Some Researches in the field of the Use of Permanent Magnet Motor for Vehicle Propulsion

BOLFA TRAIAN EUGEN
Department of Strength of Materials
Transylvania University of Brasov
B-dul Eroilor 29, 500036 Brasov
ROMANIA
t.bolfa@unitbv.ro

Abstract: - In this paper the author presents a laboratory bench used to test the Permanent Magnet (PM) motors for vehicle propulsion. Are indicated the general schemas for the bench, the PM motor types tested, the traction characteristics and some experimental results. All this work is very suitable to teach students in practical laboratory applications regarding the electrical and hybrid vehicles. Students are able to have good practical skills and also to develop research projects jointly with the teaching staff.

Key-Words: -permanent magnet motor, laboratory tests, traction characteristics.

1 Introduction

During the recent years, within the large urban areas, are developed EV and HEV solutions to transport passengers and goods.

On the recent estimations, in the next twenty years, within the large urban areas, the car density will increase substantially.

All these will further increase the pressure on fuel prices and will cause serious problems to the environment (pollution and green house effect). Some major requirements must be accomplished by the passengers and goods vehicles, as follows:

- having quite large autonomy;
- having short refueling time;
- providing acceleration of 10 to 15s from attending speeds of 0 to 100km/h;
- can be driven uphill a 5-10% ramps at the legal top speed;
- be safe and cause no environmental hazards.

In this case, is very important to have a good selection of an appropriate traction motor for the vehicle propulsion system.

Within research projects, in Transylvania University of Brasov, Romania, are developed some practical applications within testing PM motors for vehicle propulsion.

2 Traction Characteristics

The traction characteristic makes it possible an evaluation of the dynamic, economic and other vehicle indexes being determined by calculation (the theoretical characteristic), or by practical testing.

To have good dynamics and respecting the vehicle's operating constraints, it requires an extended speed range and a constant power operating flexible region for different hill climbing conditions. To obtain a complete estimation of traction characteristics, it must to calculate the dependence between the vehicle power (P_v) and its speed (v) within the traffic, as follows:

$$P_v = \left(m_v \cdot g \cdot C_r + \frac{\rho_a \cdot A_f \cdot C_d}{2} \cdot v^2 \right) \cdot v \quad , \qquad (1)$$

where: m_v is the loaded vehicle mass, g is the gravity acceleration, Cr is the wheel rolling coefficient, v is the vehicle speed, ρ_a is the air density, A_f is the vehicle frontal area and C_d is the aerodynamic drag coefficient usually estimated by experiments or using computer programs.

The power characteristic presents also two regions: linearly power increasing until the base speed (30 km/h) - known also as constant torque region and the constant power region between the base speed and the maximum extended one. The extended speed ratio (v_{max}/v_{base}) is almost independent of the vehicle mass, because the aerodynamic drag is not weight depending and has less impact on the extended speed ratio than the tire friction which linearly depends on the weight [2, 3].

Taking into account the equation (1) and the numerical values of the traction powers for different vehicle classes [2, 4], in the Fig.1 are depicted the traction characteristics for some vehicle classes driven by PM electrical traction motors.

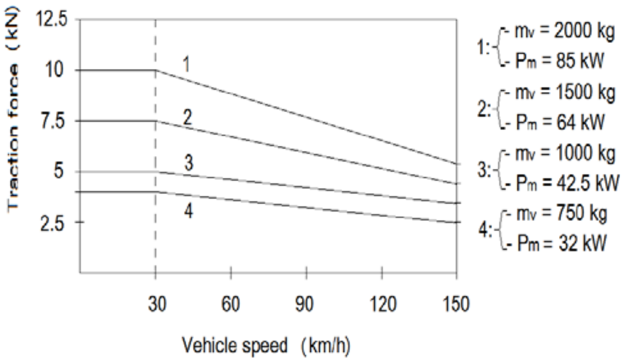

Fig. 1 Traction characteristics.

3 Permanent magnet motors testing

The general schema of the test bench where the PM motors have been tested is presented in the Fig.2.

