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Imbalance signal analysis in switched reluctance motor

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Abstract: *Imbalance signal analysis in switched reluctance motor*. This article briefly analyzes the impact and damage to electric motors on the example of a reluctance motor (SRM). In this case, it was an imbalance. It was screwed onto a disk mounted on the motor shaft. The results of the analysis are shown in the case of a load of 1 Nm and a speed of 1,000 rpm. Fourier analysis (FFT), Hilbert in the form of amplitude, phase and velocity and wheel speed were compared. The studies did not show a large dependence on modulation. This was due to the stiffness of the whole element. Nevertheless, it may be an introduction to further analysis and later verification of the model.

Key words: SRM, motor, diagnostics

INTRODUCTION

The switched reluctance motor – SRM (Fig. 1) can be an attractive drive with variable speed control, low cost, robust construction, reliable power converter, high efficiency with high speed range and simple control. It can be applied for traction drives of electric and hybrid electric vehicles. It can also work as a starter or generator in planes, mining equipment, washing machines, door actuators and others [Ehsani and Gao 2009]. It can be used also in modern agriculture applications, tractors, combines and other types of vehicles.

The switched reluctance motor has a simple, durable and inexpensive construction. It does not have magnets nor windings on the rotor. This reduces the cost of motor production and also allows it to work at high revs (over 10,000 rpm).

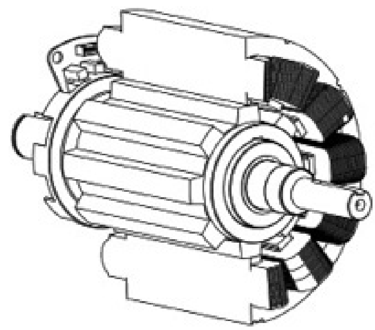

FIGURE 1. Section of typical switched reluctance motor (https://www.farm-equipment.com/blogs/6-opinions-columns/post/11724-ahead-of-the-curve-vr-motors-finding-ag-applications)

In contrast to induction or permanent magnet motors the SRM is able to achieve high speeds without risk of mechanical damage resulting from high centrifugal force.

For this motor a power converter is used. Stator windings are connected in series with the upper and lower connectors on the inverter.

A typical SRM drive consists of the motor itself, the power converter, the current, voltage and position sensors and control circuit, i.e. digital signal processor (DSP) and its peripherals. The switched reluctance motor converter is connected to the DC power supply via battery or diode rectifier.

The control circuit provides a gateway signal to converter keys according to particular control strategy and signals from individual sensors.

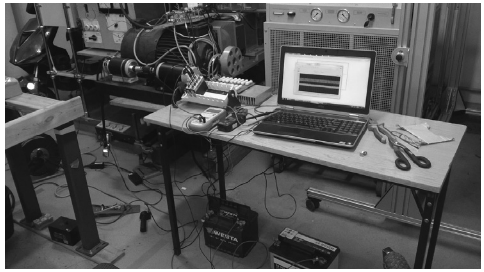
FIGURE 2. Test bed for motor diagnostics

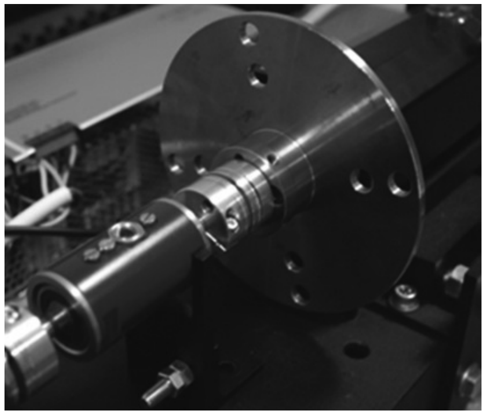
FIGURE 3. Shield for imbalance simulation

EXPERIMENT

Mechanical faults

The switched reluctance motor, like another types of electric motors is susceptible to damages: mechanical (e.g. eccentricity, imbalance, bearing damages) and electrical ones. This work focus on one of the mechanical damages – imbalance.

The fault analysis of motors is usually described by acceleration or current signal. My previous studies describe previous experiments with motor diagnostics [Lorencki 2015, Lorencki and Radkowski 2013a, b, 2014, 2017, Lorencki et al. 2015].

This paper presents effects of imbalance fault. The experiment was conducted on a special test bench (Fig. 2). It consisted of examined motor (SRM), brake motor (DC motor), torquemeter, current clamps and acceleration sensors. For imbalance simulation a special shield was mounted (Fig. 3) with holes in which it was possible to assemble a screw. Thus it was three states: healthy state (no screw), screw in hole closer to the shaft center (imbalance A) and screw in hole further from shaft center (imbalance B).

One of the experiment was the comparison between healthy and faulty states at the speed of 1,000 rpm with 1 Nm load. The acceleration signal is presented in Figure 4. It can be seen that acceleration signal transmits a lot of noise. There are also not much differences between different signals.

The next analysis shown in Figure 5 is current signal. It is significantly more legible. The peak at about 100 Hz is very clear and somewhat smaller 200 and

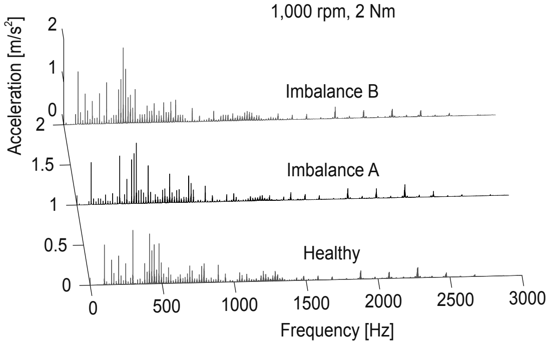

FIGURE 4. Healthy and faulty state shown in acceleration (vibration) analysis in frequency domain (FFT)

300 Hz are seen. This is because of the fact that 100 Hz peak is sixth harmonic which is form the fact that the motor has six salient poles on the rotor.

