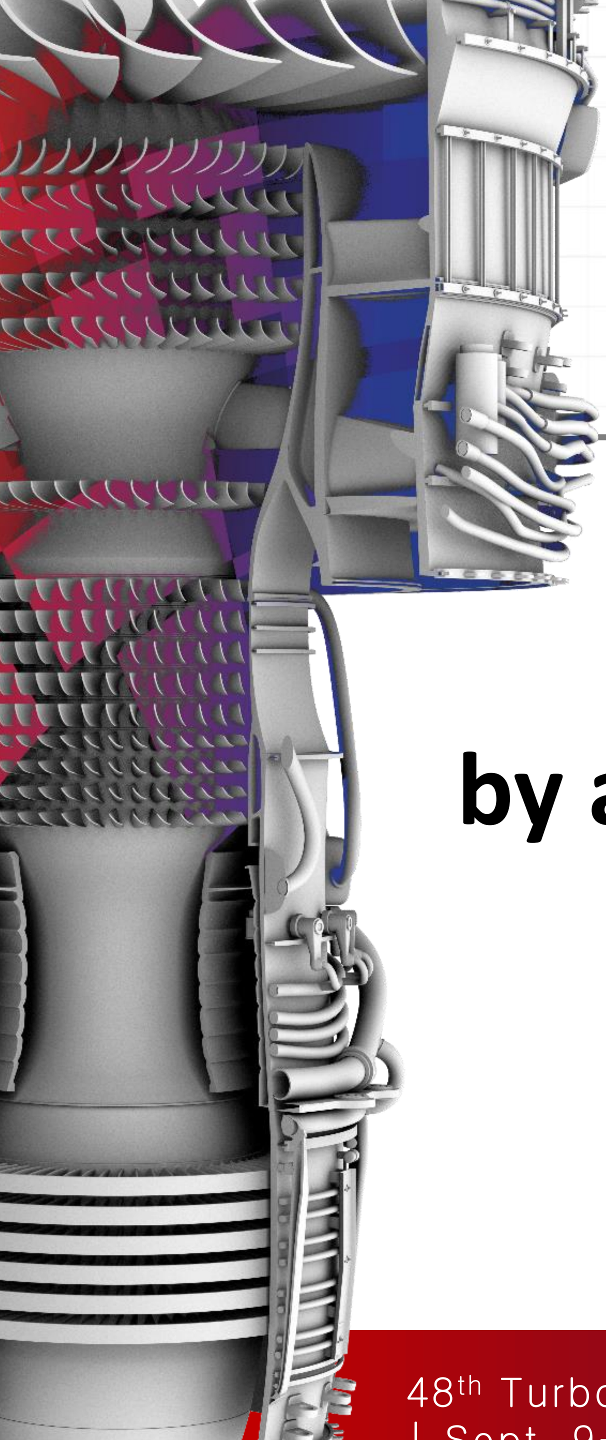


Fault diagnosis of electric motor by analyzing vibration and current spectrum

- Junseok Heo, Hyoseok Jeong -

Presenter & Author bios.

Presenter, Mr. Junseok Heo

Engineer in Electricity Reliability & Engineering Team of SK Energy Ulsan, Korea, since 2012.

Received a B.S.degree (Electrical Engineering and Business Management from Kyungpook National University, Korea).

Co-author, Mr. Seungsoo Ryoo

Senior Engineer in Electricity Reliability Reliability & Engineering Team of SK Energy Ulsan, Korea, since 1996.

Received a B.S.degree (Electrical Engineering from Yeungnam University, Korea).

Co-author, Mr. Jongoh Jang.

Senior Engineer in Rotating machinery Reliability & Engineering Team of SK Energy Ulsan, Korea, since 1988 a key member of KRMEA (Korea Rotating Machinery Engineers Association).

Co-author, Mr. Seungil Bae

Engineer in Rotating machinery Reliability & Engineering Team of SK Energy Ulsan, Korea, since 2010.

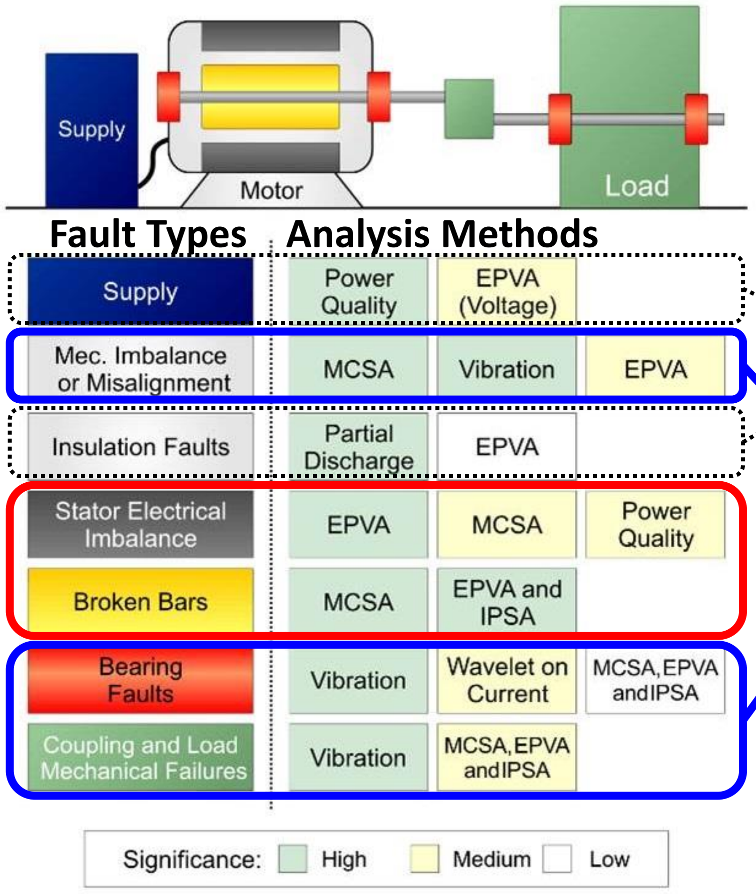
Received a M.S.degree (Mechanical Engineering from Busan National University, Korea).

Co-author, Mr. Hyoseok Jeong

Engineer in Rotating machinery Reliability & Engineering Team of SK Energy Ulsan, Korea, since 2017.

Received a B.S.degree (Mechanical Engineering from Hanyang University, Korea).

Why do you use Electrical Signature Analysis with Vibration method to induction motor?

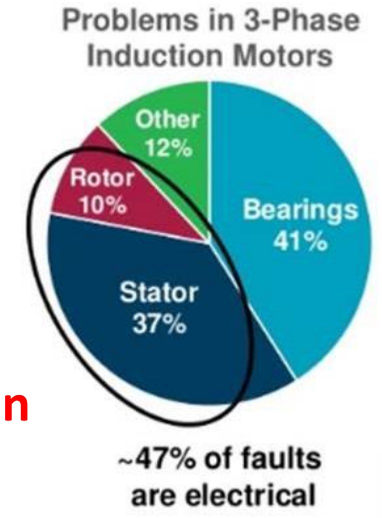


- **<u>Various Electrical Signature Analysis (ESA) Methods</u>**
  : Power Quality / EPVA (Extended Park's Vector Approach)
  IPSA (Instantons Power Sig Analysis) / Partial Discharge
  MCSA (Motor Current Signature Analysis)

ESA required for coverage of critical electrical fault

Hybrid detection combining vibration & ESA (especially MCSA)

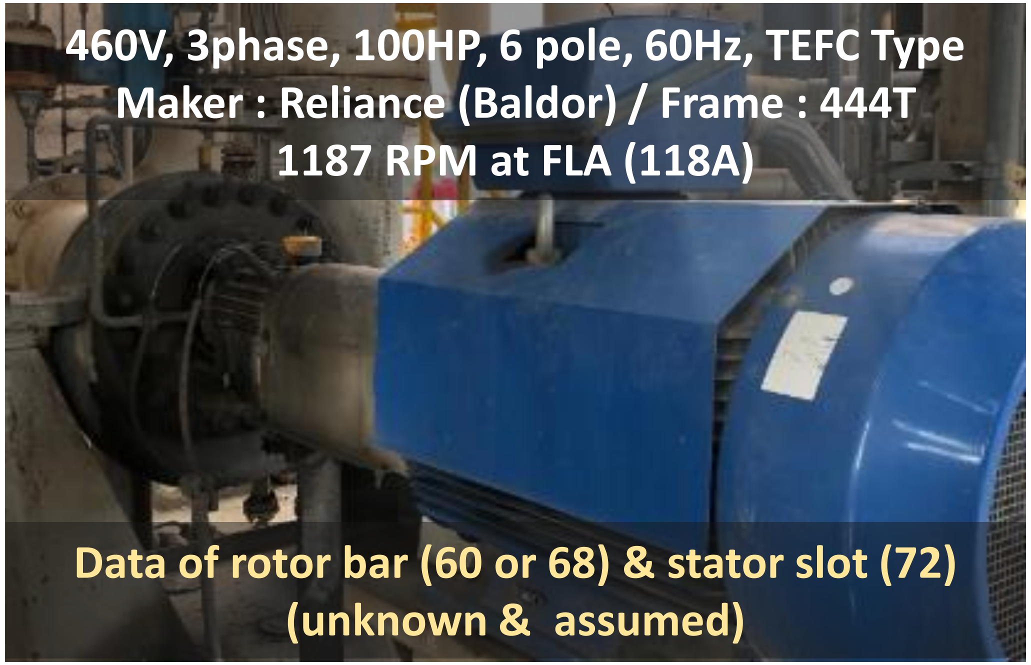
ESA also significantly some vibration for coverage of mechanical faults



