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ELECTROMECHANICAL BRAKING SERVOS FOR ELECTRIC VEHICLES - SIMULATIONS AND EXPERIMENTAL VALIDATION

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The paper presents the operation principle of the second generation of electromechanical car braking systems, suited for electrical vehicles from the family ID3. The real dynamic performances of a recent type of high voltage electric battery car are investigated by digital simulation and experimental identification in harsh traffic conditions on a highway. The specific type of diagnosis device using a CAN with 12 modules allowed a deep "view" inside the whole car, both in the power supply system, and the braking one. The simulation results of the braking phases are in good agreement with those supplied by the dedicated CAN sections. The time response of the electromechanical brake covers all the needs of any sudden braking process, which activates the ABS system. The behavior of the high-voltage battery, specified by its dedicated CAN section, corresponds to the harsh traffic conditions encountered on the highway: a long row of cars accelerating periodically from about 60 km/h till 130 km/h needs a relatively high energy consumption from the high-voltage battery, specific to a town traffic.

Keywords: electromechanical vehicles brakes, structures, dynamic performances, energy saving possibilities

1. Modern electrohydraulic brake systems

In the most advanced electric vehicles, the braking full security in normal or autonomous drive manner is achieved following the classical electrohydraulic aerospace design. It is called "Sensotronic Brake Control", (SBC) and includes two different sections by supplying the ABS, TCS, ESC and ECU systems with an electrical driven hydraulic piston pump [1]. A small volume fluid accumulator allows a few braking sequences without an important energy consumption (fig.1) with the functions of a conventional hydraulic brake: reduces the vehicle speed, bring the vehicle to a halt, or keep the vehicle stationary.

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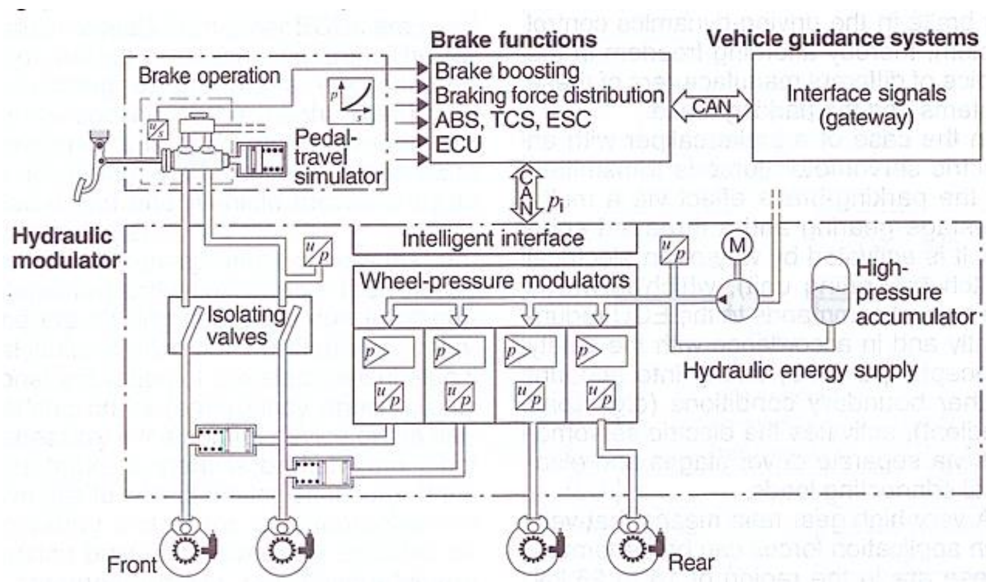

Fig. 1. The Sensotronic Brake Control scheme. [1]

As an active braking system, it takes the control of brake operation, braking-force boosting and braking-force control. Mechanical operation of the brake pedal is detected by the actuation unit by means of electronic sensors with redundant backup. The pedal-travel sensor consists of two separate angle-position sensors. Together with the brake-pressure sensor for the pressure applied by the driver, this produces a *threefold system* for detecting driver input.

