ENGINE, BATTERY AND VEHICLE SIMULATION STRATEGIES FOR TRANSMISSION TESTING

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WHY DO WE NEED SIMULATIONS?

This paper is intended to provide a broad presentation of the simulation techniques focusing on transmission testing touching a bit on power train testing. Often, we do not have the engine or vehicle to run live proving ground tests on the transmission. By simulating the vehicle and engine, we reduce the overall development time of a new transmission design. For HEV transmissions, the battery may not be available. However, the customer may want to run durability tests on the HEV motor and/or the electronic control module for the HEV motor. What-if scenarios that were created using software simulators can be verified on the test stand using the real transmission. NVH applications may prefer to use an electric motor for engine simulation to reduce the engine noise level in the test cell so transmission noise is more easily discernable.

TRANSMISSION TESTING

Transmission testing involves two major simulation technologies. First, engine simulation is required to provide proper inputs to the transmission to mimic an engine. Secondly, output simulation must provide proper loads to the output of the transmission to mimic vehicle loads. The inputs and outputs of the transmission can be as simple as torque and speed control. The input to the transmission can be as complicated as engine torque pulse simulation. The output loading can be as complicated as full vehicle simulation with wheel slip models and suspension models.

With the introduction of hybrid technology into the transmission, battery simulation for the HEV motor becomes a priority for transmission testing. The wide range of battery types demands a flexible battery simulation.

Modern engine simulation now invariably requires communication with transmission control modules for torque management. So engine simulation must not only create proper speeds and torques at the transmission input, but it must provide proper electrical sensor simulation and communication with other control modules. Sensor simulation may include cam sensor, crank sensor, various temperatures and pressures. Sensor simulation is invariably customer specific.

On the vehicle side, customers are demanding more advanced simulation techniques such as wheel slip models so that traction control and torque vectoring can be tested. The combination of differentials and transfer cases into the transmissions often blurs the distinction between the transmission and the rest of the drive train. So transmission testing often requires a complete power train test stand. As a result, this paper covers vehicle simulation as a requirement for transmission testing. Vehicle simulation may include RLS simulation, road surface models, tire forces and tire models.

TRANSMISSION TEST STAND

Several simulations run simultaneously in order to control the actual test bed in a typical transmission test. As shown in figure 1, light blue blocks represent simulation blocks and yellow blocks represent physical test bed devices and/or parts under test. The focus of this document will be to look at the various simulations. We will also touch on the test bed devices to point out the characteristics of these devices that are important. On top of the simulations runs an automation platform (green) that orchestrates the simulations.

- Green - Automation computer and software
- Light Blue – Simulation by software
- Yellow – Unit under test and physical test stand

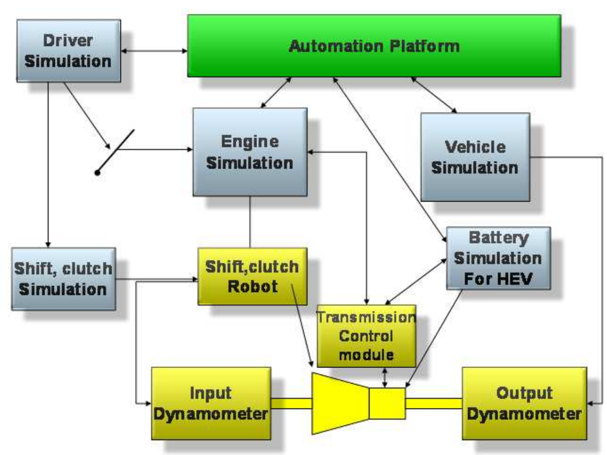


Figure 1 Transmission Test Stand

ENGINE SIMULATION

The engine simulation controls the input dynamometer. In addition, the engine simulation must provide sensor and communication inputs to the transmission control module to mimic the real engine. The engine simulation is influenced by ambient conditions such as atmospheric pressure. Pedal position controls engine torque.

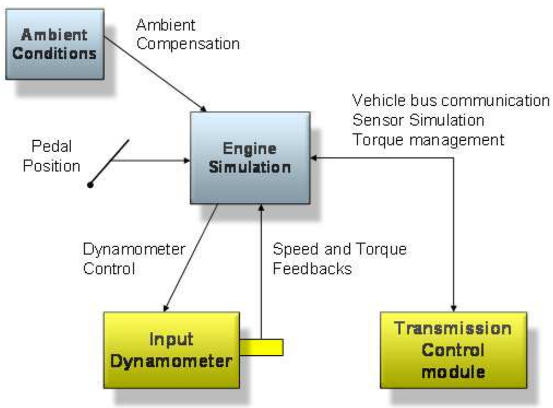


Figure 2 Engine Simulation

VEHICLE SIMULATION

Vehicle simulation can range from simple speeds and torques to RLS with wheel slip to full vehicle dynamics simulation using commercially available simulation software packages such as CarSim® or TruckSim®[1]. The output of the simulation drives the control loops that send demand values to the drives.

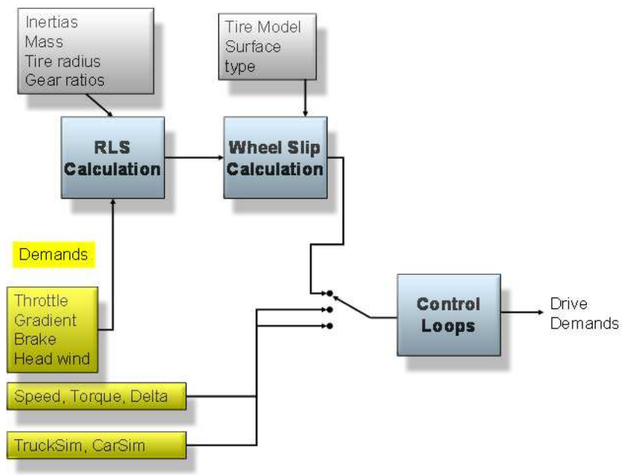


Figure 3 Vehicle Simulation

[1] CarSim® and TruckSim® are products of MSC Corporation, Ann Arbor, Michigan.

TRANSMISSION TEST STAND VARIATIONS

A transmission test stand may include only an input dyno/engine and output loading unit. Or it may include two or more wheel dynos. Invariably, front wheel drive transmissions require at least two wheel dynos.

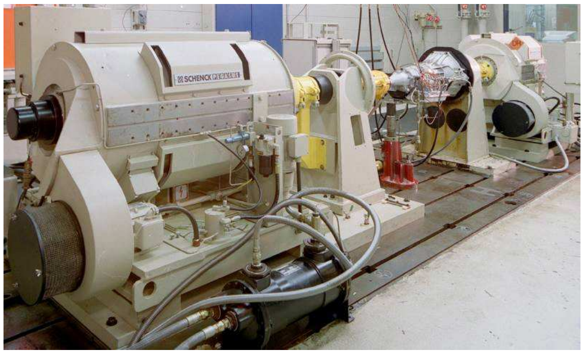


Figure 4 Transmission test with Input and Output Dynos

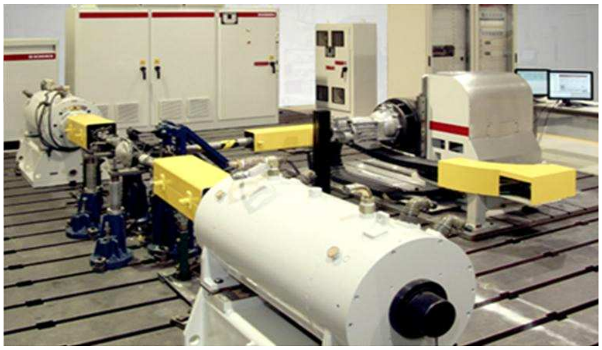


Figure 5 Transmission test stand with two Wheel Dynos

ENGINE SIMULATION FOR THE TRANSMISSION INPUT

The engine simulation consists of maps, an engine controller (similar to the TCU), a parametric model similar to the mechanical engine followed by an adaptive mechanism. The engine controller controls cranking, idling and torque reduction during a shift. It also simulates the various delays that a typical engine/ECU might have. A parametric engine model calculates torque due to kinematics of the parts and gas pressures. An adaptive mechanism assures that the response torque amplitude follows the demand amplitude. It also provides a means to limit frequencies and orders.

