Induction Motor Vibration - Electrical Problems

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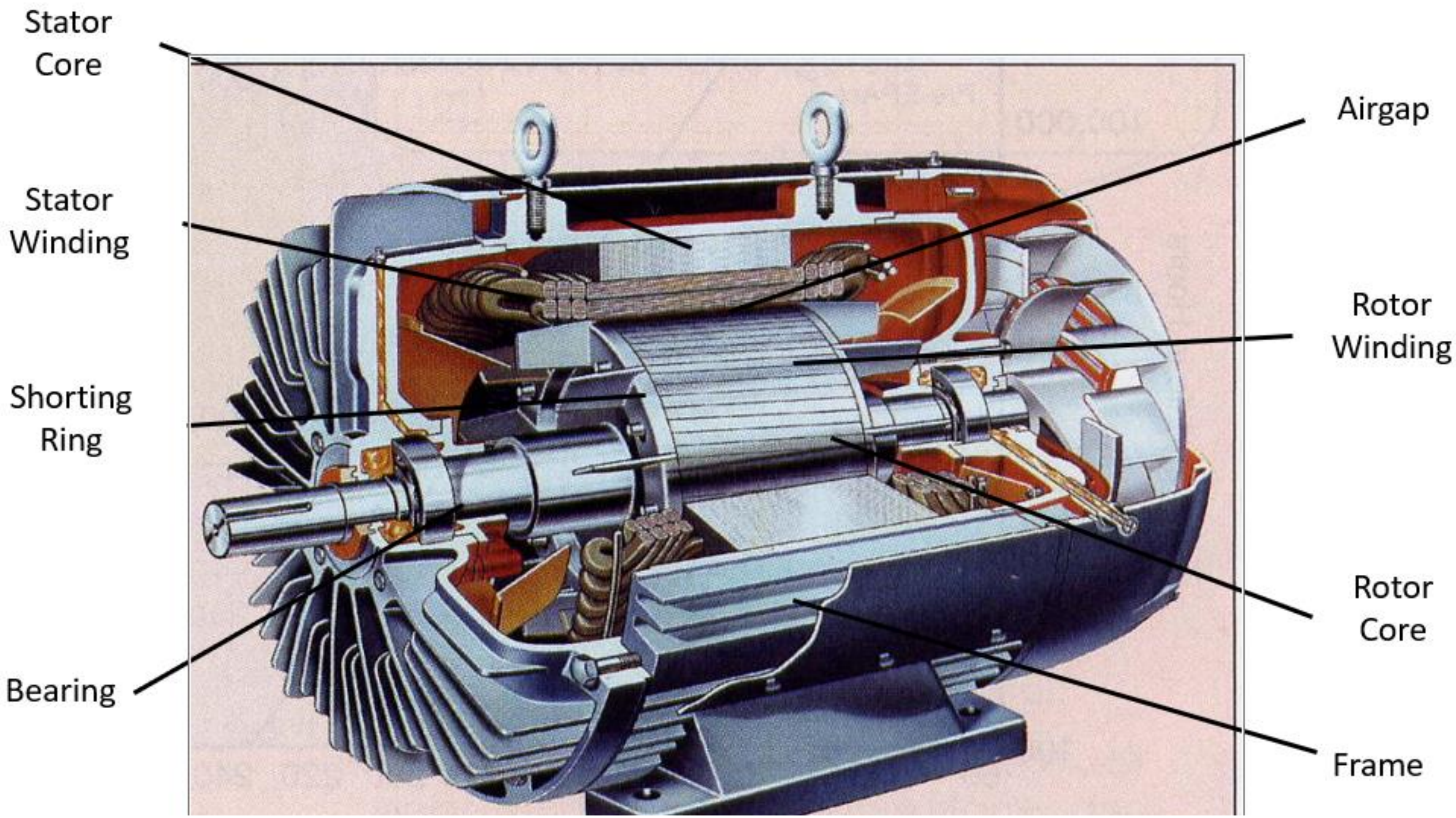
Agenda

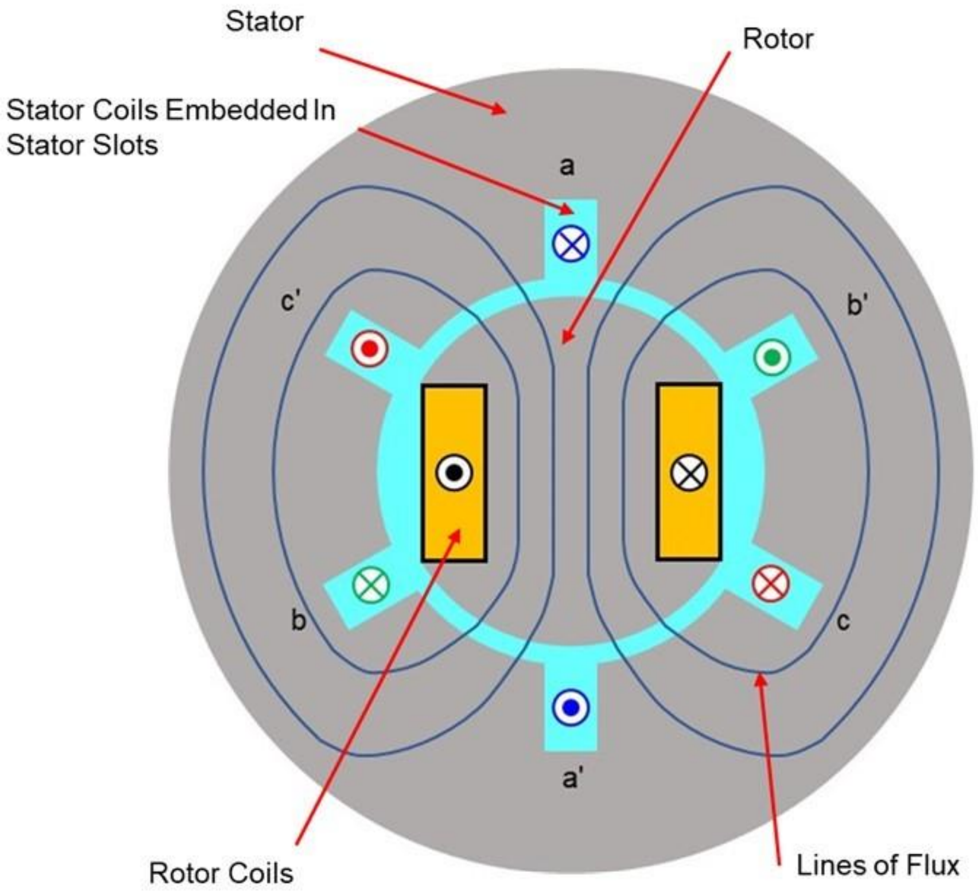
- Introduction – Synchronous vs Induction Motors
- Induction Motor Vibration
    - Rotor Bar Defect
    - Airgap
    - Loose Iron
    - Resonance
- Summary