The system can continue to function normally, even one of sensors fails. The pedal-brake simulator produces an appropriate force/travel curve and calculates the amount of brake-pedal damping. The driver experiences the same “brake feel” with electrohydraulic brakes as with a very well designed conventional braking system. A conventional brake booster is not required here. Only the driver’s brake request is determined in the actuation unit during normal operation; the brake pressure is generated in the hydraulic modulator.

The brake master cylinder performs its function in the event of a system failure. The expansion reservoir supplies the hydraulic modulator with brake fluid.

The brake request is determined in the remote-mounted ECU from the sensors signals of the actuation unit. An intelligent interface with the CAN bus provides the link between ECU and the add-on of the hydraulic modulator.

This high technical level system, created by Robert Bosch and Daimler Chrysler, was promoted by Mercedes with wide warranty in the luxury class domain. However, the interest of the basic automotive market for SBC remained limited.

The conventional vacuum-based brake systems, including an electric vacuum pump, are still used on low-cost electric or hybrid vehicles [2]. The BOSCH variant of the vacuum brake booster with innovative Tie Rod technology (Fig. 2) stands out by virtue of its low weight and optimized braking power (steel variant up to 20 percent lighter than conventional vacuum brake boosters). The aluminum variant reduces weight by an additional 20 to 25 percent. The aluminum brake booster thus contributes to lower fuel consumption and CO_2 emissions. The high rigidity of the vacuum brake booster shortens the brake pedal travel in maximum braking situations, thereby enhancing safety and comfort.

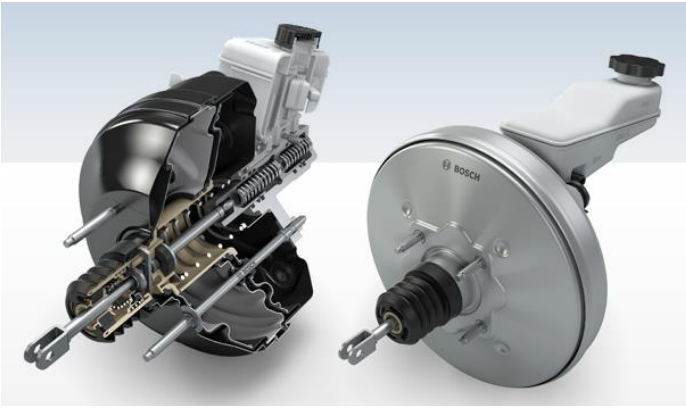

Fig. 2. Vacuumatic brake booster for light and medium load vehicles. [2]

2. Electronic brake servo

The first step in avoiding the use of a vacuum source (engine admission gallery or a vacuum pump) was the parallel driving of the brake pump piston. Some automotive components companies patented different electro-mechanical systems. The iBooster [3]...[8] created by Bosch Company (Figs. 3, 4 and 5) can be used with all drivetrain configurations and is particularly suited to hybrid and electric vehicles. The actuation of the brake pedal is detected via an integrated differential travel sensor and this information is sent to the control unit. This unit determines the control signals for the electric motor, while a three-stage gear unit converts the torque of the motor into the necessary boost force. The power supplied by the booster is converted into hydraulic pressure in a standard master brake cylinder. The electromechanical design of the iBooster also offers a host of benefits for driver assistance systems. Using the electric motor, the iBooster can build up the pressure independently, without the need for the driver to apply the brake pedal. Compared with typical ESP® systems, the required braking pressure is built up three times more quickly and is adjusted with much greater accuracy through the electronic control system. This offers significant benefits for automatic emergency braking systems. In combination with the ESP® from Bosch, the iBooster provides the braking system redundancy required by automated vehicles for safety reasons.

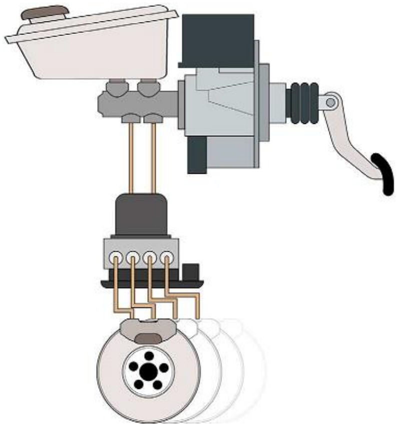

Fig. 3. The components of the vacuum-independent brake booster eBKV.