* This page is from "The Road Ahead of IoT ", Analog devices company

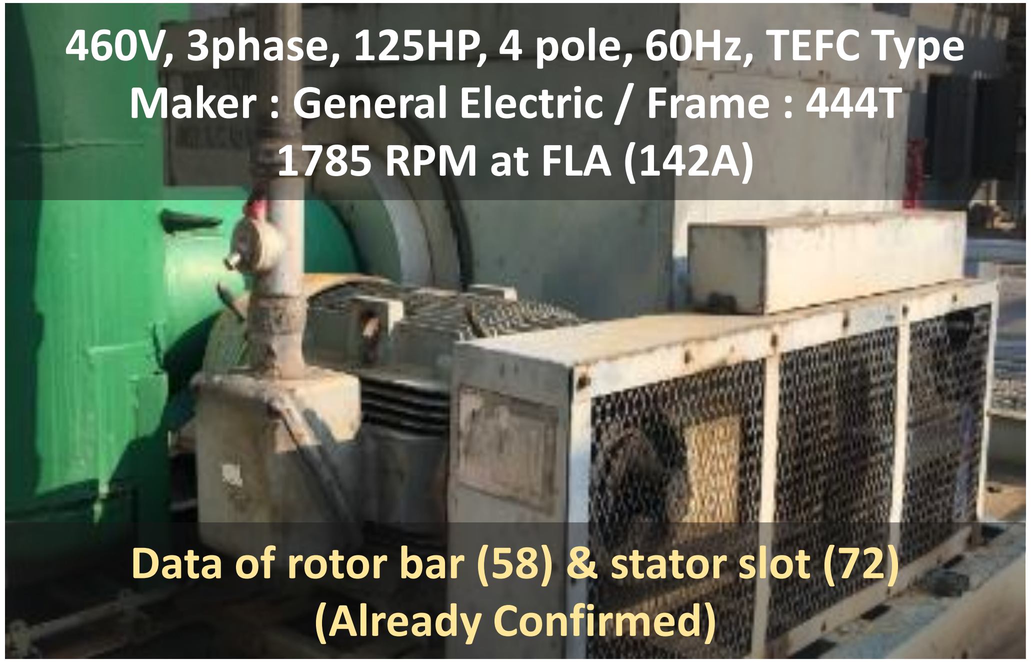
Case Study : Two Case of fault diagnosis by using MCSA and Vibration at polymer plant

1. CASE I. Stator Looseness Trouble Analysis



Reactor jacketing pump which located in polymer plant have no stand-by equipment.

2. CASE II. Bearing Looseness Trouble Analysis

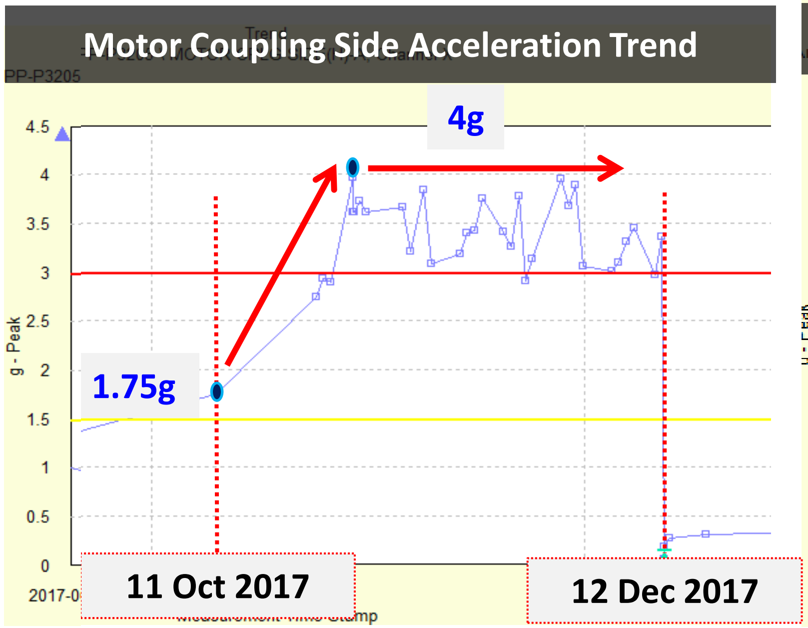


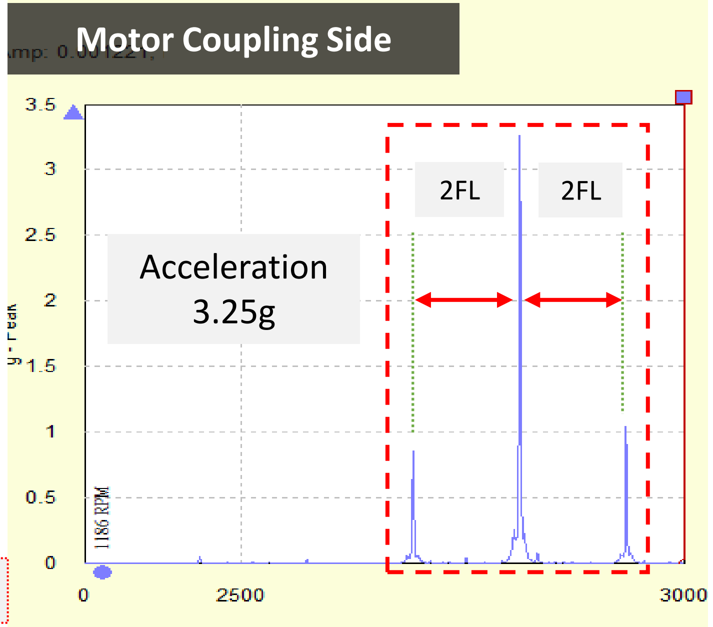
N2 blower which located in polymer plant for supply N2 for polymer drying.

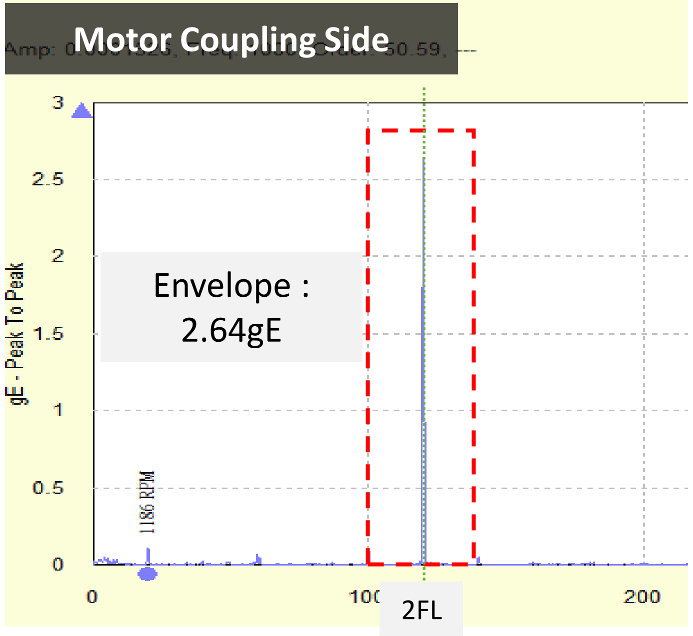
Mechanical View

1-1. Case I. Chronology of events

Reactor Jacketing Pump (no stand-by equipment) vibration gradually increase 1.75g to 4g and maintain vibration about 4g for 2month.







→ By looking at 2FL side band(Acceleration Spectrum), RBPF was expected cause. However this is uncertain, as number of Rotor bar is unknown.

