

Practical Motor Current Signature Analysis Taking the Mystery Out of MCSA

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Introduction

The purpose of this paper is to provide the MCSA user with practical instruction in identifying key frequencies detected using MCSA. Several items will be assumed based upon previous white papers and articles produced by the author: Definitions such as 'slip speed,' 'synchronous speed,' 'running speed,' 'harmonics,' etc. Will not be defined. Also, the difference between RPM and RPS (Hz), etc. Will be the RPM/line frequency (ie: 60 Hz in the USA).

It must be noted that most of the frequencies and faults identified within this ALL-TEST Pro white paper are automatically identified when using the ALL-TEST PRO OL (ATPOL) motor current signature analyzer and associated software. In many cases, the only information that you will need is the motor nameplate information. The number of rotor bars and stator slots, if unknown, is estimated directly by the ATPOL system.

In this paper, however, we will identify the need to review a complete motor system as identified in the 'Multi-Technology Approach to Motor Diagnostics.' This will assume that all information is obtained, including:

1. Number of rotor bars
2. Number of stator slots
3. Driven equipment diameters, etc.
4. Bearing sizes and manufacturers.

Our next white paper will focus on the identification of MCSA results when little, or none, of this information is known.

What is MCSA?

Motor Current Signature Analysis (MCSA) is a system used for analyzing or trending dynamic, energized systems. Proper analysis of MCSA results will assist the technician in identifying:

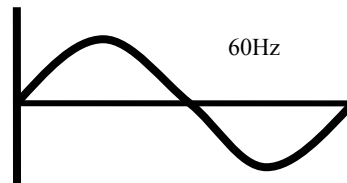
1. Incoming winding health
2. Stator winding health
3. Rotor Health
4. Air gap static and dynamic eccentricity
5. Coupling health, including direct, belted and geared systems
6. Load issues
7. System load and efficiency
8. Bearing health
9. Much more

(Note that all MCSA systems are not the same and may be limited in performing the analysis cited here - The ATPOL system can perform well beyond the analysis identified within this paper)

MCSA uses the electric motor as a transducer, allowing the user to evaluate the electrical and mechanical condition from the Motor Control Center (MCC) or disconnect. For accurate analysis, MCSA systems rely upon FFT analysis, much the same as vibration analysis. Most MCSA systems also rely upon analysis of demodulated voltage and/or current, which involves the removal of the fundamental frequency (Line Frequency or LF).

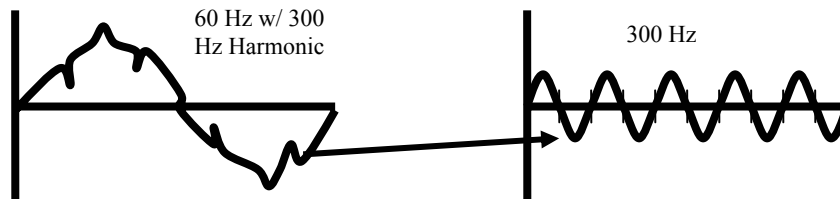
The frequencies found within the LF are used to identify faults. These frequencies are found as 'ripples' within the LF caused by incoming power or load-related (including motor condition-related) effects.

Figure 1: Line Frequency



If we take the frequency shown in figure 1 as the LF of the system, this would be a good or 'perfect' frequency. Now if we add a 'sub-harmonic' or a second frequency to the sine-wave, it will appear as shown in figure 2.

Figure 2: Line Frequency with Harmonic Content



If these frequencies are calculated by using FFT, the result will look like figure 3.

Figure 3: FFT Analysis



What could be causing these frequencies? How can they be determined? These answers are to be provided.

Electrical Analysis

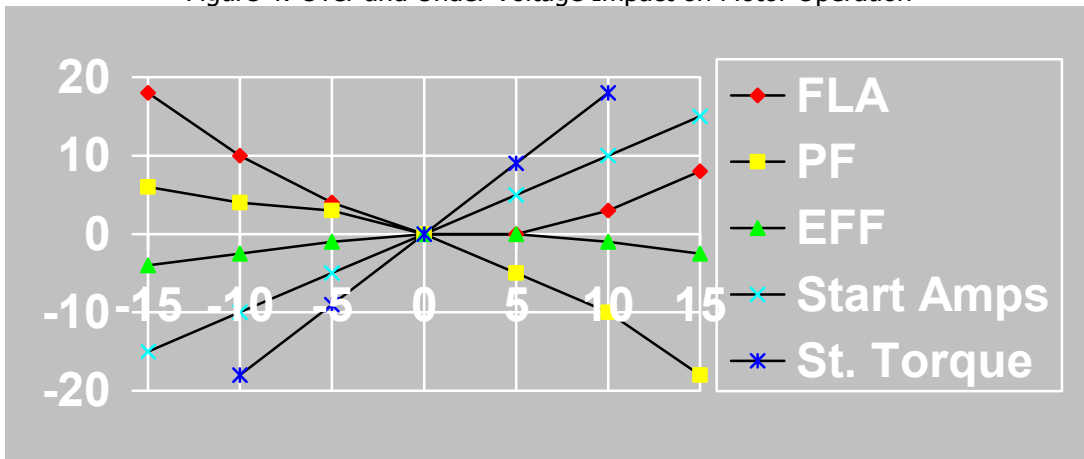
Power Quality

Power quality involves the condition of power supplied to the motor system. In a perfect world, the supply power will have a perfectly balanced voltage and current sine-wave. However, rarely, if ever, will you find a 'perfect' system. Power quality, alone, will be covered more in-depth in a following paper. We shall cover the more common issues that meet the requirements of this paper here.