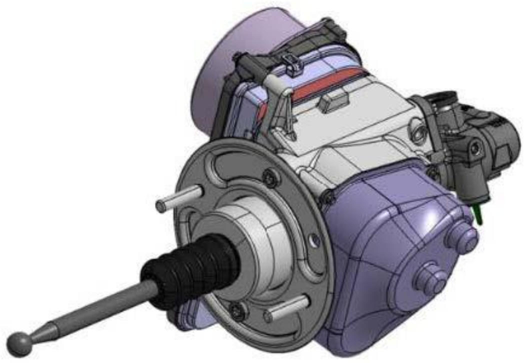

Fig. 4. Overall view of an IBooster electronic brake servomechanism.

The torque of a small high-speed brushless motor is multiplied be a three stages gear mechanism with clearances compensation (Fig.3).

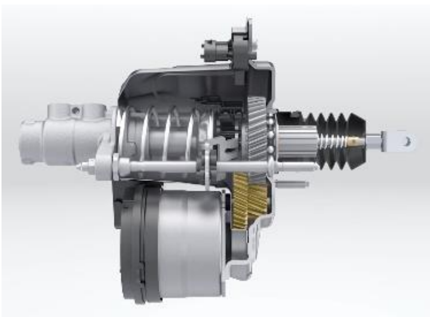

Fig. 5. Cut view of the second generation of IBooster [5]

The nominal power of the motor is small enough (370W) in order to limit the energy consumption from the car low voltage battery. The electromechanical control of the brake systems allows the overall control of the car dynamics by a synergic action with ABS, ESP etc.

5. Modeling and simulation of the IBooster used on ID3 electric car

The prediction of the performances of such a complex hybrid system can be performed by numerical simulations with languages which include realistic models of all the components. The authors are currently using Simcenter Amesim [9], [10], [11] which is completed with some structural parameters of the control system of the brushless motors used for driving the small size pumps. Simulink and other languages were also used [12], [13], [14]. The basic simulation network from Fig. 6 was used to predict the IBooster dynamics.

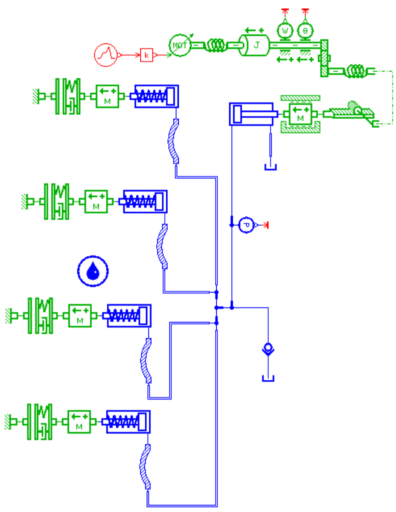

Fig. 6. Simulation network of IBooster for a normal braking procedure

A common duty cycle of the system introduced by the pedal travel sensor is specified in Fig. 7.

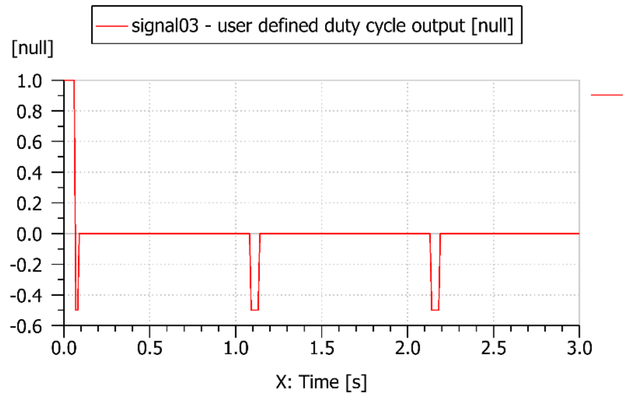

Fig. 7. The duty cycle output introduced by the pedal travel sensor.

The results of the simulations are presented in the following diagrams (8…13), showing very useful details of following the process.