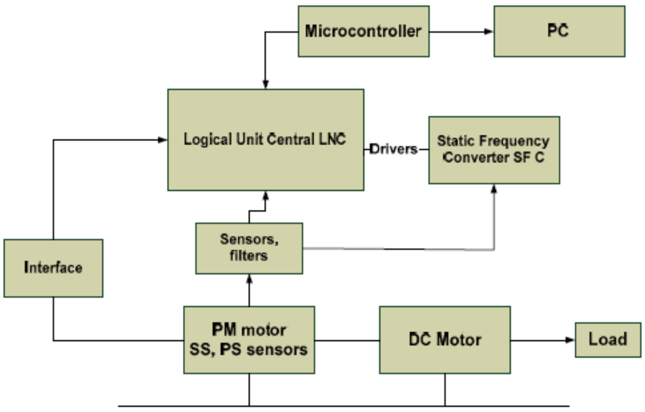

Fig. 2 General diagram of the test bench

To obtain the experimental PM motor model measurements it has been used the testing bench presented in the Fig.3. Two types of traction PM motors are proposed and their models are developed, using experimental tests and data processing.

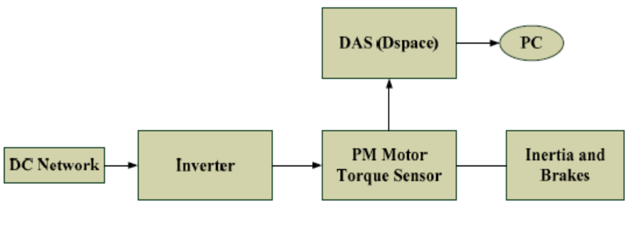

Fig. 3 Testing bench for motor measurements

Are obtained the main traction characteristics for the followings PM motors:

a) Brushless motor type NX840, with the main rated parameters: V_n = 230 V, I_n = 42.9 A, T = = *35 Nm*, *n* = 3300 *rpm*, *P* =12 *kW*.
The motor has been presented in paper [6], with a complete analysis. It is equipped with a torque sensor to directly measure the torque to the motor shaft.
The measurement system contains three outputs and of these analog/digital output values for torque and speed are readable. The output signal for the torque is voltage V_{out} = *0...10 V* or current I_{out} = *4...20 mA*. The voltage across the inverter, coming from the DC bus, is acquired by voltage sensors type LV100-100. Current measurements of DC bus have been obtained through current sensors type LEM LA 205-S.
Brakes develop a resistant torque with a manual adjustable value by adjusting the field current. Inertia, type VI100B, *1.5 kW* power, permits the permanent rotation quite safety at 8000 *rpm*.
Inertia and brakes represent the mechanical load of the vehicle powered by the PM motor.
The data acquisition system (DAS) is provided by the DSpace real-time-board. Tests are performed within load operating, the inertia and brake being coupled gradually, in a dynamical way.

b) synchronous motor type ST142-2/6 M, having the following data: rated voltage *196 V*, rated current *9.3 A*, maximum rotation speed *6000 rpm*, rated/maximum torque *2.2/2.9 N/m*, pole pair number *3*. The motor is equipped with two sensors:
- rotor speed sensor (RSS) with output signal of *1.6 mV/rot*;
- position sensor (PS) with three Hall probes placed at *120 degrees*.
The DC machine representing the load of PM motor is of CD 42 UV type. In Table 1, the data sheets of the DC machine are given.

Table 1 Data sheets of the DC machine

Parameter	Symbol	Value
Power, kW	P	2.2
Rotor speed, rpm	n_{max}	3000
Armature voltage, V	V	275
Current, A	I	12.5

Using this load, traction typical operating modes are realized: constant torque, constant power and dynamical breaking (through rheostats).
The static frequency converter is composed by a bidirectional three-phase rectifier and three-phase VSI inverter, with a maximum power of *30 kVA*, voltage

of *200 V* and current of *15 A* at a frequency of *1000 Hz*.
In order to reduce the current harmonics and to decrease its amplitude, a control PWM strategy to the supply voltage between (+ 0.5 *V*, 0) and (0, - 0.5 *V*) has been used.
The logic control unit (LCN) provides an independent control of the PM stator voltage and of frequency so that their ratio is constant (V/f = const.).

