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Development and validation of Dynacar RT software, a new integrated solution for design of electric and hybrid vehicles

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Abstract

Vehicle modelling and simulation is becoming a key competence for the development of the electrified vehicle systems, from preliminary designs to implementation and validation phases. Usually different vehicle models are used in design phases, leading to lack of traceability and robustness in the design process. An integrated approach is presented in order to allow automotive engineers to use a single vehicle model from the very beginning of the design to the most severe hardware in the loop and powertrain in the loop requirements. The new modelling concept presented has been validated with a 100kW electric race car in a test track. Validation results compared to simulation predictions are presented in the paper.

Keywords: simulation, modelling, hardware in the loop, real-time software, validation test bench

1 Description of the Dynacar framework

Dynacar RT is a full vehicle model developed in LabVIEW RT, allowing a real time simulation of an entire vehicle, with hardware and driver in the loop capabilities. It can be used through the whole powertrain design process, allowing rapid prototyping, implementation and real-time testing of ECU´s and powertrain components. Dynacar RT tool has been combined with real time test and automation software NI Veristand from National Instruments, in order to have the possibility of sequences automation testing combined with the accurate Dynacar RT vehicle model. A basic configuration with a use case for electric motor testing is showed in the following figure:

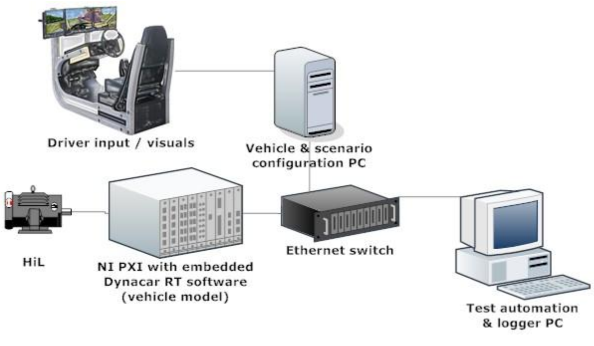

Figure 1: Example configuration of Dynacar RT for HiL testing of an electric motor with driver in the loop (real driver driving the virtual car in simulated environment).

In the previous figure is showed how the Dynacar RT vehicle model computes all the vehicle dynamic parameters providing the right values to the HiL test bench.

The combination of Dynacar RT vehicle model with NI Veristand test and automation software, offers two main benefits[1]:

- Custom control algorithms and simulation models generated with other modelling languages can be easily integrated into the vehicle model. Dynacar RT allows powertrain engineers to quickly generate their own vehicle model and test it, using the graphic user interface and the driving virtual environment. This fast vehicle model generation is very helpful in order to allow the testing of different powertrain models in final target vehicle, from the very beginning of the design stages [2].

- Safe and robust management of the real time testing, with enhanced post processing and reporting capabilities.

In the following figure, the Dynacar RT software-hardware architecture is detailed. In order to understand the Dynacar RT approach, the "virtual rolling chassis" concept has to be defined as a vehicle model computing the vehicle dynamic behaviour in real time (aero forces, tyre contact forces, driver inputs), and generating outputs for all the other available models (fig. 3).

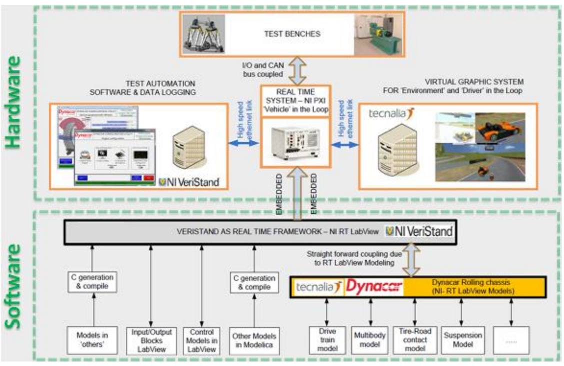

Figure 2: Detailed Dynacar RT architecture with vehicle in the loop approach.

Figure 3: Example of real rolling chassis without aero parts.