Engine simulation provides inertia simulation, throttle and pedal map simulation, torque reduction during shift, other TCU torque management, engine cranking and idle control, ignition simulation, coast simulation, fuel cut and closed throttle simulation, engine pulse simulation, cylinder firing reduction, front end accessory loading and ambient condition adjustment. The torque pulse simulation includes simulation of gasoline, diesel, turbo-charged, super charged and normally aspirated engines. Two and four cycle engines are supported from 1 to 16 cylinders.

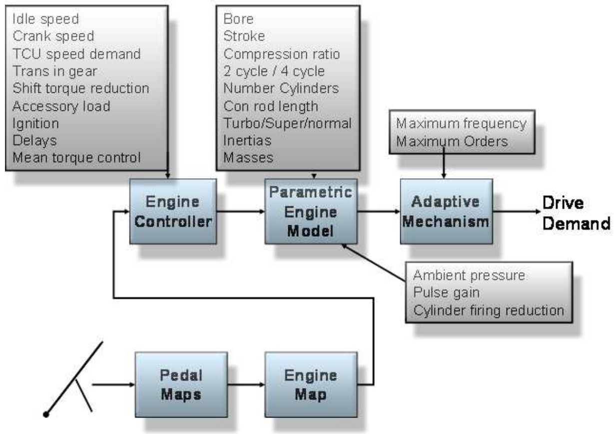


Figure 6 Engine Simulation for the Transmission Input

PEDAL MAP SIMULATION

Current generation engine technology uses fly-by-wire throttle control. This imposes additional simulation responsibility on the engine simulation to reproduce the demand from pedal to throttle demand to the engine simulation. Typically this requires a set of maps (ECU maps) to map pedal demand to throttle demand. The throttle demand is then sent to an engine map to create the proper engine torque output. Typically, pedal mapping is highly customer dependent. Horiba provides a very flexible controller to support these customer specific pedal mappings.

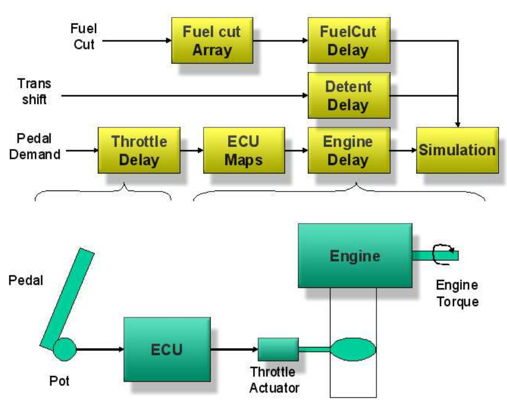


Figure 7 Pedal Map Simulation

ENGINE TORQUE MAP SIMULATION

An engine is typically throttle (or pedal) controlled. Based on the throttle setting and the current engine speed, the engine will produce a given torque. On the other hand, a dynamometer is speed or torque controlled. Unlike an engine, the dynamometer used for engine simulation can produce maximum torque at zero speed. Some means is required in the engine simulation to limit the dynamometer torque to the torque that the engine would produce and to create the throttle to torque function to mimic the engine. Engine torque map simulation provides this capability.

Shown in figure 8 is an engine map for the engine simulation. A throttle demand sent to the engine simulation is used along with current engine speed to determine the torque the engine simulation should produce. Since many vehicles are now "fly-by-wire" current ECU implementations also typically provide additional mapping to map the pedal position to an internal throttle or torque demand. This additional pedal mapping may be a function of transmission speed or other parameter as the vehicle manufacturer sees appropriate. Horiba's engine map simulation provides multiple levels of mapping to support pedal mapping. This additional mapping is customer specific so it requires a controller capable of supporting these changes without major software efforts.

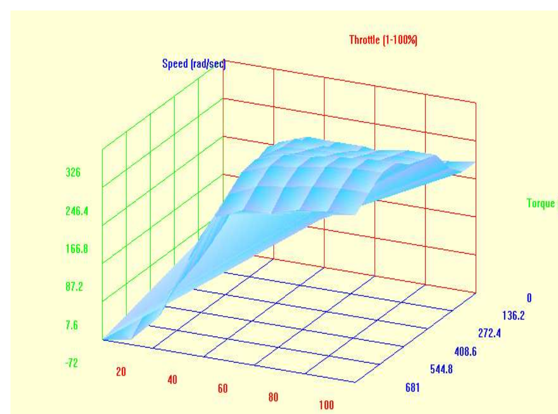


Figure 8 Engine Torque Map Simulation

ENGINE TORQUE REDUCTION DURING A SHIFT

Shown in figure 9 is a full throttle acceleration run of an automatic transmission vehicle with engine simulation on the transmission input and vehicle simulation on the transmission output. Of key importance is the engine simulation must reduce torque during the transmission shift to limit wear on the transmission clutches. The transmission control module sends a message over the vehicle bus to the engine module to reduce torque. In this case, the engine simulation takes the place of the engine and engine control module. The purple tracer (blown up for clarity) is the signal to the engine simulation to reduce torque. The actual torque reduction from the engine simulation is shown in the green trace. The effects of vehicle loading on the transmission output are shown in a grey trace and the resulting vehicle speed is shown in a grey trace. The vehicle bus interface and the methodology for torque reduction is highly customer specific, so the controller must be very flexible in its implementation.

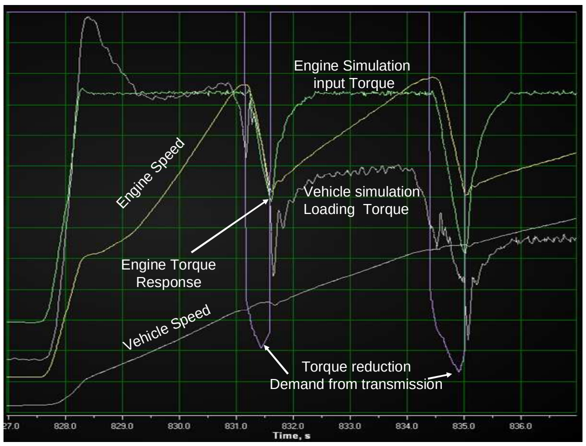


Figure 9 Engine Torque Reduction during a shift

ENGINE INERTIA SIMULATION

Transmission testing requires that the engine inertia is correct so that loading on the transmission is equivalent between the real engine and the dynamometer performing engine simulation. Often, the dynamometer inertia is larger than the engine inertia, so compensation (inertia simulation) is required.

