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Electromechanical Transmission Equipped with Switched Reluctance Electrical Machines

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Abstract: Electromechanical transmission is used in a number of vehicles to transfer power from the internal combustion engine to wheels. The given article considers the electromechanical transmission equipped with switched reluctance electric machines. It has been produced the transmission prototype and performed the tests demonstrating transmission efficiency equal to 88.7%.

Key words: Switched reluctance machines, test bench, efficiency, electromechanical, transfer power

INTRODUCTION

Many countries have already come into effect the tighten standards on vehicle exhaust emission which caused to struggle for improving of vehicle fuel efficiency. Thus, for instance, in the USA the fuel standards for heavy vehicles have been in operation starting from 2014 and it will reduce specific fuel consumption by 10, 15 or 20% depending on the vehicle type. In addition, Germany has introduced "Toll Collect" system, the missions of which are to improve heavy vehicle efficiency and to unload the road traffic, transferring the part of the loads to railway and water cargo transport.

Some countries have taken action directed to more efficient fuel consumption by heavy vehicles. One of these countries is Finland which concluded the agreement with transport companies. Moreover, Spain and Ireland have applied the training and retraining program for commercial drivers. The energy efficient ways of vehicle driving can save up to 8-12 % of fuel for passenger cars drivers and about 4 %-for truck and bus drivers (NEEAP-3, 2014).

The level of energy efficiency is the product characteristic reflecting its energy efficiency, as a rule, it is the efficiency in nominal mode. The efficiency is defined as a ratio of output power to input power under the nominal values of output power, supply voltage and frequency supply in percentage terms.

Considering the vehicle we can say that energy efficiency can be achieved by different ways: to set "cruise control" Autopilot mode, to apply a fuel efficient internal combustion engine, to use hybrid energy storage unit, to apply electrical power transmission with high efficiency. The electrical transmission efficiency is mainly defined by the following factors: generator and motor efficiency, power converters efficiency, control modes of generator, motor and electrical power transmission as a whole.

Electrical motors are the main electrical energy consumers. About 40 and% of all generated energy is consumed by electrical motors used in industry (IEC 60034-30, 2008), for this reason the development of energy efficient electrical motors and converters, as well as their implementation as a part of electrical power transmission, is an important task. The total potential of energy saving due to electric drive improvement can reach 30- 60% (IEC 60034-30, 2008).

In 2008, International Electrotechnical Commission published the new world efficiency standard for motors operating at frequency 50 and 60 Hz, the high level of efficiency is "Super-Premium" (IEC 60034-30, 2008). This level was designed for marketing development as well as for development of more efficient motors. At the same time it was noticed that in order to reach "Super-Premium" class the manufacturers of motors probably will have to go beyond the technologies of AC asynchronous motors.

At the present time it is available the new types of electrical motors such as motors with permanent magnets, switched reluctance motors which are capable to reach higher level of efficiency than asynchronous motors. One of the most advanced types of electrical machines is switched reluctance motors and generators. The given

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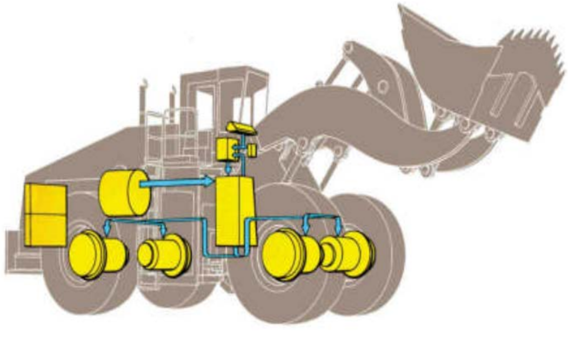