Using Dynacar RT with the "virtual rolling chassis" approach, powertrain engineers can introduce their own models generated with other modelling tools like Simulink tm (e.g. gearbox model), which can be linked with the output variables computed in Dynacar RT (e.g. resistant torques coming from the car when driving by a human driver in a test track), allowing the testing of custom vehicle models with very close to reality simulated conditions.

Dynacar RT also features a graphic 3D immersive environment with "driver in the loop" testing purposes (fig. 4), and can be used for different applications:

- Evaluation of new concepts: Quick trade studies can be carried out for real efficiency estimation, vehicle drivability, performance assessment, either with "driver in the loop" or in autonomous mode.

- Model in the loop/ Software in the loop: Development of models and control strategies which can be tested/proven in a fully virtual environment with real driver. Traction control, electrical braking, energy management strategies, torque vectoring or other strategies combining longitudinal and lateral dynamics.

- Hardware in the loop: The electronic control unit is integrated in the virtual vehicle that provides the same stimulus and response as the real vehicle. Even in rapid prototyping stage, hardware can be connected to the real time platform and conduct HiL testing.

- Test bed / Dynamometer: The propulsion system and its components interact with the models in real time, so that the relevant torques are applied in real time to the mechatronic loads.

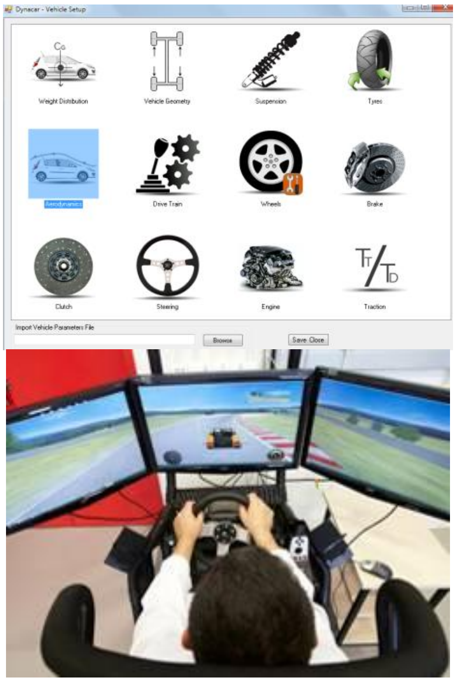

Figure 4: Dynacar configuration utility and virtual driving hardware.

2 Dynacar RT model description

2.1 Chassis and tire modelling

The vehicle model calculates the different forces acting on the vehicle for a driving situation, in order to determine the vehicle dynamic behaviour. Different models are available in the literature for vehicle dynamic simulation, starting from the simple “bycicle model”, to the roll stiffness model, and finally the multibody formulation with different degrees of freedom (ref). As Dynacar RT is mostly focused on the development of powertrain components with testing in real time, a good compromise between accuracy and execution time is required. For that reason the roll stiffness model has been implemented in Dynacar RT, due to the combination of high accuracy not only in linear conditions but also in the limits, and very good computing time. In order to obtain the forces and moments generated by the tires, widely used and proven formulation has been implemented [3], taking into account the linear and non linear behaviour.

The vehicle model can be executed in an NI PXI real time platform in less than 1ms loop time.

2.2 Dynacar model validation results and conclusions

In order to validate the results of the analytical model, different activities have been carried out. First of all, hundreds of models have been compared with bibliography. Secondly, the longitudinal and lateral dynamic behaviour has been compared with other non real time tools based on multibody mathematical formulation, and third, a validation vehicle has been modelled, constructed, instrumented and tested in the track in order to gather an extensive set of validation evidences. Besides of that, conventional vehicles have been modelled, instrumented and tested by the research group during the development of several research projects (Hiriko-City Car, Electric Bus of 18 tons, electric Mercedes Vito van conversion).

2.2.1 Model behaviour correlation with real vehicle

In order to validate Dynacar dynamic model and the results obtained, a race car electric vehicle has been built by the research team. This vehicle has a very high power to weight ratio in order to allow the validation of the model either in linear and non linear behaviour of the vehicle dynamics. This is of interest in non linear applications like torque vectoring strategies or electronic stability programs.