In the graphs in figure 10, the simulation is run in throttle/speed with the throttle ramped in an attempt to hold the torque relatively constant during a shift. During this part of the shift, the deceleration is constant. This results in the engine speed decelerating from 3900 rpm to 900 rpm. The speed change results in an inertia torque. If the dyno inertia and engine inertia are the same (top Chart), no compensation is required. The bottom chart shows where the dyno inertia is twice the engine inertia.

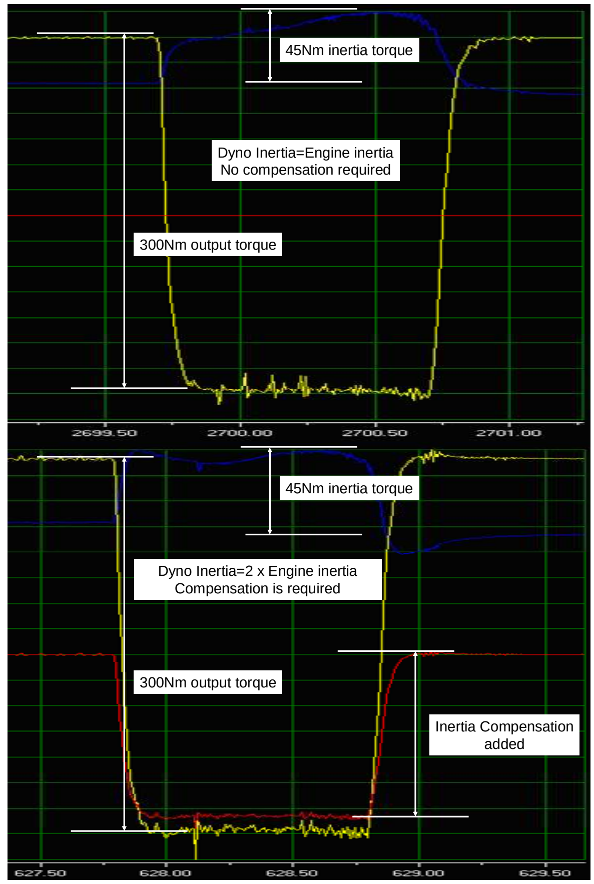


Figure 10 Engine Inertia Simulation

ENGINE TORQUE PULSE SIMULATION

Shown in figure 11 is an 8 cylinder engine running at 2000 rpm, part throttle with a mean torque of 118 nm. The mean torque is not shown on this display. Only the torque pulses are shown. We clearly see 8 distinct pulses over the 720 degrees (two crankshaft rotations). To produce 118 Nm of mean torque, we must produce 145 Nm of firing pulses.

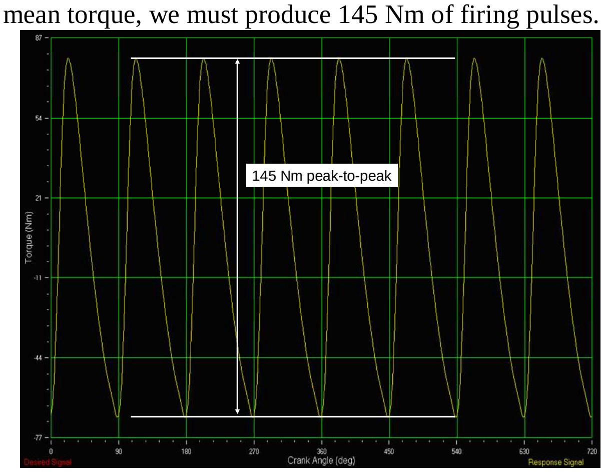


Figure 11 Engine Torque Pulse Simulation

VALIDATION OF SIMULATION TO REAL ENGINE DATA

Validation of the engine simulation pulses is crucial to the acceptance of engine torque pulse simulation. Here, we compare a 4 cylinder gasoline engine in the bottom chart to the engine simulation on the top chart. We have good correlation between simulation and the engine. A gasoline engine is typically quite inconsistent in its firing.

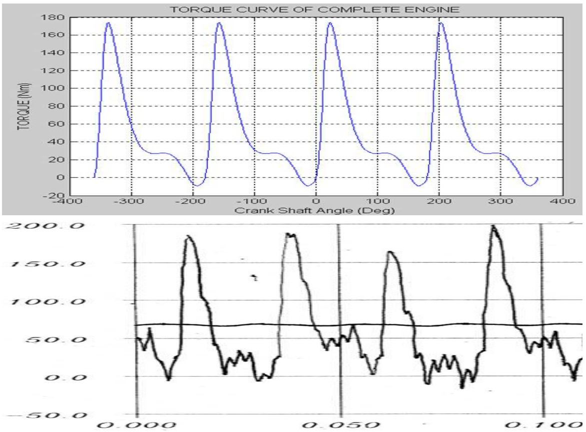


Figure 12 Validation of Simulation to Real Engine Data

The table in figure 13 shows the amplitude of the spectral components of the engine simulation and the real engine. Inconsistent firing and certain torsional resonances present in the real engine may attribute for the minor differences in the data

	Real Engine	Simulation
40 hz	37 nm	37 nm
80 hz	23 nm	30 nm
120 hz	8 nm	15 nm
160 hz	5 nm	7 nm
200 hz	3.7 nm	5 nm
240 hz	1.4 nm	2.5
280 hz	1.1 nm	2
320 hz	0.9 nm	1.5

Figure 13 Real Engine and Simulation Table

CYLINDER FIRING REDUCTION

Shown in figure 14 is an 8 cylinder engine running at 2000 rpm and a mean torque of 118 nm. This is the same engine simulation as shown in chapter 0. Half the cylinders are shut off by closing the intake and exhaust valves. The result is four cylinders firing and the other four are operating in a compression/expansion cycle. Notice the peak pulses rise dramatically because 118 nm of mean torque still must be produced by only four cylinders

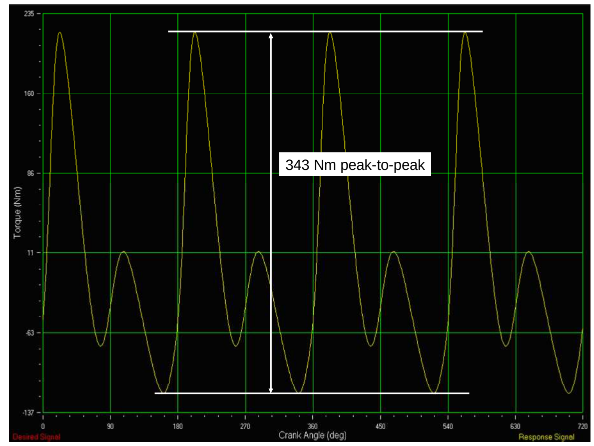


Figure 14 Cylinder Firing Reduction

STARTUP/SHUT DOWN SIMULATION INCLUDING HEV START

The typical startup profile for an engine is shown in figure 15. Idle speed, crank speed and their ramp rates are controlled. After cranking for a fixed period of time, the speed ramps up to idle speed and the idle speed controller takes over. Torque limits are placed on both cranking and idling. HEV startup for mild hybrids is easily parameterized by adjusting these parameters to shorter time intervals.