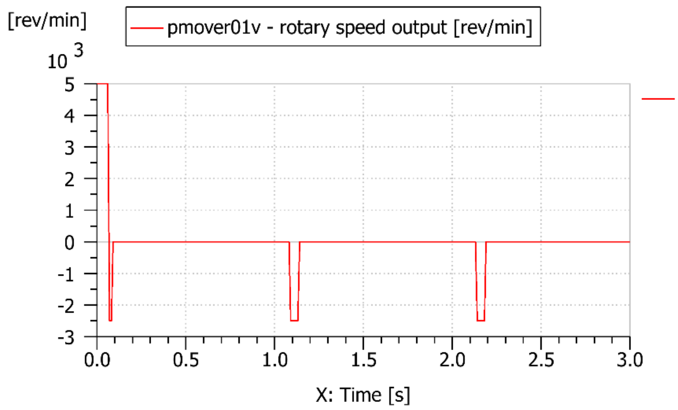

Fig. 8. Brushless motor rotary speed variation.

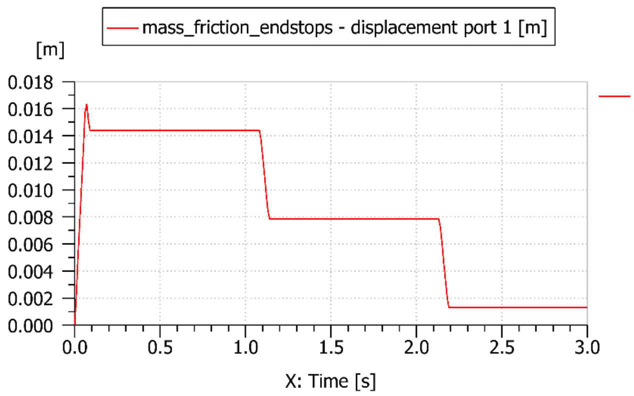

Fig. 9. Displacement of the pump piston actuated by the brushless motor.

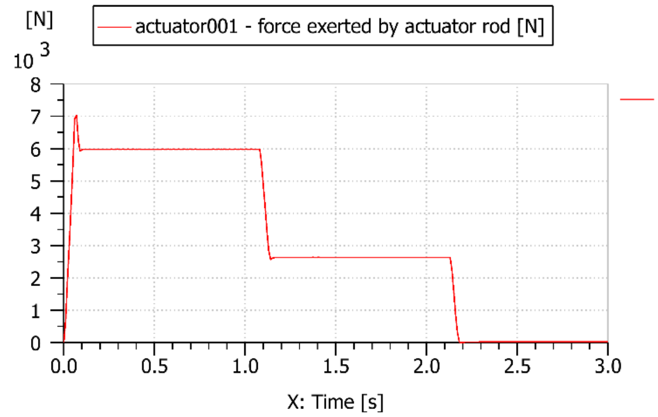

Fig. 10. Force exerted by the actuator rod on the pump piston.

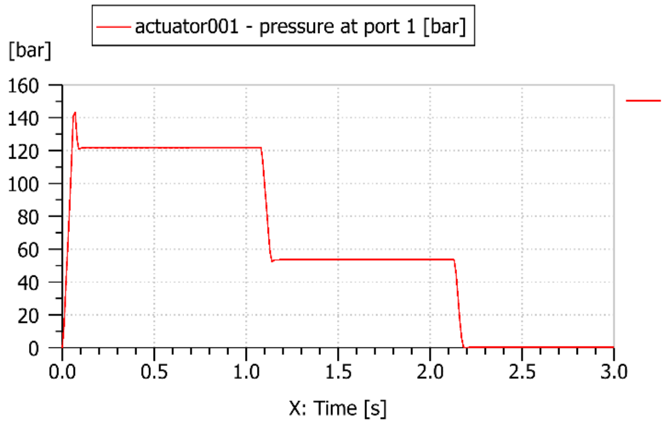

Fig. 11. Pressure variation in the delivery port of the electromechanical pump.

