# ELECTRIC MOTORS

## OPERATION AND VIBRATION CASE HISTORIES

# TOPICS COVERED

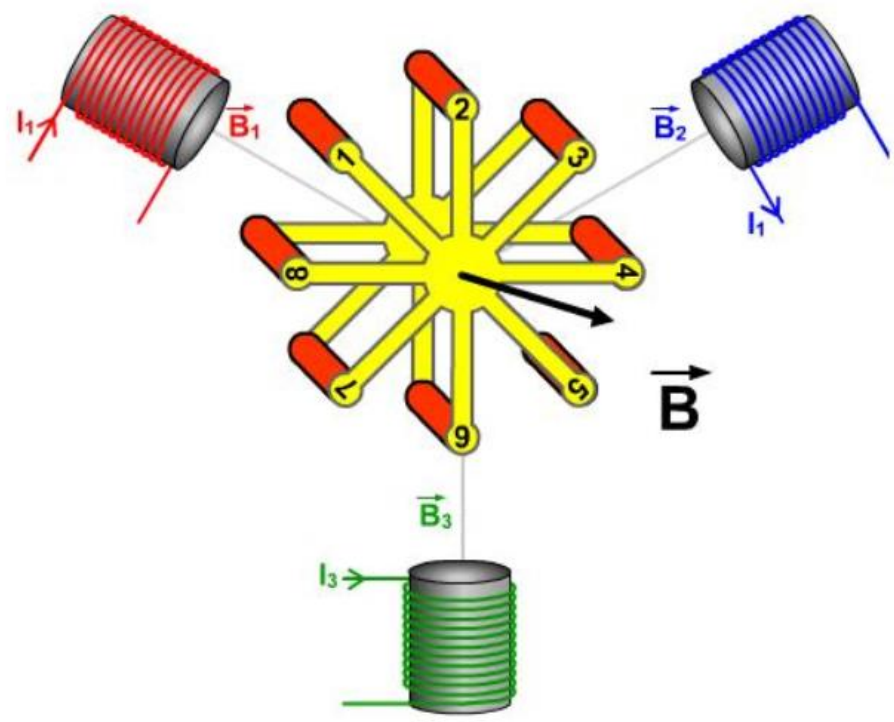
- INDUCTION MOTOR CASE HISTORIES
- CURRENT SPECTRAL TESTING
- SYNCHRONOUS MOTORS
- LINE HARMONICS
- DC MOTORS
- VARIABLE FREQUENCY DRIVES

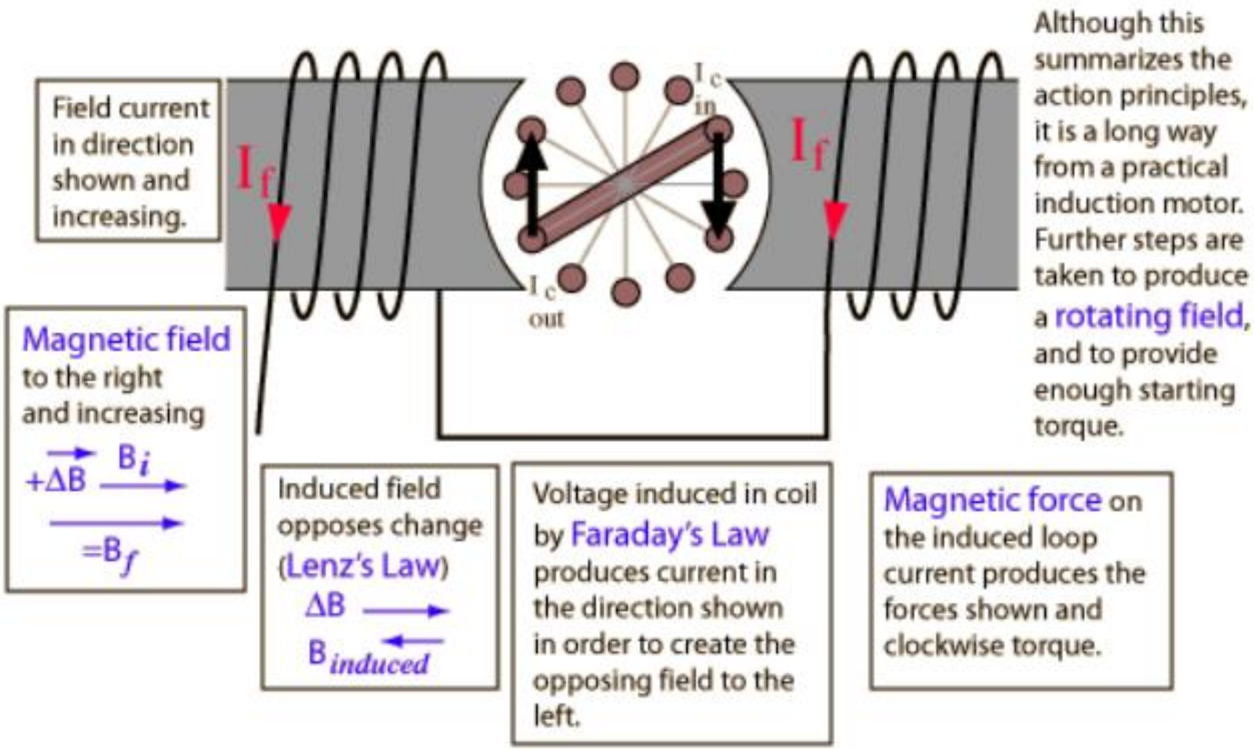
# ELECTRIC INDUCTION MOTORS

# INDUCTION MOTORS

- THE STATOR CONTAINS A ROTATING MAGNETIC FIELD PRODUCED BY THE 3 PHASE ELECTRIC CURRENT THAT FLOWS THROUGH THE WINDINGS.
- YOU MIGHT THINK OF THIS FIELD AS AN INVISIBLE GHOST ROTOR.
- THE ROTOR CONSISTS OF A SERIES OF BARS THAT ARE SHORTED TOGETHER BY THE END RINGS.
- AS THE INVISIBLE ROTATING MAGNETIC FIELD PASSES THROUGH THE BARS, CURRENT IS INDUCED IN THE BARS. BY LENZ'S LAW, THIS CURRENT PRODUCES A MAGNETIC FIELD THAT GENERATES TORQUE, CAUSING THE ROTOR TO TURN.
- The magnetic field frequency for 60 HZ induction motors is always 120HZ. This does not depend upon the speed of the motor.