4 Experimental results

To obtain accurate results, precise experimental models of PM synchronous motor drives, were acquired with the DSpace system.
The stage of data processing has been done helping with Matlab Simulink software.
In simulations, measured values as rotation speed n and mechanical power P_m have been introduced as input data, in order to obtain the output of electrical power P_e required by the motor to work in the specified traction operating modes.
The Simulink schema that leads to the experimental model of PM motor is presented in the Fig. 4.
Than, using **netlab** library from Matlab that allows working with neural netwok and motor data acquired, several types of cartographies have been obtained.

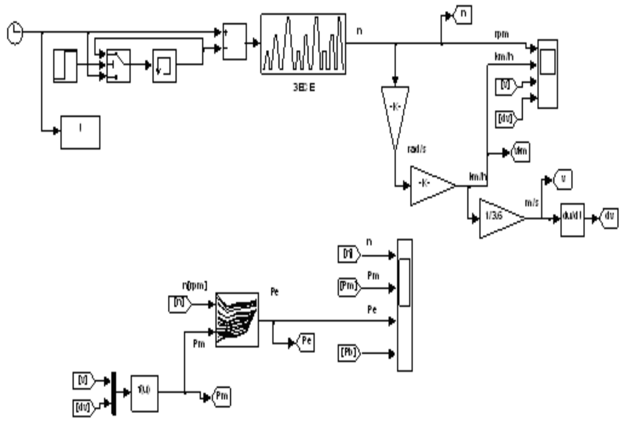

Fig. 4 Simulink schema for experimental model of the PM motor

For the PM motor type ST142-2/6 M it has been established the rated regime, characterized by measured and computed data, presented in Table 2 and Table 3.

Table 2 Rated measured data of PM motor

Parameter	Symbol	Value
Torque, Nm	T_n (C_n)	2.85
Power, W	P_n	900
Frequency, Hz	f_n	152
Phase voltage, V	U_{fn}	50
Phase current, A	I_{fn}	8.5
Rotor speed, rpm	n_n	3000
Power factor	$\cos\varphi_n$	0.998

Table 3 Rated computed data of PM motor

Parameter	Symbol	Value
Power, W	P_n	895.35
Frequency, Hz	f_n	150
Rotor speed, rpm	n_n	3000
Phase voltage, V	U_{fn}	48.1

The rated operating mode of PM motor has been established so that the PM motor is not overloaded and a power reserve is achieved: $I_n < I_{max} = 9.3\ A$ and $T_n < T_{max} = 2.9\ Nm$.

Once defined the operating mode and using the data acquisition system, the following parameters, presented in Table 4 for the PM motor, have been determined.

Table 4 Measured parameters of PM motor

Parameter	Symbol	Value
Relative permeability of PM(Nd-B-Fe)	μ_r	1.05
Remanent magnetic induction, T	B_t	1.25
Permanent magnet resistivity, Ωcm	ρ_{PM}	$15\cdot10^5$
Stator winding resistance, mΩ	R_s	1.7
Synchronous reactance, mΩ	$X_s=X_d$	30
Rated power factor	$\cos\varphi_n$	0.998
Proper flow of permanent magnet, Wb	ψ_{pr}	0.0745

According to the rated operating modes experimentally defined, the constant torque and the constant power regions have been analyzed.
Constant torque curves are presented in Fig. 5 and they have been layout for three values of the field current of the dc motor (as load):

- curve 1 I_{e1} = 0.21 A – rated mode,
- curve 2 I_{e2} = 0.71 I_{e1},
- curve 3 I_{e3} = 0.51 I_{e2}.