Vehicle
Weight: 750 kg
Maximum power: 100kW
Energy storage capability: 10kWh
Maximum speed: 140km/h
Lay out: front motor, rear wheel drive

Figure 5: Electric race car developed for Dynacar model correlation.

Additionally to the vehicle model, the test track has been accurately modelled using accurate terrain information and on site measurements.

In the following figure the test track at INTA facilities (Madrid, Spain) is showed.

Figure 6: Accurate test track model.

The model prediction (Dynacar RT in the figure) is very accurate especially in full acceleration phase and high cornering speeds. Maximum deviations are observed mainly during the braking phase, as the braking is more dependants on human behaviour.

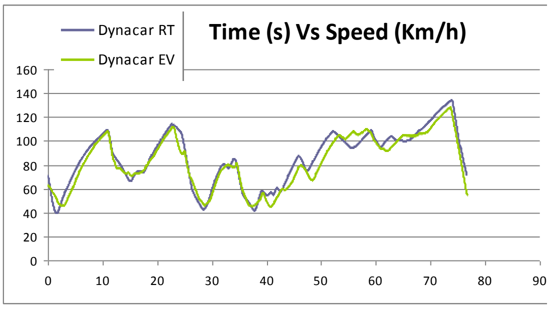

Figure 7: Time Vs. Speed at INTA test track, for Dynacar RT software in virtual simulator and the real EV car raced at the track.

The results of the virtual simulation test and the physical real measurements are presented and discussed in 2.4.2.

2.2.2 Dynacar comparison with other vehicle dynamics tools and bibliography

The Dynacar modelling strategy, which is based on the "roll stiffness" model [4] combined with non linear behaviour of tyre contact, has been compared with other current codes, some of them based on multibody modelling approach. Different road vehicles have been modelled with Dynacar and other multibody vehicle dynamics analysis tools, and the results have been compared with technical bibliography from physical testing carried out by professional drivers in test tracks.

As a summary of the results, the following figure shows the correlation between the physically measured performance figures in the longitudinal domain (Dynacar in orange). In this domain, it should be highlighted that the results are very similar to reality for a wide range of vehicles, from front wheel drive small cars to high power rear wheel driven models.

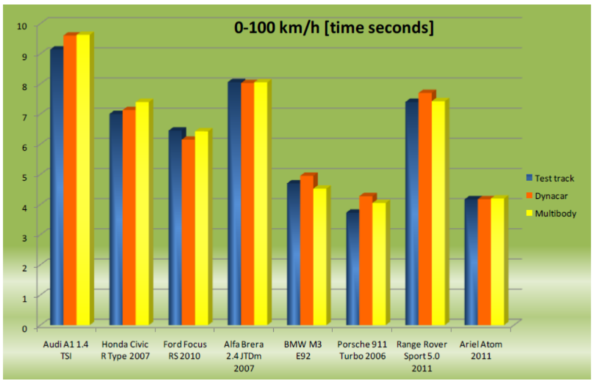

Figure 8: Longitudinal performance of different vehicles measured in the test track versus simulations in Dynacar and reference multibody dynamics simulation tool.

Concerning the results related to lateral dynamics, the results when predicting the maximum lateral forces obtained on the skid pad are shown in the following picture (Dynacar results in orange):

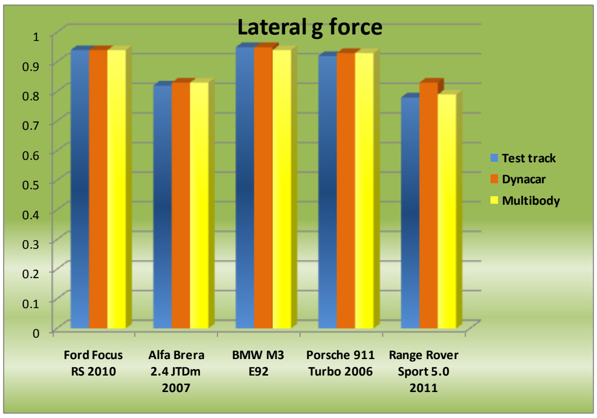

Figure 9: Lateral performance of different vehicles measured in the test track versus simulations in Dynacar and reference multibody dynamics simulation tool.

