Truck transmission performance evaluation during accelerations up to 80 km/h and subsequent decelerations by uphill simulations on flat roads by a Towing Trailer with an electromagnetic brake

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ABSTRACT

On road truck tests with a Towing Trailer Prototype were already presented by the Authors concerning cooling, accelerated durability of power train, fuel consumptions as well as transmission and truck performance by acceleration up to 60 km/h in flat roads. The on road Real Driving Test results depend on many variables such as: the road characteristics, traffic, the way of driving, transmission (gears, manual, semi-automatic or automatic), the convoy weight, among others. In this present paper it was tested on flat road a 440 HP truck 6 x 4 with a semi-automatic transmission with 16 gears. For tests simulation of truck with lower power, the accelerator pedal was limited during some tests. The present tests showed the feasibility for evaluating the performance of power train on flat roads in accelerations of the convoy up to 80 km/h followed by a deceleration at full engine power by simulating various levels of uphill, performed by the electromagnetic brake. In addition to the mechanical behavior of the transmission as gear change, the convoy deceleration curves were used to evaluate performance of the powertrain. Electromagnetic braking torque and the forces between truck and trailer were measured by sensors with strain-gauges developed by the authors. Convoy speed, latitude and longitude, test distance and testing route were measured by GPS. Electromagnetic brake control data as temperature, rotation, batteries voltage and braking current were also measured and registered in a lap top placed in the truck cab. The application of towing trailer for evaluations of truck/ convoy and transmissions performance is therefore recommended, allowing an excellent reproductivity and easy performance of the tests.

INTRODUCTION

The commercial vehicles on-road tests in real application conditions are normally extensive, take long time and therefore have high costs. The results depend on many variables such as: application mode, the road topography characteristics, traffic, the way of driving, the convoy weight, among others. The tendency of on road simulation tests to replace the real application is being pointed out, with emphasis on fuel consumption and emissions, as showed in some following examples.

The Standard SAE J1321 has defined since 2002 [1], fuel consumption tests of the complete heavy trucks with GVWR over 10,000 pounds performed on public road or on testing track. Those tests are not easily comparable due to the different road topography, traffic conditions and the way of driving.

Procedures are discussed and proposed in USA by UCS – UNION OF CONCERNET SCIENTIST in “Brief History of U.S. Fuel Efficiency Standards: Where we are and where we're going”, [2]. Test Procedure for Measuring Fuel Economy and Emissions of Trucks Equipped with Aftermarket Devices is proposed by the Low Carbon Vehicle Partnership [3].

The European Committee for Standardization created [4] the CEN Workshop Agreement "General guidelin on real drive test methodology for compiling comparable emission data".

Standard EN CEN/WS 090 has defined since September 2017 with "Real drive test method for collecting emission" [5] the type approval of all new introduced cars. This includes on-road testing as part of the latest emissions standard known as RDE (Real Driving Emissions).

AVL Handbook 2016 presents Real Driving Emission Test, page 41 [6]: "PEMS (on-board-portable-measurements-devices) testing will be used by US environmental protection agencies for in-use scanning, in that case also CH4 measurement will be beneficial. EU is discussing to change from PM (particulate mass) to PN (particulate number) for heavy duty".

AVL Handbook 2016 presents also "TYPE APPROVAL: EMISSION", page 24 [7] and "HEAVY DUTY VEHICLES – CERTIFICATION" page 68, [8].

ON-ROAD TESTS WITH TOWING TRAILER

Worldwide there are examples of Towing Trailer to test on-road commercial vehicles such as those offered by Taylor [9] and Mustang [10] in THE USA. BLOM, M. [111 presented the ATP Push-Pull Trailer, applied up to 4.6 t.

In Australia bus cooling tests were presented in the AARC Proving Ground Cooling Circuit, 600 m long x 7,3m [12]. using a towing trailer. Mercedes Benz do Brasil presented a towing trailer to perform bus cooling tests, Padua and all [13].

Truck on road simulation tests with easy execution and reproductivity are therefore important and testing methodologies with towing trailer should be enhanced.

TOWING TRAILER PROTOTYP IN BRAZIL - A Towing Trailer Prototype was developed by the Authors, with partial support from a FAPESP PIPE I project [14]. It is approved by the Traffic Authority CONTRAN [15] for circulation on public roads up to 20t weight. A Patent is being evaluated by the INPI [16].

The initial idea was to replace the stationary tests performed abroad with a chassis dynamometer, not existent in Brazil, for heavy commercial vehicles, such as that one from Mahle in Germany [17]. The purpose was also to replace the on-road tests performed in Brazil using one or more towed trucks.

On road truck tests with a Towing Trailer Prototype were already performed in Brazil and presented by the Authors concerning cooling [18], accelerated durability of power train [19], fuel consumption [20] to [23], as well as convoy and transmission performance by acceleration until 60 km/h [24]. In this present paper, the performance of power train on flat roads in accelerations of the convoy up to 80 km/h followed by a deceleration at full engine power by simulating various levels of uphill is shown [25]. Ongoing to presented in 2021:"Test review and potential of on-road commercial vehicles testing with a towing trailer"

The Trailer Prototype, shown in Fig.1 with the truck tractor, was built based on a sugar cane crop transport trailer, The Trailer Prototype has 2 axles and a central lowered chassis. The Trailer body with doors and windows is covered by aluminum sheets, included its roof recently. In the Trailer front is placed the electro electronic cabin. In the back, over the rear axle is placed the ballast. Fig. 2 shows Trailer inside.

