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TITLE:

ANALYSIS OF THE VEHICLE DYNAMICS USING ADVANCED INSTRUMENTATION

Topic:

- ● FUTURE AUTOMOTIVE TECHNOLOGY
- ○ USER FRIENDLY AUTOMOBILE
- ○ VEHICLES & THE ENVIRONMENT
- ○ INTELLIGENT TRANSPORTATION SYSTEMS
- ○ ADVANCED PRODUCTION AND LOGISTICS

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Abstract:

Lots of improvements in future vehicles look for increasing levels of safety; consequently, among other aspects, the dynamic behaviour of the vehicle represents a relevant factor influencing the safety. It is important for the driver to predict the response of the vehicle while he manoeuvres, therefore any improvement to be introduced that help in such a manner should be studied from the dynamics point of view. This paper describes a methodology to obtain the most relevant parameters of a vehicle and a systematic method to prepare tests and to deal with the data provided by advanced instrumentation (e.g. gyroscopic platform, optical distance sensors, rotating wheel dynamometer) in order to validate vehicle models or to study experimentally the complete dynamics of the vehicle. It is also included the application of the methodology to real data resulting of tests in a vehicle.

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ANALYSIS OF THE VEHICLE DYNAMICS USING ADVANCED INSTRUMENTATION

INTRODUCTION

Lots of improvements in future vehicles look for increasing levels of safety for the occupants and other road users; consequently, among other aspects, the dynamic behaviour of the vehicle represent a relevant factor that have influence on safety. It is important for the driver to predict the response of the vehicle while he manoeuvres, therefore any improvement to be introduced in the vehicle that help in such a manner should be studied from the dynamics point of view.

Since the experimentation is expensive and it is difficult to consider the whole range of possibilities, a solution could be achieved by simulating the vehicle dynamics in a computer. In this way it is allowed to analyse multiple manoeuvres reducing costs and risks. The problem associated to this technique is the validation of the vehicle model.

However, in both situations (experimental study of dynamics or tests for model validations) the following milestones should be solved when our research involves tests in tests tracks:

- Tests definition
- Interesting variables definition
- Necessary instrumentation definition
- Tests execution
- Data processing

Although initially the phases may seem obvious, several factors make the whole process difficult. If a systematic methodology is applied, the time taken by this study is reduced and a greater efficiency in data processing is obtained. Obviously, the methodology should fit the final objectives of the study, the available means and the accuracy level required.

The methodology presented is of general purpose and tries to solve the different phases looking at the most common requirements and limitations that researchers find in practice. This methodology is not only a summary of rigorous rules, but also a help to solve the problems appeared when studying the vehicular dynamics in real tests.

TESTS DEFINITION

The most important idea that should be taken into account to define the tests carried out is that the tests should be chosen systematically paying attention to the objectives of the study. It should be distinguished between steering tests and longitudinal tests.

ISO regulations provide information related to the first group:

- ISO 15037-1: Vehicle dynamics test methods. General conditions for passenger cars (7)
- ISO 7401: Lateral transient response test method (6)
- ISO 4138: Steady-state circular driving behaviour. Open-loop test procedure (5)
- ISO 9816: Power-off reactions of a vehicle in a turn. Open-loop test method (4)
- ISO TR 8725: Transient open-loop response test method with one period of sinusoidal input (2)
- ISO TR 8726: Transient open-loop response test method with pseudo-random steering input (3)

These technical reports suggest the test conditions, the variables that should be measured and the way of presenting final data. They also define specific parameters of practical interest for the vehicular dynamics analysis.

