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# The comparison of traction properties of UTV sport-recreational vehicle with combustion engine drive and conceptual electric drive

***Streszczenie.*** *Poniższy artykuł przedstawia porównanie właściwości trakcyjnych pojazdu sportowo-rekreacyjnego UTV-ATV z zamontowanym fabrycznie silnikiem spalinowym wraz z koncepcyjnym napędem elektrycznym opracowanym specjalnie do tego typu pojazdów. Dodatkowo w artykule została przedstawiona krótka charakterystyka silnika elektrycznego oraz zalety napędu elektrycznego.*

***Abstract****. This article provides a comparison of traction properties of sport-recreational UTV-ATV vehicle with factory-mounted combustion engine and conceptual electric motor drive designed specifically for this type of vehicle. In addition, the article presents a brief description of an electric motor and the advantages of an electric drive.* ***(Porównanie właściwości trakcyjnych pojazdu sportowo-rekreacyjnego UTV o napędzie spalinowym z koncepcyjnym napędem elektrycznym).***

**Słowa kluczowe**: UTV, magnesy trwałe, właściwości trakcyjne, napęd elektryczny.
**Keywords**: UTV, permanent magnets, traction properties, electric drive.

## Introduction

Research and Development Centre of Electric Machines *"Komel"* is concerned with widely understood electric drives' issues, including their designing and constructing. In the following article motor properties of UTV sport-recreational vehicle and conceptual electric motor with permanent magnets were presented and compared with traditional combustion engine drive.

Using motion theory and on the basis of calculations performed, the charts for both sources were prepared: traction, which showed the change of the driving force in wheels as vehicle speed function and charts with acceleration, which showed the capabilities of vehicle acceleration on individual ratios as vehicle speed function at full engine power.

## The description of the vehicle and the advantages of PA132S4SMws electric motor assembly

UTV-ATV sport-recreational vehicle was produced abroad with originally mounted combustion engine with a capacity of 350cm$^3$ and maximum power 8kW and rotation speed 4750 rpm.

UTV (Utility Terrain Vehicle) (Fig. 7) or ATV (all-terrain vehicle) (Fig. 1) are vehicles with similar construction to quad bikes but with huge loading box (UTV). UTV vehicles can carry heavy object, so they are ideal for the usage in agriculture and forestry. The innovation to use electric driver in these types of vehicles is highly recommended as they can be helpful in reducing pollution and noise in places like forests and fields.

Fig.1. ATV sport-recreational vehicle

Electric motor with permanent magnets of alternative current (Fig. 2) will be directly coupled with the gear shaft of UTV-ATV vehicle, which eliminates belt transmission that generates additional costs and losses that can occur because of such solutions. The whole is supposed to be powered by lithium-ion batteries without the memory effect of capacity 7 kWh. The convertion of direct current to alternative current of adjustable frequency will take place through inverter, where finally the engine will be powered by voltage of 81V AC.

The electric motor cooled by liquid will be mounted to assembly plate, which will be screwed to the already existing in the transmission of UTV holes. This solution lets for an easy and non-invasive assembly and disassembly without the necessity for frame and other original sub-assemblies of UTV vehicle modification. The engine-transmission connection will be appropriately protected against different types of pollution.

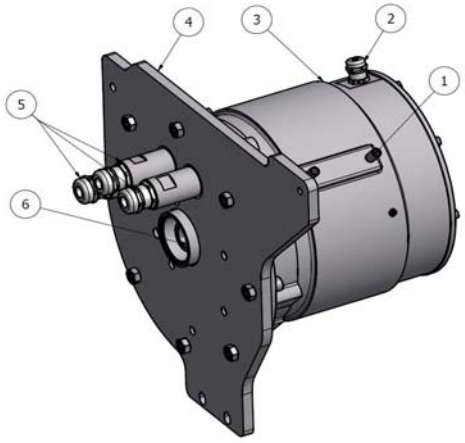


Fig.2. Conceptual model of electric engine with permanent magnets
1 - water jacket, 2 - enkoder cable gland, 3 - machine body, 4 - assembly plate, 5 - power supply cable glands, 6 - seal sleeve

## Specifications of UTV-ATV sport-recreational vehicle for electric motor and combustion engine

The best description of motion properties of the vehicle can be shown graphically on traction charts:

- Vehicle's capabilities to overcome road resistance and to develop specific speed for motion established for individual ratios,
- The possible accelerations on individual ratios as speed function.