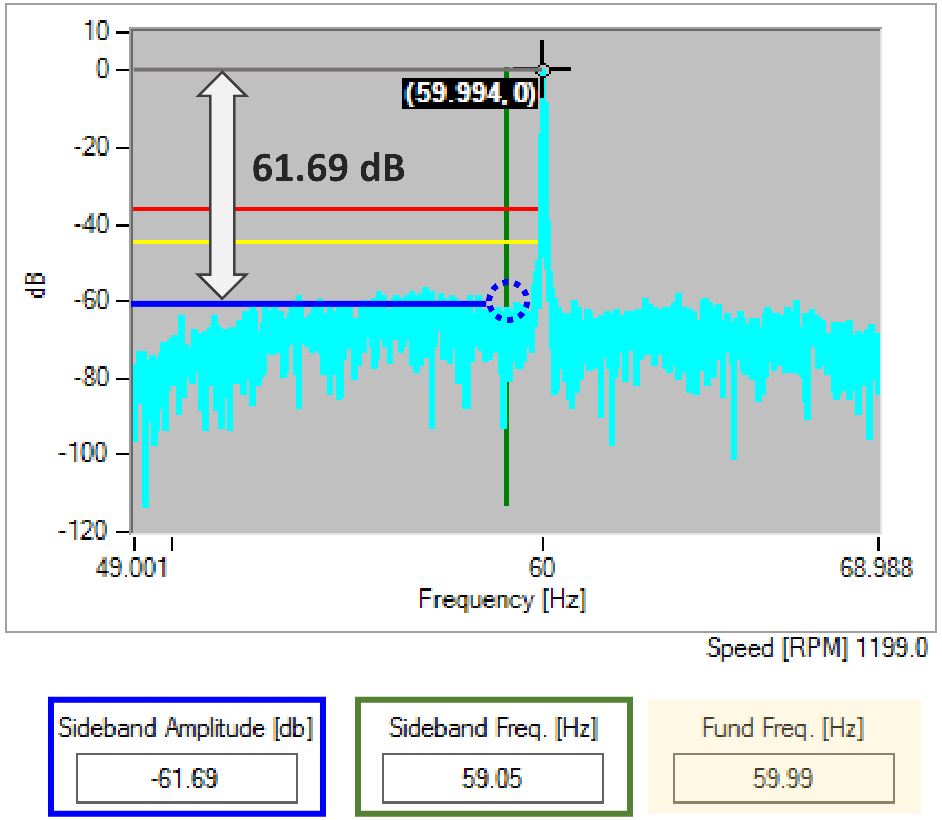
→ Electric Fault was expected by 2FL frequency in the envelope spectrum.

1-2. Case I. Trouble Shooting

Electrical View

Due to occurred RBPF & 2FL, testing to check rotor bar trouble at first.

But, Sideband frequency (f_{rb}) of rotor bar didn't occur at this motor.



Measured side band frequency

PP-3205	460.0 [V]	117.0 [A]	100.0 [Hp]	1188 [RPM]	Waveforms [LN]

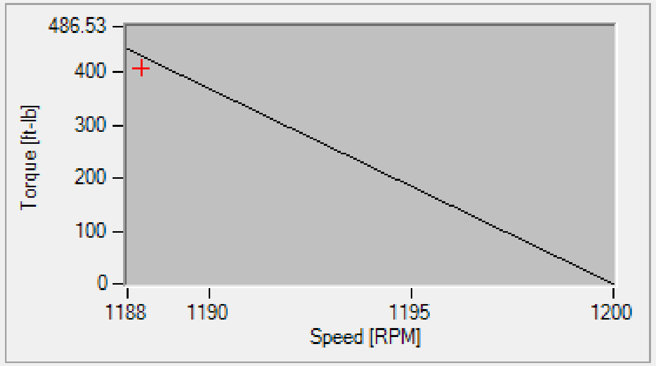
※ **Calculated to find rotor bar frequency & side band by formula.**

$$N_s = 120 \times f_s \div P = 120 \times 59.99 \div 6 = 1,199.8\ RPM$$

$$s = (N_s - N_r) \div N_s = (1,199.8\ - 1,188.3) \div 1,199.8 = 0.009585$$

$$\therefore f_{rb} = f_L \times (1 \pm 2s) = 58.84Hz, 61.14Hz$$

Although unknown rotor bar's data,
it is possible to find the rotor bar frequency.



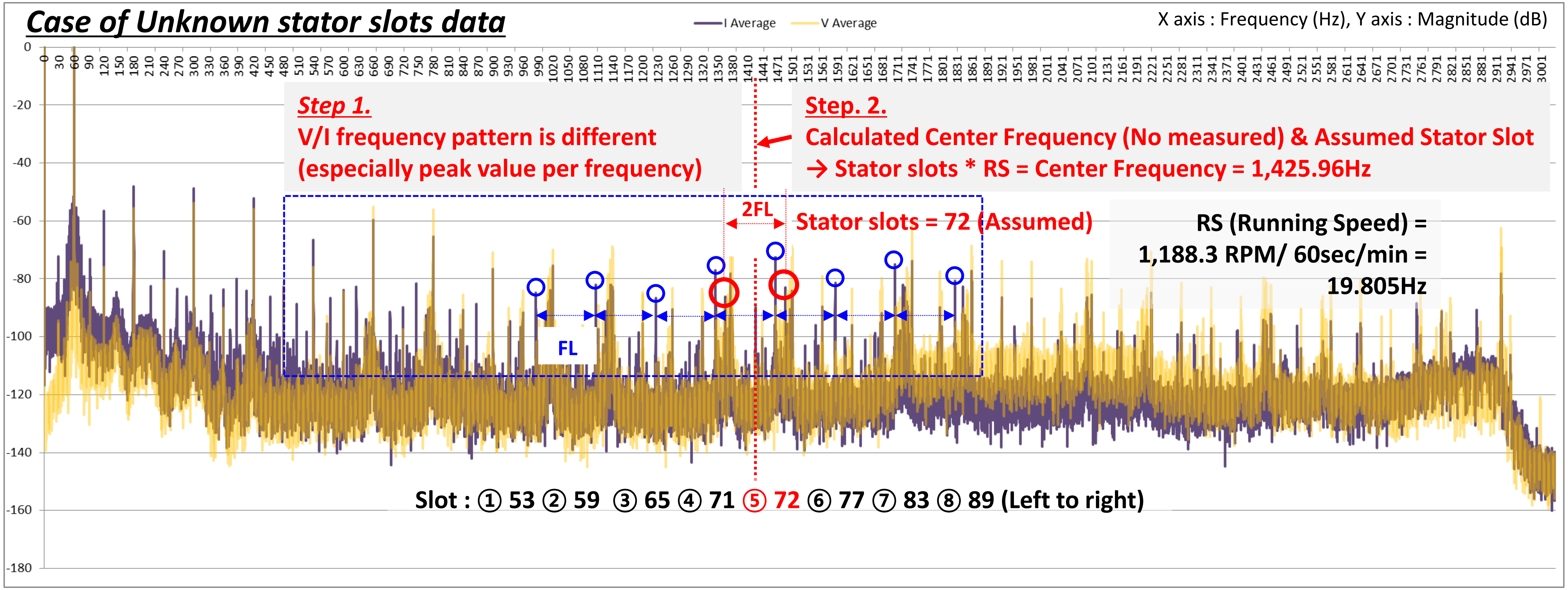
Efficiency [%]	93.7
Torque [ft-lb]	407.0
Load [%]	92.0
Load [hp]	92.0
Speed [RPM]	1188.3

1-2. Case I. Trouble Shooting

Electrical View

And then, checked to V/I spectrum for find other reasons & troubleshoot step by step.

According to below spectrum stator had certain trouble such as looseness or short.