Fig. 1: Electrical power transmission of loader L1350

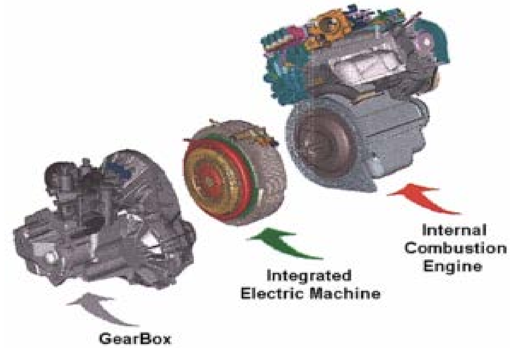

Fig. 2: Hybrid electric power unit

Fig. 3: The functional scheme of electromechanical transmission

electrical machines are equipped with passive toothed rotor of high mechanical strength which removes restrictions for mechanical torque transmission, typical for conventional electrical machines. They have the properties of electromagnetic reduction as well as have the simple design of stator winding with lumped coils. In addition, the presented electrical machines have the high efficiency in the wide range of rotation frequency and loads due to the lack of windings at the rotor and at the same time their converters have a simple topology design. All these properties allow us to predict the possibility of designing the system of Electrical Power Transmission (EPT) with improved traction-energy and operational characteristics.

The AC-AC electrical power transmission with non-conventional electrical machines is the new one in the transport technology. Despite the fact that the pilot projects at the vehicles equipped with switched reluctance machines have shown that this area is the area of potential possibilities for improvement of traction-energy, performance and economic characteristics, there is a certain skepticism with regard to these systems which constrains considerably the development of advanced models.

LeTourneau Inc company (LeTourneau Inc, 2016), located in Texas, used the inductor drive technology for mining loaders 50 series. The wheel loader L1350 is the first of its kind which equipped with switched reluctance motors ensuring the independent rotation of each wheel. The loader height is about 6 m, the length is <16 m, the weight is 180 and lifting capacity is 38 ton. The electrical power transmission (Fig. 1) consists of four motors with 300 kW for independent drive of each wheel (LeTourneauInc, 2016). Each motor is controlled by the central controller. The electrical transmission replacement made it possible to increase the servicing period up to 20000 h instead of 500 h in case of commutator motors application. After successful testing LeTourneau Inc company has designed a line of mining loaders (Le Tourneau Inc, 2016). Moreover, automobile companies are taking interest in switched reluctance machines. Nidec SR Drives in cooperation with Volvo, Fiat and other partners have developed hybrid electrical power unit (Fig. 2) (Drives, 2016). The switched reluctance motor-generator with new dual clutch was integrated between motor and gearbox to ensure the excess torque under acceleration and regenerative braking, thereby improving the fuel saving. However it is required to us the motor-generator having the high specific capacity at the minimum space for active material.

As a consequence, it is essential to perform investigations aimed at developing of the design concept of EPT system equipped with switched reluctance machines, taking into account the vehicle characteristics and restrictions in terms of internal combustion engine and power electronics. Furthermore, the given investigations are intended to provide the optimal components performance in connection with mass, overall dimensions and efficiency considering the manufacturing technological constrains.

Test bench of electrical transmission equipped with switched reluctance electrical machines: Electromechanical transmission (Fig. 3) equipped with switched reluctance electrical machines, in overall view, consists of two switched reluctance machines SRM1 and SRM2, two power converters PC1 and PC2 with common DC link (DC). The Vehicle Working Gear VWG is put in motion by SRM2. The electrical transmission provides energy recovery and storage. DC link in parallel can be connected to Accumulator Battery (AB) or to super capacitor, then it makes possible the energy recovery and storage in EPT. While using accumulator battery of large