Fig.1. Trailer Prototype with the truck tractor.

Fig. 2: Inside view of the Towing Trailer. electromagnetic brake (EMB) with cooling ventilators. In the background, the electro electronic cabin.

LAPTOP - In the truck cab, a lap top is monitored by the test engineer by the driver´s side. Fig. 3 shows an example how the measured data appear in the lap top screen as described below.

Digital present measured values, for example speed, temperatures, rotation, batteries voltage and current.

- Diagrams of measured data during the test, as torque, temperatures, speed and rotation.
- Indication of critical measured variables, pointed in red, as rotation and temperatures.
- Measured errors, as temperatures DE2 and EE2 can be seen.

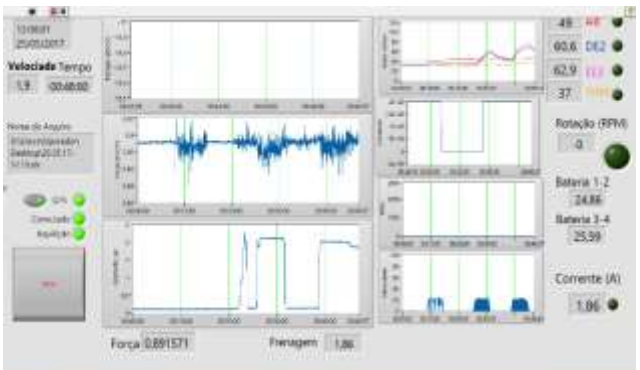


Fig. 3: Example of a screenshot used in the towing trailer test. Measured data will be discussed in next chapters.

The measured data are stored in tables in the lap top and can be transformed into diagrams, as shown in next chapters.

TRANSMISSION EVALUATION TESTS

To evaluate the truck and transmission performance, measurements were performed on 21.02.2019 on an almost flat road with the Towing Trailer and a 440 HP 6x4 Truck with a 16 gears semi-automatic transmission. The total gross weight of the convoy was 26 ton. Example of GNT and Test Time diagram is shown in Fig. 4.

GPS - On the cab's roof the GPS sends the coordinate data to the lap top and also the convoy speed. The GPS supplies the longitude and latitude data to the lap top in the truck cab, extracts are presented in Fig. 5 and 6. With those data, test distance was calculated and presented in Fig. 7.

Based on the latitude and longitude data, the test route, including the way to the test site, were calculated and presented in Fig. 8. The measured route was between the two roundabouts in longitude -47,35 and -47,327 degrees. The test route plotted on a Google Map was presented in Fig 9.

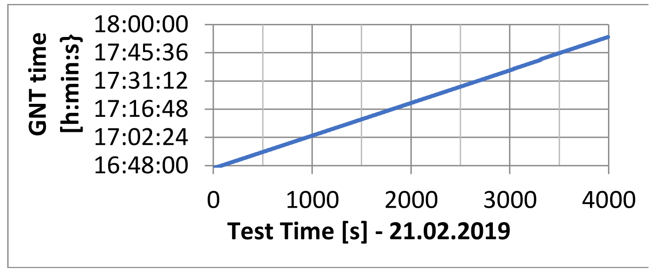


Fig. 4. Example of GNT Time [hour] in function of Test Time [s]

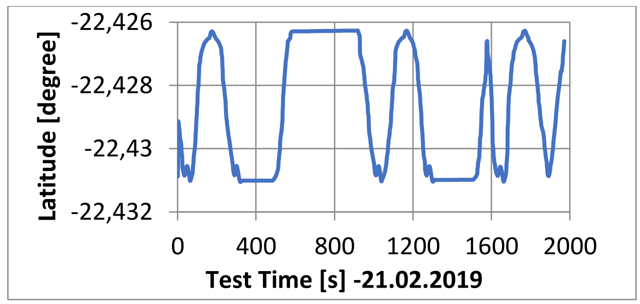


Fig. 5. Latitude [degrees] x Test Time [s], up to 2.000 s.

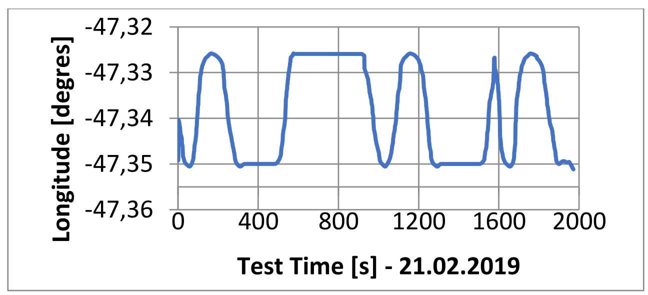


Fig. 6. Longitude [degrees] x Test Time[s], up to 2.000 s.

