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RICE

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Measurement and analysis of Parker PMSM voltage constant

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SKODA MACHINE TOOL a.s.

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Abstract

This report introduces results of measurement of the Parker permanent magnet synchronous machine voltage constant. The maximum back EMF of the motor in the field weakening region and its dependency on the rotor operating temperature are analyzed. Recommendations for SKODA MACHINE TOOL are discussed.

Keywords

Permanent magnet machine, voltage constant, back EMF, measurement.

List of Symbols and Shortcuts

rpm	Rotations per minute
f_{re}	rotor electrical frequency
f_s	stator electrical frequency
k_{ER}	voltage constant of the real motor
k_{ERm}	voltage constant of the real motor for maximum line to line voltage
k_{ERwarm}	voltage constant of the real warm motor for maximum line to line voltage
k_{EP}	voltage constant given by Parker manufacturer
k_{EPm}	voltage constant given by Parker manufacturer for maximum line to line voltage
k_{EPwarm}	voltage constant given by Parker manufacturer for warm motor and maximum line to line voltage
n_{maxw}	motor maximum demanded speed
p_p	motor polepairs
U_{im}	maximum line to line back EMF
U_m	maximum line to line voltage for converter protection
$U-V,\ V-W$	line to line voltages

Contents

1 Introduction

This report introduces results of measurement of the Parker permanent magnet synchronous machine voltage constant. The maximum back EMF of the motor in the field weakening region and its dependency on the rotor operating temperature are analyzed. Recommendations for SKODA MACHINE TOOL are discussed.

2 Measurement and voltage constant calculation

The back EMF was measured using an oscilloscope. The machine was not loaded and rotated using an external electric drive at $822\ rpm$ and then at $1000\ rpm$. The line to line voltage was measured and thereafter, the voltage constant was calculated.

The motor temperature was 20^oC.

The figure 2.1 shows the first measurement result.

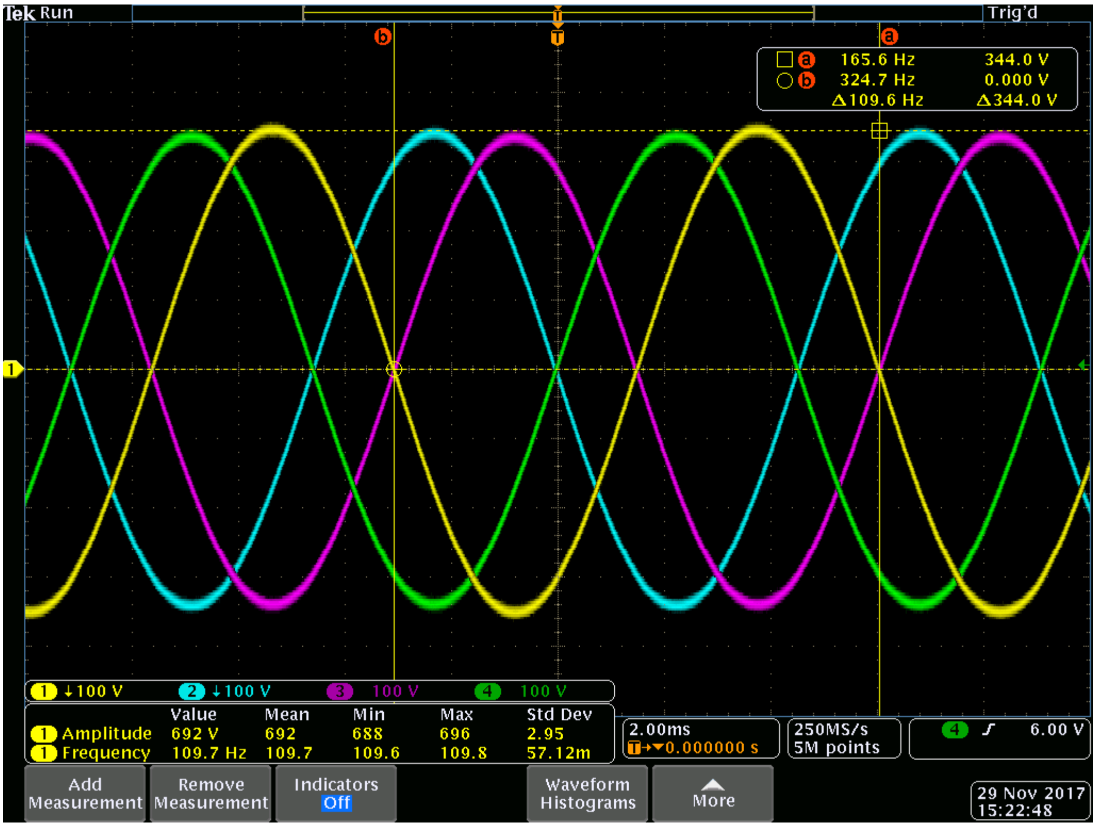

Fig. 2.1: Measured back EMF at $822\ rpm$. Ch1: Line-to-line voltage U1-V1 (first stator winding section); Ch2: Line-to-line voltage V1-W1 (first stator winding section); Ch3: Line-to-line voltage U2-V2 (second stator winding section); Ch4: Line-to-line voltage V2-W2 (second stator winding section).

