

COMPARING TWO INDUCTIONS MACHINE NOISE AND VIBRATION CHARACTERISTICS USING HiL TESTING

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Abstract: In this paper the noise and vibration characteristics of two induction motors are compared. The motors are tested in the same conditions considering their potential application as propulsion for an electric vehicle. The motors were run over a specific testing speed profile while signals from mounted accelerometers and microphones were registered.

1. INTRODUCTION

One of the greatest inventions of the XIXth century is self-propelled machinery, in other words the automobile. Today the cars enjoy great popularity, because according to a study from 2012, 1.1 billion vehicles are registered on Earth. 97% of these vehicles are equipped with an internal combustion engine, which pollutes the environment. When functioning, an ICE emits gases like CO, NO₂, SO₂ that are harmful to living organisms. To solve or reduce this problem, an alternative propulsion system is needed: here there is the forefront of hybrid and electric propulsion. In the hybrid technology an ICE is still used but it is either smaller or it is working as range extender, and thus producing lower pollution. The full electric system does not emit harmful gases, but vibro-acoustic problems could occur, which affect the vehicle's passengers' comfort.

To overcome these problems, a comprehensive analysis of the noise sources is necessary the early phase of the electric powertrain development and noise mitigation solutions are to be developed. Therefore, engineers started to use the real-time testing (RT), which is performed in two steps. The first step is the Model-in-the-loop (MIL) testing. At this stage a virtual model is created for the full system. The model is optimized and when the required values are reached, the virtual elements to be tested are replaced with the real ones stepping forward to the Hardware- in-the-Loop (HiL) evaluation. HiL testing procedures facilitate the evaluation of different electric powertrain components, in real conditions, without asking for the complete vehicle prototype to be available. Since the procedure can be implemented in flexible open-architecture test benches, the measurements are reproducible and applied to different types of electrical machines, reducing testing time and costs.

The present paper describes the HiL procedure implemented on a new developed test bench for the evaluation of noise and vibration level in two induction machines. The results will be used for the validation of the test bench built for electrical vehicles propulsion motors HiL testing.

2. EXPERIMENTAL SETUP

In this study the noise and vibration characteristics of two induction motors are compared. The motors were tested in the same conditions, running over the same testing cycle. The structure of these motors is different, showed in table 1.

Previously a 45 kW induction motor was tested. This IM is supplied through a three-phase inverter from a DC power source (bus voltage) of 720Vdc and rotational speed is 750 rpm, as rated value. The IM has 8 poles (4 pole pairs) and having a rated torque of 580 Nm.

These measurements were repeated on a 22 kW induction motor. The machine under study has 4 poles (2 pole pairs) with the rated torque of 172 Nm.

Table 1.
Tested motors parameters.

Parameter	Value IM 22kW	Value IM 45kW	Unit
Inertia	0.109	2.599	kg*m ²
Phase resistance	0.121	0.271	Ω
Phase current (no-load)	15.1	18.35	A
Phase current (load)	56	90	A
Phase voltage	400	380	V
Nominal speed 50Hz	1365	730	rpm
Rated torque	140	580	Nm

The data acquisition was made with a *Scadas Mobile* interface and *Test.Lab* software, which offer the necessary analog to digital channels for numeric conversion and accurate signal processing capabilities. All this equipment was installed to determine the motor's N&V characteristics. A picture of the analyzed system is depicted in Fig.1 Supplementary elements were considered for the noise and vibration (N&V) analysis. Four accelerometers (mounted around the machine circumference, on the machine's housing) and two microphones were also used – one placed in the motor's immediate proximity and the second at a certain distance. The same data acquisition and post processing unit was used to compute and process the accelerometers and microphones signals response.

