Testing and Benchmarking a Powertrain with Independent Wheel Control for Heavy Machinery

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Abstract

This paper treats about “Line Traction 3” (LT3), which is a mechatronic driveline for heavy machinery like agricultural tractors, combines, or wheel loaders. LT3 is expected to improve the performance and augment new functions to the existing ones of conventional drivelines. For testing and validating this assumption for LT3 and similar driveline systems, we introduce “MOBiL” , a hardware-in-the-loop method adapted for mobile machinery. The MOBiL method will be explained to bring out the differences in modelling and test procedures compared to on-road hardware-in-the-loop methods. Then, we will present the validation of the LT3 driveline in an agricultural context by using the MOBiL method. A discussion of the relevant results obtained for tractors and wheel loaders will be followed by a final summary.

Motivation for independent wheel control

Mobile machinery are machines with the capability to work and drive. Both functions are propelled via separate powertrains, each of them having significant power flows. This is the definition according to [1] (Fig.1).

Continuous efforts are being made to optimized these two powertrains. They interact to fulfil the tasks of the vehicle. The driveline itself is adapted for each machine and its special uses. Besides the efforts to reduce losses, engineers also are trying to augment the functionalities of the drivelines in such a way that the machine fits precisely into their intended tasks. In the field of agricultural engineering, this often means to not only improve efficiency, but also to optimize the traction of tractors, combines, or wheel loaders. In most cases, these are conflicting objectives [1].

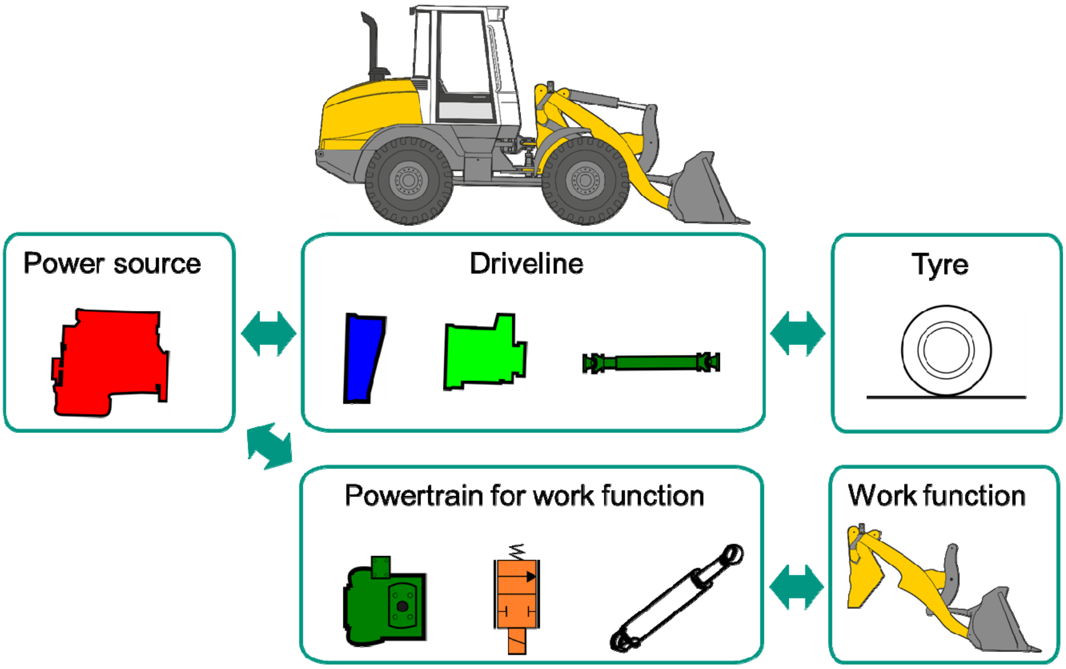

Fig. 1: Generic mobile machine with powertrains

To give an example, mechanical drivelines provide high efficiency, but under poor traction conditions, only the amount of torque of the wheel with the poorest traction can be transmitted to all other wheels. To avoid loss of traction, state-of-the art heavy machines have the possibility to lock their differentials or, like in the case of tractors and wheel loaders, the longitudinal distribution is equipped only with a fixed gear stage acting like a locked differential. This mode of operation causes problems in that each wheel runs at one and the same speed, and turning corners with the vehicle causes tensions in the driveline [2] or forced slip on the tyres. Hence, the requirement arises to drive each wheel separately and independently from the other ones. One possible way is to design vehicles with hydraulic or electric wheel hub drives. In this case, each wheel has his own motor to drive it. However, also such kind of driveline needs gear boxes/stages when used in mobile machinery to provide the wheels with the required torque. In addition, drivelines of that type have more losses under certain circumstances e.g., in the case of a mechanical equivalent and an increased unsprung mass, especially when the possible estimated power for each wheel is near to the system power of the vehicle due to the high mass of the required motors.

