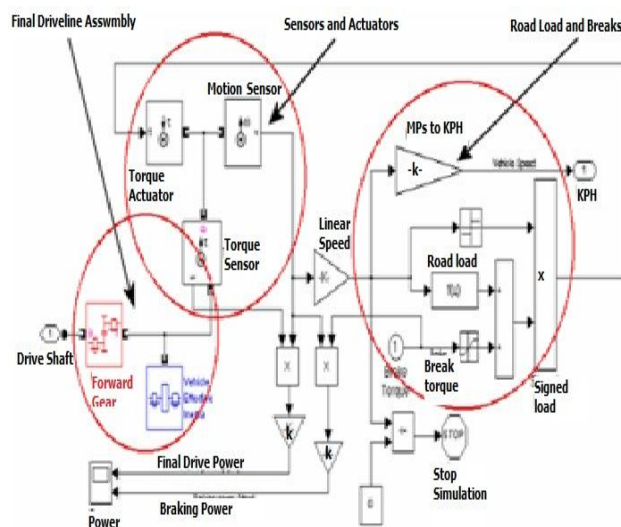
To mimic engine idling at the start of the simulation, the initial condition (IC) actuators start the input and output shafts at nonzero velocities.

The clutch in this subsystem is present to lock the input and output shafts together once the main clutches of the transmission have reached the highest gear. See Control the Clutches and Braking following.

Model Wheel Assembly and Road Coupling

The CR-CR 4-speed transmission feeds its output torque to the final drive subsystem, Vehicle Load - Wheels - Road - Power Scope, which represents the vehicle inertia (the load on the transmission), the wheels, and the wheel contact with the road. This subsystem also incorporates a brake model that describes that with the appropriate input signal, a brake torque on the wheels. This torque acts on the driveline in addition to the reaction stress imposed by the wheel contact with the road. The wheel-road load model is implemented with Simulink alone.

Final Drive Subsystem: Vehicle Load, Wheels, and Road Coupling



The subsystem has three major areas:

1. In the diagram the leftmost part is the terminus of the driveline proper, where the driveline connection lines end.

2. In the diagram the upper left are a collection of sensor and actuator blocks coupling the driveline proper to the wheels and brakes.
3. In the center and right are the Simulink blocks that model the wheel-road coupling and braking.

Workspace Variables to Modeling the Final Driveline Assembly

The driveline connection line sequence of the whole full car model ends with the first set of blocks on the left of the subsystem. The torque and motion are transferred forward through the Forward Gear and are loaded down with the Vehicle Effective Inertia. Two workspace variables specify the relevant variables.

Workspace Variable	Meaning
ratioForwDrive	Gear: follower-to-base gear ratio in the final driveline stage
inertiaVehicle	Inertia: effective rotational inertia of the final driveline assembly (kg-m^2)

The final driveline connection emerges from the Forward Gear-Vehicle Effective Inertia assembly into a sensor-sensor-actuator set.

- The Torque Sensor measures the final torque along the driveline. This torque is used to calculate the power transferred along the drivetrain.
- The Motion Sensor measures the final angular motion of the driveline. This angular motion is used to calculate the driveline and braking power and to model the wheel-road contact.
- The Torque Actuator feeds the torques from the road load and the braking back to the driveline.

Modeling the Road Load — Adding Brakes

The road load and braking are discussed in Modeling the Road Load — Adding Brakes and Measuring the Driveline and Braking Power following. The road load-braking requires the final drivetrain angular velocity to compute the road load, which is the reaction torque of the road back on the driveline via the wheel-tire assembly. This road load torque is a function of the vehicle's linear speed implemented by

the Road Load block. (This function is controlled by a set of workspace variables. Open the Road Load block dialog to view the functional form.) The Linear Speed (Gain) block converts the driveline speed to a linear velocity with an effective wheel radius, the workspace variable radius Wheel.

The braking torque is provided by the Brake Torque input signal. The total torque is computed from the road load torque and the brake torque. The overall sign of the total torque is set by the sign of the linear vehicle speed. This total torque is fed back as a reaction torque on the end of the driveline by the Torque Actuator to the left.