Synchronous Machines

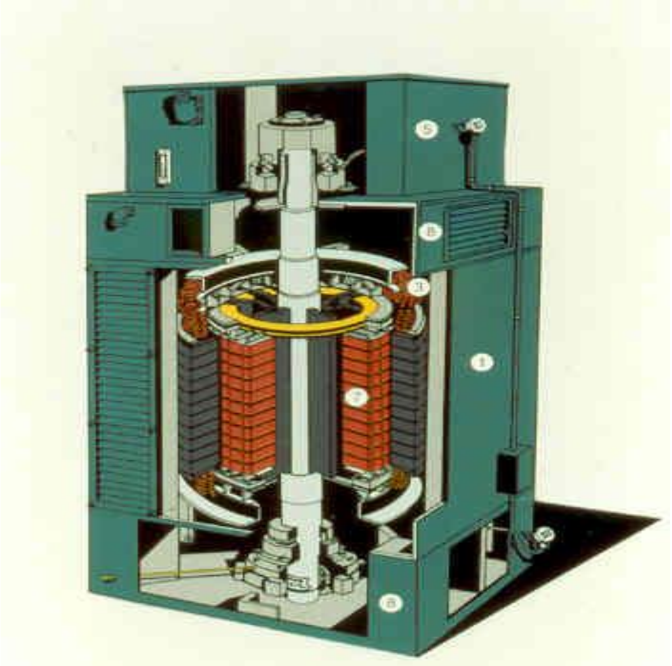
	50 Hz	60 Hz
2 poles	3000 rpm	3600 rpm
4 poles	1500 rpm	1800 rpm
6 poles	1000 rpm	1200 rpm

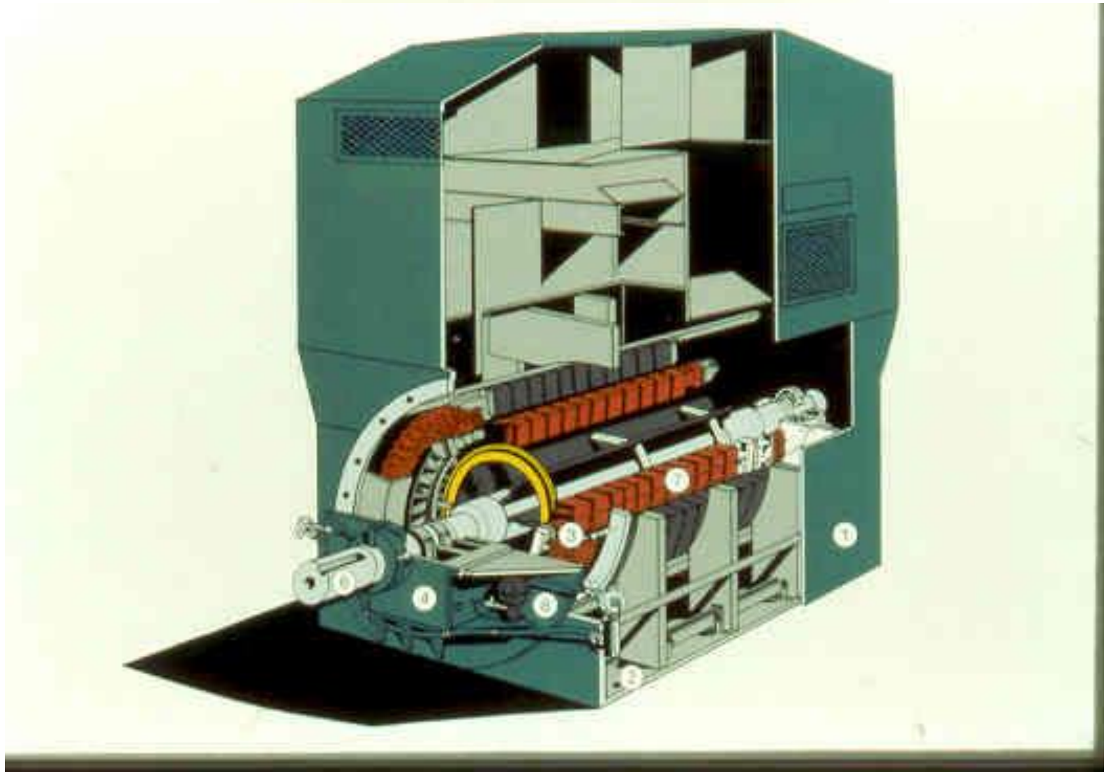
- Motor synchronous speed N_s equals
  - $N_{s(RPM)} = 120 \times F_{Line(Hz)} / p$
- Where F_{Line} is line frequency (Hz) and p is the number of poles
- Large generators or motors
  - >10,000 Hz
  - Equipped with hydrodynamic (Babbitt or “sleeve”) bearings



Induction Motors

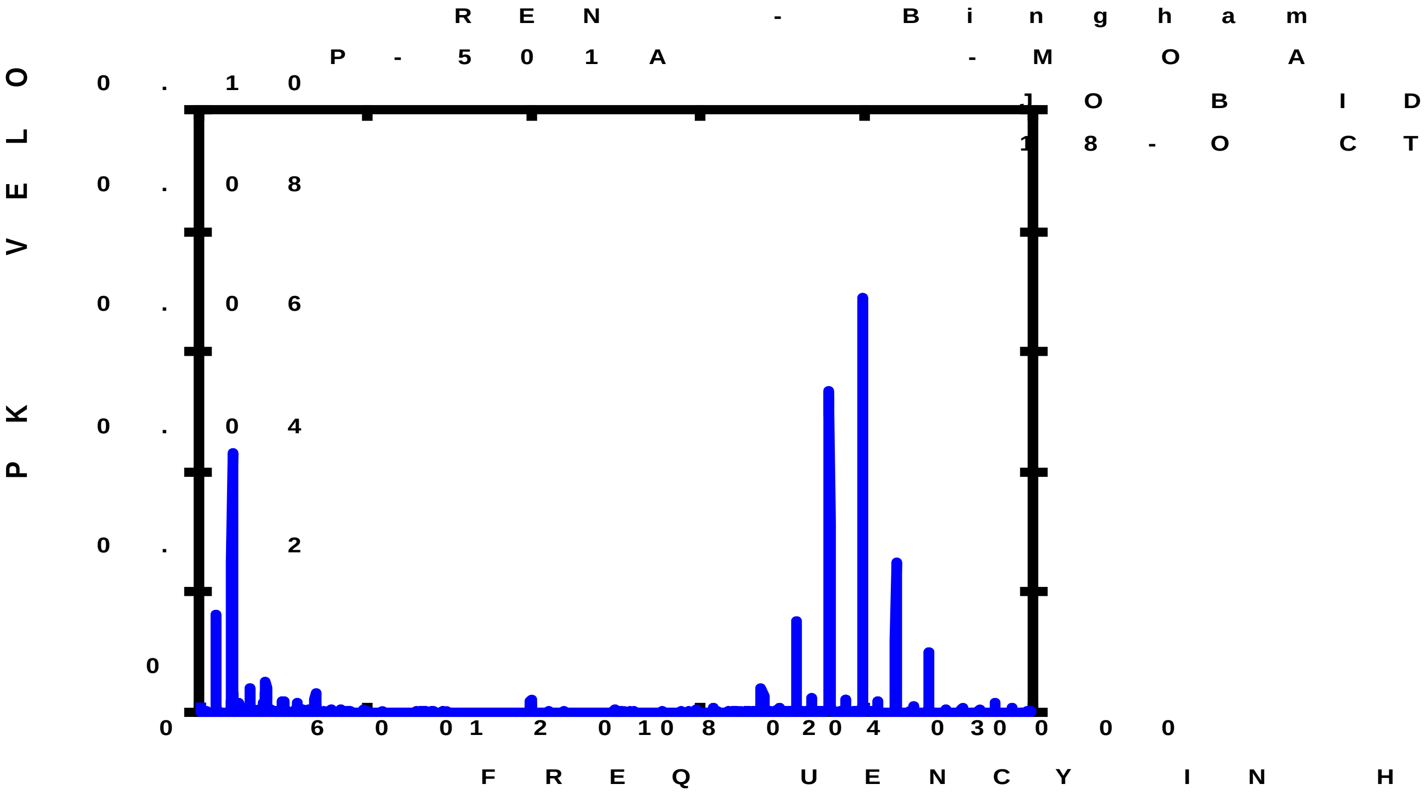
- Relative motion required between rotating magnetic fields of rotor and stator
- Full speed no load ~= N_s
- Slip = Synchronous Speed – Operating Speed
- Slip increases with load up to nameplate rating
  - Not simply proportional
- Most common motors in industry
- Can be equipped with either anti-friction (rolling element) or hydrodynamic (Babbitt) bearings