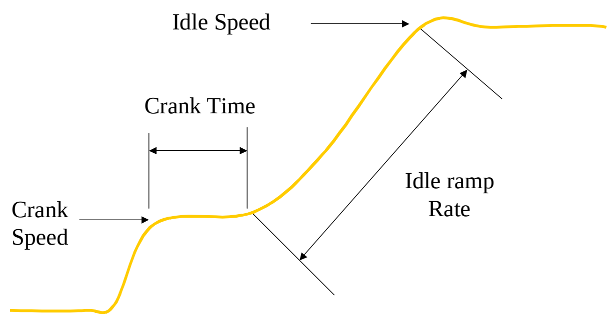


Figure 15 Typical Startup Profile

Engine shutdown/coast is controlled by the ignition, engine map near zero speed and the **StandStillSpeed** value. The engine map determines what torque is applied to cause the engine to stop. The StandStillSpeed value determines when the dyno command is zeroed.

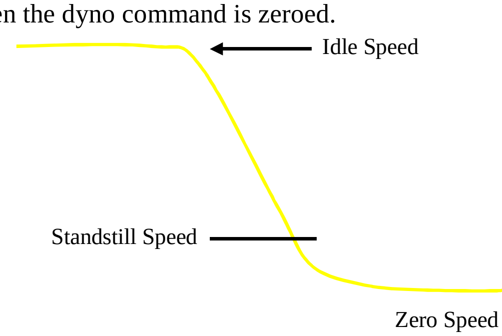


Figure 16 StandStillSpeed Value

Shown in figure 17 is engine startup simulation with ETPS (torque pulse simulation) turned on. Note that for all engine simulation, torque pulses can be turned on or off. If turned off, then only mean engine torque is simulated. The engine first cranks for a short time after which the engine starts firing and accelerates to idle speed. Prior to firing and during cranking, engine torque pulses are the result of pumping forces in the engine.

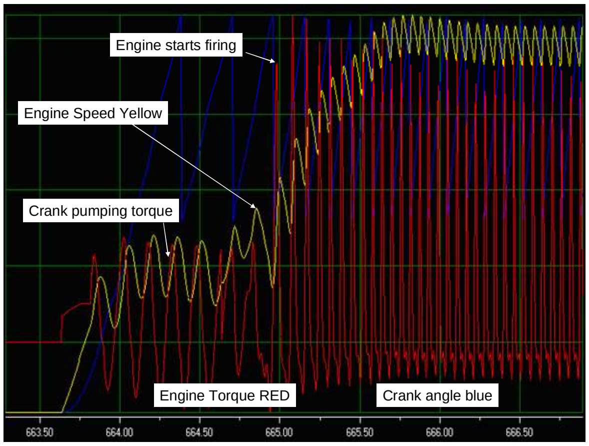


Figure 17 Engine Startup Simulation with ETPS

SENSOR SIMULATION

Sensor simulation is highly customer specific. Some customers require little sensor simulation and some customers require dozens of sensor simulations. In addition, some sensor simulations must be tightly coupled to the controller and others can be controlled by the automation system. A flexible controller and automation platform is required to support the wide variety of sensor simulation.

CRANK AND CAM SENSOR SIMULATION

Some customers require crank and CAM angle simulation. CAM and crank sensor simulation is used particularly in the case where the transmission and engine control module are combined into a single unit. In this case, the sensor simulation must provide inputs to satisfy the engine portion of the control module. In addition actuator simulation or the actual actuators may be connected.

In a real engine, these pulses are strictly synchronized with crankshaft position. The simulation crank and cam sensor signals must also be strictly synchronized to the crankshaft position. The Horiba implementation allows the user a simple means to specify the timing of these signals along with asymmetric TDC or starting pulses. The accuracy of these pulses is defined by the accuracy of the encoder that is attached to the engine simulator dynamometer. A flexible controller along with special hardware embedded in the controller is programmed (by the customer) to create most any shape pulses.

Figure 18 Crank and Cam Sensor Simulation

RESIDUAL BUS SIMULATION

At a minimum, the transmission test stand requires values to be transmitted between the transmission control module and the engine simulation. Shown in figure 19 is a block diagram of the residual bus simulation as implemented in the controller for a particular application. The controller allows simple modification of residual bus simulation by editing block diagrams.

Shown in figure 19 (yellow), we require the transmission control module to send transmission output speed (for customer specific control). Torque detent request is required for torque reduction during a shift. Transmission speed demand is required to limit the engine simulation speed when the transmission requires it.

The transmission control module requires a number of simulation values from the engine simulation to satisfy its needs (light blue). The engine speed, map torque and engine torque are required for transmission control purposes. Pedal position defines the throttle pedal position. Engine coolant temperature tells the transmission controller if the engine is at operating temperature or not.

These values are typically sent over a CAN bus communication link for automotive applications. The controller implements a number of CAN channels to provide this communication path

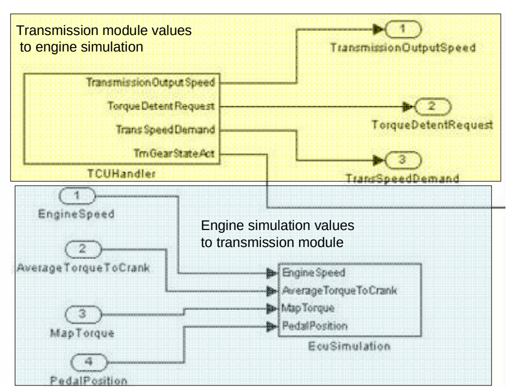


Figure 19 Residual Bus Simulation

SPECIAL REQUIREMENTS FOR DYNO MOTORS AND DRIVES FOR ENGINE SIMULATION

Horiba provides low inertia dynos for the engine simulation. Dyno inertia as low as 0.084 kg-m^2 are available in a 260kW dynamometer. These dynos provide similar inertia to the engines they replace. The low inertia is required to faithfully reproduce torque pulses and/or inertia effects. Less costly high inertia dynos used with engine inertia simulation provide lower performance for cost sensitive solutions.

Shown in figure 20 is a 0.084 kg-m^2 inertia engine simulation dyno TP260 capable of 800 Nm peak torque. It is placed on a standard Horiba base that has adjustment for tilt and height. Transmission testing often requires flexibility in height alignment and angle.

Hybrid transmission testing often requires very high speeds, so this motor can be rated to over 20,000 rpm for such applications.

The dynamometer needs a proper torque to inertia ratio to accomplish > 50,000RPM/sec accelerations and sub millisecond current rise times required for engine torque pulse simulation. Physical rotor properties (inertia and stiffness) have first torsional natural frequency > 600Hz when connected to the transmission under test.

Figure 20 Horiba 0.084 kg-m^2 Inertia Engine Simulation Dyno TP260

High performance drives provide frequency bandwidths to 1000Hz. High bandwidth drives are required to faithfully reproduce torque pulses, torque shift management and inertia simulation. Shown in figure 21 is a sinusoid just shy of 700 Nm peak-to-peak at 500Hz using the low inertia TP260 engine torque pulse dyno. Yellow is demand and red is response. The Horiba ETPS algorithm time aligns the demand and response as part of its proprietary amplitude compensation algorithm.