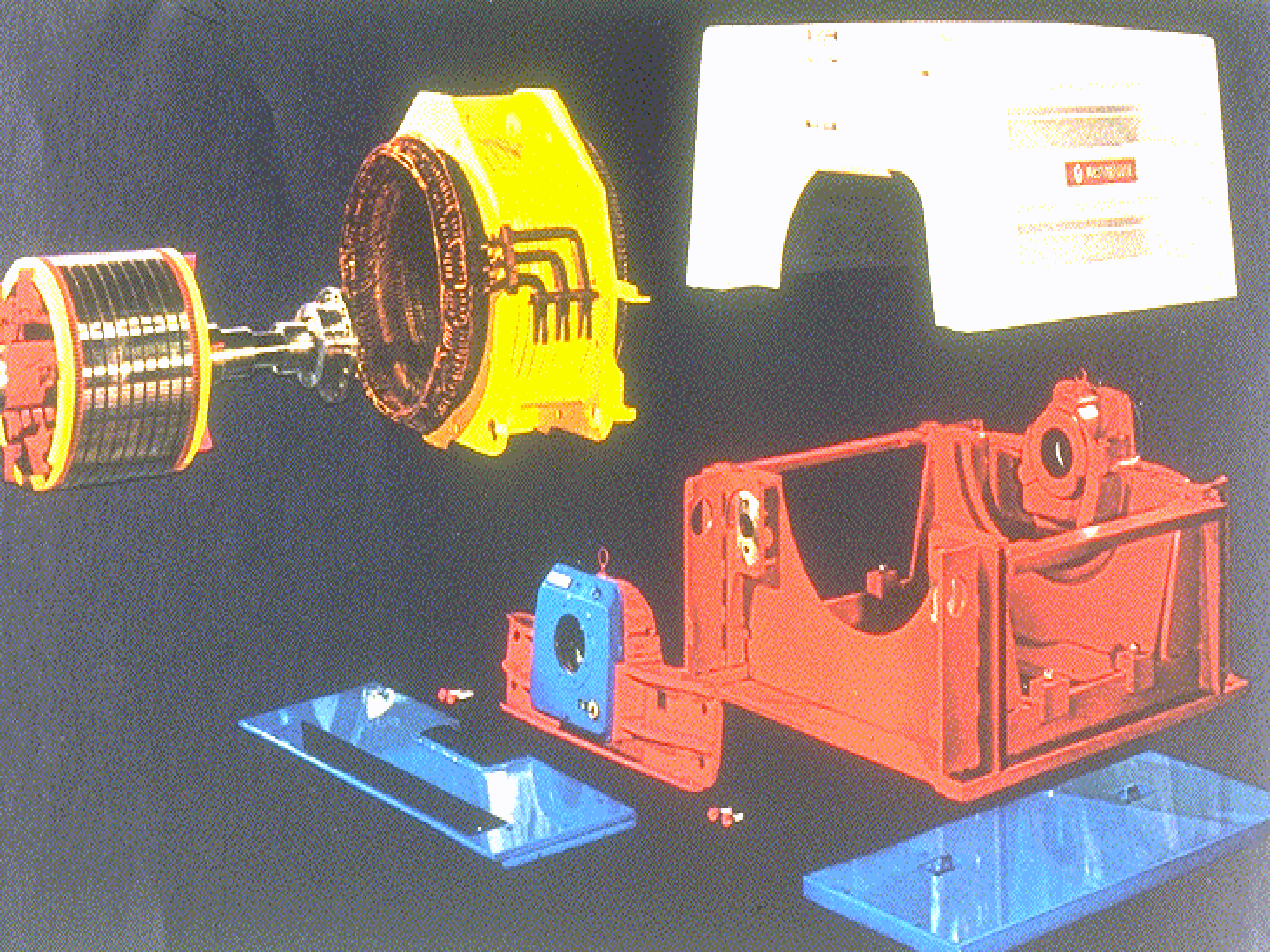
## Three-phase motor rotating field

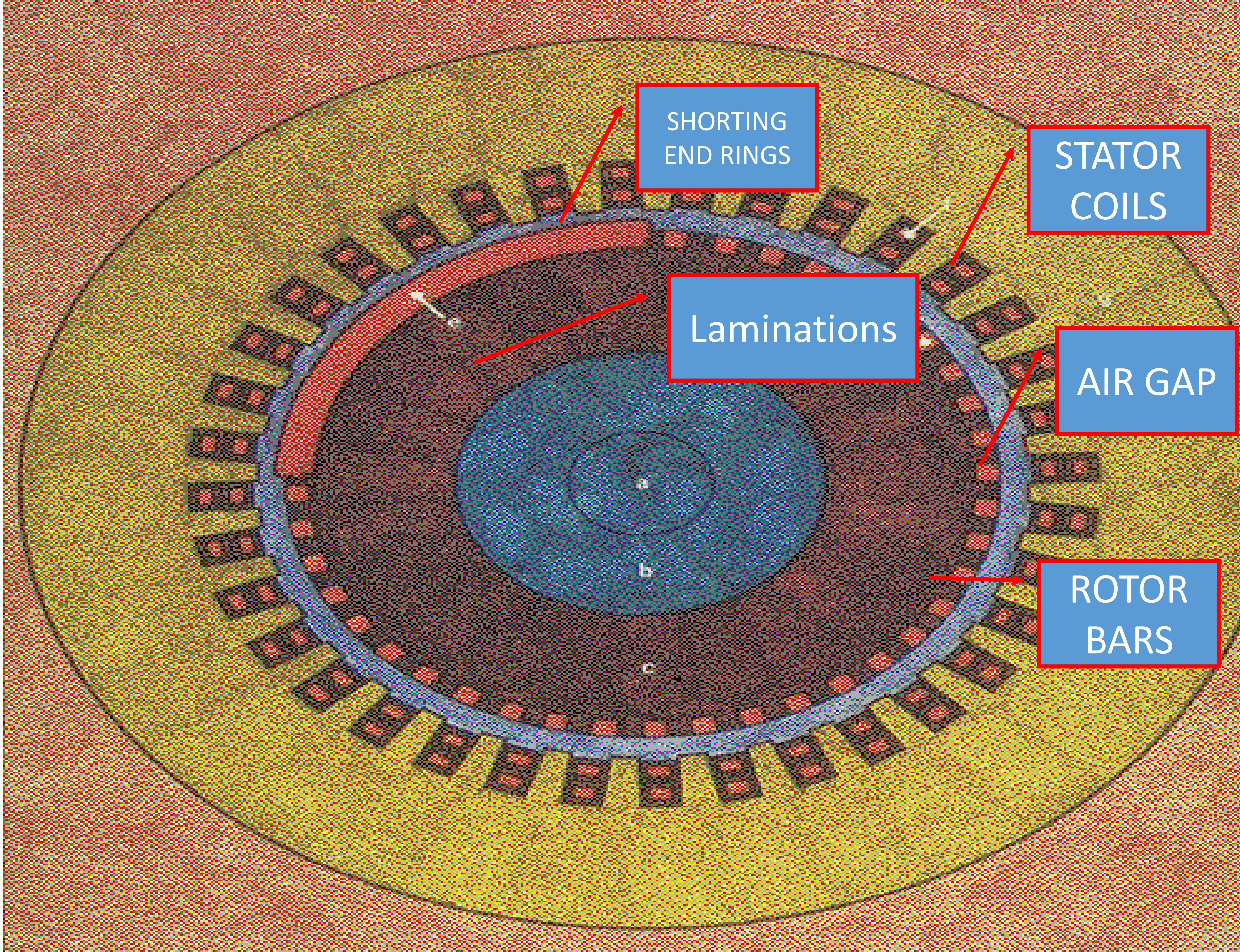


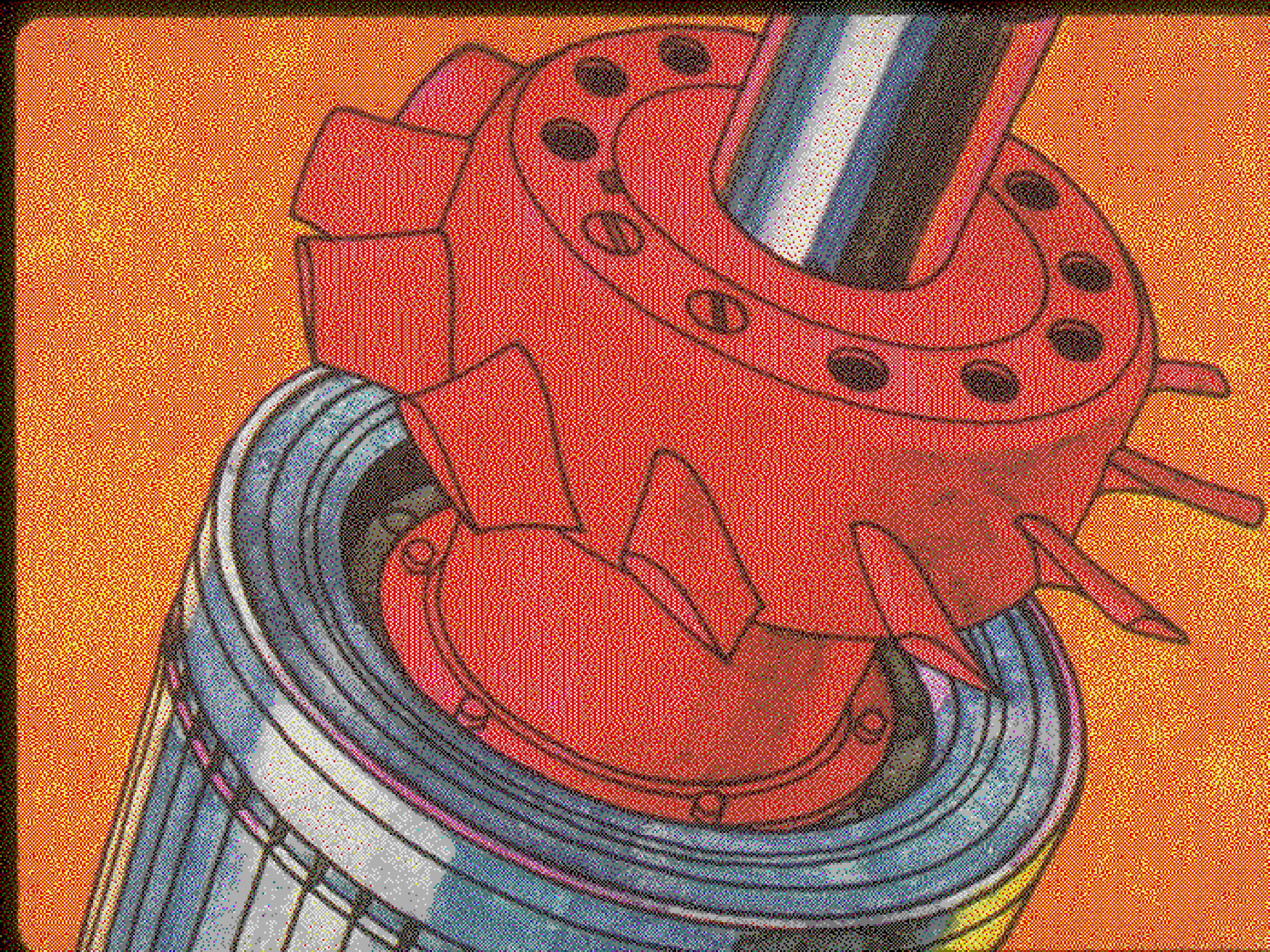

Field current in direction shown and increasing.
$I_f$
$I_f$
$I_c$ in
$I_c$ out
Magnetic field to the right and increasing
$+\Delta B$ $B_i$
$=B_f$
Induced field opposes change (Lenz's Law)
$\Delta B$
$B_{induced}$
Voltage induced in coil by Faraday's Law produces current in the direction shown in order to create the opposing field to the left.
Magnetic force on the induced loop current produces the forces shown and clockwise torque.
Although this summarizes the action principles, it is a long way from a practical induction motor. Further steps are taken to produce a rotating field, and to provide enough starting torque.

# SLIP-AN IMPORTANT PRINCIPLE

- IF THE ROTOR SPEED IS THE SAME AS THE ROTATING FIELD SPEED, THEN UNDER THAT CONDITION, THE MAGNETIC FLUX WOULD NO LONGER CUT THROUGH THE BARS, THERE WOULD BE NO CURRENT FLOW IN THE ROTOR BARS AND THUS NO TORQUE.
- THE ROTOR MUST THEREFORE TURN SLOWER THAN THE SYNCHRONOUS MAGNETIC FIELD IN ORDER TO PRODUCE TORQUE.
- THAT DIFFERENCE BETWEEN THE ROTATING SPEED OF THE GHOST ROTOR IN THE STATOR AND THE ROTOR IS CALLED SLIP AND IT IS VERY IMPORTANT TO THE VIBRATION ANALYST.




SHORTING END RINGS
STATOR COILS
Laminations
AIR GAP
ROTOR BARS

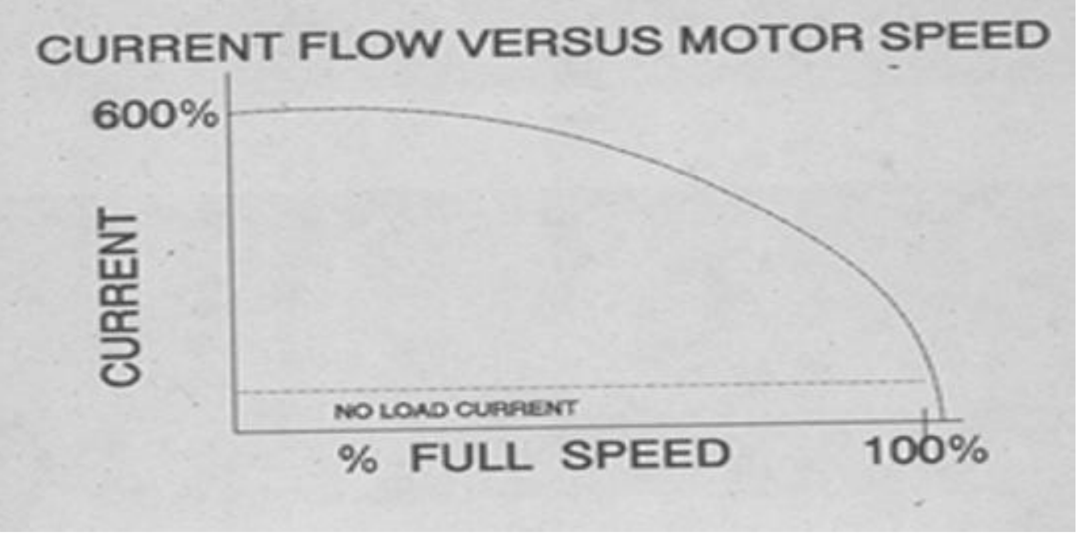



ROTOR
ROTOR BARS
STATOR WINDING

# POSSIBLE TYPES OF PROBLEMS

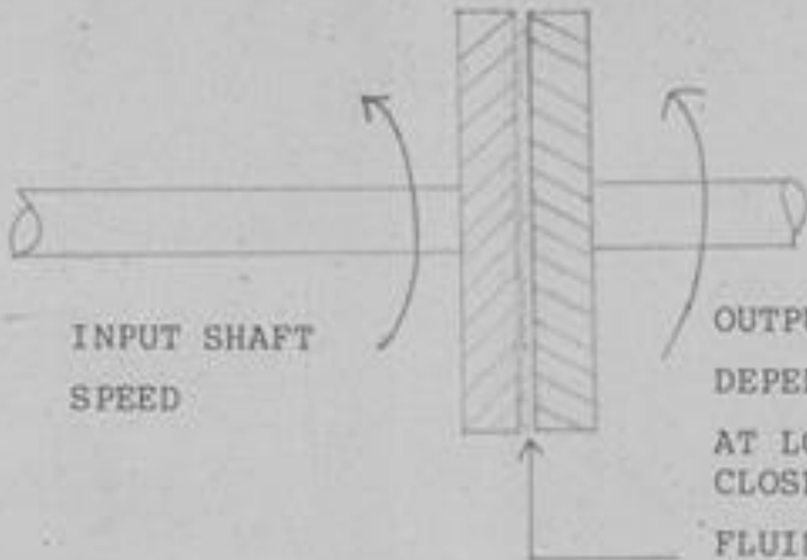
- Broken rotor bars or cracked end rings
- Shorted laminations
- Unequal static air gap ( Fixed and from soft foot distortion)
- Thermal unbalance vectors that change with load
- Rotating unequal air gap
- Loose fit between rotor and shaft (can cause sudden phase changes)
- Lowly damped critical speeds on larger 2 pole (3600 RPM) motors
- And the normal things like unbalance, misalignment & bad bearings
- Plus structural resonances matching magnetic excitation frequencies or rotor bar passing frequencies.