The measured back EMF frequency which corresponds with electrical rotor frequency was

$$f_s = f_{re} = 109.7\ Hz. \tag{1}$$

This corresponds with mechanical rpm

$$n = \frac{f_{re}.60}{pp} = 822\ rpm. \tag{2}$$

The voltage constant of the real machine k_{ER1} corresponding with the maximum value of the back EMF is then

$$k_{ER1} = \frac{U_{im}.1000}{n} = \frac{346 \cdot 1000}{822} = 421\ V \tag{3}$$

Although it is assumed that the voltage constant is constant, we performed another measurement for higher motor speed, see Fig 2.2.

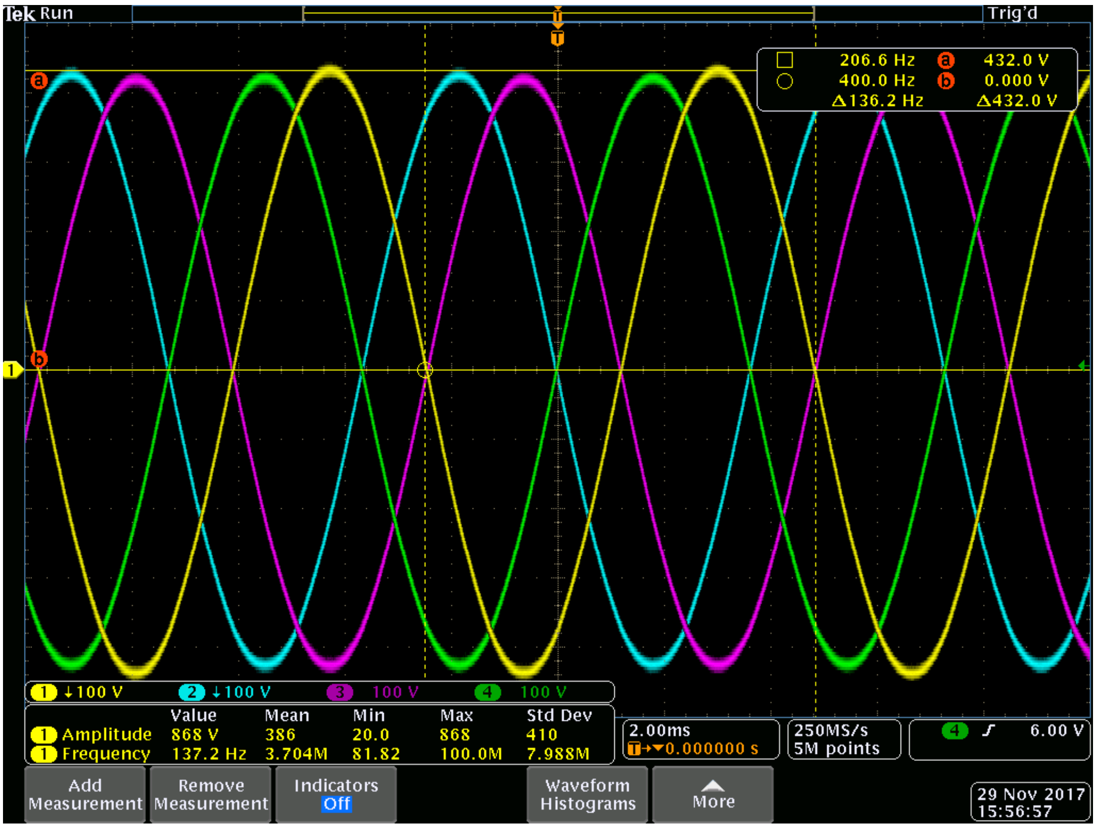

Fig. 2.2: Measured back EMF at $1000\ rpm$. Ch1: Line-to-line voltage U1-V1 (first stator winding section); Ch2: Line-to-line voltage V1-W1 (first stator winding section); Ch3: Line-to-line voltage U2-V2 (second stator winding section); Ch4: Line-to-line voltage V2-W2 (second stator winding section).

The back EMF frequency was $137.2\ Hz$ which corresponds with mechanical rotor speed of

$f_{rm} = 1029\ rpm$ (using (2)).

The voltage constant in this second case for maximum back EMF is $k_{Em2} = 422\ V/1000\ rpm$ using equation (3).

The maximum voltage constant used for the following analysis is

$$k_{ER2m} = 421\ V/1000\ rpm. \tag{4}$$

For rms values can be k_{ER2m} divided by $\sqrt{2}$:

$$k_{ER2} = 298\ V/1000\ rpm. \tag{5}$$

3 Comparison of measured and given voltage constants

The voltage constant given by the manufacturer of the machine Parker is of

$$k_{EP} = 258V/1000rpm \pm 7.5\% \cdots (@25^oC) \tag{6}$$

The highest voltage constant should be then in the maximum tolerance of $277\ Vrms$, or the maximum value is

$$k_{EPm} = 392\ V. \tag{7}$$

As can be seen from equation (5) and (6), the real voltage constant is of $29\ V/1000\ rpm$ higher than it should be as given by the manufacturer.

