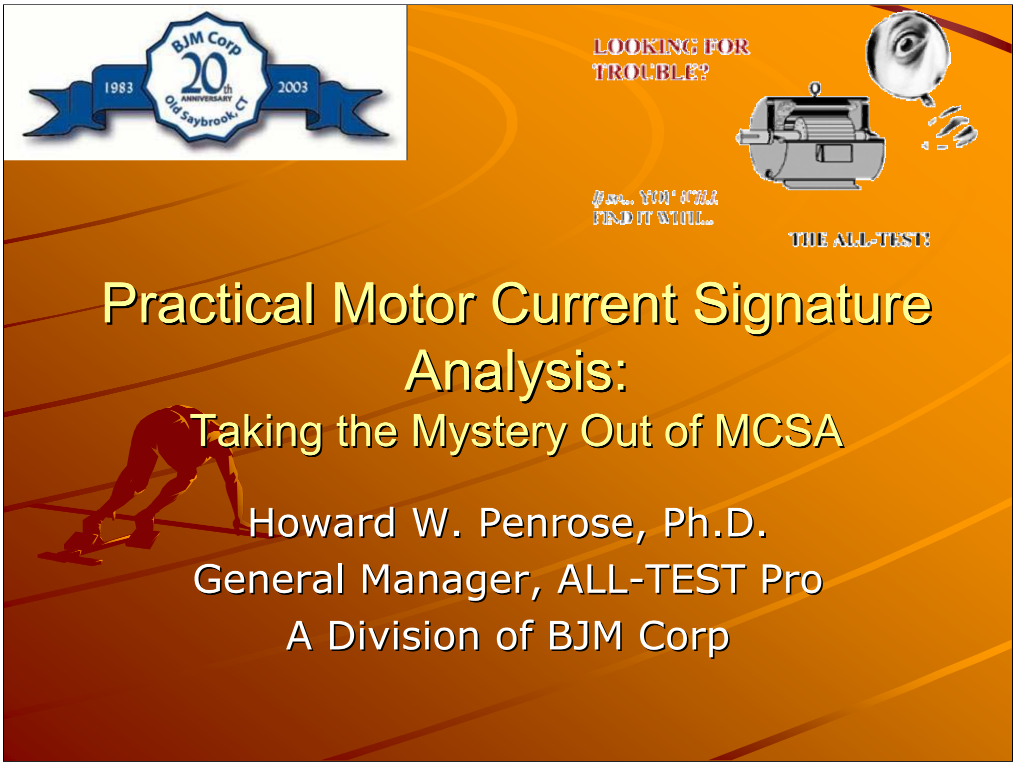
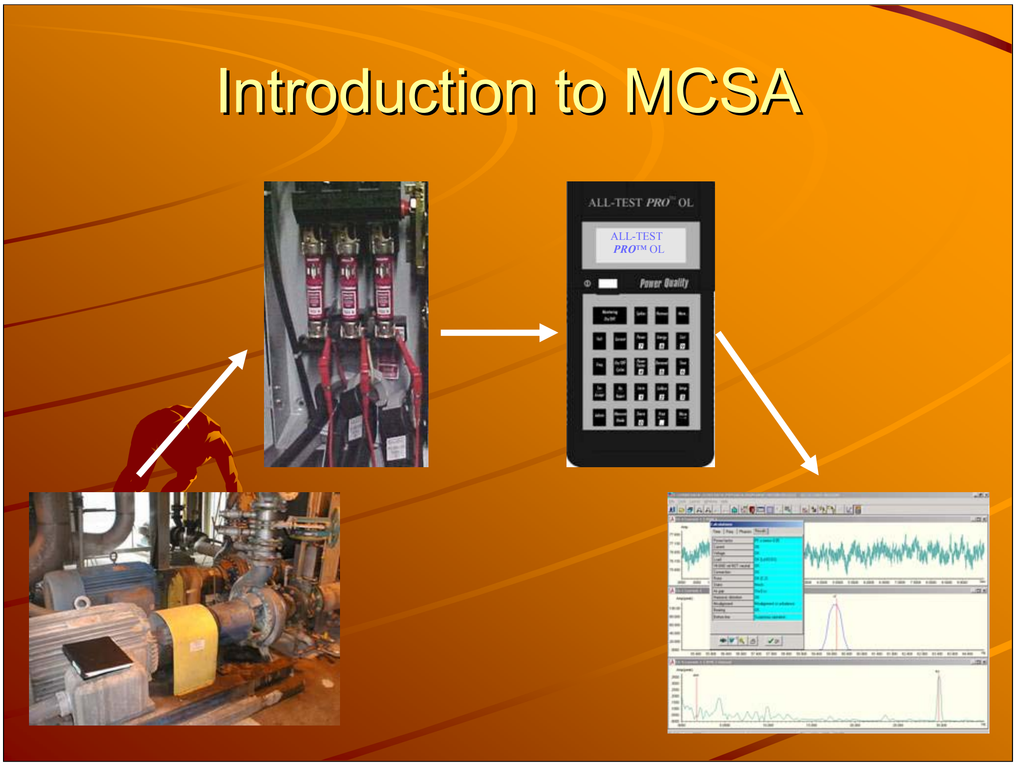


Practical Motor Current Signature Analysis: Taking the Mystery Out of MCSA, is a presentation brought to you by ALL-TEST Pro, a Division of BJM Corp, a manufacturer and researcher of submersible pumps and motor system diagnostic equipment located in Old Saybrook, Connecticut. ALL-TEST Pro products include: the award-winning ALL-TEST III motor tester; the award-winning ALL-TEST IV PRO 2000 MCA instrument; the ALL-TEST PRO OL MCSA instrument; and associated software including the flagship EMCAT motor management system.

Dr Penrose is the general manager and a leading researcher into electric motor systems diagnostics, efficiency and analysis. His combined practical and academic background allows him to provide a unique insight into the art of motor diagnostics, presenting complex concepts in easy to understand techniques and terms.

In this presentation, Dr. Penrose bypasses the advanced engineering, formulae and complex tekkie-speak to assist the user in understanding what is really needed to evaluate a complete motor system using motor current signature analysis, or MCSA. This presentation builds upon past ReliabilityWeb presentations brought to you by Dr. Penrose. For copies of these presentations, please contact ALL-TEST Pro at the email provided at the end of this presentation.



MCSA is a system used for analyzing or trending dynamic, energized, systems.

Proper analysis of MCSA will assist the technician in identifying:

•Incoming power quality

•Stator winding health

•Rotor static and dynamic eccentricity and general health

•Coupling health including direct, belted and geared

•Load issues

•System load and efficiency

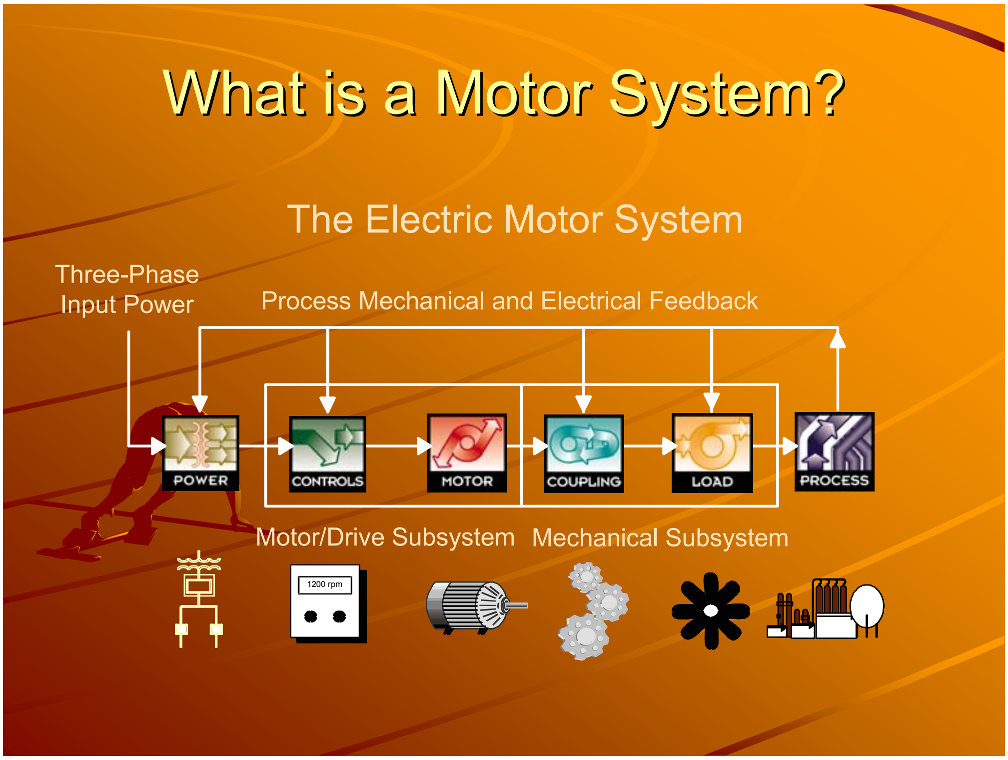
•Bearing health and much more

MCSA uses the electric motor as a transducer, allowing the user to evaluate the electrical and mechanical condition from the motor control center or disconnect. The ALL-TEST PRO OL hand-held MCSA system allows the user to perform most analysis automatically with limited information required.

For accurate analysis, MCSA systems rely upon FFT analysis, much like vibration analysis. MCSA also relies upon analysis of demodulated voltage and/or current which involves the removal of the fundamental frequency.

The purpose of this presentation is to provide the existing or potential MCSA technician or manager with the basics, using the systems approach.

For the purpose of this presentation, we will assume that all information is available, such as number of rotor bars, number of stator slots, gear teeth, bearing information, etc. In future presentations, we will review each area with a focus on how analysis can be performed when this data is unknown.



The motor system includes the power distribution system; the motor starting, control, and drive system; the motor; the mechanical coupling; the mechanical load; and the process.

The facility power distribution system includes components such as in-plant wiring and transformers.

The starting, control, and drive system includes the motor starter and adjustable speed drives.

The motor itself – in this outline is an induction motor.

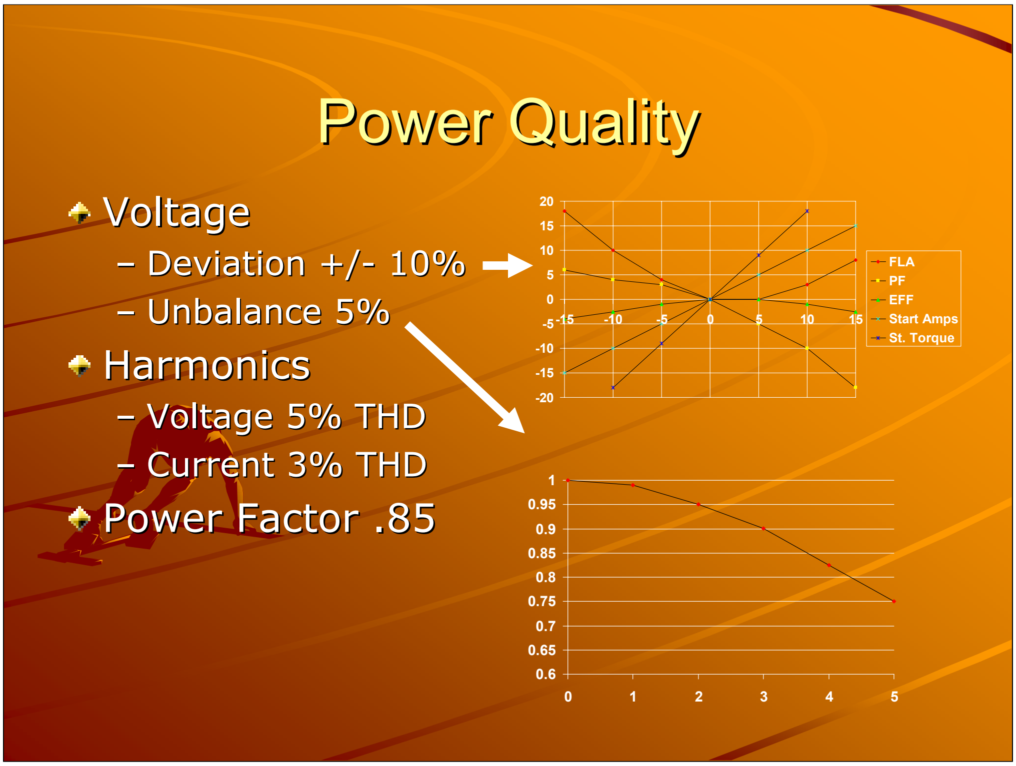
The mechanical coupling refers to components like v-belts and power transmission devices.

The mechanical load refers to the driven equipment, such as a pump, fan, compressor, or conveyor.

The process is what is being accomplished, such as water pumping, mixing, or aeration.

Most users look at motor systems from the component level and try to evaluate or troubleshoot.

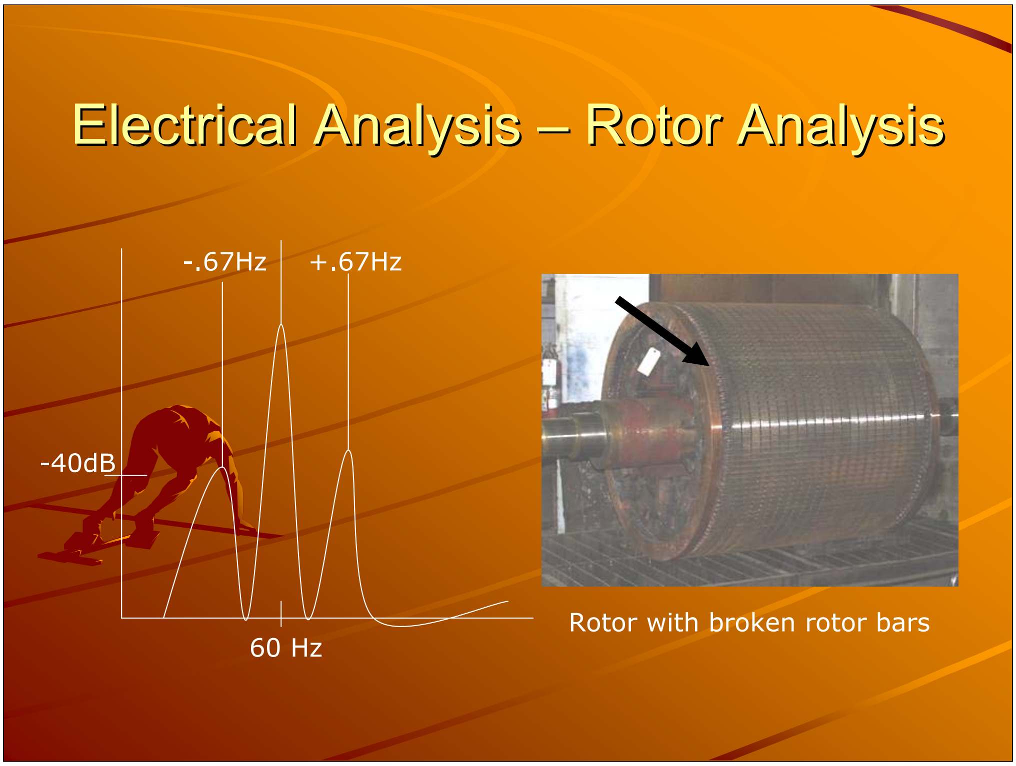
The systems approach is a way of looking at the reliability of the entire system and the relationship and synergy of the components.