# Current Draw Versus Speed




At zero speed, a motor will typically draw 600% of full load current. That is why it is not a good idea to stand near a connection box at startup. As rotor speed increases and back EMF builds up, current drops. As load increases, rotor slows down, back EMF drops, current draw increases until generated torque matches load.

TORQUE CONVERTOR



INPUT SHAFT SPEED

SLIP SPEED= INPUT-OUTPUT

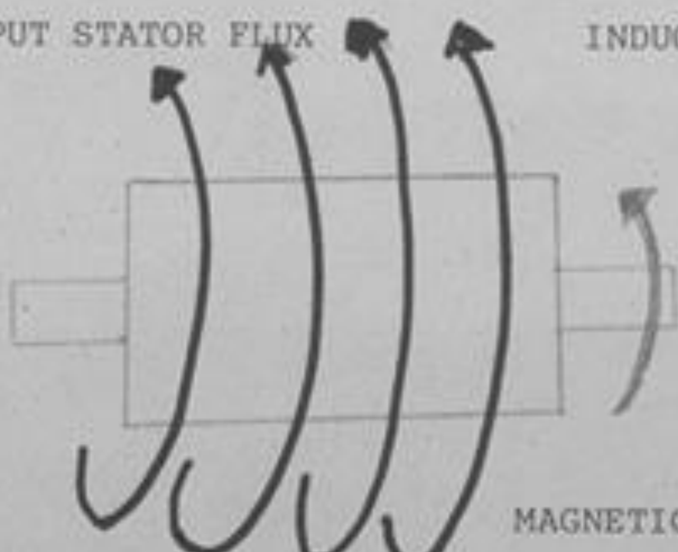
OUTPUT SHAFT SPEED
DEPENDS ON LOAD

AT LOW LOAD SPEEDS
CLOSELY MATCH

FLUID TRANSMITS TORQUE

INDUCTION MOTOR

INPUT STATOR FLUX



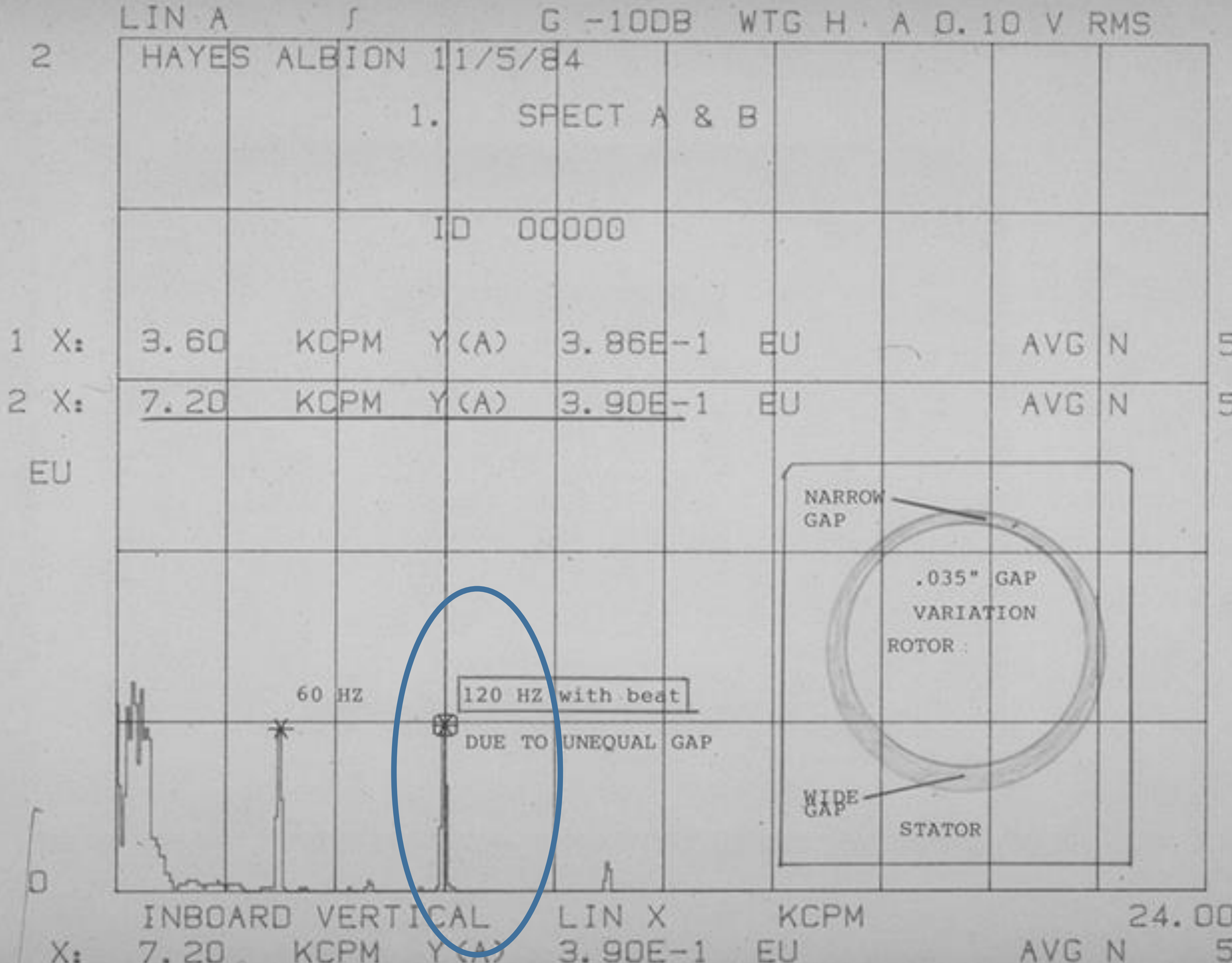
OUTPUT ROTOR SPEED
DEPENDS ON LOAD

$$\text{SLIP SPEED} = \frac{7200}{\#\ \text{POLES}} - \text{ROTOR SPEED}$$

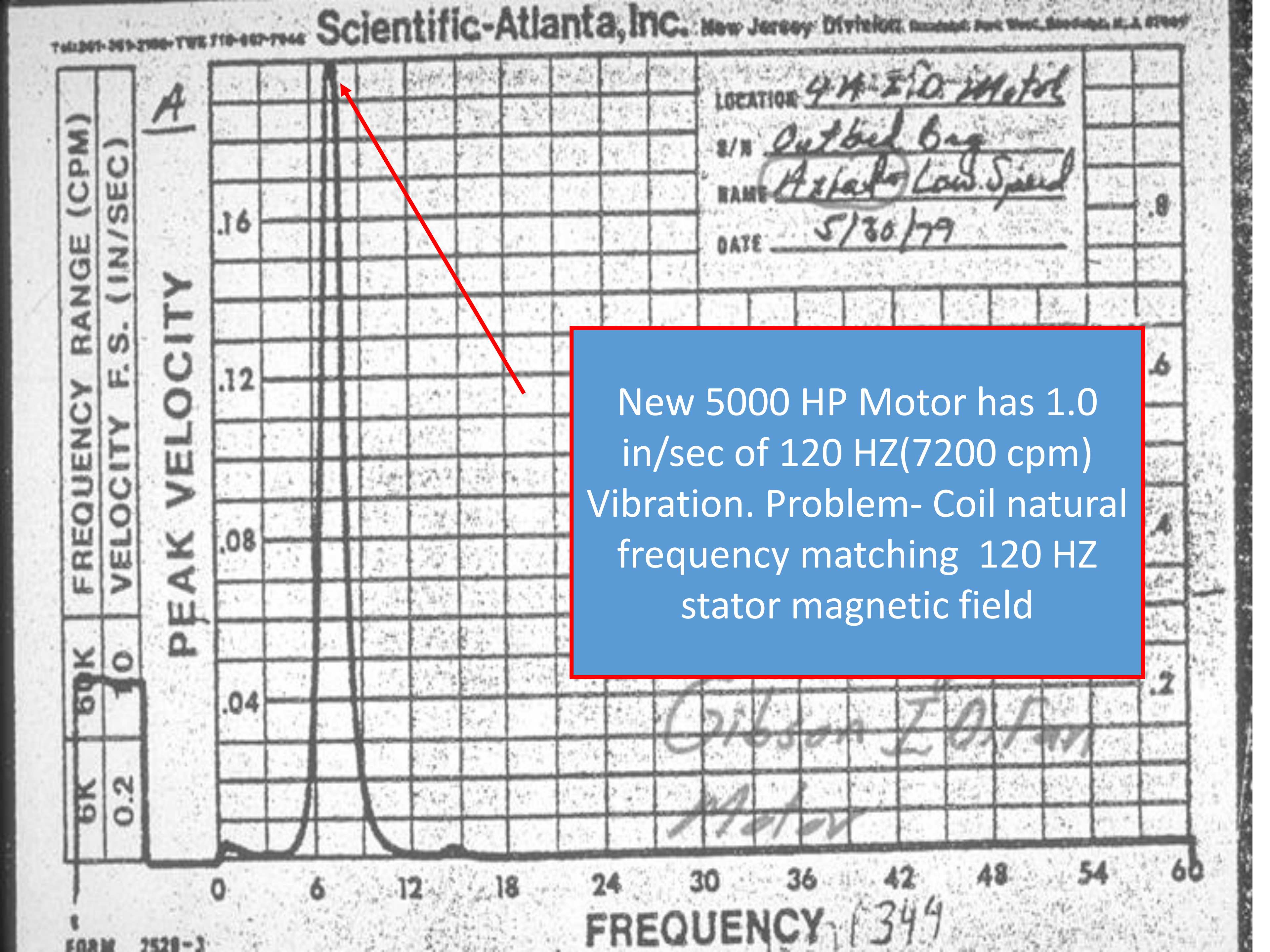
HIGHER LOAD SLOWS DOWN ROTOR INCREASING SLIP