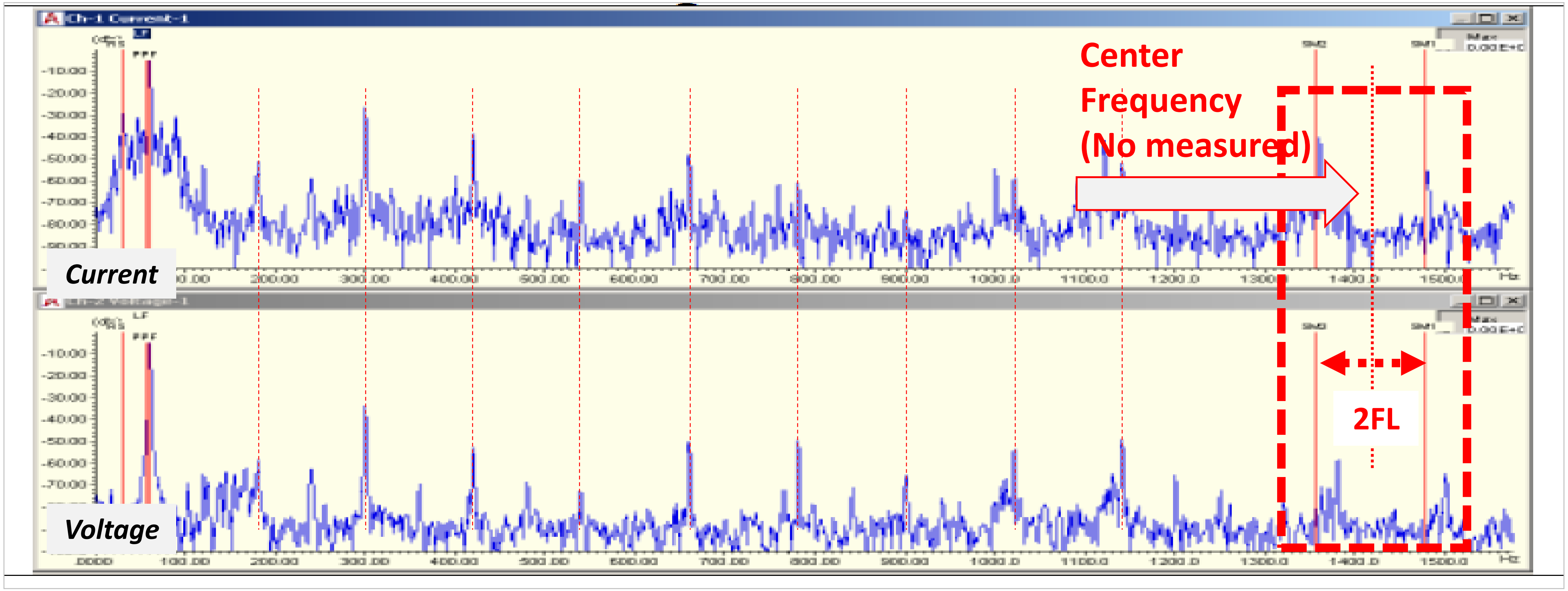


(Continuous to next page)

1-2. Case I. Trouble Shooting

Electrical View

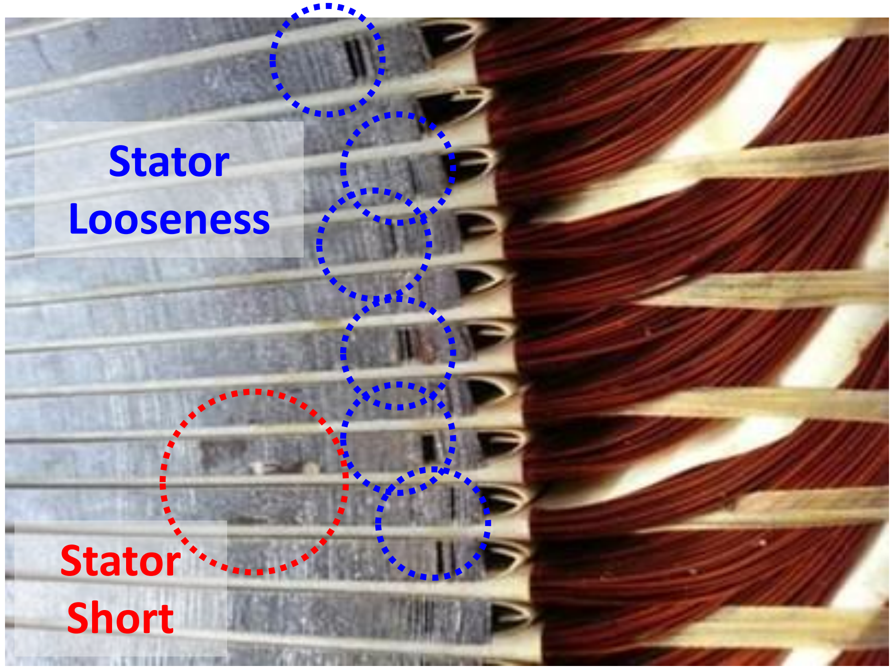
This following V/I spectrum is representative of stator anomaly condition.
Stator has specific frequency called "**Center Frequency**" and **sideband (2FL)**.



From. Manual by All test pro.

1-3. Case I. Trouble Shooting & The Solutions

This motor is critical item in terms of environment when it is unexpected stop. ***Also, this is no stand-by item so decided to replaced new motor. After replaced,*** performed disassembly and detail inspection both stator and rotor of motor.



- ✓ ***Stator → bad condition : Core lamination is loosen and short***
- ✓ ***Rotor → Good condition : made by AL die casting method, very strongly)***

1-4. Case I. Lessons Learned

- ✓ **For rotor bar fault analysis in mechanical view, rotor bar data must be needed, but *<u>electrical analysis for rotor bar can be performed without data</u>*. If data is not sufficient for mechanical analysis, electrical analysis can be good alternative**

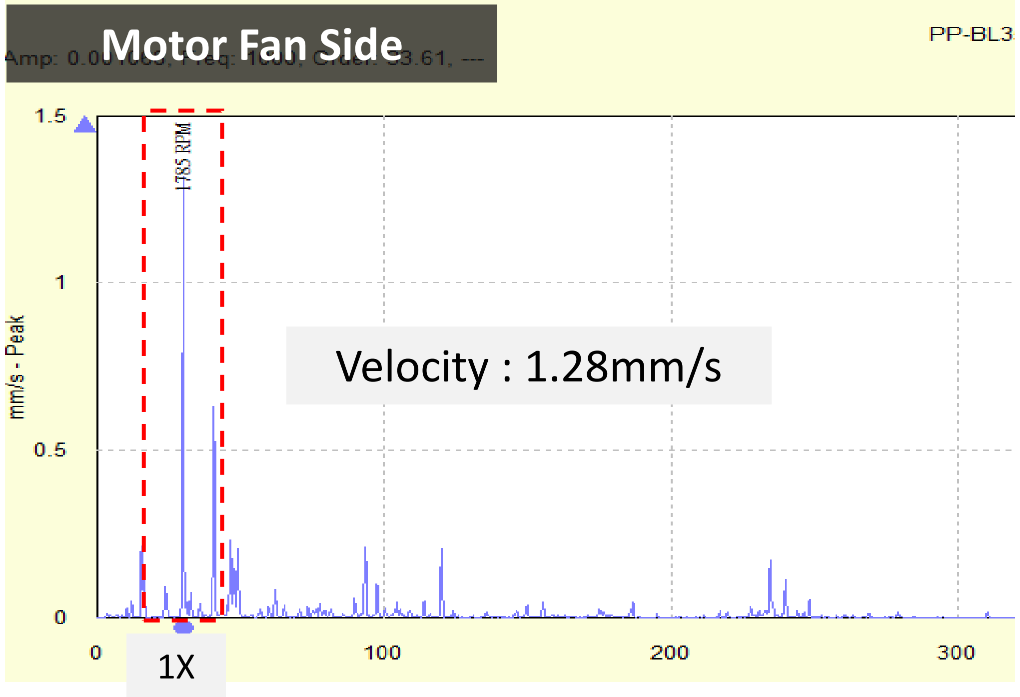
- ✓ **In stator trouble, twice line frequency side band can be shown in the acceleration trend and it can be considered as rotor bar fault. *<u>For accurate diagnosis, MCSA (Motor Current Spectrum Analysis) must be performed.</u>***