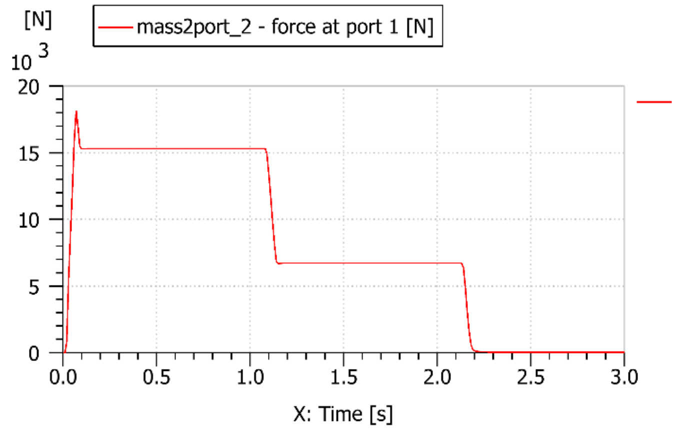

Fig. 12. Pressure force applied on the pistons of a fixed caliper of the front axle (6 pistons of 30-36-38 mm diameter).

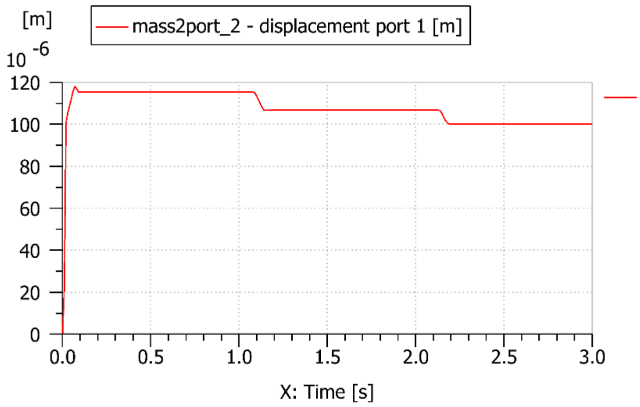

Fig. 13. Typical axial displacement of the biggest caliper piston (max. 30μm).

6. Some experimental validations of the simulation model

The understanding of a brake complete process needs a complex investigation. The presented ones were globally validated by some experimental researches carried out on a ID3 full electric car having the platform from Fig. 14, by running on a good quality highway during a few quasi-identical driving cycles.

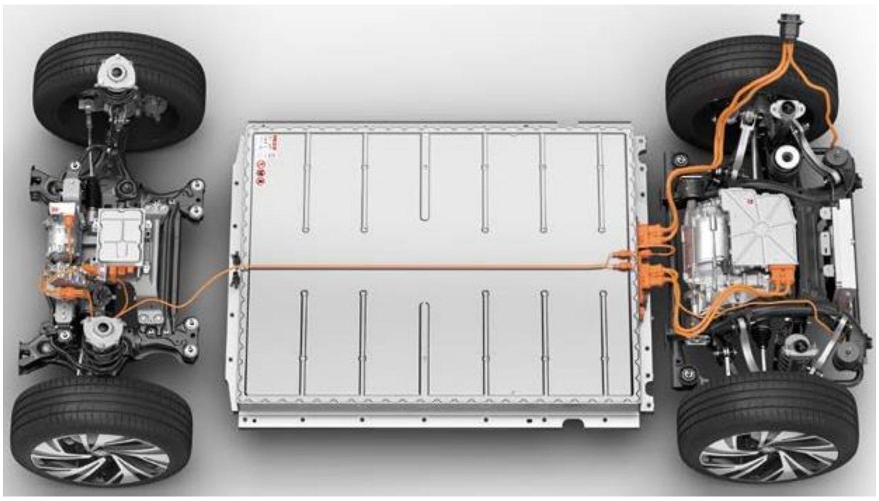

Fig. 14. Main components of the high-voltage platform of an ID4 electric vehicle: Voltage Converter, Air Conditioning Compressor, PC Heater Element, High Voltage heater, High-Voltage Battery, Charging Unit for High Voltage, Power and Control Electronics for Electric Drive, Three-phase Current Drive, and High Voltage Battery Charging Socket. [1]

The diagnosis system used to obtain the real-time results car was VCDS ver.23.1.0 (2023 MY update) from ROSS-TECH Company [16]. A sequence of the experimental activities is presented in Fig. 15.


Fig. 15. The setup of the experimental activities (partial view).