In conclusion, a possible solution to obtaining an efficient driveline with maximum traction would be a mechanically locked driveline with the same characteristics as those of wheel hub drives. Such driveline would transfer the maximum amount of torque to the wheels at maximum efficiency without building up tensions or slip by driving through curves.

Mechatronics allows to control each wheel on mechanical drivelines

The Linetraction 3 (LT3) driveline is the attempt to meet the requirements set out in the previous chapter. It is a mechanical driveline which could be propelled by any kind of engine or motor. It is quite similar to conventional drivelines but there are no differentials, thus it behaves like a locked powertrain providing the maximum traction in every driving situation. However, with the differentials being absent, the driveline needs a new possibility of realizing different speeds of the wheels when cornering to avoid tensions and slip. This is achieved by means of superposition gears in the lateral distribution of each driven wheel. Due to the missing mechanical control abilities of the differentials, it is necessary to control the superposition of the speeds separately by a dedicated electrical control unit (ECU).[3]

In the case of conventional drivetrains using differentials, the relevant strategy and behaviour are determined by the design of the gears of the differentials. With the control of the driveline by an ECU, more than one possible strategy can be implemented depending on the driving situation or driver input via human machine interfaces (HMI) [4]. The mechanical driveline parts represent the mechanical basic system, which uses hardware or software sensors, information processing in the form of an ECU, and actuators for the superposition gears and hence fulfils the requirements of a mechatronic system according to the definition given in VDI 2206 [5].

From X in the loop to the MOBiL method

According to the V-model defined in VDI 2206, which is also used in the LT3 development process, it is necessary to have a method to appropriately validate the properties once defined at the stage of system design. One commonly used validation method is the XiL concept. In this validation concept, for each step at the integration stage of the V model, validated models are used for validating the respective unit under testing. This method was first introduced in 2008 [6].

The use of validated models is essential to this method, since they replace the physically not existing or not available systems that interact with the physical system under testing. Depending on the integration level at which analyses are carried out, more or less detailed models are needed.[7]

The use of validated models of the simulated system is a key point. Normally, these models are built up in the macro cycle of the V-model following the modelling section starting during the system design phase and continuously supporting the development process.

MOBiL - A test method optimized for mobile machinery

The XiL method is a powerful tool for validation. It is often used in the passenger car industry during development processes. The original concept of XiL, however, has to be adapted for application to the investigation of heavy machinery. As stated above, mobile machines have the capability to drive and work, with both functions being propelled via separate powertrains. Hence, it is necessary to augment the existing work frame of XiL, for example for realizing the parallel structure of powertrains known from real machines.

The MOBiL method is adapted to these needs of mobile machinery.

It allows to build up a structure combined from simulation models and real units under testing. These systems, real or simulated, interact as would the systems in the real setup. [8]