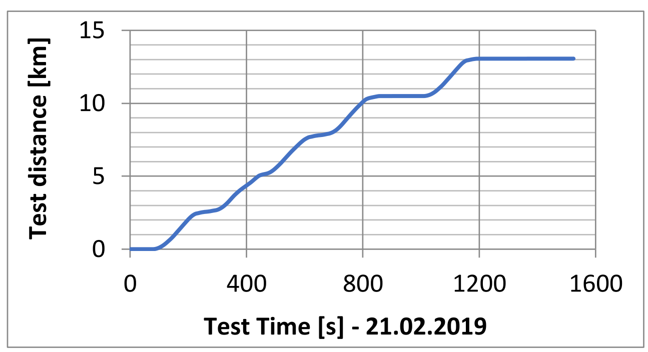


Fig. 7. Test distance in function of Test time

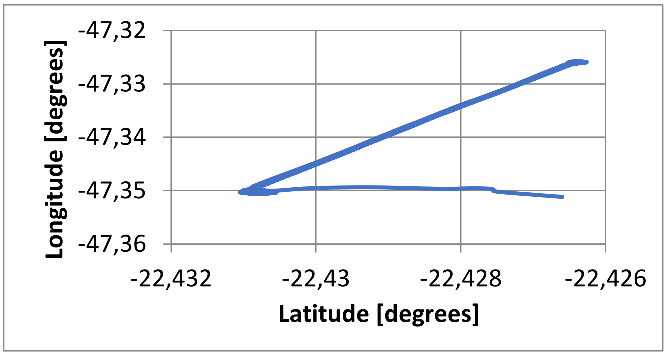


Fig. 8. Test Route: Longitude [degree] x Latitude [degree], including the way to the testing site.

Fig. 9. Test Route on the Google Map. The light blue area represents the water surface of a water reservoir.

CONVOY SPEED AND BRAKING CURRENT- Test Cycles were performed according to the description below.

- The convoy was accelerated in maximal accelerator pedal position, up to the maximal speed of 70/80 km/h without electromagnetic braking current.
- At those maximal speeds, braking current was activated and maintained the full accelerator pedal position.
- Transmission (down) changes were performed by the driver to maintain or try to maintain the speed level.
- After reaching the road limit, the accelerator pedal was released and the Cycle was ended.
- On Cycles 13 to 15, the accelerator pedal was limited on the course. Purpose was simulating test of a truck with lower power.

Measured speeds of the 15 Cycles were shown in Fig. 10, the braking current in Fig. 11, the speed and the current together in Fig. 12. The corresponding Cycles were shown at the top of these Figures

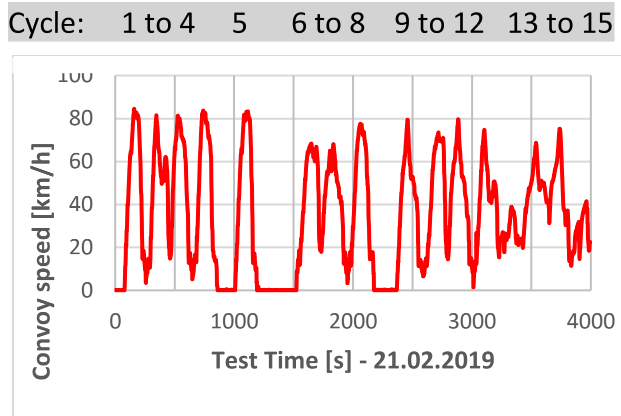


Fig. 10. Speed [km/h] x Test time [s]. 15 Cycles, each with an accelerating period and a decelerating period (after reaching top speed 80 /68 km/h).

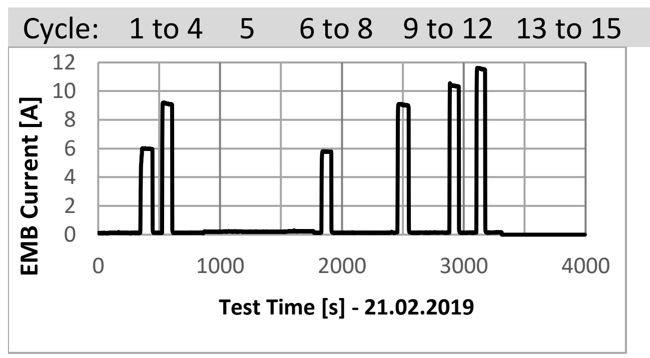


Fig. 11. Braking current [A] x Test time [s]. Curves not measured during Cycles 13 to 15,

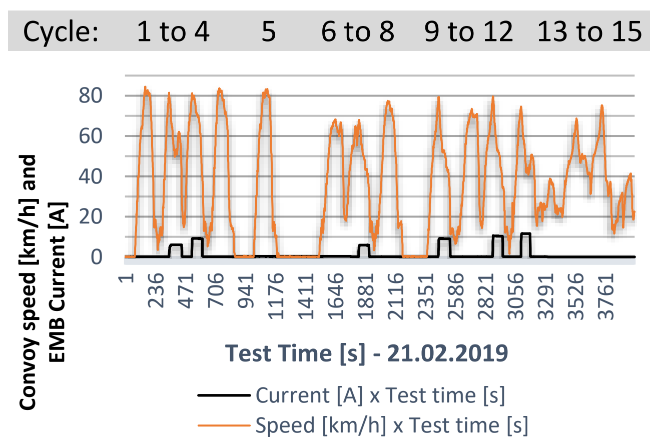


Fig. 12. Speed [km/h] and current [A] x Test Time [s]. Current was activated after reaching the maximal speed in Cycles 2, 3, 7, 9, 11 and 12. Cycles 13 to 15 were performed with limited accelerator pedal.