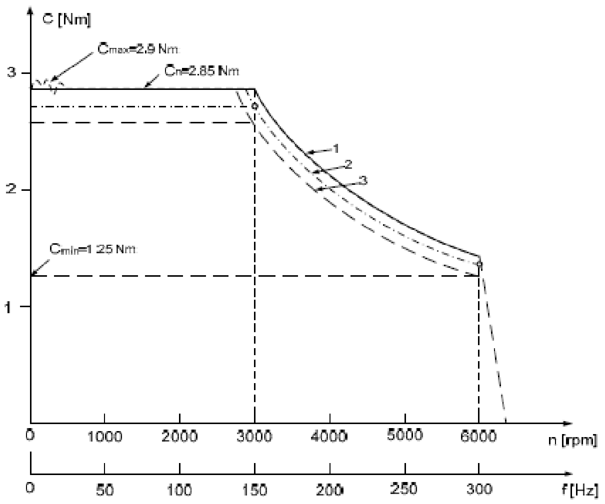

Fig. 5 Experimental torque curves of PM motor

In Fig.6 constant power curves are shown.

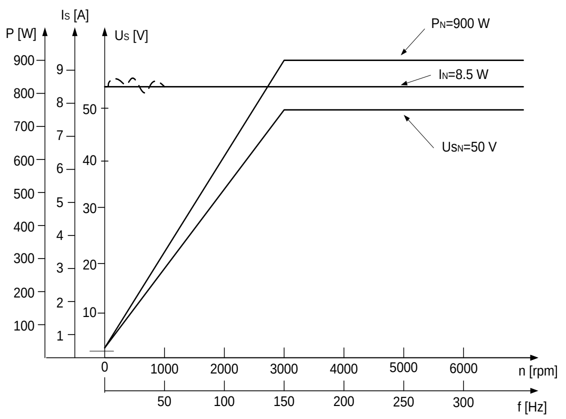

Fig. 6 Experimental power, voltage and current curves of the PM motor

It can be seen a good elasticity, achieving the maximum value of rotational speed n_{max} = 5970 *rpm* and the minimal value of torque $T_{min} = C_{min}$ = 1.25*Nm*. The ratio between the maximum and minimum values of the PM motor torque is 2.32 that show a good elasticity of the torque characteristic within traction conditions.

Also the ratio $n_{max}/n_{min} = 2$ corresponds to the literature recommended values of 1.5 – 2 [1, 5].

5 Conclusions

In this paper two types of electrical motor used for electrical propulsion have been studied and analyzed.

The NX840 motor type of, has been tested on a test bench simulating a hybrid electric vehicle. For the STS 142-2/6 second type of motor analyzed, the traction curves have been obtained, reliving the behavior of the motor in traction operating modes.

Making tests on both motors, acquiring data and processing them, main curves describing electrical and mechanical parameters have been obtained.

Theoretical aspects are practical verified by practical tests, simulations and data processing on a testing bench in laboratory conditions.

Within this research work some master students are involved in order to develop their dissertations.

References:

[1] L. Guzzella, A. Sciaretta,- *Vehicle Propulsion Systems-Introduction to Modeling and Optimization*, Second Edition, Springer-Verlag, 2007, ISBN 978-3-540-74691-1.

[2] M.Ehsani, K.M. Rahman, H.A. Toliyat - "*Propulsion System Design of Electric and Hybrid Vehicles"*, IEEE Trans. On Ind. Electronics, vol. 44, no. 1, pp.19-27, Feb. 1997.

[3] M. Georgescu, - "*Study on A.C. Electrical Transmissions with Synchronous Motors"*, Ph.D. Thesis, University Politehnica of Bucharest, Romania, July, 1997.

[5] M. Ehsani,, G. Yimin, S. Gay, - "*Characterization of electric motor drives for traction applications"*, Industrial Electronics Society, IECON, vol.1, pp.891-896, Nov.2003.

[6] C. Lungoci, D.Bouquain, A.Miraoui, E.Helerea,- "*Modular test bench for a hybrid electric vehicle with multiples energy sources ",* Proc. of IEEE OPTIM Conference, Brasov, Romania, May, 2008.