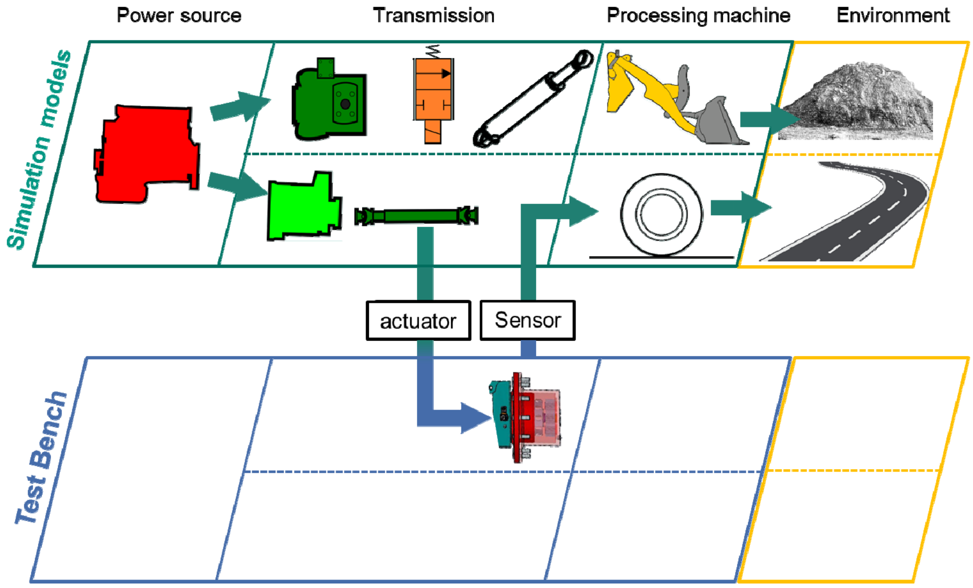

Fig. 2: “MOBiL“ effect chain for LT3

This is how work function and driveline interact, e.g. in wheel loaders: When the wheel loader shovel penetrates a bulk pile, it generates forces and interacts with the chassis which then causes a dynamic shift in axle load influencing the driveline situation driveline (Fig.2). The same is valid for e.g., tractors pulling a plough.

A second important point is to train the operator for the MOBiL method: He will no longer act only as driver as in the case of XiL but must be able to act as machine operator. The operator closes the machine control loop to enable the machine to fulfil the work task.[8]
This means that the computer-generated operator needs to be enhanced for operating work and driveline by acting like a realistic machine operator. For human operators, this implies that the typical machinery HMIs and visualisation have to be implemented to correctly close the control loop of the machine against the operator.

Testing the line traction 3 driveline with MOBiL

The basic function of the superposition gears, as the essential elements in the LT3 driveline, was tested successfully in a first project. This means that the validation was successful at the subsystem level according to VDI 2206. [4]
The next step is the validation in a vehicle such as a tractor, combine, or wheel loader.
Equipping a machine of each kind, however, would cause major costs and a big effort of time. Here, a validation method like MOBiL can exert a "frontloading" effect on the project. Frontloading means that validation of the functions and the proof of concept for each type of machinery can be achieved within a shorter period of time at lower costs.[8]
As mentioned before, the aim is to test the line traction superposition gear during typical driving situations in mobile machines.

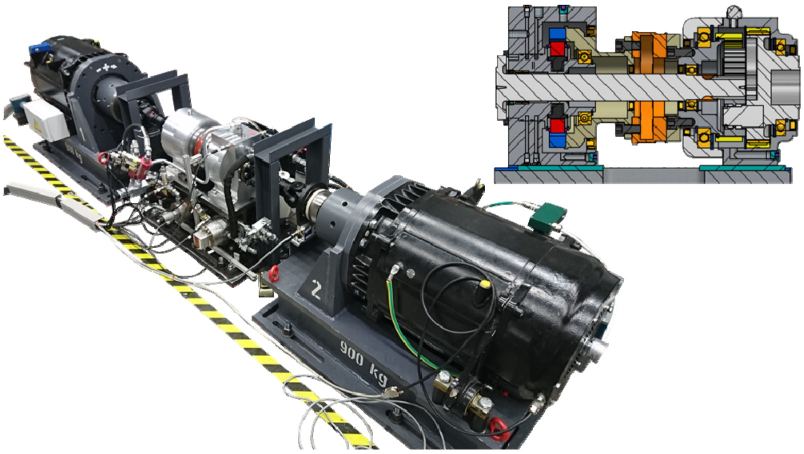

Fig. 3: Line Traction 3 unit on the test bench, and section of the LT3 unit

The superposition gear, here the unit under testing, is implemented with an own ECU on the test bench. The electric machines of the test bench drive and break the unit according to the values calculated by the real-time computer on which the simulation models run. The test bench machines and the control unit of the LT3 unit communicate via high- speed CAN bus with the real-time computer. Hence, the same unit can be tested as if mounted on different machines only by changing the machine model on the real-time computer (Fig. 3).[8]