MAGNETIC COUPLING TRANSMITS TORQUE

# UNEQUAL AIRGAP



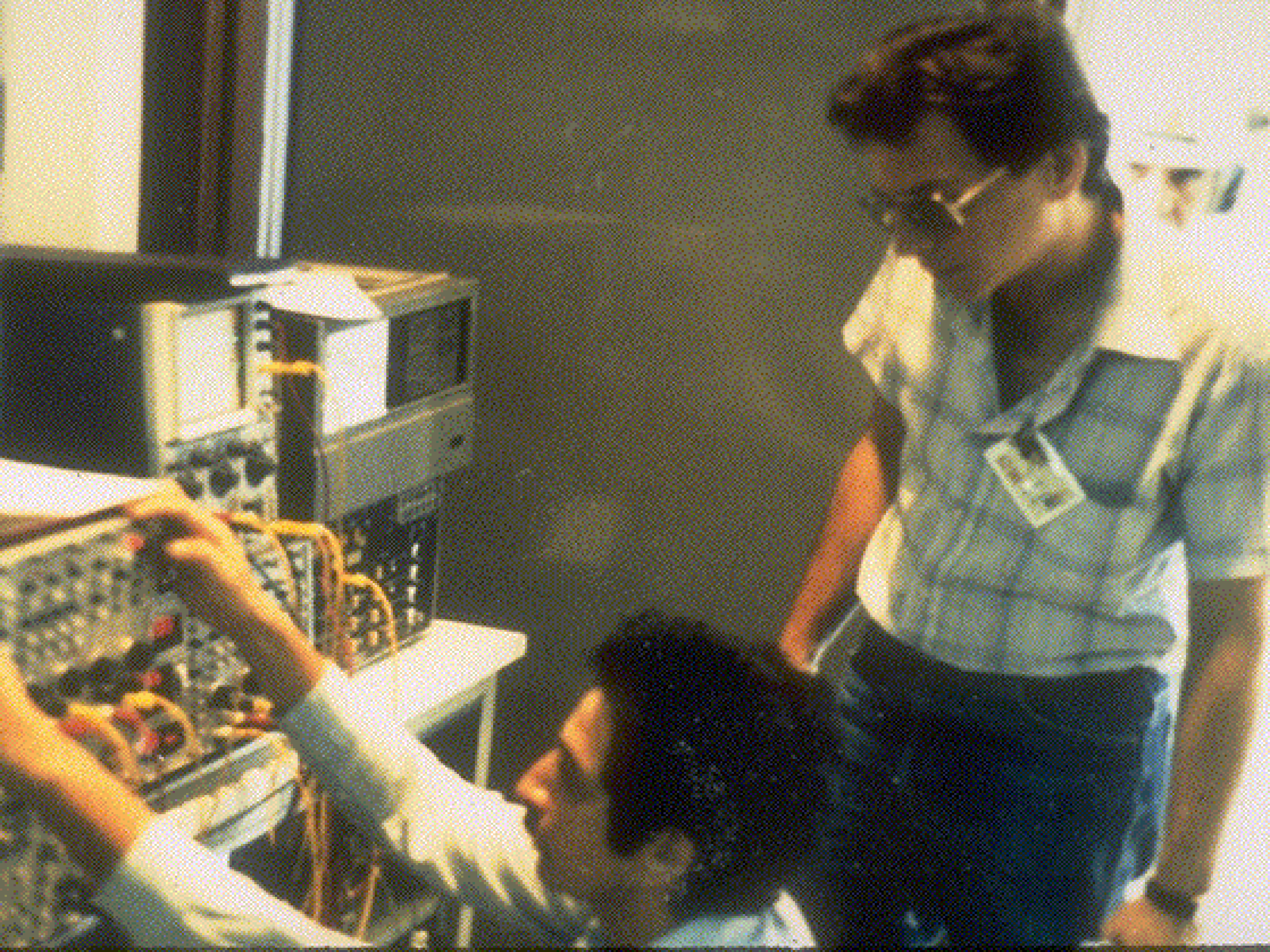
LIN A ∫ G -10DB WTG H · A 0.10 V RMS
2 HAYES ALBION 11/5/84
1. SPECT A & B
ID 00000
1 X: 3.60 KCPM Y(A) 3.86E-1 EU AVG N 5
2 X: 7.20 KCPM Y(A) 3.90E-1 EU AVG N 5
EU
NARROW GAP
.035" GAP VARIATION
ROTOR
60 HZ
120 HZ with beat
DUE TO UNEQUAL GAP
WIDE GAP
STATOR
0
INBOARD VERTICAL LIN X KCPM 24.00
X: 7.20 KCPM Y(A) 3.90E-1 EU AVG N 5

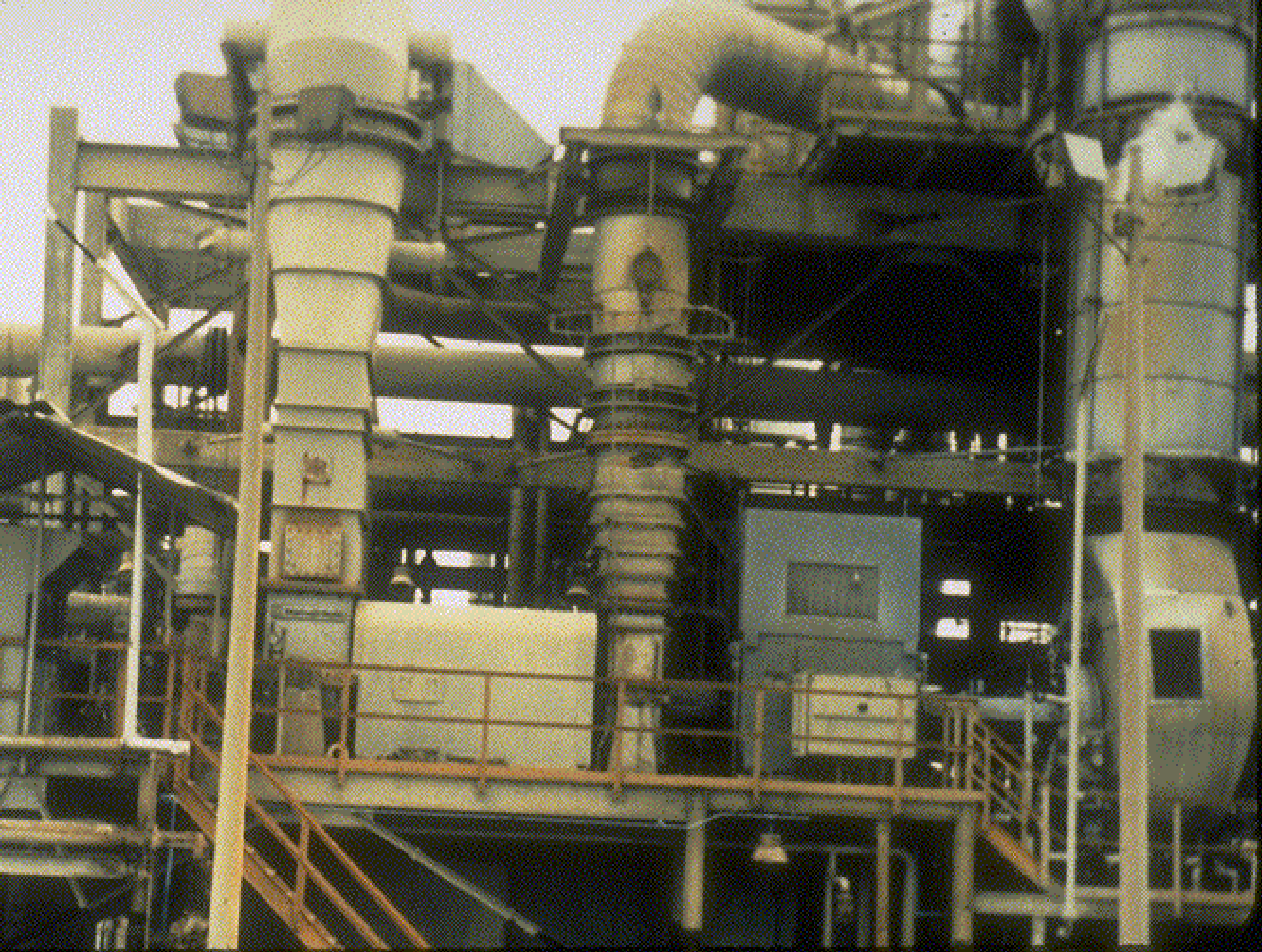



New 5000 HP Motor has 1.0 in/sec of 120 HZ(7200 cpm) Vibration. Problem- Coil natural frequency matching 120 HZ stator magnetic field

# Case 1- LARGE MOTOR IN VENEZUELA WITH THERMAL LOAD BASED UNBALANCE SENSITIVITY

- RECEIVED CALL THAT STATED “ THE MOTOR IT DOES NOT RUN ANY GOOD ANY MORE SINCE WE BALANCED IT”





Viewed From: Turbine End

Station: El Palito
Unit: [illegible] Recovery Unit
Location: GE Motor Generator
Blower End
Horizontal Probe

