

Simulation of Stator Current Signal Fault Characteristics of Induction Motor based on ANSYS

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Abstract— The diagnosis of induction motor problems is a crucial operation in industrial settings. Among the different problems that can occur in induction motors (IM), gear system faults account for almost 60 percent of all faults. At this paper, the detection of stator and rotor failures utilizing electrical signals from IM under various structural factors. The evaluation results indicate that both stator and rotor faults enhance the amplitude of the sidebands of the motor current signature in a Maxwell finite element 2D design. The Finite Element Method is used to examine the electromagnetic field of an induction motor with a faulty gear system that is fed by both the mains and a three-phase voltage source (FEM). Analyses are conducted on electromagnetic field parameters such as voltage distribution, load torque distribution, and coil pitch.

Index Terms— Finite Element, Induction Motor, Electromagnetic Field, ANSYS, Load Torque, Coil Pitch, Gear System, Signal Frequency, Fault Diagnosis.

I. INTRODUCTION

Condition monitoring of motors and drives is important because it minimizes unplanned downtime and prevents catastrophic failures. It will improve efficiency and reduce the cost of motor replacement and maintenance, including maintenance cost and production downtime. In industry, motor is a common power source. Among all kinds of motors, three-phase induction motor is the most common motor in the market today. After all, compared with other equipment, three-phase induction motor has the characteristics of high efficiency, simple structure, durability, high starting torque, low maintenance cost, large power volume ratio, etc., so it stands out in the competition. Like other motors, three-phase induction motors consist of stator and rotor. The stator has a three-phase winding (called the stator winding), while the rotor has a short-circuit winding (called the rotor winding). Only the stator winding is powered by three-phase power supply. The rotor winding obtains voltage and power from the externally energized stator winding through electromagnetic induction, hence the name. It is believed that these machines use about 40% of the world's total power generation, making them the largest energy consumers in the industrial sector [1]. This paper studies a fault feature monitoring technology based on stator current analysis. The existing research shows that current characteristic analysis is helpful to identify load anomalies under different load conditions, such as faults in gearbox

[2],[3]. This research plan uses the ANSYS finite element analysis platform to effectively simulate the electromagnetic field characteristics inside the induction motor. By applying the load under fault conditions, the fault characteristic distribution law in the current signal is studied, providing theoretical support and simulation verification for the mechanical fault diagnosis technology based on current analysis, and serving for the condition monitoring fault diagnosis of various electric drive systems such as electric vehicles [4],[5]. The analyses are performed with a computer which the specifications are listed in Table 1.

TABLE 1. SPECIFICATIONS OF THE COMPUTER USED FOR THE ANALYSES

Computer Platform:	Processor:	Core i7 12 Gen
	Ram:	16 GB
	Graphics:	6 GB

The rest of the paper is organized as follows. In Section 2, designing the Induction Motor Frame 55 KW three-phase squirrel-cage induction motor by using RMxprrt and Maxwell-2D is explained. Through the research study of this experiment, the purpose is to demonstrate the motor modeling and calculation in RMxprrt, the technology of importing the model into Maxwell 2D, and the field circuit coupling with the simplorer voltage circuit.

II. SIMULATION OF 55 KW INDUCTION MOTOR

A. Modelling Object

A notable feature of the Ansys software is that it can connect the control system simulation model (Ansys Simplorer) to the motor object, store complete field data (Ansys Maxwell 2D and 3D), and include the state of the electromagnetic field value in the specified format (two-dimensional calculated magnetic induction vector and three-dimensional formula magnetic induction vector and magnetic field intensity vector). The RMxprrt module generates the basic prototype model, and then sends it to the Maxwell 2D module for finite element analysis. As an example of this study, consider a 55kW three-phase

asynchronous induction motor. The iron core shaft of motor stator and rotor is 255mm long, and the iron core material is hot-rolled silicon steel sheet D23. The stator winding consists of a three-phase 120-degree phase band (gauge is 1). 4 copper wires, 5 strands for each, 22 turns for each slot, double layer winding, pitch 11.