Because of the limitations of the test track and the vehicle driver, the manoeuvres given by ISO regulations present difficulties, such as the following:

- The data should be corrected because of the test track (ramp and banking different from zero)
- There is not enough place to trace completely the trajectory
- A human driver can not carry out the manoeuvre with the accuracy cited by the technical reports

The first one can be treated during the phase of data processing if the geometry of the track is known. The other two difficulties require changes in the tests definitions. Table 1 shows possible modifications of the most important steering tests:

Table 1: Possible modifications for the steering tests mentioned by ISO regulations

Manoeuvre	Common limitation	Suggested modification
Steady-state circular test	ISO 4138 recommends radius over 30 meter, so the track should be wide enough	The practical radius is smaller than 30 meter and the test speed is computed in order to maintain the same levels of lateral acceleration
One period of sinusoidal input	A human driver finds difficult to carry out a steering manoeuvre if the reference is the steering wheel angle.	The manoeuvre in open- loop could be replaced by a closed-loop manoeuvre in which the driver follows a certain trajectory. The angle turned by the steering wheel should be similar to the one given by the ISO technical report

In braking or acceleration tests, the main problem arises in defining the parameters that depict the dynamic response of the vehicle. It is advisable to use standardized parameters. For example, the study of the braking capacity can be evaluated by the averaged stabilized deceleration given by the 71/320/CEE-98/12 CE Directive (Braking) (1).

VARIABLES OF INTEREST FOR THE STUDY OF THE DYNAMICS AND ON BOARD INTRUMENTATION

ISO Standards define the variables that should be taken into account during the study of the vehicle dynamics. These variables are shown in table 2. However, this list should be revised in order to fulfil the specific objectives of the study and not obviate important information. Any modification in the list should be carefully justified.

Table 2: Variables listed by ISO 15037-1 for dynamics study

Longitudinal speed	Yaw angle
Slip angle - Lateral speed	Roll angle
Longitudinal acceleration	Pitch angle
Lateral acceleration	Steering angle

The instrumentation on board should provide the data referred above but it is important to take into account the following items:

- It is not advisable to use more instrumentation than necessary for the achievement of the objectives of the study. Some variables can be indirectly obtained from other signals given by the sensors. This process needs to be assessed so that the introduced errors may be known.
- The number of acquisition channels and the maximum acquisition frequency are limited by the equipment. Nowadays, this is not generally a problem if suitable equipment is available.
- In compacts cars, the available space inside and outside the vehicle can limit the size of certain kind of instrumentation.
- Some equipment involves permanent modifications in the vehicles. This cannot be acceptable and researcher should look for alternative solutions.

The limitations above listed require to choose the more important variables for each study and to obtain the rest of the variables from indirect calculations. Obviously, we should study if the results are correct. Moreover it should be known the errors that may be introduced in case the variable is not directly obtained.

Data processing is conditioned by the corrections needed to be carried out since the track does not meet exactly the technical reports specifications and the calculation of the indirect variables. For this reason, it depends on the particular case. The next topic deals with some tests carried out by INSIA (Polytechnic University of Madrid – Spain). The final objective was the validation of a mathematical model for the prediction of the vehicular dynamics.

APLICATION OF THE METHODOLOGY TO REAL TESTS

Data from real tests are processed and shown steering manoeuvres and braking manoeuvres were carried out for the complete validation of a mathematical model. Characteristic data of the vehicle were taken from 3 sources:
- Data given by the manufacturer
- Data resulting from laboratory tests
- Estimated tests

Tests and instrumentation definition

Following the modifications given in table 1, the tests that we carried out were:
- Constant radius (14 meter) test at different speeds
- Lane change at speeds between 40 and 100 km/h. The distance in which the change should be completed was calculated taking into consideration the frequency of the steering wheel turn described by ISO standards.
- Double lane change with identical considerations to simple lane change manoeuvre.
- Braking from speeds between 50 and 100 km/h

The interesting variables for the validation are the following:
- Speed (model input)
- Steering wheel angle (model input)
- Longitudinal and lateral accelerations
- Pitch, roll and yaw angles
- Forces at wheel-road contact (not included in table 2)

The available instrumentation is shown in table 3.