The most common power quality issues and limits are:

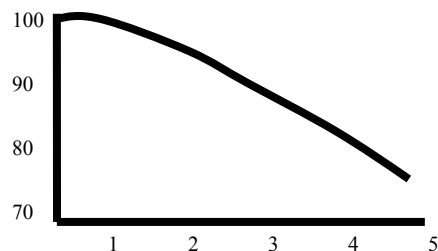
1. Voltage quality: In an electric motor system there are two primary issues with voltage:
 - 1.1. Over or under voltage or voltage deviation from nameplate. The limits on supply voltage are $\pm 10\%$ of nameplate voltage with $\pm 5\%$ being optimal. Deviation from nameplate will result in changes to the motor operating characteristics as identified in figure 4.

Figure 4: Over and Under Voltage Impact on Motor Operation



- 1.2. Voltage unbalance, which causes unbalanced current in the motor resulting in overheating of the winding. The relationship of voltage and current unbalance can be a few to over 20 times, depending on the motor size and winding design. As a result, identifying voltage unbalance has more of an impact than identifying current unbalance, alone. The limit is 5% with 2% being optimal. The increased heating of the motor windings requires de-rating of the motor load as shown in figure 5.

Figure 5: Voltage Unbalance (Derating Factor)



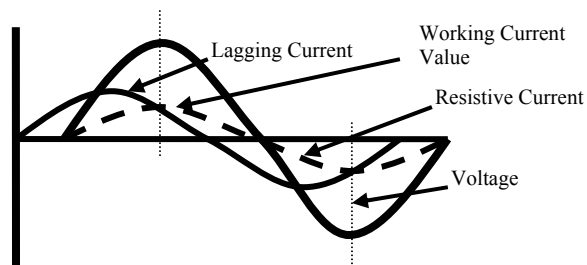
2. Harmonic distortion is another area of concern and is normally caused by electronic switching systems which cause standing, negative and positive rotating fields within the motor. Single phase systems, such as computers and electronic lighting ballasts, cause neutral, or third, harmonics that result in neutral currents and transformer heating. Fifth and seventh harmonics are caused by three phase systems, such as variable frequency drives, and cause motor stator and rotor heating. There are two major players in system power harmonics:

2.1. Voltage harmonics are of concern with a recommended limit of 5% THD (Total Harmonic Distortion) per IEEE Std 519.

2.2. Current harmonics are considered far more serious with a recommended limit of 3% THD per IEEE Std 519.

3. Power factor is represented, in an inductive circuit, as how the peak current lags behind the peak voltage. The result is additional current requirements for the same load as current lags further behind voltage (ref figure 6). The optimal is a factor of '1,' however, in most systems a power factor of 0.85 is considered OK.

Figure 6: Power Factor



Rotor Analysis

One of the primary strengths of MCSA is rotor analysis. Broken rotor bars, static eccentricity and dynamic eccentricity are three basic types of rotor issues that MCSA can evaluate.

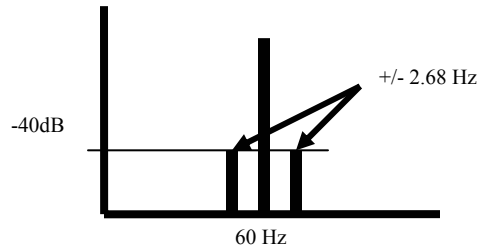
Broken rotor bars are generally found as slip frequency sidebands around the fundamental frequency. The standard rule of thumb is that faults are detected when these sidebands meet or exceed -35db (often referred to as '35 dB down').

Figure 7: Broken Rotor Bar



For example, a motor running 1760 RPM in a 60 Hz system would have a running frequency of $1760 \text{ RPM} / 60 \text{ sec/min} = 29.33 \text{ Hz}$. The slip frequency would be $((2 * LF) / \text{poles} = (2 * 60 \text{ Hz}) / 4 \text{ poles} = 30 \text{ Hz}$ (synchronous speed) then $30 \text{ Hz} - 29.33 \text{ Hz}$ (running speed) = $(0.67 \text{ Hz} * 4 \text{ poles}) = 2.68 \text{ Hz}$. If 2.68 Hz sidebands occur around the 60 Hz FFT peak and they were to have a value of -40 dB, then broken rotor bars exist.