B. Motor Design with RMXprt

Most common AC motors use the squirrel cage rotor. The squirrel cage refers to the rotating exercise cage for pet animals. The motor typically cast aluminum between the iron laminates of the rotor. The major portion of the rotor currents flow through the bars and varnished laminates. Very low voltages at very high currents are typical in the bars and end rings; in order to reduce the resistance in the rotor, high efficiency motors generally use copper. By using RMXprt, aluminum Frame 55 kW three-phase squirrel-cage induction motor is designed. The parameters of the motor are given at Table 2.

TABLE 2. MOTOR DESIGN PARAMETERS

Parameter	Dimension
Stator Outer Diameter	400mm
Stator Inner Diameter	260mm
Stator length	255mm
Stator Number of Slots	48
Slot Type	2
Rotor Outer Diameter	258.4mm
Rotor - Number of Poles	4
Rotor Inner Diameter	85mm
Length	255mm
Voltage	380 V AC 50 Hz

D23_50 material is assigned for laminated steels of rotor and stator. The B-H curve whole coiled of laminated steel is defined as Grade EN 10106. The rotor bars are selected as aluminum. The windings are copper. The shaft is assigned as cast aluminum. The user interface of RMXprt is shown in Fig 1.

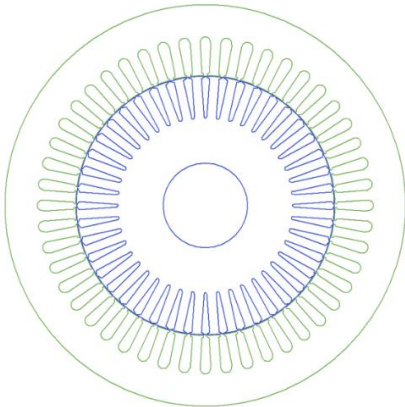


Figure 1. RMXprt Induction Motor Design

Since the RMXprt is a template base tool, the time required for analysis is in order of first, seconds and third Experiments. The parameters are presented at Table 3,4,5.

TABLE 3. EXPERIMENTS 01 PARAMETERS

Coil Pitch	3
Load Torque	3nm
Stop Time	3 seconds
Step Time	0.002s

TABLE 4. EXPERIMENTS 02 PARAMETERS

Coil Pitch	6
Load Torque	3nm+0.2*sin(2*pi*7*time)
Stop Time	3 seconds
Step Time	0.002s

TABLE 5. EXPERIMENTS 03 PARAMETERS

Coil Pitch	9
Load Torque	3nm+0.3*sin (2*pi*7*time)
Stop Time	3 seconds
Step Time	0.002s

C. Motor Design with Maxwell

The motor specified above is transferred from RMXprt to Maxwell with a direct link. Maxwell uses the accurate finite element method to solve static, frequency- domain, and time- varying electromagnetic and electric fields. At Fig 3., the user interface of Maxwell-2D and the linkage menu with RMXprt is presented.