Table 3: Available instrumentation

	Instrumentation	Variables
I1	Speedometer without contact ONO SOKKI LC-660S	Longitudinal speed of the vehicle
I2	Steering wheel angle sensor (Sensor Developments 01027)	Steering wheel angle Moment applied to the steering wheel
I3	Braking circuit pressure sensor	Braking circuit pressure
I4	Accelerometers ADXL 202 y ADXL 210	Accelerations
I5	Gyroscopic platform RMS FES 33	3 axis accelerations Angles turned around 3 axis Angular speed around 3 axis
I6	Rotating wheel dynamometer KISTLER RWD CT	Forces at the wheel – road contact Moments at the wheel – road contact Wheel rotation Temperature
I7	Optical distance sensors MEL M5L/200	Longitudinal distances

The instrumentation listed above is enough for obtaining the variables pursued. However, there are some restrictive limitations:

- The maximum number of analogy channels is given by the data acquisition system (National Instruments DAQ Card 700). This card has 16 inputs.
- It is not acceptable to make important or permanent modifications in vehicle systems.
- Power for the equipment is taken from the vehicle battery.

Some variables can be obtained only by using certain sensors. Therefore, it should be firstly considered these variables. Then, it could be introduced other measurement equipment and considered the possibility of calculating indirectly some variables from other signals. In this last case, the error committed should be weighed up.

To obtain the variables listed in table 2, a speedometer, a steering wheel angle sensor and a gyroscopic platform are necessary. Obviously, it is not convenient to obtain speed from acceleration signals by integration, since the longitudinal speed can not be calculated from the gyroscopic platform outputs.

Tyre forces and moments were not included in table 2. In validation studies, the tyre model influence is very high, so it was decided to include a rotating wheel dynamometer in one of the front wheels. Notice that longitudinal speed can be obtained from the rotation speed of the wheel, so that the speedometer without contact is not necessary.

The suspension deformation can be measured with the optical distance sensors. If the signals of 3 or 4 wheels are available, pitch and roll angles can be calculated fitting a plane. Then, some hypothesis about the tyre and the suspension behaviour are necessary. On the other hand, the signals of the distance sensors can be obtained from the gyroscopic platform signals. The same hypotheses are necessary to be considered again. It is important to bear in mind that the deformation signals taken from the optical sensors do not need to be corrected if the test track has inclinations different to zero. This advantage and the discrepancies introduced by the hypothesis are reasons to consider both sensors in the tests.

The final instrumentation chosen is listed in table 4. 16 input channels are used.

Table 4: Instrumentation used in test carried out by INSIA

INSTRUMENTATION	MEASURED SIGNALS
Gyroscopic platform	Linear acceleration X Linear acceleration Y Linear acceleration Z Roll angle Pitch angle Yaw angle
Distance sensors	Suspension deformations in 3 wheels
Rotating wheel dynamometer	Longitudinal force Lateral force Vertical force Rolling moment Alignment moment Wheel speed
Instrumented steering wheel	Angle

Data processing planning

Some variables are calculated indirectly from other signals. Figure 1 shows the path to obtain them.

