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Electrical Propulsion System for Aviation – Experimental Validation of Efficiency Improvements

Jakub Bernatt[1], Emil Król[1], Paweł Pistelok[1]
[1]*Research and Development Centre of Electrical Machines KOMEL, Katowice, Silesia, Poland*
e-mail: dyrekcja@komel.katowice.p , e.krol@komel.katowice.pl , p.pistelok@komel.katowice.pl

Abstract

This paper deals with electrical propulsion system for light airplane or paraglider. The electrical drive consists of electrical motor, frequency converter and the batterypack. Electrical motor used in a light paraglider was designed as a permanent magnet synchronous motor (PMSM) in the Research and Development Centre of Electrical Machines KOMEL, Poland. Parameters of the motor, frequency converter and battery pack were shown. In this article, an influence of different propellers (1 fixed, 2 adjustable) and results of laboratory test was described. For increasing the efficiency of the electric propulsion, influence of switching frequency of the converter were tested and presented. The results of laboratory test were discussed.

Keywords: Battery, permanent magnet synchronous motor, motor design, paraglider, electric drives

1 Introduction

Aviation waits for environment friendly drives and propulsion systems. This paper deals with electrical propulsion for a light airplane or paraglider which was shown in Figure 1.

Figure1: Paraglider with electrical drive system

The electrical drive consists of an electrical motor, frequency converter and batterypack. Electrical motor used in light paraglider was designed as a permanent magnet synchronous motor (PMSM) in Research and Development Centre of Electrical Machines KOMEL, Poland. The paraglider in flight is presented in Figure 2.

Figure2: Paraglider in flight

The designed propulsion system was mounted in paraglider's trike. Light two person paraglider is able to fly for about 25 minutes with two persons and almost 1 hour with one person. The electric motor can be turned off during the flight what conserves the energy.

2 Electric motor

Parameters of the electric motor type SMwsK90L-8 are shown in Table 1. Electrical motor was designed as an interior permanent magnet synchronous motor (IPM), air cooled, 25 kW, frame size 90 mm. The rotor of the motor has a special slots for magnets. Cross section of electromagnetic circuit of electric motor is shown in Fig. 3. Electric motor mounted in paraglider with the propeller is presented in Fig. 4.

Table1: Parameters of electric motor SMwsK90L-8

Nominal / max. Voltage DC	V	120/148
Nominal / max. output power	kW	12/25
Nominal / max. current	A	180/250
Nominal / max. torque	Nm	57/95
Nominal / max rotation speed	rpm	2000/2500
Weight	kg	22

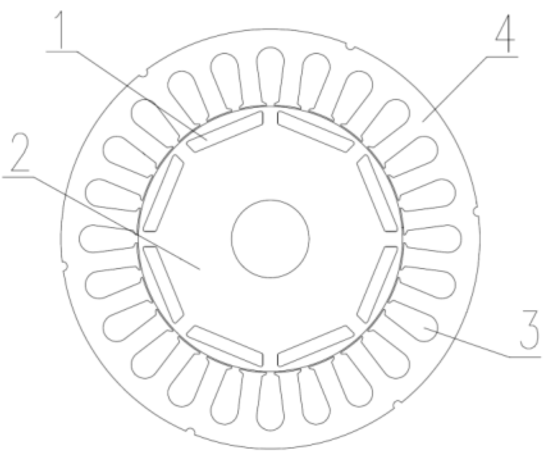

Figure3: Cross-section of electrical motor for paraglider 1 – rotor slots for magnets; 2 – iron rotor core; 3 – stator slots; 4 – iron stator core.

The eight radially magnetized permanent magnets type NdFeB are built into the rotor core. The electric motor was put in the specially designed alluminium frame which has special air duct (Fig. 4).

Figure4: The frame of electric motor mounted in paraglider

3 Battery Pack and frequency converter

Electric drives for light airplane or paraglider needs the special accumulator. According to technology, the optimal solution is lithium – ion or lithium – polymer. The battery pack has a special management system (BMS) which monitors parameters of the cells like temperature and voltage of each cell, process of charging and discharging battery, and balances the cells etc. Parameters of the battery pack are presented in Table 2. The battery pack mounted in the paraglider is shown in Fig. 5.

Figure5: The battery pack mounted in paraglider under the seat of the passenger

The battery pack has special air duct, which provides cooling during operation.