CONVOY SPEED CURVES

Transmission behavior during gear change was evaluated on road in the truck by the driver and the test engineer. To evaluate the truck performance, the convoy speeds were plotted in Fig. 13 for the 15 Cycles, each one starting almost in the beginning of the x-axis. The EMB current was indicated for each Cycle. All Cycles were decelerated by the EMB braking torque when reaching the maximum speed (58 / 80 km/h). The accelerator pedal was maintained at maximal position. Pedal was in Cycles 1 to 12 in the original state, with original total course. To simulate a truck with lower power (indicated with #), the accelerator pedal was limited to 80% of the original full course during Cycles 13 to 15.

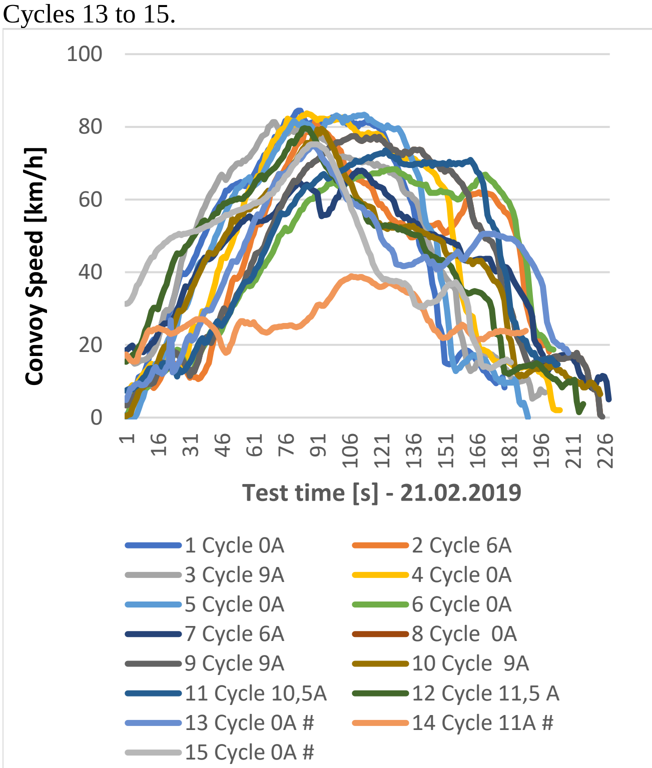


Fig. 13. Acceleration and deceleration all Curves. Cycles with # indicate limited accelerator pedal course. Current was activated after reaching the maximal speed in Cycles 2, 3, 7, 9, 11 and 12. Cycles 13 to 15 were performed with limited accelerator pedal

Fig. 14 shows Cycles 1, 4 and 5 with 0A braking current. The speed keeps, without current, almost constant the maximum speed level of 80 km/h.

Fig. 15 compares the curves with 0A, 6A and 9A. Cycles 1, 5, 6 and 8: acceleration and deceleration without Current. Maximal speeds from 60 to 80 km/h keep almost constant without current. Cycle 13 with 0A and limited accelerator pedal; indicated with #, do not maintain the maximal speed.

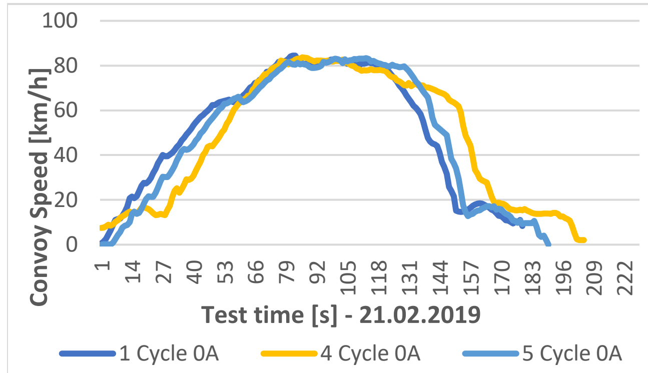


Fig. 14 Acceleration and deceleration Curves: Cycles 1, 4 and 5 without Current. (Reference curves).

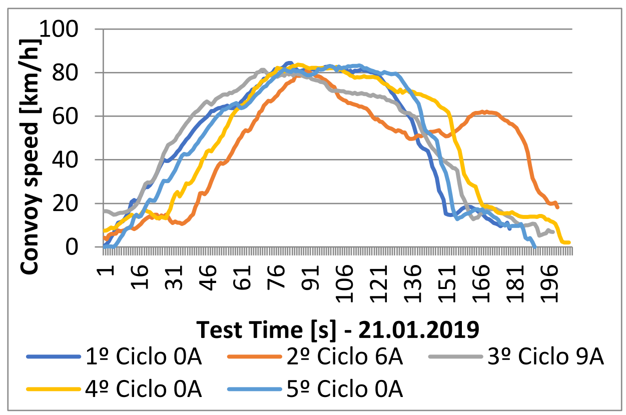


Fig. 15. Effect of current 0A, 9A and 11A.