Induction Motor Vibration Analysis

- Typical “mechanical” faults
  - Unbalance and/or misalignment
    - 1xTS and/or 2xTS
  - Looseness
    - Harmonics of TS
  - Bearing defects
    - Non-harmonics of TS
- Additional “electrical” faults
  - Rotor bar damage
  - Airgap eccentricity
  - Loose rotor iron / slot
  - Loose stator laminations / core

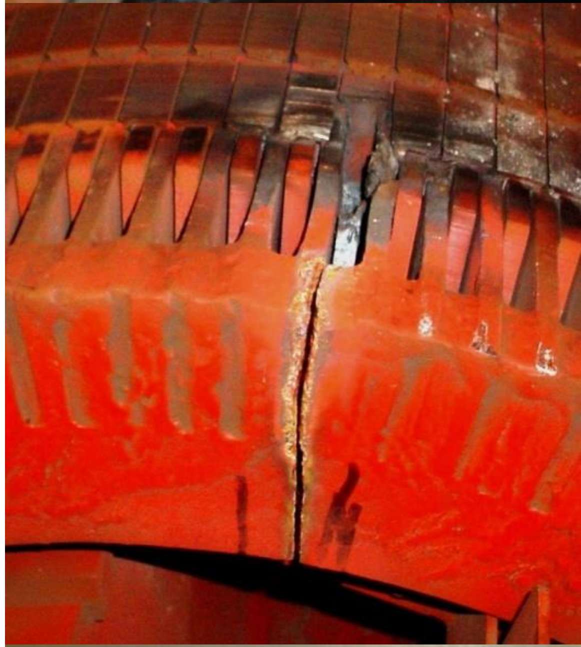


Measuring Speed – VERY IMPORTANT!

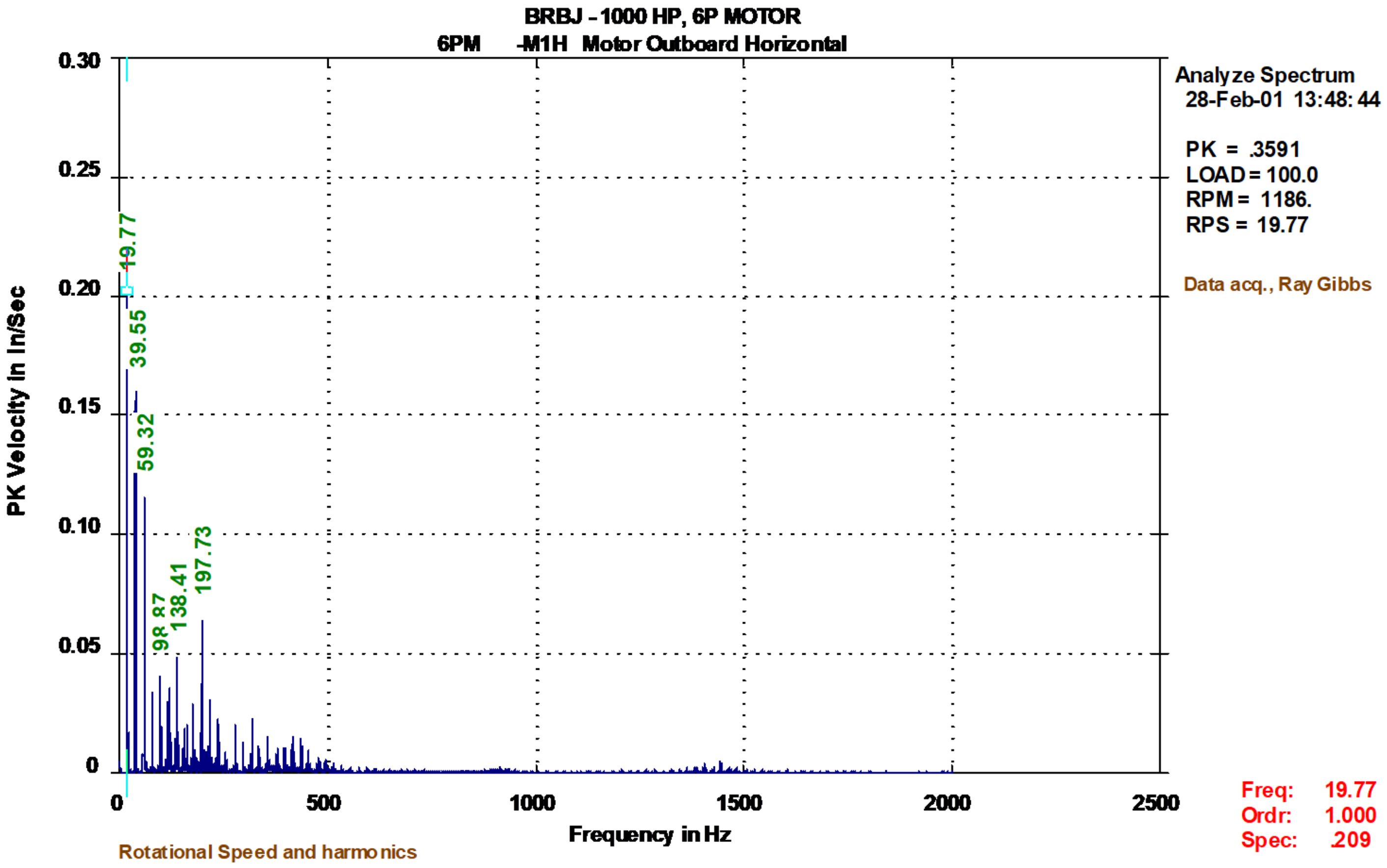
- Vibration Spectrum
  - Identify 1xTS component
  - Requires good frequency resolution
  - Can be difficult when unbalance is very small
- Stroboscope or Tachometer
  - Requires a good once per revolution reference (i.e.: keyway or reflective tape)
- Electrical (Current Signature Analysis)
  - Approximates RPM based on nameplate data and measured stator current