The diagrams from Figs. 16…27, obtained by periodical acceleration and braking orders applied on the braking pedal, are found in good agreement with the ones obtained by numerical simulation.

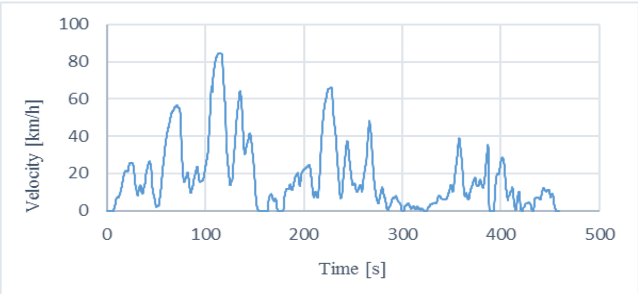

Fig. 16. Car velocity variation in the first test cycle (460 s).

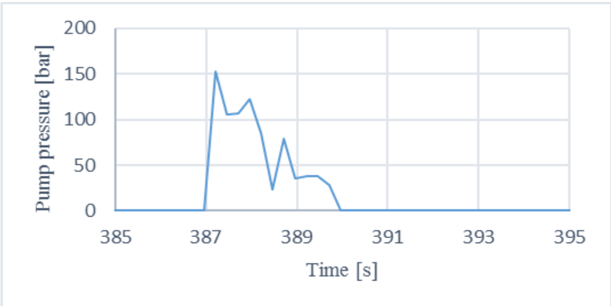

Fig. 17. The pump pressure variation during an emergency brake at 387s after the test beginning (with ABS activated for 3s).

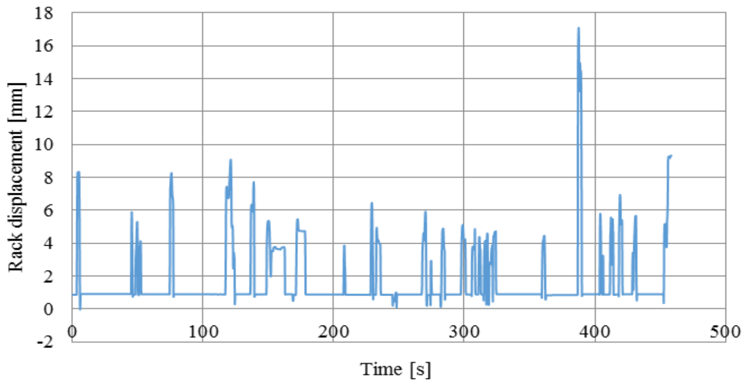

Fig. 18. The pump rack displacement during the first test cycle,
with a maximum at the second 387 (when ABS is activated).

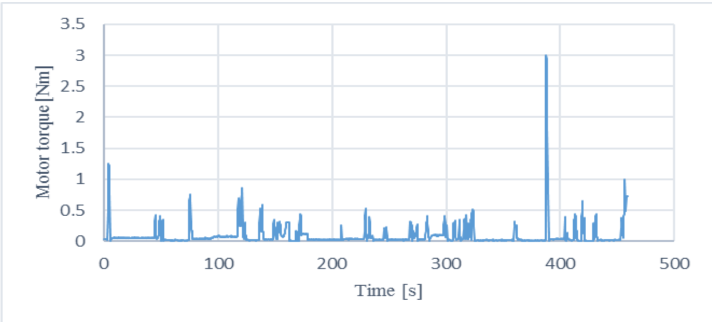

Fig.19. Variation of the brushless motor torque with a maximum at the second 387.

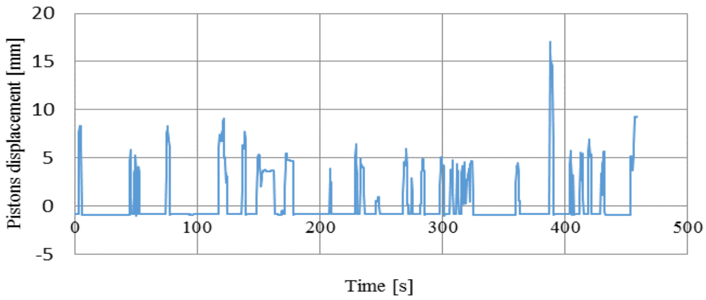

Fig. 20. Displacements of the pump pistons during different amplitude braking actions.

