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Analysis of an Electric Vehicle with a BLDC PM Motor in the Wheel Body

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ABSTRACT: The paper deals with the conception of the test bed for the permanent magnet brushless DC motor (PM BLDC) with parameter verification. The tested motor is destined for installation in the wheel body. The test bed HW and SW equipment is described in the paper. This equipment enables the automated measuring of load-rise, temperature-rise, and retardation tests. The test's aim is to obtain attested specifications for a vehicle dimensioning methodology design based on the knowledge of its dynamic behaviour and the track grading, and eventually of its energy consumption, action radius, etc.

KEYWORDS: electromobility, BLDC (brushless direct current), NdFeB, PM (permanent magnet), PWM (pulse width modulation) converter.

1 INTRODUCTION

The current basic candidates for an electrical vehicle's propulsion system are induction motors (IM), switched reluctance motors (SRM) and PM brushless motors (BLDC). The above-mentioned motors' active parts disposition is shown in mutual comparison in Fig. 1. Table 1 thereafter presents their quantitative confrontation (Gieras & Wing, 2002).

Table 1: Comparison of electric vehicle propulsion systems.

		IM	SRM	PM BLDC
specific output power	kW / kg	0.7	1.7	1.2
specific volume	10^4 x m^3 / kW	1.8	2.6	2.3
Efficiency	%	93.5	93	95.2
Overload capacity	-	2.4	1.9	2.2
torque ripple	%	7.3	24	10
maximum speed	rpm	12500	12500	9500

The main advantages of cage induction motors in Fig.1a are:

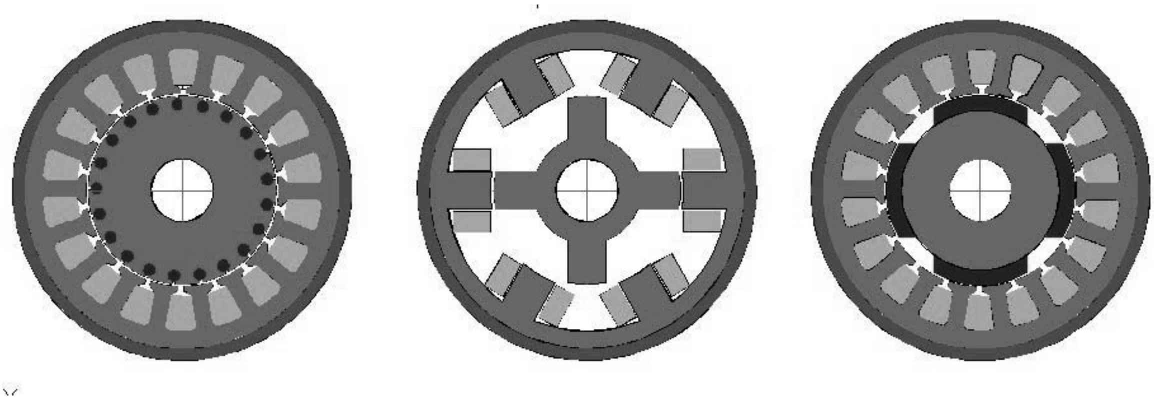
- simple construction
- simple maintenance (a standard maintenance routine concerns the sliding contacts in 90 % of cases)
- no commutator or slip rings
- low price and moderate reliability

The disadvantages of cage induction motors are:

- small air gap
- possibility of cracking the rotor bars due to hot spot at plugging and reversal
- lower efficiency

On the other hand the use of PM brushless motors (BLDC) has become a more attractive option compared to induction motors thanks to the following mains benefits:

- increase in the efficiency caused by non existing field excitation losses
- higher torque and output power per volume
- better dynamic behaviour
- simplification of construction and maintenance
- reduction of price for some types of machines



a) b) c)

Figure 1: Active parts a) induction motor, b) switched reluctance motor, c) PM brushless motor.

The power losses in PM brushless motors (Fig. 1.c) occur mainly in the stator where heat can be easily transferred through the ribbed frame, or in larger machines, a water cooling system can be used. PM brushless motor drives show the best output power to mass factor, efficiency, and compactness. PM d-c brushless and a-c synchronous motors are practically the same, with polyphase stator windings and PMs located on the rotor. The only difference is in the control and shape of the excitation voltage. A synchronous motor is fed with a more or less sinusoidal voltage which produces a rotating magnetic field. The armature current in BLDC motor has the shape of a square or trapezoidal waveform. Only two phase winding conduct the current at the same time. The switching pattern is synchronized with the rotor angular position (electronic commutation). In both types, the synchronous and brushless motors' transmission of armature current is not transmitted by sliding contacts. An important advantage is also the fact that power losses occur only in the stator, where heat transfer conditions are good. Consequently, the current density can be increased, in comparison to a classical commutator d-c motor and, in addition, considerable improvements in dynamics can be achieved due to the air gap magnetic flux density being high and the rotor having a lower inertia; there are also no speed-dependent current limitations. The volume reduction of the BLDC motor in comparison with a classical commutator motor with PM can be as much as 40 %.

2 TYPICAL REALIZATION OF THE wheel body BLDC MOTOR

Modern drive units of road vehicles are mostly engineered with a magnetic circuit excited by permanent magnets in an axial or radial arrangement. The rotor is formed by the outer frame with the PM, the stator armature winding is built by the laminated magnetic core with the three-phase winding in slots. The winding is in a star or delta connection with terminals which are led out through a hollow shaft, see Fig.2. The number of slots per pole and phase is usually $q = 1$.

Control is realized by the three-phase PWM converter in a synchronous mode by Hall probes placed in the stator teeth. The general advantage of electrical vehicle drive, i.e., a multiple overload capacity in comparison with the combustion engine, is mentioned in the literature. However, this statement is valid only up to a certain point. Current rotating machines are produced usually in the insulation class F and H, and so a steady-state temperature rise could theoretically reach up to 150° C in class F and even 180° C in class H. However, the deciding factor, from the point of view of the vehicle drive dimensioning, is the NdFeB permanent magnet's maximal working temperature usually being 80 – 140° C. The permanent magnet's maximal temperature exceed threats with the machine demagnetization and herewith its non-reversible defect.

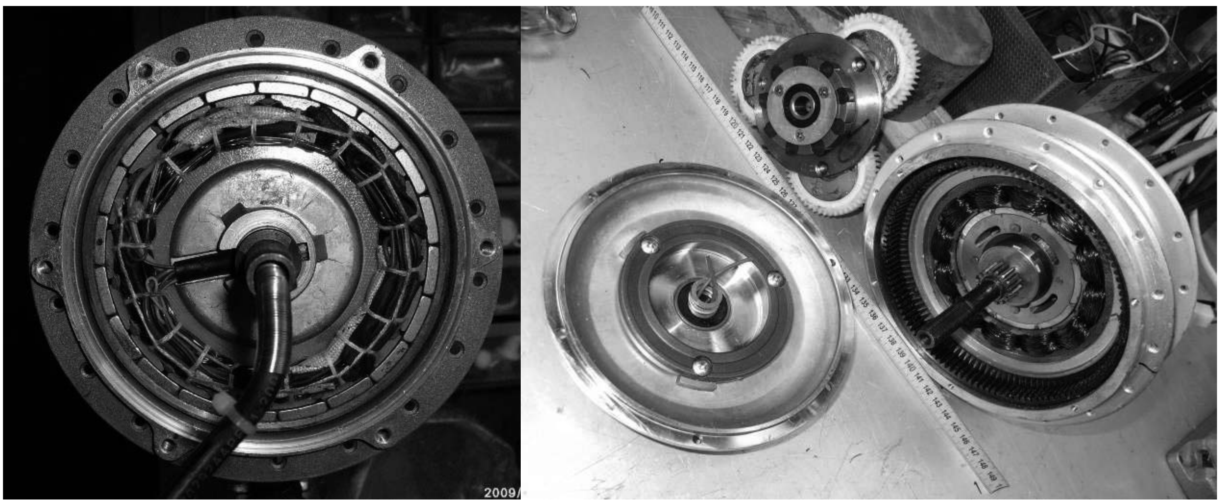


Figure 2:Comparison – construction of BLDC motors direct drive (left) and with planet gear (right).

Therefore, for the correct dimensioning of the vehicle drive it is essential to go out of the knowledge in thermal capacity of the actual BLDC motor and from the knowledge of vehicle working mode. In the case of the working mode, it is possible to go out from the passport of the European committee ENECE defining typical city traffic regime, see Fig. 3.

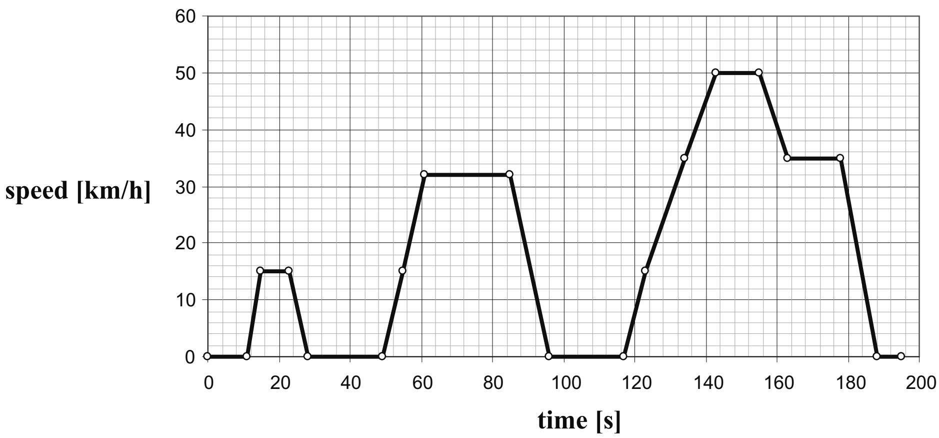


Figure 3: Typical city traffic regime by the ENECE 100.

It is obvious from the diagram that the mode of driving during acceleration and electro-dynamic braking has a major influence on the drive dimensioning. When it is not possible to take away the heat or arrange cooling in transient modes it is necessary to evaluate the drive dimensioning experimentally, for example on a vehicle model representing one axis or one wheel only.

3 DRIVE DIMENSIONING

Three fundamental types of road resistances have to be respected:

1. passive vehicle resistances
2. resistances for overcoming inertial forces of moving masses
3. resistances given by the profile of the track

Passive vehicle resistances have a main influence on running characteristics. They can be enumerated from:

a. <u>Rolling resistances</u>

$$F_{val} = o_{val} \cdot m_{voz} \cdot g \qquad [\mathrm{N}, \mathrm{N \cdot kN^{-1}}, \mathrm{t}, \mathrm{m \cdot s^{-2}}]$$

where o_{val} is given in Tab.1:

Table 2: Rolling resistances.

Wheel type	Traffic road type	Rolling-resistance force [N·kN^{-1}]
Passenger vehicle diagonal tyre radial tyre	Asphalt track	15 ÷ 22 12 ÷ 18
Motor-truck diagonal tyre radial tyre	Asphalt track	10 ÷ 15 8 ÷ 12
Motor-truck	Terrain	150 ÷ 200
Motor-truck / tractor	Plump terrain (plough)	250 ÷ 500
Rail vehicle	Rail	0,3 ÷ 1

b. Axle bearing friction

$$F_L = o_L \cdot m_{voz} \cdot g \qquad [\text{N, N/kN , t , m/s}^2]$$

The value of the coefficient of bearing rolling friction o_L depends on the speed, temperature, and pasting quality. Its value is given in the production catalogue.

c. Aerodynamic resistance

$$F_A = c_x \cdot S_{\check{c}el} \cdot \frac{\rho}{2} \cdot \left(\frac{v_R}{3{,}6}\right)^2 \qquad [\text{N, - , m}^2\text{, kg·m}^{-2}\text{, km·h}^{-1}]$$

The vehicle's nose form factor c_x and its cross sectional area $S_{\check{c}el}$ have a decisive influence on the aerodynamic resistance. The relative vehicle speed v_R has a considerable influence as well. Additionally air density play a role. Air density depends on the temperature and on atmospheric pressure. In European conditions, where - 25° C ÷ + 40° C and 98.5 ÷ 103.5 kPa are assumed, air density ρ is 1.326 kg·m^{-2}. Form factor $\mathbf{c_x}$ is given in Tab. 2.

Table 3: Vehicle nose form factor.

Vehicle Type	Nose form factor
One-track (bicycle/motor-cycle)	0.6 ÷ 1.2
Passenger vehicle	0.25 ÷ 0.4
Open passenger vehicle	0.5 ÷ 0.65
Van	0.4 ÷ 0.5
Motor-truck	0.8 ÷ 1.0

A summary of vehicle resistance F_V for the resistance given by the profile of the track neglected is:

$$F_V = F_{val} + F_L + F_A = A + B \cdot v + C \cdot v^2$$

It is therefore evident that passive vehicle resistances have generally a parabolic form which is considerably influenced by its geometry, mass, and running speed.

Track profile, namely slope α, positively influences the rolling resistance magnitude by the normal component of the gravity force, i.e., the magnitude of the first term *A*:

$$F_{val} = F_{val\cdot} \cdot \cos\alpha$$

The gravity force component F_g, given by the summary vehicle mass *m,* has to be added to the passive vehicle resistances F_V which the driving unit must overcome for the track slope.

$$F_g = m \cdot g \cdot \sin\alpha$$

Running resistances from acceleration (i.e., dynamical resistances) are influenced by vehicle rotating masses and by resistances given by the masses of the translation motion. For the drive dimensioning, it is advantageous to reduce both the passive and dynamical resistances to the motor shaft. Therefore, inertia masses have to be related to the wheel circumference and expressed in a form of moment of inertia as:

$$J_{cel} = J_P + m \cdot \left(\frac{d_{kol}}{2}\right)^2 \cdot \frac{1}{i^2 \cdot \eta} \qquad [\mathrm{kgm^2, kg, m}]\ ,$$

where i is a ratio and η is a summary of the efficiency of the power transmission on the axletree or on the wheel circumference.

The determination of drive moments of inertia J_p can produce some problems, as it usually is not included in the catalogue specified parameters. One possible method is an experimental moment of inertia evaluation using the method of the retardation test, where the machine is disconnected from the load and time dependence on the speed is measured, see Fig.7.

The balance between inertia mass torque and braking torque given by the machine's losses exists in any time point. A specific problem of PM motors is the fact that machine iron losses take part on the breaking torque and must be extracted from the inertia mass power:

$$\Delta P = J_p \cdot \omega \cdot \frac{d\omega}{dt}$$

4 EXPERIMENTAL PARAMETER SPECIFICATION METHODS

The type of the tested BLDC motor is introduced in Fig.4. It is a low speed motor without an inbuilt gear box assigned for the individual drive of the motor car wheel (direct drive). The motor was installed with four screw bolts for direct wheel mounting and also with a disc brake. The drive was made in China and it was delivered without any specification of a particular production type and without any sheet parameters. The type's output was estimated in the range of between 1500 - 3000 W, supply voltage 48 V, any other information about the drive components and specifically of its converter is not known. The machine's mass of 18 kg was found by weighing it.