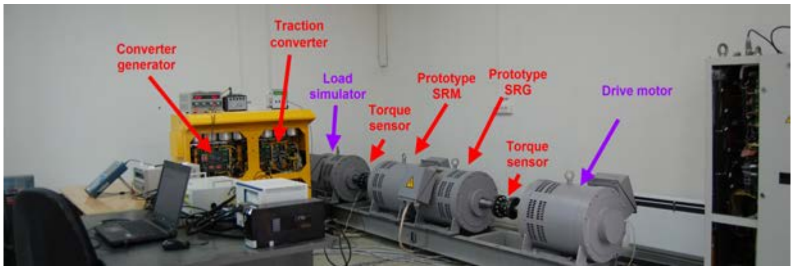

Fig. 4: Test bench for electric power transmission

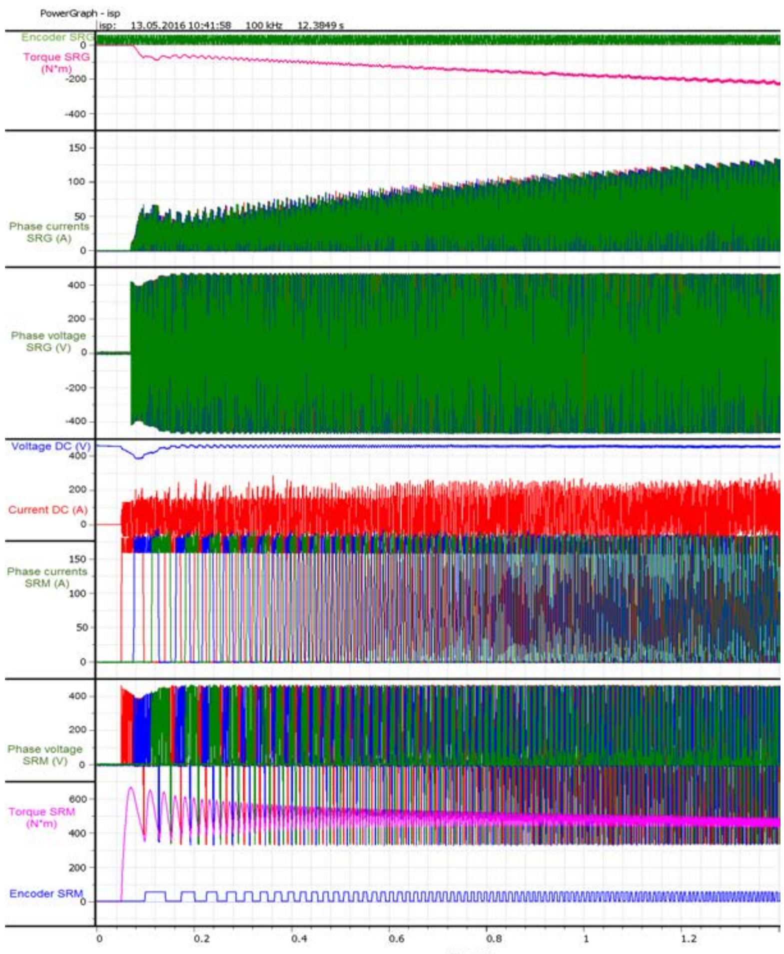

Fig. 5: Acceleration oscillogram

capacity it is permitted to have the vehicle battery operation on conditions that the internal combustion engine is stopped. In order to investigate the operating modes of components including into the model of electric power transmission system with switched reluctance machines it has been developed the test bench giving the possibility to simulate different operating modes of EPT system and to measure the main performance parameters of electric equipment. Figure 4 demonstrates the photo of produced test bench. The drive motor is supplied by traction converter connected to rectifier unit. The voltage at rectifier input is regulated by three-phase autotransformer powered from three-phase voltage circuit of 380 V. The traction converter of drive motor is regulated by microprocessor control system allowing us to set various operating modes for drive motor. The prototype ofswitched traction Reluctance Ggenerator (SRG) is driven by drive motor which shafts are joined by expansion couplings through the torque sensor. The mechanical energy of rotor rotation in SRG prototype is converted into electrical energy by means of regulated generator converter. Collected electrical energy is transmitted to traction converter for supplying the prototype of Switched traction Reluctance Motor (SRM).

Therefore electrical power transmission is arisen from the shaft of drive motor to the output shaft of SRM prototype. To simulate the load of the vehicle it is applied the load simulator designed as regulated electrical machine and loaded at the load resistor. The shafts of SRM prototype and load simulator are joined by expansion couplings through the torque sensor (Fig. 5).