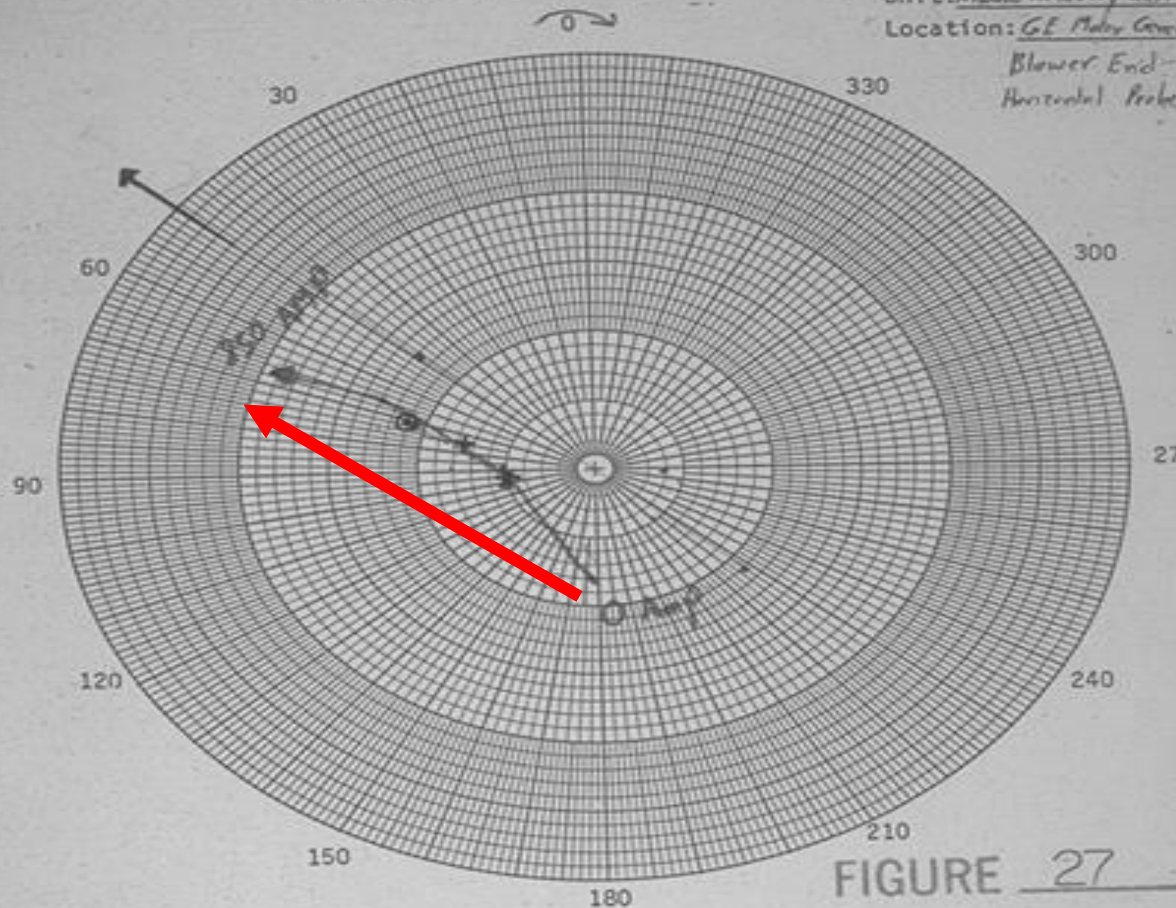



FIGURE 27

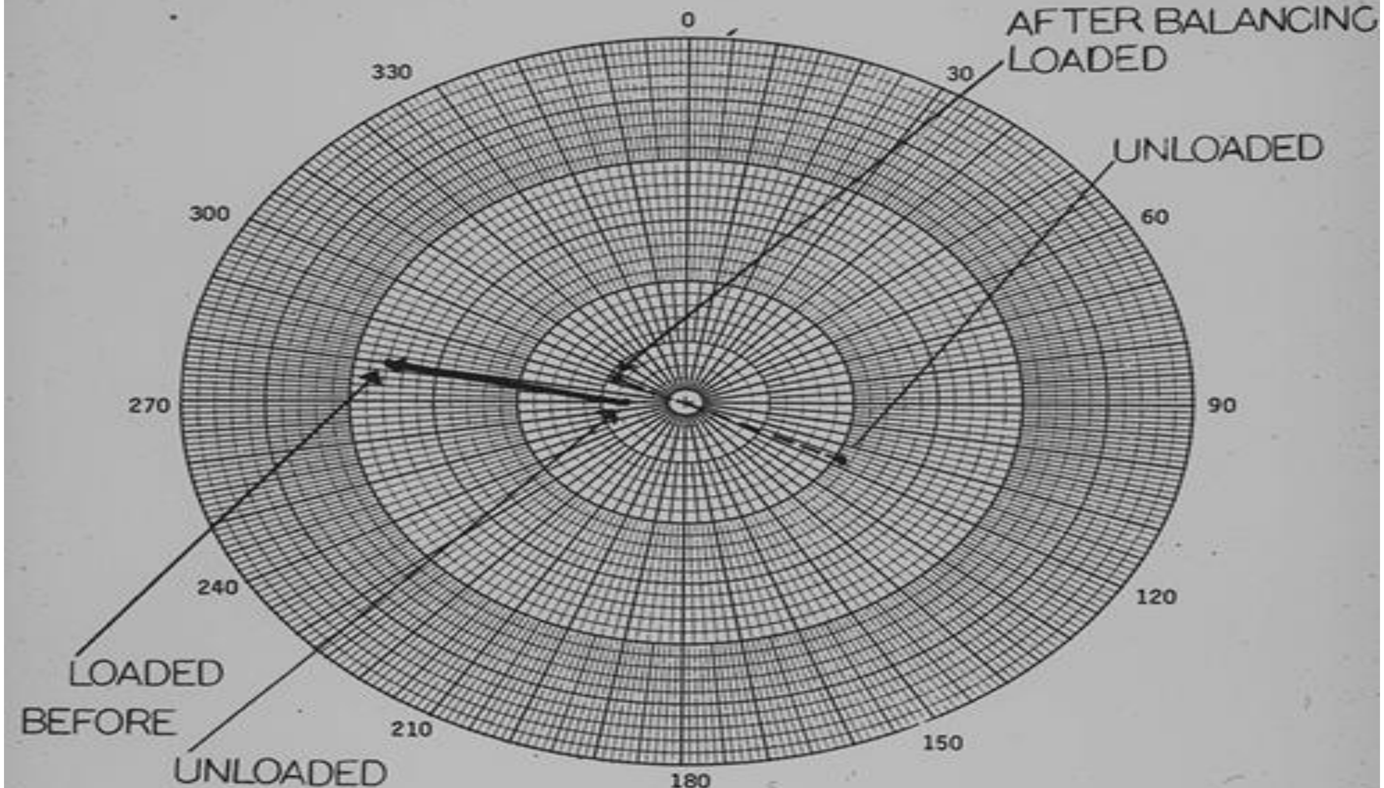
| Date | Overall | 1X | Phase | AMPS | TAPE-HP | TEAC | | |
|---|---|---|---|---|---|---|---|---|
| 6-22-85 | | 1.6 | 176° | 0 | A . 185 Ft. | | | |
| " | * | 1.0 | 97° | 240 | A 40 | 25-50 | | |
| " | | 2.6 | 66° | 640 | A 120 | | | |
| " | | 3.9 | 68° | 850 | A 485 | 410-460 | | |
| AFTER Balancing | | | | | | | | |
| 15-7-85 | ⊙ | 2.2 | 70 | 200 | IV 250 | 505-565 | | |
| 27-1-86 | + | 1.5 | 74 | 200 | V 100 | 630-680 | | |

# Case 2- Large 8000 HP Feed Pump Motor in ARIZONA.

- Received Message- The motor, runs with such high levels of unbalance that it destroys the bearing in 45 minutes.  This happened after we sent it to the motor shop.
- Sent motor rotor to be rebalanced.  Upon returning to operation, the bearings were destroyed again in 45 minutes.
- Sent motor rotor to high speed balance pit for balancing at full speed. Upon return, the bearings were again destroyed.

# THERMAL SENSITIVE MOTOR

Station: UTILITY   Protractor Numbered: CW   Rotation: CCW
Unit: 3   Viewed From: 1B   Viewed From: 1B
Location: BFP MOTOR   Instrument Lag: 0°   Test Equipment: M-747




Date readings were taken:
Operating Conditions: UNLOADED TO LOADED

| | Amplitude | Phase | Corrected Phase |
|---|---|---|---|
| Bearing # 1B UNLOADED | 1.5 | 270° | 270° |
| Bearing # 1B LOADED | 7.2 | 280° | 280° |

Description of weight change: 200 GMS. AT 90°

Date readings were taken:
Operating Conditions: UNLOADED TO LOADED

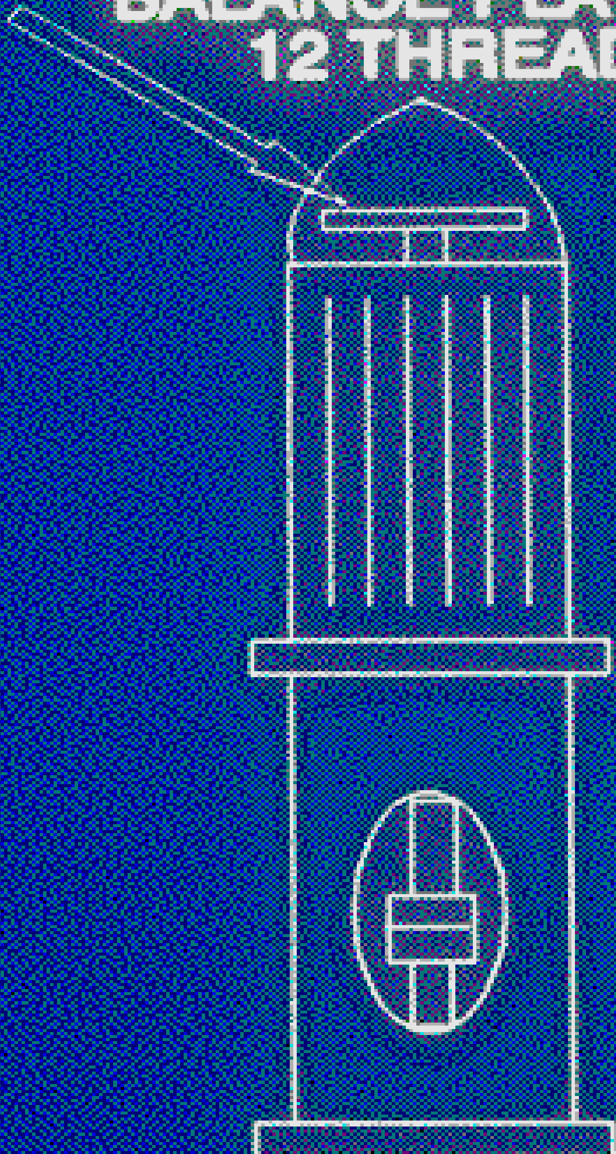
| | Amplitude | Phase | Corrected Phase |
|---|---|---|---|
| Bearing # 1B UNLOADED | 4.1 | 118° | 118° |
| Bearing # 1B LOADED | 1.9 | 325° | 325° |

Notes: 5.6 MIL THERMAL CHANGE

# What happened

- Examination of rotor showed what looked to be damage to rotor laminations. Motor shop had dropped rotor, but did not think there was any significant damage.
- Shorted laminations cause a hot spot which causes the rotor to bow.
- Solution was to install proximity probes and compromise balance the rotor at full load. Balance solution was extremely non-linear. Had to put in only half what balance solution calculated.
- Motor operated like this for the next 8 years until it was finally sent out for its normal repair cycle.
- I hope whoever got this rotor did not take out the compromise balance weights because it they did, someone is going to say " The motor it does not run well anymore ever since we balanced it". See case history 1.

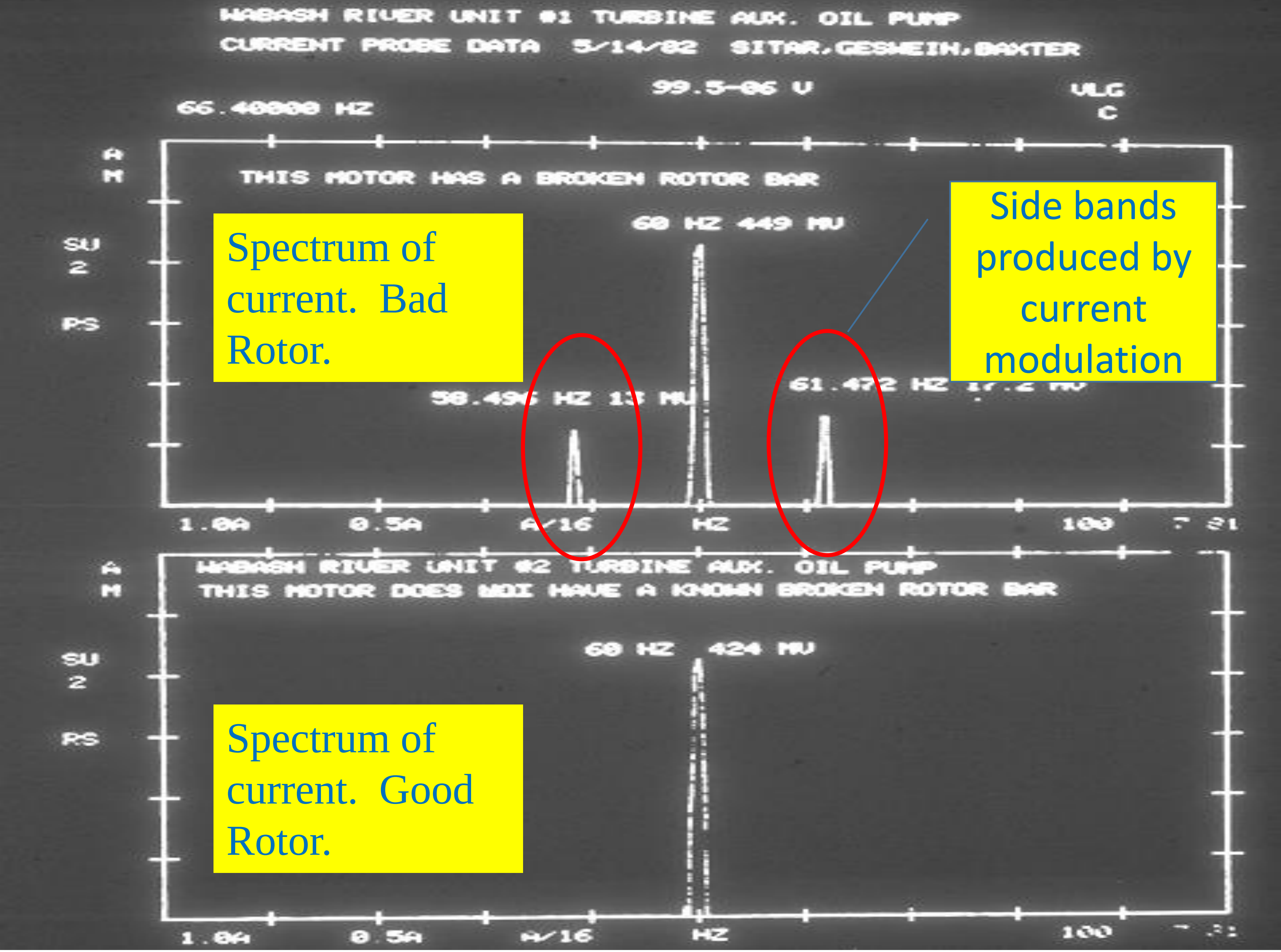
# VERTICAL PUMPS WITH HIGH MOTOR VIBRATION