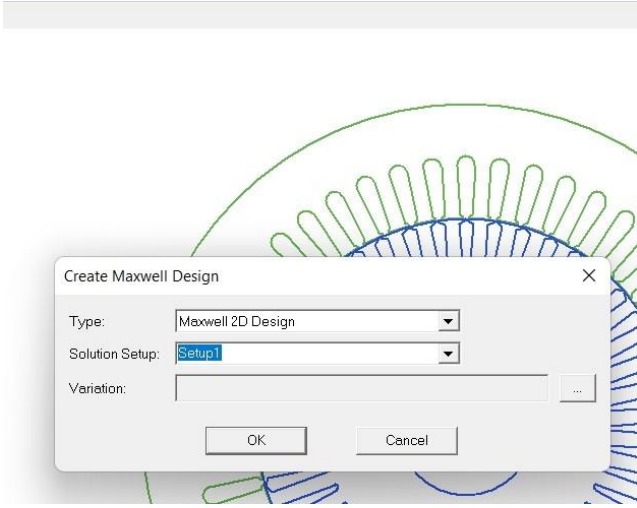


Figure 2. Maxwell User Interface

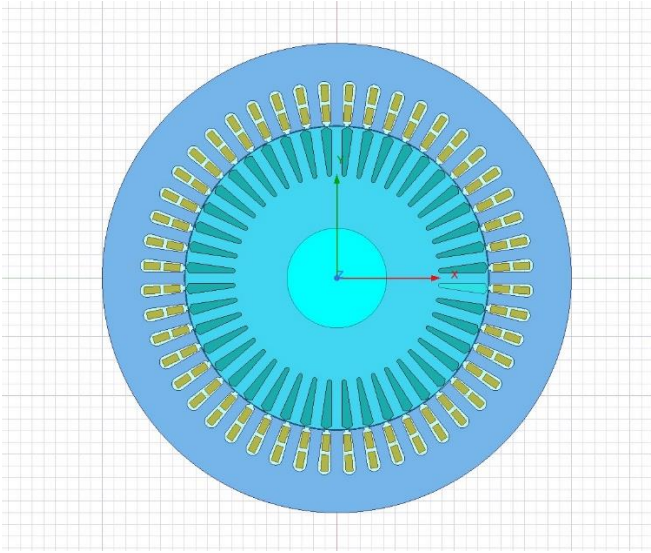


Figure 3. Mesh Model of 55KW Three-Phase Squirrel- Cage induction motor

The motor starts up performance is simulated while it's directly connected to network (380 V AC 50 Hz).

D. MATLAB Coding for Current Signal Analysis

The solution time is 3s, the minimum step is 0.002s, and the maximum step is 0.003s. After the time domain waveform needs to be determined, the result of the winding diagram needs to be exported to the txt file, so that MATLAB programming language can be used to solve this problem. The following programming codes can be used to determine the waveform and signal spectrum characteristics.

TABLE 6. MATLAB CODE OF CURRENT SIGNAL ANALYSIS

```
1. clear all
2. % close all
3. % clc
4.
5.
6. Fs=5000;%sampling frequency
7. id = fopen('C:\Users\CHEN\Desktop\Case 1 Winding Plot
1.txt');
8. data = textscan(fid,'%f %f','delimiter',
',' , 'headerlines',8,'EmptyValue', 0,'MultipleDelimsAsOne', 1);
9. t = cell2mat(data(1));
10. sig=cell2mat(data(2));
11. fclose(fid);
12.
13. Figure;plot(t,sig,'b');xlabel("Time (ms)");ylabel('Amplitude
(A)');
14. set(gcf,'Units','centimeters','Position',[5 3 16 10]);
15. set(gca, 'Position', [0.1 0.13 0.8 0.8]);
16. set(gca,'fontsize',11,'FontName','Times New Roman');
17.
18. N=length(sig);
19. f=(0:N/2-1)/N*Fs;
20. sigspec=abs(fft(sig,N))*2/N;
21. figure;plot(f,sigspec(1:end/2),'b');xlabel('Frequency
(Hz)');ylabel('Magnitude (A)');
22. set(gcf,'Units','centimeters','Position',[5 3 16 10]);
23. set(gca, 'Position', [0.1 0.13 0.8 0.8]);
24. set(gca,'fontsize',11,'FontName','Times New Roman');
```

