

# Selected Problems of Electric Vehicle Dynamics

J. Kovanda\*

*Department of Security Technologies and Engineering, Czech Technical University in Prague, Faculty of Transportation Sciences, Prague, Czech Republic*

*\* Corresponding author: kovanda@lss.fd.cvut.cz*

P. Koblíček

*Department of Electrical Drives and Traction, Czech Technical University in Prague, Faculty of Electrical Engineering, Prague, Czech Republic*

DOI: 10.2478/v10158-012-0016-1

**ABSTRACT:** This paper deals with the analysis of unsprung masses of electric vehicles with the in-wheel drive, from a dynamics point of view. The system safety and comfort are evaluated. This paper also brings together the modern possibilities of use of the propulsive components of the in-wheel drive – the basic types of electronic commutated motors. The technical note presents the ROMO vehicle – a project of DLR (German Aerospace Center).

**KEY WORDS:** Electric Vehicles, Suspensions, Vehicle Dynamics, In-wheel drive.

## 1 INTRODUCTION

The “motor in wheel” design concept of electrical vehicles brings essential advantages in the possibility of independent traction and the steering control of each wheel, a compact design and easy production technology. The drawback is the increasing unsprung mass of wheel assembly, which is even relatively higher when considering the contemporary effort of car body mass reduction leading to lower energy consumption, reduction of the batteries weight impact and enabling a further operating range. The relatively high unsprung mass decreases the handling quality of the vehicle. The general and basic requirement of vehicle active safety is that the tyre must be in good and continuous contact with the road surface, even on a rough and uneven track. The length of the rebound depends on the unsprung mass, therefore a wheel with additional equipment suffers with a worse tyre-road contact (or this contact is lost on some obstacles). This leads to a reduction of braking efficiency on an uneven or poor road surface, and to the limited handling capabilities, especially cornering characteristics and behavior.

The design of the in-wheel motor is described as well and the mass of the parts is taken into the consideration. There are several possibilities how to realize this type of motor. The most widespread are the motors with electronic commutation, due not only to their suitable construction design, but also their control as well.

The conclusion is devoted to the successful design of a DLR vehicle ROMO, which significantly inspires the electrical vehicles design ways.

## 2 INFLUENCE OF THE HIGHER UNSPRUNG MASS DUE TO THE MOTOR INSTALLED IN THE WHEEL ASSEMBLY

The design strategy of the electric vehicle based on electric motors assembled in the wheel centre, the so-called in-wheel drive (or wheel hub drive), brings new challenges in vehicle traction control, handling, and maneuverability due to the independent wheel steering. Moreover, the vehicle concept with drives in the wheels gives new design possibilities and therefore innovative car body structural conditions, including the utilization of non-conventional materials in car body design, can be developed. Both passive and active safety receives the new dimensions and solutions.

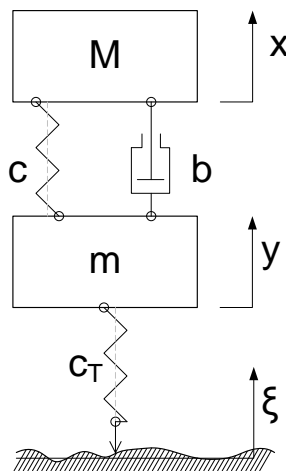
The negative feature of motor installation in the wheel assembly part is the higher unsprung mass  $m$  to the sprung mass  $M$  (Figure 1) when compared to a conventional power train of road vehicles, and, consequently, the lower level of handling and ride safety (braking and line changing capability) (Kovanda et al., 1997). The usual design demands and generally accepted condition is to reduce the unsprung mass to achieve a tyre-road contact as stable as possible. There are some examples of relatively complicated design solutions to minimize the wheel assembly mass (break system and assembly are fixed to the car body), the utilization of light materials at suspension mechanism, etc.

Therefore, the mass of the electric motor added to the wheel assembly systems brings serious problems from a ride dynamics point of view. This understanding gives us the two-mass (quarter car) model (see Figure 1).

The Eigen frequency of an unsprung mass is:

$$\Omega = \sqrt{\frac{c + c_T}{m}}$$

The influence of a higher mass  $m$  is a lower eigen frequency and, consequently, a lower vertical acceleration of the wheel on the uneven surface. This is quite a good feature from a vibration propagation and comfort point of view.



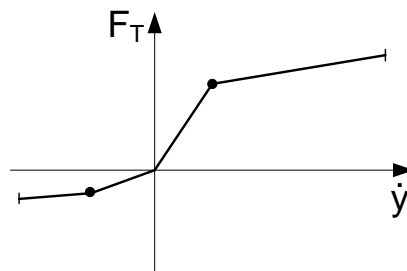
**Figure 1: Two-mass vehicle suspension model.**  
(Kovanda et al., 1997)

The drawback is significant declination of the handling quality due to the loss of the tyre – road contact on the road irregularities. The higher unsprung mass leads to the smaller critical unevenness high on the road  $\xi$ , where the tyre loses contact with the road surface due to jumping away.