3.1 Influence of temperature

It is given by the manufacturer that the permanent magnet flux temperature drift is of $(0.12 - 0.14)\%\ ^oC^{-1}$. It means that for temperature difference of $75\ ^oC\ (100 - 25)^oC$, where 100^oC is assumed machine rotor working temperature, the voltage constant drops of $(0.12 - 0.14)\% \cdot 75^oC = (9 - 10.5)\%$. Slightly different measured machine temperature and the typical manufacturer temperature is for further calculations neglected.

For the highest magnet flux drift the voltage constants represents 89.5% of the original value. The voltage constant given by the manufacturer with magnets flux drift can be then calculated as

$$k_{EPwarm} = k_{EPm} \cdot 0.895 = 392 \cdot 0.895 = 350\ V/1000\ rpm, \tag{8}$$

and the measured (real) constant corresponding to the maximum magnets flux drift is

$$k_{ERwarm} = k_{ER2m} \cdot 0.895 = 421 \cdot 0.895 = 377 \; V/1000 \; rpm, \tag{9}$$

4 Maximum back EMF evaluation

By operating of the machine, it should be ensured that the back EMF will not be higher than $U_m = 2000 \; V$ because of converter protection. The maximum demanded speed is of $n_{maxw} = 6000 \; rpm$ which can be reached when the converter works well and the machine is operated in the field weakening area. A dangerous problem can be caused by an accident in the system when the converter has to be switched off.

4.1 Back EMF of a cold machine

The back EMF can be calculated for the cold machine with manufacturer data as

$$U_{im} = n_{maxw} \cdot \frac{k_{EPm}}{1000} = 6000 \cdot \frac{392}{1000} = 2352 \; V, \tag{10}$$

or for the cold machine with the measured data:

$$U_{im} = n_{maxw} \cdot \frac{k_{ER2m}}{1000} = 6000 \cdot \frac{421}{1000} = 2526 \; V. \tag{11}$$

4.2 Back EMF of a warm machine

For the warm machine operated at $100^o C$ the maximum back EMF with manufacturer given data is

$$U_{im} = n_{maxw} \frac{k_{EPwarm}}{1000} = 6000 \cdot 350/1000 = 2100 \; V, \tag{12}$$

and for the measured data the back EMF is

$$U_{im} = n_{maxw} \frac{k_{ERwarm}}{1000} = 6000 \cdot 377/1000 = 2262 \; V. \tag{13}$$

It is obvious that the operation at $6000 \; rpm$ can be dangerous for all mentioned cases. The recommendation could be to have the machine with lower voltage constant (lower magnets flux). The voltage constant for maximum line to line voltage should be around

$$k_{Erecom} = \frac{2000}{6000} \cdot 1000 = 333\ V/1000\ rpm, \tag{14}$$

5 Machine operability at lower speeds

The second possibility is to operate the machine under the dangerous speed. This means for the cold machine and manufacturer data

$$n_{maxp} = \frac{U_m}{k_{EPm}} \cdot 1000 = \frac{2000}{392} \cdot 1000 = 5102\ rpm, \tag{15}$$

and for the cold machine and real data

$$n_{max} = \frac{U_m}{k_{ERm}} \cdot 1000 = \frac{2000}{421} \cdot 1000 = 4750\ rpm, \tag{16}$$

Or for a warm machine with manufacturer data

$$n_{maxp} = \frac{U_m}{k_{EPwarm}} \cdot 1000 = \frac{2000}{350} \cdot 1000 = 5714\ rpm, \tag{17}$$

and for a warm machine with measured data

$$n_{maxp} = \frac{U_m}{k_{ERwarm}} \cdot 1000 = \frac{2000}{377} \cdot 1000 = 5305\ rpm. \tag{18}$$

6 Conclusion

From measurement results follows that the voltage constant is higher than the manufacturer introduces. The measured voltage constant is $421\ V/1000\ rpm$ for maximum line to line voltage in comparison with $(\sqrt{2})258\ V/1000\ rpm \pm 7.5\%$ of the manufacturer parameters.

It is obvious that the installed machine cannot be safely operated up to $6000\ rpm$, because the maximum converter limit of $2000\ V$ is reached at $4750\ rpm$ with a cold machine or at $5305\ rpm$ with a warm machine.

It is not possible to reach the demanded speed safely with a machine with manufacturer given values of the voltage constant (assuming the machine has those parameters).

The recommendations are: (i) to lower the voltage constant to aroud $333\ V/1000\ rpm$ by modification of the machine design or (ii) to operate the machine at lower speeds.

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Revision history

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1	All	Document release	30.11.2017	T.Glasberger