Rotor Bar Defect

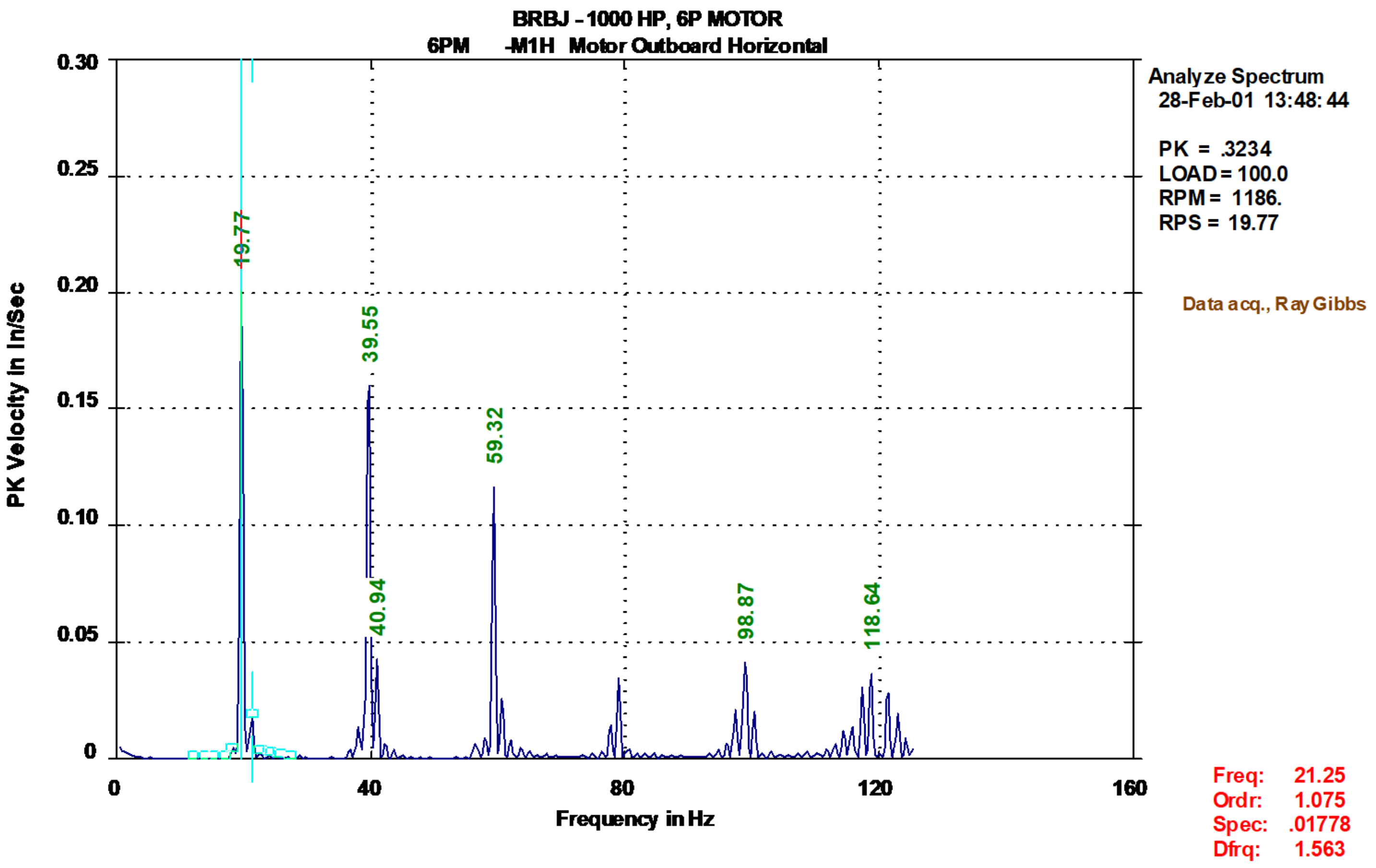
- Rotor limited designs (larger units)
  - Fabricated rotor cage can fail at joints between copper bars and shorting rings
  - Cracked shorting rings are also possible
- Stator limited designs (smaller units)
  - Die cast aluminium rotors susceptible to porosity
- Causes include:
  - Excessive (across-the-line) starts
  - Driving high inertia loads (i.e.: large FD or ID fans)
  - High torsional stresses (i.e.: reciprocating compressors)
- Symptoms include:
  - High 1xTS vibration due to thermal bow, modulated by #poles x slip sidebands causing an audible “Growling” noise, typically sensitive to load
  - Loss of efficiency resulting in increased starting time, elevated stator currents to satisfy load demand (current frequency modulated by #poles x slip), and elevated operating temperatures (I^2R losses)