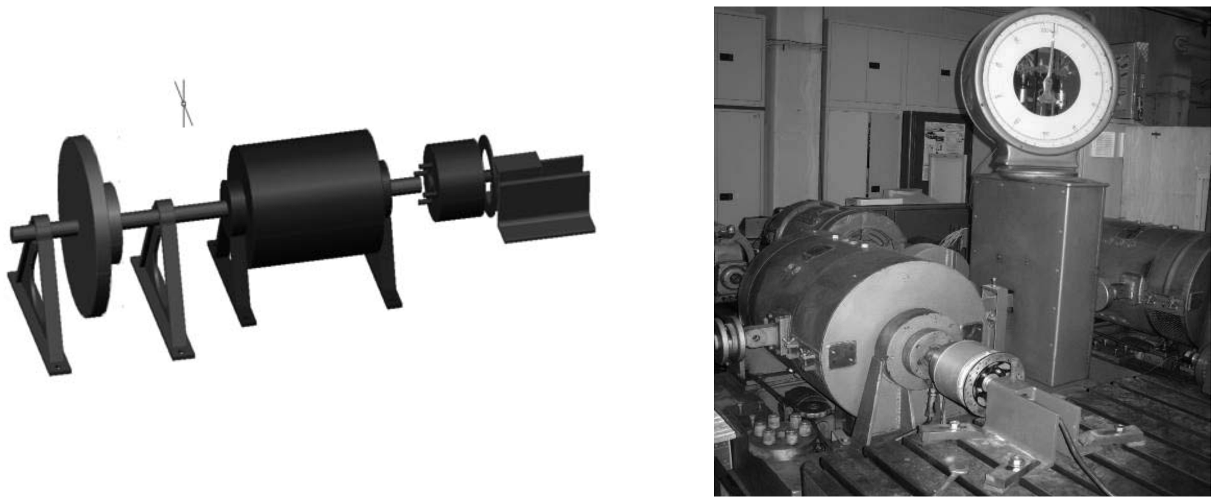


Figure 4: Front view of the workplace, mechanical coupling of motor – dynamometer.

Experiments were focused on parameter verification and on the drive dimensioning in terms of the ideas mentioned in the 2nd and 3rd chapter:

- method for the measurement verification of the drive's mechanical characteristics
- verification and realization of temperature-rise test for a steady state duty cycle
- verification of the methods for the moment of inertia measurement using the retardation test

The aim of the authors was to build an experimental workplace for experiments ona complete model of a vehicle's drive reduced to one wheel. The thinking is based on the fact that a vehicle's passive resistances can be replicated by the dynamometer load. The vehicle mass or its load can be replicated using a fly-wheel on the reverse side of the dynamometer, see Fig.4. Therefore load tests of any vehicle with a chosen driving cycle can be realized only on basis of the above-mentioned three tests.

5 DESCRIPTION OF THE WORKPLACE – TEST RESULTS

The base of the experimental workplace mechanical part includes:

- Dynamometer 50 kW, 200 Nm
- Ward-Leonard motor-generator set
- Set of fly-wheels

Unified instrumentation includes a power analyser NORMA 4000, equipped with ac/dc current LEM clip-on probes. The power analyser is connected by the series interface RS 232 to a PC installed with Norma X software for the transmission and storage of the measured data.

The motor's speed can be derived from the frequency of the armature induced voltage with regard to the control mode of the BLDC motor when the magnetic field rotates synchronously with the rotor. It is not necessary to install the speed indicator permanently.

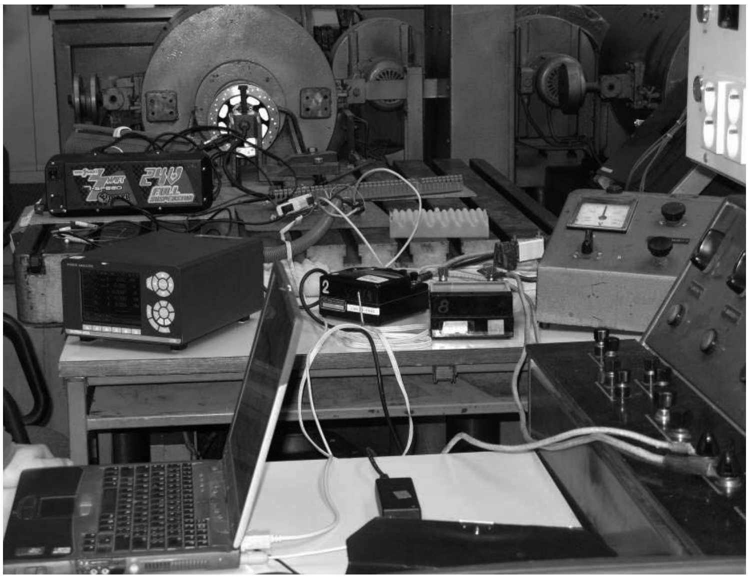


Figure 5: View of the improvised measuring workplace.

The measured torque-speed characteristic for the two different supply voltages, 55 V and 60 V d-c, is shown in Fig. 6. The values of the torque were so far read manually. Automated torque data collection will, in the future, be realised with a given rate, using the dynamometer armature current measurement. Regarding the suppressed speed-axis origin, see Fig. 6, it is possible to claim that motor is a sufficiently hard source of the mechanical power. The temperature-rise test was realized using the "Resistance Method" and is documented in the cooling curve shown in Fig.8. The machine was loaded with a constant load of 40 Nm at a speed of 665 min^{-1} until temperature stabilization, i.e., about 30 minutes. Then the converter was switched off and the winding of one phase was switched to the d-c source after about 4 minutes (accumulator 12 V).

The voltage and current were measured using a power analyser in about 6000 points and the resistance was calculated. The winding resistance was evaluated after the extrapolation of the cooling curve to the point of switch off time.

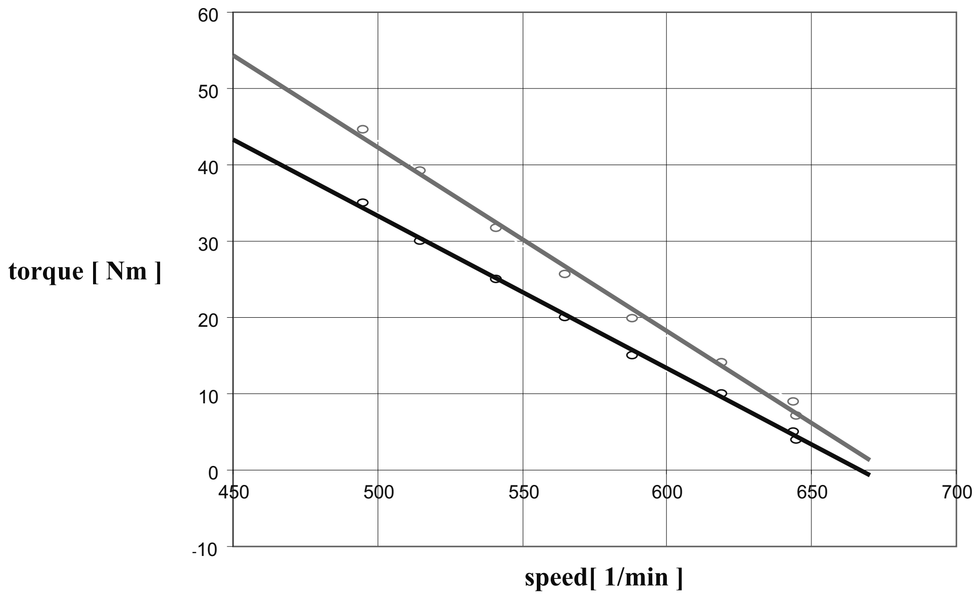


Figure 6: Torque-speed characteristic.

The winding temperature-rise was evaluated using the hot and cold resistance difference. The medium winding temperature-rise in this case was 51.6° C and the temperature was 71.1° C. That is tolerable from the point of view of the limit operation temperature of the permanent NdFeB magnets used. The machine's 30 minutes power was then determined as 2.8 kW.

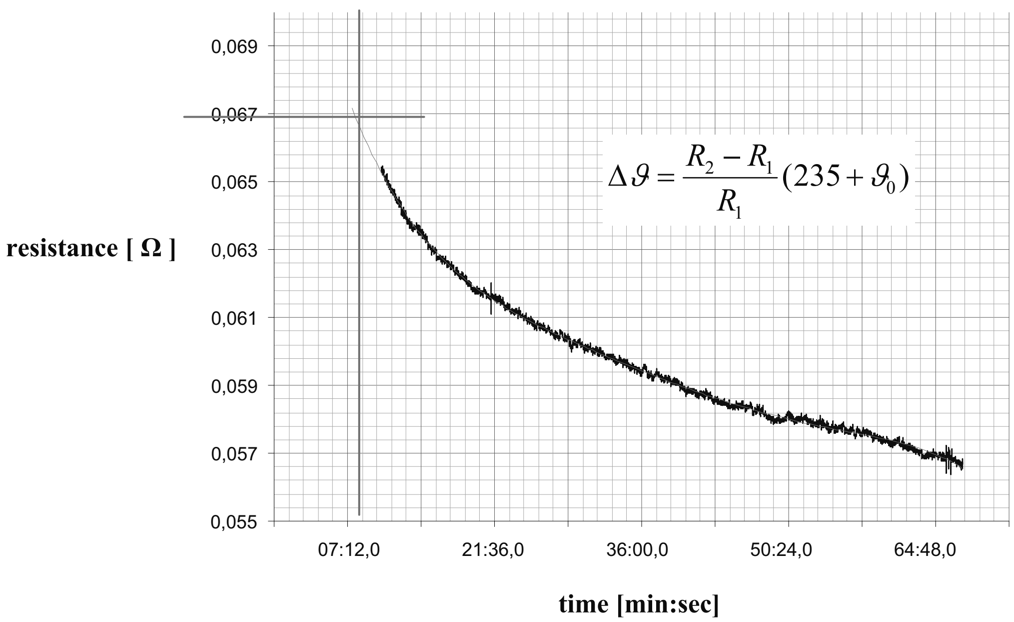


Figure 7: Cooling test – winding resistance, extrapolation to the point of switch off.

The machine moment of inertia J_p possibility of experimental determination is shown in Fig. 8. As was cited above it is necessary to find experimentally the speed-losses dependence for the correct evaluation of the moment of inertia. Finally, the moment of inertia can be determined from the length of subtangent T_{st} at known speed:

$$J_p = 91{,}2 \cdot \Delta P \cdot \frac{T_{st}}{n^2} \qquad [\text{kgm}^2, \text{W, s, min}^{-1}]$$

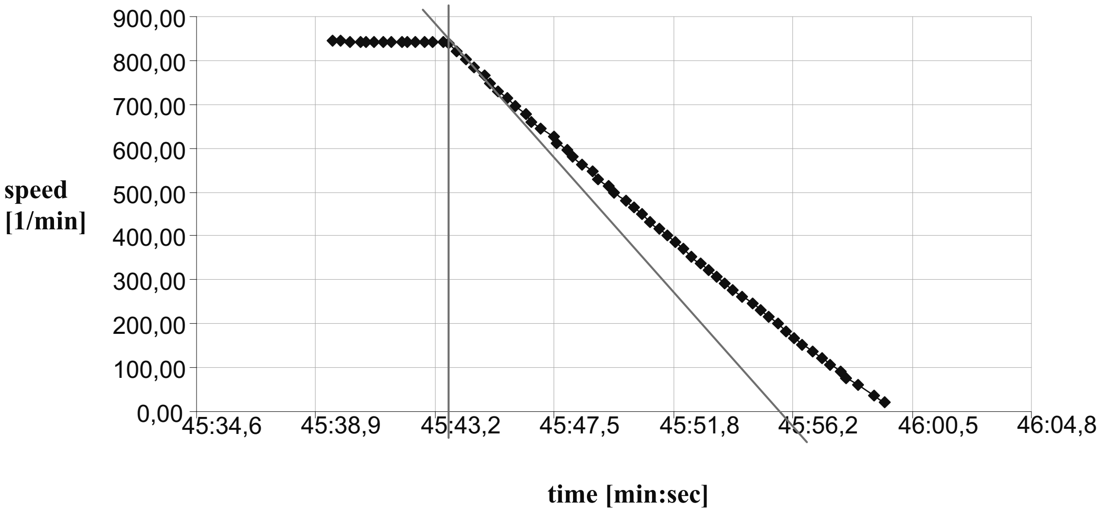


Figure 8: Retardation test for the moment of inertia determination.

6 CONCLUSION

The realized measurements confirm that an electric drive can be simulated like a rotating system on the basis of some above cited experimentally found characteristics knowing the vehicle running diagram and its load. The vehicle is then reduced to one driven axletree or to one wheel with in-built drive and a particular part of the total vehicle load which represents the dynamic torque. It is possible to realize the model, e.g., as a rotating set: motor – dynamometer (calibrated machine) – fly-wheel. It is possible to simulate the vehicle's operation on a given road profile at a given running mode and to verify the availability of the drive unit dimensioning.

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A Contribution to the Economical and Ecological Assessment of Electromobiles

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ABSTRACT: Six vehicles of the same class (3 with combustion engines, 3 electromobiles) were compared and the results are that the total life cycle costs (LCC) of the electromobiles are distinctively lower. The relation between fuel usage and carbon dioxide production (CO_2) is shown in the second part of the paper. The vehicles with the combustion engine meet maximum carbon dioxide production (CO_2) outline requirements (the requirement of the EU committee is 120 g/km) with a maximum fuel usage of 5.1 l/100 km. Electromobiles meet maximum carbon dioxide production (CO_2) outline requirements with a maximum fuel usage of 4.5 l/100 km.

KEY WORDS: life cycle costs (LCC), electromobiles, ecological economy, fuel usage, carbon dioxide production.

1 INTRODUCTION

The number of vehicles on the roads is constantly growing. At the end of the year 2009 there were more than 6.4 million insured vehicles registered in the database of the Czech insurer´s office (Finance.cz, 2009). Rice in process of the fuels, adverse effects of exhaust pollutants, the restriction of “dirty” vehicles’ entry to town centers (Adac, 2009), new EU limits on CO_2 production in vehicles with gas-engines (Směrnice komise 1999/100/ES, 1999) and electric power were the most dominant aspects which have initiated the use of electromobiles. It can be expected that the present consumer will not only consider the type, comfort, and technical parameters, but also the economical and ecological properties of the vehicles during their selection. From the aforesaid it is evident that it would be useful to set the general procedure to economical and ecologic efficiency classification.

2 RANKING OF VEHICLES’ ECONOMICAL EFFICIENCY

For the ranking of vehicles’ economical efficiency it is necessary to choose the right economical parameters and make the cost items selection.

2.1 Choosing the right economical parameters

The right economical parameter (for the vehicles' economical efficiency) could be cumulative expenses N. In the case where the vehicles have a different lifetime (range) to the outage, the right economical parameter could be the specific costs n. The specific costs n could be expressed by the following formula:

$$N = \frac{n}{s_v} \quad (1)$$

where: n – specific comparative costs [CZK/km], N – expense items (cumulative costs) [CZK], s_v - lifetime to the outage [km].

2.2 Selection of the cost items

The basic guideline for ranking a vehicles' economical efficiency is the standard (ČSN 300-3-3, 1997). According to this standard life cycle costs (LCC) are divided into the six following stages – the stage of concept and establishment of the requirements; the stage of design and development; the stage of production; the stage of installation; the stage of operation and maintenance; and the removal stage. It is logical that each period is characterized by the economic costs.

It is not necessary, during the comparison of the economic efficiency of the vehicles, to calculate with the overall costs of the vehicles' life cycle in the stage of operation and maintenance. For a comparison of the critical cost items a quick and basic orientation suffices. The critical costs items of this stage are the initial costs (N_{POR}) and the costs of ownership (N_{VL}). These costs can be expressed mathematically as follows:

$$N = N_{POR} + N_{VL} \quad (2)$$

A more accurate and detailed separation of each vehicle's conclusion would be attained by an evaluation of additional costs items. However, a huge range of costs items is not useful, as this procedure becomes too complex and is often inefficient.

The critical cost items of the ownership costs of electromobiles are the price of the vehicle NV, electric power costs (accumulator charging) N_{DB}, accumulator costs N_B, tire costs N_P, preventive maintenance costs $N_{PU,}$ and corrective maintenance costs N_{NU}.

The cost items of electromobiles N_{EL} can be expressed mathematically as follows:

$$N_{EL} = N_V + N_D + N_B + N_P + N_{PU} + N_{NU} \quad (3)$$

The critical cost items of the ownership costs of vehicles with a combustion engine are the price of the vehicle N_V, fuel costs N_F, lubricant costs N_O, starting accumulator costs N_A, tire costs NP, preventive maintenance costs $N_{PU,}$ and corrective maintenance costs (repair) N_{NU}.

The cost items of vehicles with a combustion engine N_{SM} can be expressed mathematically as follows:

$$N_{SM} = N_V + N_F + N_O + N_P + N_A + N_{PU} + N_{NU} \quad (4)$$

Note: Some other cost items (toll costs, technical control costs) are, for vehicles in the same category, identical. Therefore, it is possible to ignore these items during economical comparison and thereby the solving of the economical comparison is simpler.