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.

The most common power quality issues and limits are:

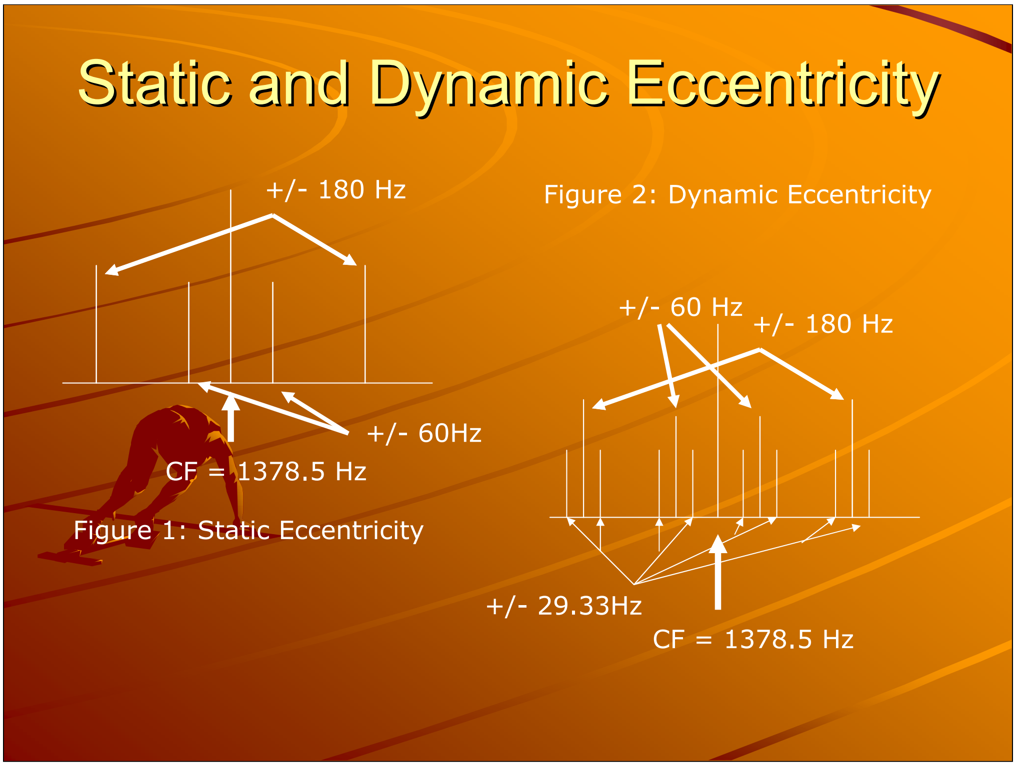
1. Voltage quality. In an electric motor system there are two primary issues with voltage:
    1. A) Over or under voltage or voltage deviation from nameplate. The limits on supply voltage are +/- 10% of nameplate voltage with +/- 5% being optimal.
    2. B) Voltage unbalance which causes unbalanced current in the motor resulting in overheating of the winding. The relationship of voltage and current unbalance can be a few to over 20 percent, 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.
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 harmonics:
    1. A) Voltage harmonics are of concern with a recommended limit of 5% total harmonic distortion per IEEE Standard 519.
    2. B) Current harmonics are considered far more serious with a recommended limit of 3% THD per IEEE Standard 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. The optimal is a factor of 1, however, in most systems a power factor of .85 is considered OK.



One of the primary strengths of MCSA is rotor analysis. There are three basic types of rotor faults: Broken rotor bars; static eccentricity; and, dynamic eccentricity.

Broken bars are generally found as slip frequency sidebands around the fundamental frequency. The rule of thumb is that faults are detected when these sidebands meet or exceed -35dB.

For example, a motor running 1760 RPM in a 60Hz system would have a running frequency of 1760 divided by 60 or 29.33 Hz. The slip frequency would be 30 Hz minus 29.33 Hz or .67Hz. If .67 sidebands occur around the 60 Hz peak and they show a value of -40db, then broken rotor bars exist.

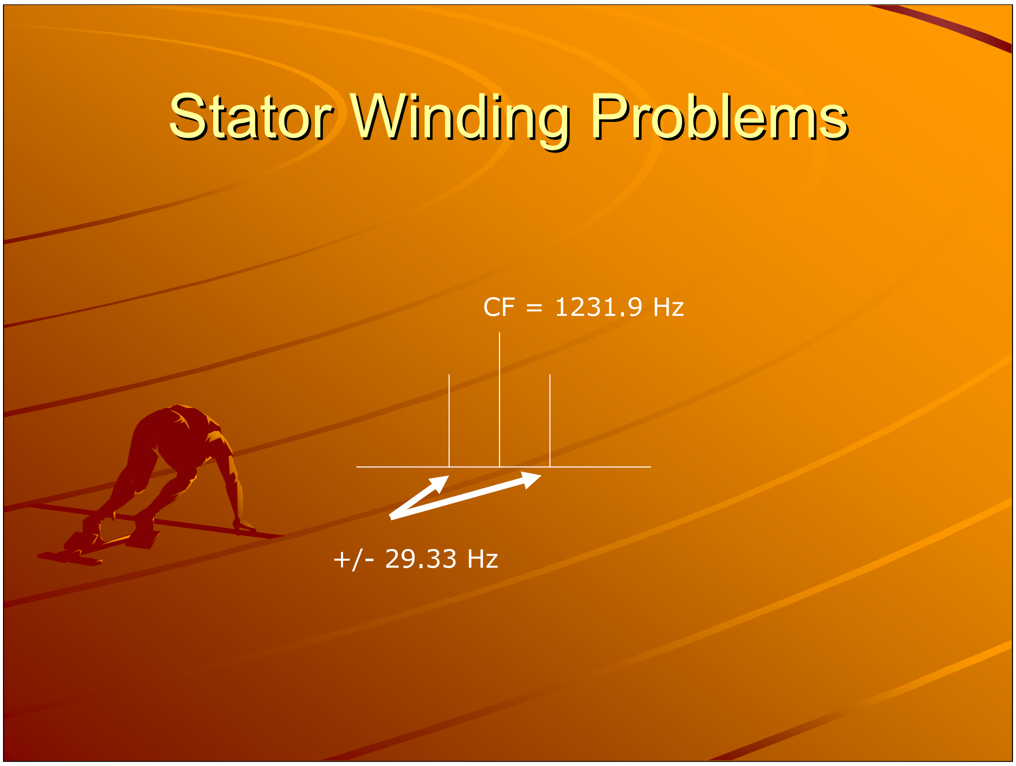


Static eccentricity can be found in the high frequency spectrum. Static eccentricity is calculated as running speed times the number of rotor bars with line frequency times N sidebands, where N is an odd integer.

Note: On the next few slides, the rotor bars times running speed and stator slots times running speed are referred to as 'center frequencies,' that will be indicated as CF, and do not represent peaks that will be detected. These frequencies represent the center of the patterns that indicate faults.

For example, if the 1760 RPM motor on the previous slide had static eccentricity, and was known to have 47 rotor bars, the base frequency would be 29.33 times 47 or 1378.5 Hz with 60 Hz, 180 Hz, 300 Hz, etc. sidebands as shown in figure 1.

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 2.



Stator winding problems are found by first identifying stator slot passing frequencies.

Stator frequencies are found by multiplying the number of stator slots by the running speed.

For example, the running speed of 29.33 Hz times 42 slots would be a stator frequency of 1231.9 Hz. If the center frequency has sidebands of running speed, then stator electrical or mechanical degradation has occurred.