Essential specifications of vehicles used for traction calculations are presented below. In table 1 chosen power and torque values taken from the performance graph of electric engine were placed. In table 2 power and torque values of combustion engine were put.

Weight (with a driver +75kg): m = 573kg
The tyres AT 25x10-12: $r_d$ = 0,3m
Butting face: A = 1,33m$^2$
Aerodynamic resistance coefficient: $C_x$= 0,7
The efficiency of the power transmission system: $\eta_m$ = 0,9
Specifications of electric motor:
Max. power: $P_{max}$ = 27kW at 4200 rpm
Max. torque: $T_{max}$ = 80Nm at 200 rpm
Ratios of electric engine:
Ratio High: $i_{cH}$ = 10,75
Ratio Low: $i_{cL}$ = 27
Specifications of combustion engine:
Max. power: $P_{max}$ = 8kW at 4750 rpm
Max. torque: $T_{max}$ = 16Nm at 4250 rpm
Ratios of combustion engine:
Ratio High min: $i_{cHmin}$ = 37,2
Ratio Low min: $i_{cLmin}$ = 76,12
Ratio High max: $i_{cHmax}$ = 14,53
Ratio Low max: $i_{cLmax}$ = 29,75

Table 1. The power and torque of electric motor

| **n [rpm]** | **200** | **600** | **1000** | **1800** |
|---|---|---|---|---|
| P [W] | 1687,8 | 5053, | 8404,1 | 15054,1 |
| T [N·m] | 80,6 | 80,4 | 80,3 | 79,9 |
| **n [rpm]** | **2600** | **3400** | **4200** | **5000** |
| P [W] | 21631,1 | 26618,15 | 27103,4 | 26842,1 |
| T [N·m] | 79,5 | 74,8 | 61,6 | 51,3 |
| **n [rpm]** | **5800** | **6600** | **7400** | **7800** |
| P [W] | 26285,7 | 25472,7 | 24527,6 | 23969,7 |
| T [N·m] | 43,3 | 36,9 | 31,7 | 29,3 |

Table 2. The power and torque of combustion engine

| **n [rpm]** | **2500** | **2750** | **3000** | **3250** |
|---|---|---|---|---|
| P [W] | 4000 | 4370 | 4800 | 5300 |
| T [N·m] | 15,3 | 15,2 | 15,3 | 15,6 |
| **n [rpm]** | **3500** | **3750** | **4000** | **4250** |
| P [W] | 5670 | 6100 | 6670 | 7140 |
| T [N·m] | 15,5 | 15,5 | 15,9 | 16 |
| **n [rpm]** | **4500** | **4750** | **5000** | **5250** |
| P [W] | 7450 | 8030 | 7820 | 7540 |
| T [N·m] | 15,8 | 16,1 | 14,9 | 13,7 |

**The calculations' results for electric motor collected in tables**

Traction chart (Fig. 3) shows the change of wheels driving force as vehicle speed function. Driving force which has an effect on driving wheel of the vehicle depends on the value of engine torque, the ratios and mechanical efficiency of the power transmission system. Driving force will change similarly as the combustion engine torque is also changing, which results from its performance.