III. RESULTS

A. Time Domain Waveform Analysis

1) Effect of Different Structural Parameters on Time Domain Characteristics

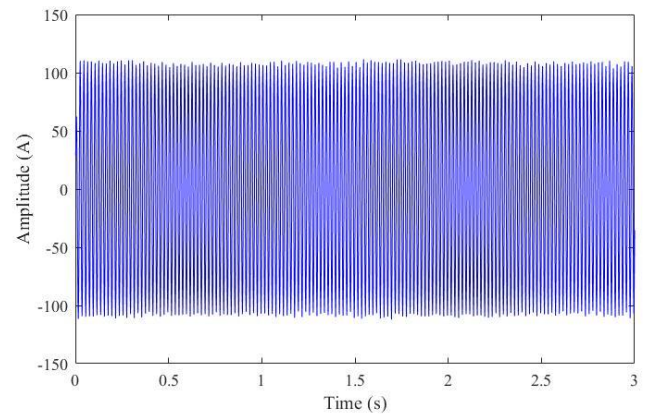


Figure 4. Signal Spectrum of Experiment 1 (Coil Pitch 3, Load Torque 3nm)

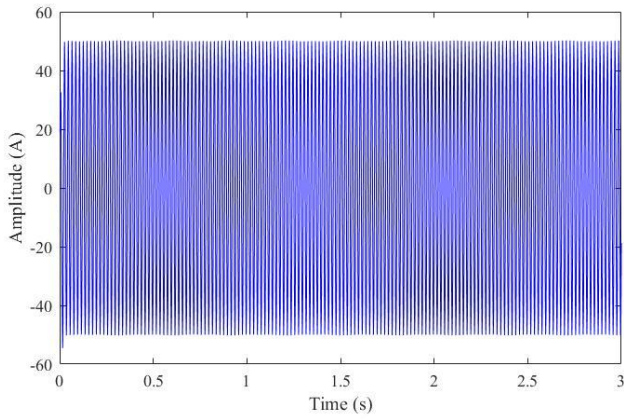


Figure 5. Signal Spectrum of Experiment 2 (Coil Pitch 6, Load Torque $3\text{nm}+0.2*\sin(2*\pi*7*\text{time})$)

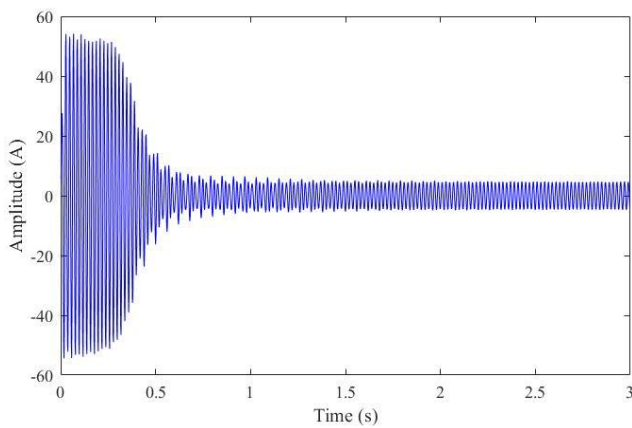


Figure 6. Signal Spectrum of Experiment 3 (Coil Pitch 9, Load Torque $3\text{nm}+0.3*\sin(2*\pi*7*\text{time})$)

In the following two figures, it is determined that when the motor parameters change, the corresponding current signal will also change. Similar to Fig. 5, when the dynamic parameters are very small, the speed of the current signal waveform will not drop too much. However, when the load torque in Fig. 6 increases more, the speed of the current signal will decrease, because the load torque is greater than the motor torque, and with the further increase of the load torque in Fig. 7, the gap between the motor torque and the load torque will increase. Even if the coil pitch and pole pitch are equal, the armature winding is also called full pitch. In this configuration, two opposite sides of the coil pitch are located below two opposite poles. Therefore, the electromotive force (EMF) generated on the pitch side of the coil will be 180 degrees out of phase with the electromotive force induced on the other side of the coil. Therefore, the DC signal of these two EMFs will change the total voltage of the coil pitch. When the coil pitch is greater than other motor coil pitches, the winding phase current signal is called the fractional pitch in the coil. In this coil pitch parameter, the winding phase difference between the EMFs generated on both sides will be less than 180 degrees. Therefore, the