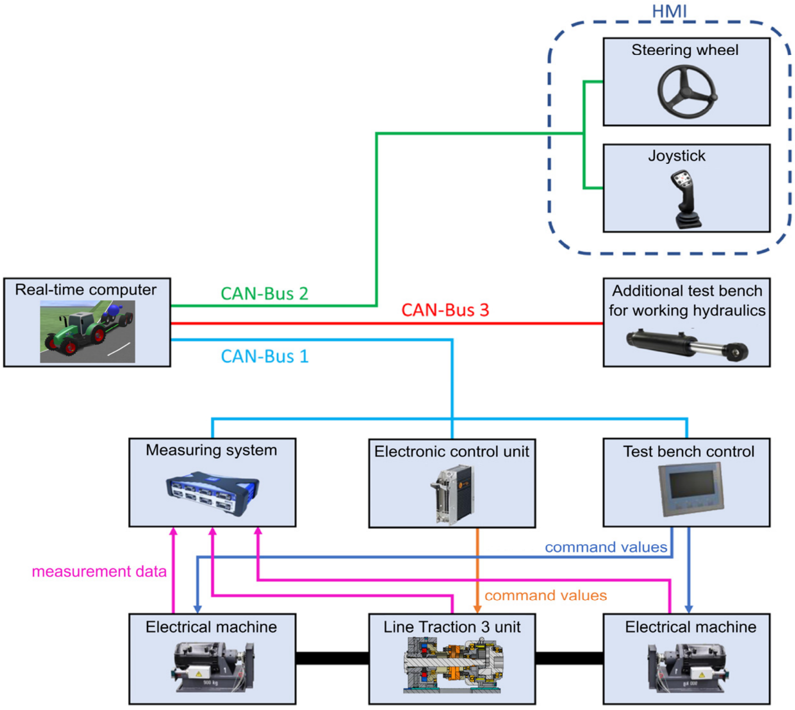

Fig. 4: MOBiL test bench architecture

Also, different control strategies can be tested easily by chancing the settings on the ECU of the unit or chancing the CAN communication between the real-time computer and the ECU. In addition, the interaction of human machine operators with potential new assistance systems can be tested through the new degrees of freedom of the driveline.

Validation of Line Traction 3 Driveline

A first step to proving the concept is to validate the algorithm which calculates the necessary differential speeds for each wheel (Fig.5). It should be able to calculate the correct speeds without building up forced slip.

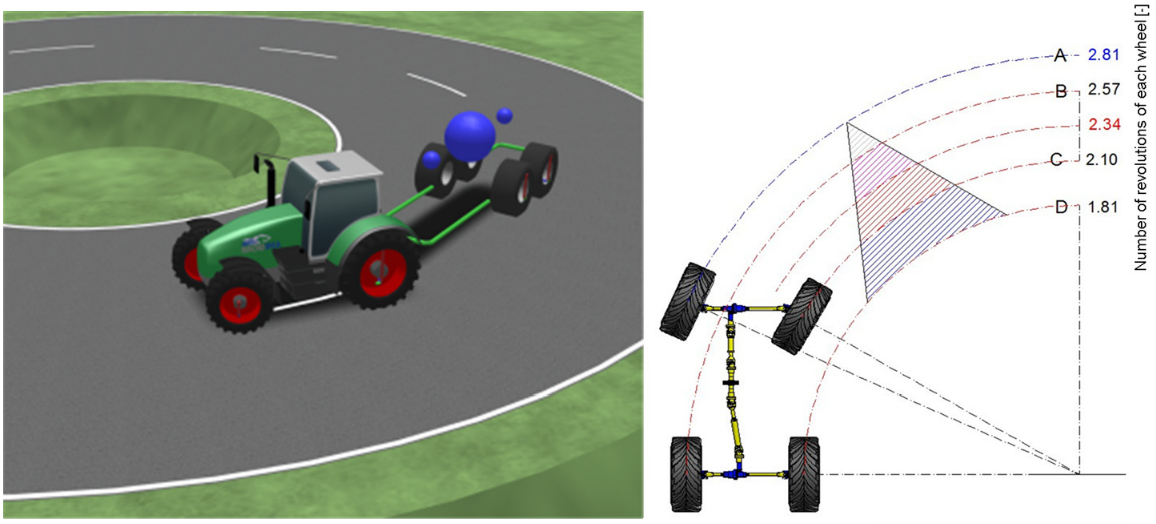

Fig. 5: Right: Tractor model during steering, and left: Calculated differential speeds

The tested LT3 unit (speed controlled) is compared in Figure 6 with other simulated drivetrains in which the operator tries with a wheel loader to reach 20 km/h in a curve with a curve radius of 10 m and a constant μ =1.. The locked differential is not able to produce the necessary differential speed for the wheels, and suffers a high slip. The differential and both LT3 drivelines are able to compensate the wheel speeds. As seen, both of the possible control modes for the LT3 driveline fulfil their intended purpose. After testing the basic functions, more advanced strategies which use the ability to control each wheel independently can be investigated. One possible strategy is yaw control, for example to optimize and improve avoiding manoeuvres (Fig 7). To improve turning manoeuvres, the skid steer mode could be combined with the normal steering to reduce the turning radius of the vehicle, as seen in Figure 8.