3 Development use cases

Dynacar RT has been used in the following developments, in early stages of design, as a rapid prototyping tool.

3.1 Validation of electric van conversion and rear steering algorithm

The electrification of the powertrain will allow the implementation of new active devices in the chassis and suspension domains. In this use case Dynacar has been used for the development of a rear steering electrical system on a fully electric van. Dynacar was first used to identify manoeuvre loads and the initial control strategy. When initial prototypes were manufactured, the Dynacar tool was used to conduct HiL testing of the electronic control unit and electric drive used for the actuation of the steering mechanism.

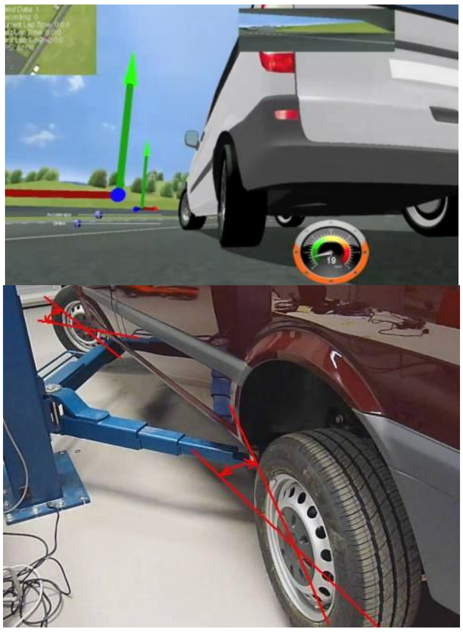

Figure 10: Virtual modelling and physical testing and of rear steering electric module.

3.2 Validation of energy management strategies of NCV vehicle for emission reduction

NCV (Networked Clean Vehicle) vehicle is able to adapt in real time the powertrain energy management strategy. Thus, the powertrain subsystems state variables, the information variables received through the on-board V2X communication systems, and the trip schedule defined for the driver, is used in the overall energy management strategy for the optimization of the range, consumption and emissions.

Dynacar has been used in NCV development in order to validate final strategies with human in the loop (driving Dynacar in the driving simulator), in terms of consumption and emissions reduction [5].

3.3 Validation of Formula Student race car preliminary dynamic design

Formula Student (FS) is Europe's most established educational motorsport competition, run by the Institution of Mechanical Engineers. The competition aims to inspire and develop enterprising and innovative young engineers. Universities from across the globe are challenged to design and build a single-seat racing car in order to compete in static and dynamic events, which demonstrate their understanding and test the performance of the vehicle. Using the Dynacar software the EHU University of Basque Country team, has been able to validate quickly preliminary designs with driver in the loop (in terms of vehicle dynamics, lateral forces, driver impression), in order to define a preliminary vehicle dynamic setup to start with the detailed development.

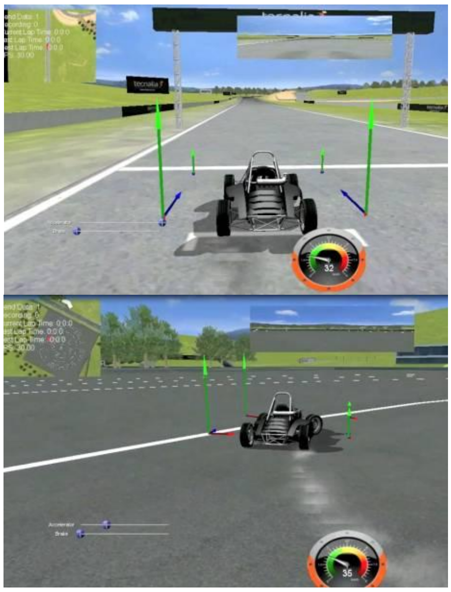

Figure 11: Virtual testing of the F-Student race car in order to validate the preliminary vehicle dynamic design.

4 Test bench use cases

Dynacar has been implemented in laboratories as a powerful development environment for vehicle systems. As representative examples, two laboratories are presented.