Mechanical Analysis - Bearings

NTN 6305 Brg

BPOR = 4.394
BPIR = 2.606
2xBSF = .372
FTF = 1.83

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

Faulty outer
Race of bearing

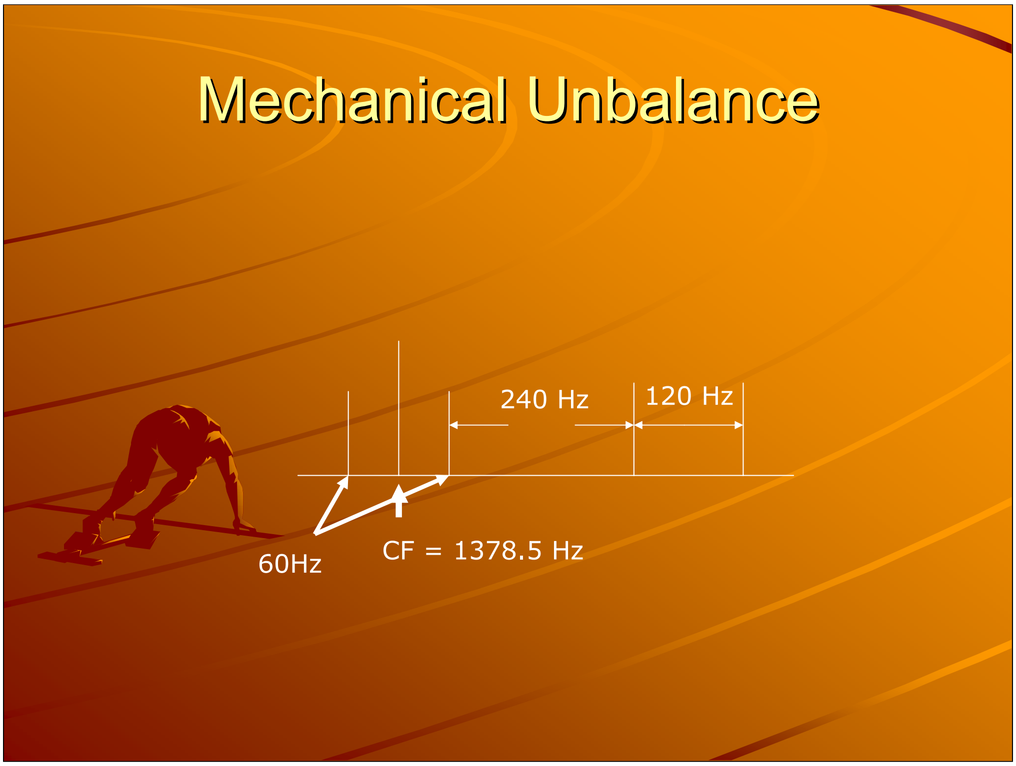
In order for bearings to be indicated through MCSA, the condition will be severe. Bearing findings must be addressed as soon as possible following detection.

In order to determine bearing issues, you must obtain the appropriate bearing multipliers, which can be obtained from the manufacturer’s catalog or the MCSA software. These multipliers include the ball pass outer race, BPOR; the ball pass inner race, BPIN; the 2 times ball spin frequency, 2xBSF; and, the cage frequency, FTF.

The bearing frequencies are found as the multiplier times running frequency with line frequency sidebands. Harmonics of the frequencies can be found by multiplying each bearing frequency by integers with line frequency sidebands around each.

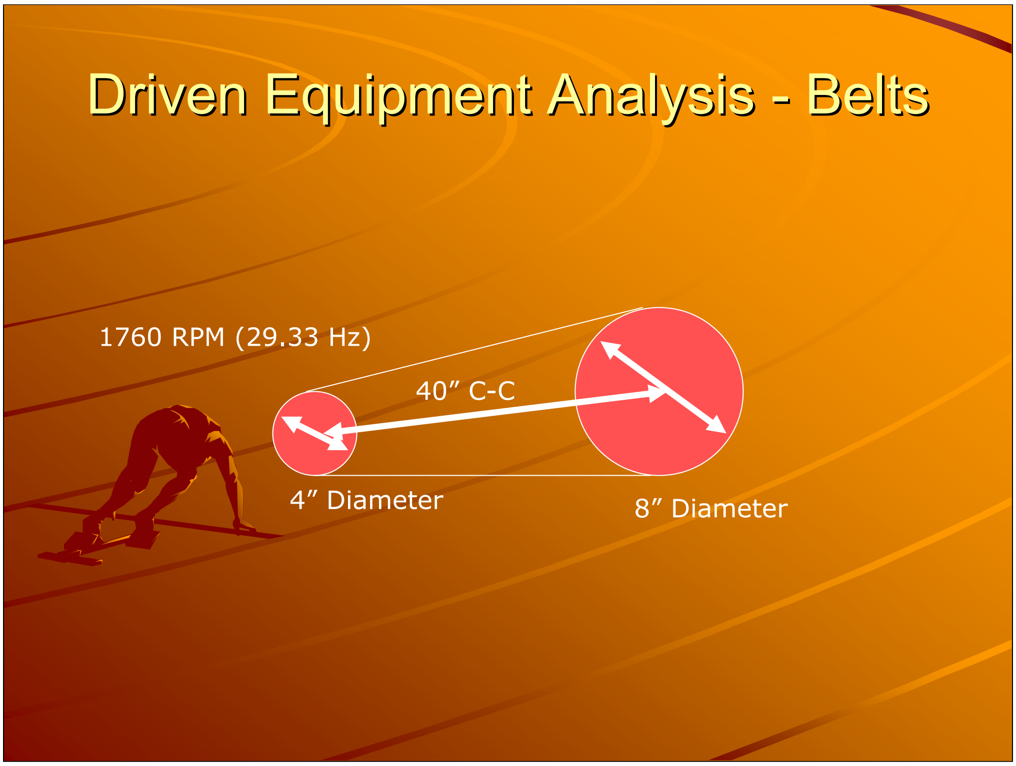
For instance, the bearing frequencies for a 6305 NTN bearing in a motor with 29.33 Hz running speed would be found as: BPOR = 4.394; BPIR = 2.606; 2xBSF = .372; and, FTF = 1.830

When calculated, the fundamental bearing frequencies would be: BPOR = 128.9 Hz; BPIR = 76.43 Hz; 2xBSF = 10.91 Hz; and, FTF = 53.67 Hz



Mechanical unbalance is found by determining the rotor bars times running speed, as in our example, 47 bars times 29.33 Hz is 1378.5 Hz. There will be line frequency sidebands around the center frequency, then a space of 4 times line frequency, then two twice line frequency peaks.

The pattern 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.



In this case, we will look at a belted application:

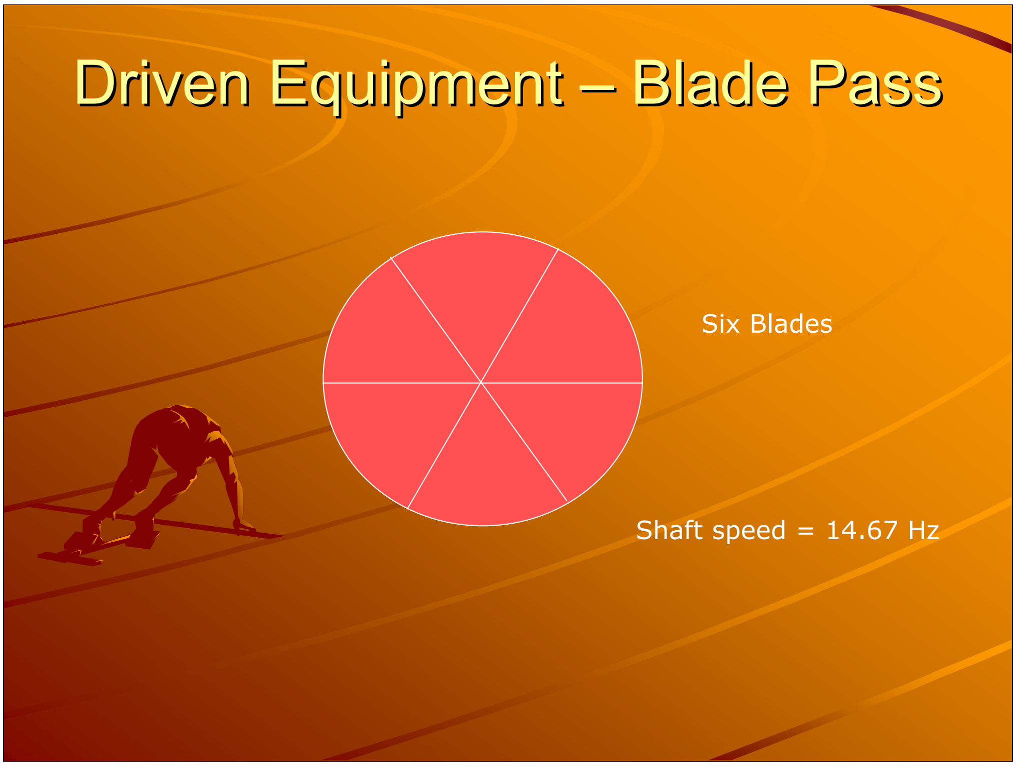
Step 1: Determine driven shaft speed by determining the pulley ratios. In this case, it will equal the operating speed times the sheave ratio or four inches divided by eight inches times 1760 RPM or 880 RPM or 14.67 Hz.