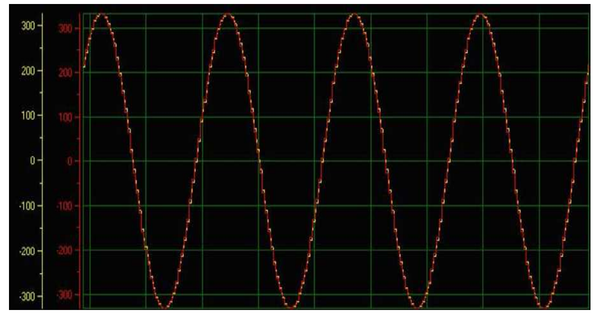


Figure 21 TP260 500 Hz, ~700 Nm peak-to-peak

VEHICLE SIMULATION FOR THE TRANSMISSION OUTPUT

Vehicle simulation involves providing a load at the output of the transmission that mimics the loading the transmission sees when installed in the vehicle and driving on or off-road. Vehicle simulation can be as simple as defining speeds and torque to the transmission controller. Or vehicle simulation can be as complicated as providing a full vehicle simulation using a software package such as TruckSim®[1].

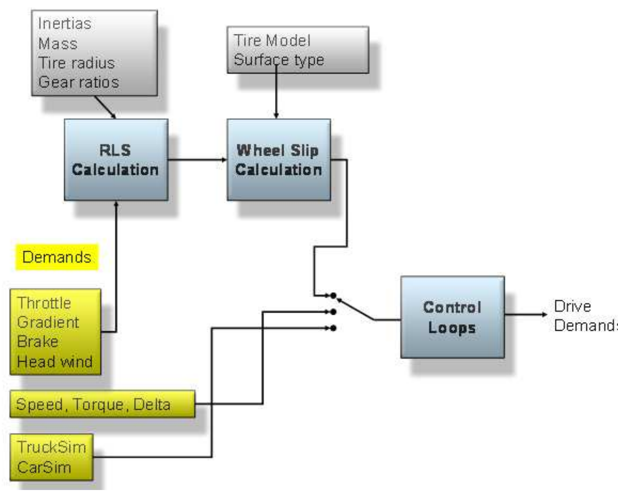


Figure 22 Vehicle Simulation for the Transmission Output

ROAD LOAD SIMULATION

The road load equation probably represents the most basic form of vehicle simulation that solves a great percentage of customer demands. A typical road load equation applies a force at the tire patch equivalent to the force shown in the equation below. The road load equation includes a constant component K_0, a frictional component K_1 and a drag component related to the frontal area A.

$$F = K_0 + K_1 \cdot v + \frac{A}{2} \cdot c_w \cdot \rho \cdot (v + v_{Headwind})^2$$

Simulation of the vehicle driving on hills is taken into account with the force equation of vehicle mass times the sine of the hill. This force is added to the road load equation above.

$$F += m \cdot g \cdot \sin(\alpha)$$

Lastly, vehicle braking is added to the road load equation to allow the simulation of braking.

$$F += F_{Brake}$$

Two types of vehicle simulation are provided for road load control of the transmission output. Road resistance control is a simplified version of the road load equation where only road resistance is calculated. The road resistance control does not include vehicle mass with acceleration in the force calculation. This is the fundamental difference between road resistance and road load simulation.

In addition to the RLS equation, a number of vehicle parameters are required to properly calculate the vehicle simulation. Other parameters include axle/transmission ratios, tire inertia, vehicle mass, tire radius and load distribution.

WHEEL SLIP SIMULATION

Wheel slip simulation provides a means to create realistic loads at the wheels that depend on the tire and road surface interaction. Different tires on the same vehicle most often have different loads because of the differing forces at the tire patches. This causes unequal torques and speeds at the transmission output shafts. The wheel slip simulation allows intelligent torque vectoring devices in axles and transfer cases to react properly during an extreme wheel slip event such as one tire spinning on ice.

Shown in figure 23 is a plot of the Pacejka magic formula that is often used as a tire model. This tire slip model integrated into the controller provides the wheel slip simulation.

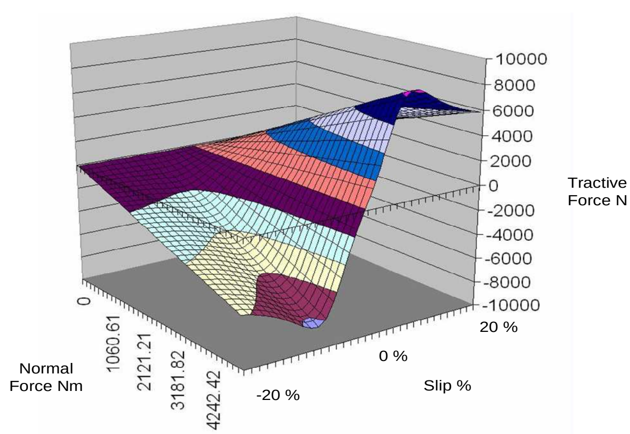


Figure 23 Plot of Pacejka Magic Formula

BRAKING SIMULATION

Most often, the test specimen does not include physical brakes as the vehicle would normally have. So vehicle braking must be simulated by applying a torque to the vehicle simulation that is acting such to slow the simulated vehicle speed. The braking command is a brake force that is entered into RLS calculation as described in the RLS section.

DRIVER SIMULATION

Driver simulation includes control of the transmission gear, clutch and throttle when the transmission is not manipulated manually by a human operator. For driver simulation, the throttle, shifting and clutch actions are coordinated by the controller using predefined tables of behavior. In addition, the controller can be programmed to determine when to shift in addition to how to shift.

Shown in figure 24 is a simple shift profile that illustrates how a shift may be programmed. The duration of the shift is defined by the green trace. The clutch (blue) is suddenly released at the start of the shift then ramped back on after the gear change. The throttle (light blue) is dropped to zero at the start of the shift and reapplied as the clutch comes back on.

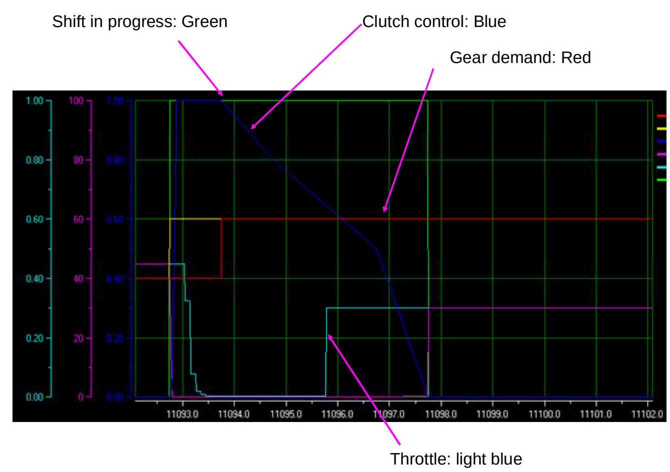


Figure 24 Simple Shift Profile

Driver simulation at a higher level is often controlled by an automation system such as the Horiba Stars®[2] automation platform. Typically, an automation system provides a sequence of throttle demands to the controller that defines a driving cycle. If the controller does not determine the shift points, then the automation system may also provide a sequence of gears demands to the shift controller

[2] Stars® is a product of Horiba Instruments, Troy, Michigan

ADVANCED FULL VEHICLE SIMULATION WITH TRUCKSIM®[1]

For very complex test requirements, the dyno speeds and torques may be controlled by a full vehicle simulation such as "TruckSim®[1]". TruckSim®[1] runs the vehicle simulation in real-time and sends demands to the test stand controller. A transmission test stand may only look at the front and rear propshaft speeds and torques even though the simulation is a complete vehicle simulation. The transmission controller must be flexible enough to provide inputs and outputs to the vehicle simulation at reasonably high rates. Shown in figure 25 is a HMMWV climbing a sand hill. As the vehicle climbs the hill, tire forces change from wheel to wheel due to suspension and body movement. These forces determine prop shaft speeds and torques to be sent to the dynamometer controller. Such complex simulation requires a comprehensive road profile, vehicle suspension model and tire models. The Horiba controller provides hooks to allow a connection to TruckSim®[1].