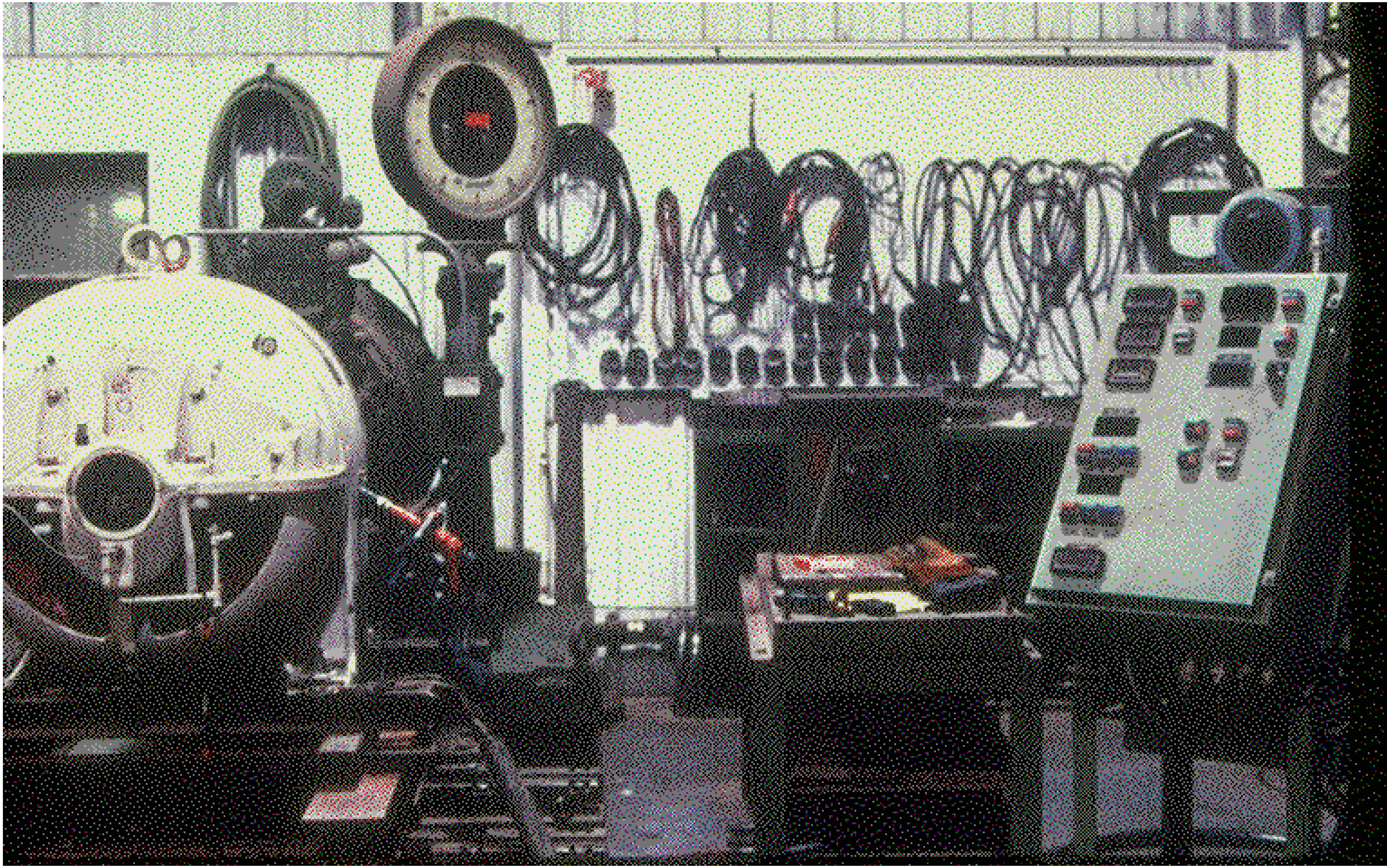

IF PUMP IS KNOWN TO BE IN GOOD CONDITION AND RESONANCE HAS BEEN ELIMINATED AS A POSSIBILITY THEN INSTALLATION OF A BALANCE PLATE ON THE MOTOR HAS PROVEN TO BE A VERY EFFECTIVE METHOD OF ELIMINATING RUNNING SPEED VIBRATION.