Figure 8: Example of Broken Rotor Bar Sidebands

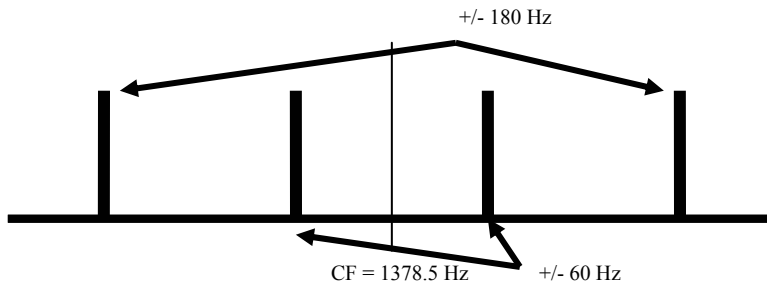


Static eccentricity can be found in the high frequency spectrum. Static eccentricity occurs where the Center Frequency (CF - Definition: The rotor bars times running speed and stator slots times running speed are often referred to as CF. CF's are not peaks in the spectrum but are made up as $(\text{frequency} + \text{frequency})/2$ $CF = \text{Running Frequency (RF)} * \text{the number of rotor bars (RB)}$ with line frequency times N sidebands, where N is an odd integer.

Formula 1: Static Eccentricity = $(RB * RF) +/- (N * LF)$, where N = odd integer

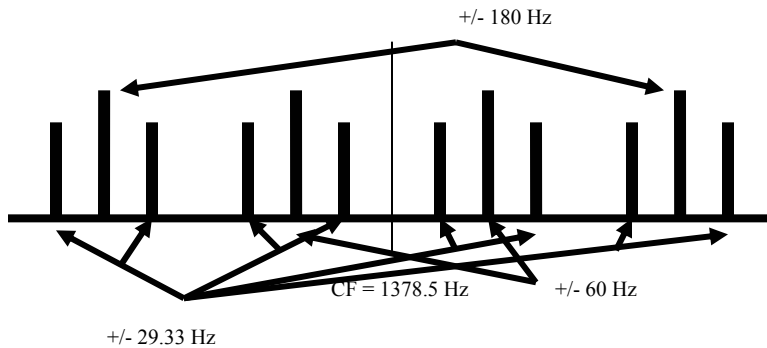
For example, if the 1760 RPM motor, cited earlier, was known to have 47 RB, the base frequency would be: $29.33 \text{ Hz} * 47 \text{ RB} = 1,378.5 \text{ Hz}$ CF with 60 Hz, 180 Hz, etc. Sidebands (reference figure 8).

Figure 8: Static eccentricity



Dynamic eccentricity differs from static eccentricity only in that there will also be running speed sidebands around the static eccentricity sidebands of the base frequency as shown in figure 9.

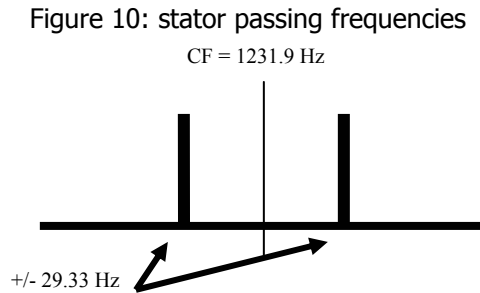
Figure 9: dynamic eccentricity



Stator Analysis

Stator winding problems are found by first identifying stator slot passing frequencies (SP). CF is found by multiplying the number of stator slots by the running speed. Problems are found when sidebands appear around the SP CF.

For example, the running speed of 29.33 Hz * 42 Slots = 1,231.9 CF. If the CF has sidebands of running speed, then stator mechanical or electrical degradation has occurred.



Mechanical Analysis

Bearings

In order for bearing problems to appear in MCSA, the condition will be severe. Bearing problems found through this method should be considered urgent and addressed as soon as possible.

To determine bearing issues, you must first obtain the appropriate bearing manufacturer and size, then obtain the bearing multipliers, which can be obtained from the manufacturer's catalog or directly through ATPOL's MCSA software. These multipliers include:

1. Ball Pass Outer Race (BPOR)
2. Ball Pass Inner Race (BPIR)
3. 2x Ball Spin Frequency (2xBSF)
4. Cage Frequency (FTF)

The bearing frequencies are found as each multiplier times running frequency with line frequency sidebands (ie: (BPOR * RF)+/-LF). Harmonics of the bearing frequencies can be found by multiplying each bearing frequency by integers (N) with line frequency (LF) sidebands around each.