If the applied braking torque is large enough and acts for long enough, it brings the vehicle speed to zero. At that instant the Stop Simulation block ends the simulation, if it has not already reached the end of the simulation time specified in the model toolbar.

Measurement of the Driveline and Braking Power

The power transferred is $P = \omega \cdot \tau$. Where ω is the angular velocity and τ is torque transferred along the shaft. The final drive subsystem computes the final drive power and braking power by multiplying the angular velocity by the final driveline torque (measured by the Torque Sensor) and by the brake torque, respectively, then converting the MKS result to horsepower units. The Power scope displays both horsepower values. Open the Power scope, and close the final drive subsystem.

Alternative Differential, Wheel, Road, and Braking Models

The drive_full_car model uses the purely Simulink part of the final drive subsystem to model the end of the driveline and its connection to the wheels and road.

The Vehicle Components library provides a set of specialized blocks to model the end of a driveline and the resulting motion of the wheels and vehicle. You could create an alternative model to the final drive subsystem of drive_full_car by using these specialized blocks. The model uses one of these blocks already, the Gasoline Engine, as discussed in Model the Engine previously. For wheel-vehicle modeling, you can use the Tire and Longitudinal Vehicle Dynamics blocks instead of creating such models in Simulink. The drive_4wd_dynamics and drive_vehicle example models illustrate the use of

these blocks. The braking model of drive_full_car applies a brake torque directly to the final driveshaft with a Torque Actuator. You could build an alternative brake model around a clutch. See Brake Motion with Clutches and Model Simple Two-Speed Transmission with braking previously.

Control the Clutches and Braking

Return to the main model window of drive_full_car. Like any engineering system, the full car model requires control signals. One of these signals controls the throttle, as explained in Model the Engine previously. The other signals control the clutches and the braking. Run the Model following presents the full interplay of these control signals and how they determine the simulation results.

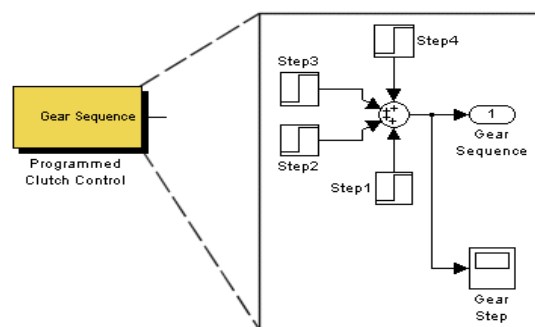
Programming the Transmission and Lockup Clutches

The Programmed Clutch Control is the central subsystem for the clutch signals. Its master signal controls two clutch sets, the four clutches of the CR-CR 4-Speed transmission and the one lockup clutch of the Converter subsystem.

1. Open the subsystem. Four Step blocks contribute to the total or master clutch signal, which steps from 1 up through 5, through the intermediate integers, each step at a 10-second interval, from 0 to 40 seconds of simulation time.