4.1 GKN Driveline electric drive laboratory

GKN is the world leader in automotive driveline technology. The purpose of this laboratory is mainly the development and testing of complex integrated electric drives and gearboxes for electric and hybrid vehicles. The test bench consists of two high performance mechatronic loads for each wheel, the test automation HW/SW and the real time Dynacar model. This test bench offers the possibility of testing the power inverter, electric motor, gearbox, differential and output shafts at the same time in a fully realistic environment, governed by the Dynacar real time model, which calculates wheel speeds and loads. In addition to the testing, this test bench allows GKN engineers to develop complex algorithms for functions such as regenerative braking and torque vectoring strategies, evaluating the effects in the vehicle handling.

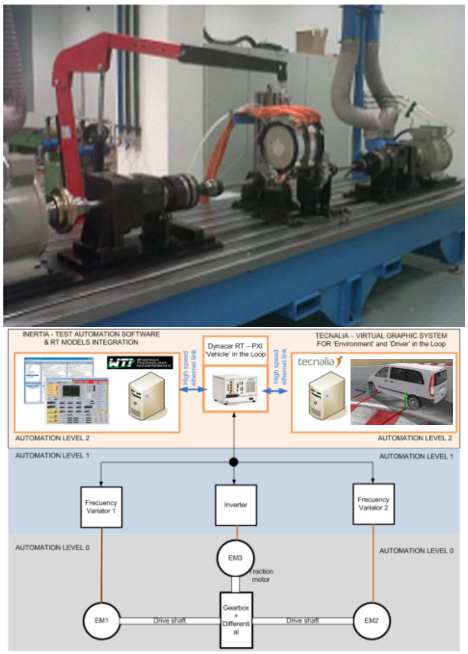

Figure 12: GKN Driveline test bench with Dynacar RT.

4.2 City Car (Hiriko) development laboratory

The Hiriko City Car is a vehicle which features very advanced characteristics; four wheel drive and rear steering are challenging features to be safely implemented in a vehicle. For the development of the vehicle control algorithms, a “state of the art” laboratory has been developed. Using the Dynacar real time model environment, the City Car design team is able to develop the control algorithms for the 4wD systems, as well as the functions related to the rear steering systems. In addition to that, once that the prototypes for the most important components have been developed, full HiL testing can be carried out using either defined driving cycles, or having the “driver in the loop” in order to evaluate the handling characteristics. In addition to this, it is necessary to develop the control strategies in conjunction with the existing safety systems, such as the ABS/ESC. The real time model approach can be used for the effective integration of new algorithms in a structured and safe manner, analyzing the logic of existing systems [6].

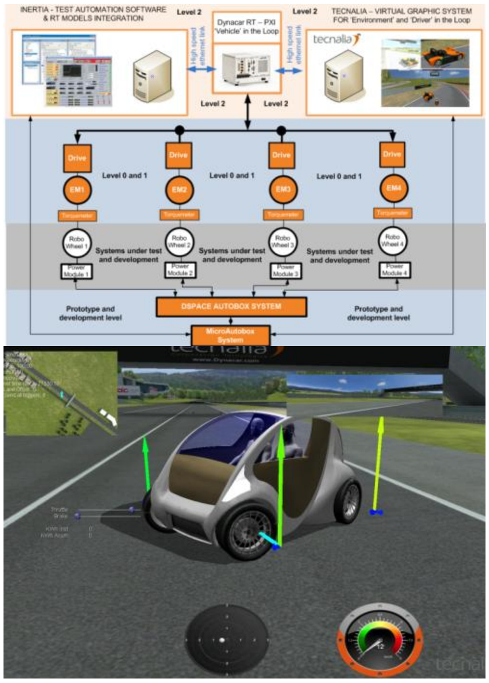

Figure 12: HIRIKO city car development laboratory layout and virtual model.

5 Conclussions

Main conclusions are:

- Dynacar RT is an accurate tool for vehicle system development, and allows rapid prototyping in very early stages of the design cycle.
- Dynacar RT allows the advanced simulation techniques such as HiL and Human in the loop, appropriate for vehicle subsystem fast prototyping.
- Deviation from reality is less than 4% in longitudinal and lateral dynamics.
- Accurate energy consumption, acceleration and velocity estimation can be carried out.

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