terminal voltage of the coil is the vector sum of the two EMFs, which is less than the terminal voltage of the full pitch coil. In the research of current signal change of dynamic parameters of induction motor, the coil pitch as low as three ninth of the coil pitch (or span) shall be used in each dynamic parameter of induction motor to determine the current signal change without causing significant loss of electromotive force. The purpose of fractional coil spacing and windings is to reduce the amount of copper required for end connections and improve commutation. In Fig. 7, when the coil pitch, stop time and step time increase, the torque load speed also increases, causing the motor speed to increase for a few seconds and then decrease, because the torque load speed is greater than the motor torque speed and cannot be connected to the current signal in the winding assembly. Even if the setting of induction motor is modified by changing stator parameters, coil pitch, time tension of rotor and/or stator winding, there will be no effect. For various parameters of induction motor, increase stator coil pitch and change parameters to analyze current signal loss and performance. Through the experimental study of dynamic parameter changes, the required tests are carried out to obtain the time domain waveform of the current signal, and the performance characteristics of the motor are compared with those of the standard design motor. This research finally proves that the current signal problem is the result of time varying with various factors.

2) Time Domain Fault Characteristics

Stator current signal fault (caused by stator winding fault or asymmetrical phase supply voltage) is also common in induction motors. In the ANSYS experiment, the stator system fault is actually implanted by reducing one of the three-phase power supply voltages. These power supply voltage imbalances will produce sidebands in the stator current spectrum of induction motors. According to the spectrum of healthy exercise in Fig. 5, the appearance of amplitude around the fundamental wave can be observed in Fig. 6 and Fig. 7. These amplitudes are the result of defects in normal and abnormal gear systems by changing different structural parameters. For IM with a constant number of different structural parameters operating at different load levels, it is clear from Fig. 7 that the sideband amplitude around the power frequency increases with the increase of load torque. Therefore, this indicator component is sensitive to load changes.

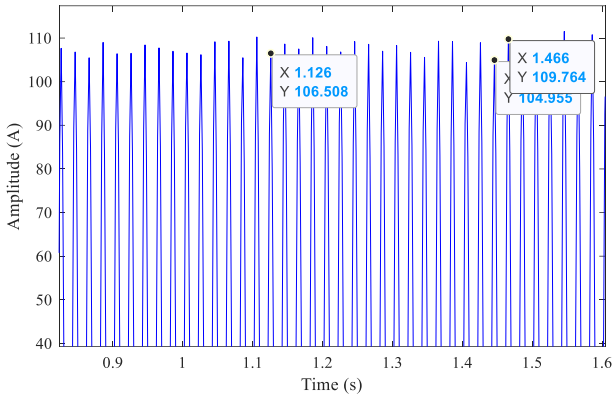


Figure 7. Signal Waveform Difference (Coil Pitch 3, Load Torque 3nm)

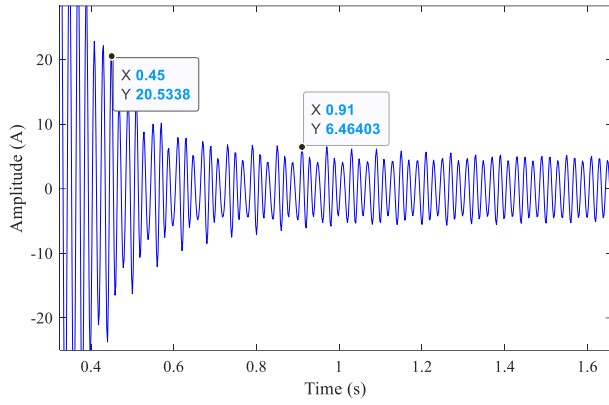


Figure 8. Signal Waveform Difference (Coil Pitch 9, Load Torque $3\text{nm}+0.3\sin(2\pi\cdot 7\cdot \text{time})$)