Step 2: Determine the belt speed by determining the belt length which is equal to the center to center distance times two plus half the circumference of each pulley. In this case, 40 inches times two plus half of four times pi plus eight times pi or 97.28 inches. Next, the surface speed can be determined by calculating the conveyor speed for either sheave. In this case, we can use the motor sheave and calculate four times pi times 1760 RPM or 22,117 inches per minute or 368.6 inches per second. The belt speed can then be determined by taking the conveyor speed and dividing by the belt length. In this case, 368.6 inches per second divided by 97.28 inches or 3.79 RPS or 3.79 Hz.

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. In this instance, that would be 1760 RPM times the value of 20 teeth divided by 100 teeth or 352 RPM or 5.87 Hz.

The Gear mesh frequency is determined by taking the running speed times the number of teeth. The value is the same for either gear. In this case, 1760 times 20 teeth or 35,200 or 587 Hz. Sidebands around this frequency would indicate gear mesh problems.

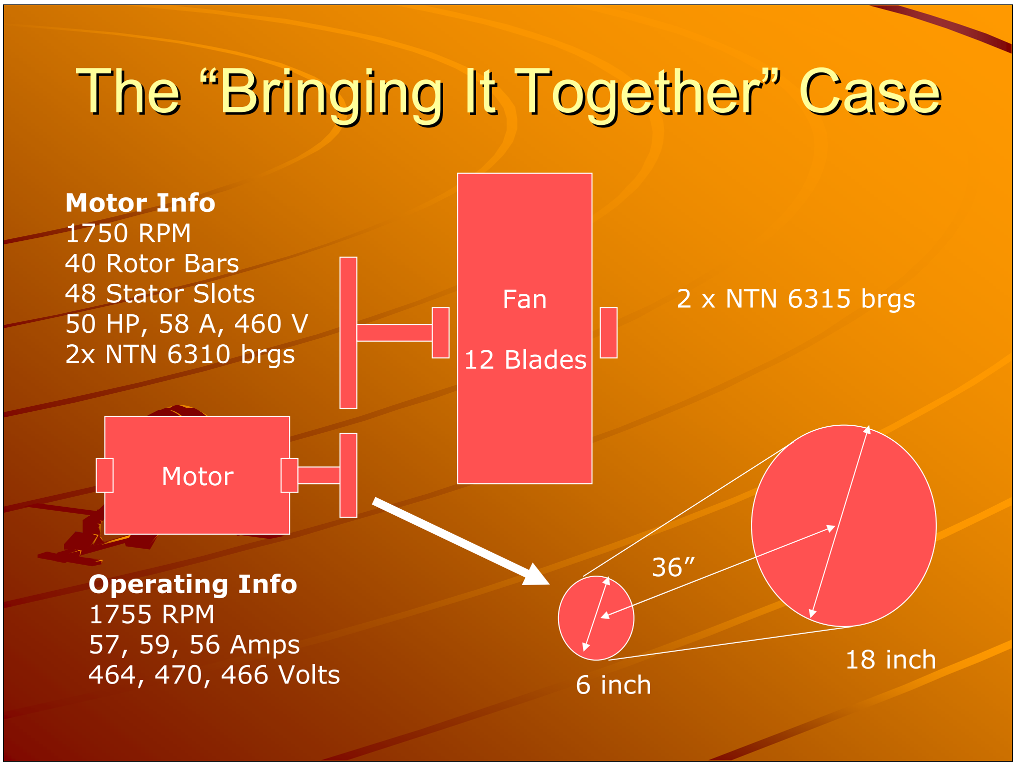


Calculating blade pass frequencies for either fans or impellors is straight forward.

The number of blades multiplied by the shaft speed.

In this case, the blade pass frequency would be six blades times 14.67 Hz or 88 Hz. Faulty impellors or blades would be indicated at this frequency regardless of how many blades had faults.

As a note, in direct drive applications, the driver and driven speeds are the same.



In order to bring it all together, we shall use a motor and fan system with a belted coupling.

In this example, we will calculate all of the critical frequencies that would help us identify problems in this system.

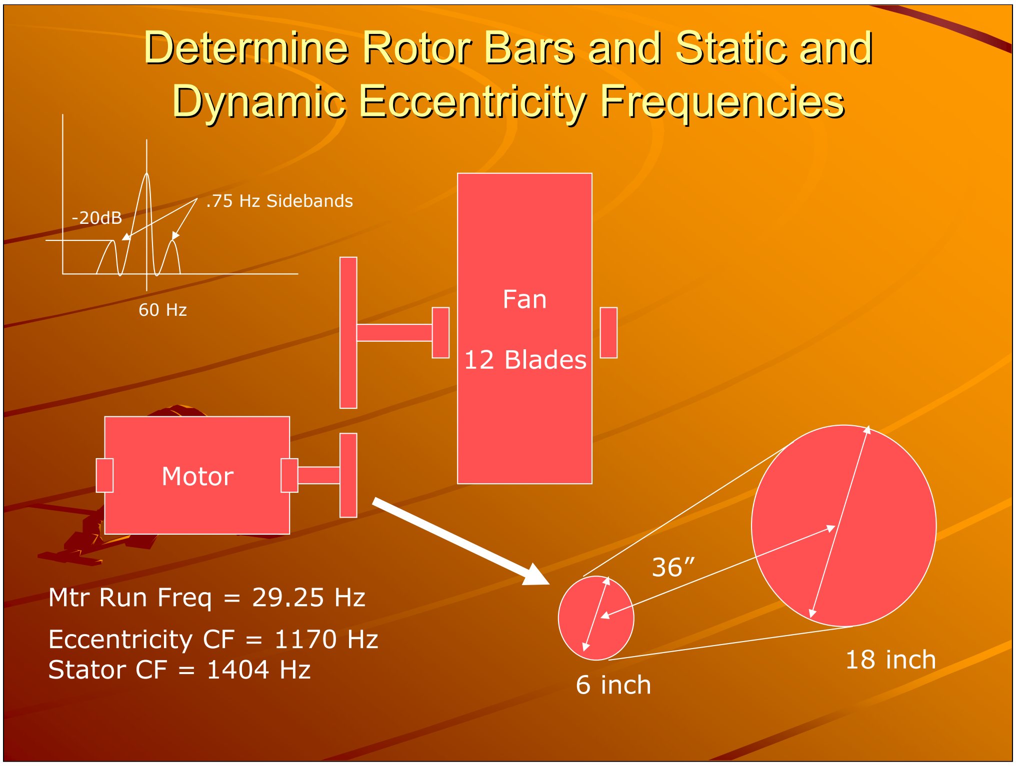
The system consists of a 50 horsepower motor with the following nameplate information: 1750 RPM, 58Amps, 460V, with 40 rotor bars and 48 stator slots, as determined from information provided in the US Department of Energy's MotorMaster Plus software. Normally, the opposite drive end bearing is smaller than the drive end bearing, but for this example, we shall use two NTN 6310 bearings.