III. SIMULATION

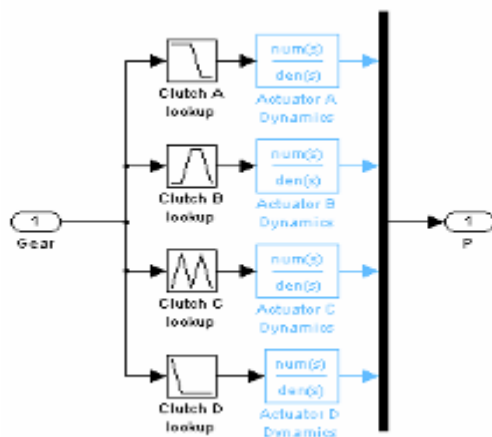
Master Clutch Control Signal



2. Close the Programmed Clutch Control subsystem.

3. Open the Clutch Hydraulics subsystem.

Clutch Hydraulics Subsystem

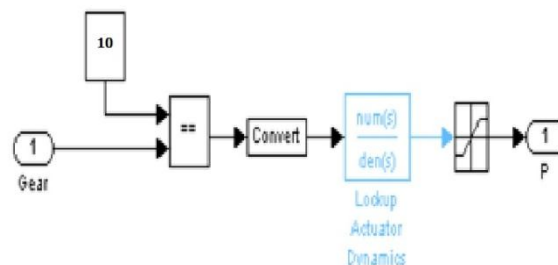


This subsystem, consisting of Simulink Lookup and Transfer Fcn blocks, converts the single clutch control signal to a set of four clutch signals that shift the CR-CR 4-speed transmission through a fixed gear sequence: first gear, second gear, third gear, and fourth gear, at 0, 10, 20, and 30 seconds, respectively, of simulation time. Each gear is reset when the master clutch signal from Programmed Clutch Control steps up to the next higher integer, from 1 through 4. At 40 seconds, the master clutch signal reaches the value of 5. All the transmission clutches then unlock, and the CR-CR transmission shifts into neutral. (See Shaping Clutch Pressure Signals following for more about the transfer function blocks.) You can view the clutch schedule for the CR-CR 4-speed transmission by opening the CR-CR 4-Speed subsystem, then double-clicking the Clutch Schedule block.

4. Close the Clutch Hydraulics subsystem.
5. Now open the Converter with Lockup Clutch subsystem, which was discussed in Couple the Engine to the Transmission previously. This subsystem waits for the master clutch signal to reach the value of 5 before locking the two shafts and bypassing the motion transfer through the Torque Converter. Before 40 seconds of simulation time (before the transmission shifts into neutral), the driveline motion is transferred through the Torque Converter. The Lockup Clutch is triggered to lock by the Lockup

Control subsystem. Like the transmission clutch pressures, the clutch pressure signal is reshaped by a transfer function.

Lockup Control Subsystem



This behavior mimics a common drivetrain behavior. When the engine speed reaches a critical value or the transmission reaches the highest gear and the driveline coasts, a lockup clutch closes and forces the engine and the transmission input shafts to spin at the same rate. (A torque converter requires the two shafts to have different velocities to transfer any torque.) You could redesign the lockup control logic by instead implementing a conditional locking of the clutch, testing for a critical value of the engine shaft angular velocity.

6. Close all the torque converter-related subsystems.

Shaping Clutch Pressure Signals

Both the Clutch Hydraulics subsystem and the Lockup Control subsystem filter the clutch signals through Simulink Transfer Fcn blocks in order to shape the pressure signals from sharp steps to smooth rises or falls.

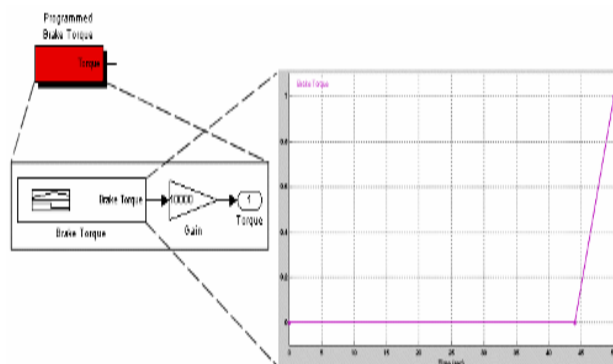
The characteristic rise/fall time of the transfer functions in the Clutch Hydraulics subsystem is set by the workspace variable `clutchRise`, with units of seconds. If $s_0 = 1/\text{clutchRise}$, the transfer functions have the form $s_0/(s+s_0)$.

You can determine the rise/fall time of the lockup clutch by inspecting its Transfer Fcn block.

Applying the Brake Torque

A separate control subsystem, Programmed Brake Torque, designed around a Signal Builder block, generates the Brake Torque signal fed into the final drive subsystem, Vehicle Load - Wheels - Road - Power Scope. Open the subsystem.