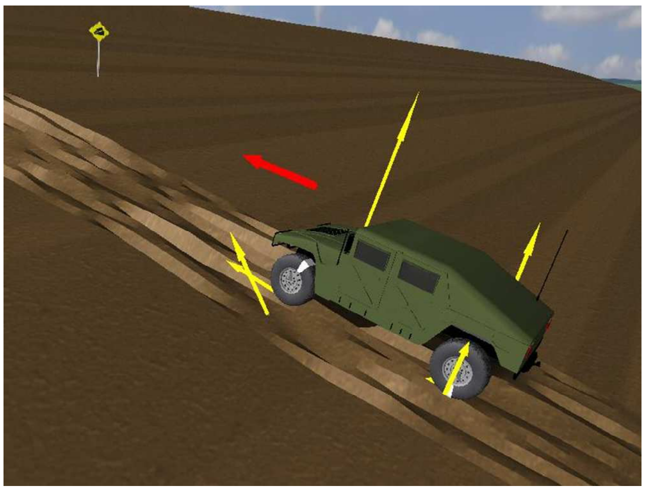


Figure 25 Advanced Full Vehicle Simulation with TruckSim®[1]

SPECIAL DYNO MOTORS AND DRIVES REQUIRED FOR VEHICLE SIMULATION

Horiba can provide a PM4000 low inertia (1 kg-m^2) wheel dynos to simulate vehicle loads with high fidelity. These dynos have inertia similar to that of a vehicle tire and wheel. This provides high performance wheel slip capability. And yet they provide up to 4000 Nm of continuous torque. Higher inertia wheel dynos can be supplied for systems that demand less dynamic performance. Figure 26 shows the PM4000 permanent magnet wheel dyno mounted on a standard Horiba adjustable base.

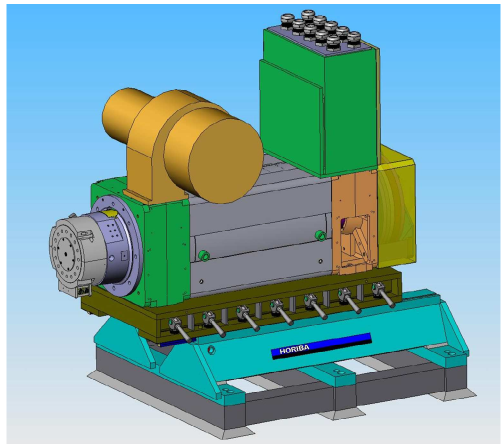


Figure 26 PM4000 Wheel Dyno mounted on a standard Horiba adjustable base

Very high torque requirements can be fulfilled with tandem configurations similar to that shown in figure 27. Tandem configurations may consist of dual motors (as shown in figure 27), motor and water brake, motor and eddy current or motor and shear brake.

These configurations along with high performance controllers and drives provide accurate wheel torques needed for proper vehicle simulation.

Figure 27 Tandem Configuration

Transient testing requires low latency and fast rise time controllers, drives and motors. Horiba systems typically provide millisecond range torque step response. Shown in figure 28 is a 1600 Nm step response on a Horiba low inertia wheel dyno. The yellow trace shows the torque demand. The red trace shows the drive torque response. The rise time of the torque is about 700 micro-seconds. The settling time to 10% from demand is 2 milliseconds.

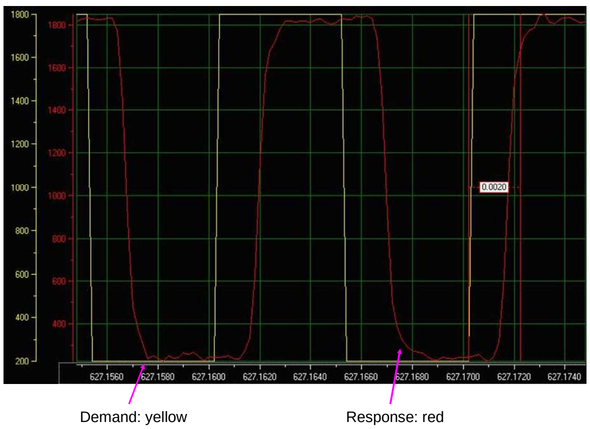


Figure 28 1600Nm Step Response on a Horiba Low Inertia Wheel Dyno

BATTERY SIMULATION FOR HEV TRANSMISSIONS

HEV transmissions require a battery or a battery simulator to test the electric motor. Horiba provides a battery simulator to provide the power to operate the HEV motor in the transmission. The battery simulator consists of a power source to supply power and the software simulator to simulate battery conditions and control the power unit. Interface cabinets connect the power source to the customer specific HEV controller.

Power, current, voltage, power + additional currents can be used to simulate battery models. Or actual battery pack test data can be used for cold and hot test condition simulations.

The battery simulator simulates realistic battery current, voltage, power, SOC, pack temperature, cell/module temperature difference, power limit, pack resistance, capacity, battery life based on different HEV battery technologies such as Lithium-Ion or NiMH battery cell.

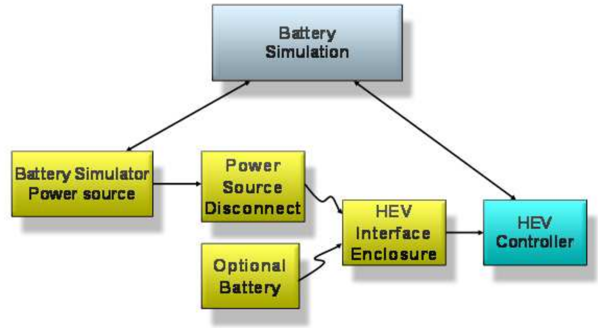


Figure 29 Battery Simulation for HEV Transmissions

DIFFERENT BATTERY TECHNOLOGIES SIMULATION

A number of battery pack models incorporating cell technology such as Li-Ion, $LiFePO_4$, NiMH, and Lead Acid AGM are supported by the battery simulation software. In addition, interfaces to simulate RLC based custom battery models are provided in the simulation.

STATE OF CHARGE SIMULATION

The battery simulation incorporates SOC (state of charge), DOD (Depth of Discharge), and power limits to simulate the HEV/EV/PHEV battery packs. Shown in figure 30 is the state of charge of various battery packs over a 23 minute FTP simulation.

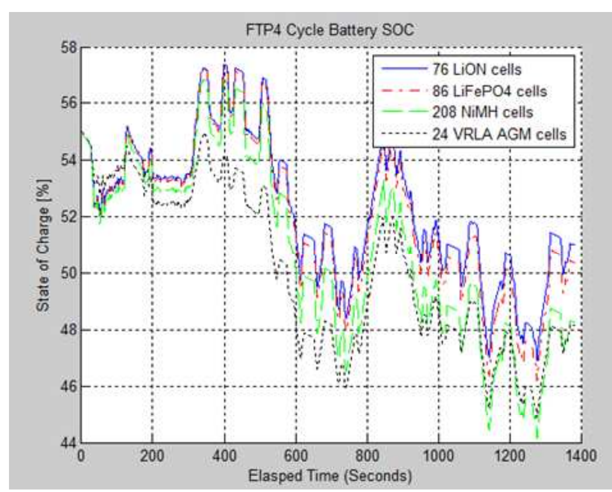


Figure 30 State of Charge Simulation

TEMPERATURE EFFECTS SIMULATION

The battery simulation incorporates thermal simulation to show temperatures values in the battery pack. Shown in figure 31 is a simulation of temperature for the various battery technologies.