The sheaves are a 6 inch driver and 18 inch driven with 36 inches center to center. The fan has twelve blades and is supported by two NTN 6315 bearings.

The running information shows a 1755 RPM running speed, 57, 59 and 56 Amp draw with voltage values of 464, 470, and 466 volts. There is no perceptible harmonic distortion.

This provides a voltage unbalance calculated as: 464 + 470 + 466 divided by 3 or 467 Volts average. 467 – 464 Volts divided by 467 volts times 100 provides a voltage unbalance of .6% which is acceptable.

The voltage deviation is 470 – 460 divided by 460 or 2.2%, which is well within tolerance.



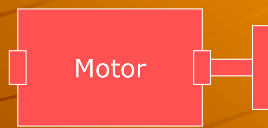
The running frequency is determined by calculating 1755 divided by 60 or 29.25 Hz.

The rotor bar condition shows sidebands around 60 Hz of .75 Hz (slip frequency) sidebands at -20dB.

The Center Frequency for static or dynamic eccentricity is 29.25 Hz times 40 rotor bars or 1170 Hz.

The stator Center Frequency is 29.25 Hz times 48 stator slots or 1404 Hz.

Determine Motor Bearing Frequencies and Mechanical Unbalance



NTN 6310 Brgs
BPOR = 4.929
BPIR = 3.071
2xBSF = .384
FTF = 2.036

	1	2	3	4
BPOR	144	288	432	576
BPIR	89.8	179.7	269.4	359.3
2xBSF	11.23	22.5	33.69	45
FTF	59.55	119.1	178.7	238.2

Mechanical Unbalance CF = 1170 Hz

Determine bearing frequencies by determining the ball pass outer race, ball pass inner race, two times ball spin frequency and the train frequencies for the 6310 bearings.

The BPOR is 4.929

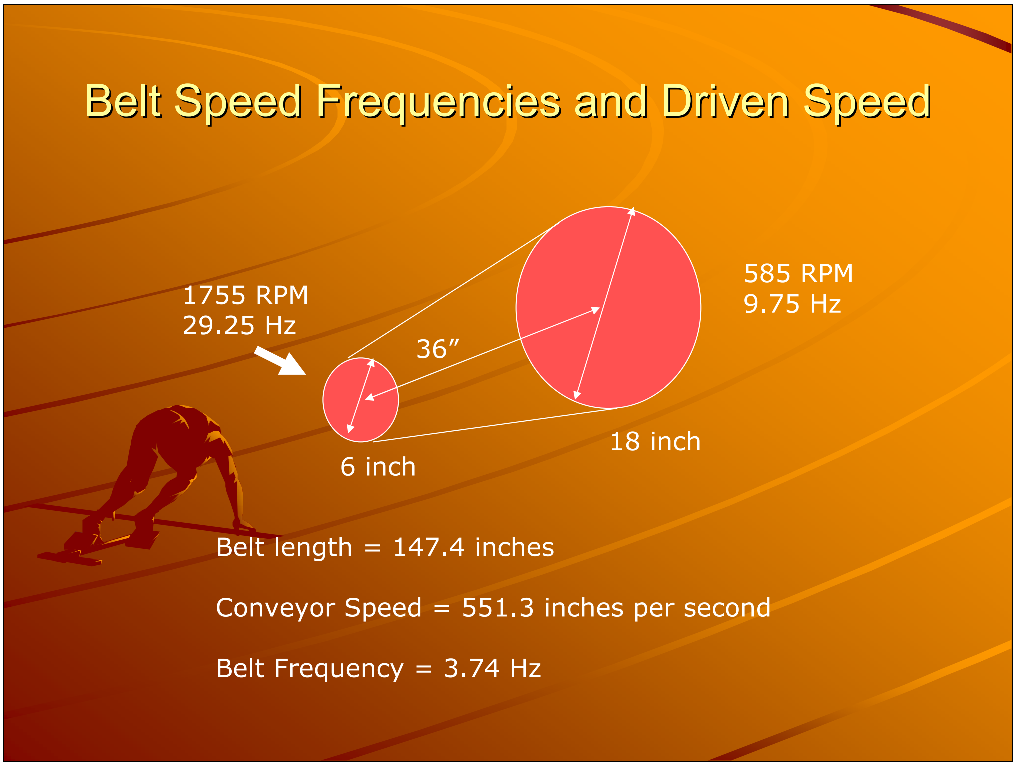
BPIR is 3.071

2xBSF is .384

FTF is 2.036

The frequencies are calculated by multiplying the bearing multipliers by the running frequency then by integers to come up with harmonics of the bearing frequencies.

The mechanical imbalance center frequency is calculated by multiplying the number of rotor bars by the operating frequency. As you will notice, the 1170 Hz value is the same as the frequency calculated for eccentricity.



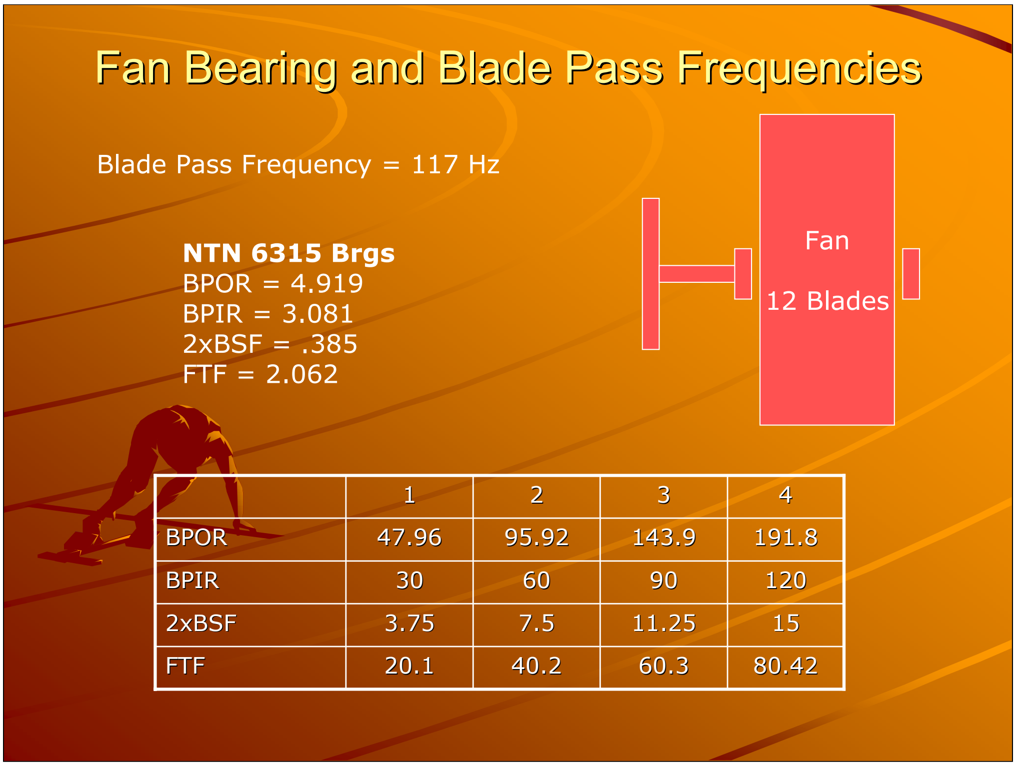
Next, the belt speed and driven speed frequencies are calculated.