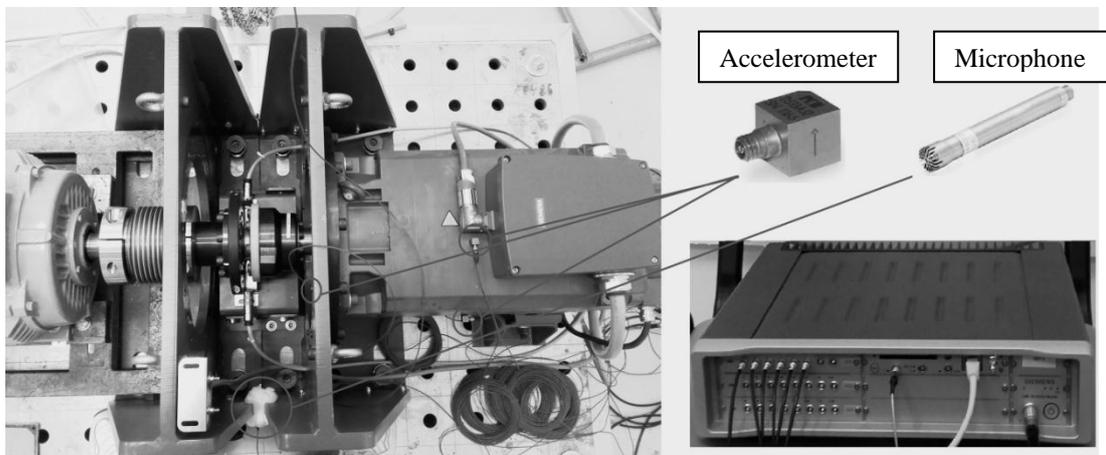


Fig. 1.

The tested motor, equipped with sensors and connected to Scadas mobile interface.

The model is running over the New European Driving Cycle (NEDC) mission profile. The New European Driving Cycle is a speed profile, designed to assess the emission levels of car engines and fuel economy in passenger cars. This cycle is supposed to represent the typical usage of a car in Europe. The full NEDC profile is 1200 seconds. It contains four repeated urban driving cycles (UDC) with a maximum speed of 50 km/h and duration of 200 seconds and one extra urban driving cycle of 400 seconds with a maximum speed of 120 km/h.

3. MEASUREMENT RESULTS

Electromechanical characteristics

The measurements were conducted in the same way like for the 45 kW induction motor which had been previously tested. It was simulated for the same virtual car, with the same ambient conditions and wind speed.

A full NEDC cycle was too long to record the data with high precision, therefore only the first 200 seconds are recorded. In Fig. 2 are presented the 22kW induction motor's mechanic and electric characteristics running over the first 200 second of the NEDC, which is a full UDC cycle. On the first graph the virtual car speed is visible, which is similar to the NEDC. On the second graph the traction motor's speed is showed, on the third the motor's torque is visible; the fourth graph shows the currents.

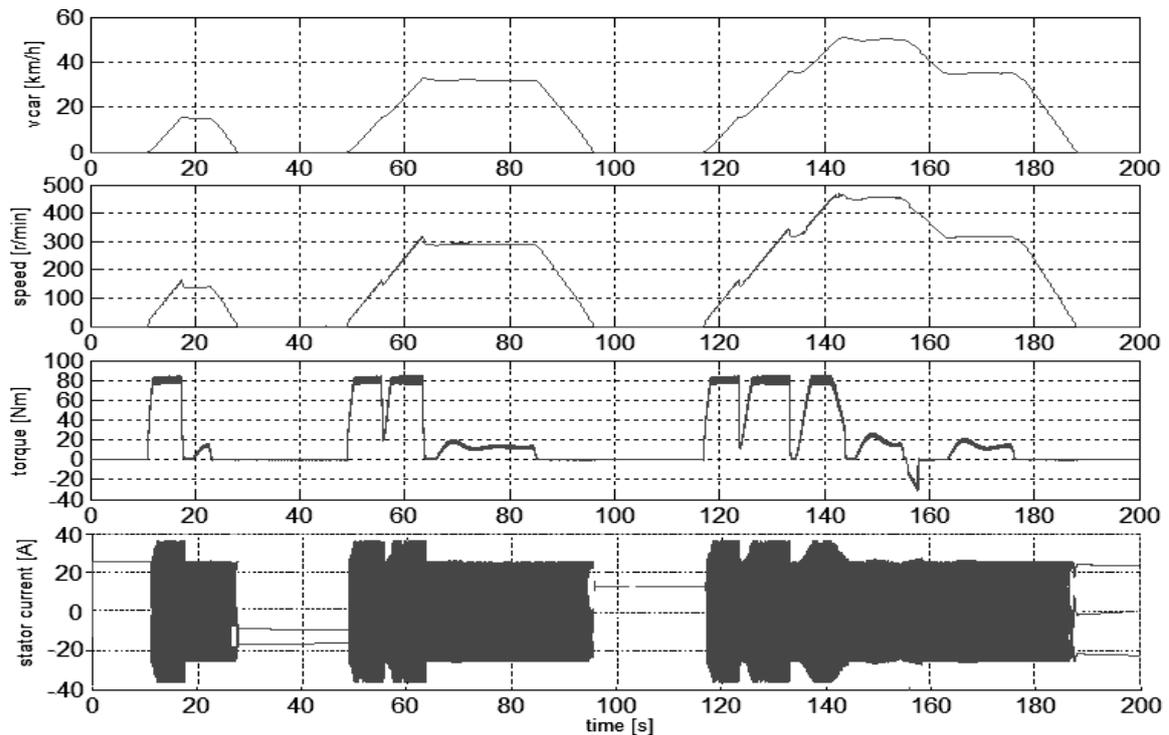


Fig. 2.