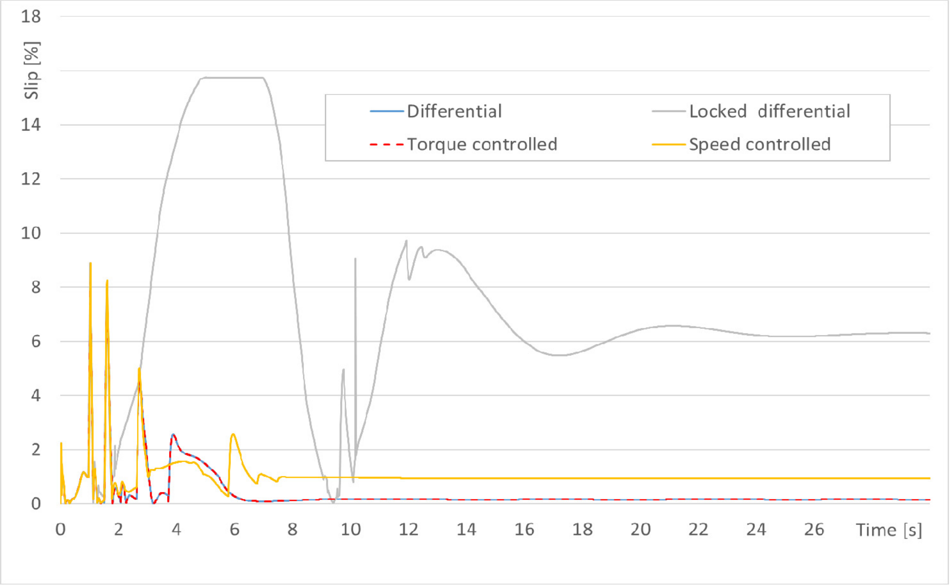

Fig. 6: The diagram shows slip over time for different drivelines

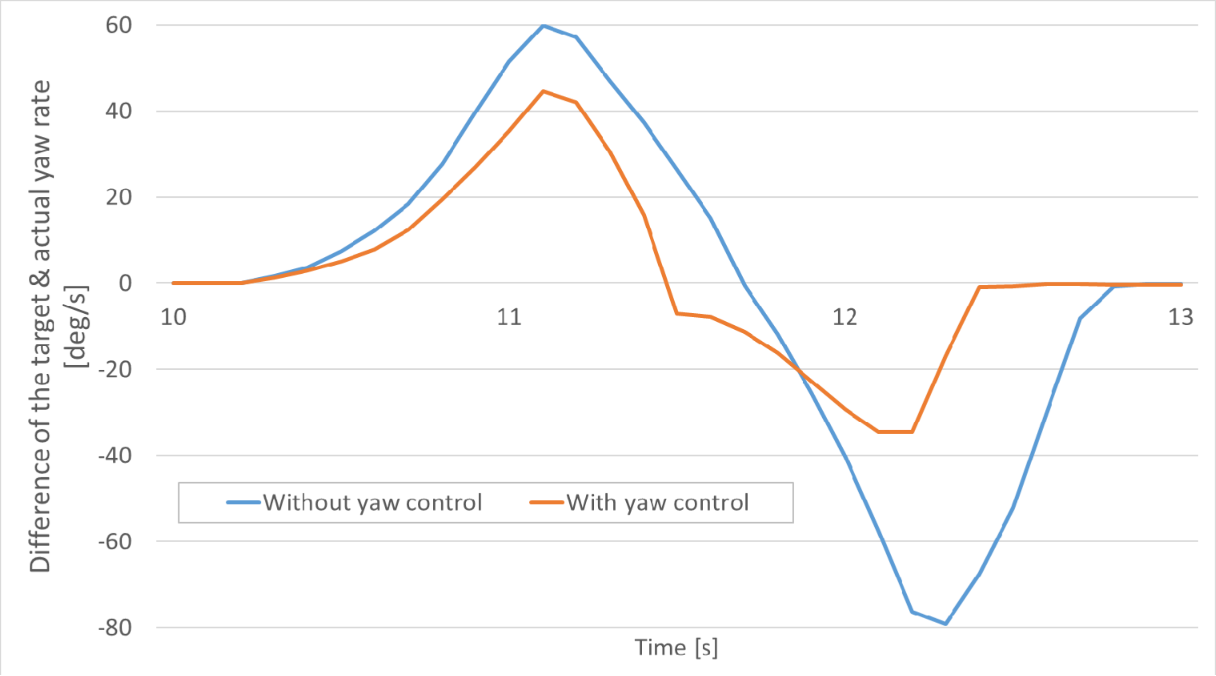

Fig. 7: Yaw rate difference with and without yaw control

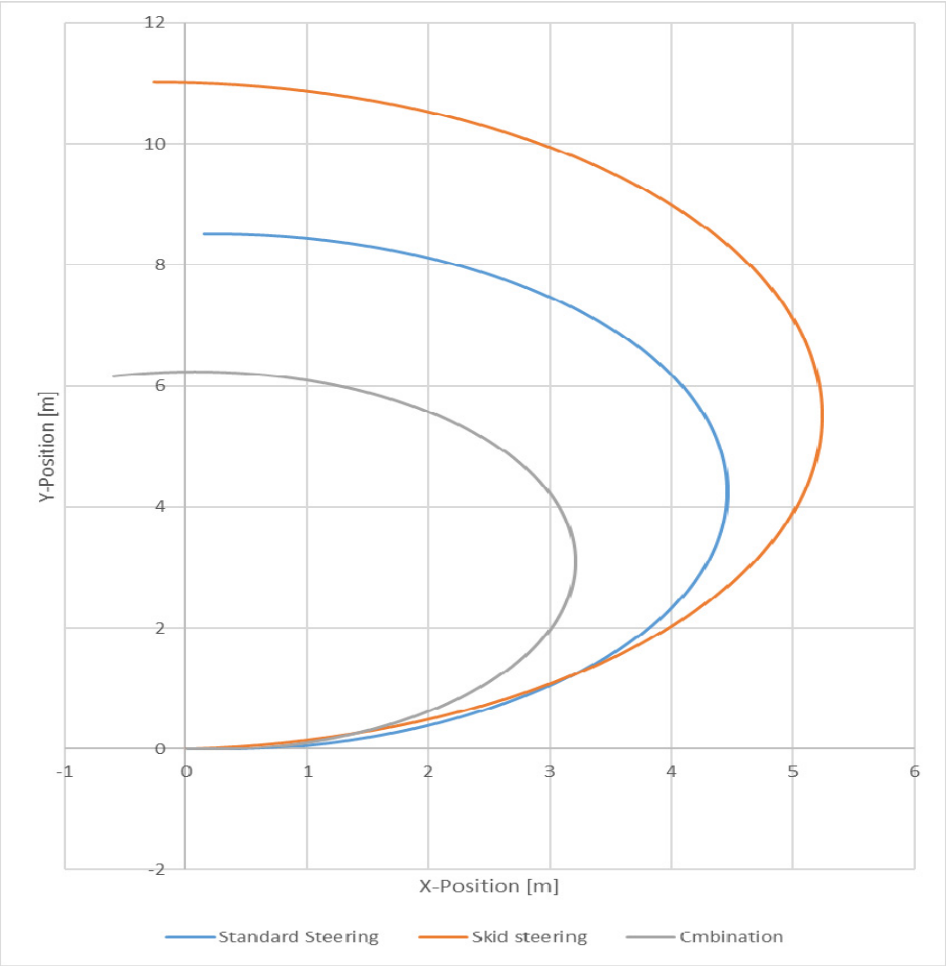

Fig. 8: Turning radii with different steering types

Summary & Outlook

The MOBiL method is the first attempt to introduce XiL validation also to the field of mobile machinery. It allows to test the components and subsystems in a holistic way. In the present LT3 project, MOBiL helps to achieve a massive frontloading in the development process because it allows to test the LT3 units in different generic types of mobile machines due to the use of validated simulation models so that no physical prototypes are needed. This reduces costs, now and in future projects. The MOBiL method allows an early proof of concept at the level of in-vehicle use. Now, customized and representative cycles and scenarios for each machine type in the context of LT3 can be developed and tested to provide a realistic work scenario for each machine. This will continue to show the advantages of mechatronic drivelines such as LT3. It also provides the possibility now to test critical driving situations of the machines to achieve an improvement in such dangerous situations without risking damage to the machines or life of the operator. In addition, the interaction of the machine with the operator can be investigated and the results obtained allow taking a deeper look into the field of HMi.

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