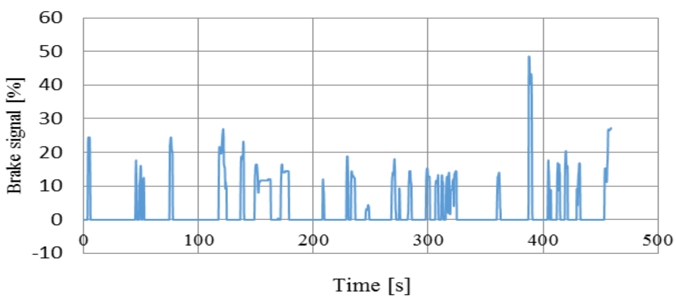

Fig. 21. The variation of the relative brake input signal during the test (max. value: 48%).

The main information needed for an objective assessment of the high-voltage battery sizing is the variation of the energy consumption in standard traffic conditions on a highway. The following figures offer a realistic image of the energy needs for as relatively short cruise in harsh traffic conditions (Figs. 22…27).

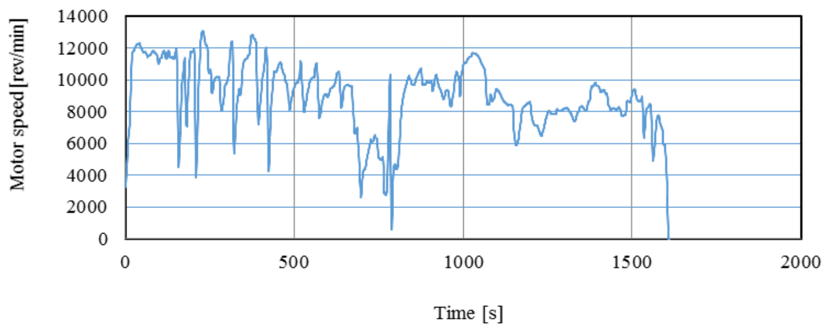

Fig. 22. Motor speed variation during the test (1600s).

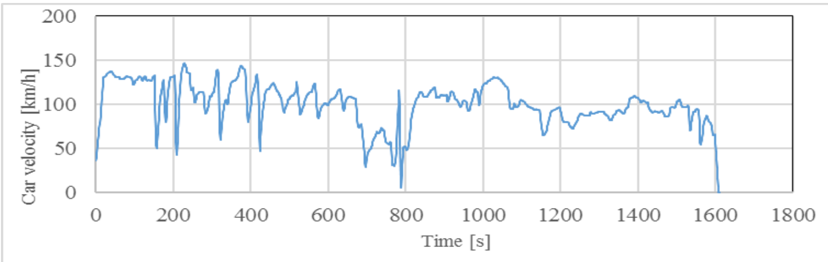

Fig. 23. Car velocity variation during test.

The traffic conditions specific to a holiday beginning obliged the driver to change the car velocity many times and suddenly changing the direction. The same time, the hot weather demanded the use of the refrigerating spiral compressor (about 5kW) both for the high-voltage battery refrigeration, and for keeping the cabin normal temperature. Such traffic conditions demanded a lot of energy: 18% from the nominal capacity for a relatively small average car velocity (fig. 23).