Table 3. The driving force as vehicle speed function – electric motor

| **n [rpm]** | | **200** | **600** | **1000** | **1800** |
|---|---|---|---|---|---|
| T [N·m] | | 80,6 | 80,4 | 80,3 | 80,1 |
| Ratio H | $F_{nH}$ [N] | 2599,4 | 2592,9 | 2589,7 | 2583,2 |
| | $V_H$[km/h] | 2,1 | 6,3 | 10,5 | 14,7 |
| Ratio L | $F_{nL}$ [N] | 6528,6 | 6512,4 | 6504,3 | 6488,1 |
| | $V_L$[km/h] | 0,8 | 2,5 | 4,2 | 5,9 |
| **n [rpm]** | | **2600** | **3400** | **4200** | **5000** |
| T [N·m] | | 79,5 | 74,8 | 61,6 | 51,3 |
| Ratio H | $F_{nH}$ [N] | 2563,9 | 2412,3 | 1986,6 | 1654,4 |
| | $V_H$[km/h] | 27,4 | 35,8 | 44,2 | 52,7 |
| Ratio L | $F_{nL}$ [N] | 6439,5 | 6058,8 | 4989,6 | 4155,3 |
| | $V_L$[km/h] | 10,9 | 14,3 | 17,6 | 21 |
| **n [rpm]** | | **5800** | **6600** | **7400** | **7800** |
| T [N·m] | | 43,3 | 36,9 | 31,7 | 29,3 |
| Ratio H | $F_{nH}$ [N] | 1396,4 | 1190 | 1022,3 | 944,9 |
| | $V_H$[km/h] | 61,1 | 69,5 | 77,9 | 82,1 |
| Ratio L | $F_{nL}$ [N] | 3507,3 | 2988,9 | 2567,7 | 2373,3 |
| | $V_L$[km/h] | 24,3 | 27,7 | 31 | 32,7 |

$F_{nH,L}$[N] – driving force, V[km/h] – vehicle speed

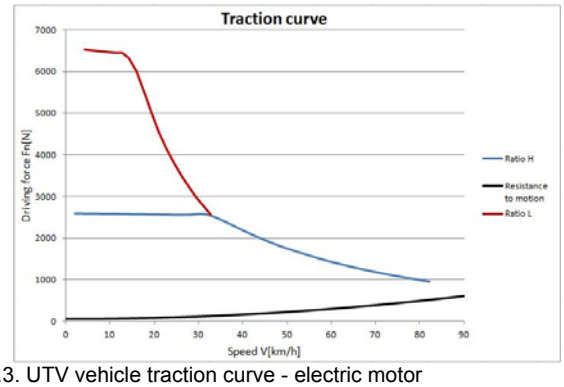


Fig.3. UTV vehicle traction curve - electric motor

Traction curve (Fig. 4) presents the course of acceleration of the vehicle at different transmission ratios (High and Low) as vehicle speed function at full engine power. Calculations were made on the basis of table 4.

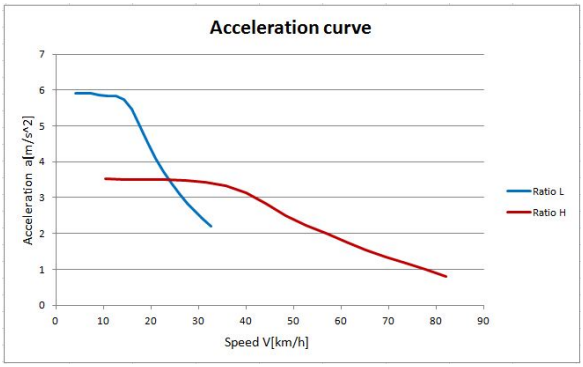


Fig.4. UTV vehicle acceleration curve – electric motor

Table 4. Acceleration values - electric motor

| **n [rpm]** | | **200** | **600** | **1000** | **1800** |
|---|---|---|---|---|---|
| T [N·m] | | 80,6 | 80,4 | 80,3 | 79,9 |
| Ratio H | $F_{nH}$ [N] | 2599,4 | 2592,9 | 2589,7 | 2576,9 |
| | $V_H$[km/h] | 2,1 | 6,3 | 10,5 | 19 |
| | $a_H$[m/s$^2$] | 3,6 | 3,5 | 3,5 | 3,5 |
| Ratio L | $F_{nL}$ [N] | 6528,6 | 6512,4 | 6504,3 | 6471,9 |
| | $V_L$[km/h] | 0,8 | 2,5 | 4,2 | 7,5 |
| | $a_L$[m/s$^2$] | 5,9 | 5,9 | 5,9 | 5,9 |
| **n [rpm]** | | **2600** | **3400** | **4200** | **5000** |
| T [N·m] | | 79,5 | 74,8 | 61,6 | 51,3 |
| Ratio H | $F_{nH}$ [N] | 2563,9 | 2412,3 | 1986,6 | 1654,4 |
| | $V_H$[km/h] | 27,4 | 35,8 | 44,2 | 52,7 |
| | $a_H$[m/s$^2$] | 3,4 | 3,2 | 2,5 | 2 |
| Ratio L | $F_{nL}$ [N] | 6439,5 | 6058,8 | 4989,6 | 4155,3 |
| | $V_L$[km/h] | 10,9 | 14,3 | 17,6 | 21 |
| | $a_L$[m/s$^2$] | 5,8 | 5,5 | 4,5 | 3,7 |
| **n [rpm]** | | **5800** | **6600** | **7400** | **7800** |
| T [N·m] | | 43,3 | 36,9 | 31,7 | 29,3 |
| Ratio H | $F_{nH}$ [N] | 1396,4 | 1190 | 1022,3 | 944,9 |
| | $V_H$[km/h] | 61,1 | 69,5 | 77,9 | 82,1 |
| | $a_H$[m/s$^2$] | 1,5 | 1,2 | 0,8 | 0,6 |
| Ratio L | $F_{nL}$ [N] | 3507,3 | 2988,9 | 2567,7 | 2373,3 |
| | $V_L$[km/h] | 24,3 | 27,7 | 31 | 32,7 |
| | $a_L$[m/s$^2$] | 3,1 | 2,6 | 2,2 | 2 |