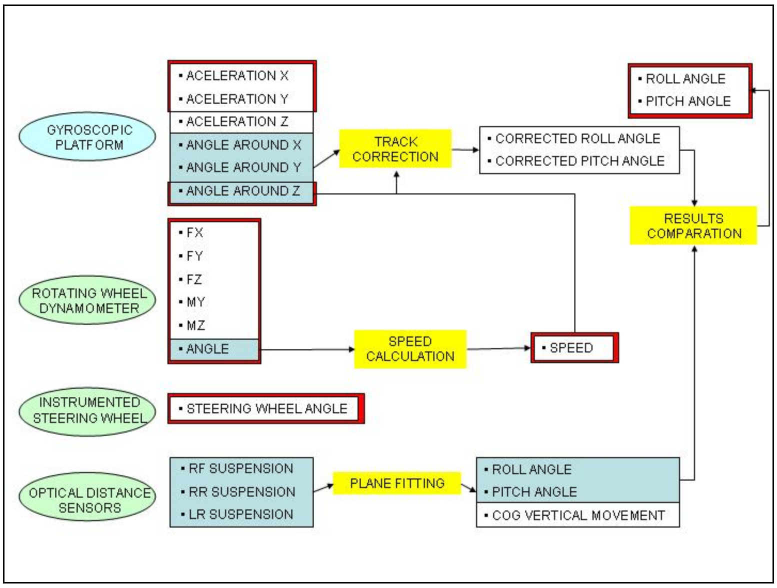

Figure 1: Calculation of dynamic variables of the vehicle (The variables pursued are shaded in red)

The most important phases are the following:

- Instantly, the wheel roll period is obtained. Then, if the mean dynamic radius of the tyre known, the longitudinal speed of the vehicle is calculated. Of course, this method is not correct in severe braking or acceleration manoeuvres.
- The angular measures provided by the gyroscopic platform include the slope and the banking of the test track. In order to obtain the roll and pitch angles, a correction should be done. To make this correction, it is necessary to know the position of the vehicle and the geometry of the track.

- The roll and pitch angles given by the optical sensors are obtained fitting a plane. This method provides us the deviations from the initial position at each moment.
- The comparison of the angles obtained with the latest two methods has to reference to the same coordinate system.

<u>Preliminary verifications</u>

Before data processing, some suppositions should be verified:
- The error made calculating the speed by using the wheel roll speed.
- Differences in the roll and pitch angles obtained when three distance sensors are used and when four sensors are available.

1. Error in the speed calculation

In order to obtain the longitudinal speed from the rolling speed of a wheel, a certain acquisition frequency is necessary. This minimum frequency can be estimated by the error propagation law.

The most important source of errors is the estimation of a dynamic radius. This estimation is acceptable when the test conditions are similar to the radius calibration conditions. Some comparisons have been made between the results obtained from the rotating wheel dynamometer and the data given by a speedometer without contact. Figure 2 shows that the differences are not relevant if no sudden changes occur in the vehicle behaviour.

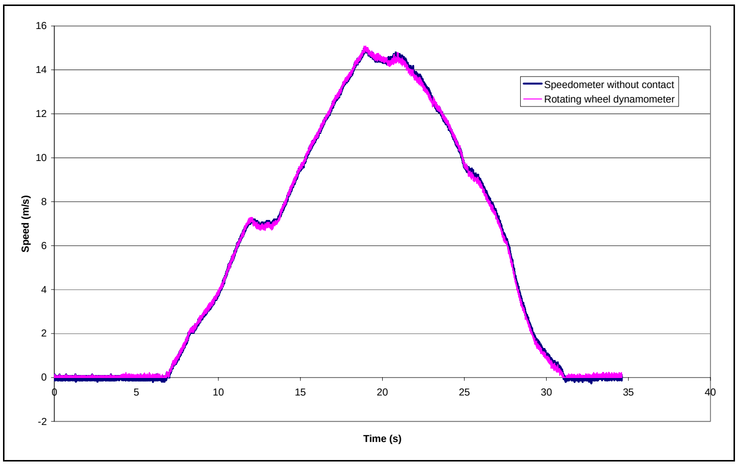

Figure 2: Comparison between speed data

2. Roll and pitch angles calculations by using 3 or 4 points

The calculation of the roll and pitch angles form the optical distance sensors data involves 2 hypotheses:
- The tyres have infinite vertical stiffness
- Camber and toe variations effects are neglected

Because of the fact that only 3 optical sensors are available in the final test (the forth wheel is the rotating wheel dynamometer), it will be studied whether the differences in the vehicle angles calculation are relevant or not when 3 or 4 set of deformation data are used. In a preliminary phase, 4 sensors were put and manoeuvres similar to the planned final tests were carried out. The results (figure 3) show that the forth sensor is not essential.