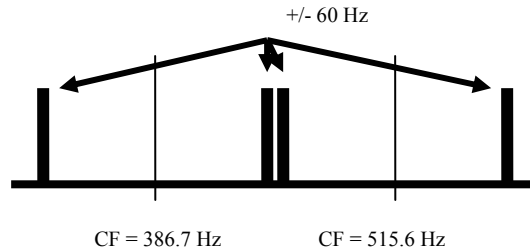
$$\text{Formula 2: Bearing frequencies} = (\text{BPOR} * \text{RF} * \text{N}) +/- \text{LF}$$

For example, the bearing frequencies for a 6305 NTN bearing in a motor with 29.33 Hz running speed would be found as: BPIR = 4.394; BPOR = 2.606; FTF = 0.372; and, 2xBSF = 1.830. When calculated, the results are found in table 1.

Table 1: NTN 6305 bearing frequencies

	1X	2X	3X	4X
BPIR	128.9	257.8	386.7	515.6
BPOR	76.43	152.9	229.3	305.7
FTF	10.91	21.82	32.73	43.64
2xBSF	53.67	107.3	161.0	214.7

Figure 11: Bearing fault frequencies

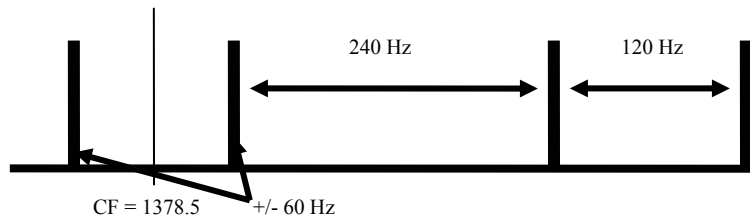


Mechanical Imbalance

Mechanical imbalance is found by determining the $RB * RS$ center frequency, as in static and dynamic eccentricity, $47 RB * 29.33 Hz RS = 1,378.5 Hz$. There will be LF sidebands around the CF, then a space of four times LF, then two $2*LF$ peaks. You may also see a heightened running frequency peak.

The pattern to view is twice line frequency, four times line frequency, twice line frequency. In a 60 Hz system, this will appear as 120 Hz, 240 Hz, 120 Hz.

Figure 12: Mechanical Imbalance

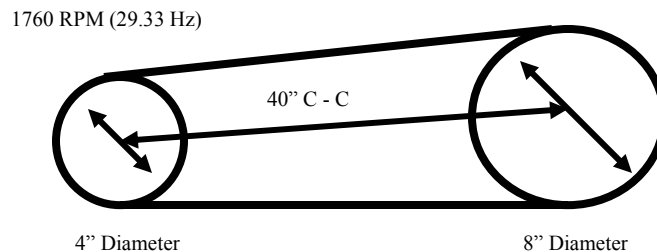


Driven Equipment

Driven equipment frequencies can also be detected. We will cover belted, geared, direct drive and fans and impellers in this paper.

Belts

Figure 13: Belts and Sheaves



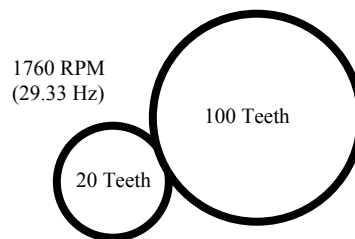
In order to determine the frequencies associated with the system identified in figure 13, there are several steps. In this example we shall identify the motor speed as 1760 RPM (29.33 Hz), one 4 inch (driver) and one 8 inch (driven) diameter sheave with a 40 inch center to center sheave distance.

Step 1: Determine the driven shaft speed by determining the sheave ratios. In this case, it will be $RS * (\text{driver dia}/\text{driven dia}) = 1760 \text{ RPM} * (4 \text{ inch}/8\text{inch}) = 880 \text{ RPM}$ which is 14.67 Hz.

Step 2: Determine the belt speed by determining the belt length which is equal to: $(\text{center to center distance (C-C)} * 2) + \frac{1}{2}((\text{driver}'' * \pi) + (\text{driven}'' * \pi)) = (40'' * 2) + \frac{1}{2}((4'' * \pi) + (8'' * \pi)) = 97.28''$. Next, the surface (conveyor) speed can be determined by calculating the conveyor speed for either sheave. In this case, we can use the motor sheave and calculate $(\text{radius} * 2\pi * \text{RPM}) = 2'' * 2\pi * 1,760 \text{ RPM} = 22,117 \text{ inches per minute (IPM)}$ or 368.6 inches per second (IPS). The belt speed can then be determined by taking the conveyor speed and dividing it by the belt length. In this case, $368.6 \text{ IPS} / 97.28 \text{ inches} = 3.79 \text{ Hz}$.

Gear Mesh

Figure 14: Gear Mesh



The driven shaft speed in a geared system is fairly straight forward to determine, as well as the gear mesh frequencies.

The driven shaft speed can be determined by multiplying the driver speed times the ratio of the driver gear to the driven gear number of teeth: $\text{Driven} = 29.33 \text{ Hz} * (20 \text{ Teeth}/100 \text{ Teeth}) = 5.87 \text{ Hz}$.

The gear mesh frequencies are determined by taking the running speed times the number of teeth. The value is the same for either gear: $\text{Gear Mesh} = 29.33 \text{ Hz} * 20 \text{ Teeth} = 587 \text{ Hz}$. Sidebands around this CF would indicate gear mesh problems.