The following formulas (Čorňák, Braun, Petříček, 2005), (Čorňák, Braun, 2009), (Havlíček, 1989), (Kočár, 2004), (Vintr, 2000) could be used for quantitative determination of these items:

- electric power costs (accumulator charging) for the whole life cycle:

$$N_D = \frac{i_B . U_B . Q_B . p_{EL} . s_v}{1000 . \eta_B . s_{DB}} \text{ [CZK]} \qquad (5)$$

where: s_{DB} - trailing throttle with fully charged accumulators on one charging cycle [km], i_B – number of accumulators [no], U_B – voltage of one accumulator [V], Q_B – accumulator capacity [A.h], t_{NB} – charging time for one charging cycle [h], p_{EL} – electric power cost [CZK/kW.hour], s_V – lifetime (technical life = 100 000 km), η_B – energy losses, η_B = 0,9 (charger and accumulator heating losses).

- accumulator costs N_B for the whole life cycle:

$$N_B = \frac{s_v}{\bar{s}_{ZB}} . i_B . p_B \text{ [CZK]} \qquad (6)$$

where: p_B – price of one accumulator [CZK],

- average lifetime of the accumulator:

$$\bar{s}_{ZB} = c_{NB} \cdot s_{DB} \text{ [km]} \qquad (7)$$

where: c_{NB} – number of charging cycles per one accumulator.

- fuel costs N_P:

$$N_F = \frac{N_F}{100} \cdot p_F . s_v \text{ [CZK]} \qquad (8)$$

where: N_F- specific fuel consumption [l/100 km], p_F – fuel price [CZK/l],

- lubricant costs N_{OL}:

$$N_O = \frac{N_O}{100} \cdot p_O . s_v \text{ [CZK]} \qquad (9)$$

where: N_O – specific lubricant consumption [l/100 km], p_o – lubricant price [CZK/l],

- starting accumulator costs N_A:

$$N_A = \frac{i_A . p_A . s_v}{\bar{s}_A} \text{ [CZK]} \qquad (10)$$

where: i_A – number of starting accumulators [no], p_A – price of the one starting accumulator [CZK/no], $\bar{s}_A$ - average accumulator lifetime [km],

- tire costs N_{PN}:

$$N_P = \frac{i_P . p_P . s_v}{\bar{s}_P} \text{ [CZK]} \qquad (11)$$

where: i_P – number of vehicle tires [no], p_P – price of one tire [CZK/no], $\bar{s}_P$ - average tire lifetime [km],

- preventive maintenance costs N_{PU}:

$$N_{PU} = \frac{s_v}{\bar{s}_{PU}} . \bar{N}_{PU} \text{ [CZK]} \qquad (12)$$

where: $\bar{s}_{PU}$ - average running between preventive maintenance [km], $\bar{N}_{PU}$ - average costs of one preventive maintenance [CZK],

- corrective maintenance costs (repair) N_{NU}:

$$N_{NU} = \frac{(s_v - s_z)}{\bar{s}_{NU}} . \bar{N}_{NU} \text{ [CZK]} \qquad (13)$$

where: $\bar{s}_{NU}$ - average running time between failures [km], $\bar{N}_{NU}$ - average costs of one corrective maintenance (repair) [CZK], S_z - running of the vehicle within the guaranty [km].

2.3 Implementation of the designed model for the evaluation of the vehicle's economic efficiency

Six karts were chosen (3 with combustion engines M1, M2, M3; 3 electromobiles E1, E2, E3) for a practical implementation of the designed model. They were karts from the same category, and, therefore, it is supposed they have similar running conditions.

The initial values of the electromobiles E1, E2 and E3 are shown in tables no. 1 and 2. The initial values of the vehicles with combustion engines are shown in tables no. 3 and 4.

Table 1: Technical data of the electromobiles.

Specification	Vehicle values:		
	E1	E2	E3
number of accumulator - i_B [no]	8	8	2
voltage of one accumulator - U_B [V]	6	6	24
accumulator capacity - Q_B [Ah]	190	190	300
charging time for one charging cycle - t_{NB} [h]	8		
number of the charging cycle of the one accumulator - c_B [no]	1 400		
trailing throttle with fully charged accumulators on one charging cycle - t_{EB} [km]	70	70	90
energy losses during the charging – η_B [-]	0.9		
Number of the tires - i_P [no]	4		
average tire lifetime $\bar{s}_P$ [km]	50 000		
average running to preventive maintenance - $\bar{s}_{PU}$ [km]	10 000*		
average running time between the corrective maintenance - $\bar{s}_{NU}$ [km]	20 000**		
running of the vehicle within the guaranty - s_z [km]	10 000		
running to the removal (lifetime) - s_v [km]	100 000		

Note: Some items are not complex observed during operation (namely the items of corrective maintenance). These items were determined using expert judgment.

Table 2: Economical specifications of the electromobiles.

Specification	Vehicle values:		
	E1	E2	E3
vehicle price N_v [CZK]	436 000	468 000	568 000
vehicle price without accumulators N_v [CZK]	339 000	372 000	423 000
price of the one accumulator p_B [CZK/no]	12 000	12 000	72 500
electric power price p_{EL} [CZK/kW.hour]	2		
price of the one additive accumulator p_B [CZK],	3 500		
price of the one tire p_P [CZK/no]	6 000		
average costs to preventive maintenance $\overline{N}_{PU}$ [CZK]	2 500*		
average cost of one corrective maintenance (repair) $\overline{N}_{NU}$ [CZK]	5 000**		

Next specifications are published in the publication (Čorňák & Braun, 2009).

Note:
- *prices are mentioned in Czech crowns without VAT,*
- *notes in some data:*
  * *recommended by the vehicle producer (*Čorňák, Braun, 2009*).*
  ** *judgment (double preventive maintenance).*
  ^{ZM} *– vehicle with spark ignition engine,*
  ^{VM} *– vehicle with diesel engine.*

Table 3: Technical data of the vehicles (combustion engine).

Specification	Vehicle values:		
	M1 ZM	M2 VM	M3 VM 4x4
fuel usage N_F [l/100 km]	10	8	14
lubricant usage N_O [l/100 km]	0.1	0.15	0.2
number of starting accumulators i_A [no]	1	1	1
accumulator average lifetime $\bar{s}_A$ [km]	30 000	30 000	30 000
number of the tires - i_P [no]	4	4	4
tire average lifetime $\bar{s}_P$ [km]	33 000	33 000	33 000
average running between preventive maintenance - $\bar{s}_{PU}$ [km]	2 000*	4 000*	4 000*
average running time between failures - $\bar{s}_{NU}$ [km]	4 000**	8 000**	8 000**
running of the vehicle within guaranty - s_z [km]	10 000	10 000	10 000
running to the removal (lifetime) - s_v [km]	100 000	100 000	100 000

Table 4: Economical specification of the vehicles (combustion engine).

Specification	Vehicle values:		
	M1 ZM	M2 VM	M3 VM 4x4
vehicle price N_v [CZK]	345 000	420 000	500 000
one litre fuel price p_F [CZK]	25	27	27
one litre lubricant price p_O [CZK]	300		
one starting accumulator price p_A [CZK/no]	3 500		
one tire price p_P [CZK/no]	6 000		
average costs to preventive maintenance $\overline{N}_{PU}$ [CZK]	2 500*		
average costs of one corrective maintenance (repair) $\overline{N}_{NU}$ [CZK]	5 000**		

The values of the cumulative costs comparison of the electromobiles E1, E2 and E3 are shown in figure 1. The values of the cumulative costs comparison of vehicles with a combustion engine M1, M2 and M3 are shown in figure 2. There is a relative comparison of the specific costs of the electromobiles (E1, E2, E3) and vehicles with a combustion engine (M1, M2, M3) shown in figure 3.

It is possible to make the following conclusion from the results:

- the operational costs of the electromobiles during their lifetime (running 100 000 km) forms about 22 % of the overall vehicle price,
- the operational costs of the vehicle M1 forms about 122 %, of the vehicle M2 about 103 % and of vehicle M3 (4x4) about 121 % of the overall vehicle price,

- the specific costs of accumulator charging are 0.29 CZK/ km (vehicles E1, E2) and 0.36 CZK/ km (vehicle E3),
- specific fuel costs are 2.50 CZK/km (vehicle M1), 2.16 CZK/ km (vehicle M2) and 3.78 CZK/ km (vehicle M3 4x4),
- electromobiles overall costs during their lifetime (running 100 000 km) are about 5.97 CZK/ km, the overall costs of vehicles with a combustion engine are about 9.10 CZK/ km.

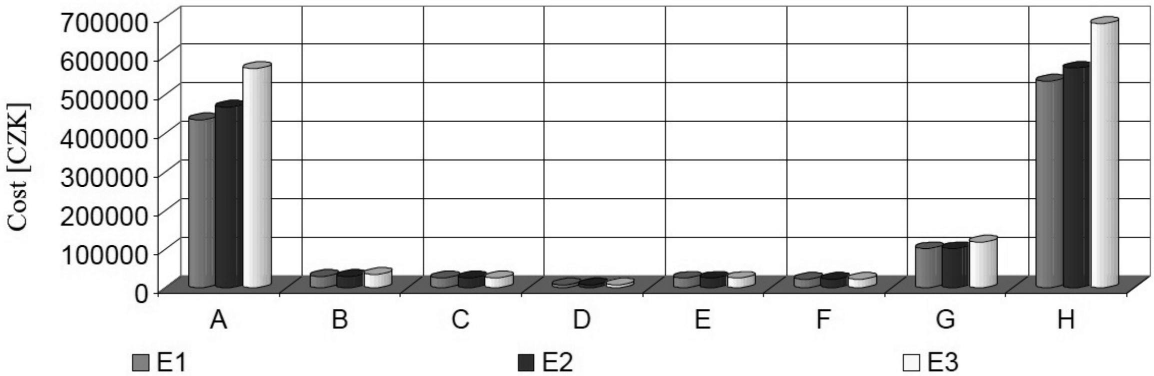

Figure 1: Cumulative costs comparison of the electromobiles.

Where: A – vehicle price, B – electric power price, C – tire price, D – additive accumulator price, E - preventive maintenance price, F – corrective maintenance price, G – operating costs, H - overall costs during lifetime.

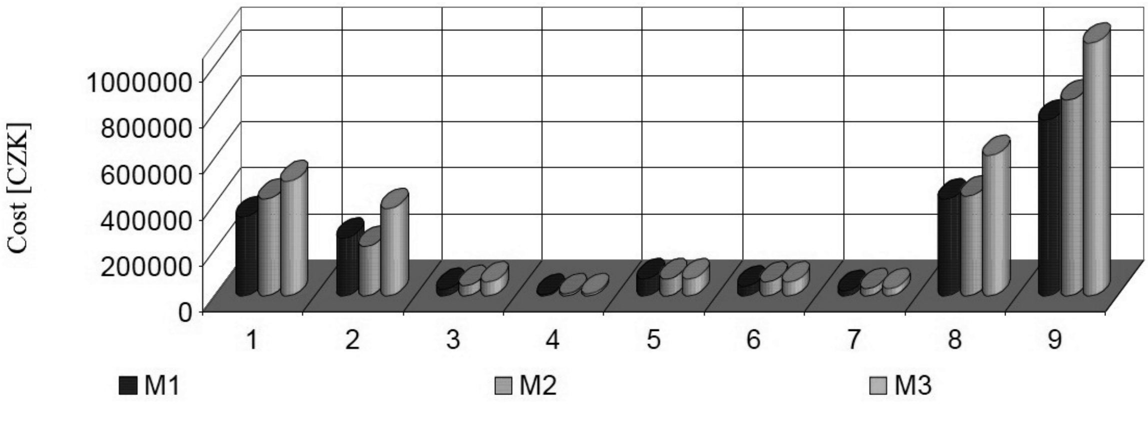

Figure 2: Cumulative costs comparison of vehicles with a combustion engine.

Where: 1 – vehicle price, 2 – fuel price, 3 – lubricant price, 4- starting accumulator price, 5 – tire price, 6 – preventive maintenance price, 7 – corrective maintenance price, 8 – operating costs, 9 – overall costs during lifetime.

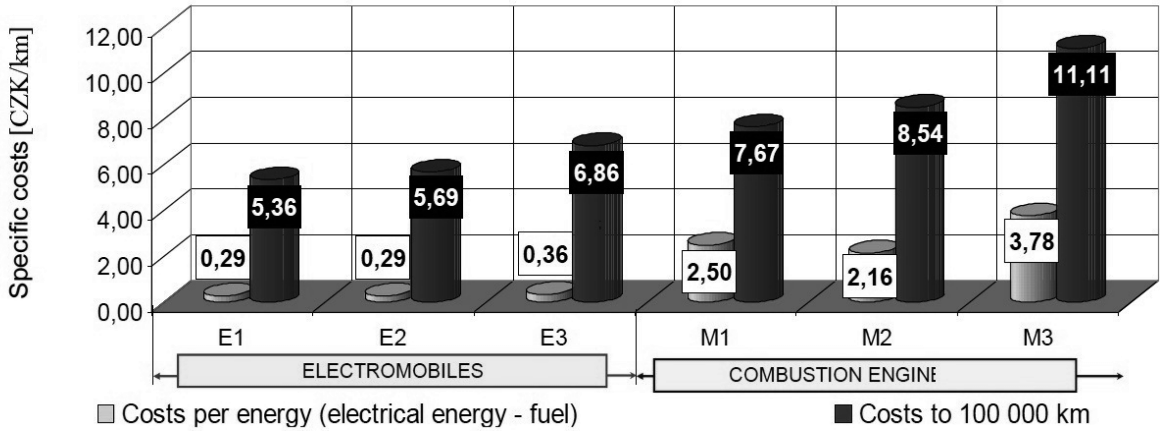

Figure 3: Relative comparison of the specific costs of electromobiles and vehicles with a combustion engine.

The result of the analysis is that the overall operational costs are lower than in vehicles with a combustion engine. The reason for this is that there are no demands for POL and other material exchanging in electromobiles (lubricants, coolant, clutch, exhaust...).

The overall results of the relative comparison of the vehicles in the publication are published (Čorňák, Braun, 2009).

3 ECOLOGICAL RANKING OF THE VEHICLES

The main advantage of electromobiles is their ecological operation. For electromobile operation there are no taxes for exhaust-emission measurement. Electromobiles could be freed from road-traffic taxing and insurance costs could be lower. The lifetime of the break lining is generally longer, due to recuperation breaking (breaking is one of the polluters). On the opposite side vehicles with a combustion engine are a source of noxious emissions, especially carbon monoxide (CO), hydrocarbons (THC), nitrogen oxide, and solid particles (PM) (ES 78/2009, 2009). These dangerous substances are a result of the imperfect combustion of fuel in the engine.

During the combustion of fuel in the engine additional pollutants are produced, such as carbon dioxide (CO_2). Carbon dioxide is not a dangerous pollutant, but it is a significant source of global warming (NRC, 2008). This is a reason why the present discussion focuses on new EU limits on CO_2. These limits could be obtained from the year 2012 and they could be solved from the average vehicle distribution of the one vehicle producer.

Carbon dioxide production has a direct relation to fuel usage. The basic source of comparison for the relation between carbon dioxide production and fuel usage could be used norm (Směrnice komise 1999/100/ES). According to this norm CO_2 production is measured during the testing cycle, which simulates operation within and outside of the city.

This cycle is described in the 1st addition of the 3rd supplement of the directions 70/220/EHS (about carbon dioxide production and fuel usage of vehicles).