The driven shaft is calculated as 1755 times 6 inches divided by 18 inches or 585 RPM or 9.75 Hz.

The belt length is 36 inches times 2 plus half of six inches times pi plus 18 inches times pi or 147.4 inches

The conveyor speed is 6 inches times pi times 1755 RPM or 33,080 inches per minute or 551.3 inches per second.

The belt speed is then calculated by dividing the conveyor speed by the belt length. In this case, 551.3 inches per second divided by 147.4 inches or 3.74 rps or 3.74 Hz



	1	2	3	4
BPOR	47.96	95.92	143.9	191.8
BPIR	30	60	90	120
2xBSF	3.75	7.5	11.25	15
FTF	20.1	40.2	60.3	80.42

The blade pass frequency is calculated by multiplying the shaft speed by the number of fan blades. In this case, 9.75 Hz times 12 blades is 117 Hz.

The BPOR for an NTN 6315 bearing is 4.919, the BPIR is 3.081, the 2xBSF is .385 and the FTF is 2.062.

The base, or fundamental frequencies, are: BPOR is 47.96 Hz; BPIR is 30 Hz; 2xBSF is 3.75 Hz; and, FTF is 20.1 Hz.

Consolidation and Review of Data

Motor

Nameplate RPM	1750	Operating RPM	1755
Rotor Bars	40	Operating Amps	57,59, 56
Stator Slots	48	THD	N/A
HP, Amp, Volt	50hp, 58A, 460V	Operating Volts	464,470 466
Mtr Brgs	NTN 6310	Fan Brgs	NTN 6315

Calculated Values

Line Freq	60 Hz	Driven Freq	9.75 Hz
Motor Running Freq	29.25 Hz	Belt Length	147.4"
Rotor CF	1170 Hz	Conv Freq	551.3 IPS
Stator CF	1404 Hz	Belt Freq	3.74 Hz
		Blade Pass	117 Hz

Bearing Frequencies

NTN 6315	1	2	3	4
BPOR	47.96	95.92	143.9	191.8
BPIR	30	60	90	120
2xBSF	3.75	7.5	11.25	15
FTF	20.1	40.2	60.3	80.42

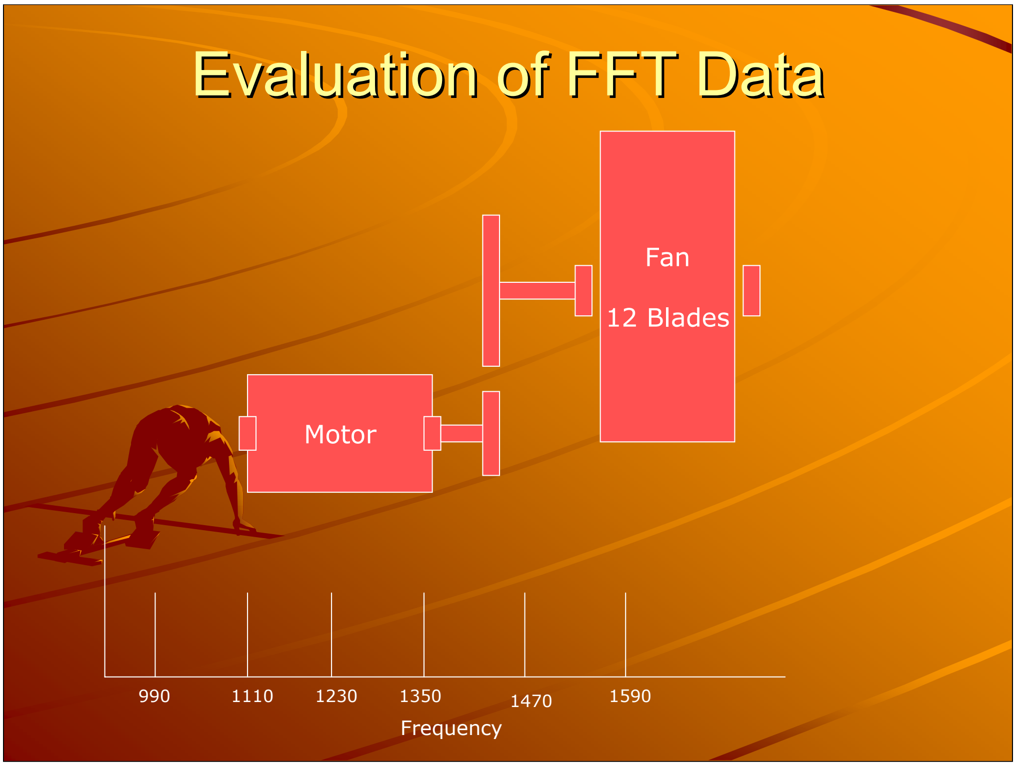
NTN 6310	1	2	3	4
BPOR	144	288	432	576
BPIR	89.8	179.7	269.4	359.3
2xBSF	11.23	22.5	33.69	45
FTF	59.55	119.1	178.7	238.2

All of the data should be collected for review and analysis of the FFT spectra. With this information the complete system can be evaluated.

Through review of the data, several 'rules of thumb' can be determined:

1. Broken rotor bars are figured as slip frequency side bands of the fundamental frequency. For example, .75 Hz sidebands of 60 Hz for this example. The amplitude must be at least -35dB for the bars to be in poor condition.
2. Side bands around center frequencies indicate problems.

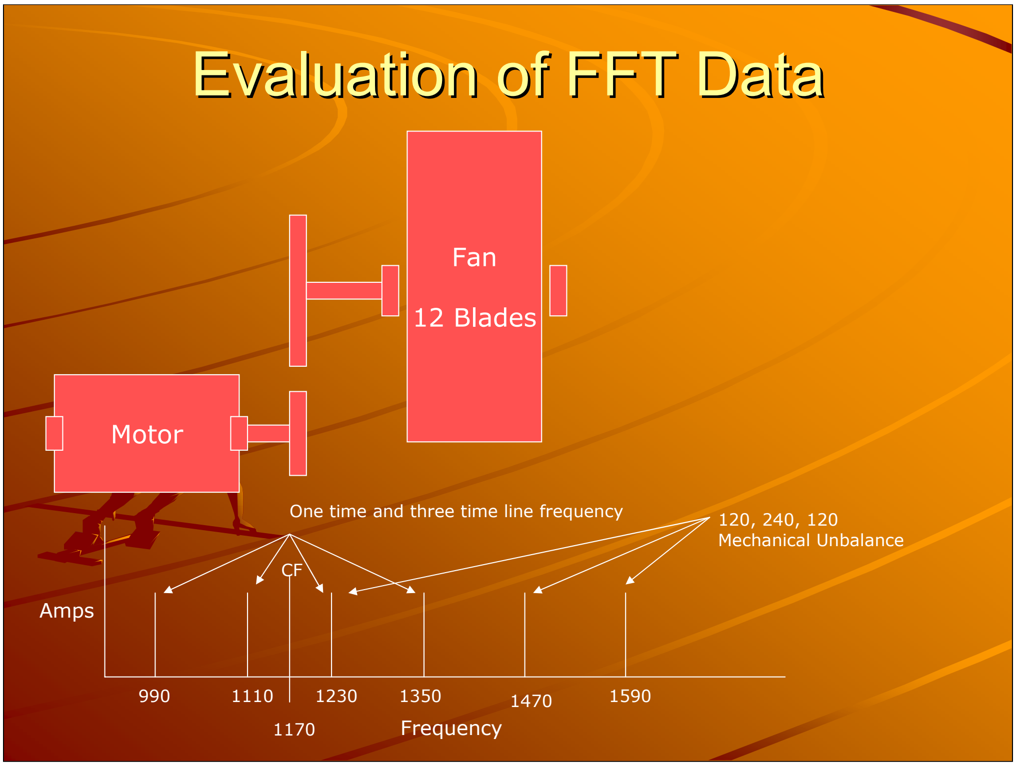
Using this data, we can evaluate the data on the next slide.