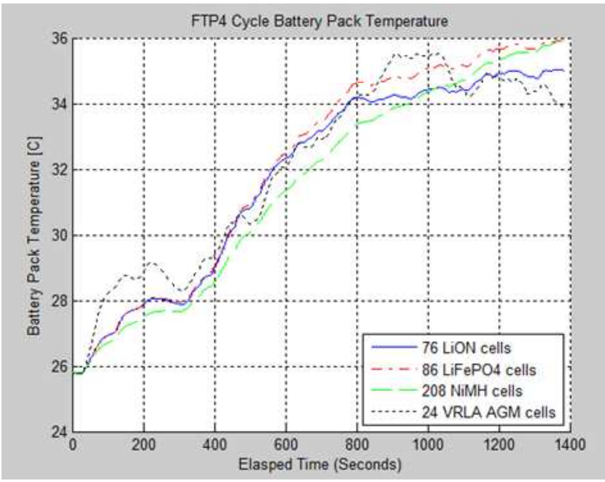


Figure 31 Temperature Effects Simulation

RESIDUAL BUS SIMULATION

A complete simulation of the battery pack requires CAN (or other vehicle bus) communication with the TCU or ECU. For instance, the TCU may require state of charge to determine if the HEV motor can provide power or the engine should provide power. The Horiba controller provides multiple CAN channels to support this communication. Approximately 200 variables are available to be sent or received over the CAN bus connection to/from the battery simulation.

HORIBA PRODUCTS TO SUPPORT BATTERY SIMULATION

Of crucial importance is that power must be safely distributed in the transmission test cell. Convenient plug-in style connectors provide safe connection to the HEV controller and power source. Two interface cabinets provide connection between the transmission HEV motor and power. The first cabinet (hybrid interface enclosure) connects the HEV motor controller to the power source. The power source may be the battery simulator or it may connect to an actual battery. The second cabinet, the wall mounted connecting box is the DC disconnect. It provides connection between the battery simulator power source and the hybrid interface cabinet. The two enclosure system assures safe, convenient connection between power source and HEV motor.

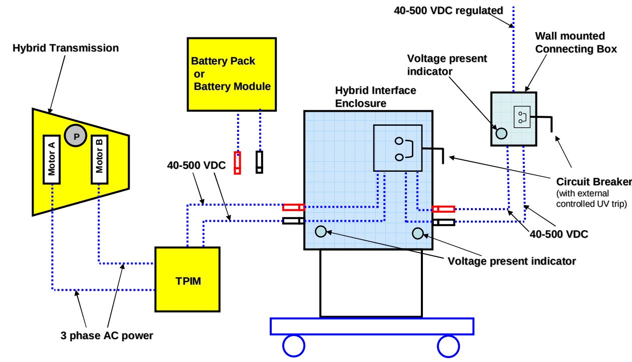


Figure 32 Horiba Products to Support Battery Simulation

Shown in figure 33 is the hybrid interface enclosure. The front view shows disconnect and power on indicators. This enclosure provides loss of isolation detection and it is connected into the emergency stop chain to support power removal without damaging the HEV motor controller. It is rated up to 600 VDC. The enclosure rear view shows the convenient power connectors.

Enclosure front view Enclosure rear view

Figure 33 Front and Rear View of Enclosure

INTEGRATION OF SIMULATIONS/TRANSMISSION WITH AUTOMATION PLATFORM

The various simulations require an automation platform to orchestrate the test and record data for post processing. Horiba uses the Stars® automation platform for this task. Stars is uniquely suited to control transmission test stands as it provides a broad range of drivers for interfacing with transmission control modules and third party devices. In addition, it provides a tightly integrated solution with the Horiba power train controller Sparc®[3]. Horiba also provides

[3] Sparc® is a product of Horiba Instruments, Troy, Michigan

a number of interfaces to the Sparc®3 power train controller to allow the Sparc®[3] controller to connect to competing automation platforms.

A key to reliable power train test stand operation is the separation of the controller from the automation system. The controller having only test stand control as its primary responsibility limits the complexity of the code it runs to only a few megabytes. As a result, the software tends to be more reliable than a general purpose computer that may run gigabytes of code. During a failure, the Sparc®[3] controller brings the test stand down in an orderly fashion. And of course the simulations all run in the Sparc®[3] controller to assure reliable execution of the simulations.

A tight integration of the automation system and the controller is tantamount to reliable and consistent execution of the transmission test. Stars and Sparc®[3] share a common heritage in their real-time systems that assure compatibility. Real-time code that runs on the Sparc®[3] can also run on the Stars automation system. Horiba is unique in providing such a system.

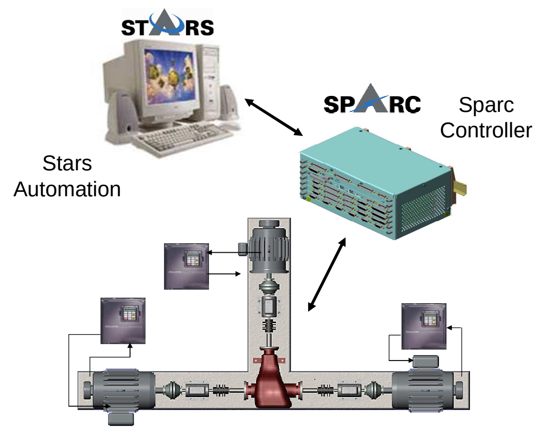


Figure 34 Integration of Simulations/Transmission with Automation Platform

DATA LOGGING, CONTROL PANELS and LIMITS

Our transmission test stand requires basic functionality from the automation system. This functionality typically includes the ability to create custom displays, acquire real-time data from the test and apply limits to protect the transmission. Shown in figure 35 are typical Stars®[2] GUIS that provide this functionality. The Horiba Stars®[2] automation platform is unique in its ability to load and unload loggers, limits, scopes and control panels while the test is running.

A key requirement to acquire and monitor transient data for transmission testing is to provide a highly responsive interface between the automation system and the transmission controller. Horiba's solution utilizes a high speed link between the Sparc®[3] power train controller and the Stars®[2] Automation system to transfer data at up to 5000 samples per second.