Table2: Battery Pack parameters

Battery Pack		
Capacity of the energy	kWh	7
Max voltage (full charged)	V	148
Min voltage	V	105
Max current	A	250
Charging time (up to 80% capacity)	hr	3.5
Charging time (up to 100% capacity)	hr	5
Max operating temperature	ºC	30
Weight	kg	62

In the electrical propulsion intended for light airplane or paraglider the special frequency converter was used. MOSFET SKAI module, manufactured by SEMIKRON, works supplied from the lithium – ion battery pack. Parameters of the frequency converter, which was mounted in paraglider under the electric motor {fig4}, are presented in Table 3.

Table3: The frequency converter parameters

SKAI 4201MD20-1450W		
Max operating DC link voltage	V	160
Max inverter voltage AC	V	75
Inverter current AC	A	370
Max. inverter current AC t < 20sec	A	420
Max. switching frequency	kHz	20
Operating temperature	°C	-40 to +175
Max auxillary supply voltage DC	V	18
Weight	kg	3

4 Optimization process

During the optimization process influence of 2 aspects (phases) on the efficiency of the particular components, i.e on efficiency of the motor and frequency converter separately, as well as on efficiency of the whole drive (motor + converter) were investigated: First phase - switching frequency of the converter - adjusting of the switching frequency changes switching losses in the converter and the additional losses in the motor. Second phase – propellers - 3 different propellers (1 fixed, 2 adjustable) were used and tested. The examinations process of an influence of switching frequency on the efficiency, two switching frequencies – 10 kHz and 15 kHz were set in the converter. According to literature, switching frequency influences on working time of MOSFET transistors what causes changing commutation losses of the transistors, what was proven. Additional losses of electric motor rise, but the efficiency of the entire propulsion practically do not change {fig8}. By changing the switching frequency only the distribution of losses can be changed. Differences between efficiency of inverter and motor (separately) were presented in figure 6 and 7.

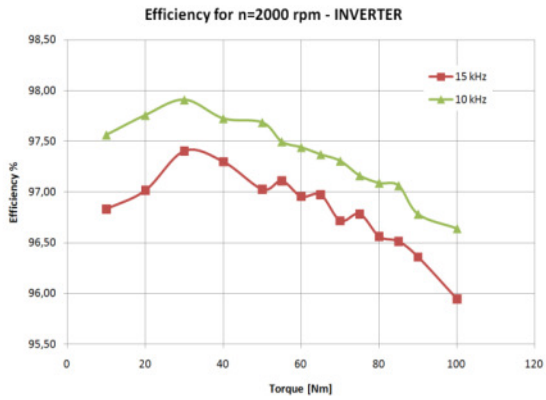

Figure6: Comparison of η=f(T) – only inverter

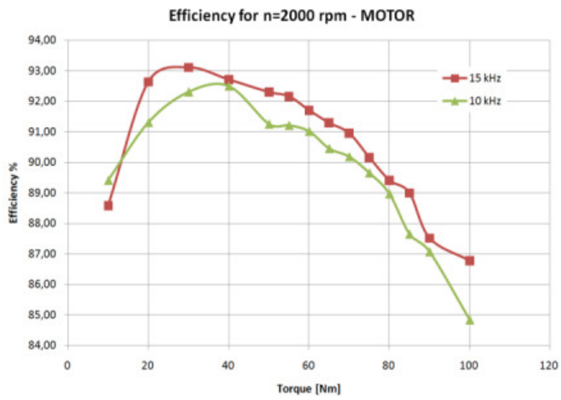

Figure7: Comparison of η=f(T) – only electric motor

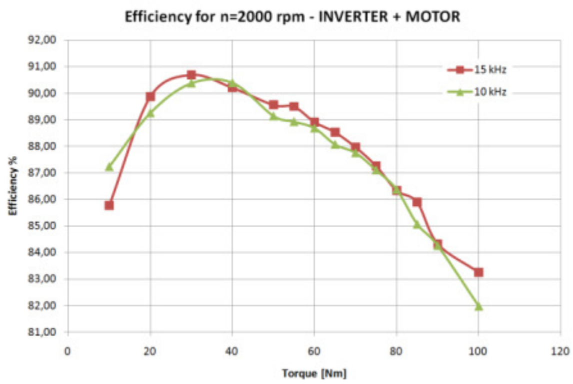

Figure8: Comparison of η=f(T) – inverter + motor

The efficiency of the inverter is clearly highest for 10 kHz switching frequency {fig6}. It can be recognized, from Figure 7, electric motor reaches the highest efficiency during the examinations at

15 kHz switching frequency. From the characteristic comparison of efficiency vs. torque {fig8} it can be seen the efficiency of complete drive system (inverter+motor) practically do not change.