Stator current waveform and frequency spectrum of a healthy or defective induction motor at 1495 rpm. If the signal is static, the induction motor operates under full load, and the terminal voltage is sinusoidal, then the task of distinguishing fault conditions from normal conditions can be completed accurately according to the FFT spectrum obtained. The electrical waveform in Fig. 8 is different from that in Fig. 9. This is because in Fig. 8, the load torque and coil pitch parameters are 3 nm and 3 respectively, and the voltage of winding phase A is 380. Based on these indicators, it is easy to realize the typical behavior of signal waveform; Therefore, these structural parameters of IM are healthy. However, the current signal waveform in Fig. 9 shows that the synchronous speed and torque of the motor are different, and they do not maintain the same signal waveform between 0 and 3 seconds (Fig 7), which indicates that IM has defects based on these parameters. On the other hand, as shown in Fig. 8 and Fig. 9, the stator current is a non-stationary signal, and its characteristics change with the time-varying operating conditions of the motor. These situations include changes in load torque and power supply.

B. Frequency Spectrum Analysis

1) Influence of Different Structural Parameters on Spectrum Analysis

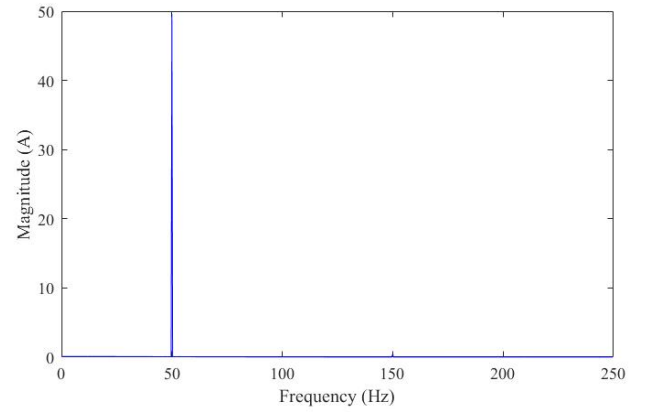


Figure 9. Frequency Results of Experiment 1 (Coil Pitch 3, Load Torque 3nm)

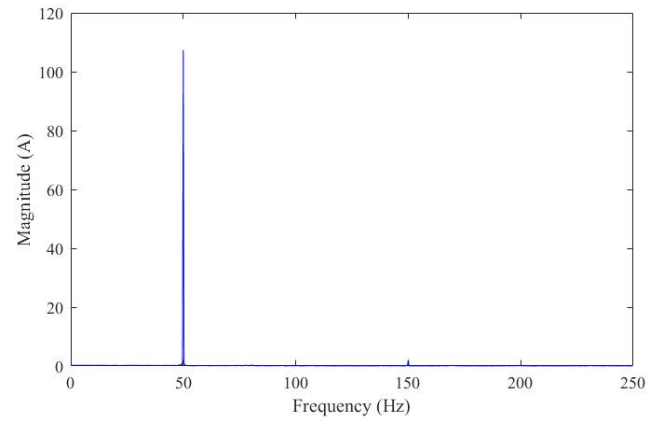


Figure 10. Frequency Results of Experiment 2 (Coil Pitch 6, Load Torque $3\text{nm}+0.2\sin(2\pi\cdot 7\cdot \text{time})$)

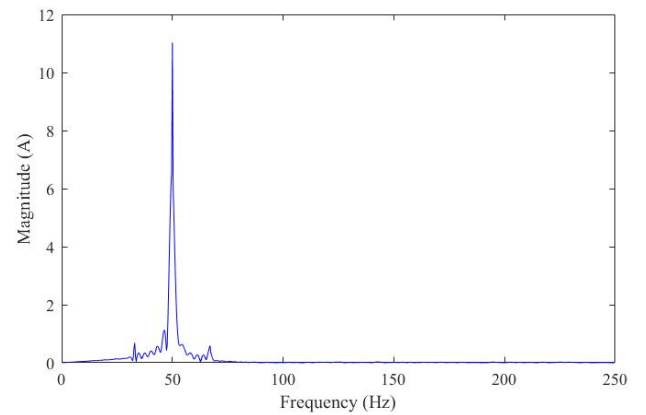


Figure 11. Frequency Results of Experiment 3 (Coil Pitch 9, Load Torque $3\text{nm}+0.3\sin(2\pi\cdot 7\cdot \text{time})$)