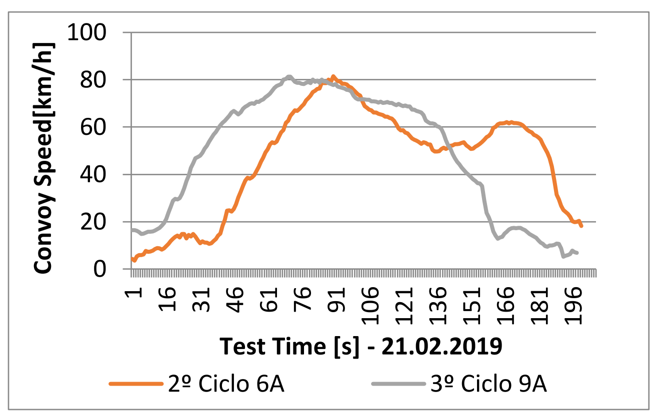


Fig. 16. Effect of 6A and 9A.

Fig. 16 shows the effect of higher current levels of 9A and 11A currents, when the maximal speed of 80 km/h cannot be maintained with these currents. The maximal speed keeps around 60 km/h with 6 A but falls quickly with currents of 9A. Ciclo (Cycle) 2° and 3°: acceleration without current, deceleration with 6A and 9A.

Fig. 17 compares the effect of 0 A, 9 A, and 11 A:

- Ciclo (Cycle) 1° and 5°: acceleration and deceleration without Current.
- Ciclo (Cycle) 3° and 12°: acceleration without current, deceleration with 9A and 11A; the maximal speed cannot be maintained with 9A and 11A.

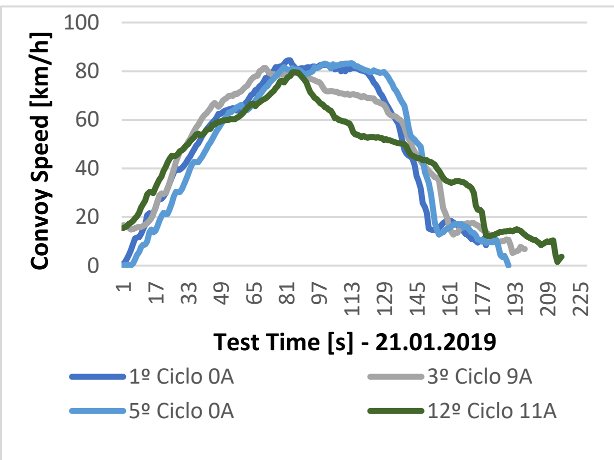


Fig. 17. Effect of 0A, 9A and 11 A.

The truck with 440 HP used in the test was oversized for the Towing Trailer in some conditions. For simulating tests of a truck with a lower power, the acceleration pedal course was limited, being reduced in 1 cm, corresponding to 20 % of the total course. The Cycles 13 to 15 measurements with pedal limitation were indicated with #, as mentioned before.

Fig. 18. Shows the acceleration and deceleration Curves:

- Cycle 5 with 0A maintain maximal speed at about 80 km/h;
- Cycle 2 (6A) and Cycle 12 (11,5A): the speed falls to 50 km/h and 40 km/h;
- Cycles 13 and 15 with 0A and limited accelerator pedal, the speed falls to 30 and 40 km/h;
- Cycle 14 with 11A, it was possible to reach only maximal speed of 40 km/h
- Cycle 14 with 11A, it was possible to reach only maximal speed of 40 km/h

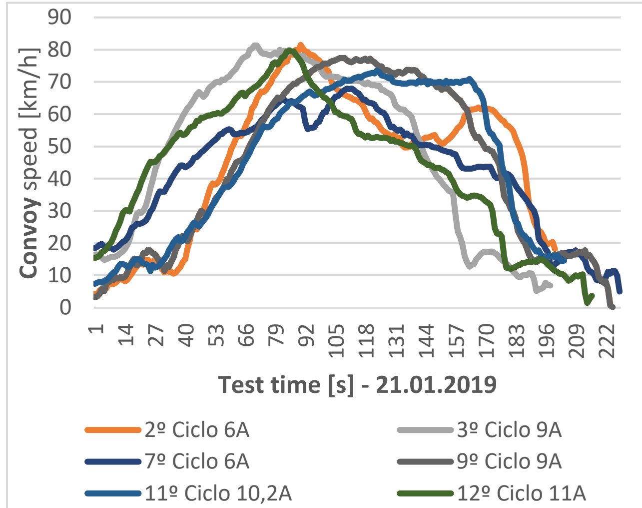


Fig. 18 shows the effect of the 6A up to 13 A

Fig. 19 shows the effect of the 11,5 and 13 A and the pedal limitation (#):

- Cycles 1 and 5: acceleration and deceleration without Current.
- Cycles 3 and 12: acceleration without current, deceleration with 9A and 11A. The maximal speed cannot be maintained with 9A and 11A