The formulas for calculating the fuel usage from the measuring emissions in this norm are also published (Směrnice komise 1999/100/ES). If we know the real fuel usage FC, fuel density D, CO and THC, we can formulate the relation specific CO_2 emission from the fuel usage through the following formulas:

- vehicles with petrol engine used petrol:

$$m_{CO_2} = 23{,}489.FC_{BA}\left[g/km\right] \tag{14}$$

- vehicles with petrol engine used gas (LPG):

$$m_{CO_2} = 16{,}259.FC_{LPG}\left[g/km\right] \tag{15}$$

- vehicles with petrol engine used NG:

$$m_{CO_2} = 21{,}132.FC_{NG}\left[g/km\right] \tag{16}$$

- vehicles with diesel engine:

$$m_{CO_2} = 26{,}640.FC_{NM}\left[g/km\right] \tag{17}$$

where: FC_{BA} – fuel usage (petrol) [l/100km], FC_{LPG} – gas usage (LPG) [l/100km], FC_{NG} – fuel usage (NG) [m3/100km], FC_{NM} – fuel usage (diesel) [l/100km].

On the basis of the above-mentioned formulas (14 – 17) a graph was constructed, shown in figure 4. From the results we can make the following conclusion: vehicles witha combustion engine meet the maximum carbon dioxide production (CO_2) outline requirement (requirement of the EU committee is 120g/km) with a maximum fuel usage of 5.1 l/100 km (with a petrol engine), 7.4 l/100 km (with an LPG engine), 5.7 l/100 km (with a NG engine) and 4.5 l/ 100 km (with a diesel engine).

4 CONCLUSION

This paper is focused on an evaluation of the economic and ecological efficiency of vehicles. Only some basic methours and their practical applications are presented in this paper, due to the limited length of this paper. Therefore only six vehicles were compared, but the method and procedures used are general and could be used generally for an evaluation of a vehicle's economic efficiency (from the user's point of view).

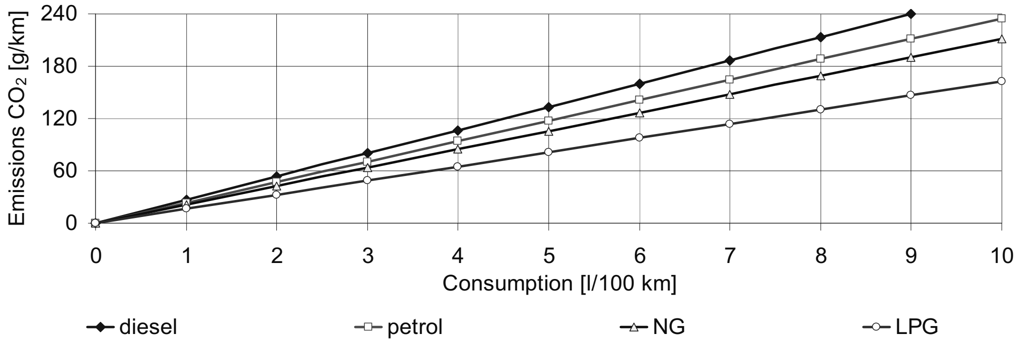

Figure 4: Graphical dependence of the calculated values of CO_2 on fuel usage.

5 ACKNOWLEDGMENT

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Influence of Mental Load on Driver's Attention

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ABSTRACT: This paper deals with influence of mental load on drivers' attention. EEG (electroencephalography) and ERP (event related potentials) techniques are used for investigation of the level of the drivers' attention. A short overview of experiments dealing with drivers' attention is given and the ERP technique and the P3 component are described. General assumptions related to P3 amplitude and P3 latency are introduced. Then the experimental design and the course of the experiment are described. The resulting EEG/ERP data are analyzed and their interpretation is provided.

KEY WORDS: event related potentials (ERP), driver, mental load, attention, P3 component.

1 INTRODUCTION

Our research group at the Department of Computer Science and Engineering, University of West Bohemia, in cooperation with other partner institutions (Czech Technical University in Prague, University Hospital in Pilsen, Škoda Auto Inc., amongst others), specializes in the research of attention, especially the attention of drivers and seriously injured people. We widely use the methods of electroencephalography (EEG) and event related potentials (ERP). Within our partner network we are responsible for technical and scientific issues, e.g., EEG/ERP laboratory operation, the development of advanced software tools for EEG/ERP research, or the analysis and proposal of signal processing methods.

In this paper we focus on the influence of the mental load on the drivers' attention. The ERP technique and the P3 component are used for developing an experimental design related to this issue. A set of testing subjects (university students) was selected to undergo an EPR experiment and their results were analyzed and interpreted.

The remainder of the paper is organized as follows: Section 2 gives a short overview of experiments dealing with drivers' attention and summarizes the basic principles of ERP technique and the assumptions related to P3 amplitude and P3 latency. A description of the experimental design is given in Section 3. Experimental results and their interpretations are provided in Section 4; they are followed by introducing the necessary modifications of the scenario used. Section 5 comprises of concluding remarks.

2 STATE OF THE ART

This section provides a short overview of the published EEG/ERP experiments, which deal with the attention of drivers. Basic principles and advantages of the ERP technique and the P3 component are then introduced. The relation of P3 amplitude and P3 latency to attention is described.

2.1 Previous Research Dealing with the Attention of Drivers

Several methods exist in order to examine the attention of drivers. A lot of experiments use so-called behavioral methods (meaning that the behavior of the driver under certain conditions is investigated – e.g., how often he/she leaves his/her lane), while some experiments use EEG and ERP techniques.

The paper “Changes in EEG alpha power during simulated driving” (Schier, 2000) deals with the suitability of EEG-based techniques for recording drivers’ activity during a driving simulation task. As the result, an increase in alpha activity was interpreted as less attentional activity and a decrease as more attentional activity. Significant differences between drivers were also observed.

The ERP technique was used in (Wester et al., 2008) where the impact of secondary task performance (an auditory oddball task) on a primary driving task (lane keeping) was investigated. The study showed that when performing a simple secondary task during driving, the performance of the driving task and this secondary task are both unaffected. However, analysis of brain activity showed reduced cortical processing of irrelevant, and potentially distracting, stimuli from the secondary task during driving.

2.2 Event Related Potentials

ERPs were first used as an alternative to measurements of the speed and accuracy of motor responses in paradigms with discrete stimuli and responses. ERPs have two advantages compared to behavioral methods. They are useful for determining which stage or stages of processing are influenced by a given experimental manipulation; for a detailed set of examples see (Luck, Woodman & Vogel, 2000). The second advantage of ERPs is that they can provide an online measure of the processing of stimuli even when there is no behavioral response (Luck, 2005).

2.3 P3 component

The P3 component (which is an endogenous component) depends entirely on the task performed by the subject and is not directly influenced by the physical properties of the stimulus. The P3 component is sensitive to a variety of global factors, such as time since last meal, weather, body temperature, and even time of day or the time of year (Luck, 2005).

Thousands of experiments related to the P3 component have been published; however, we still do not know exactly what the P3 component really means. In general, the proposal that the P3 component is related to a process called “context updating” seems to be approximately correct (Luck, 2005).

However, the factors which influence the amplitude and the latency of the P3 component are known. First of all, the P3 component is sensitive to the probability of the target stimulus. P3 amplitude increases when the probability of the target stimulus class (not the probability of the target physical stimulus) decreases. The amplitude of the P3 component also becomes larger when it is preceded by a greater number of non-target stimuli. P3 amplitude is also larger when the subject pays more attention to a task. On the other hand, P3 amplitude is smaller if the subject does not know whether a given stimulus is / is not a target. This means that more difficult tasks can increase P3 amplitude, because the subject pays more attention to these tasks and simultaneously decreases P3 amplitude as the subject is not certain of the stimulus category (Luck, 2005).

Ideas and assumptions related to the latency of the P3 component are again associated with stimulus categorization. If stimulus categorization is postponed (this also includes increasing the time required for low-level sensory processing), P3 latency is increased. While P3 latency depends on the time required for stimulus categorization it does not depend on consequent processes (e.g., response selection). Thus P3 latency can be used to determine if a performed experiment influences the processes of stimulus categorization or the processes related to a response. P3 latency is also postponed if the perception of stimuli is impaired (Luck, 2005).

3 EXPERIMENT DESCRIPTION

This section provides information about the objectives of the experiment and experimental design in detail.

3.1 Objectives of Experiment

The general assumptions described in Section 2 are taken into account in our study. The objectives of the experiment are to:

- Examine if a more difficult track with sharp turns and collisions with an oncoming car can be used as target stimuli for the P3 component elicitation (P3 amplitude is especially examined).
- Compare the latency of the averaged P3 component for two groups of drivers; one group of drivers is unaffected by alcohol, while the level of alcohol in blood reaches 0.5 mills in the second group of drivers.

3.2 Data Acquisition Conditions

The following experimental conditions were met (and devices were used) for data acquisition:

- All experiments were performed in the neuroinformatics laboratory (the quiet room) equipped with an experimental car-simulator (the front part of a real car; wheel, accelerator, and brake were connected to the computer).
- Drive's view was powered by Virtual Battlespace software (VBS) projected on the projection screen.
- EEG cap with the 10/20 system was used; Fz, Cz, and Pz electrodes were selected for data acquisition; a reference electrode was located near the Fz electrode; A1 and A2 electrodes (ground) were placed on ears.
- Brain Amp recording device synchronized with VBS was used (sampling frequency was set to 1 kHz).

3.3 Experimental Design

The experimental design has to take into account constraints resulting from the ERP technique and the P3 component described in Section 2. Moreover, occurrence of artifacts (which are common in EEG/ERP experiments) is more intensive than in the case of common experiments, due to the natural movements of the testing subject during driving simulation.

Two different stimuli evoking the P3 component were defined:

- Sharp turns. The driver is asked to negotiate these turns in his/her direction without leaving the track.

- Passing an oncoming vehicle. The oncoming vehicle does not keep precisely to its direction. The driver is asked to try and avoid a collision without leaving the track.

The next step included construction of a test track (Figure 1) according to the stimuli presented above. There are eleven sharp turns and four places where oncoming vehicles appear on the test track.

Figure 1: Test track (highlighted in red color), turns (highlighted in yellow color) and passing of oncoming vehicle (highlighted in blue color).

The set of testing subjects comprised of seven males and two females between 23 and 30 years of age. All of them were right handed and had no visual or auditory defects. Only one of them did not have a driver license (however, the subjects had enough time to learn to control the car simulator).

Each testing subject was informed about the experiment's scenario in detail (they knew that sharp turns and oncoming vehicles were the target stimuli in the simulation). They had enough time to get familiar with the test track and the car simulator. After this preliminary phase the main experiment started. The subject completed the test track and simultaneously the EEG/ERP signal was recorded. The same experiment was repeated the next day (to eliminate fatigue), but the subject was affected by alcohol. The level of alcohol in the blood reached approximately 0.5 mills (a certified alcohol tester was used). The testing subject had enough time to become familiar with the test track and the car simulator again. The main experiment was then performed with the same parameters.

4 RESULTS

It is to be supposed that the drivers' attention reaches maximum values at the beginning of the drive, and then decreases during driving. For this reason the first collision with the oncoming vehicle and the fourth sharp left turn were selected for a detailed analysis. The first collision is supposed to invoke the largest P3 amplitude, as the testing subject is not yet accustomed to the collisions.

The collected data were divided into epochs (each epoch starts 200 ms before stimulus onset and ends 1000 ms after stimulus onset). Epochs were preprocessed; the methods of artifacts rejection, baseline correction and filtering (IIR low pass filter with high cutoff set to 40 Hz) were used. The grand average of both groups of testing subjects (affected/

unaffected by alcohol) was computed separately for the first collision and the fourth sharp left turn.

Due to the montage used (the reference electrode is located near the Fz electrode) and the supposed occurrence of the P3 component on the scalp, the Cz and Pz electrodes were selected for the analysis of the P3 component occurrence. The Pz electrode was selected for the presentation of the results. Figure 2 provides the grand average waveform for the Pz electrode and the fourth sharp left turn.

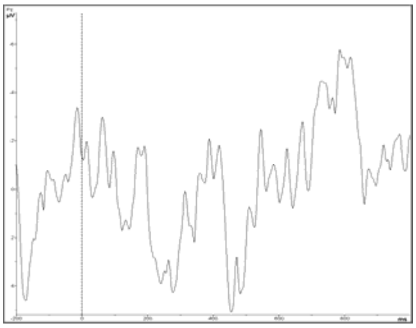

Figure 2: The grand average waveform - the fourth sharp left turn (the Pz electrode, testing subjects are not affected by alcohol).

According to our assumptions the P3 component should be visible in the time range between 300 and 400 ms. However, looking at Figure 2 there is no positive wave similar to a P3 component within the defined time range. Moreover, the averaged signal in the depicted time range (Figure 2) contains several waveforms with a higher frequency. This leads to an idea that the experimental design is too difficult for the use of the ERP technique. The first collision and the fourth sharp left turn were probably not well categorized as target stimuli by the test subjects. This also means that the mental load placed on the test subjects cannot probably be supposed as the same one (or similar) and therefore cannot be easily recognized and interpreted.

Since the P3 component was not recognized in the averaged waveforms, we cannot say anything about the differences in the latency of the P3 component looking at grand average waveforms for the two groups of test subjects (affected/ unaffected by alcohol). However, comparing the grand average waveforms for these two groups, the same trend in the ERP waveforms can be seen. Figures 3 and 4 show this trend for the Pz electrode in the case of the first collision and the fourth sharp left turn consequently.

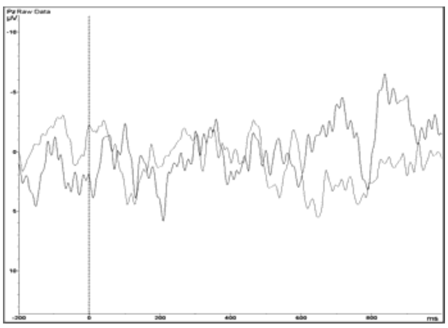

Figure 3: Two grand average waveforms - the first collision with an oncoming vehicle (the Pz electrode; the black line waveform - testing subjects are not affected by alcohol, the red line waveform - testing subjects are affected by alcohol).

The similar results (the P3 component was not detected) were also observed for other collisions and sharp turns. As a consequence, we have proposed a simpler experimental scenario. The target stimuli are no longer a part of virtual world, but are evoked by external hardware devices (blinking diodes or sound generators). The preliminary results of the experiments that we performed using the new experimental design showed that the P3 component was easily observable in the averaged waveforms.

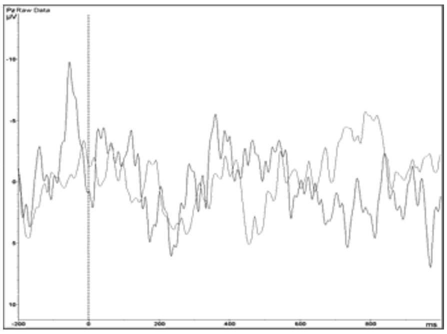

Figure 4: Two grand average waveforms - the fourth sharp left turn (the Pz electrode; the black line waveform - testing subjects are not affected by alcohol, the red line waveform- testing subjects are affected by alcohol).

5 CONCLUSION

In this study we proposed an experimental design for investigating the influence of mental load on drivers' attention. The ERP technique was used to perform experiments on a set of test subjects. The results did not prove the occurrence of the P3 component in the grand average waveforms. We observed a similar trend of the grand average waveforms for two groups of test subjects (affected/ unaffected by alcohol). Since the proposed experiment was most probably too complex, we proposed a new experimental scenario and performed the preliminary experiments, which provided more successful results.

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Control Problems in Electric and Hybrid Vehicles

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ABSTRACT: The new method of vehicle propulsion for hybrid and electric vehicles involves solving new problems with their control, primarily the control of electrical propulsion units. The new approach requires energy management for the hybrid vehicles. Specific control is necessary for battery management. Using electrical batteries in vehicles presents a multidisciplinary problem in cooperation of great amount of batteries and the electrical grid, the control vehicle to grid (V2G) systems.

KEY WORDS: electric vehicles, motor control, energy management, battery management, V2G (vehicle to grid systems).

1 INTRODUCTION

Electric propulsion systems in hybrid and electric vehicles utilize the majority of currently used control systems; on the other hand, it is necessary to use new, and often more sophisticated, methods for control.