The solution is in a higher damper coefficient  $b$ . This can be seen in Figure 2, especially from the upper part (after the break point) for higher frequencies. The more efficient dampers improve the handling quality, but “harder” dampers bring lower levels of passenger ride comfort.

Possibly the electric motors built in the wheel center member will activate higher attention to the active control and feed-back systems utilization in the field of wheel suspension systems and vertical dynamics.

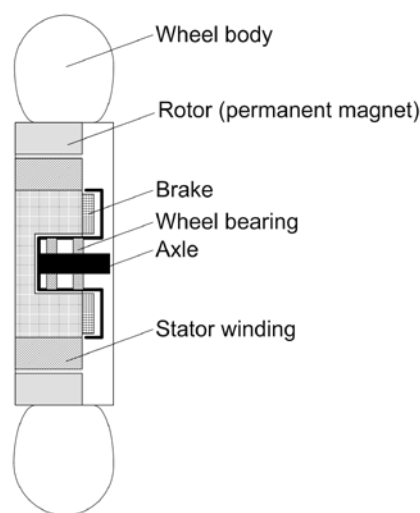
The controllable dampers (semi-active suspension) and/or springs (fully active suspension) can solve the conflict between safety and comfort, which is amplified by additional unsprung mass. Even the simple on-off damper with a basic sky-hook control strategy can bring significant improvements to the vehicle's characteristics.



**Figure 2: Damper characteristics: velocity  $\dot{y}$  vs. force  $F_T$ .**  
(Kovanda et al., 1997)

### 3 IN-WHEEL MOTORS

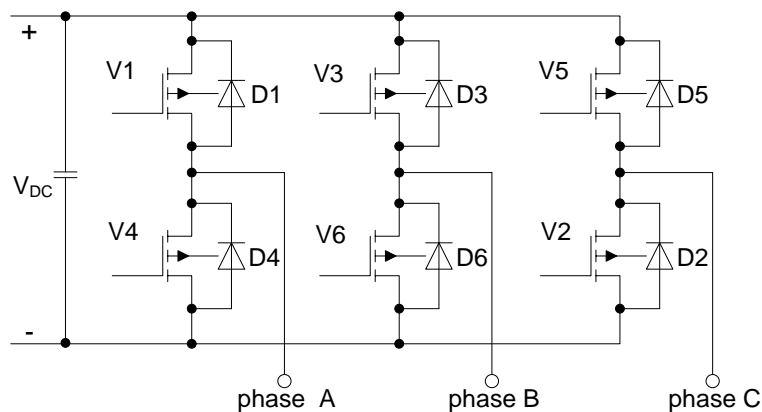
As said before, the heart of the discussed electric vehicle is the electric drive in the wheel's centre. An electric drive generally consists of an electric motor, a power converter, a part of an electric apparatus, and a necessary drive system. It is no different in the case of an in-wheel drive. The drive is composed of a kind of electric motor, power electronics converters, and control electronics. It can be said that the whole mass is really concentrated in the middle of wheel. Not only is the electric drive there, but also the mechanical parts, such as wheel bearings, a brake, a suspensions interface, or heat sink, account for the mass in the middle of wheel.



**Figure 3: Cross-section of a common in-wheel motor.**

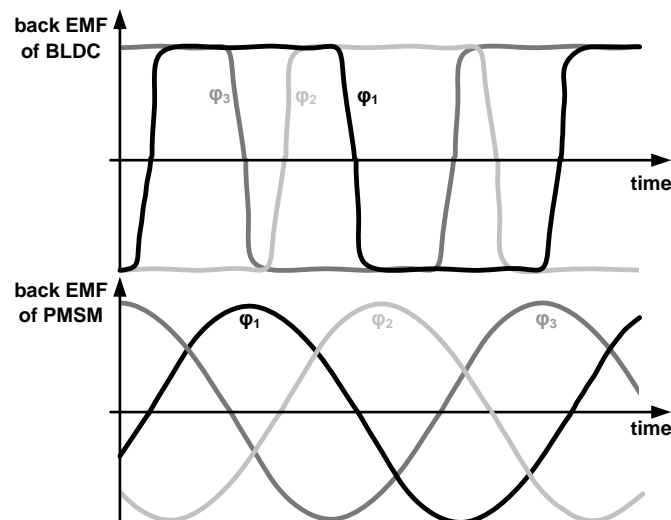
Several types of electric machines can be used as a motor. However, the three-phase synchronous motor has been shown to be a very good option (Li & Qian, 2011). The unusualness of a synchronous motor construction, unlike a classical construction, is a rotor from permanent magnets surrounding the fixed stator, with the stator winding in the middle (see Figure 3). The rotor is a fixed component of the wheel's body.

This type of a motor is known as an electronically commutated (EC) motor. EC motors are of two types: brush-less DC (BLDC) motor and permanent magnet synchronous motor (PMSM). The accumulator or the batteries are the main power sources in an electric vehicle. These sources are sources of DC voltage, but the synchronous motor is the AC machine. It is only the question of terminology. An electronic commutator is a semiconductor converter which produces the required AC supply of EC motor waveforms from the DC source (Figure 4). Both the BLCD motor and the PMSM are machines of almost the same construction (Lis, 2011). The only one difference between them is the distribution of a magnetic field course.