The tested motor's electromechanical characteristics.

Vibration and acoustic characteristics

In the figures on the left column, the noise and vibration results of the 45 kW induction motor, are presented. In the figures on the right column, the vibration and acoustic results of the 22 kW induction motor, are showed.

On the left part of both of vibration maps Fig 3, the vertical bands show the motors own resonance frequencies. A dominant resonance frequency is visible at 2720 Hz in case of 45 kW IM (Fig. 3.a) and in case of 22 kW IM (Fig. 3.b) this is at 2380 Hz. While the 45 kW IM has 4 pole pairs (8 pole) the 2720 Hz is the eighth order resonance frequency. In case of 22kW IM the pole pair number is 2 (4 pole), the 2380 Hz is the fourth order resonance frequency.

The oblique lines show the motor's order of harmonic frequencies. In case of the 45 kW IM the first order is 8 (Fig. 3.a), related to the motor's poles number. The 22 kW motor's first order is 4 (Fig. 3.b) the motor has 4 poles. To make as much visible these maps Fig. 3 are zoomed in to Fig 4. In the middle of both vibration maps (Fig. 3), a vibration at 8 kHz is visible, which is generated by the inverter switching frequency. This vibration has a second harmonic, at 16 kHz, visible on the right part of the maps. The speed increase will be clearly to follow to several counts of harmonic oscillations in both cases.

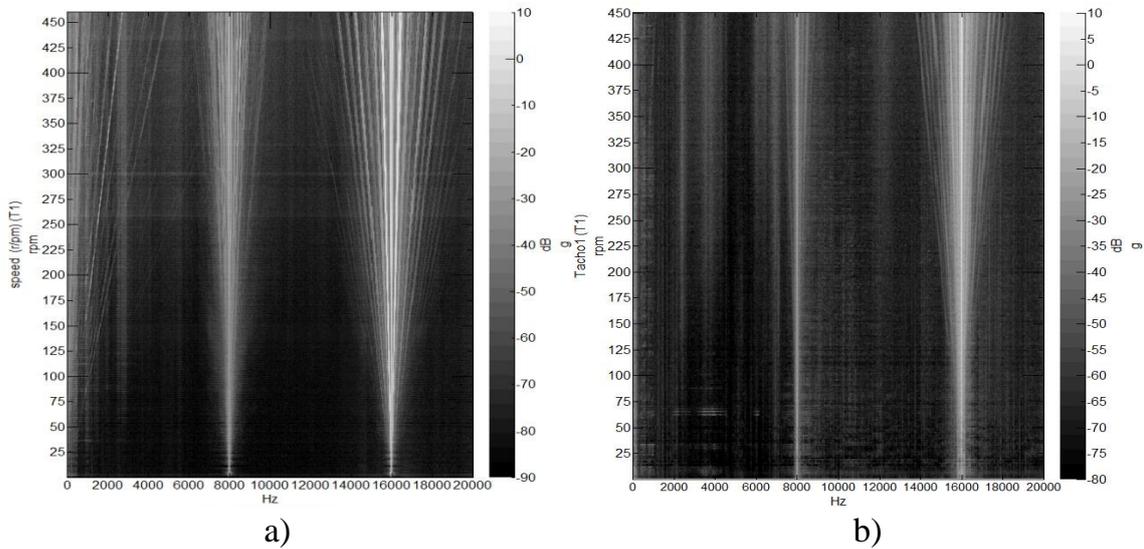


Fig. 3. The motors vibration map, a) 45kw IM, b) 22kW IM.