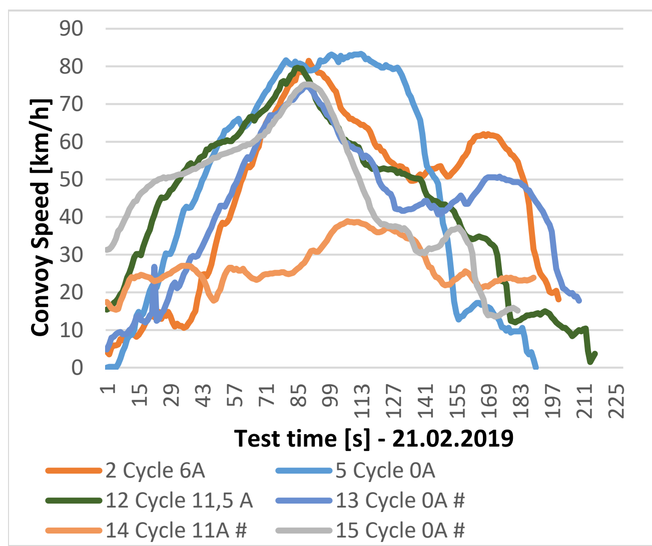


Fig. 19. In Cycle 12 the effect of 11,5 A and in Cycle 13 the effect of the pedal limitation.

The speed curves presented in the figures led to the conclusions:

- Cycle 2 with 6A and not limited pedal and Cycle 13 without current and limited pedal: curves are similar, Cycle 13 with little lower speed levels.
- Cycle 14: with limited pedal and 11,5A, speed does not reach 80 km/h and falls to 40/20 km/h.
- Tests with the Towing Trailer prototype with trucks around 300 HP seems to be adequate and should be performed in the future.

TORQUE AND FORCE MEASSUREMENT

Electromagnetic braking torque and the forces between truck and trailer were measured by sensors with strain-gauges developed by the authors. Those are measured in mV/V. Both sensors were calibrated statically by a mechanical analogical dynamometer and a hydraulic jack.

The dynamic torque as well as the force between truck and Towing Trailer measurements are shown in Figs. 20 and 21. The Cycles were indicated at the top.

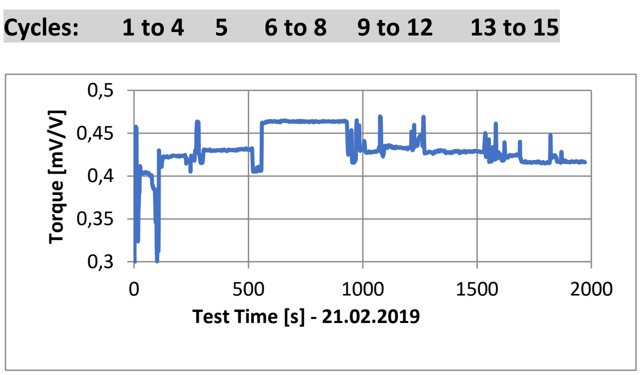


Fig. 20. Torque measurements in function of test time

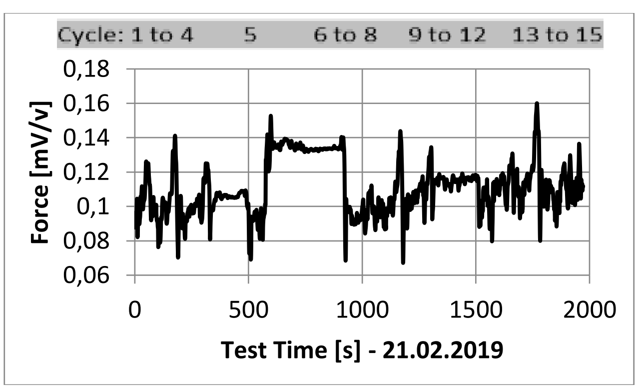
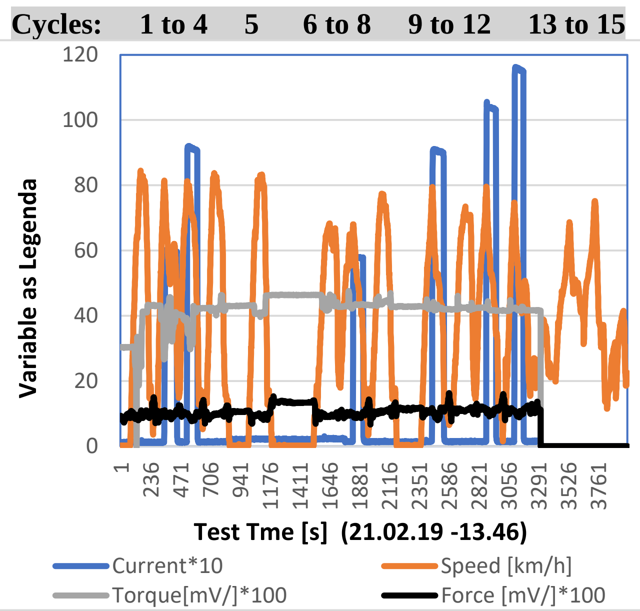


Fig. 21. Force Measurements in function of test time

To evaluate in Cycles 1 to 12 the effect of speed and current on torque and force, Fig. 22 shows those variables in function of the Test Time. Those variables were multiplied by convenient factors to better analyze their relationship.

To better analyze, Figs. 23, 24 and 25 show separately the relationship between the variables for Cycles 1 to 5, Cycles 6 to 8, Cycles 9 to 15.



. **Fig. 22. Cycles 1 to 5. Current, Speed, Torque and Force in function of Test time**.