- Fundamentally it is necessary to control the velocity and torque of electrical motors.
- Hybrid vehicles (HEV) need energy management systems which switch to the propulsion mode with the best efficiciency. (IC internal combustion engine, electric motor, both engines, recuperation).
- Electric vehicles (EV) need energy management, to distribute energy between the motor and the sources of electrical energy (batteries or hypercapacitors).
- A specific problem is the control of charging (and recharging during recuperation) of chemical batteries. It is necessary to accommodate the charging process to the different properties of the individual elements of a battery and to guarantee reliable functioning of the battery in the case of the malfunctioning of one or several elements.
- An additional adjacent problem for hybrid and electric vehicles (and a very critical one in the near future) is the cooperation of charging devices with electrical grids by means of “smart grids”, or by using “vehicle to grid” (V2G) technology.

2 ELECTRIC MOTOR CONTROL

The method used for motor control depends on the choice of the motor; the choice of the motor depends on the type of electrical vehicle (EV) or a hybrid vehicle (HEV). Having decided on the type of vehicle the appropriate motor may be selected. There are the following types of electric motors suitable for the propulsion of EV, HEV, and PHEV vehicles: the DC motor, the induction motor, the PM (with permanent magnets) synchronous or the PM brushless motor, and the switched reluctance motor.

DC motors have been prominent in electric propulsion due to their torque-speed characteristics suiting traction requirements well, along with their speed controls being simple. They have been used for electric railway traction for a long time. However, DC motor drives have a bulky construction, a small density of power on unit mass, low reliability and a high need for maintenance, due to the commutator and the brushes.

The most popular traction unit for medium and high power is the induction motor. An induction motor is usually controlled through variable frequency (VFD) by means of a pulse width modulation (PWM), created by different types of inverters. Due to the decreasing cost of semiconductor power and control elements, inverted output or multilevel pulse width modulation is used. Using of higher frequencies (and higher voltage) minimizing of the power density of the induction motors. A further advantage is the contactless transmission of energy between the stator and rotor. No maintenance of the commutator and brushes is necessary. On the other hand, control by means of variable frequency rather complicates the design of control loops for velocity and torque control. This means that the motor becomes nonlinear. Due to a different reactance of winding on different frequencies the current in individual coils varies, and, as a result, the magnetic flux and torque vary as well. For this reason it is necessary to control both frequency and voltage simultaneously.

Usually, there are two methods for this simultaneous control. They are called “scalar” or “vector” methods. A standard scalar drive puts out a PWM pattern designed to maintain a constant V/Hz pattern for the motor under ideal conditions. How the motor reacts to that PWM pattern is, to a great extent, dependent upon the load conditions. However, from this point of view, this is feed – forward control without any information on the real output torque of the motor. Problems associated with the scalar VFD’s inability to alter its output according to changes in the load increase as the speed reference decreases.

A vector drive uses the feedback of various variables to further modify the PWM pattern to maintain a more precise control of the desired operating parameter, be it speed or torque. Using a more powerful and faster microprocessor, it uses the feedback information to calculate the exact vector of voltage and frequency to attain the goal. In a true closed loop fashion, it goes on to constantly update that vector to maintain it. It tells the motor what to do, then checks to see if it did it, then changes its command to correct for any error.

The structure of the scalar control of the drive is shown in fig. 1. It is necessary to detect the actual speed with the help of a sensor. We then have direct feedback control of the speed, but the torque is controlled indirectly through the velocity control.

The best independent control of the speed and torque is provided by a complete vector control of the IM according to fig. 2. (Caratolozo & Canseco, 2006). This method needs additional sensors for measuring the stator current. The three components of stator current are transformed into a two phase equivalent and then are transformed into rotating coordinates connected with the vector of rotor magnetic flux. Thus we obtain current carrying information on torque and current carrying information on magnetic flux.

They are used for an independent torque and flux control with torque and flux current regulators. Both currents are transformed to a 3 phase system and with the help of pulse width modulation (PWM) regulate the inverter supplying the motor.

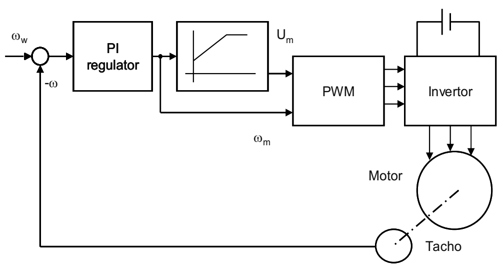

Figure 1: "Scalar" control of induction motor.

Vector control is more effective, and provides excellent dynamic properties for the motor, but is more expensive than a simple scalar control. To avoid the necessity of using the current and position or speed sensors, values of these variables are often estimated from other directly measurable variables with the help of estimation methods, such as observers, Kalman filters, etc.

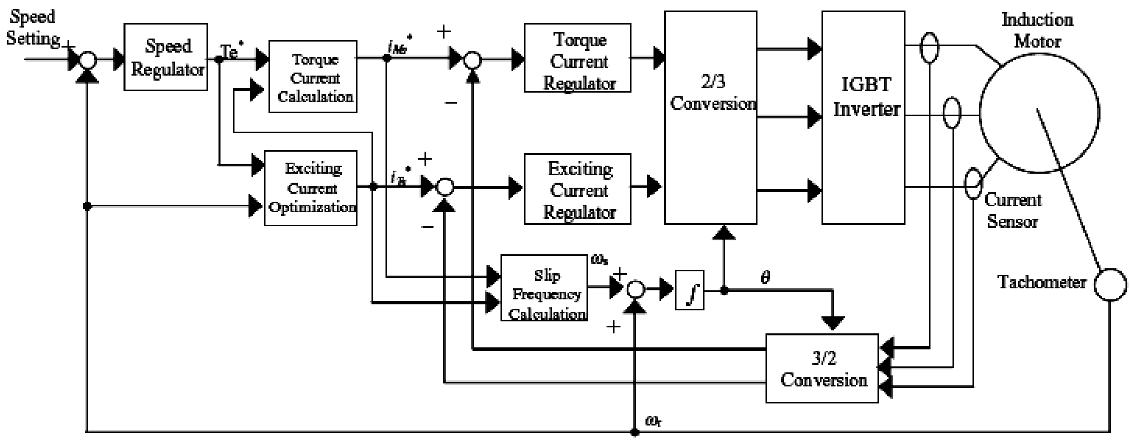

Figure 2: Vector control of induction motor.

Another motor utilized in the HV and EV is a permanent magnet synchronous motor (a brushless synchronous motor). Instead of the cage anchor, a synchronous motor has an anchor with strong permanent magnets. This leads to a rotation with a synchronous speed of a rotating magnetic field. These motors have a number of advantages. Firstly, higher power density, and secondly, better efficiency due to small eddy current loses in comparison with the squirrel-cage rotor, and an efficient dissipation of heat. On the other hand this motor has a short constant power region. However, a synchronous PM motor is the best motor provided that it is directly embedded in the vehicle's wheel. The necessary equipment for its control (the sensors, controllers, and semiconductor actuators) is the same as for the case of the induction motor.

The last type available for EV and HV propulsion is a switched reluctance motor. The reluctance motor is an electric motor in which torque is produced by the tendency of its moveable part to move to a position (due to Thomson's principle of minimum energy) where the inductance of the excited winding is maximized. This means that the reluctance of the magnetic circuit is minimized. The reluctance motor is a type of synchronous machine. It has the wound field coils of a DC motor for its stator windings, but there are no coils or magnets on its rotor. These motors have definite advantages, such as simple and durable construction, fault-tolerant operation, simple control, and outstanding torque–speed characteristics. Its disadvantages are strong acoustic noise, torque and current ripple and specific structure of the actuator, specifically.

Now some remarks on control algorithms. For simple applications, conventional linear regulators, e.g., the PI (PS in digital form) are used. For more sophisticated control problems "bifurcation" can be seen in two main branches. One branch, which can be called "analytic", is based on the correct analytical description of the system (state control, optimal control, robust control, predictive control, etc.).

The second branch, which can be called "rule based", often utilizes simple algorithms which do not need a correct formal mathematical description of the system. These are methods ranging from the simplest lookup table control, through fuzzy control, as far as sophisticated adaptive methods and neural nets control. Ordinarily we can say that the first approach is mainly used within the area of academic research. However, for the real production of EV and HEV, the second approach is mainly utilized, e.g., (Salmasi, 2007; Li & Liu, 2009). This approach is also successfully applied in the design of auxiliary and assistive systems.

3 ENERGY MANAGEMENT

One of the HEV and PHEV specific control problems is energy management. HEV have both an IC engine and electric motor and two or three sources of energy (oil in the tank, and an electric charge in the battery or in the ultracapacitor). One advantage of the HEV is the possibility of combining these sources and drives to obtain the best resultant efficiency. This requires however sophisticated energy management. There are six possible different operation modes in both series and parallel HEV:

1. The battery alone mode: the engine is off; the vehicle is powered by the battery only
2. The engine alone mode: powered by the ICE/G (the engine and the generator)
3. Combined mode: both the ICE/G set and the battery provide power for the traction motor
4. Power split mode: the ICE/G power split to drive the vehicle and charge the battery
5. Stationary charging mode
6. Regenerative braking mode

The control problem is how to distribute power between different sources and different drives to obtain maximal efficiency. Usually we have a set of empirically measured points which allows the construction of approximate efficiency "maps". Examples of efficiency maps for an ICE engine and an electrical motor according to (Schouten et al., 2003) are shown in fig. 3. and fig. 4. The lines in angular velocity and torque coordinates are not torque characteristics, but are contour lines connecting points with the same effectiveness. For ICE the efficiency is indirectly proportional to fuel consumption. The thick line connects the local extremes and the arrows are directed to the global extreme, corresponding to maximum efficiency and minimum fuel consumption. A similar efficiency map can be created for the battery, in coordinates, the state of the battery (SOC) in [%] and power, as is depicted in fig. 6. (The grey area shows the highest efficiency).

Optimal control is difficult to apply because appropriate characteristics are not available in a formal mathematical form. The optimal distribution of power between sources (the ICE engine and electrical motor/generator and energy accumulators (batteries or ultracapacitor) is not merely an optimization problem but a decision problem as well. It is usually possible to formulate simple rules in the form of logical implications.

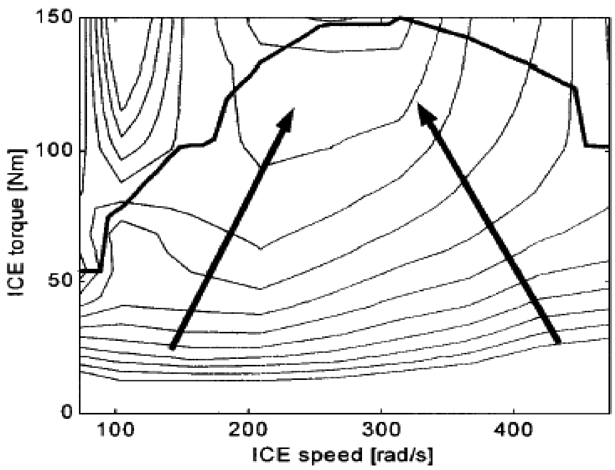

Figure 3: Efficiency map for IC engine.

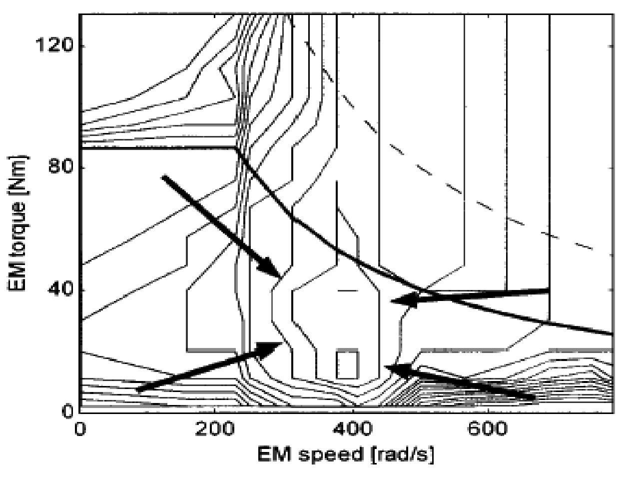

Figure 4: Efficiency map for electrical motor.

These rules may be utilized as a rule base for a fuzzy controller, such as Mamdani's or Sugeno's fuzzy controllers (Li & Liu, 2009; Schouten et al., 2003).

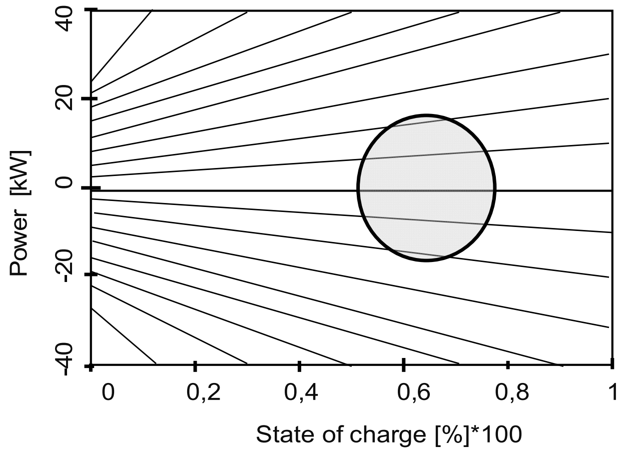

Figure 5: Efficiency map for battery.

4 BATTERY MANAGEMENT

The most expensive part of any EV or HEV is the battery. It is therefore necessary to control the charging and discharging process to attain its maximal service life. This is the main task of the battery management system. However, this system has many other significant functions (Conte, 2006). Any element of a battery is monitored (the charging or discharging current, the voltage and/or the temperature are measured). These data are necessary for a qualified protection from out of tolerance operating conditions. The EV or the full HEV battery usually consists of many serially connected elements in order to reach a higher voltage. The same current flows through all elements during the charging. From this point of view it is necessary to balance the voltage on any element to equalize the charge on all cells in the chain, thus extending the battery life. However, individual elements may have the same tolerances but different source resistance. This leads to different voltage on individual elements and their possible damage. If an element is damaged the balancing system is able to inactivate it (e.g., by shunting) to keep the whole battery in operation.

The state of charge (SOC) and the state of health (SOH) of the whole battery is computed from the measured data and stored. Parameters, such as the number of cycles, the maximum and minimum voltages and temperatures and maximum charging and discharging currents, can be recorded for subsequent evaluation. The fundamental function of the battery management system is control when charging it. The charge control strongly depends on the type of battery. Some types enable quick charging with heavy current, while other types may be damaged by such charging. For these reasons the battery management system must be able to communicate with the charging station or the test equipment.

Communications interfaces are also needed to enable the user the access to the battery for modifying the BMS control parameters or for diagnostics and tests. The structure of the battery management system is in Figure 6.

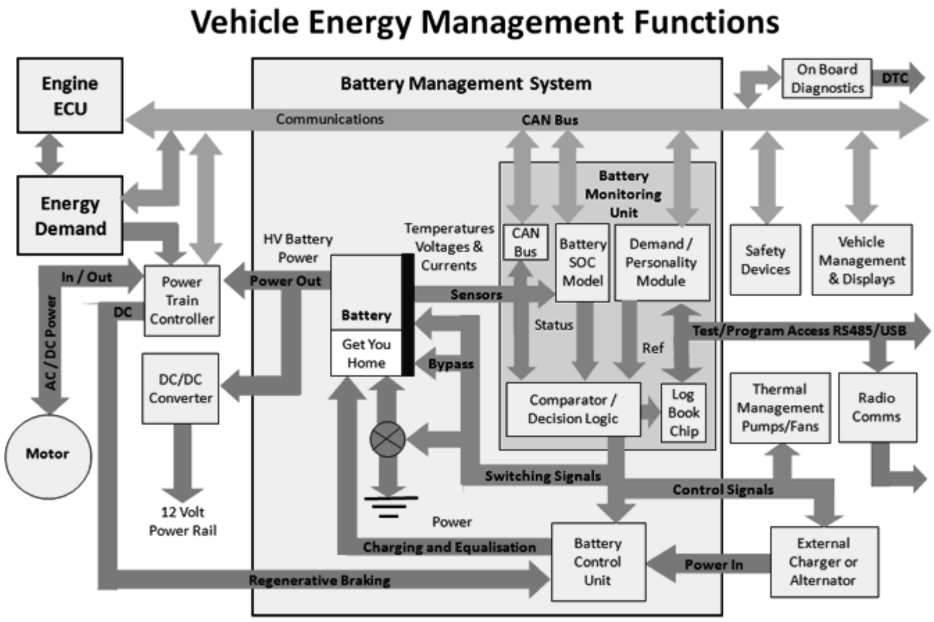

Figure 6: Structure of battery management system.