Driven Equipment – Blade Pass Frequencies

As with calculating the driven speed in a geared system and gear mesh, calculating blade pass frequencies for either fans or impellers is straight forward: The number of blades multiplied by the shaft speed.

In the direct drive system used in the previous examples, the operating speed is 29.33 Hz. A pump with six blades would have a blade pass frequency of $29.33 \text{ Hz} * 6 \text{ Blades} = 175.98 \text{ Hz}$.

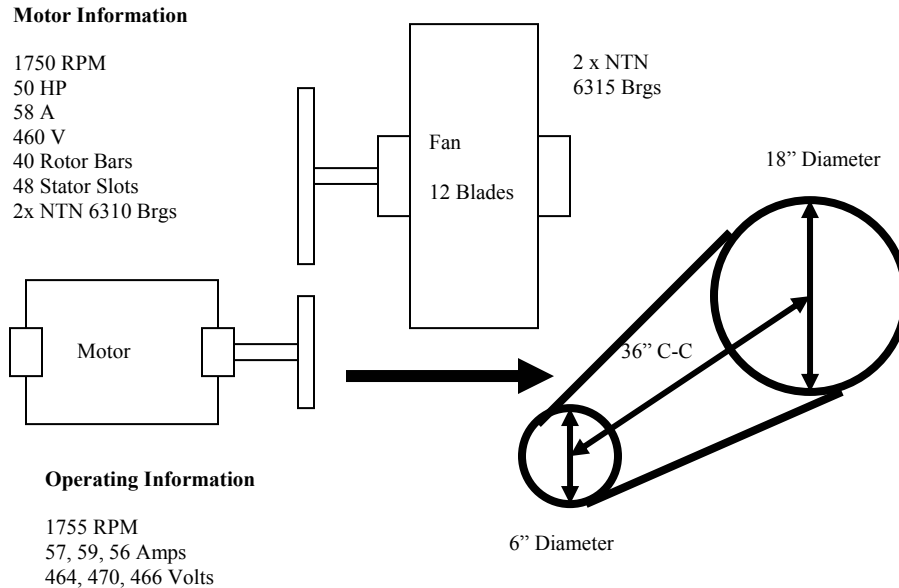
If it was a fan with 12 blades using the pulley system in the belts section of this paper, the blade pass frequency would be $14.67 \text{ Hz} * 12 \text{ Blades} = 176.04 \text{ Hz}$.

Faulty impellers or blades would be indicated at these frequencies and may include sidebands. The frequencies and harmonics remain the same regardless of how many blades have faults.

Bringing It All Together

Now, to tie it all together, we shall review the system as found in Figure 15. As noted in the beginning of the paper, we shall assume that all necessary data is available.

Figure 15: Fan System for Evaluation



In this section, we will calculate all of the critical frequencies that would help us identify problems in this system. The system consists of a 50 horsepower motor with the identified Motor Information, fan information and bearing information.

Basic Power Quality

The running information shows a 57, 59 and 56 Amp draw with voltage values of 464, 470 and 466. There is no perceptible harmonic distortion and the power factor of the system is above 0.85.

Example 1: Voltage Unbalance

$$(464V_a + 470V_b + 466V_c)/3 = 467 V_{ave}$$

$$(467V_{ave} - 464V_a)/467V_{ave} * 100\% = 0.6\%$$

0.6% Voltage unbalance is acceptable.

Example 2: Voltage Deviation

$$(467 V_{ave} - 460 V_{np})/467 V_{ave} * 100\% = 1.5\%$$

Determine Rotor Bar Sideband Frequencies and Eccentricity CF

The running frequency is determined by calculating the operating speed divided by the LF. In this case, 1755 RPM/60 Seconds/min = 29.25 Hz. The sidebands are determined by subtracting the running frequency by the actual speed: 30Hz - 29.25Hz = 0.75Hz * 4 Poles = 3 Hz.

In this exercise, we shall consider two frequencies around the 60Hz line frequency peak of 59.25

Hz and 60.75 Hz (+/- 3 Hz) with a value of -20 dB. This is less than the -35 dB that would indicate a severe problem, but sidebands do exist, indicating that the condition of the equipment should be watched. If multiple sidebands of slip frequency occur, there may be high resistant connections (in copper rotor bar machines) or casting voids. Either condition can be confirmed using a de-energized motor circuit analysis rotor test.

The center frequency for static or dynamic eccentricity is: 29.25 Hz * 40 Rotor Bars = 1170 Hz.
The stator center frequency would be: 29.25 Hz * 48 Stator Slots = 1404 Hz.