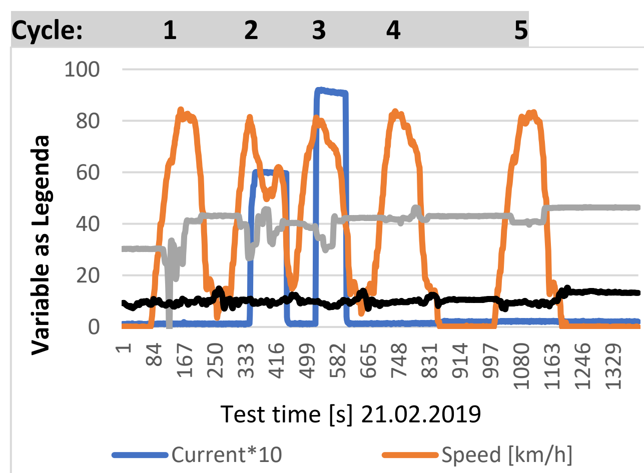


Fig. 23. Cycles 1 to 5. Current, Speed, Torque and Force in function of Test time.

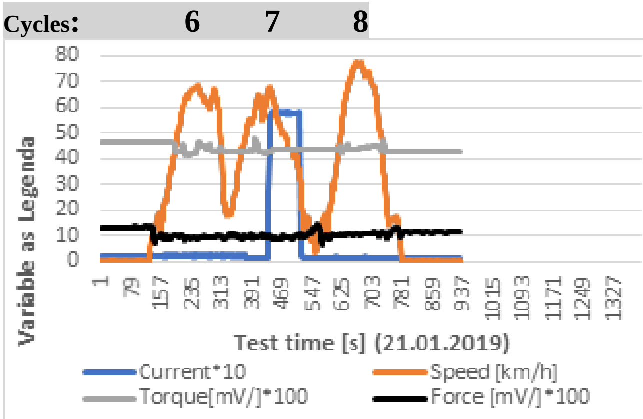


Fig. 24. Cycles 6 to 8. Current, Speed, Torque and Force in function of Test time.
Deceleration with 6A in Cycles 7, high force values due to convoy dynamic, specially by slowdown to 0 km/h and recovery speed.

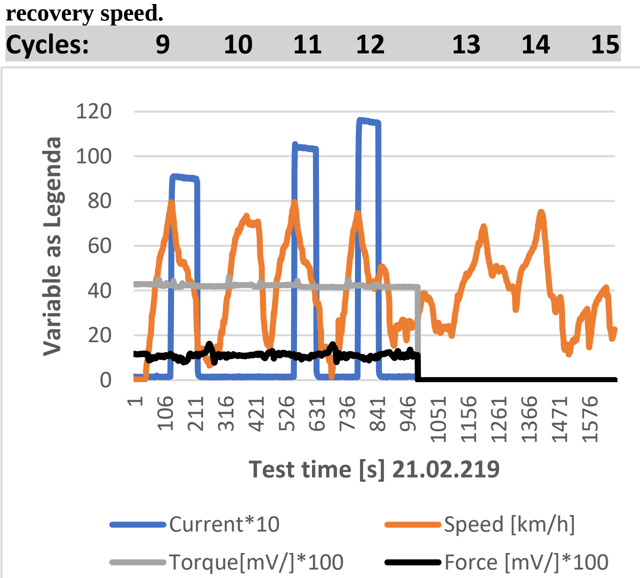


Fig. 25. Cycles 9 to 15.
Cycles 13 to 15 only speed measured, no other variables.
High force values due to convoy dynamic, specially by slowdown to 0 km/h and speed after Cycles 9 and 11.
Torque sensibility measurements due to the braking current disturbed by the high convoy dynamic forces.

The tests show the possibility to measure Torque and Forces, but due to the high values caused by the convoy dynamic, it is difficult to separate the torque values caused by EMB brake and the convoy dynamic. Future tests should study a methodology to better separate both influences.

The tests showed that transmissions can be evaluated with towing trailers, included gear changes by elevated torque / power, during accelerations and decelerations.

The limits of testing trucks with the Towing Trailer as truck power, convoy speed, test time duration and other variables, should be defined in each future test.

Due to the elevated dynamic forces between truck and Trailer, it is difficult to analyze separately the effect of the electromagnetic braking on traction and torque during changing processes as during acceleration, deceleration and transmission gear changes. To define those effects, it is necessary measurements at constant conditions.

ELETRIC AND THERMIC MEASSUREMENTS

During the 15 Cycles measurements on 21.02.2019, on an almost flat road and speeds up to 80 km/h, evaluations of the electrical and thermic variables were performed.

The most important limitations of the Towing Trailer are the electromagnetic brake rotation and braking current as well as the temperatures.

Fig. 26 shows the Current, the convoy Speed and the electromagnetic brake Rotation and the Batteries tension [VDC]. During Cycles 13 to 15 only the speed was measured. The Cycles are indicated at the top of the figure.

The batteries tension measures the capacities of the electrical system. The battery tension reaches 27 VDC by the alternator and EMB rotation. During the standstill, the voltage lows to 22,7 VDC, due to the cooling ventilators. The drop of battery voltage due to the electromagnetic braking current up to 11,5 A seems not to be so significant with the towing trailer in movement.