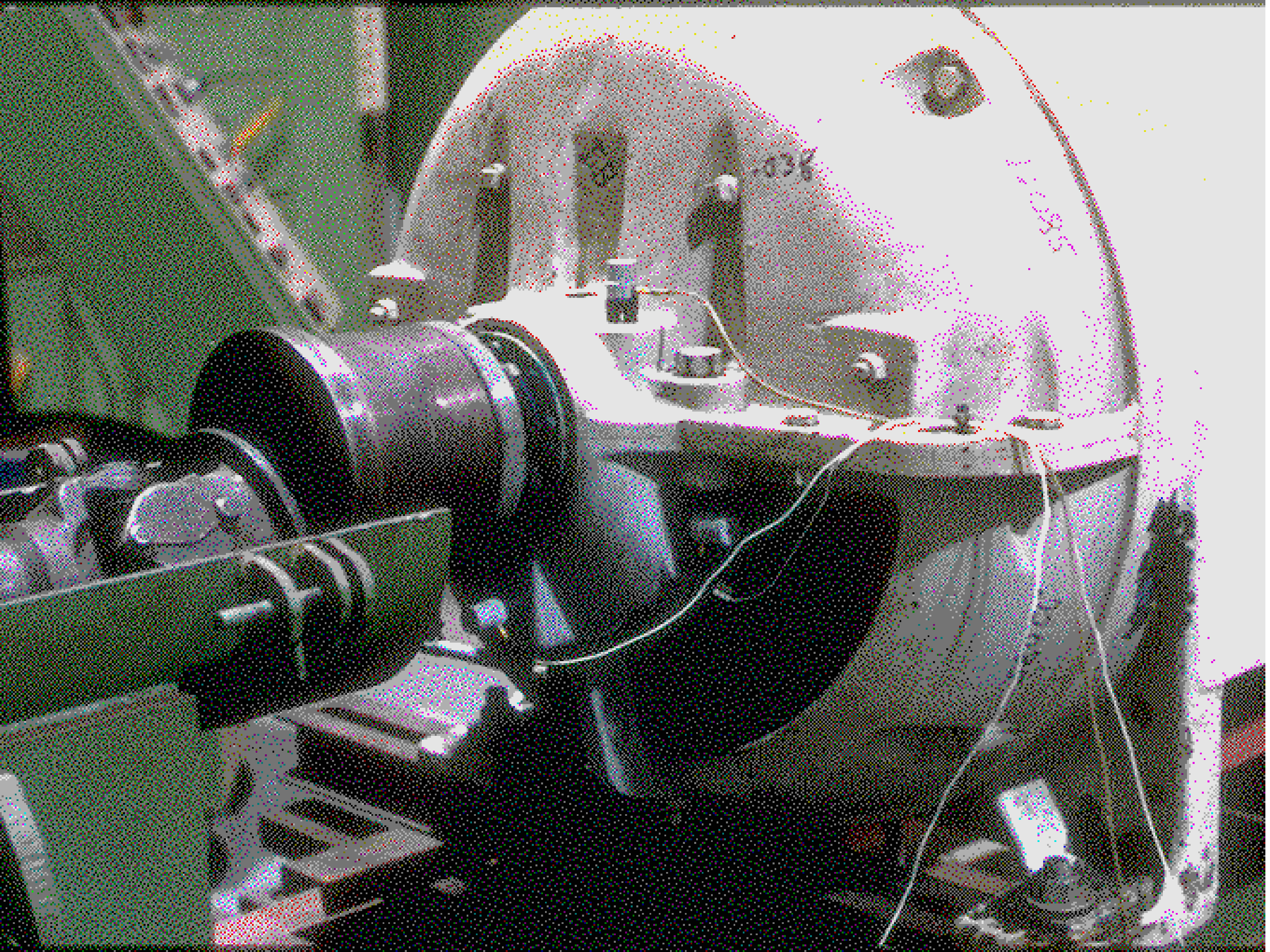
# MOTOR CURRENT WAVEFORM TESTING

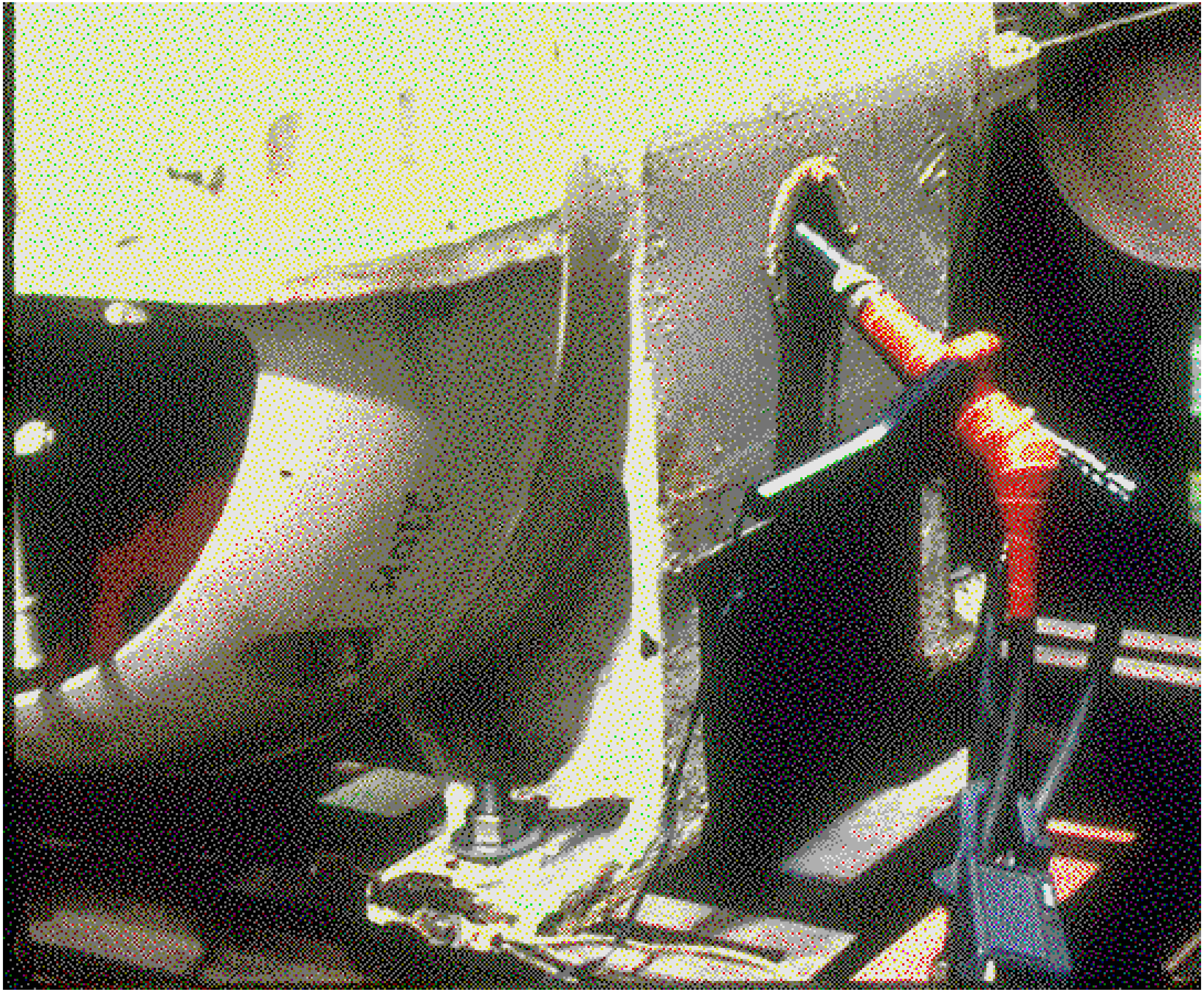
- Induction motors operate under the principle of a rotating magnetic field in the stator inducing current in the rotor. The current flowing in the rotor bars produces a counter EMF which opposes the incoming current to the stator. The amount of current flow is therefore dependent upon the impedance of the rotor bars.
- For a motor with good rotor bars and un-cracked weld joints or end rings, the current flow is constant because of uniform resistance from bar to bar. However, for a rotor with broken bars or cracked end rings, the impedance varies. This causes the current flow to the stator to modulate. The modulation rate is equal to # poles times slip.
- Motor current waveform testing measures the amount of modulation as a method of determining rotor health.



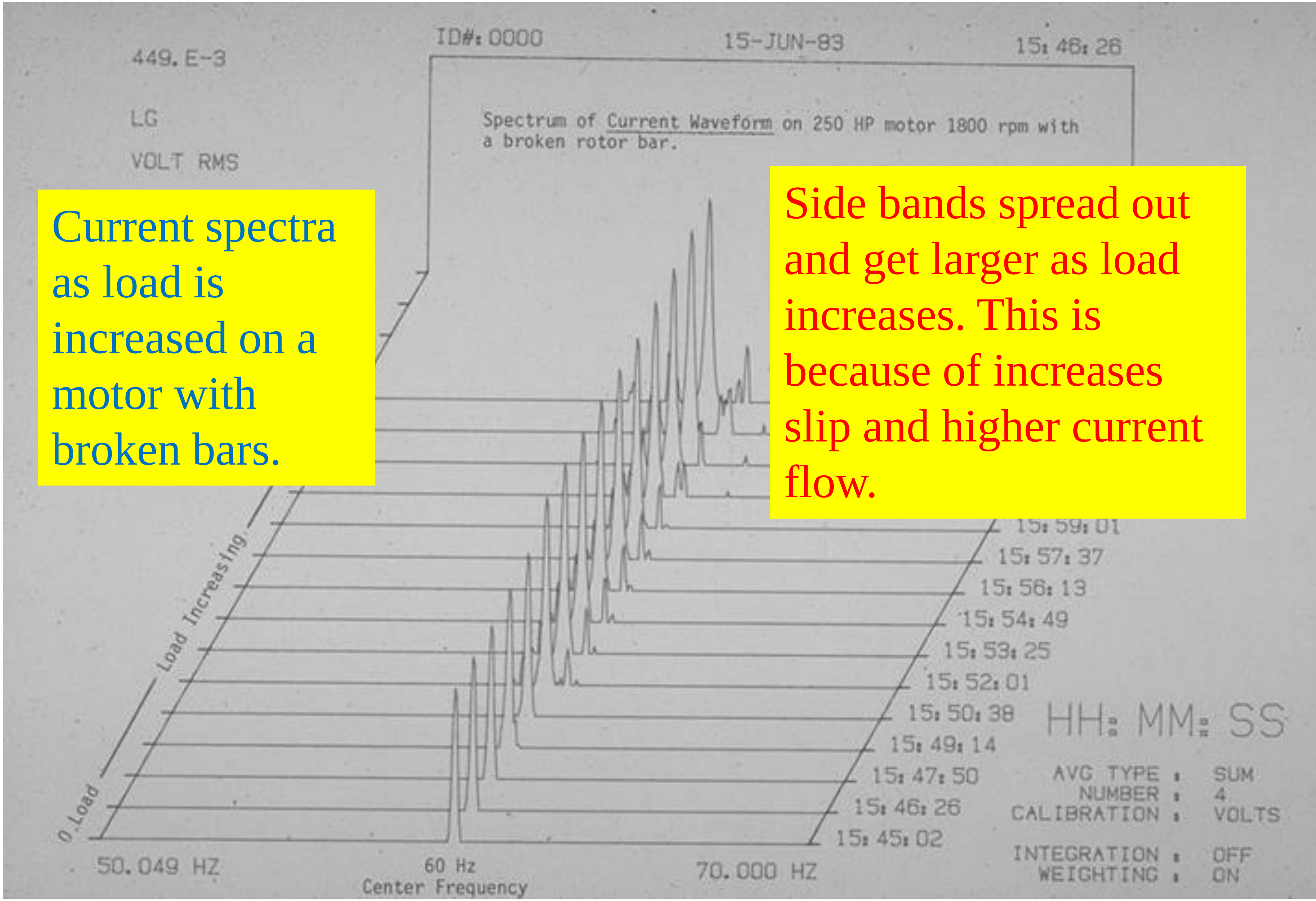
WABASH RIVER UNIT #1 TURBINE AUX. OIL PUMP
CURRENT PROBE DATA 5/14/82 SITAR,GESWEIN,BAXTER
99.5-06 V
VLG
C
66.40000 HZ
THIS MOTOR HAS A BROKEN ROTOR BAR
60 HZ 449 MV
Spectrum of current. Bad Rotor.
Side bands produced by current modulation
AM
SU
2
RS
1.0A
0.5A
A/16
HZ
100
WABASH RIVER UNIT #2 TURBINE AUX. OIL PUMP
THIS MOTOR DOES NOT HAVE A KNOWN BROKEN ROTOR BAR
60 HZ 424 MV
Spectrum of current. Good Rotor.
AM
SU
2
RS
1.0A
0.5A
A/16
HZ
100