Brake Torque Signal Profile



The brake torque signal is designed not to be applied until after the CR-CR 4-speed transmission is set into neutral and the lockup clutch is triggered. The signal is 0 N•m until 44 seconds of simulation time. It then rises to a large value at the end of the simulation at 50 seconds. The brake torque is strong enough to stop the driveline completely before 50 seconds. Close the Programmed Brake Torque subsystem and related windows.

Run the Model

Now simulate the car.

1. After closing all subsystems, open the Road Speed scope.
2. Also open the Engine Scopes, Drive Ratio Scope, and Clutch Scopes subsystems. Then open the Engine RPM & Torque, Drive Ratio, Clutch Modes, and Clutch Slippages scopes. Close the subsystems.
3. Review the simulation sequence before starting the model. The Brake Torque signal stops the vehicle before the nominal 50 seconds of simulation time.

Time Range (s)	CR-CR Gear Setting	Brake Torque (N-m)
0 – 10	1	0

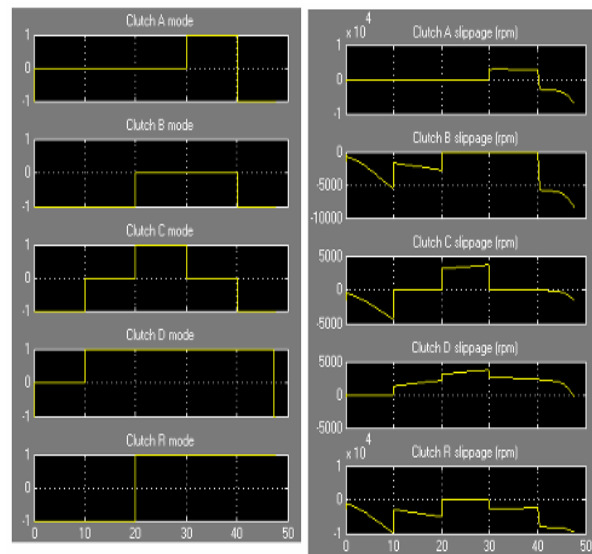
Time Range (s)	CR-CR Gear Setting	Brake Torque (N-m)
10 – 20	2	0
20 – 30	3	0
30 – 40	4	0
40 – 44	Neutral	0
44 – 50	Neutral	0 – 10,000

4. Start the simulation, then review the scope outputs.

IV. SIMULATION OUT PUTS

Clutch Modes and Slippages

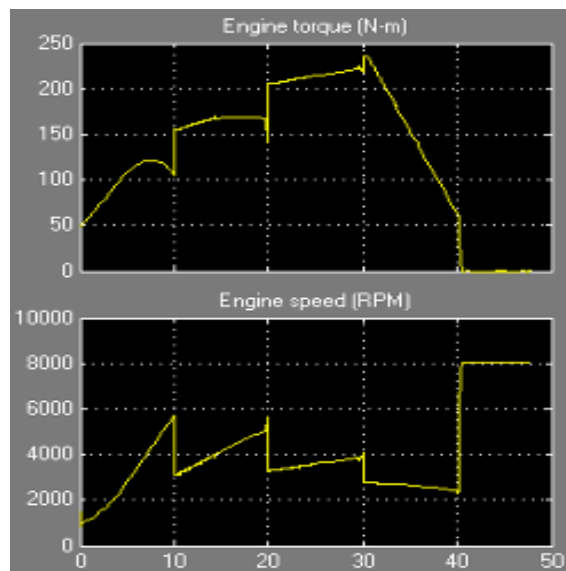
The Clutch Modes scope shows the sequence of clutch locking and unlocking that moves the transmission through its gear stages, first through fourth gear. The Clutch Slippages scope displays how much each clutch slips (relative angular velocity between the follower and base shafts in each clutch) when it is unlocked.