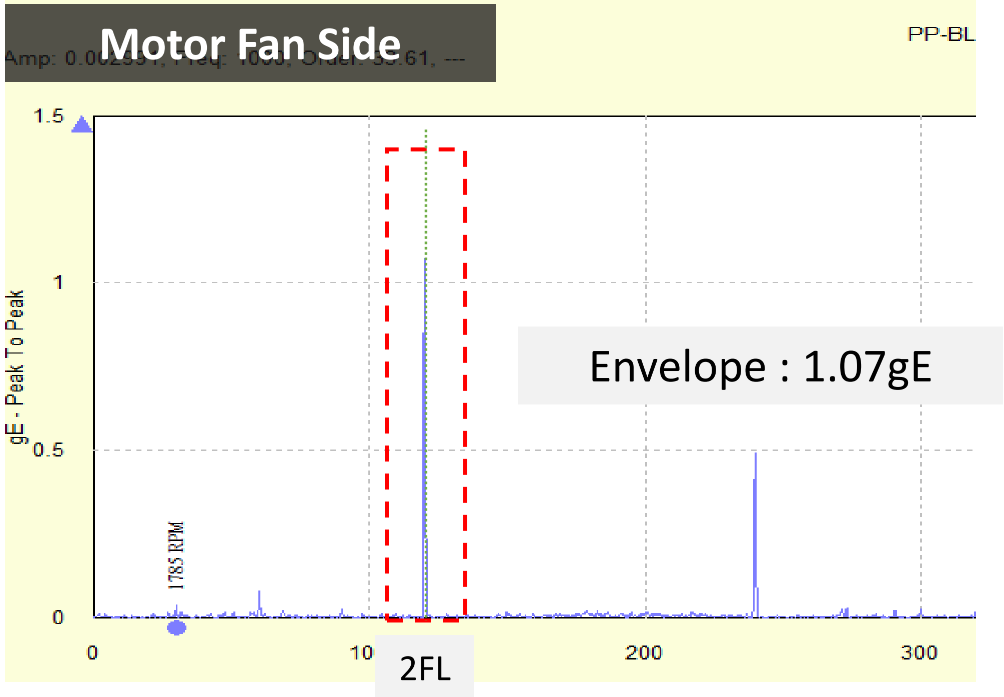
- ✓ **For rotor bar passing frequency analysis, detail rotor data should be include at the purchasing stage.**

2-1. Case II. Summary of Mechanical Events

Mechanical View

The blower that supply N2 for polymer drying noise and vibration appeared. Blower switch to spare equipment and carry out overhaul work.





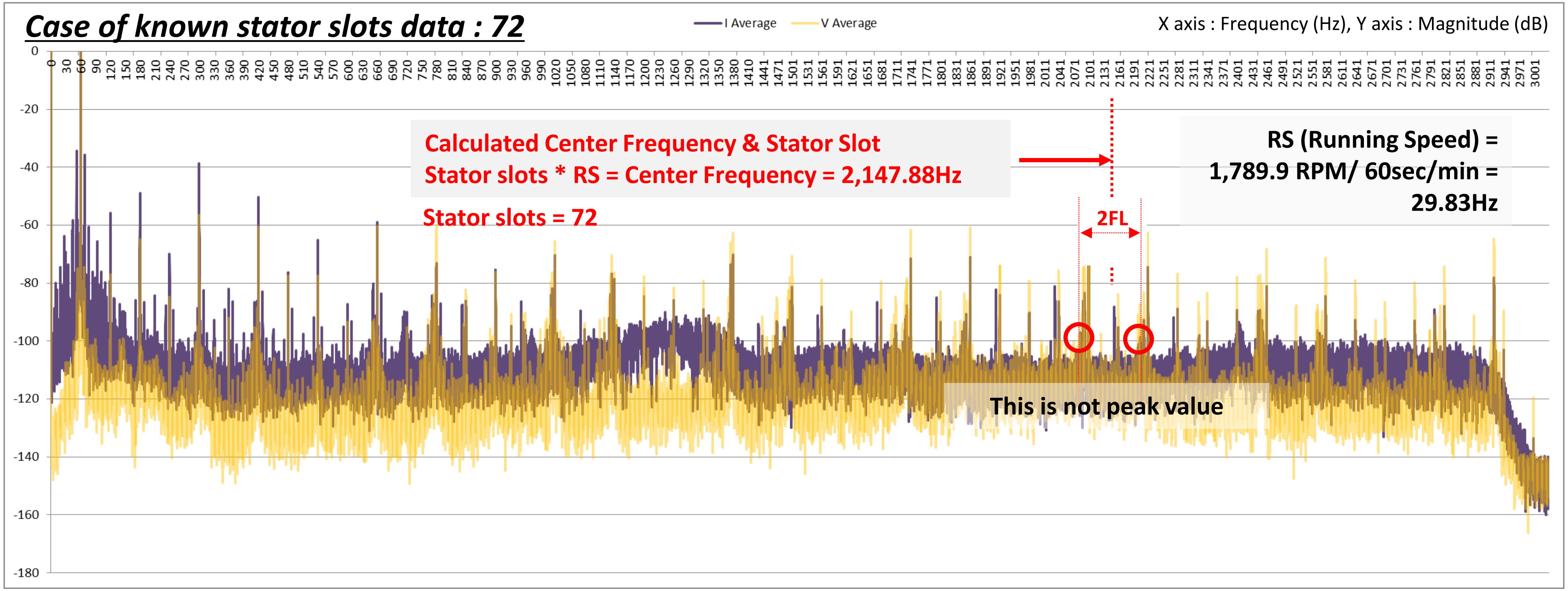
→ **By looking at 1X frequency, mechanical fault was suspected, but electric analysis carry-out before motor overhauling due to 2FL frequency.**

2-2. Case II. Trouble Shooting

Electrical View

Due to occurred 1X & 2FL, testing related to check stator or unbalance trouble at first.

According to below spectrum Stator didn't has trouble such as looseness or short.