**The calculations results for combustion engine collected in tables**

Table 5 as in the case of an electric motor (table 3) shows the change in driving force on the wheels as a function of vehicle speed at various ratios.

Table 5. The driving force as vehicle speed function - combustion engine

| **n [rpm]** | | **2500** | **2750** | **3000** | **3250** |
|---|---|---|---|---|---|
| T [N·m] | | 15,3 | 15,2 | 15,3 | 15,6 |
| Ratio $H_{max}$ | $F_{nH}$ [N] | 666,9 | 662,6 | 666,9 | 680 |
| | $V_H$[km/h] | 19,5 | 21,4 | 23,4 | 25,3 |
| Ratio $L_{max}$ | $F_{nL}$ [N] | 1366 | 1357,1 | 1366 | 1392,8 |
| | $V_L$[km/h] | 9,5 | 10,5 | 11,4 | 12,4 |

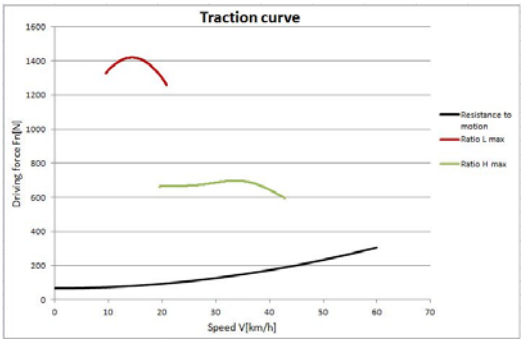


Fig.5. UTV vehicle traction curve - combustion engine

Table 6 contains the calculations needed to draw a graph of acceleration (Fig. 6) on the High and Low ratios as a function of speed at full engine power.

Table 6. Acceleration values - combustion engine

| **n [rpm]** | | **2500** | **2750** | **3000** | **3250** |
|---|---|---|---|---|---|
| T [N·m] | | 15,3 | 15,2 | 15,3 | 15,6 |
| Ratio $H_{max}$ | $F_{nH}$ [N] | 666,9 | 662,6 | 666,9 | 680 |
| | $V_H$[km/h] | 19,5 | 21,4 | 23,4 | 25,3 |
| | $a_H$[m/s$^2$] | 2,1 | 2,1 | 2,1 | 2,2 |
| Ratio $L_{max}$ | $F_{nL}$ [N] | 1366 | 1357,1 | 1366 | 1392,8 |
| | $V_L$[km/h] | 9,5 | 10,5 | 11,4 | 12,4 |
| | $a_L$[m/s$^2$] | 2,9 | 2,8 | 2,9 | 2,9 |
| **n [rpm]** | | **3500** | **3750** | **4000** | **4250** |
| T [N·m] | | 15,5 | 15,5 | 15,9 | 16 |
| Ratio $H_{mx}$ | $F_{nH}$ [N] | 675,6 | 675,6 | 693,1 | 697,4 |
| | $V_H$[km/h] | 27,3 | 29,2 | 31,2 | 33,1 |
| | $a_H$[m/s$^2$] | 2,1 | 2,1 | 2,2 | 2,2 |
| Ratio $L_{max}$ | $F_{nL}$ [N] | 1383,8 | 1383,8 | 1419,6 | 1428,5 |
| | $V_L$[km/h] | 13,3 | 14,3 | 15,2 | 16,2 |
| | $a_L$[m/s$^2$] | 2,9 | 2,9 | 3 | 2,9 |
| **n [rpm]** | | **4500** | **4750** | **5000** | **5250** |
| T [N·m] | | 15,8 | 16,1 | 14,9 | 13,7 |
| Ratio $H_{max}$ | $F_{nH}$ [N] | 688,7 | 701,8 | 649,5 | 597,2 |
| | $V_H$[km/h] | 35,1 | 37 | 39 | 40,9 |
| | $a_H$[m/s$^2$] | 2,2 | 2,2 | 2 | 1,9 |
| Ratio $L_{max}$ | $F_{nL}$ [N] | 1410,6 | 1437,4 | 1330,3 | 1223,1 |
| | $V_L$[km/h] | 17,1 | 18,1 | 19 | 20 |
| | $a_L$[m/s$^2$] | 3 | 3 | 2,8 | 2,6 |