It seems, when excluding the charging control, that the battery management system is a type of measuring and communicating system. However, for its correct functioning, many control approaches are necessary. For example, the SOH is not directly measurable from the accessible data. It must be estimated from the measured currents, voltages and temperatures. The extended Kalman filters or neural nets are usually used as estimators.

5 VEHICLE TO GRID (V2G TECHNOLOGY)

Sophisticated control for the cooperation of the battery management system with "smart grids" is quite a challenging issue. A growing number of electric and plug-in hybrid vehicles need non negligible electrical power for charging their batteries. At first sight this requires the building of new power plants and a net reconstruction. However, due to sophisticated control and utilizing "smart nets" it is possible to charge them generally with existing power plants and nets, and, moreover, the batteries may also help increase the stability of the existing nets. This idea is called a vehicle-to-grid (V2G) system.

The PHEVs and EVs are mainly used for commuting. A typical or average commuting distance is about 50 km and the average commuting time is 50 minutes. This means that the typical vehicle is idle an average of 22 hours a day. The average commuting distance is smaller than the potential range of theses cars (which is 80–100km) but not all the energy stored in the battery is consumed for commuting. The typical time necessary for charging a battery (at home) is 5h, and usually less.

It follows from this fact that the battery is not utilized by the vehicle for a minimum of 17 hours, and thus can be utilized by another user, such as by a grid system operator.

The storage capability of the battery is from 1 to 60 kWh (from PHV to EV). The battery as a source has a very fast response, in the order of ms. The available power from the battery is in the 0.2–6kW range. On the other hand it is necessary to take into account some limitations. Of critical importance is the state of the charge (SOC) as a percentage of a fully charged battery. The best efficiency of a battery is around of 60%, but there are a lot of further constraints required in the charging – discharging process making the life of the battery longer. Tens of thousands and more aggregated vehicles may have a significant impact. From this follows the necessity to establish a new link between the producer and the consumer of energy, a link called an aggregator. The Aggregator will aggregate the demand of energy (power), for charging the batteries of individual vehicles, and withdraw it from the provider at the appropriate time according to the requirements of the grid operator. In contrast, the aggregated power may be utilized as a prompt power for overlay peaks of energy demand.

For example, let us take into account 12500 aggregated vehicles. Let us consider the capacity of an individual battery as 20kW and with 5h charging. This is a 50MW load, which may be connected in off-peak conditions. The shifting load phase into the night off-peak conditions may be deployed to levelize the load. On the other hand, the aggregated batteries may serve as a source of standby power for the peaks. This power may be connected to the grid in milliseconds. The functioning of the aggregator is depicted in fig. 7. (Guille & Gross, 2009).

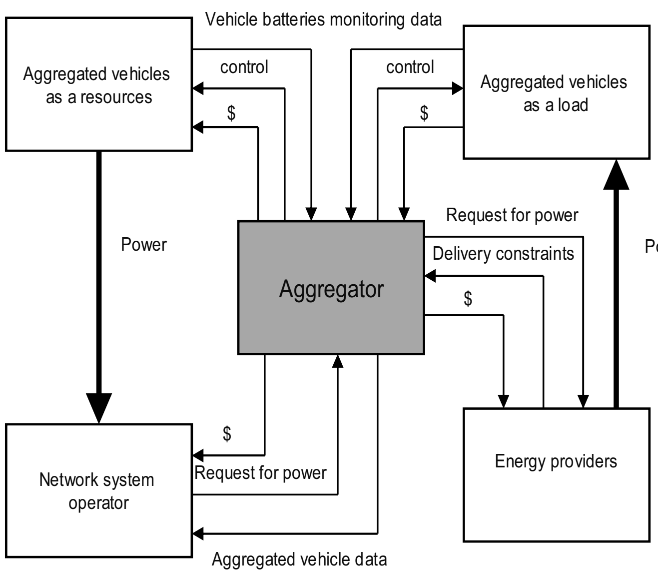

Figure 7: Supposed function of V2G system.

The aggregator is connected through a communication link with the aggregated vehicles. Any vehicle is capable of operating as a consumer or source of electrical energy. The individual batteries are monitored and the aggregator obtains information on the state of charge and other parameters of any battery. The Aggregator is capable of switching the vehicle into a charging phase or discharging phase. Any owner of the vehicle has an individual agreement with the aggregator specifying the conditions of charging and discharging the battery. The aggregator is connected with the electrical energy provider and negotiates with him about the time and the amount of energy delivered to the individual vehicles according to the provider's possibilities. The aggregator is also connected with the grid operator, optionally informs on the state of the stored energy and, on the operator's request, is also capable of providing peak power from batteries if necessary.

The information and energy (power) flows are accompanied by money flows. Prices of energy strongly depend on the time of day and on the origin of the energy (primary energy from a power plant or stored energy from batteries). Any battery owner pays to the aggregator for energy delivered to the battery. The aggregator pays for all delivered energy to the provider. On the other hand, the aggregator pays to the individual owners of cars for the stored energy utilized during peak hours, and obtains money for this service from the grid system operator. The approach described above seems to be a very attractive method of energy management. It enables more efficient exploitation of conventional and especially nuclear power plants. It also may solve many problems with renewable sources of energy, such as photovoltaic energy and wind turbines. However, V2G technology is at present a mere concept. It is a very complicated C3S (Computer, Communication and Control system) and it will need great effort in order to realize it in practice.

6 CONCLUSION

The main control problems connected with the utilization of electric and hybrid vehicles are discussed in the paper. Propulsion control by means of electric motors is solvable through common methods. A similar situation can be seen more or less in energy management and battery management. However, the cooperation of vehicle batteries with electrical grids is a great challenge for the near future. V2G systems need a multidisciplinary approach in order to utilize the possibility of controlling the distribution of electrical power from current sources.

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Hybrid Two-stroke Motor Drive

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ABSTRACT: The article describes the implemented and tested K.E.R.S. (Kinetic Energy Recuperation System) system. The system uses braking energy to charge the operative source of energy. The captured energy is used to enhance energy for the subsequent acceleration of the combustion engine.

KEY WORDS: KERS system, supercapacitor, additional torque.

1 INTRODUCTION - TECHNOLOGY, PRODUCT OR SERVICE DESCRIPTION

The project aims to develop a braking energy recuperation system. It is possible to use this system with single-track vehicles (especially scooters, race bikes) and small two-track vehicles with a combustion engine of up to 50 kW of power or greater with necessary modifications.

Our goal is to develop a driving unit consisting of a conventional combustion engine and a braking energy recuperation system. This will allow lower levels of both emissions and combustion engine fuel consumption in the acceleration phase or outside the optimal engine working band, and also better engine efficiency dynamics.

The technical side of the solution focuses on improving the combustion engine acceleration which is provided by an additional synchronous electromotor with electronic commutation, alternator, and controlled supercapacitors with charging and discharging based on the requirements of the operator or system itself.

The combustion engine is connected to a synchronous electromotor and a generator. The three-stage generator feeds its output into the three phase synchronous rectifier. The rectified voltage from the rectifier is sent through a controlled disconnector into the supercapacitors. The generated voltage can also be used for supplying the electronic equipment of the vehicle with power and for recharging the battery instead of the alternator used in existing models.

The supercapacitors´ energy is brought to a controlled regulator of the three-stage engine. The regulator sends its output into a three-stage driving synchronous electromotor with electronic commutation. The disconnector and regulator are controlled electronically.

After switching on the supercapacitors are flat. After starting the combustion engine the generator connects and the supercapacitors are charged. The regulator then initializes and the generator is disconnected. While the vehicle decelerates, electric power recharging the supercapacitors is being generated. The controlled disconnector is in the "connected" mode. After having charged the supercapacitors the controlled disconnector enters the "disconnected" mode and the generator provides only the power required by the electric circuits of the vehicle. While accelerating, the synchronous electromotor is being spun via the regulator, helping with the acceleration. After having used all the supercapacitors' energy, the electromotor turns off. Charging of the supercapacitors can also be forced by the operator, regardless of the deceleration.

The additional power supplied by the electric driving unit can amount to 15 kW (this being 30% of the power of the considered combustion engine). This power is limited due to our laboratory equipment and the limited financial resources we have invested in the project. We have a working prototype offering 4 kW of power.

For this reason we focus on small combustion engines with power up to 50 kW. With the power of the electromotor up to 15 kW this system allows the running of the combustion engine within the range of the best power/weight/consumption/emissions ratio. This also goes for modes in which conventional engines are the worst – i.e., acceleration. We saw a significant drop in fuel consumption in acceleration modes while making use of the kinetic energy of the vehicle, which is normally wasted during braking.

2 WORKING PROTOTYPE DESCRIPTION

We test the device on a city scooter with an engine capacity of 125 ccm (further on referred to as the 'motorcycle' and motoGP 125 ccm from a KTM). The combustion engine is directly connected to a generator and to a synchronous motor through a toothed belt. The motorcycle also features supercapacitors and an electronic controlling system.

While braking the generator connects to the supercapacitors and recharges them. While accelerating the electromotor connects to the combustion engine and adds its power to it. The amount of the additional power depends on the type of electromotor, regulator, and super-capacitors, and the current needs.

While driving, the following signals are fed into the controlling unit:

- braking system pressure,
- throttle valve position,
- current gear,
- revolutions of the combustion engine,
- supercapacitors' voltage,
- recharging current flowing from the generator to the supercapacitors,

- discharging current flowing from the supercapacitors to the electromotor,
- switch of the forced recharging of the supercapacitors,
- required power mode.

The electronics of the controlling system offers:

- recording for all the parameters in the internal memory for later post-processing,
- information of the recharged level of the supercapacitors,
- predicted time of acceleration,
- predicted time of recharging of the supercapacitors to a specified level in %.

The amount of energy passed from the supercapacitors to the electromotor depends on the throttle valve position, increase of the combustion engine revolutions, the current gear and the supercapacitors' voltage.

The amount of energy passed from the generator to the supercapacitors depends on the braking system pressure, throttle valve position, combustion engine revolutions, the super-capacitors' voltage and the supercapacitors' maximum recharging current and actual track condition.

Figure 1: Mechanical realization of the power unit with supercapacitors.

3 PRODUCT DEVELOPMENT PLAN, INCLUDING RISK ANALYSIS

After completing the product the aim is its mass production. Our goal is not to produce it on our own - we want to license the product to producers of small-capacity vehicles and motorcycles. At the moment, we must do the following:

- to finish the product line of 5 – 15 kW of power (there is a working prototype of 4 kW of power). 15 kW is the technological upper limit that we want to test – this being due to financial and technical reasons,
- to test it in real life (install it in existing vehicles, motorcycles, and scooters) and to test the lifespan (various wind conditions, various modes of operation, etc.),
- to finish the intellectual property protection by patent protection and a utility model,
- to establish partnerships and to commercialise the product,
- thanks to its small size, low weight, and compact design, we also consider direct selling of the product to those interested in adding the recuperation feature to their existing vehicles.

4 PARTNERSHIPS VITAL TO THE SUCCESS OF THE PROJECT

The product is very interesting for producers of small-capacity vehicles and motorcycles. In order to get to know the market and the technological possibilities of potential producers better, we contacted a well-established European motorcycle producer (we don’t disclose the name, this cooperation being confidential at this point) with whom we have cooperated on previous development projects. Additionally, we talked to the representatives of the formula 1 HONDA RACING, Williams, and BMW team who showed a serious interest in our knowledge in this field (before it back out from F1) for new Formula BMW. The main reason for this being that the FEDERATION INTERNATIONALE DE L'AUTOMOBILE (FIA) requires all formula 1 cars to have an energy recuperation system. They confirmed the development direction suggested by us as correct and the only way to get a lightweight and efficient device is through our design. For this reason we added the goal of higher engine-power limits to our originally environmentally friendly concept. This should improve the dynamic features of sport motorcycles and vehicles.

Due to the ongoing patent proceedings concerning the main idea, the negotiations with potential partners is at very early stages. We need to finish the patent protection worldwide, finish another type of working prototype, and prove the efficiency of our solution to the potential partners through gauging and testing. Unfortunately, that is where we are running low on resources at the moment.

5 TARGET MARKET DESCRIPTION, INCLUDING SIMPLE FINANCIAL ESTIMATIONS

Mass production is critical – the current prototype price being € 3000 (over USD 4000). Mass production will make lowering the price to about € 300-400 (USD 400-550) possible. For a price of about € 600 (over USD 800) the capital returns after about 50,000 km (only from fuel savings calculations based on the European prices of fuel); additionally it is possible to use engines with a smaller capacity and the same dynamics, saving more with newer vehicles (thus motivating buyers to purchase our product). We assessed the market using data for EU markets (specifically the ACEA (European Automobile Manufacturers Association - www.acea.be), statistical data, and the Eurostat statistical office (www.europa.eu/eurostat)*.

In the year 2006 there were 15,819,022 personal vehicles † registered in EU 25. Due to its power, our product is only suitable for small vehicles, which are typically used in the city. Nevertheless, this segment is rather strong – it comprises of up to about one third of the total number of cars, and is getting stronger and stronger ‡.

Even when a very low estimate of sales of 100,000 units§ at € 500 with a profit margin of € 200 the gross income is € 20 million (about USD 28 million). Based on our calculations, this gross income is sufficient to cover our development and commercialization costs.

Greater selling opportunities (but with smaller profit margin) can also be expected due to the pressure of the European Commission on lowering the CO_2 emissions to the level of 130g of CO_2/km by 2012. ACEA claims the price per car will increase by up to € 2500 on average, we offer a much cheaper solution, at least for small-capacity vehicles.

There is also a demand in the USA and other countries where car transportation is highly concentrated and puts pressure on the environment. The segment of small-capacity vehicles, suitable for fitting our product to, is not so strong outside the EU.**

Another target market is the market of motorcycles – here we also base our calculations on EU 25 data (and here the sales potential is also worldwide; we base our calculation in the EU region only due to data availability). There are more than 1,200,000 motorcycles registered in EU 25 (the total number in use in the EU is over 16,000,000) – and since we are able to produce a recuperation unit of various sizes and power, we can also saturate this market. The pressure of meeting strict emission limits is similar to that in the car industry. The planned production of 100,000 units is a sales estimate on the low side.

The theoretical potential of sales and estimates of financial indicators are very rough with regard to the contemporary situation of the development, but, even so, the potential of our product is very interesting.

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* Relevant statistics available at: http://epp.eurostat.ec.europa.eu/portal/page?_pageid=0,1136228,0_45572945&_dad=portal&_schema=PORTAL

† The number of registrations in 1996-2007 is increasing, in 2003 it reached a total of 15,000,000

‡ Data for 2003 available only for 9 EU countries (Estonia, Greece, France, Hungary, Lithuania, Austria, Poland, Finland, United Kingdom) mention 1,936,920 vehicles within 1400 cm3 out of total 6,048,584 newly registered. About one third of newly registered vehicles can use our product directly in contemporary power range (within 15 kW of electromotor power).

§ The yearly production only of TCPA in CR, producing small vehicles suitable for using our product, amounts to more than 300,000 units.

** With increasing pressure on lowering the greenhouse gas emissions, this segment will probably grow as well – such tendencies to lower the impact of vehicle use on the environment can be seen in California, New York City, and other American centers.

6 NECESSARY RESOURCES BOTH IN THE SHORT- AND LONG TERM

Estimated resources (Low mean estimate):

- Finishing - USD 250,000 (wages, technology, material).
- Testing - USD 280,000 (testing vehicles, installation - work + material, testing).
- Patent protection – 10,000 USD (worldwide).
- Commercialisation – at least USD 20-50,000, considering only legal and consultation advice, the commercialisation itself would be financially aided by our partners. No direct commercialization costs are included (start of production 200,000-500,000 USD).