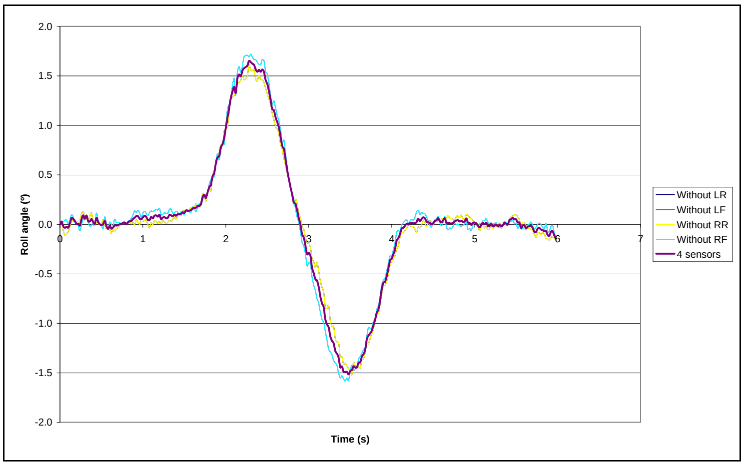

Figure 3: Roll angle calculation from suspension deformation data (lane change at 60 km/h)

The errors introduced due to the initial hypotheses will be seen when comparing them with data provided by the gyroscopic platform (figures 5 and 6).

Data processing

Data processing is carried out following figure 1 indications. Then the indirect variables are obtained and the mathematical model validation can be done. This validation is out of the scope of this paper.

The following figures show the calculations performed in a double lane change test at 55 km/h. In the graphs depicted below, the first figure shows the measured variables and the second one contains the calculated variables.

When comparing roll angles obtained using the gyroscopic platform and the optical distance sensors (figures 5 and 6), it can be seen that the differences are significant. These differences are caused by the initial hypotheses done in the calculations. For this reason, the data that should be used in subsequent studies are the corrected angles that the gyroscopic platform provides.