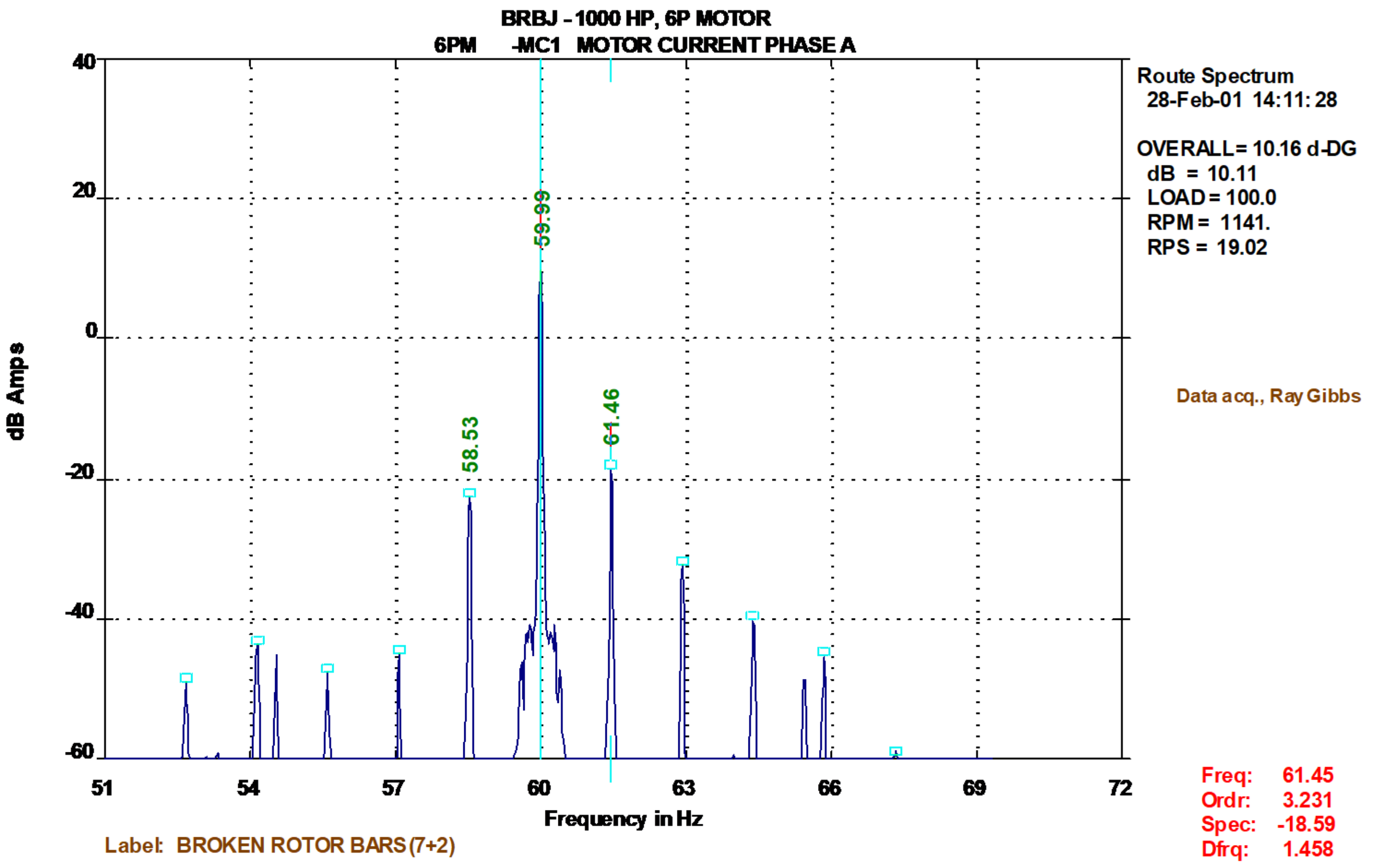
Rotor Bar Defect – Vibration Spectrum



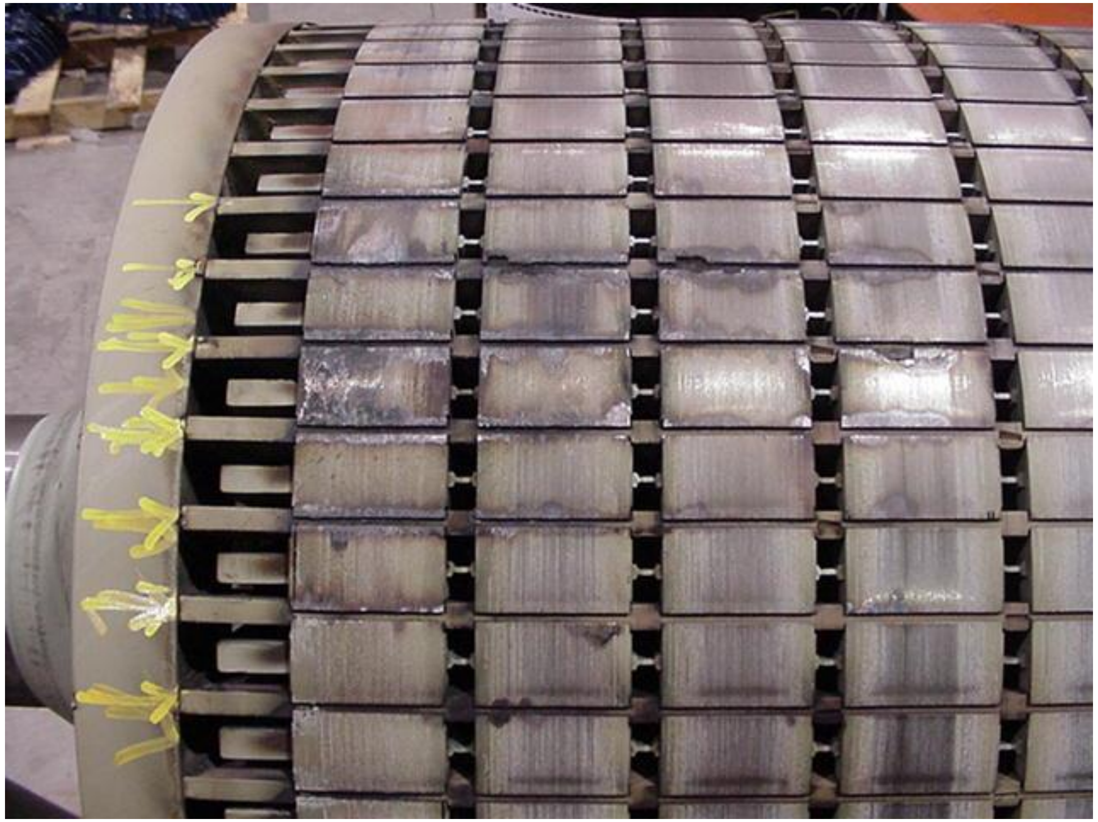
Rotor Bar Defect – High Resolution Zoom

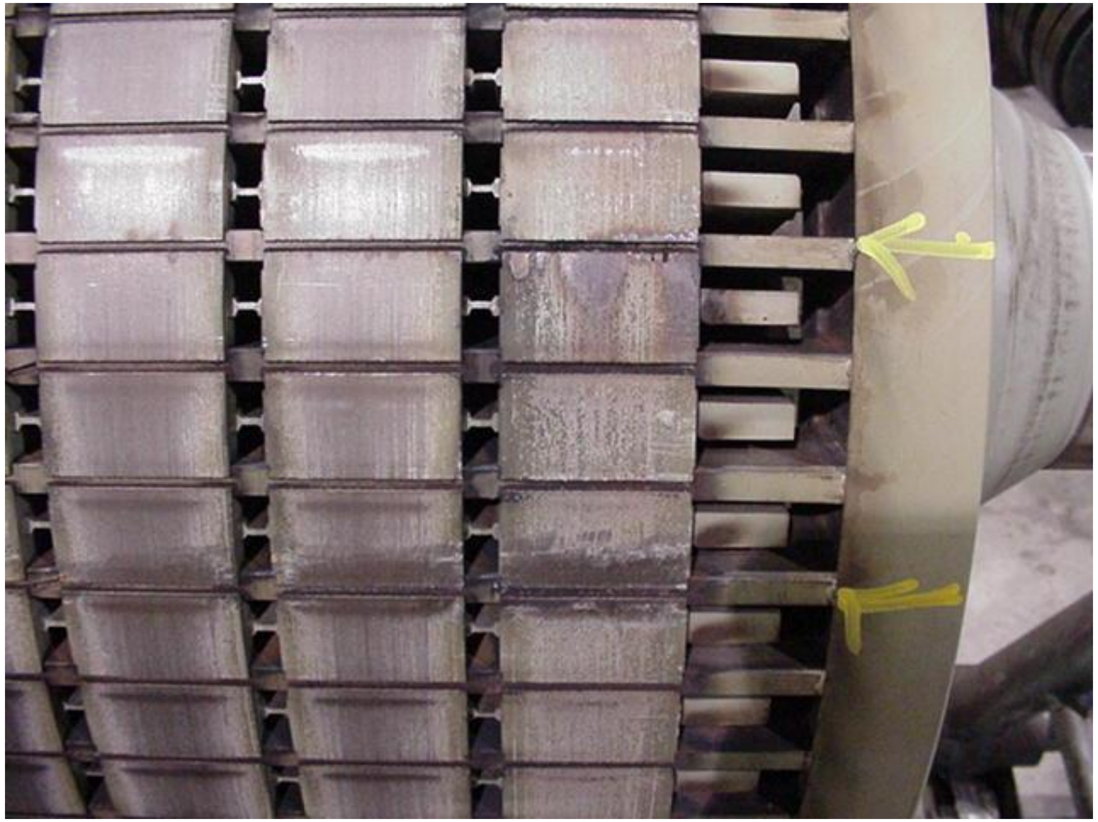


Rotor Bar Defect – Current Signature Analysis



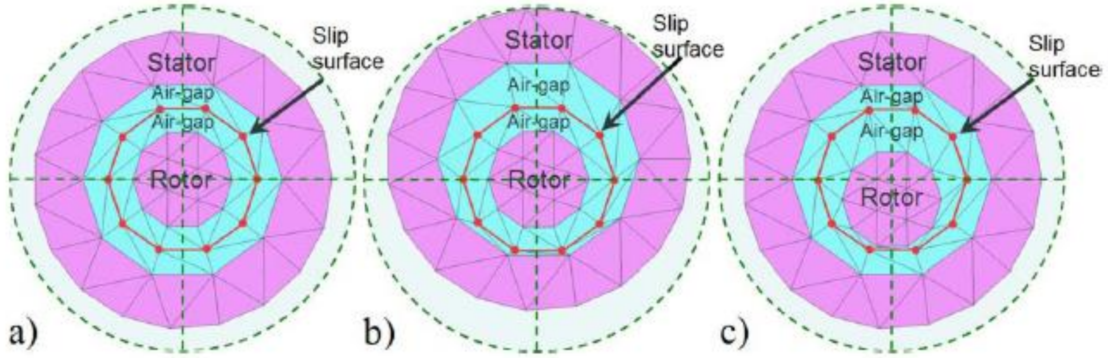
Rotor Bar Defect – Rotor Inspection





Airgap – Problems

- Rotor out-of-round
- Stator out-of-round
- Rotor not centered in stator (parallel or angular offset)
- Bearing centers not coincident with rotor center-line, typically due to a bent shaft
- Combinations thereof



a) Uniform airgap