7 ESTIMATED REDUCTION OF GREENHOUSE GASES AND ITS IMPACT ON SUSTAINABLE DEVELOPMENT

Up to 20-25 per cent lower fuel consumption, together with reducing the transitional modes of combustion engines, will lead to a significant reduction in emissions. The reduction is most significant while driving in the city (gas-brake driving style), where our product can provide acceleration for up to about 20 sec[*]. Based on our gauging, this is sufficient capacity for real-life driving.

In comparison with existing hybrid products, our solution is much more environmentally-friendly, due to the components used – it does not contain batteries and other components that are difficult to recycle. The savings are based on making use of braking energy, which is otherwise wasted in the form of heat energy. The product itself is very small and compact (the weight is approx. 6 kg with 4kW of power), which also reduces the energy necessary for the production, making the energy requirements, with regards to the lifespan of the product, rather low. It can replace the currently used alternator and reduce the weight and complexity of the vehicle.

It also allows the use of smaller-capacity engines (less than 1 liter), while keeping the dynamics of a small urban vehicle.

The compact design also allows for fitting the product into existing vehicles, and for increasing the possibilities of hybrid drive use and lowering greenhouse gas emissions.[†]

[*] The amount of decrease in emissions can be estimated based on the fuel consumption savings – but, as mentioned above, this depends on the style of driving.

[†] Based on current fuel prices, this solution is reasonable for modified vehicles for driving more than 30-60,000 km.

8 TECHNOLOGY, PRODUCT OR SERVICE DESCRIPTION KTM – KERS

Our goal is to develop a driving unit consisting of a conventional combustion engine and a braking energy recuperation system. This will allow lower levels of both emissions and combustion engine fuel consumption in the acceleration phase, and also better engine efficiency dynamics.

The technical side of the solution focuses on improving the combustion engine acceleration, which is provided by an additional synchronous electromotor with electronic commutation, alternator and controlled supercapacitor with charging and discharging based on the requirements of the operator.

The combustion engine is connected to a synchronous electromotor and a generator. The three-stage generator feeds its output into the rectifier. The rectified voltage from the rectifier is sent through a controlled disconnector into the supercapacitors. The generated voltage can also be used for supplying the electronic equipment of the vehicle with power and for recharging the battery instead of the alternator used in existing models.

The super-capacitors´ energy is brought to a controlled regulator of the three-stage engine. The regulator sends its output into a three-stage driving synchronous electromotor with electronic commutation. The disconnector and regulator are controlled electronically.

After switching on the super-capacitors are flat. After starting of the combustion engine the generator connects and the super-capacitors are being charged. Then the regulator initializes and the generator is disconnected. While the vehicle decelerates, electric power recharging the super-capacitors is being generated. The controlled disconnector is in the "connected" mode. After having charged the super-capacitors the controlled disconnector enters the "disconnected" mode and the generator provides only the power required by the electric circuits of the vehicle. While accelerating, the synchronous electromotor is being spun via the regulator, helping with the acceleration. After having used all the super-capacitors' energy the electromotor turns off. Charging of the super-capacitors can be forced also by the operator regardless of the deceleration.

9 OUR ACQUIRED EXPERIENCES AND PROBLEMS SOLVED DURING THE PROJECT KERS- MOTO GP 125CCM KTM

During our development we worked step by step on each part. These parts are summarized on the next table.

The results are as follows:

- We made a calculation of all available accumulative sources of the energy (Li-On, Li-Pol, Li-FePo, super-capacitors, flywheel), their advantages and disadvantages. We had to solve the cooling system for the motor and generator.
- Our system is fully autonomous with ABS, AHS, kerbs protection).
- The whole system was tested for two years with approximately 12.000 km.

- Low budget (paid from private money).

Component name	**No. of modification**
Propulsive motor	8 types
Generator	10 types
Converter	4 types
Regulator	3 types
ECU	3 types
SW	6 versions
Implementation (build-up area)	3 types
Component name	**No. of modification**
Placing super-capacitors (centre of gravity)	4 positions

CONCLUSION

According to our experience and calculations achieving a better time per lap is possible, and, at the same time, the system is cheaper. This device can be called a "real recuperation unit", with smaller additional power which can be added during all possible moments at one lap. We can document this statement through calculations and simulations and through real-world results from Jerez.

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Vehicle Energy Management System

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ABSTRACT: The paper deals with power management systems in a vehicle comprising of an internal combustion engine which is connected via a gearbox with a clutch and transmission to a main generator of electricity. The battery and supercapacitors, as the central independent power source, are connected via the control module and via a bidirectional communication bus to the vehicle state evaluation unit. Both modes charging and discharging of the battery and supercapacitors together with alternator control is the most affected by the evaluation unit.

KEY WORDS: intelligent power system, operational energy storage - supercapacitor, automotive onboard network, control unit, vehicle energy management system.

1 INTRODUCTION

The arrangement of the Vehicle Energy Management System (V.E.M.S.) consists of a traditional combustion engine connected through a transmission mechanism plus clutch and a transmission mechanism to the main generator connected (through the first power lead) to the first converter, which is further connected (through the fifth power lead) to the sixth voltage converter (which is further connected to the energy storage through the sixth power lead) and to a bi-directional voltage converter. It is then connected through the seventh power lead – onboard network – to an accumulator, while its control module is connected (through a bi-directional communication bus) to a signal-converting unit, which is connected (through a communication bus) to a vehicle state evaluation unit included in the control module. Vehicle inputs are connected to both the evaluation unit and the signal-converting unit, to which a bi-directional bus and outputs are connected. The essence of the system is in its connection (through the third converter and the fifth power lead) to an auxiliary generator interconnected with this third converter through the third power lead, while the auxiliary generator is mechanically interconnected with a turbine inserted in the turbocharger's bypass, or with a turbine inserted into the exhaust pipe of the combustion engine.

2 TECHNOLOGY AREA

V.E.M.S. separates the combustion engine from providing the power for the supply of electric appliances and minimalizes the required power for the air-conditioning. This is achieved through the Electronic Intelligent Alternator, together with the Electronic Air-Conditioning, Supercapacitors, and sets of uni/bi-directional rectifiers. It also deals with the method of V.E.M.S. management, which can be described as being a hierarchical state machine with which the vehicle enters different states, illustrated in the form of different state diagrams.

3 CURRENT TECHNOLOGY STATE

Nowadays a maximum amount of attention is paid to complying with emission limits (the amount of CO_2 produced per kilometer driven) in developing new cars. Emission reduction can be achieved through design modifications in the combustion engine itself, by reducing the vehicle weight, and by reducing the electricity consumption for times when the engine runs outside its optimum revolution range. Contrary to this trend, however, are the ever-growing requirements of the onboard electricity network. Ever-richer car features (automatic air-conditioning, heated seats, heated windscreen and side mirrors, power-steering boosts, safety systems, etc.) significantly increase the electricity consumption. Modern vehicles are equipped with high-efficiency (up to 80%) alternators and use two electricity distribution networks? with different voltages (12V / 24V / 48V). The transition to a higher voltage brings with it a number of benefits arising from the reduced weights of power harness and components (starter, alternator, pumps). Unfortunately, these modifications do not eliminate the high electricity drain from the alternator during moving off after engine starting, during vehicle acceleration, or during steady driving. Electricity is currently produced only by transforming the fuel's chemical energy into mechanical energy by means of combustion within an engine, and this is further transformed into electrical energy by means of an alternator. The power taken from the engine by the alternator manifests itself in the engine's increased nominal consumption and in the amount of CO_2 produced, which is directly related to it. This can be partly solved by combining a combustion engine and an electric motor, i.e., by "hybrid propulsion". Even vehicles with hybrid propulsion, however, struggle with two limiting factors: 1. the battery – a structural element with a slow charging cycle, great weight and great volume, and 2. the weight of the whole system (around 200 kg). Thanks to these factors, such vehicles are economical when operated with frequent and long decelerations (i.e., driven in cities), but have a great disadvantage when operated on motorways, where they feature increased consumption due to the higher vehicle weight and due to the battery being charged mainly from the combustion engine (from petrol). A complete solution of the exhalation and consumption problems is provided by electric cars. Their utilization, however, is limited by battery technologies. Due to their weight, means of charging, price, and environmental impact, today's batteries cannot provide a technical solution with parameters comparable to conventional propulsion.

Apart from deceleration, exhaust gas is another energy source in combustion engine vehicles. Current vehicles do not fully utilize the energy contained in the exhaust gas. The only currently utilized energy is a small portion used for propelling the turbocharger compressing the air in the suction pipeline in turbo vehicles. The remaining large amount of energy is released through the exhaust pipe into the atmosphere.

4 ESSENCE OF THE INVENTION

The objective of the invention is to propose a new arrangement of the vehicle energy management system (V.E.M.S.), as well as a method for its control to reduce the fuel consumption and thus the CO_2 emissions produced. The vehicle's electrical management combines and controls the following mechanical/electrical vehicle components: the turbocharger or turbo compressor connected to the combustion engine, to which an actuator (motor generator) is connected, as well as an intelligent alternator (described in the patent application No. PV (286-2009), the main electric motor (booster), electronic air-conditioning and an electricity storage (super-capacitors or batteries).

The above weaknesses are eliminated by arranging the V.E.M.S. consisting of a combustion engine connected through a transmission mechanism plus clutch and a transmission mechanism to the main generator connected (through the first power lead) to the first converter, which is further connected (through the fifth power lead) to the sixth voltage converter (which is further connected to the energy storage through the sixth power lead) and to a bi-directional voltage converter. Then it is connected through the seventh power lead – onboard network – to an accumulator, while its control module is connected (through a bi-directional communication bus) to a signal-converting unit, which is connected (through a communication bus) to a vehicle state evaluation unit included in the control module. Vehicle inputs are connected to both the evaluation unit and the signal-converting unit, to which a bi-directional bus and outputs are connected. The essence of the system is its connection (through the third converter and the fifth power lead) to an auxiliary generator interconnected with this third converter through the third power lead, while the auxiliary generator is mechanically interconnected with a turbine inserted into the turbocharger's bypass or with a turbine inserted into the exhaust pipe of the combustion engine.

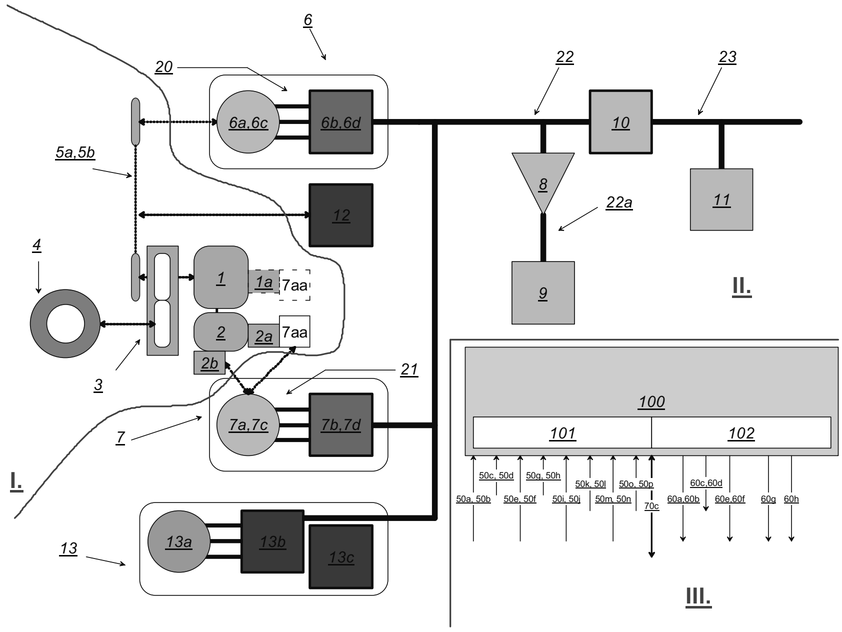
To reduce the combustion engine consumption, it is beneficial if the fifth converter is connected to the fifth power lead and further interconnected with an electric motor, which is mechanically connected to the compressor of the air-conditioning unit.

To improve the combustion engine's acceleration and to reduce its emissions while in transition modes, it is beneficial to have the main electric motor connected to the fifth power lead through the second converter, and further connected to the combustion engine through a transmission mechanism and a transmission mechanism plus clutch.

To reduce the combustion engine fuel consumption and its emissions, it is beneficial to have the main electric motor connected to the fifth power lead through the second converter, and further connected to the combustion engine through a transmission mechanism and a transmission mechanism plus clutch.

To reduce weight and to simplify insertion of a motor and a generator into the engine compartment, it is beneficial if the main electric motor forms an integral part of the main generator and the second converter forms an integral part of the first converter.

To improve the turbocharger's dynamics, it is beneficial if the auxiliary electric motor is connected through the fifth power lead and the fourth converter, and further connected to this fourth converter through the forth power lead and mechanically connected to the turbocharger shaft.



Legend of Reference Points

I – Mechanical part,
II – Electrical part,
III – Control system,
1 – Combustion engine,
1a – exhaust system,
2 – combustion engine's turbocharger,
2a – bypass for turbocharger's exhaust gas (waste gate),
2b – turbocharger's shaft,
3 – Transmission mechanism+clutch,
4 – Driven axle,
5a – Rpm-changing transmission (for generator),
5b – Rpm-changing transmission (for electric motor),
6 – Set – motor-generator (actuator),
6a – Main generator,
6b – First converter (isolating switch),
6c – Main electric motor,
6d – Second converter (controller),
7 – Set – turbo-engine-generator,
7a – Auxiliary generator,
7aa - Turbine
7b – Third converter (isolating switch),
7c – Auxiliary electric motor,
7d – Fourth converter (controller),
8 – Sixth converter (isolating switch for energy storage),
9 – Energy storage (super-capacitors or batteries),
10 – Bi-directional voltage converter or two single-directional voltage converters,
11 – Onboard accumulator,
12 – Adjusting mechanism of rpm-changing transmission,
13 – Set – electronic air-conditioning,
13a – Third electric motor for air-conditioning compressor
13b – Fifth converter (controller),
13c – Controlling electronics for electronic air-conditioning
20 – Power lead to main motor-generator (main generator, booster),
20a – First three-phase power lead (generator / converter),
20b – Second three-phase power lead (converter / electric motor),
21 – Power lead to auxiliary motor-generator (turbocharger),
21a – Third three-phase power lead (generator / converter),
21b – Fourth three-phase power lead (converter / electric motor),
22 – Fifth power lead,
22a – Sixth power lead,
23 – Seventh power lead – onboard network,

50 – Inputs
50a – battery voltage 11,
50b – current to/from battery 11,
50c – voltage of super-capacitors 9,
50b – current to/from super-capacitors 9,
50e –generator rpm 6a,
50f – revolutions of rpm-changing transmission at connection with transmission mechanism+clutch (nodes 5 and 3),
50g – rpm of combustion engine 1,
50h – rpm of turbocharger 2,
50i – combustion engine 1 temperature,
50j – gas throttle valve/pedal position,
50k – braking system pressure or braking pedal position,
50l – clutch pedal state
50m – input for forced energy accumulation from motor-generator 6 (electronic brake),
50n – currently engaged gear,
50o – switching on the vehicle starter,
50p – ambient temperature,
50q – onboard network 23 off-take,

60 – Outputs
60a – control signal for first converter (isolating switch) 6b,
60b – control signal for second converter (controller) 6d,
60c – control signal for third converter (isolating switch) 7b,
60d – control signal for fourth converter (controller) 7d,
60e – control signal for fifth converter (controller) 13b,
60f – control signal for sixth converter (isolating switch) 8,
60g – control signal for bi-directional converter 10,
60h –position control 12,
70 – communication and diagnostic buses (CAN, RS485, RS232 or others),
70a – bi-directional communication bus (intermodular 100 – 101),
70b – communication bus (intermodular 101 – 102),
70c – bi-directional communication bus (CAN, RS485, RS232 or others),
100 – Control module (unit),
101 – Signal-converting unit 100,
102 – Vehicle state evaluation unit 100.