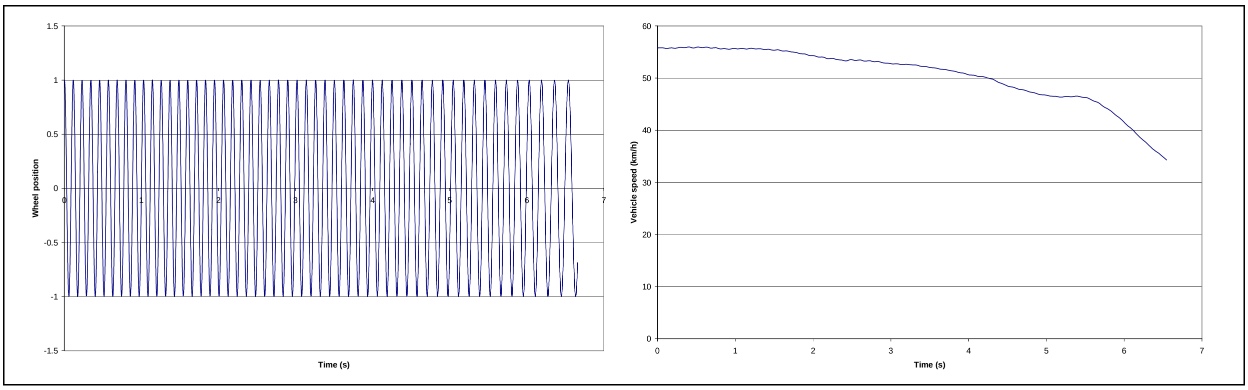

Figure 4: Calculation of the vehicle speed from the wheel rolling speed

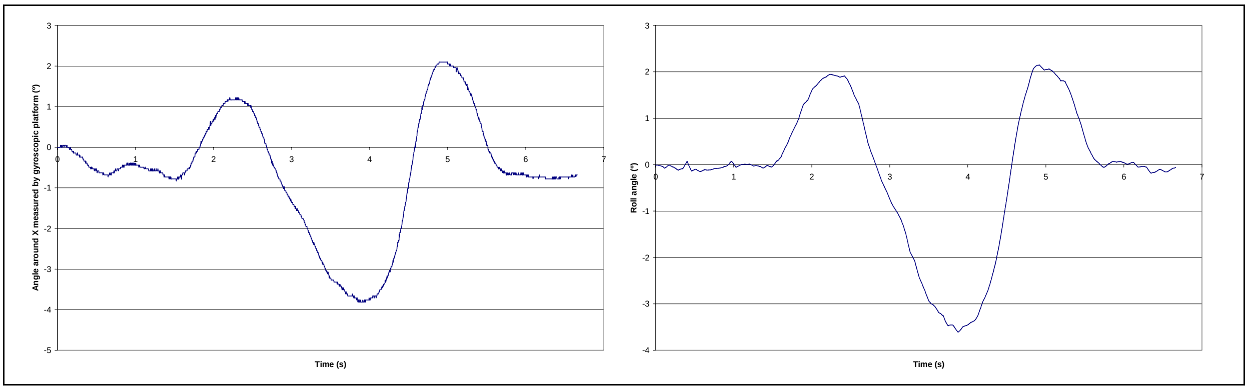

Figure 5: Correction of the roll angle signal given by the gyroscopic platform due to the track banking

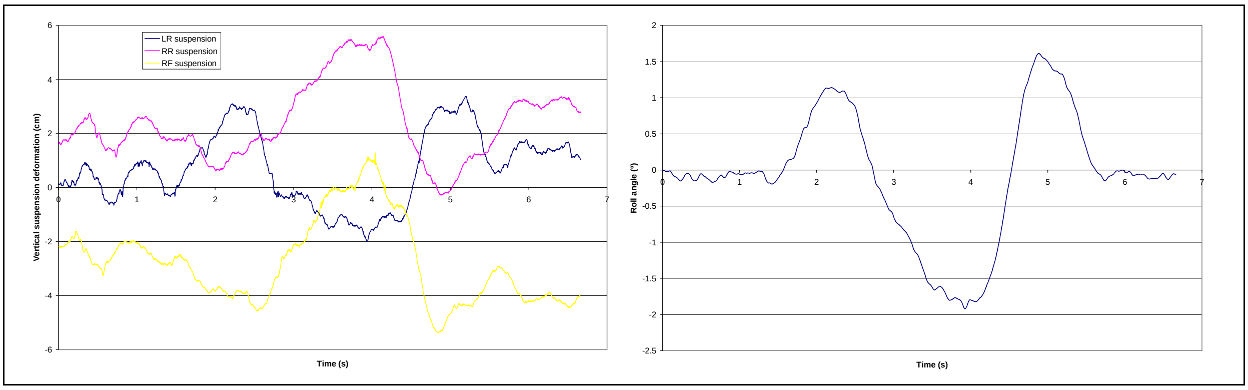

Figure 6: Calculation of the roll angle from the optical sensors data

CONCLUSIONS

In this paper, a systematic methodology for the definition of tests for dynamic analysis in test tracks and for data processing is presented. The most typical limitations found are shown and solutions are proposed.

The indirect calculation of some variables is not always correct so, before carrying out them, preliminary test are necessary in order to know the error made. It has been shown that the calculation of longitudinal speed from the wheel rolling speed is correct in smooth manoeuvres. On the contrary, the hypotheses done to calculate the roll and pitch angles from the optical sensors data introduce large errors that are not acceptable.

Obviously, the proposed methodology is general. Some modifications may be necessary depending on the situation, the available resources and the specific objectives of the study. These objectives are important since they define the relevant variables and the required accuracy.

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