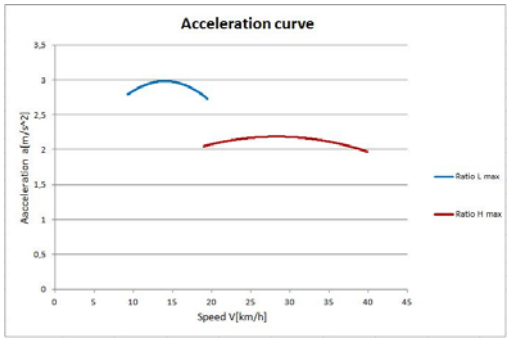


Fig.6. UTV vehicle acceleration curve - combustion engine

The traction and acceleration graphs for an internal combustion engine present the High and Low ratios of maximum belt transmission ratio. $High_{max}$, $Low_{max}$ transmissions and $High_{min}$, $Low_{min}$ ratios result from the application of additional variable transmission (CVT-Continously Variable Transmission) in the case of a vehicle with a combustion engine. The operation of the continuously variable transmission is based on the change of diameters, on which the belt or chain that connects the two gear shafts is rolled. This change occurs, for example, as a result of separating or moving closer of each pair of conical rollers that create the variable diameter "pulley" which allows for a belt wedge and the power transmission.

Unfortunately, in the case of such transmission adequate cooling should be provided and materials that are durable and can prevent getting dirt into the transmission (for example sand) used. This can be an emergency and it can entail high costs of repairs, which are avoided in the case of electric drive, where the motor is coupled directly to the High-Low transmission.

Fig.7. UTV sport-recreational vehicle

## Conclusion

As a result of calculations based on technical data of Vehicle UTV Sports and Recreation and the characteristics of the electric motor and combustion engine above charts were prepared. While analyzing the results of the calculations it can be stated that the vehicle with electric motor is better when it comes to the traction properties than the internal combustion engine vehicle.

Maximum speed of vehicle with electric motor with a total weight on Low ratio is about 32 km / h, while at High ratio it is about 80 km / h and it is limited by the maximum rotational speed of the electric motor. The acceleration of the vehicle with a total weight of the various ratios are: Low-ratio maximum acceleration of about 5.9 m/s$^2$ and falls within the range of from 200 to 3000 rpm for High ratio is approximately 3.4 m/s$^2$ in the same range of rotation. In the case where the vehicle is fitted with internal combustion engine maximum vehicle speed at $Low_{max}$ ratio is 20 km / h, and at the $High_{max}$ ratio is about 40 km / h. The acceleration of the vehicle in ratio $Low_{max}$ is 3 m/s$^2$ and the ratio $High_{max}$ 2.2 m/s$^2$.

The chart shows that a vehicle equipped with a conceptual electric drive has much better traction properties, because of power source which is an electric motor. It provides us with several times more torque almost from zero speed and is available in its wide range. Thanks to this, the vehicle with such a drive is not only quiet and clean, but offers incomparable traction properties while compared to the combustion engine. In addition, by proper control we can freely control the torque or engine speed to suit it to the individual demand.

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