b) Static Eccentricity

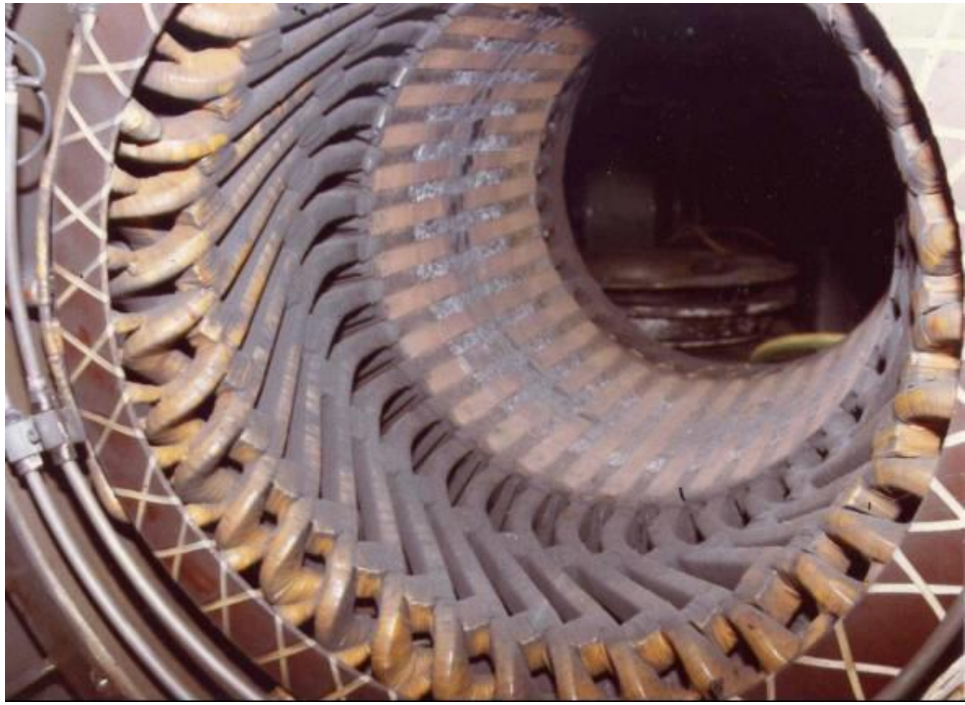
- Minimum airgap in same position
- Unbalanced Magnetic Pull (UMP) causes shaft deflection, resulting in temporary dynamic eccentricity as well
- Elevated 2xLF vibration, directional, may be caused by frame distortion due to “soft foot” condition, rotor bar/slot pass +/- 2xLF

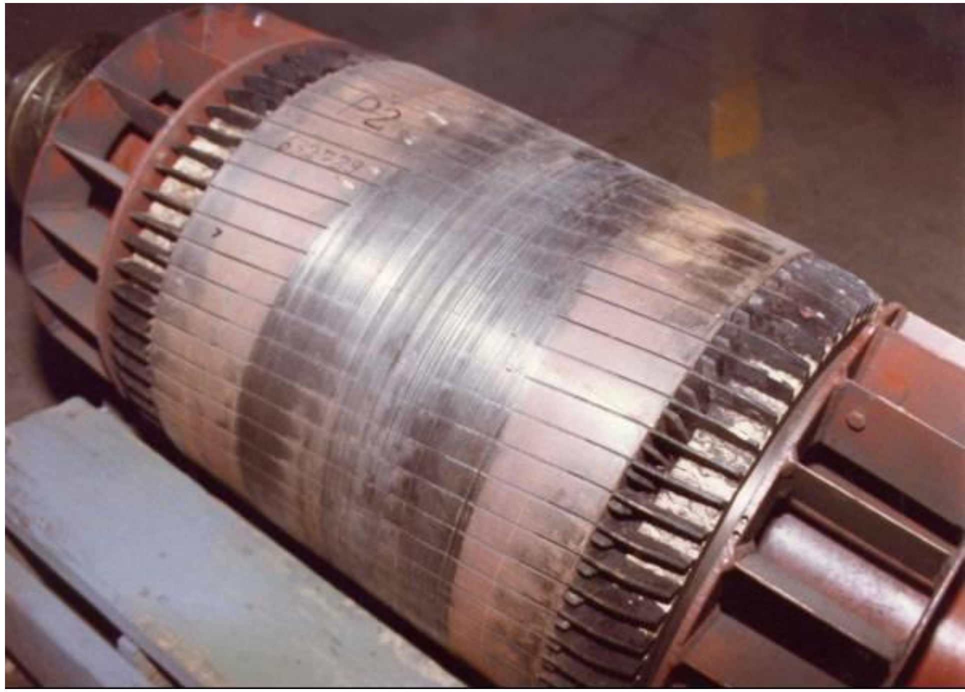
c) Dynamic Eccentricity

- Minimum airgap changes with rotor angle
- High 1xTS vibration, resembles mechanical unbalance, rotor bar/slot pass +/- 2xLF
- Caused by poor assembly, bent shaft, severely worn or damaged bearings