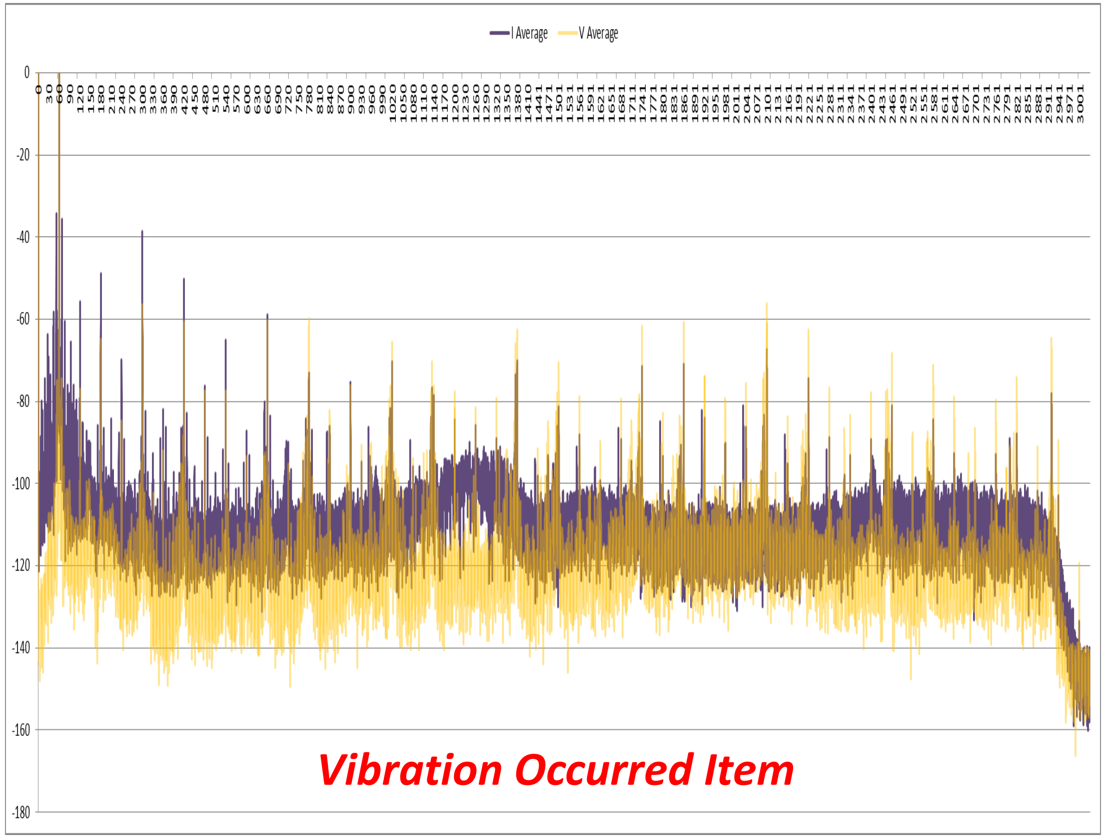


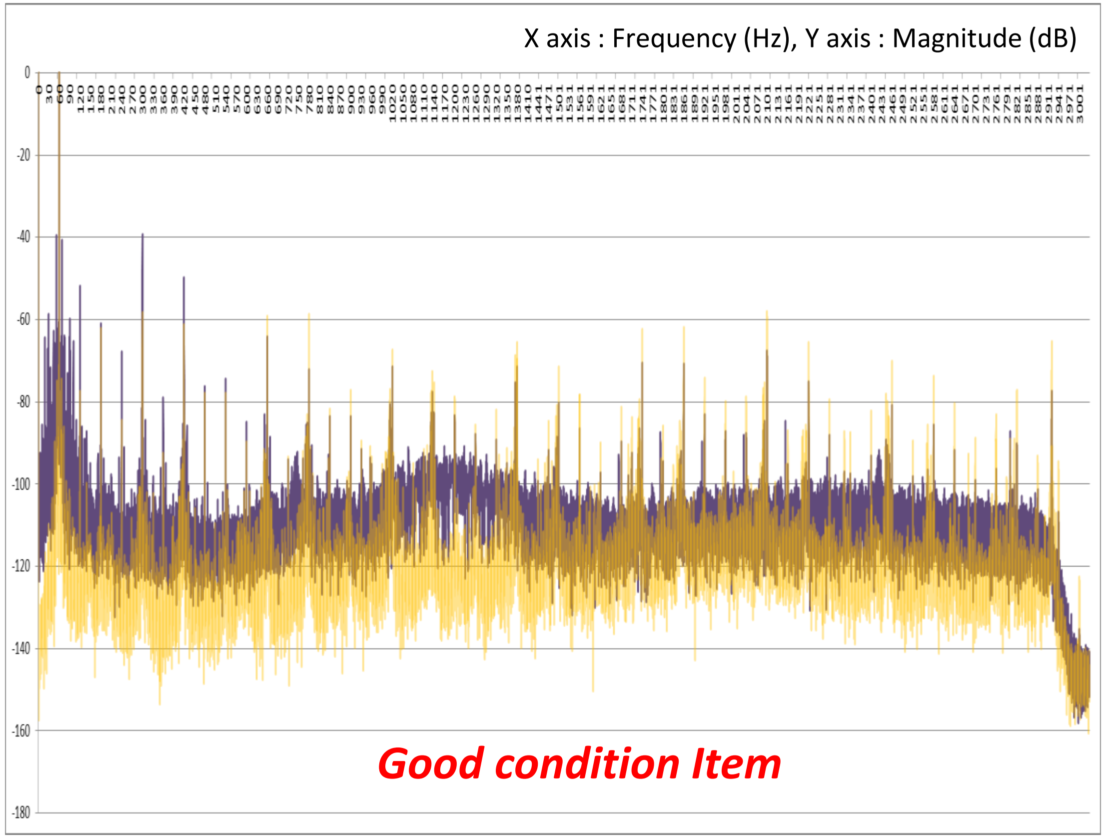
2-2. Case II. Trouble Shooting

Electrical View

And also, this motor has stand by with 100% same spec. blower.

The result of checked V/I spectrums between them, Couldn't not find out anything.



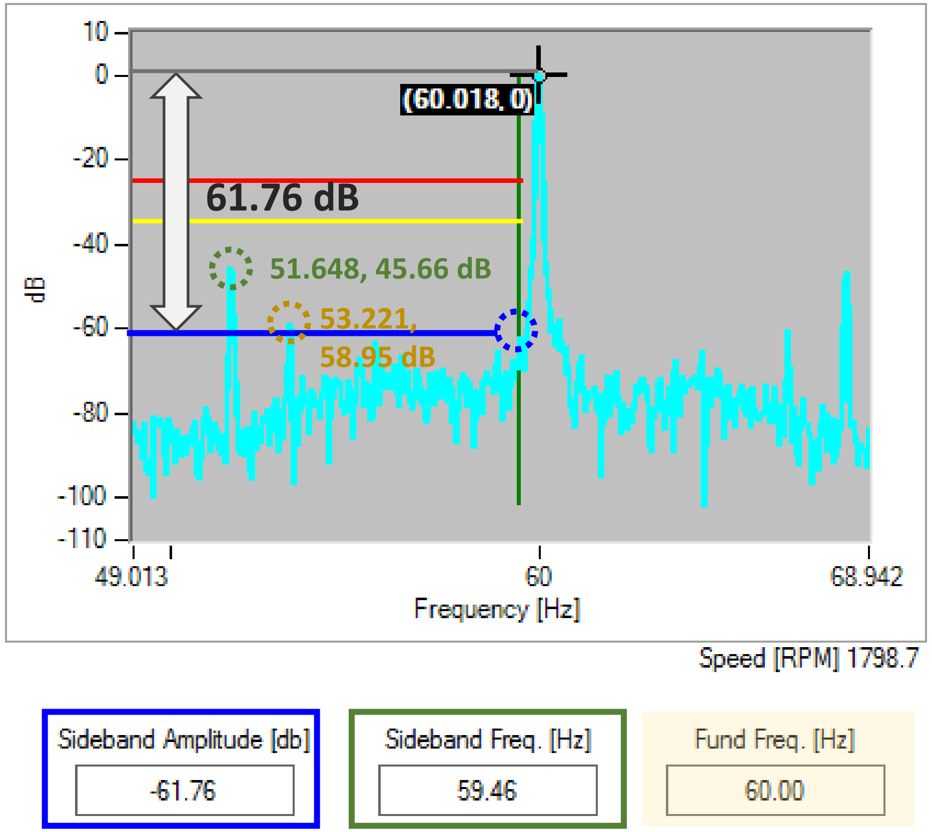


Electrical View

2-2. Case II. Trouble Shooting

Finally, testing to check rotor bar trouble in the slightest sense.

knew it, Sideband frequency (f_{rb}) of rotor bar didn't occur at this motor.



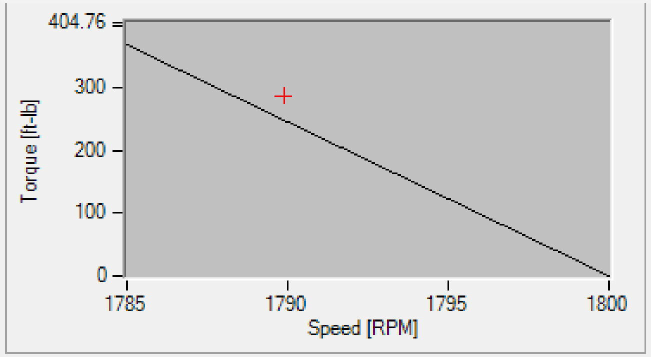
Measured side band frequency

PP-BL3502B 460.0 [V] 142.0 [A] 125.0 [Hp] 1785 [RPM] Waveforms [LI

※ Calculated to find rotor bar frequency & side band by formula.

$$N_s = 120 \times f_s \div P = 120 \times 60.00 \div 4 = 1{,}800.0\ RPM$$
$$s = (N_s - N_r) \div N_s = (1800.0 - 1{,}789.9) \div 1{,}800.0 = 0.005611$$
$$\therefore f_{rb} = f_L \times (1 \pm 2s) = 59.32Hz, 60.67Hz$$

Although unknown rotor bar's data,
it is possible to find the rotor bar frequency.



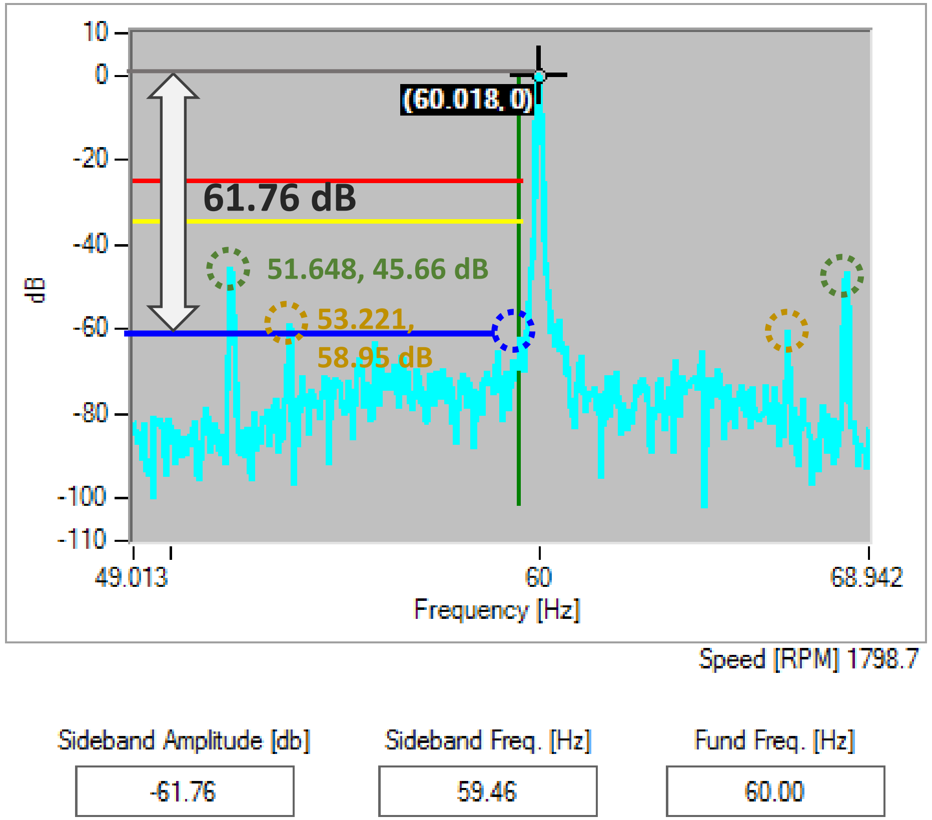
Efficiency [%]	95.1
Torque [ft-lb]	286.3
Load [%]	78.0
Load [hp]	97.5
Speed [RPM]	1789.9