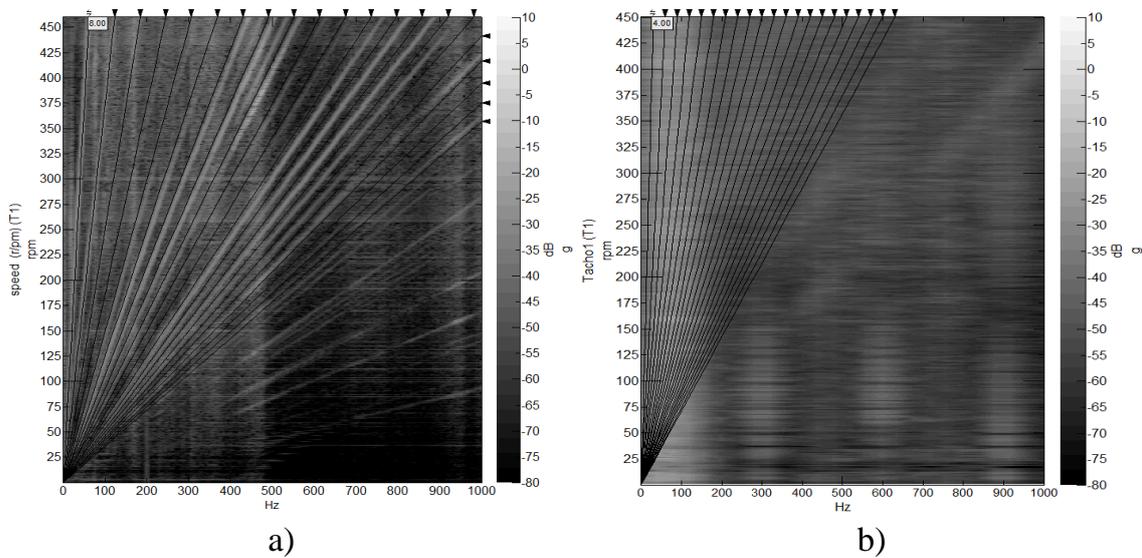


Fig. 4. The motors zoomed vibration map, a) 45kw IM, b) 22kW IM.

In the acoustic map the vertical bars show those frequencies at which the motor is noisier, these points coincide with the motor own resonance frequencies, however, on the dominant resonance frequencies the motor emits less noise. In both of the cases (Fig. 5), is clearly visible the 8 kHz noise, generated by the inverter and its 16 kHz Harmonic.

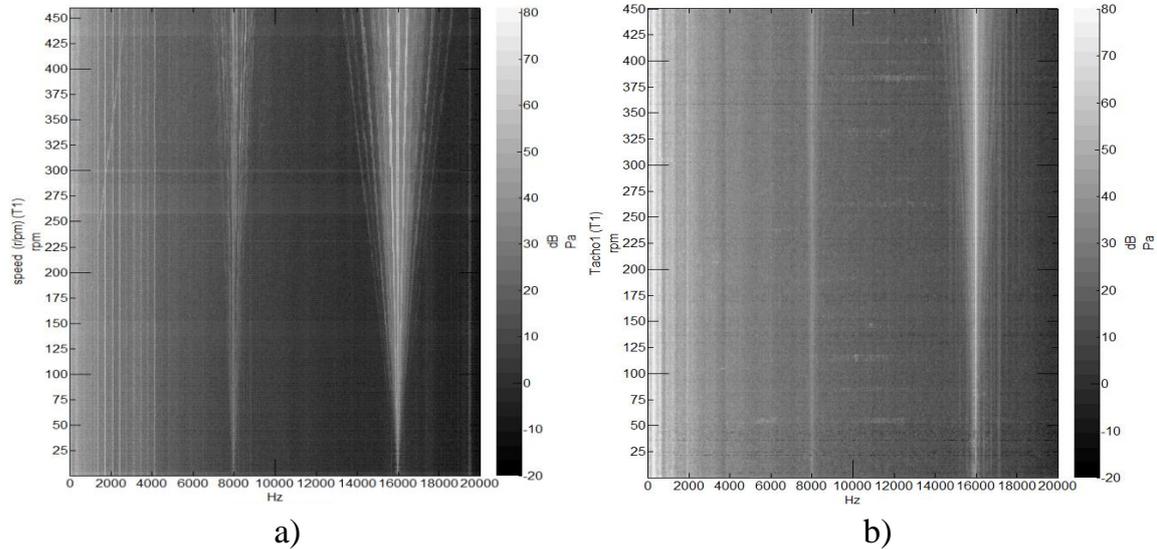


Fig. 5.

The motors zoomed vibration map, a) 45kw IM, b) 22kW IM.

4.CONCLUSIONS

This paper presents the HiL testing results of two induction motors with different power, structure, nominal- speed, torque and mass for validating the new HiL test bench built for EV propulsion motors testing. The induction motors were tested in similar conditions, simulated as propulsion for a virtual car. The results show that the 45 kW induction motor generates more vibration, but the 22 kW motor was noisier. Both motors generate noise at 300 Hz, the 45 kW IM has 60dB, the 22kW IM has 75 dB. The 45 kW motor's dominant resonance frequencies are 200 and 400 Hz; on both frequencies the motor vibration level is -30 dB. In case of the 22 kW IM the dominant resonance frequencies are 300 and 600 Hz, for these frequencies the level of vibration is -50 dB. In the future, different types of motors will be tested, in the same conditions, to make a comparison of the noise and vibration characteristics of them.

5. REFERENCES

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