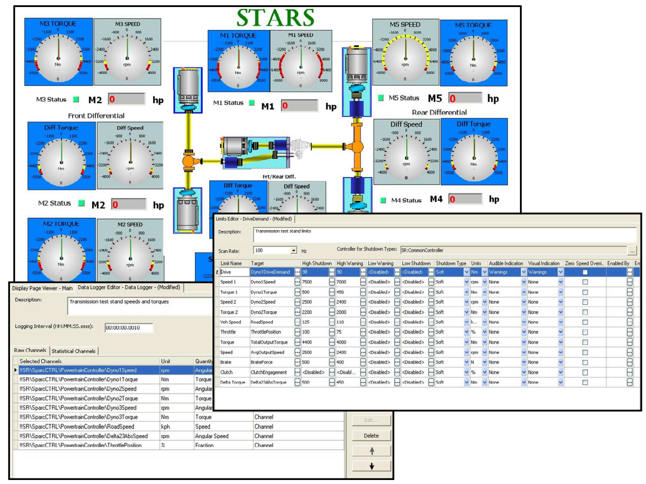
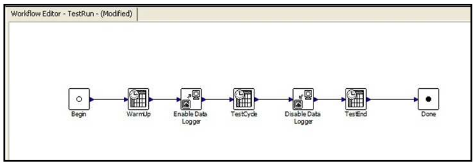


Figure 35 Data Logging, Control Panels and Limits

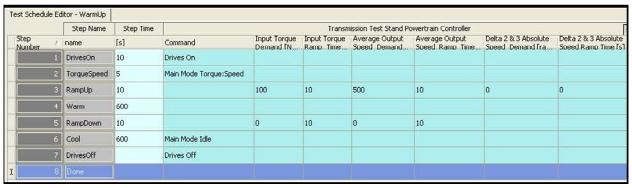
TEST SCHEDULES AND WORK FLOWS

An automation platform must provide a means to cycle the transmission through a sequence of operating points to create a usable test. The Horiba Stars®[2] automation platform provides two levels of control to sequence through the operating points. The lowest level of control called a test schedule can be used, for instance, to send a sequence of torques and speeds to the test stand (in the most primitive case). Work flows are the next higher level of control. Work flows are used to sequence multiple test schedules. Work flows also perform high level tasks like starting data loggers and then subsequently cause an analysis of the logged data.

The test schedule affects the various simulations by, for instance, triggering the transmission to shift by changing the gear in the driver simulation. Or it may run a list of throttle positions to the engine simulation. For wheel slip simulation, the test schedule may change the vertical force on a tire or change the road surface. The Horiba Stars automation platform allows a rich range of access to the parameters of the various simulations running on the controller without reloading the controller after a parameter change.



Work flow



Test schedule

Figure 36 Test Schedules and Work Flows

USER INTERFACE TO CONTROLLER SIMULATIONS

Horiba user interfaces provide the means to change parameters for the various simulations in real time. Competitor systems often require reloading of the simulations after parameters are changed. Graphics within the GUIs remind the user how the parameter affects the simulation. Embedded strip charts show real-time values relevant to the simulation.

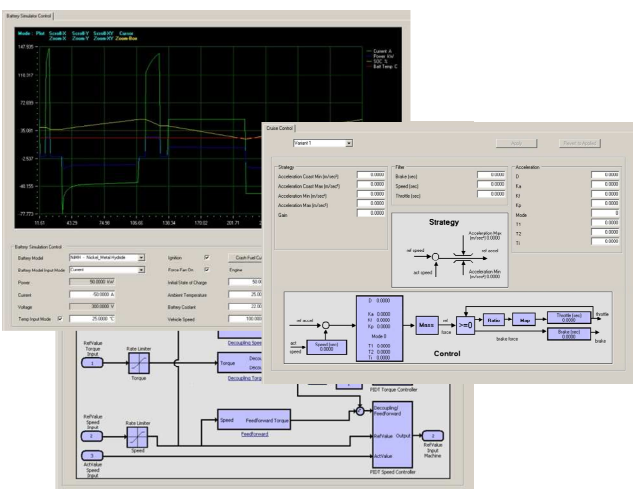


Figure 37 User Interface to Controller Simualtions

PULLING IT ALL TOGETHER TO CREATE THE CUSTOMER APPLICATION

A complete customer solution has the components shown in the diagram in figure 38. Each component has a well defined responsibility in the customer application. Customer HIL simulations can be implemented in a separate unit in a similar fashion to the TruckSim®/CarSim®[1] unit. One unique aspect of the Horiba customer solution is that all levels of the solution are easily modified to fit a particular customer requirement. Competitors often restrict changes in the power train controller as it often is a fixed blob of software that is difficult to modify. The Horiba Sparc®[3] power train controller is made up of many modules wired together which can be easily changed to provide a unique solution for each customer. Horiba application engineers can often times make controller changes in minutes without software engineers. The Horiba solution is clearly unique in the industry.

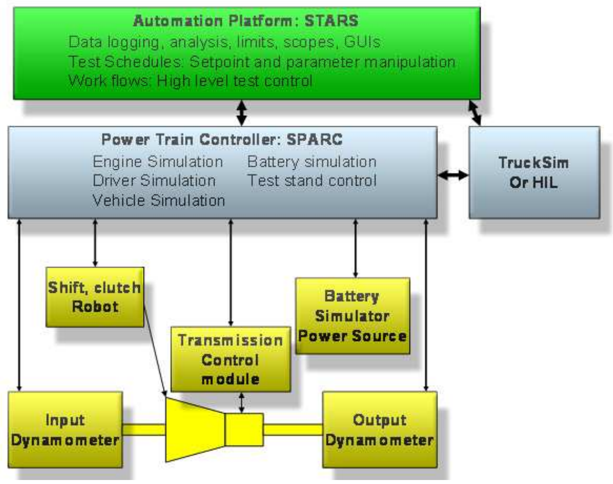


Figure 38 Complete Customer Solution Diagram

PARTS AND PIECES: SPARC, STARS: HOW IT BENEFITS CUSTOMER

Both Sparc®[3] and Stars®[2] implement a high performance real-time that can run as fast as 5000 samples per second. The customer benefit is that high speed transient events in the test cycle can be faithfully reproduced and verified.

Both Sparc®[3] and Stars®[2] provide very flexible program environments supporting modifications without requiring expensive software engineers. The benefit to the customer is that software development is generally not needed to implement his/her special requirements.

The Sparc®[3] controller is a very open controller that provides various high speed communication channels to customer and third party systems at the real-time level. The benefit to the customer is that he can easily insert his own special controls as he requires. Another benefit is that the customer can easily tie into any automation platform his company uses.

Separation of the automation platform and the power train controller creates a reliable controller. The customer benefit is that the test stand is always under closed loop control assuring a safe system.

Watchdogs between Sparc®[3], Stars and each external controller assure that subsystem failures are identified and reacted on. The customer benefit is a safe system that detects faults and shuts down in a controlled fashion.

Limits in the power train controller protect the test stand in the event of excessive torque, speed or power. Limits in the Stars automation system protect the customer specimen based on customer specified limits. The customer benefit is that both the test stand and the specimen are protected from excessive events.

HOW THE SIMULATIONS WORK TOGETHER TO CREATE CUSTOMER BENEFIT

The customer decides at run time which simulations with be in effect. All simulations are available (if the customer buys them) and can be switched on and off as the test specimen or test requires. The benefit to the customer is that he does not need even a Horiba service person to enable or disable the simulations.

The simulations are parameterized by GUIs that enable the customer to change each simulation as the test specimen or test requires. Most every change can be made without even restarting the controller. The benefit to the customer is that test stand setup can be quickly changed when the specimen or test changes. TruckSim/CarSim®[1] simulations may require a reload of the TruckSim/CarSim®[1] simulation.

WHAT'S IN STORE FOR THE FUTURE?

FUEL USAGE

A future extension of the engine simulation will probably include fuel usage. Fuel usage is useful for comparative studies that involve changes in the customer specimen or control of the customer specimen. A good example for a transmission test stand might be that the customer has modified his transmission controller to reduce fuel consumption. The customer runs the transmission through a drive cycle with various shift strategies. The cycle that results in the lowest fuel usage (as defined by the engine simulation) could indicate the correct shift strategy to use to reduce fuel consumption in the real vehicle.

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