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# COMPARISON OF NUMERICALLY DETERMINED NOISE OF A 290 KW INDUCTION MOTOR USING FEM AND MEASURED ACOUSTIC RADIATION

In this paper a comparison of numerically determined and measured electromagnetically exited noise of an induction motor is presented. The calculations are accomplished using FEM for an example motor, which is a 290 kW inverter-fed asynchronous machine. The approach starts with the electromagnetic and mechanical consideration. The focus is set on acoustic considerations, which contain the 3D-FE-model and measurement setup in the sound chamber. The determination of the induction and force waves is presented using parts of the results. In the case of the mechanical modeling the three dimensional FE-model is shown.

## 1. INTRODUCTION

Calculating the noise emission of electrical machines has been very important for decades now. In [5] for example basic considerations and efforts to deduce the noise emission have been performed. The air-gap field has also been investigated in [1, 4]. However, the increasing use of inverters has drastically increased the relevance of these investigations. Up to now, the calculation has been based on analytical methods. However, to establish the transient behavior and to take the geometry and non-linearities into account, it is necessary to use the finite element method. In [3], the Eigen frequencies and Eigen modes have been studied using a three-dimensional finite element model. The procedure when carrying out all of the calculations using FEM has been shown in [7]. In [6] the electromagnetic consideration has been treated lengthy and the mechanical consideration detailed so that the focus in this paper will be set on the acoustic consideration including the measurement, calculation and comparison of both.

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## 2. ELECTROMAGNETIC CONSIDERATIONS

The determination of induction and force waves up to 10 kHz requires a well-designed modeling. Especially the air-gap needs a very fine mesh, which is able to build up the rotor steps at the chosen time step of 5 µs. This can easily result in a huge computational effort. Fig. 1 shows the electromagnetic model in Flux to calculate the force waves up to 10 kHz.

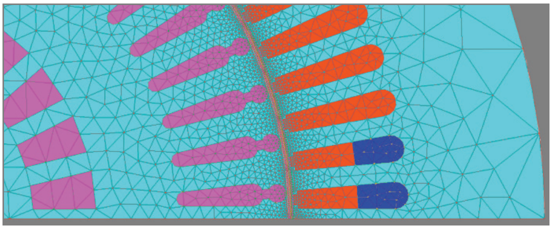


Fig. 1. Electromagnetic model in Flux to calculate the force waves up to 10 kHz

It is necessary to use a transient calculation to take the rotor rotation into account. This simulation leads to the induction in the middle of the air-gap as a curve over the time and location in the air-gap. Using the two-dimensional Fourier-Transformation it is possible to decompose the curve into radial induction waves ([2]), which can be analysed. Table I show the largest induction waves in rated operation and for sinusoidal voltages.

The comparison of rated and no-load operation as well as consideration of inverter-fed has been presented in [6]. Further the calculation of the force waves using Maxwell's stress tensor and the transition to the mechanical model has been shown in [6], too.

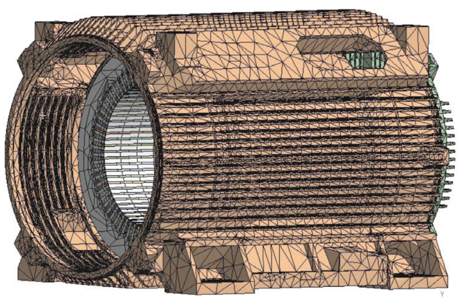
Table 1. Largest induction waves determined with Flux using sinusoidal voltages at rated operation

| | Harmonic number $\|\nu_1\|$ ( ) | Frequency $f$ (Hz) | $B_{rad}$ |
|---|---|---|---|
| Fundamental | 2 | 50 | 100.00% |
| 5th winding harmonic | 10 | 50 | 2.58% |
| 1st stator slot harmonics | 70 | 50 | 14.99% |
| | 74 | 50 | 9.55% |
| 2nd stator slot harmonics | 142 | 50 | 6.46% |
| | 146 | 50 | 5.01% |
| 1st rotor slot harmonics | 50 | 1237 | 12.54% |
| | 54 | 1337 | 12.24% |
| 2nd rotor slot harmonics | 102 | 2524 | 4.48% |
| | 106 | 2624 | 4.76% |

## 3. MECHANICAL CONSIDERATIONS

To determine the surface vibrations, which are the input values for the following acoustic calculation, it is necessary to build up a three-dimensional structural model (Fig. 2a). This model is very detailed to approximate the real vibrational behavior of the machine very well.

To verify the mechanical FE-model a numerical modal analysis and experimental modal analysis (Fig. 2b) has been performed and compared. The accordance of the Eigen frequencies is for the considered Eigen modes ($r \leq 3$, $n \leq 2$) in a band of 10% as shown in [6]. Remarkable is that for the $r = 0$ modes the deviation is less than 1%. These results lead to the conclusion that the FE-model approaches the real vibrational behavior of the machine very well and is used to determine the surface vibration for the following acoustic simulations.



a) FE-model

b) experimental modal analysis

Fig. 2. Mechanical FE-model used for the modal analysis and calculation of the surface vibration as well as the test setup for the experimental modal analysis

## 4. ACOUSTIC CONSIDERATIONS

Even for the acoustic considerations, very detailed measurements have been accomplished. The example motor has been measured in no-load operation for sinusoidal voltages and inverter-fed motor. Further weak foundation (Fig. 3a) and rigid foundation (Fig. 3b) has been considered. The measurement has been performed using the enveloping surface method according to ISO 3744. Therefore 14 microphones have been used.