In this experiment, three different types of parameters are studied. The stator is installed in a 55 kW bipolar pair induction motor, powered by variable frequency

motors with different structural parameters. This paper proposes to use the frequency edge band in digital extraction to detect bearing faults, which has a good confidence rate, and compares its performance with other structural parameters. This paper studies the influence of gear fault on mechanical parameters such as coil pitch and load torque. The results show that the frequency spectrum change and eccentricity of stator current signal caused by gear defect can be ignored. Therefore, the research focus is on the load torque change caused by gear failure in the system (Fig. 10, 11 and 12). A stator current frequency model is reviewed, which proves that there are sideband components (Fig. 12) in the current spectrum caused by load torque oscillation. A gain graph was established to study the amplitudes of these specific sidebands relative to the frequency of load torque oscillation. A gear system fault automatic detection method based on current spectrum energy estimation (difference frequency between Fig. 11 and Fig. 12) is proposed. Then, the limitations of the proposed index in its definition and use of the gain graph, as well as the general comparison between the signal frequency and the stator current detector, are discussed.

2) Frequency of Domain Fault Characteristics

The characteristic frequency of a faulty gear system is well known in theory. In addition, the frequency harmonics caused by defects can appear as a combination of the characteristic frequency and the rotating frequency of the stator current signal. For a local defect on one of the components of the gear train, the frequency previously given in is shown in the vibration spectrum (Fig. 10). In addition, the natural frequency will also be excited and modulated with the characteristic frequency (Fig. 12). Hilbert transform is used to calculate the analysis signal generated by the stator current signal [6]. The spectrum of the corresponding complex envelope or inherent mode function (IMF) generated by the complex envelope allows detection of amplitude modulation at the characteristic fault frequency (Fig. 10 and 12). The frequency failure of the gear system may cause the side belt eccentricity; Then, the load torque oscillation can be considered, because it is easy to detect the difference between the dynamically changing structural parameters of the induction motor from Fig. 10, 11 and 12. The form of frequency response generated by these filters depends partly on the type of parent wavelet analyzed and its analysis order. In order to prevent overlapping between two adjacent frequency bands, it is necessary to use a higher-order mother wavelet. When the wavelet is applied, a higher-order frequency filter will be generated, as shown in Fig. 14. In order to successfully separate different frequency bands, an obvious trade off must be reached between the order of the parent wavelet and the amount of computation required. Therefore, in-depth research is needed to modify the order of the parent wavelet to meet the requirements. Take the standard wavelet as an example. If we only need to modify it, the time shape of the parent wavelet will show an evolution (see Fig. 13). However, this does not provide us with clear facts about our goals.

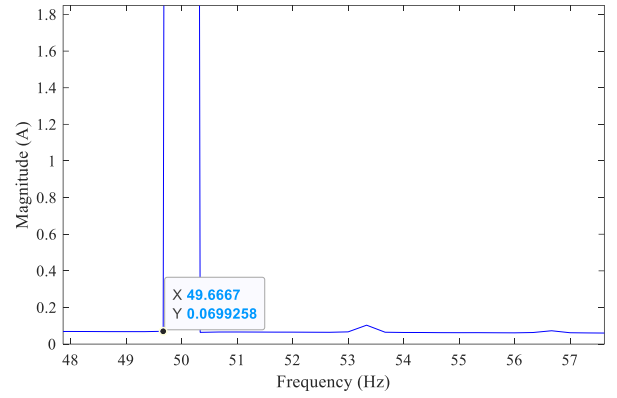


Figure 12. Frequency difference through sideband (Coil Pitch 3, Load Torque 3nm)