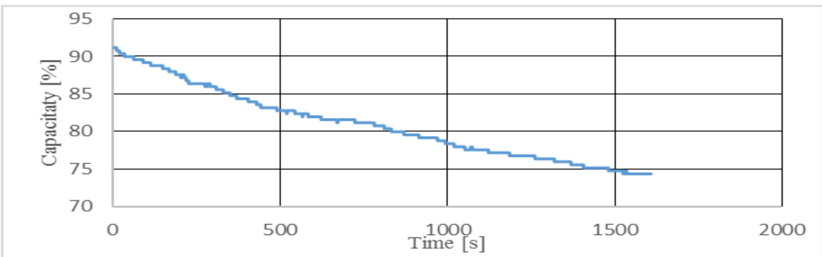

Fig. 24. High-voltage capacity variation during the test

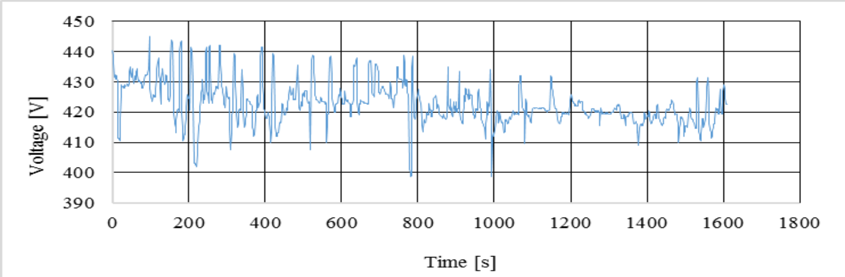

Fig. 25. The main battery voltage variation during the test.

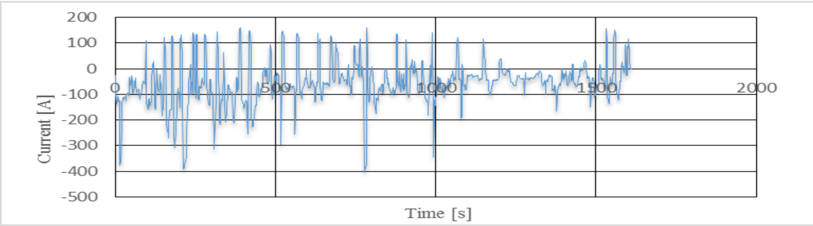

Fig. 26. Current intensity delivered by the high-voltage battery during the test.

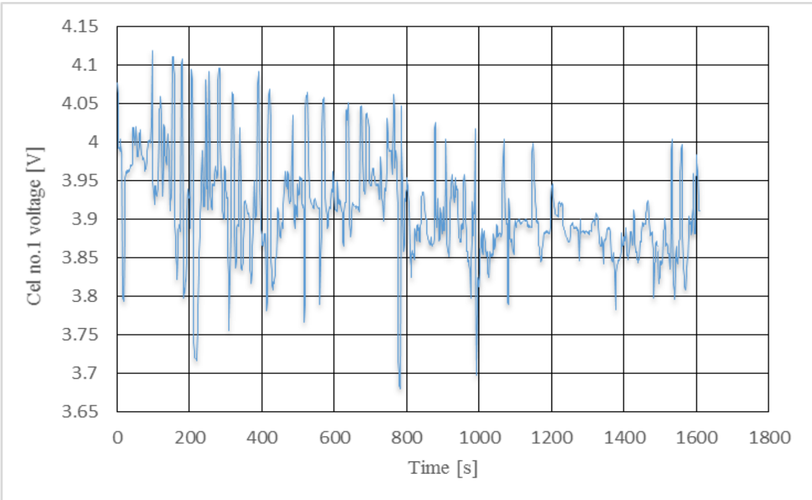

Fig. 27. The variation of the voltage of the first cell of battery (from all of 109 included).

7. Conclusions

The main target of this research was the assessment of the electromechanical brake from the point of view of driver brake force, response time, repeatability, accuracy, energy consumption and compatibility with the modern assistance programs for drivers, in any conditions.

In the most difficult driving situation, which demanded a sudden stop of the car, the brake pedal force generated by the driver was amplified by about 7.6 times. The vehicle speed was reduced continuously from 120 km/h to zero without shocks in four seconds activating the ABS system. The calipers actions were identical, no car direction change being remarked. The trace of the four new tires on the road were identical, with the same dimensions and texture. However, the rate of discharging the high-voltage battery was too high! The difficult traffic conditions can't explain a loose of 18% from the initial value in a short trip of 1600 s.

As a general conclusion regarding the opportunity of the replacing the vacuumatic booster system, there is no doubt about the overall advantages of the electromechanical booster. As the compatibility of this type with all the other assistance programs available for medium class cars is not at all affected, the first conclusion of this research is the opportunity to replace other types of brake boosters by one actuated by a brushless motor, using different kind of mechanical gain of the electromechanical torque offered by the brushless motors. This option was predicted more than ten years before [15] and is in full development [16].

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