Figure 4 presents the campbell diagram for no-load operation and with sinusoidal voltages fed motor. The sound pressure level is visualized using the colorbar whereas the frequency and rotational speed are shown on x-axis respectively on $y$-axis. The red diagonal progressions display the noise components which depend on the rotational speed.

a) weak foundation b) rigid foundation

Fig. 3. Measurment setup in the sound chamber

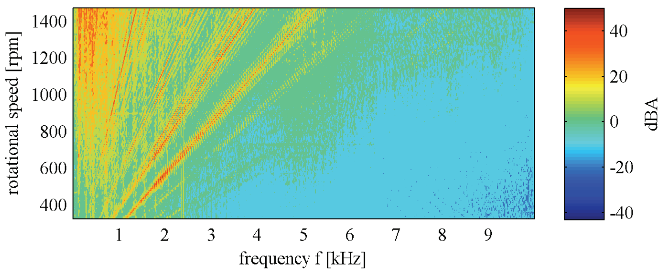



Fig. 4. Measured sound pressure level dependent on the rotational speed and sound frequency for sinusoidal voltages

Comparing the results of Fig. 5 to the results of Fig. 4 it becomes obvious that the influence of the inverter is visible. The pre-existing components are still present but with a lower amplitude. In addition more or less vertical bars with clearly higher amplitude are visible at the inverter clocking frequency and it's multiple.

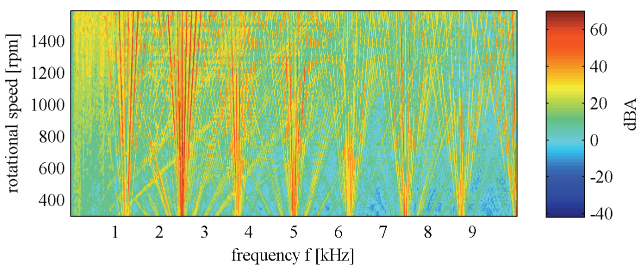
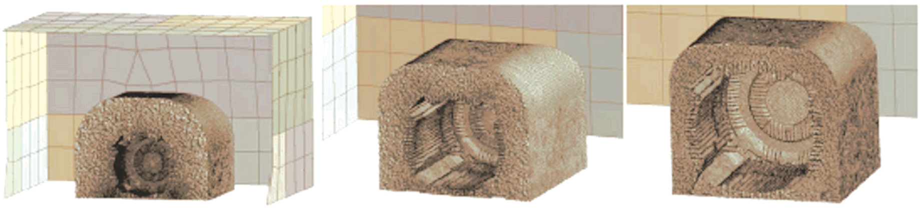



Fig. 5. Measured sound pressure level dependent on the rotational speed and sound frequency for inverter-fed motor at 1250 Hz inverter clocking

In Figure 6 the model used to calculate the noise emission in different bands up to 10 kHz is presented. The size of the shown enveloping body has to be the minimum of either to factor 0.5 larger than the calculated body, or the maximum considered wavelength. Therefore to reduce the calculation time the frequency band has been split in 0–2 kHz, 2–5 kHz and 5–10 kHz. Furthermore the model consists of a coupling surface, which is the surface of the motor. Based on this the finite element domain is defined, which is the enveloping body. Then on the enveloping body infinite elements are chosen. Last the post mesh or any points are set as microphones.

Finally numerical results of the radiated noise are compared to the measured noise. This is presented for inverter-fed machine at no-load operation in Fig. 7. It can be seen that in sum a good agreement results over a wide frequency band. Some amplitudes are determined too low because of the neglected tangential component of the force. This will be considered in coming publications.



a) 0–2 kHz,　　b) 2–5 kHz,　　c) 5–10kHz

Fig. 6. Acoustic FE-models for the three frequency bands

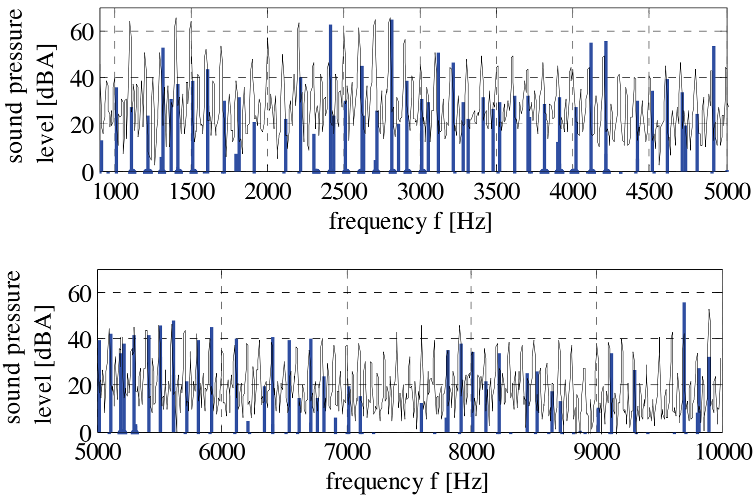



Fig. 7. Comparison of the measured noise (black line) and for discrete frequencies numerically determined noise (blue bars)

## 5. CONCLUSIONS

The previous sections have shown that the calculation of radial force waves can be performed with an acceptable effort. Transient simulations are required, which allow any current curves to be obtained. To allow a comparison between different cases or to analytical calculations, the transient curves have to be transformed into force and induction waves.

For the mechanical part, the modal analysis has shown that the created model is close to the real machine.

At last the acoustic considerations have shown that the numerical results lead to a good agreement to the measured noise. This follows that in future the FEM can be used more often to design new prototypes.

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