Further, the current consumption for the electromagnetic brake as well for the cooling ventilators should be very well controlled in each test. Discharge of batteries at standstill must be observed.

Measurements of the electromagnetic brake current, the alternator temperatures as well speed and current are shown in Fig. 27.

The main conclusions about these diagrams are presented below.

- Effect of the current is the quick rising of the cooling air output temperatures, reaching 120 ° C. It will be necessary to check the limits of de EMB concerning these temperatures. The effect of the 3 cooling ventilators should be optimized.
- EMB internal temperature was low, indicating a high reserve of the EMB system.
- Alternator temperature was low, indicating also a very good reserve related to the battery charging during convoy movement.
- Increasing of the cooling air output temperatures up to 90°C by elevating the speed, for example at 1018 and 1555 s and without current was observed. Phenomenon should be better studied in future.

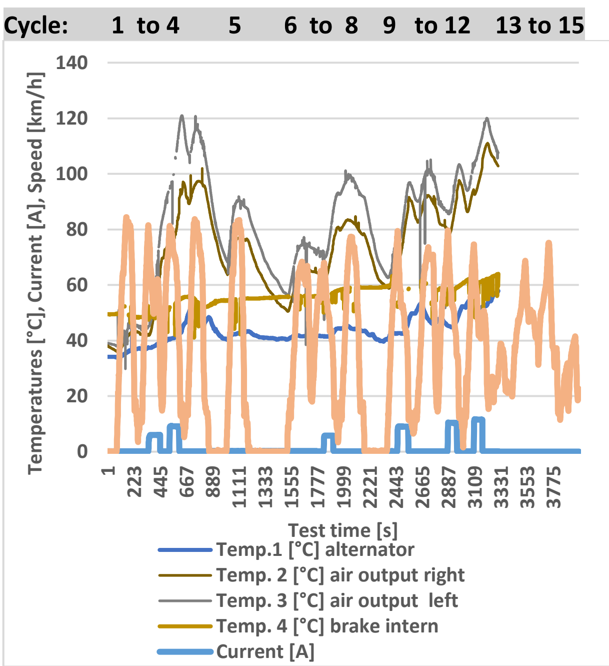


Fig. 26. Temperatures {°], current [A] and speed [km/h] in function of Test time [s]. Cycles 1 to 15. Cycles.13 to 15 without temperatures and current measurements.

TEST METHODOLOGY EVALUATION

In this present work, the power train of a 440 HP truck 6 x 4 with a semi-automatic transmission with 16 gears was evaluated. For the evaluation of a truck with lower power, the truck was also tested by limiting accelerator pedal.

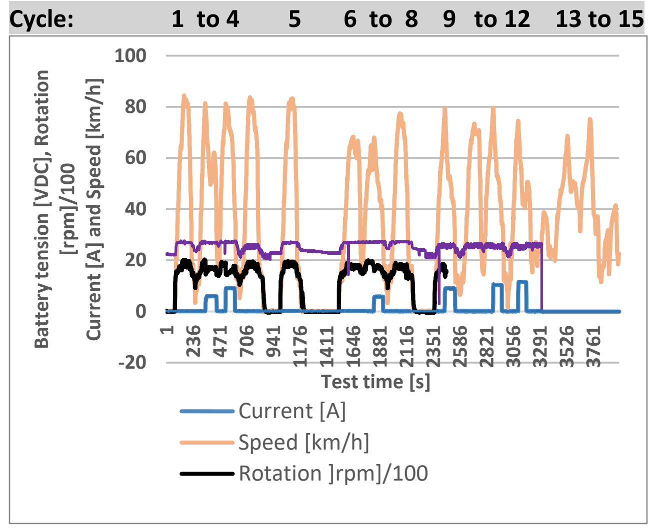


Fig. 27. Battery voltage [VDC], Current [A], Speed [km/h] and Rotation [rpm] /100 in function of Test time [s] until 3.370 s. Speed up to 3.983 s.

The tests with Towing Trailer showed the feasibility to evaluate performance of the transmission and the power train by simulating on flat road various levels of uphill. It was tested accelerations of the convoy up to 80 km/h and then followed by a deceleration at full engine power. During the tests, it was possible evaluate the mechanical and temperature behavior, vibration and gear changes.

Convoy speed, latitude and longitude, test distance and test route were measured and defined by GPS. Electromagnetic brake control data as well as temperature, rotation, batteries voltage and braking current were also measured and registered in a lap top placed in the truck cab.

Electromagnetic braking torque and the forces between truck and trailer were measured by sensors with strain-gauges developed by the author. Measurements of those variables should be enhanced in future.

CONCLUSIONS

The evaluation on flat road of truck transmission by uphill simulation using the Towing Trailer Prototype show potential for an easy test performance as well a good reproductivity. The present and former tests showed the feasibility to evaluate the performance of power train during accelerations and decelerations of the convoy up to 80 km/h, even up to 90 km/h. The behavior of transmission under load concerning gear changes, vibration, temperature and noise can be evaluated. Power train performance can be verified by the convoy acceleration and deceleration from the measured curves. Test methodologies with towing trailer can be extended, as presented in former papers, to other applications as fuel consumption and emissions. Support from heavy commercial vehicle manufacturers, system suppliers, universities and/or government institutions are needed to continue the tests, involving a great portfolio of tests.

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