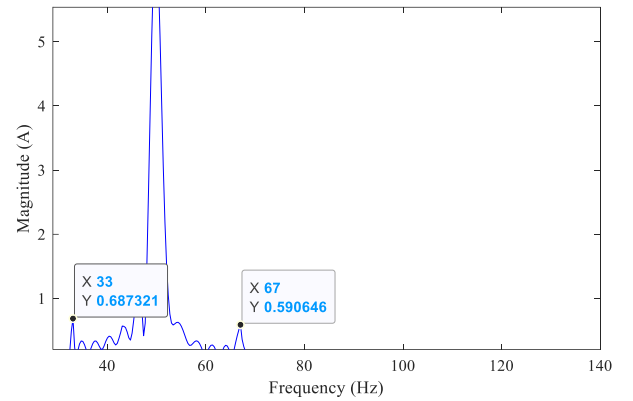


Figure 13. Frequency difference through sideband (Coil Pitch 9, Load Torque 3nm+0.3*sin(2*pi*7*time))

The frequency response of low pass and high pass filters is shown in Fig. 13. This response determines the level of detail and approximate decomposition of each order. In the low order case, the power of a single harmonic very close to the cut-off frequency can be subdivided into two different aspects. This gives a misleading picture of the time evolution of the signal frequency component being studied. If the load torque and coil pitch in Fig. 14 increase, the filter can be idealized to obtain an improved frequency decomposition. Fig. 14 illustrates this disadvantage in more detail. The test signal is composed of two harmonic components, one is 10 Hz, the other is 65 Hz, and the signal is sampled at 140 Hz. The harmonic frequencies of these two components are different. The parent wavelet is used in the wavelet analysis. The harmonic content caused by the 10 Hz superimposed frequency appears in detail Fig. 14, although it should only exist in Fig. 13, which corresponds to the 52 Hz analysis band. Since the filter is not perfect enough to filter the 10 Hz harmonic content in Fig. 13, this problem must be avoided by adding a higher-order mother wavelet in the design. Variable load torque is introduced by using permanent magnet synchronous motor (PMSM) and inverter. This allows for load control. As a reference for torque

management, the installed slope has a rising slope followed by variable load torque. Fig. 13 and 14 describe the evolution of the current obtained and show that it depends on various structural features in IM.

IV. CONCLUSION

A. Summary

This study defines the load torque requirement, which is the torque required to drive the load at a given speed. The load torque demand is proportional to the square of the speed. This is typical for gear systems. The information provided defines the motor torque capability as a function of speed. The steady running speed and torque of the motor driving the load are the intersection of the motor torque capacity curve and the load torque demand curve. If the actual operating speed is higher or lower than the normal operating point when the induction motor is initially energized, the excessive motor torque capability will be applied to accelerate the gear system and load inertia to the normal operating speed.

B. Limitations

Conceptually, the mechanical structure must always be kept in mind. In the analysis of induction motor performance, "no load" is assumed to operate without any connection to the shaft. Unless otherwise specified, rotor speed=load speed. Torque generated in the rotor=load torque plus mechanical losses in the motor, including bearing friction and aerodynamic resistance on the rotor. In this problem, the mechanical loss seems to be considered as part of the load or can be ignored. Stator speed=torque speed=magnetic field speed=synchronous speed. In this problem, the stator current signal loss seems negligible. In the equivalent circuit, the current signal loss will be expressed as a resistor in parallel with the load torque. This is a huge loss worth ignoring, but I think it may be necessary to ignore it in order to build the way of the problem.

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Azrugh Islam Badhon is a Bangladeshi Electrical Engineering graduate and Working as an Assistant Engineer (Electrical) in Chittagong Dry Dock Limited (CDDL), Bangladesh Navy. His research interests include Information theory, Optical Network, Photonics, Signal Processing and Renewable energy.