2-2. Case II. Trouble Shooting

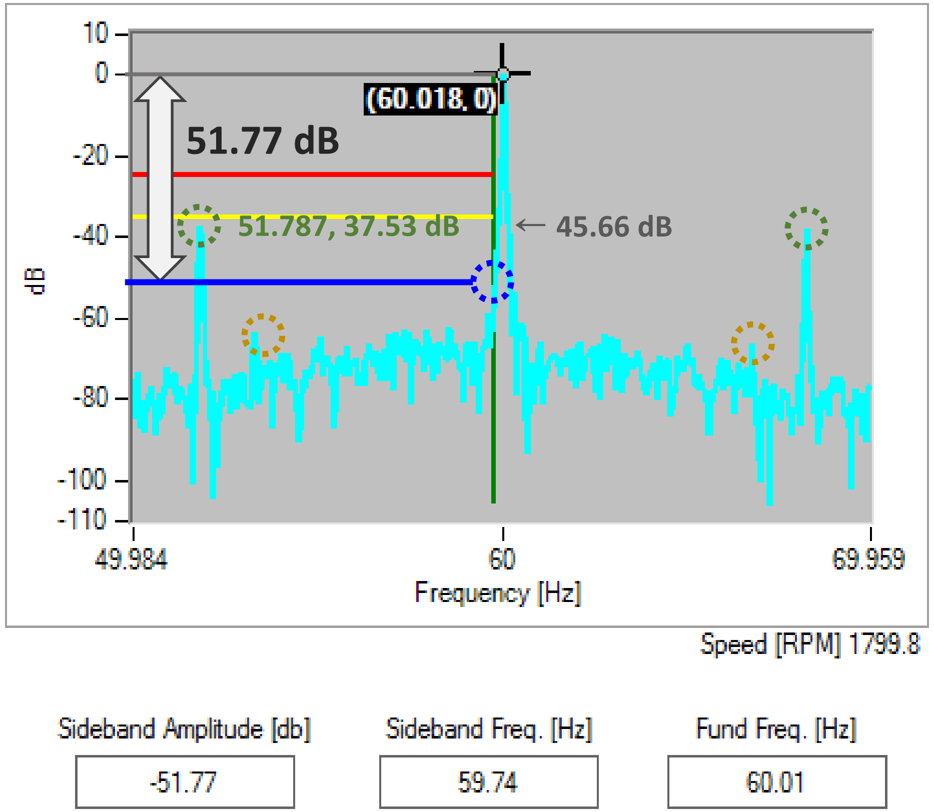
Electrical View

But, the remark is present. Other peak value (not rotor bar frequency) occurred.

The reason is presumed to operated by belt driven at this motor. (belt frequency)



Vibration Occurred Item



Good condition Item

2-2. Case II. Trouble Shooting

Mechanical View

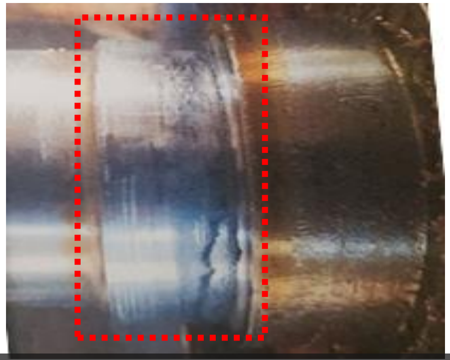
After return and focus on mechanical defects, found below things

Both bearing have poor clearance and shows the scratch (rotation mark) on the shaft surface and bearing housing

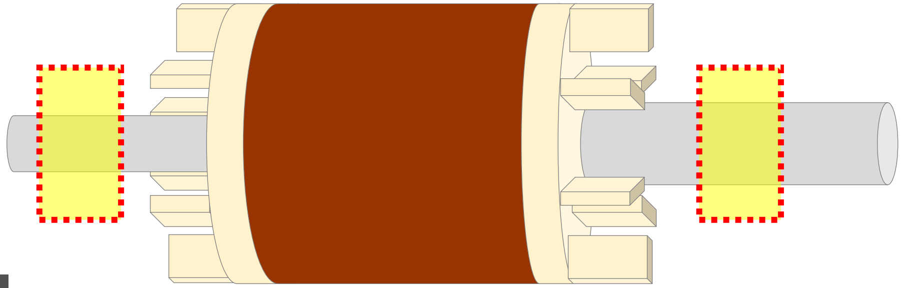
Poor bearing & shaft clearance
Poor bearing & housing clearance

→ **Uneven Air Gap Variation** → **2FL Frequency**

→ **Bearing Looseness** → **1X Frequency**



Shaft Surface Scratch
(Fan Side)



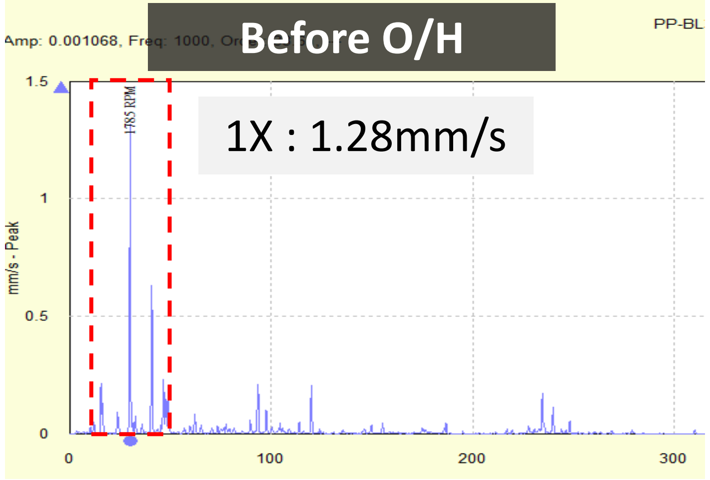
Shaft Surface Scratch
(Coupling Side)

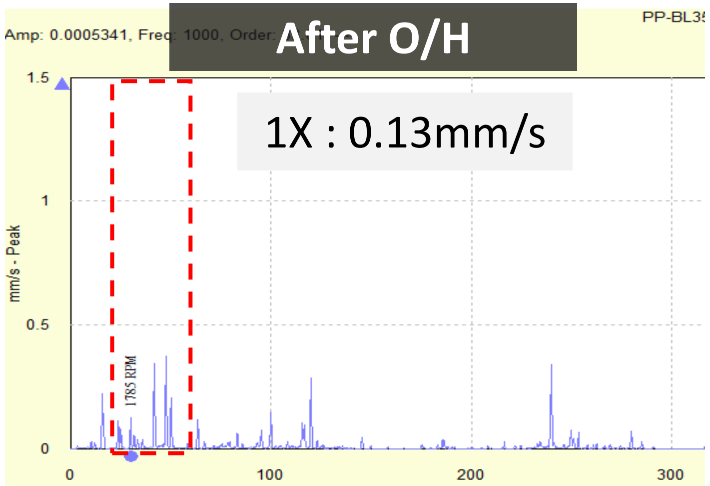
2-3. Case II. The Solutions

Mechanical View

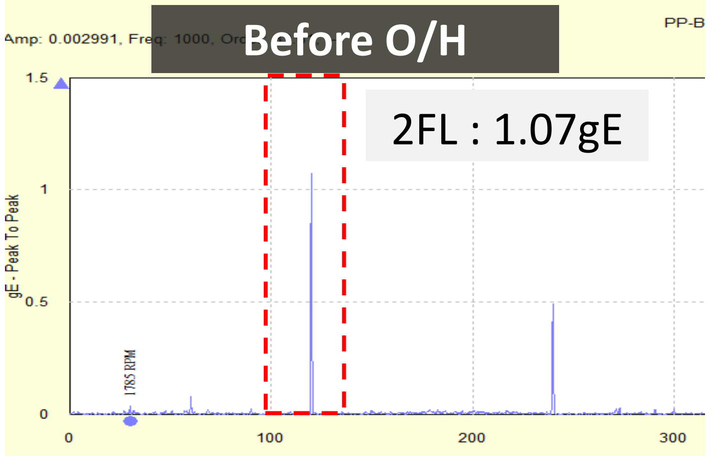
After overhaul performed (Shaft surface welding repair / mounting bushing in the bearing housing) 1X and 2FL dramatically decreased.