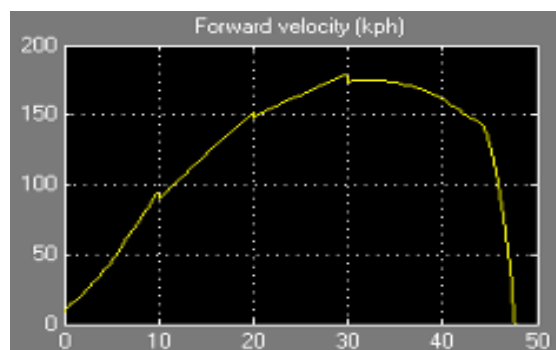
Engine Speed & Torque — Road Speed

The Engine RPM & Torque scope shows the engine speed in revolutions per minute (rpm), as well as the engine output torque, in newton-meters (N-m), delivered to the Converter subsystem. When the transmission shifts into neutral at 40 seconds, the

engine speed jumps to its maximum and its output torque to zero.

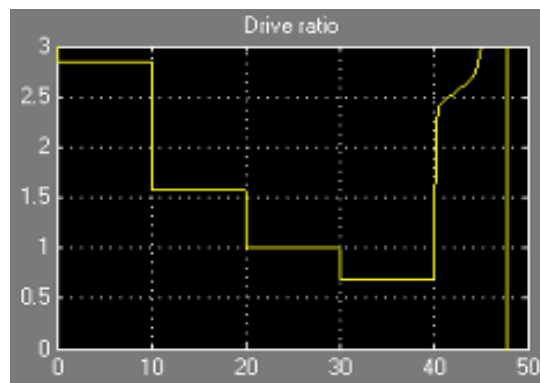


The Road Speed scope displays the vehicle's linear velocity in kilometers per hour (km/h). Note that the braking stops the driveline and the vehicle before 50 seconds — to be exact, at 47.5 seconds.



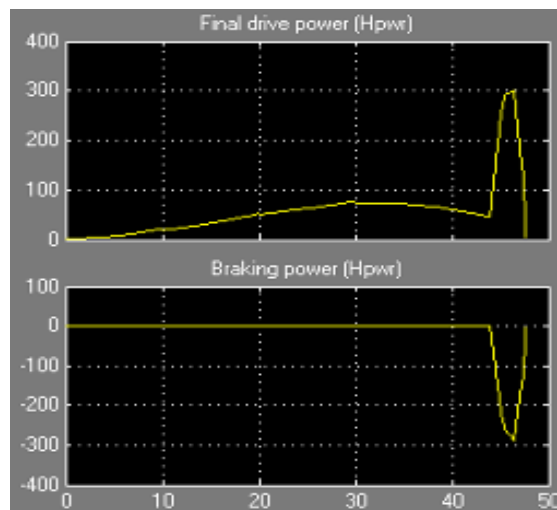
Drive Ratio

The Drive Ratio scope measures the effective gear ratio of the CR-CR 4-speed transmission by computing the ratio of the input shaft to the output shaft angular velocities, respectively. (Open the CR-CR 4-Speed subsystem to locate the Motion Sensor blocks.) As the transmission shifts through each gear from 1 to 4, its drive ratio goes down. (The speed ratio is the inverse of the drive ratio.) After 40 seconds, when the transmission shifts to neutral, the drive ratio is no longer well defined.



Driveline and Braking Power

Finally, the Power scope displays the total power exerted by the driveline, measured at the output of the final drive subsystem, and the braking power exerted by the brake torque necessary to bring the driveline to a stop. The braking power is negative, as the brake torque opposes the forward motion of the driveline.



The braking power is zero until 44 seconds, when the brake torque begins to rise from zero. Both the total and the braking power then quickly peak and drop to zero as the braking stops the driveline motion in under 4 seconds.

V. CONCLUSION

So by using this full car drive train simulation of the drive full car encompasses all the points of its dynamics. It includes engine and transmission models and a simplified model of the drivetrain-wheel-road coupling. Programmed clutch control steps the transmission through four gears and neutral before a

braking torque is applied to get the good performance. The clutch pressure signals are smooth and more realistic than the sharp clutch pressure signals used in this are usefull for perfect dynamics. so by this simulation design of this dynamics will be use full to know the actual real time behavior of this cars in low cost in order design a better vehicles.

VI. REFERENCES

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