From Figure 5 it could be seen that the small peaks were presented next to harmonic peaks from left and right side. For seeking whether there is modulation effect a Hilbert transform was used, also for checking for envelope of a signal. Before applying Hilbert analysis from the original signal I just used peaks from fourth to eighth, so two neighbouring from left and right side to the crucial sixth. In Figure 6 amplitude function of Hilbert is presented. There is just a little presence of the first harmonic (at about 16 Hz) and somewhat higher at 1.6 Hz. However the magnitude of those peaks are very small.

In Figure 7 a phase function of Hilbert is shown for looking for frequency modulation in time function and in Figure 8 in frequency function. The magnitudes are also very small thus, the frequency modulation is hardly visible. In Figure 9 a derivative of phase – angular velocity is shown.

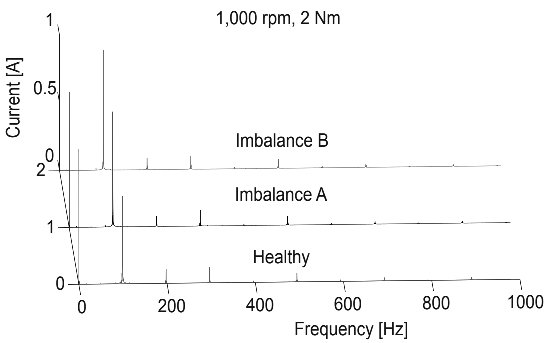

FIGURE 5. Healthy and faulty state shown in current analysis in frequency domain (FFT)

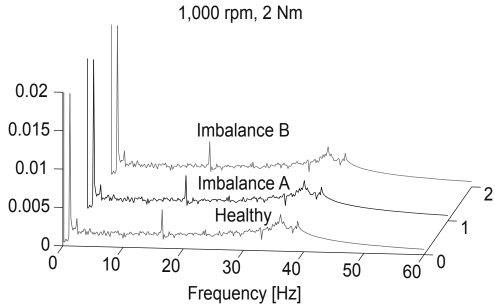

FIGURE 6. Hilbert amplitude analysis

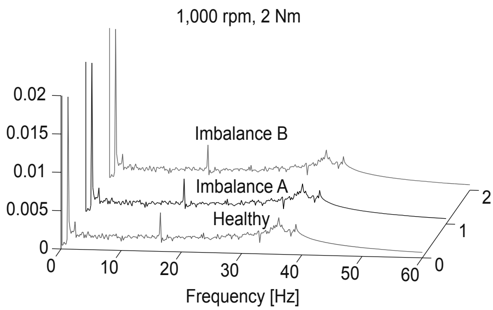

FIGURE 7. Hilbert phase analysis in time domain

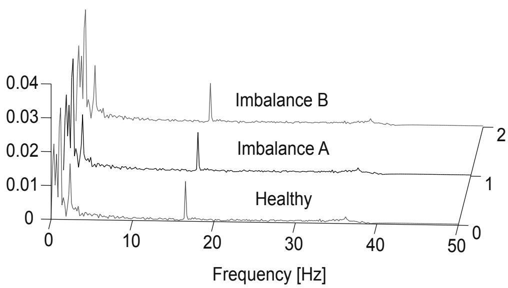

FIGURE 8. Hilbert phase analysis in frequency domain

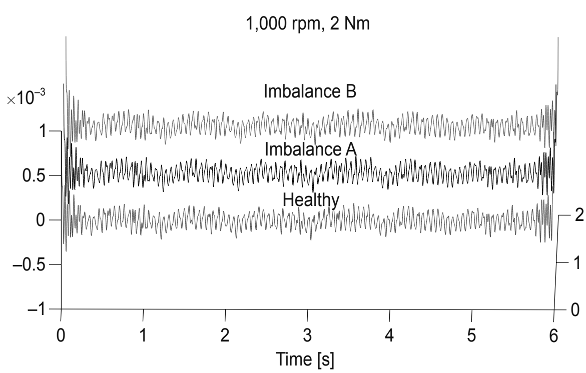

FIGURE 9. Hilbert phase differential analysis (angular velocity) in time domain

CONCLUSIONS

The measurements presented in this article presented little differences between health and fault state of the motor. Also Hilbert analysis showed just a little effect of amplitude and frequency modulation. This is probably due to the fact that shaft mounted for imbalance is rigid, thus even if there is a screw assembled inside, no noticeable effects can be observed. There is also probability that imbalance effect itself has minor effect on the measurement signal and operation of the motor.

In future a model can be built for a verification how experiments correlate with theory.

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Streszczenie: *Analiza sygnału niewyważenia w silniku reluktancyjnym.* W artykule przedstawiono pokrótce analizę i wpływ uszkodzeń na silniki elektryczne na przykładzie silnika reluktancyjnego (SRM). W tym wypadku było to uszkodzenie niewyważenia, które wykonane śrubą wkręcaną w tarczę zamontowaną na wale silnika. W pracy pokazano rezultat z analizy eksperymentu w warunkach obciążenia 1 Nm i przy prędkości równej 1000 obr./min. Porównano analizę Fouriera (FFT), Hilberta w formie amplitudy, fazy prędkości oraz prędkości kołowej. Badania nie wykazały dużych zależności w modulacji. Spowodowane to było zapewne sztywnością zamocowania całego elementu. Nie mniej jednak może to być wstęp do dalszej analizy i późniejszej weryfikacji modelu.

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