Airgap – Forces

- The forces in the air gap between rotor and stator are of the order of twice the rotor weight
- If these are balanced, we have no problem, but if there is an unequal air gap then the net lateral forces on the rotor can be very high
- Such forces can force the rotor over and damage bearings or seals
- Worst case can result in a rotor to stator rub



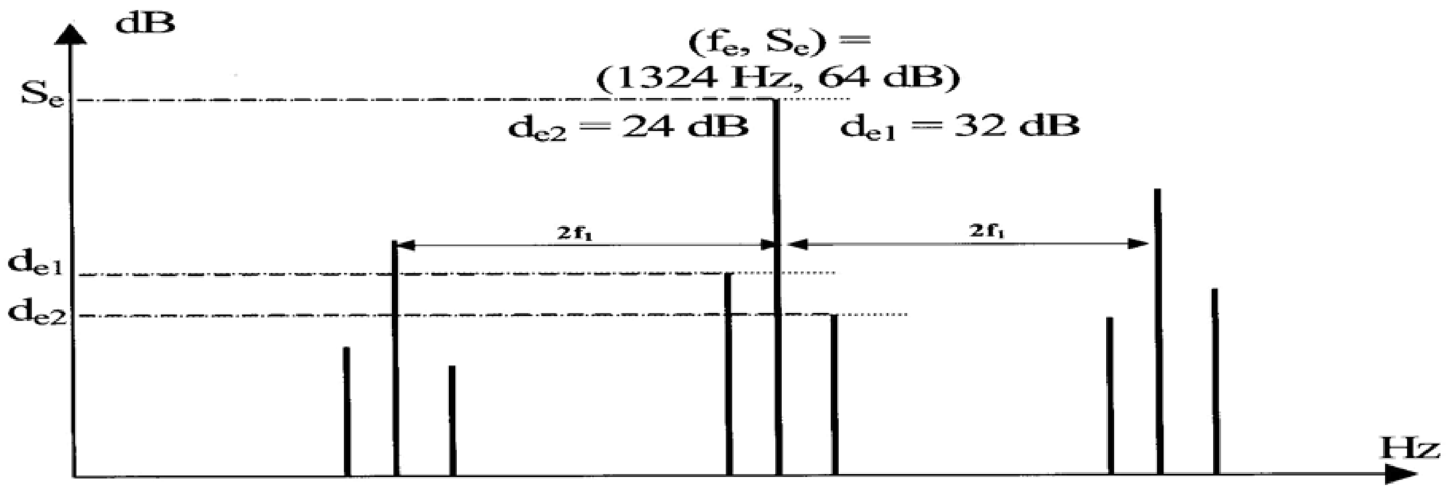


Airgap – Current Signature Analysis

- Number of rotor bars/slots may not be known
- Easily confused with the number of stator bars/slots
- Modulated by 2xTS (not 2xLF)

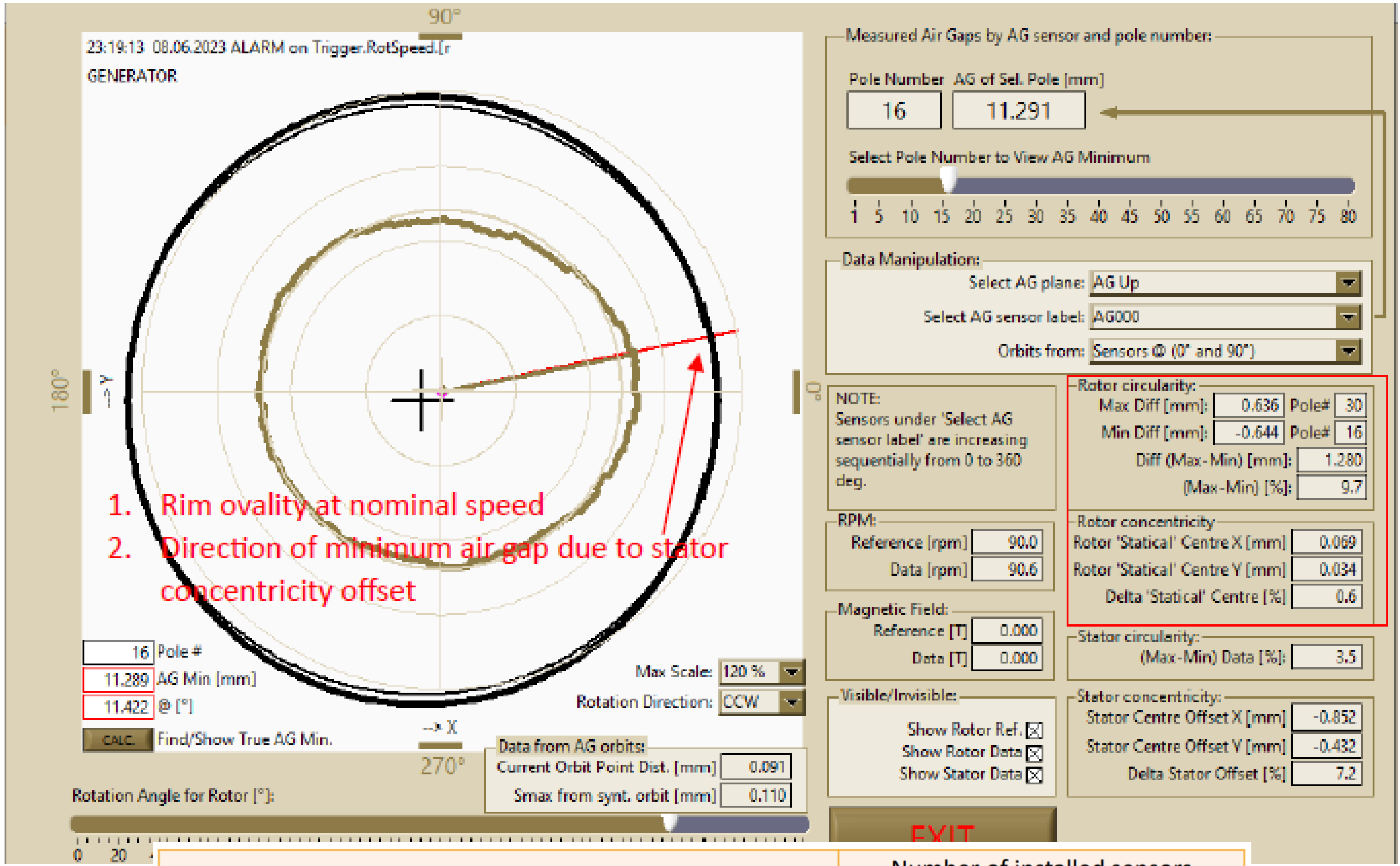
Static: Rotor slot passing frequency component — Dynamic: Rotational speed frequency component f_r

$$f_{ec} = f_1\left[R\left(\frac{1-s}{p}\right) \pm n_{ws}\right] \pm f_1\left[\frac{1-s}{p}\right]$$