Through a review of the higher frequency peaks of the FFT analysis, 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 the Rotor eccentricity and unbalance, 1110 plus 1230 divided by two or 1170 Hz, which is the rotor central frequency.

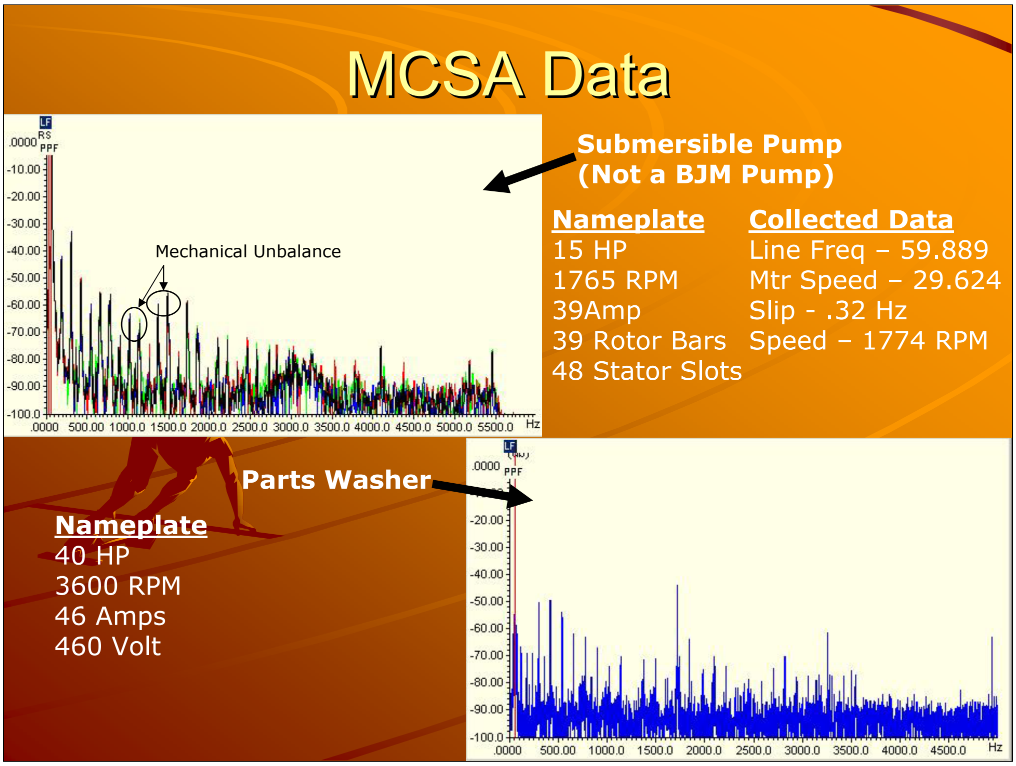
For stator central frequencies, 1350 plus 1470 divided by two or 1410 Hz, which does not meet the stator central frequency.



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 indicates static eccentricity. The additional peaks show the 120 Hz, 240 Hz, 120 Hz pattern that indicates mechanical unbalance.

Unfortunately, data is seldom this clean.



In the first case, the data is related to a submersible pump. Some information is known.

The Rotor Central Frequency is 1155.3 Hz

Mechanical imbalance (120Hz, 240Hz, 120Hz) frequencies exist.

In the low frequency spectra, slip frequency sidebands of .319 at -46dB which indicates rotor bar issues.

Information on the pump impellor and bearings would be required in order to continue detailed analysis.

The parts washer was a 40 Horsepower, 3600 RPM, 46 Amp, 460 Volt motor. Data was not taken on the load which made up a gearbox and chain drive. Observation identified bearing, chain and gear noise.

In our next presentation, we will investigate how to evaluate these types of conditions where information is limited.

For additional information on motor diagnostics, please contact Dr. Penrose with the contact information at the end of this presentation.

Motor System Health

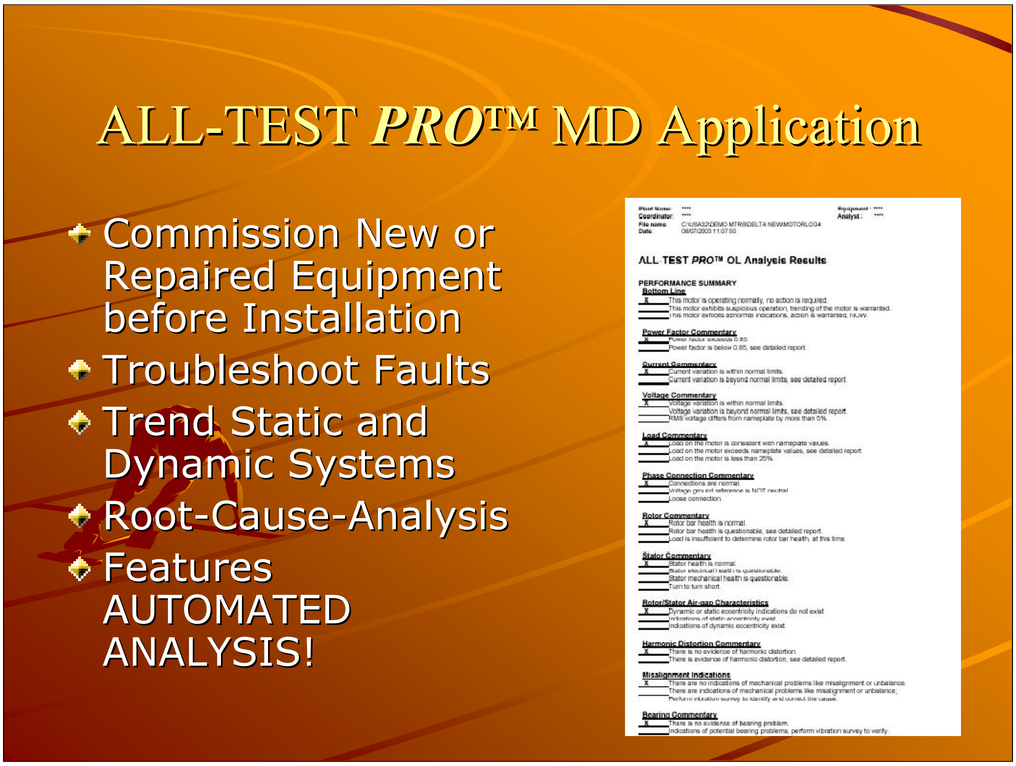
- When potential faults are found
- Recommend complimentary tests such as MCA or Vibration

As discussed in the Multi-Technology presentation, whenever a potential problem is found, it is normally recommended that complimentary tests are performed. For example, if a winding fault is detected, follow up with de-energized motor circuit analysis. In cases of bearing problems, it is recommended that vibration is performed to confirm the condition of the bearings. This practice, if practical, will provide a high level of confidence in any faults detected.

ALL-TEST Pro now introduces the complete solution for electric motor system health and motor diagnostics.

The kit includes the award winning ALL-TEST III motor tester, which includes a rapid rotor test for motors from fractional to tens of thousands of horsepower; The award winning ALL-TEST IV PRO 2000 motor circuit analyzer for automated data collection and analysis; The ALL-TEST PRO OL motor current signature analyzer for automated data collection and analysis. All instruments are hand-held.

Contact ALL-TEST Pro for pricing.



The ALL-TEST PRO MD kit and combined motor circuit and motor current signature analysis provides for immediate analysis and commissioning of new or repaired equipment before and after installation. Immediate and high quality troubleshooting, trending and root-cause-analysis.

The ALL-TEST PRO MD system also includes automated analysis of both motor circuit analysis and motor current signature analysis findings and produce simple-to-use reports.

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