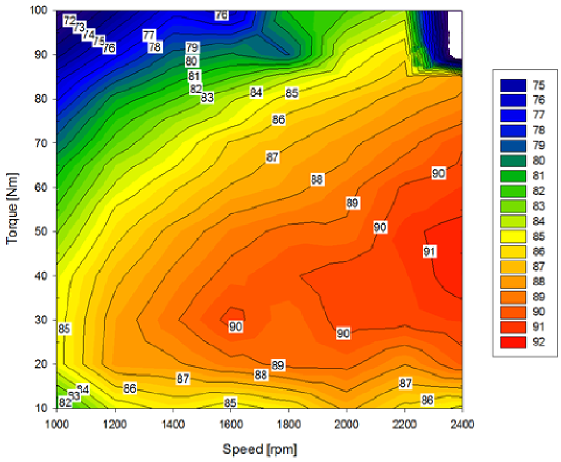

Figure9: Comparison of η=f(T) – inverter + motor for 10 kHz switching frequency

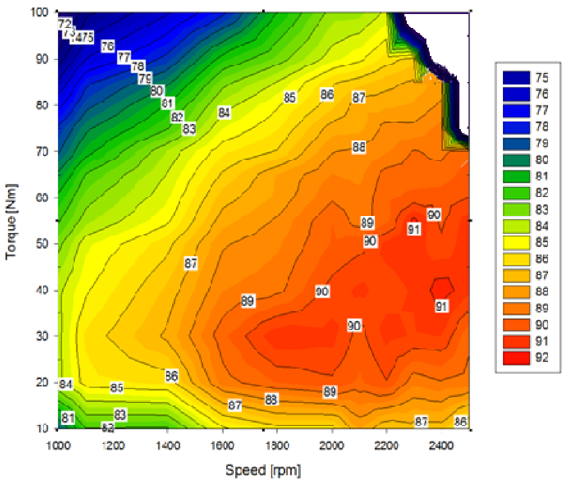

Figure10: Comparison of η=f(T) – inverter + motor for 15 kHz switching frequency

Efficiency map for 10 kHz switching frequency (inverter+motor) is shown in figure 9. The highest efficiency of the propulsion system is obtained at the range of rated torque between 20 to 60 Nm and rotational speed between 1900 to 2400 rpm. The very similar situation, like in case of figure 9, is for 15 kHz switching frequency for inverter and motor {fig10}. The area with highest efficiency appears for 20 to 60 Nm and rotational speed between 1800 to 2500 rpm.

After performing the first flight, which provided many data needed for further research, an influence of different propellers (1 fixed, 2 adjustable) was investigated. Results of tests are presented in figure 11.

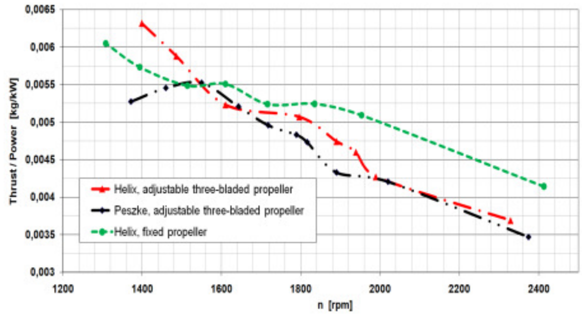

Figure11: Comparison of Thrust/Power=f(n) characteristics

The fixed Helix propeller has larger thrust than remaining examinated propellers but it is also lauder. The fixed Helix propeller has two blades and it is not adjustable. The two remaining investigated propellers have three adjustable blades. The angle of three-bladed propellers was set to reach thrust of 100 KG at maximal rotation speed. The electric paraglider was tested in air during two persons flight. The course of output power taken from battery during the flight was presented in figure 12.

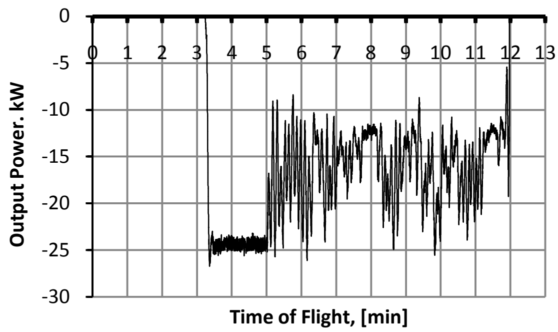

Figure12: Output power taken from battery during the two persons flight

During the two persons flight which had about 25 minutes, 2.6 kWh energy were used. The weight of pilot and passenger was 90 and 60 KG.