Airgap – Analysis

- Special monitoring techniques, typically reserved for very large salient pole machines such as hydro generators
- Non-contact probes installed within the airgap measuring distance between the rotor and stator



Possible result of applied analysis procedure	Number of installed sensors		
	1	2	4+
Minimum/Maximum/Average air gap (AG_{min}) – measured from each sensor	•	•	•
Maximum neighboring poles difference (AG_{diff})	•	•	•
Rotor poles profile	•	•	•
Rotor centre position		•	•
Rotor rotation centre position		•	•
Rotor dynamics		•	•
Stator shape – stator deformation			•
Stator centre position			•
Minimal air gap with stator shape impact			•

Loose Rotor Iron or Bar/Slot

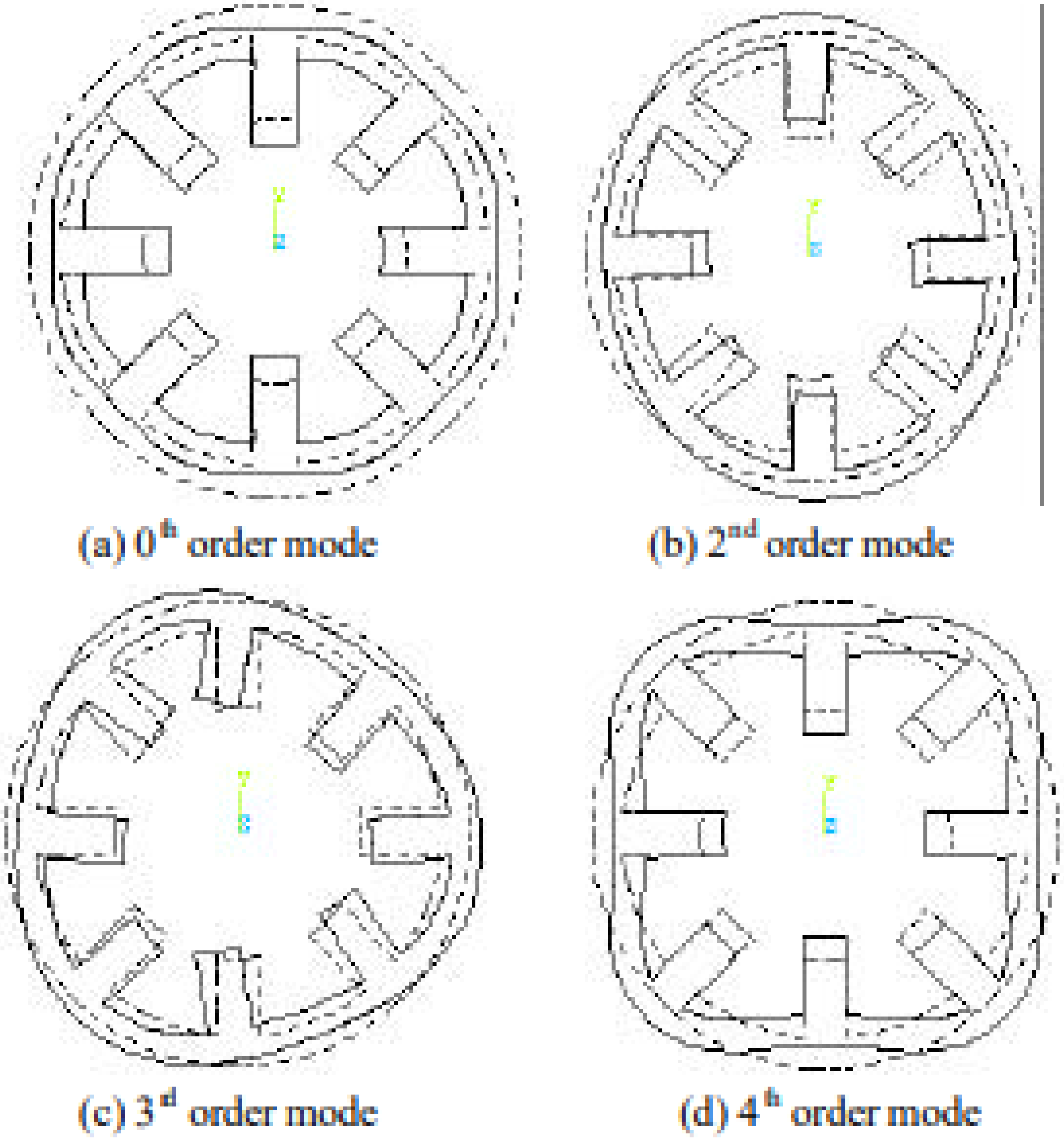
- The primary vibration appears in the spectrum at 2xLF and slot frequency with sidebands spaced at 2xLF
- The waveform shows a dominant cycle of 2xLF
- Loose rotor iron sometimes produces vibration at 2xLF modulated by 1X rotation speed frequency

Loose Stator Laminations or Core

- Vibration components will occur at 2xLF
- The primary vibration appears in the spectrum at 2xLF and harmonics of 2xLF
- Likewise, the waveform demonstrates cycles at frequencies related to 2xLF

Stator Resonance

- Core dimensions
- Frame dimensions
- Mounting of core in frame
- Measurement location (node vs antinode)
- Very load (speed) sensitive
- Audible noise (VFDs)
- Excitation from rotor or stator bar/slot pass frequency, modulated by 2xLF
- Soft foot condition or poor base (changes in stiffness, structural resonance)



Notes on VFDs

- Lowest speed that a motor can operate at without overloading
  - Speed - torque characteristics
  - Cooling problems at low speeds
- Insulation stresses
- Bearing currents
  - Premature degradation in both antifriction and hydrodynamic bearings
- Acts to vary line frequency
  - Measure accurate RPM
  - Slip is a function of load (and speed)
  - 2xLF ~= #poles xTS + Slip
- Excitation of lateral and torsional natural frequencies at different speeds
  - Analytical study of rotor assembly
  - Transient vibration and torsional analysis of the rotor assembly
  - Predict and measure the shaft stresses

Summary – Testing

- Online
  - Vibration analysis
  - Motor current signature analysis
- Shutdown/Startup
  - “Electrical” vibration will vanish once power to motor is cut, while “mechanical” vibration will persist
  - Monitor inrush current and starting time
  - Can be challenging to accurately capture the relatively rapid event
- Offline
  - Disassembly and inspection
  - Standard and specialized electrical testing

Summary – Induction Motor Electrical Faults

Fault	Fault Frequencies
Broken or open rotor bars	1xTS with sidebands at # poles time slip frequency 2xLF Hz amplitude modulation 2x per rev of slip frequency for 2 pole 4x per rev of slip frequency for 4 pole, etc
Dynamic eccentricity (rotating air gap)	1xTS with sidebands at # poles times slip frequency and 2xLF
Static eccentricity (stationary air gap or stator eccentricity)	2xLF very directional Possible slot pass frequency with sidebands at 2xLF
Loose rotor iron or slot	2xLF and slot pass frequency with sidebands at 2xLF
Loose stator laminations or loose stator core	2xLF and harmonics