Figure 1: Schematic diagram of the V.E.M.S.

To reduce the combustion engine fuel consumption, it is beneficial if the auxiliary electric motor is connected through the fifth power lead and the fourth controller, and further connected to this fourth converter through the forth power lead and mechanically connected to the turbocharger shaft.

To reduce weight and to simplify the insertion of a motor and a generator into the engine compartment, it is beneficial if the auxiliary electric motor forms an integral part of the auxiliary generator and the fourth converter forms an integral part of the third converter.To increase the efficiency of the control module structure, it is recommended that the vehicle state evaluating unit and the signal-converting unit are integrated into it.

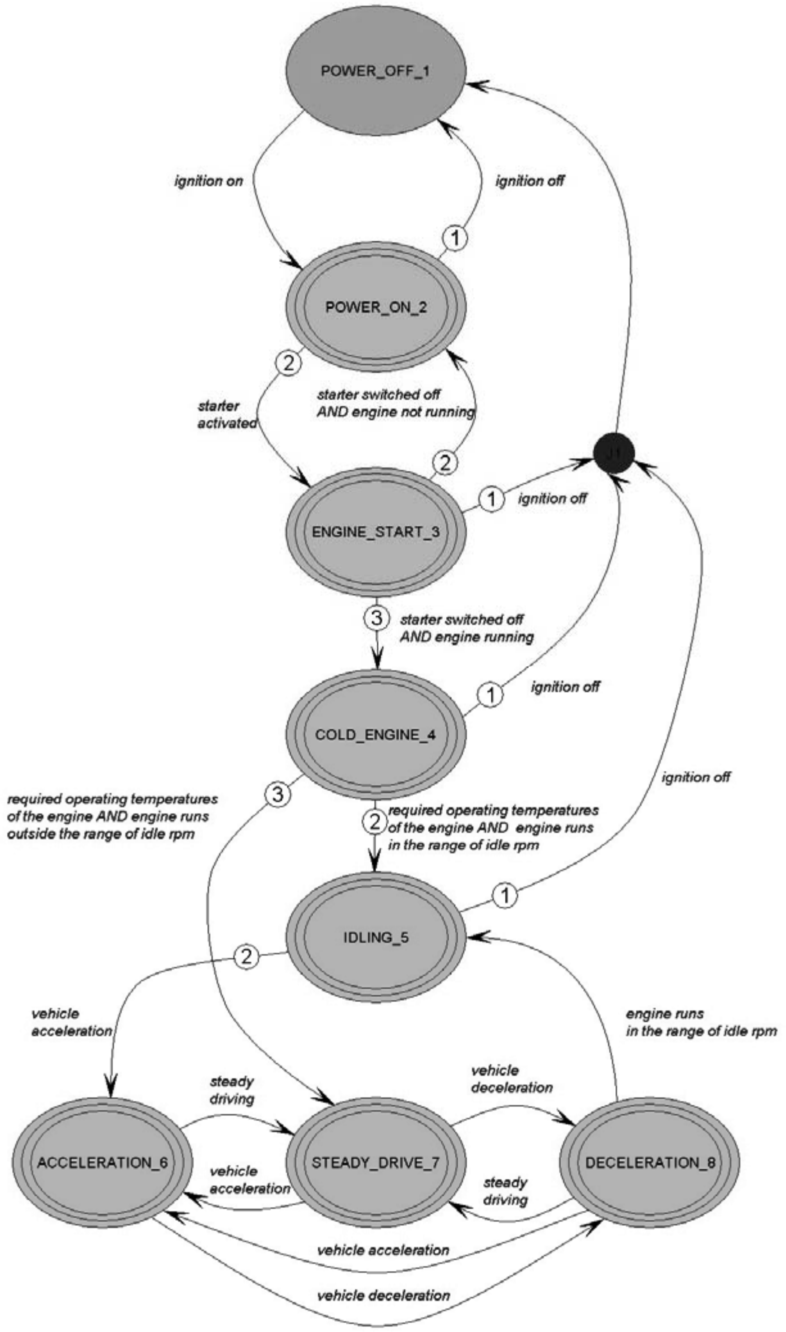


Figure 2: State diagram of the V.E.M.S.

It is beneficial for the V.E.M.S: control if the control module is connected through a communication bus to the signal-converting unit, the outputs of which are connected to different blocks within the arrangement. The signal-converting unit is further wired to the vehicle state evaluation unit through a communication interface, while vehicle inputs are connected to the vehicle state evaluation unit and to the signal-converting unit, to which a bi-directional bus is conveniently connected.

To simplify the implementation of the control algorithms in the V.E.M.S. control module, it is beneficial if the vehicle state evaluation unit has output 1 connected to the input of the first voltage converter, output 2 to the input of the third voltage converter, output 3 to the input of the sixth converter (at the electricity storage), output 4 to the input of the bi-directional voltage converter, output 5 to the input of the module setting the correct rpm ratio of the transmission mechanism, and output 6 to the input of the fifth converter (at the electronic air-conditioning). The signal-converting unit should have its inputs 1 and 2 connected to the accumulator outputs, inputs 3 and 4 to outputs of the electricity storage (super-capacitors or batteries, for example), input 5 to the main generator's rpm sensor, input 6 to the rpm sensor of the rpm-changing transmission mechanism installed at the link to the transmission mechanism plus clutch. Input 7 should be connected to the combustion engine's rpm sensor, input 8 to the turbocharger's rpm sensor, input 9 to the engine's temperature sensor, input 10 to the accelerator pedal position sensor, input 11 to the pressure sensor of the vehicle's braking system, input 12 to the clutch pedal position sensor, input 13 to the input of the forced accumulation of the energy from the motor-generator, input 14 to the gear sensor, input 15 to the starter switch sensor, input 16 to the ambient temperature sensor, and input 17 to the onboard network off-take sensor. To make system diagnostics possible, the control module is also connected to the vehicle control unit through a communication/diagnostic bus (this connection is not shown in diagrams).

The key is the arrangement of the V.E.M.S., which better utilizes the energy in the vehicle as a whole. Thanks to gaining energy from the exhaust gas and from deceleration, and to its logical distribution between the electronic air-conditioning, main electric motor (booster), auxiliary electric motor (for faster turbocharger start-up) and the onboard network power supply, significant reductions in fuel consumption, as well as CO_2 emissions, are achieved at the current weight of the system below 25 kg. The main philosophy of the V.E.M.S. is to use the combustion engine only for driving the vehicle, while all the vehicle's peripherals would be powered by electricity generated from other sources. This is associated with: "electronic air-conditioning", i.e., an air-conditioning unit driven by an electric motor powered by electricity generated from alternative sources (deceleration and exhaust gas), not by the combustion engine, as is currently common (with an increase in fuel consumption when the air-conditioning is in operation). This is an important component of the whole system significantly reducing both the fuel consumption and CO_2 emissions.

Apart from the re-use of the energy from braking, the use of energy contained in the exhaust gas is another path towards reductions in consumption and CO_2 emissions. Exhaust gas contains between 50% and 80% of the energy produced by the combustion engine, which is currently not fully utilized, but rather released into the atmosphere. In combustion engines equipped with a turbocharger, the solution proposes using the residual energy contained in the exhaust gas for electricity generation, or applying a turbocharger in the combustion engine's exhaust pipe – used solely for electricity generation.

The essence of the controlling method of the V.E.M.S. is in the fact that the control module 100 is in the *POWER_OFF_1* initial state, in which all components are off. This eliminates discharging the energy storage 9 by the accumulator 11 or by active appliances of the onboard network 23 when the ignition is off. The system then switches from the *POWER_OFF_1* state to *POWER_ON_2* provided the condition of the ignition being on is fulfilled. The system remains in this state unless one of the two possible conditions is met – with the following priority:

- Ignition switched off, the system returns to the initial *POWER_OFF_1* state.
- Starter activated, the system goes to the *ENGINE_START_3* state.

In the *POWER_ON_2* state, the system charges the energy storage 9 with electric current acceptable for the current state of accumulator 11. It then goes from the *POWER_ON_2* state to *ENGINE_START_3* provided that storage 9 is charged and the starter activated. If the accumulator 11 voltage drops to below the acceptable limit, or the ignition is switched off during the process of storage 9 charging, the system goes to the *POWER_OFF_1*.

In the *ENGINE_START_3* state, the system arranges controlled starter powering from the electricity storage 9 or from the accumulator 11. The *ENGINE_START_3* state is terminated if one of three conditions is met – in the following priority order:

- Ignition switched off, the system returns to the initial *POWER_OFF_1* state.
- Starter switched off and engine not running, the system returns to the *POWER_ON_2* state.
- Starter switched off and engine running, the system goes to the *COLD_ENGINE_4* state.

Controlled connecting and disconnecting of the electricity storage 9 takes place while in the *COLD_ENGINE_4* state. This state is terminated under the following conditions:

- Ignition switched off, the system returns to the initial *POWER_OFF_1* state.

The required operating temperatures of the engine 1 and other necessary components affecting engine 1 operation:

- are reached. If the engine runs in the range of idle rpm, the control goes tothe *IDLING_5* state.
- The required operating temperatures of the engine 1 and other necessary components affecting engine 1 operation are reached. If the engine runs outside the range of idle rpm, the control goes to the *STEADY_DRIVE_7* state.

In the *IDLING_5* state, the system controls the electronic air-conditioning 13 and the main electric motor 6c. The electronic air-conditioning 13 management takes place with respect to minimizing the combustion engine 1 load, however, provided that the condition of maintaining the set temperature in the vehicle is met. The main electric motor is controlled in such a way as to minimize mechanical losses.

The idling state is terminated by:

- Ignition switching off, the system returns to the initial *POWER_OFF_1* state.
- Vehicle acceleration, when the system goes to the *ACCELERATION_6* state.

In the *ACCELERATION_6* state, the system operates the electronic air-conditioning 13, the auxiliary generator 7a, the auxiliary electric motor 7c, the main generator 6a and the main electric motor 6c in such a way as to utilize the energy previously accumulated in the storage

9 and the accumulator 11 as much as possible, as well as to accelerate the vehicle by means of the main electric motor 6c and to increase the combustion engine dynamics by means of the auxiliary electric motor 7c.

The acceleration state is terminated by:

- The vehicle settling into steady driving, the system returns to the *STEADY_DRIVE_7* state.
- Vehicle deceleration, when the system goes to the *DECELERATION_8* state.

In the *STEADY_DRIVE_7* state, the system controls the electronic air-conditioning 13, the auxiliary generator 7a and the main generator 6a in such a way as to fulfill the operator's requirements on the pre-set temperature and to guarantee the minimum off-take of electricity generated in the auxiliary generator 7a and the main generator 6a and accumulated in the electricity storage 9 and the accumulator 11.

The steady driving state is terminated by:

- Vehicle acceleration, when the system goes to the *ACCELERATION_6* state.
- Vehicle deceleration, when the system goes to the *DECELERATION_8* state.

In the *DECELERATION_8* state, the system controls the electronic air-conditioning 13, the auxiliary generator 7a and the main generator 6a in such a way as to provide the maximum possible utilization of the braking energy for the electronic air-conditioning 13, for charging firstly the electricity storage 9 and the onboard accumulator 11.

The deceleration state is terminated by:

- The vehicle settling into steady driving, the system returns to the *STEADY_DRIVE_7* state.
- Vehicle acceleration, when the system goes to the *ACCELERATION_6* state.

CONCLUSION

The invention is further clarified in diagrams, where Fig. 1 represents a block diagram of V.E.M.S. and its connection to the combustion engine in the basic arrangement, and Fig. 2 represents the state diagram of its behavior. This is the result of long-term collaboration between academic laboratories (university departments) and an innovative company specializing in the manufacture of internal combustion engines.

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Technical Notes on Project of the Database of Czech Transportation

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ABSTRACT: A centralized database of transport data is missing in the Czech Republic. This paper points to an example of the budget of the State Fund for Transport Infrastructure that is necessary to create such a database of data which impacts the economy of the whole system and to gradually convince state institutions, regions, municipalities, transporters and other involved parties to support this project with their opinions and provided data.

KEY WORDS: Database, transport, State Fund for Transport Infrastructure, Czech Republic

1 INTRODUCTION

The problems of the economy have been increasing pressure on the economic efficiency not only in the transport sector. Its infrastructure is one of the domains with a large difference between needs and possibilities, which is true not only of the Czech Republic. The ministers of transport have been trying to make conceptions, ("Super") strategies and transport policies determining the direction for and goals of transport development, but these documents lack the definitions of basic parameters and indicators of the transport system, describing the actual state of the quality of railway tracks, roads, bridges, crossings, stops, etc.), and it is primarily very laborious to get the relevant time series showing development trends. The total conceptions are unfortunately vague and so it is difficult to plan the resources.

2 SFDI BUDGET IN FOCUS

The expenses of the State Fund for Transport Infrastructure (SFDI) dramatically decreased year-on-year. This brought about negative effects in the lower benefits from European subventions and also negatively influenced the economy of building companies. Not only through lower revenues, but also the lower use of contracted or purchased production capacities, which will result in the level of calculated prices of construction works. The question is whether state savings will have the desired effect. The cutbacks of the SFDI expenses negatively influences the unit prices of construction works and the economy of building companies and also state tax revenues (VAT, income tax, etc.) It is necessary to know the total amount and also the structure of the expenses of the SFDI. This structure shows that the national revenues account for approximately only one third of total revenue from which "uncertain" sums, such as state subsidies, dividends, and privatisation revenues, also account for approximately one third of the total budget.

For finding the respective trends one can use, for example, the SFDI yearbooks, but the problem is the data for the revenue structure (divided according to foreign and domestic sources or according to the particular categories) and the expense structure (divided according to the type of transport infrastructure, according to investor organisation or according to the character of the expense on the investment, repair, (winter) maintenance, according to the regions etc.). These data are, of course, available, but the possibility of their acquisition and analysis can be complicated for the users (professionals, schools, clerks, and media) from both a time and factual viewpoint.

Economic data such as infrastructure expenses are important, but so are the technical parameters of the transport network (e.g., the network length) and not only the quantitative, but also the qualitative factors. For instance, bridge constructions are assessed on a scale from 1 to 7 (7 being the worst). The transport policy should be based on economic calculations, using both quantitative and qualitative factors. The authors feel there is a lack in the state transport planning of such an approach with clear and verifiable goals.

3 ABSENCE OF A CENTRALIZED TRANSPORT INFRASTRUCTURE DATABASE

In the Department of Economics and Management of the Transport and Telecommunications of the Faculty of Transportation Sciences of the Czech Technical University in Prague we try to give the students an idea of the economic laws in transportation and we are conscious of the aforementioned facts (the unavailability of relevant data and the lack of a systematic use of efficient indicators) in everyday teaching, especially when seeking some statistical data connected with the topics being taught. We therefore decided to create a database of indicators that influence the economy of the whole system, and that we will try to convince state institutions, regions, municipalities, carriers, and other subjects to support this project through use of their data and opinions.

Our goal is to enable users online access to a database of a series containing data now available at various institutions (the Ministry of Transport, SFDI, Road and Motorway Directorate, Railway Infrastructure Administration, the Czech Statistical Office, the Police, Regional administrations, ČESMAD BOHEMIA-the association of road transport operators, etc.) and to enable a simple data export in both table and graphical form. This database could help with the discussion of indicators that should lead in the long run to a conceptual and stabilized situation in transport, and to long term efficient transport infrastructure funding.

4 CONCLUSION

The intention for the creation of an online database of transport has been in existence in the Faculty of Transportation Sciences of the Czech Technical University for many years, and, since last year, it has gained more actual contours thanks to the students of the faculty, the enterprise Capsa.cz, and the support of the Ministry of Transport of the Czech Republic. The aim is to create on the web an interactive environment that would easily enable access to all the main transport relevant time series, as well as to display and to analyse them. It would enable managing organisations to analyse system development trends, and to simplify their decision making.

AKNOWLEDGMENT

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CONTENTS