5 Conclusion

As can be recognized from figure 7 the electric motor at the 15 kHz switching frequency has the efficiency higher than 90% in range of torque operation between 15 to 70 Nm. In case of electric motor controlled with 10 kHz switching frequency, situation is very similar. The efficiency is above 90%. The difference of efficiency in whole range operation torque for converter {fig.9} is more visible. The highest efficiency of the inverter is for 10 kHz switching frequency, but from figure 8 it

can be noticed that there is no differences between characteristics of the efficiency vs. load torque for 10 and 15 kHz switching frequency if the whole propulsion system is investigated.
From examinations done and received results (Fig. 9 and 10, efficiency maps), it can be seen, the area with highest efficiency is practically the same for two examined cases (10 and 15 kHz switching frequency). The range of torque and rotational speed (for highest efficiency) do not change, even for different switching frequency. After adjusting switching frequency, only the distribution of losses can be changed. The second phase of investigations proved that the propellers have higher impact factor into efficiency level of the drive than the switching frequency. The fixed Helix propeller has a better coefficient (Thrust/Power) than two remaining examined propellers (Fig.11). The Fixed Helix propeller produce higher thrust (in range 1800 to 2400 rpm) with smaller power demand than Peszke and Helix adjustable three-bladed propellers. Producing the higher thrust by Fixed Helix propeller (in range 1800 to 2400 rpm - Fig.10) causes higher noise level. The whole electrical propulsion system mounted in paraglider was tested in air as well. It enables to fly environment friendly with no pollution and no danger of flammable fuel. The noise of the system is lower than the combustion engine drive, what is very important as well.

References

[1] J. Bernatt, *Electrical and magnetic circuits of electrical machines excited with permanent magnets*, Publishing house Research and Development Centre of Electrical Machines “KOMEL”, Katowice 2010.

[2] J. Bernatt, T. Glinka, E. Król, R. Rossa, *Electric motors with permanent magnets*, ICEM 2008 Conference Proceedings, Vilamoura, Portugal.

[3] J. Bernatt, R. Rossa, *Calculation and Comparison of Electromechanical Characteristics for SynRM and PMSynRM of the Same Frame size,* ACEMP’07 Electromotion’07, pp. 464-467, Turkey 2007.

[4] J. F. Gieras, M. Wing, *Permanent Magnet Motor Technology*, Marcel Dekker, Inc., New York, Basel, 2002.

[5] J. Bernatt, R. Rossa, *Synchronous Reluctance Motor Co-excited by Permanent Magnets – Results of Laboratory Tests,* in Proc. International Aegean Conference on Electrical Machines and Power Electronics, ACEMP’04, pp. 316-321, May 2004

[6] J. Bernatt, P. Pistelok, E. Król, *Investigation on Efficiency Improvements on Electrical propulsion System for a light Airplane*, in Proc. International Aegean Conference on Electrical Machines and Power Electronics, ACEMP’11, Turkey 2011.

[7] J. Bernatt, E. Król, *Comparison of Two Versions of Electric Motors Used in a Drivetrain of an Electric Car*, in Proc. 25th World Battery, Hybrid and Fuel Cell Symposium and Exhibition - EVS25 Shenzhen Electric Vehicle Symposium – 25, Nov. 5-9, 2010, Shenzen, China

Authors

Jakub Bernatt Assoc. Prof. Ph.D El. Eng., was born in Katowice in Poland, 1970. He graduated from the Silesian University of Technology in Gliwice 1994. Since 1995, has worked in Research and Development Centre of Electrical Machines KOMEL. In 1999 he received the degree of Doctor of Science. Since 2006, he is general director of R&D Centre of Electrical Machines KOMEL, His main area of interest and activities are electric machines assigned to special solutions, especially large power motors intended for hard work conditions. The second area coveres electric motors and generators with permanent magnets.

Emil Król M.SC.EE, was born in Zamość in Poland, on July 23, 1977. He graduated from the Silesian University of Technology in Gliwice 2002. Since 2004, he is working in Research and Development Centre of Electrical Machines KOMEL, where he is designing and making laboratory test of various types of electric machines.

Paweł Pistelok M.SC.EE, was born in Świętochłowice in Poland, on January 12, 1983. He graduated from the Silesian University of Technology in Gliwice 2008. Since 2008, he is working in Research and Development Centre of Electrical Machines KOMEL. He is working as a design engineer, designing electrical machines including machines with permanent magnets.