**Figure 4: Power scheme of the electronic commutator.**

The back electromotive force (analogue of the induce voltage in winding machines) of the BLDC motor is a trapezoidal shaped, the PMSM has physically adapted a stator winding for a sinusoidal shape of the magnetic field. The reason for the use of the trapezoidal shaped magnetic field lies in the easy control strategy of the drive (Lis, 2011).



**Figure 5: Back EMF of BLDC and PMSM.**

The converter for the supply of the BLDC motor can be driven only by a simple pulse-width modulation (PWM). Every moment only two from three phases are fed by rectangle voltage pulses in a star connection of a stator winding. Of course, it is possible to drive the BLDC motor also harmoniously. The back EMF however approximates a sinusoidal waveform, but not the same as the PMSM. Its main disadvantage is the non-uniformity of the wheel rotation. Therefore, the more sophisticated vehicles are equipped with the PMSM as the main drive. The BLDC motors are used as auxiliary drives.

The sinusoidal shaped magnetic field of the PMSM rapidly improves the uniformity of the wheel rotation compared with the trapezoidal shaped field. Both waveforms of the magnetic field are shown in Figure 5. However, the control algorithm of PMSM is significantly more difficult. It is necessary to generate with the help of a converter not only one sinusoidal wave, but waves for all three phases. The converter generates the three-phase voltage with a frequency which is proportionate to the wheel rotation (Glinka, 2008).

#### 4 CONCLUSION

The in-wheel drive system brings a new technical solution to vehicle design. The high level of maneuverability is the main advantage in city traffic. The high mass of the wheel assembly and the reduced mass of car's body can bring with it problems on uneven roads, especially in the tire – road contact quality. The solution for this conflict can be found in the active systems utilization, as described in the technical note.

#### 5 TECHNICAL NOTE

The research organization DLR (German Aerospace Center - [www.dlr.de](http://www.dlr.de)) developed a unique electric car based on sophisticated design principles (Schaub et al., 2011, Brembeck et al., 2010). The suspension and steering systems design, as well as the control concept utilized the wide experience of the research team in the field of robotics and active dynamic systems. The team of prof. Dr.-Ing. Gerd Hirzinger, director of the DLR – Institute of Robotics and Mechatronics, designed the robotic electric vehicle ROMO.



**Figure 6: DLR concept ROMO.**

The philosophy of the ROMO concept is an intelligent system with a central control system consisting of four active units (wheel assembly) integrating the functionality of the drive-train, brake, steering, spring and damper. The main advantage is excellent maneuverability enabled by four in-wheel drives and four independently actuated wheel steerings. To command such an overactuated vehicle the integrated vehicle dynamics control is supported by a camera system.

DLR has selected the solution of the in-wheel motor with an inner rotor and an outer stator from aluminium. As the main motors used, PMSM are fitted in 17'' wheels. With their nominal rate of 1 000 rpm the vehicle can reach a maximal velocity of 100 km/h and deliver a peak torque of 160 Nm. Analyses of DLR have shown that it is sufficient to cool the motor at this power rate using air. Thanks to air-cooling, the weight of a vehicle is lower than when compared to other ways of cooling (Brembeck et al., 2010).

The steer actuator is also together with the main drive in the center of a wheel. It is a 370 W harmoniously controlled BLDC motor (Brembeck et al., 2010).

The car body is made from non-conventional materials (carbon fiber structure) for mass reduction. The inspiration from aircraft design at DLR is evident (Figure 6). The ROMO vehicle is a demonstration of a successful interdisciplinary project between electro-mobility, robotics, and car body design.

## ACKNOWLEDGEMENT

Authors are grateful to the colleagues from DLR, especially Dr. Jakub Tobolář, for his kind help and support.

## REFERENCES

- Brembeck, J., Ho, L. M., Schaub, A., Satzger, C., Tobolar, J., Bals, J., Hirzinger, G., 2010. *ROMO – The Robotic Electric Vehicle*. Wessling: DLR, Institute of Robotics and Mechatronics. [promotion flyer]
- Glinka, T., 2008. Electric motors with permanent magnets. *Przegląd Elektrotechniczny*, vol. 84, pp. 1-7.
- Kovanda, J., Resl, I., Socha, J., 1997. *Design of Automobiles – Vehicle Suspension*. Prague: CTU.
- Li, X., Qian, H., 2011. The Present Status and Future Trends of In-wheel Motors for Electric Vehicles. *Advanced Material Research, Materials Science And Information Technology*, vol. 433-440, pp. 6943-6950.
- Lis, M., 2011. A comparison of magneto-mechanical time dependencies of a brushless motor with permanent magnet excitation in BLDC and PMSM modes. *Przegląd Elektrotechniczny*, vol. 87, pp. 118-120.
- Schaub, A., Brembeck, J., Burschka, D., Hirzinger, G., 2011. Robotisches Elektromobil mit kamerabasiertem Autonomieansatz. *ATZ Elektronik*, 6. Jahrgang, vol. 2.