Belt Speed Frequencies and Driven Speed

Next, the belt speed and driven frequencies are calculated:

$$\begin{aligned} \text{Driven Shaft} &= 29.25 \text{ Hz} * (6''/18'') = 9.75 \text{ Hz} \\ \text{Belt Length} &= (36'' * 2) + (0.5(6\pi + 18\pi)) = 147.4'' \\ \text{Conveyor Speed} &= 6\pi * 29.25 \text{ Hz} = 551.3''/\text{sec (IPS)} \\ \text{Belt Frequency} &= 551.3 \text{ IPS}/147.4'' = 3.74 \text{ Hz} \end{aligned}$$

Bearing Frequencies Driver and Driven

Table 2: Bearing Base Frequency Multipliers

	6310 NTN Brgs	6315 NTN Brgs
BPIR	4.929	4.919
BPOR	3.071	3.081
FTF	0.384	0.385
2xBSF	2.036	2.062

The multipliers are multiplied by the running frequency and integers in order to determine bearing CF and harmonics of CF. Following would be the base (1X) harmonic CF's for these bearings with the motor frequency at 29.25 hz and a fan shaft frequency of 9.75 Hz.

Table 3: Bearing Base Harmonic CF's

	6310 NTN Brgs	6315 NTN Brgs
BPIR	144	47.96
BPOR	89.8	30
FTF	11.23	3.75
2xBSF	59.55	20.1

Blade Pass Frequencies and Mechanical Unbalance Frequencies

The blade pass frequency would be figured using the fan shaft speed:

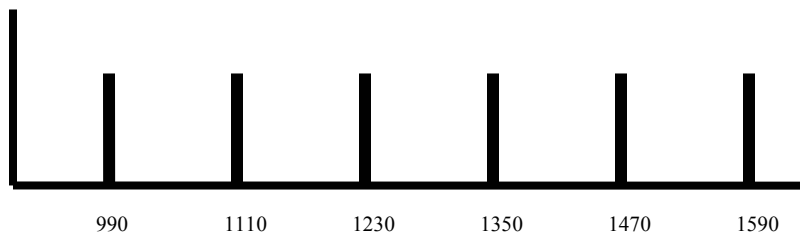
$$\text{Blade Pass} = 9.75 \text{ Hz} * 12 \text{ Blades} = 117 \text{ Hz}$$

The mechanical imbalance CF would be calculated as:

$$\text{Mechanical Imbalance} = 29.75 \text{ Hz} * 40 \text{ Rotor Bars} = 1190 \text{ Hz}$$

Sample Problem

Figure 16: Fault Frequencies

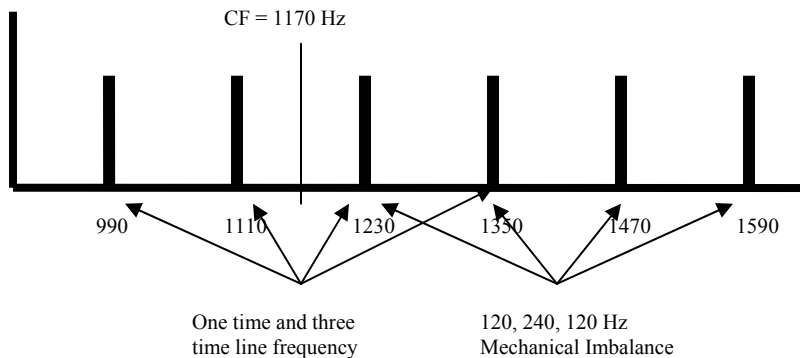


Through a review of the higher frequency peaks of the FFT spectrum, the closest values to center frequencies are the rotor and stator center frequencies. In order to determine which values fit, take the two surrounding frequencies, add them together and divide by two:

For Rotor Eccentricity and Imbalance = $(1110 \text{ Hz} + 1230 \text{ Hz})/2 = 1170 \text{ Hz}$
This meets the Rotor CF of 1170 Hz

For Stator Faults = $(1350 \text{ Hz} + 1470 \text{ Hz})/2 = 1470 \text{ Hz}$
This does not meet the Stator CF of 1404 Hz

Figure 17: Evaluation of Fault Frequencies



Once the CF has been determined, the data can be analyzed. In this case, the rotor CF has 1x and 3x line frequency sidebands which indicate static eccentricity. The additional peaks show the 120 Hz, 240 Hz and 120 Hz pattern that indicates mechanical imbalance.

Considerations in Modern MCSA Instrument Technology

At the end of 2003, ALL-TEST Pro, A Division of BJM Corp, introduced the ALL-TEST PRO OL Motor Current Signature Analysis (MCSA) system. The abilities of the system include:

- ✓ Automated analysis with limited information
- ✓ Automated detection of rotor bars and stator slots
- ✓ Complete Power Quality Datalogging capability
- ✓ Hand-Held

A typical approach using the ALL-TEST **PRO**[™] OL system for MCSA includes:

1. Follow all applicable safety requirements for your plant.
2. Collect data using the data collector – 30 to 60 seconds following connections using voltage clips and current clamps.
3. Upload data and put in nameplate information in the header – 2-3 minutes.
4. Auto-Analysis – 1-2 minutes, including printing report.