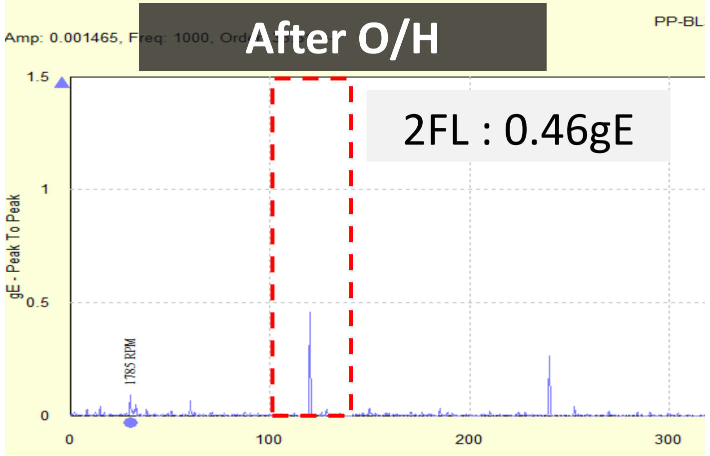
Fan Side Velocity Spectrum





Fan Side Envelope Spectrum





2-4. Case II. Lessons Learned

- ✓ **We learned *twice line frequency* is symptom of electrical trouble. But it can be *caused by other mechanical causes*. it is necessary to cross-check by the vibration spectrum and current spectrum for accurate diagnosis.**

- ✓ **Analyzing the spare equipment current can be good example for comparison. If there is no-standby equipment, recording the current spectrum is good solution just in case.**

3. Conclusion

- ✓ **The basic diagnosis tool is vibration spectrum analysis, but relating motor, only vibration analysis is not sufficient and it can make misdiagnosis. *Vibration spectrum analysis with motor current spectrum analysis can be powerful tool for accurate equipment diagnosis*.**

- ✓ **The mechanical trouble can be source of electrical vibration spectrum (e.g Case 2). Sometimes it is hard to diagnosis only have electrical vibration spectrums (e.g Case 1). MCSA can support the vibration spectrum analysis for accurate diagnosis.**

Thanks and Questions

ACKNOWKEDGEMENTS

This work has been encouraged by the Korea Rotating Machinery Engineers Association, (KRMEA). The authors are grateful for the encouragement

Attachments.

1. Motor Current Signature Analysis Desk Reference – Rotor part

Condition	dB Value	Rotor Condition	Action
1	>60	Excellent	None
2	54-60	Good	None
3	48-54	Moderate	Trend
4	42-48	Rotor Fracture or High Resistance Joint	Increase Test Intervals and Trend
5	36-42	Two or more bars cracked or broken	Confirm with motor circuit analysis
6	30-36	Multiple cracked or broken bars and end ring problems	Overhaul
7	<30	Multiple broken rotor bars and other severe rotor problems	Overhaul or Replace

*Note: Values measured through CT's may show dampened results. Results might be more severe in these cases.

Attachments.

2. Motor Fault Signatures by current spectrum analysis

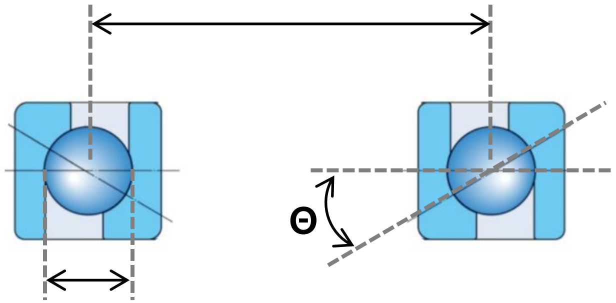
Type of Fault	Pattern (CF = Center Frequency)
Stator Mechanical (ie: loose coils, stator core movement, etc.)	CF = RS x Stator Slots Line Frequency Sidebands
Stator Shorts (shorted windings)	CF = RS x Stator Slots Line Frequency sidebands with Running Speed sidebands
Rotor Indicator	CF = RS x Rotor Bars Line Frequency sidebands
Static Eccentricity	CF = RS x Rotor Bars Line Frequency and twice Line Frequency sidebands.
Dynamic Eccentricity	CF = RS x Rotor Bars Line Frequency and twice Line Frequency with Running Speed sidebands
Mechanical Unbalance (and Misalignment)	CF = RS x Rotor Bars Line Frequency Sidebands, Space of four times Line Frequency then two Line Frequency peaks

Attachments.

3. Vibration Spectrum at Various Fault Formula

Part	Fault	Frequency
Bearing	Outer Race ($= f_{mo}$)	$\frac{N}{2}\left(1 - \frac{d}{D}\cos\theta\right) * S$, Harmonics
	Inner Race ($= f_{mi}$)	$\frac{N}{2}\left(1 + \frac{d}{D}\cos\theta\right) * S$, Harmonics
	Cage	$\frac{N}{2}\left(1 - \frac{d}{D}\cos\theta\right)$, Harmonics
	Rolling Element	$\frac{D}{2d}\left\{1 - \left(\frac{d}{D}\cos\theta\right)^2\right\} * S$, Harmonics
	Housing & Bearing Looseness / Shaft & Bearing Looseness	1X, Harmonics
Electric Motor	Air-Gap Variation	2FL, Sidebands(Slip Freq x No. Pole)
	Stator Short	2FL, Harmonics
	Rotor Bar Breakage	1X, Sidebands(Slip Freq x No. Pole)
	Rotor Bar Looseness	RBPF, Sidebands(2FL)

D = Pitch Diameter



d = Ball Diameter

Θ = Contact Angle

N = Number of Rolling Element

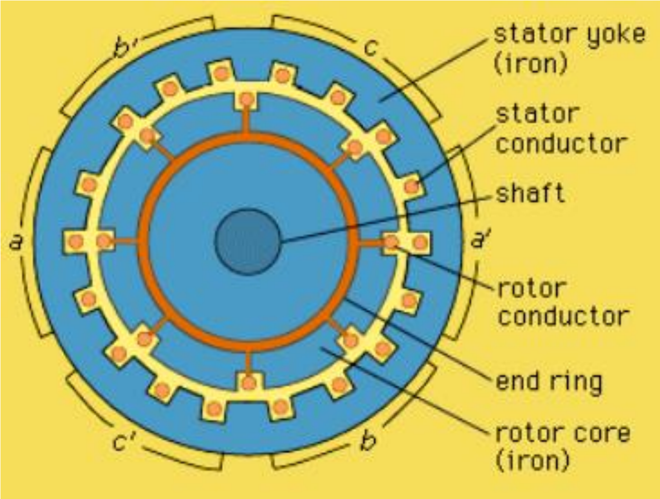
S = Shaft Speed

Attachments.

4. Motor Current Spectrum at Various Fault Formula

Part	Fault	Frequency
Bearing	Outer Race	$\lvert f_L \pm \mathrm{n} * \mathrm{f_{mo}} \rvert, \mathrm{n} = 1,2,3,\cdots$
	Inner Race	$\lvert f_L \pm n * f_{mi} \rvert, \mathrm{n} = 1,2,3,\cdots$
Gear Box	Mechanical Fault	$f_L \pm n * \left(\sum_{i}^{N} f_{gear,i} \right), n = 1,2,3,\cdots$
Electric Motor	Air-Gap Eccentricity	$f_L \left\{ 1 \pm \mathrm{n} * \frac{1-\mathrm{s}}{\mathrm{P}} \right\}, \mathrm{n} = 1,2,3,\cdots$
	Mechanical Fault : Misalignment, Looseness, etc.	or $f_L \pm \mathrm{n} * \mathrm{f_r}, \mathrm{f_r} = f_L * \frac{1-\mathrm{s}}{\mathrm{P}}$
	Stator Fault : Shorted Turns	$f_L \left\{ \frac{n}{\mathrm{P}} (1-s) \pm \mathrm{k} \right\},$ $\mathrm{n} = 1,2,3,\cdots, \mathrm{k} = 1,3,5,\cdots$
	Rotor Bar Broken & Looseness	$f_L(1 \pm 2 * n * s), n = 1,2,3,\cdots$

2 Pole Motor Example



f_L = Line frequency

f_{mo} = Bearing Outer Race freq.

f_{mi} = Bearing Inner Race freq.

p = Motor Stator Pole

s = Motor Slip
= (Synchro. – Actual Speed) / Synchro. Speed