In addition the test bench is equipped with the brake to perform the investigation in start-up modes. Two torque sensors allow us to evaluate the energy efficiency. The application of regulated electrical machines in the function of the drive motor and the load simulator gives the possibility to make investigations in various simulation modes of vehicle motion. The operating modes of drive motor are set by control system. Load parameters setting is performed by selection of required value of the load resistor. The mode parameters are visually monitored by indicators of electrical measuring instruments. As the test results of EPT prototype the following oscillograms have been obtained: phase current and voltage of generator, DC link and motor, drive torque at the generator shaft and output torque at the motor shaft. Oscillograms of acceleration process are given in Fig. 5. The oscillogram proves that at time 0.05 sec the SRM starts working while DC link voltage starts setting. After 0,002 sec the SRG activates and starts keeping the given voltage. SRM continuous accelerating under the load until getting the given rotation frequency in 1500 rpm. Moreover, it has been performed the investigation tests to define the optimal control parameters for SRG and SRM. As the tests results of electromechanical transmission prototype with power 40 kW, it has been obtained the optimal control parameters (Fig. 6) allowing to get the high efficiency of electrical power transmission. Figure 7 illustrates the characteristic curve of efficiency. Figure 6 proves that the advance angle before getting rotation frequency of 1000 rpm does not change but remains equal to 10 electric degrees. In case of further speeding up it starts linear increasing respectively. The investigation results of SRG and SRM control parameters should be taken into account when developing of control algorithms of electromechanical transmission.

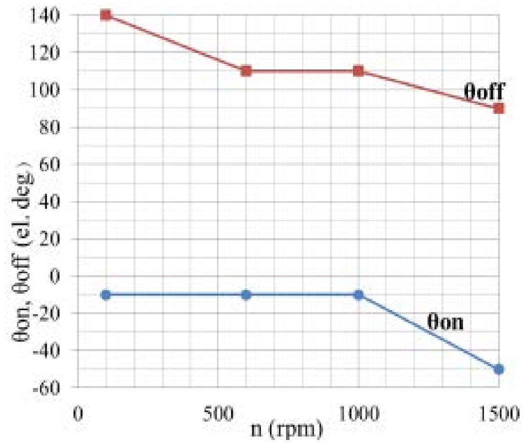

Fig. 6: Characteristic curve of motor control parameters (θ on turn-on angle, θ off turn-off angle) and motor rotation frequency

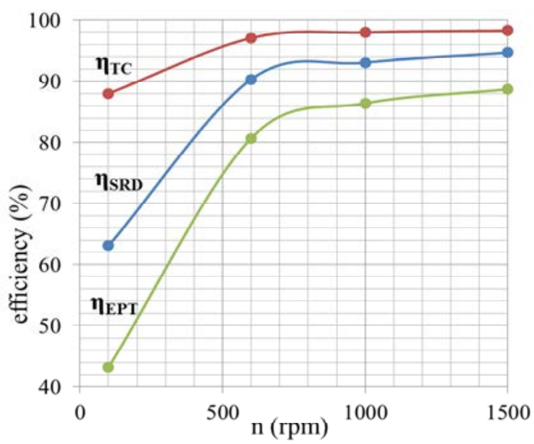

Fig. 7: Characteristic curve of maximum efficiency of EPT system (ηEPT), traction motor (ηSRD) and traction converter (ηTC) as well as motor rotation frequency

CONCLUSION

The given study has presented the test results of electromechanical transmission prototype equipped with switched reluctance machines. The submitted data shows that the design of vehicle with EPT and SRM is an efficient way bto improve the energy efficiency of the vehicle with internal combustion engine. The nominal efficiency of switched reluctance generator and motor under operation in electromechanical transmission is 96.7 and 94.7% correspondingly. Solution of assigned mission was found by searching for optimal control parameters of SRM during investigation tests.

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REFERENCES

Drives, S.R., 2016. SR Drive motor-generator for mild hybrid-electric powertrain. SR Drives Ltd, Beckwithshaw, Harrogate. http://www.srdrives. com/ hybrid-powertrain.shtml.

IEC 60034-30, 2008. Electric rotating machines. Part 30: Efficiency classes for three-phase induction cage motors of single speed (IE code).

LeTourneau Inc, 2016. Wheel Loaders. Joy Global Company, Milwaukee, Wisconsin. http://www.joyglobal.com/surface-mining/wheel-loaders

NEEAP, 2014. Finlands national energy efficiency action plan NEEA P-3. M.sc Thesis, EU Working Group, Europ. http://ec.europa.eu/energy/ sites/ener/files/ documents/ 2014_neeap_en_finl and. pdf.