For additional evaluation, the EMCAT Motor Diagnostics software system can calculate most primary frequencies (See Figure 18).

Figure 18: Motor Diagnostics Worksheet

Application Example

Routine test on a repaired submersible 1 horsepower pump, single phase, 1800 RPM system. Data was taken using one current probe only:

- ✓ Collect Data – 2 minutes, including setup
- ✓ Data Upload and Data Entered – 5 minutes, including entering header data
- ✓ Automated Report – 1 minute, including printing report (See Attachment)
- ✓ Findings – Mechanical Imbalance in the impellor under load detected in less than 10 minutes without knowing rotor bars or stator slots. Time invested was the same as technicians performing standard voltage, current and other testing.

The pump impellor was replaced and the system retested and shipped.

Savings: Future warranty repair on bearings and seal as well as reduced test times with greater accuracy.

Conclusion

Motor Current Signature Analysis techniques can be fairly simple, or complicated, depending on the system available for data collection and evaluation. In this paper, we described methods for evaluating a system when complete information is available, as well as how information can be automatically evaluated using the ALL-TEST IV PRO OL system.

MCSA technology can be used in conjunction with other technologies, such as motor circuit analysis, in order to provide a complete overview of the motor circuit. The areas under review include power quality, transformers, AC/DC motors, controls, electrical and mechanical condition of the motor, air gap and rotor circuit condition, and mechanical condition of the load. The result of using MCSA as part of your motor diagnostics program is a complete view of your motor system health.

About the Author

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BJM Corp is a manufacturer of submersible pumps and MCA/MCSA motor diagnostic equipment. For more information go to www.bjmcorp.com or www.alltestpro.com.

EMCAT Analysis Results

PERFORMANCE SUMMARY

Bottom Line

- This motor is operating normally, no action is required.
 This motor exhibits suspicious operation, trending of the motor is warranted.
 This motor exhibits abnormal indications, action is warranted, NOW.

Power Factor Commentary

- Power factor exceeds 0.85.
 Power factor is below 0.85, see detailed report.

Current Commentary

- Current variation is within normal limits.
 Current variation is beyond normal limits, see detailed report.

Voltage Commentary

- Voltage variation is within normal limits.
 Voltage variation is beyond normal limits, see detailed report.
 RMS voltage differs from nameplate by more than 5%.

Load Commentary

- Load on the motor is consistent with nameplate values.
 Load on the motor exceeds nameplate values, see detailed report.
 Load on the motor is less than 25%.

Phase Connection Commentary

- Connections are normal.
 Voltage ground reference is NOT neutral.
 Loose connection.

Rotor Commentary

- Rotor bar health is normal.
 Rotor bar health is questionable, see detailed report.
 Load is insufficient to determine rotor bar health, at this time.

Stator Commentary

- Stator health is normal.
 Stator electrical health is questionable.
 Stator mechanical health is questionable.
 Turn to turn short.

Rotor/Stator Air-gap Characteristics

- Dynamic or static eccentricity indications do not exist.
 Indications of static eccentricity exist.
 Indications of dynamic eccentricity exist.

Harmonic Distortion Commentary

- There is no evidence of harmonic distortion.
 There is evidence of harmonic distortion, see detailed report.

Misalignment Indications

- There are no indications of mechanical problems like misalignment or unbalance.
 There are indications of mechanical problems like misalignment or unbalance;
Perform vibration survey to identify and correct the cause.

Bearing Commentary

- There is no evidence of bearing problem.
 Indications of potential bearing problems, perform vibration survey to verify.

EMCAT INPUT SUMMARY

NAMEPLATE INFORMATION

		Units
Manufacturer	****	
Serial Number	****	
Model Number	****	
Motor type	Induction	
Power	1.00	HP
RPM	1800.0	Rpm
AC/DC	AC	
Poles	4	
Phases:	1	
Voltage	120.0	Volt
Full Load Current	12.00	Amp
Number Stator Slots	-1	
Rotor Bars	28	
Torque (ft-lbs):	2.9	In.Lb
CT Ratio	1.000	
PT Ratio	1.000	
Duty Cycle	****	
Service Factor	****	
Frame Size	****	
Insulation Type	****	
Ambient Temperature	70.0	F°

Detailed Calculations

LEGENDS:

Impedance	= Complex Impedance = v_i/c_i
CF	= Crest Factor = (waveform peak)/(waveform rms)
CFC	= Carrier Frequency Content = $10^{(x/20)}/\text{frms}$, %
THDF	= Transformer Harmonic De-rating Factor = $\sqrt{2}/\text{CF}$, %
VDF	= Voltage De-rating Factor = $100 - (\text{voltage unbalance, \%})^2$, %
Se, fund	= Location of EMCAT slip fundamental, Hz (EMCAT slip is the same as pole passing frequency)
Se, harm	= Number of EMCAT slip harmonics
Level	= Sum of spectral amplitudes of EMCAT slip fundamentals and harmonics
Slip %	= SRSS sum of slip and harmonic "levels" divided by RMS level of RMS DEMOD spectra between 0 and 65 Hz.
Upper sb	= dB level of upper slip sideband of power line peak
Lower sb	= dB level of lower slip sideband of power line peak
Rotor bar health	= Estimate of the percent of broken or cracked rotor bars
Thd	= Total harmonic distortion
+Ve	= Positive sequence harmonic
-Ve	= Negative sequence harmonic
Zero	= Zero sequence harmonic

Running Speed = 29.175 Hz / 1750 Rpm
Pole pass frequency = 3.174 Hz
Load = 104.4 %

Time			
	RMS	Peak	CF
Current	12.400	18.012	1.453

THDF = 32.5

Time			
	RMS	Peak	CF

	Power factor	Impedance	App. Power kVA	Real Power kW	Reac. Power kVARS

Summary of Rotor Bar Health				Power line dB diff.		Rotor bar Health index
	Se, fund	Se, harm	Level %	Upper SB	Lower SB	
Measured	3.174	0	-	-60.6	-64.9	0.0816
Severity level	Rotor Condition Assessment			Recommended Corrective Action		
2	Good			None		

Harmonic Distortion Results:

Voltage input, from 59.937 Hz harmonics

	THD Odd %	THD Even %	+ve%	-ve %	Zero %	THD All %
Current	6.073	0.287	0.979	3.409	4.938	6.079

Figure- 1: Current Harmonic distortion graph

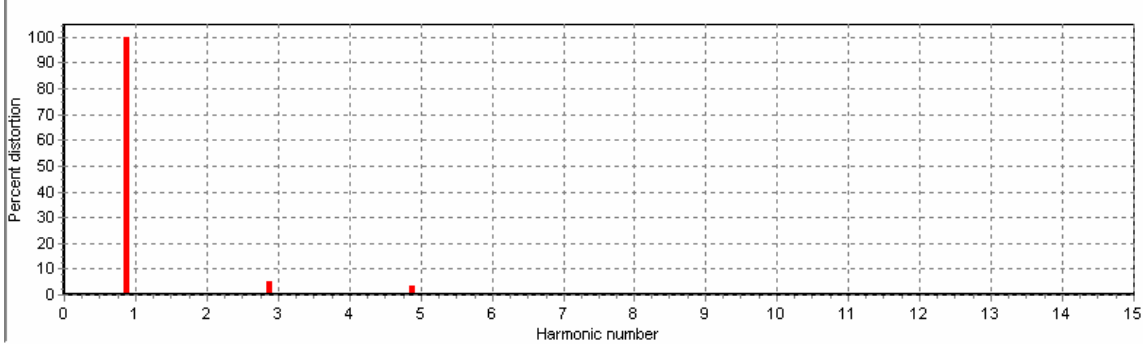
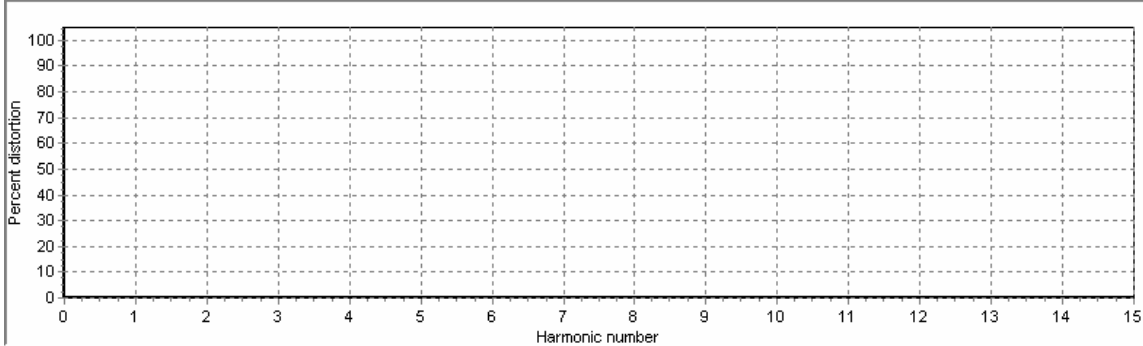


Figure- 2: Voltage Harmonic distortion graph



Harmonic distortion table						
Hz	Cur1	Vlt1	Cur2	Vlt2	Cur3	Vlt3
60	11.8	***	***	***	***	***
120	0.0	***	***	***	***	***
180	0.6	***	***	***	***	***
240	0.0	***	***	***	***	***
300	0.4	***	***	***	***	***
360	0.0	***	***	***	***	***
420	0.1	***	***	***	***	***
480	0.0	***	***	***	***	***
540	0.0	***	***	***	***	***
600	0.0	***	***	***	***	***
660	0.0	***	***	***	***	***
720	0.0	***	***	***	***	***
780	0.0	***	***	***	***	***

Description:

Mechanical Imbalance of impellor using single phase current only