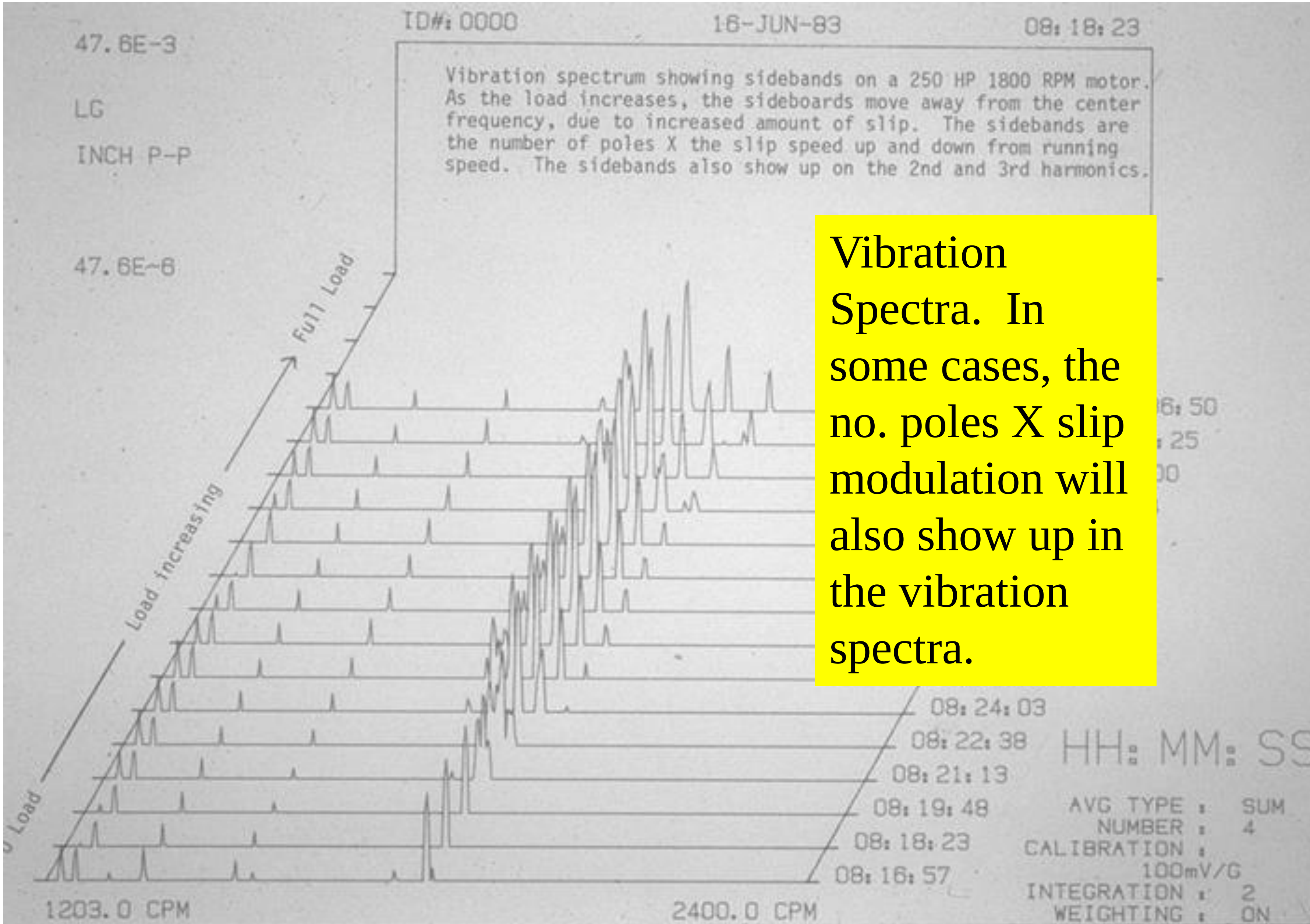




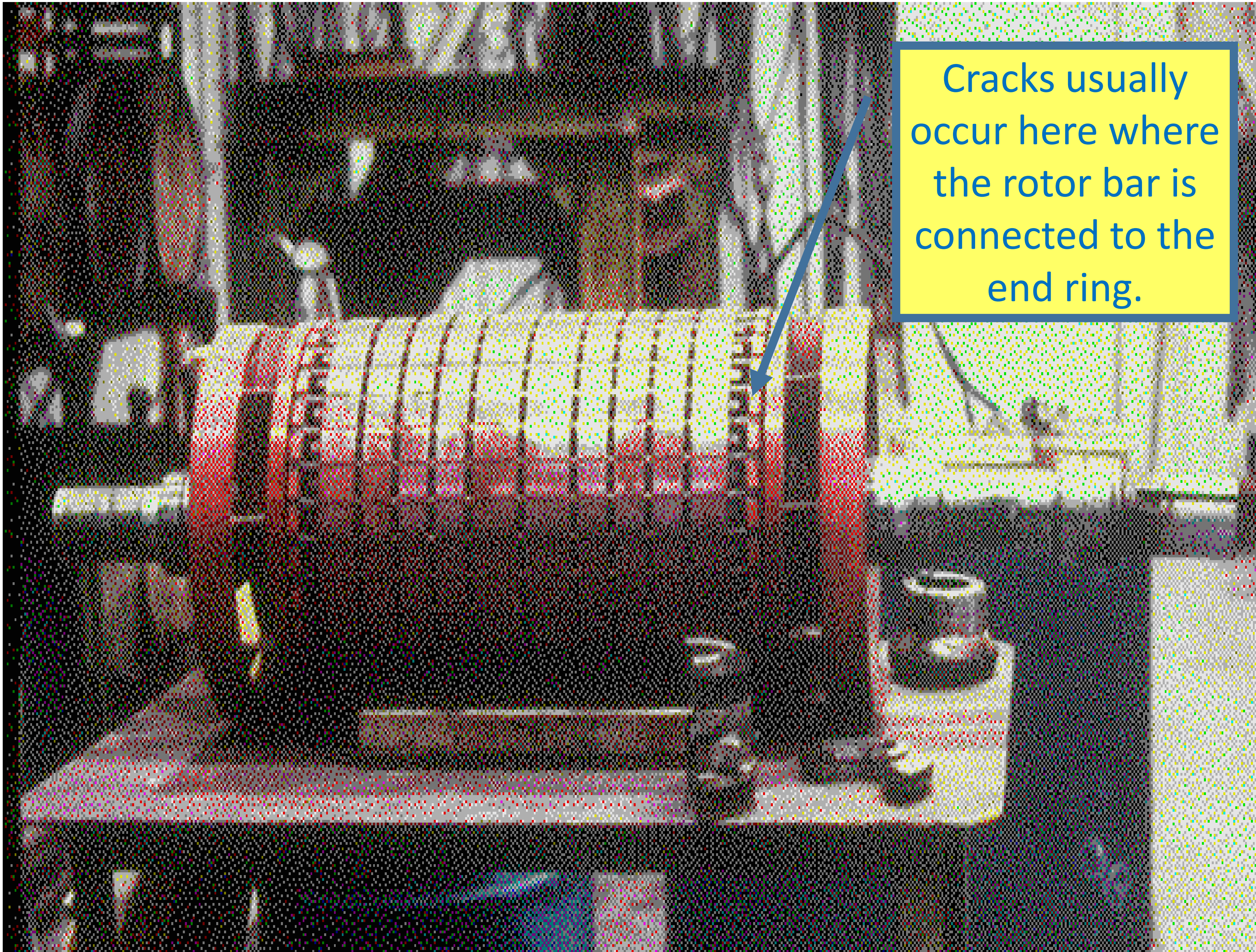
Current spectra as load is increased on a motor with broken bars.

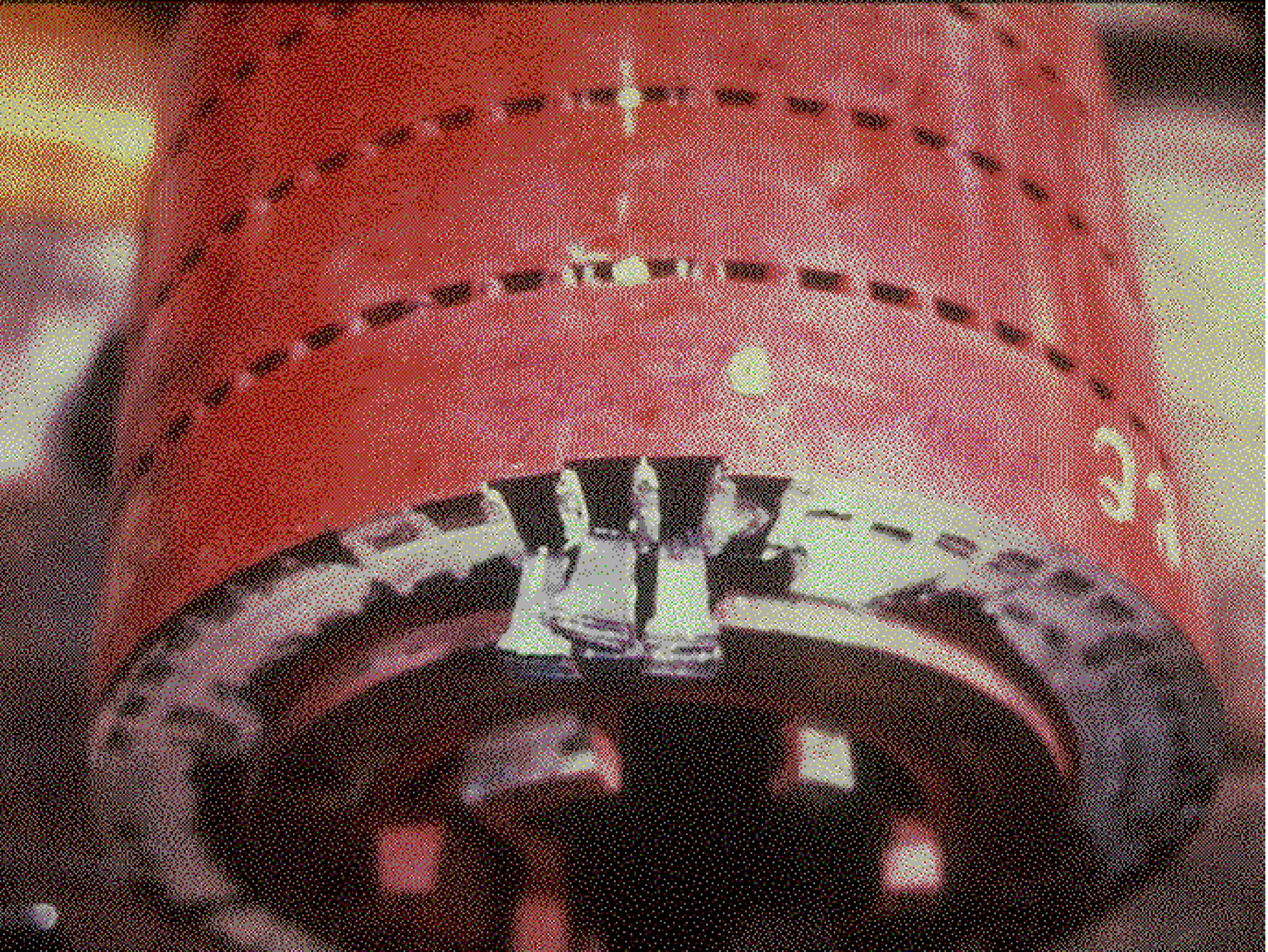


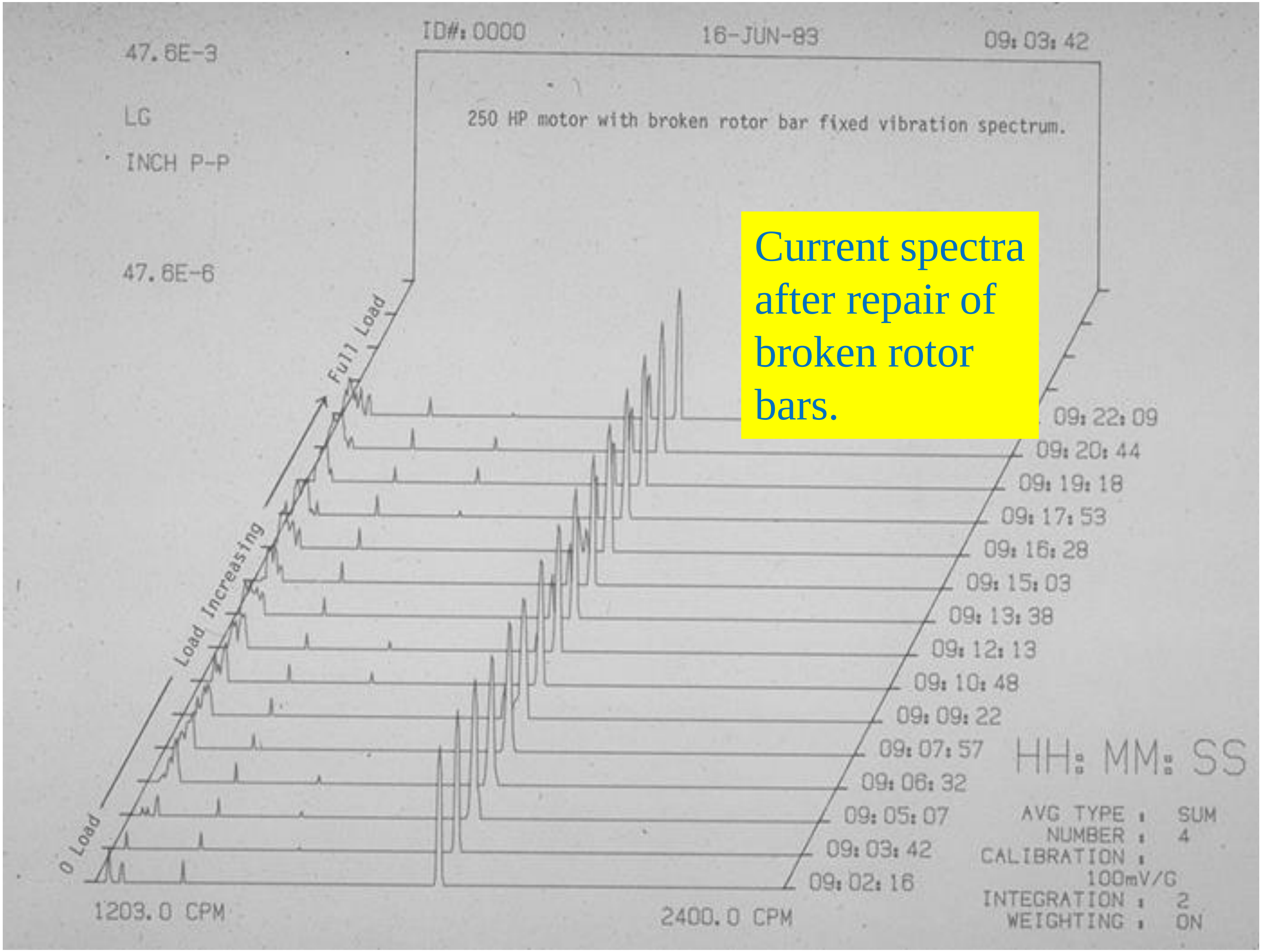

Side bands spread out and get larger as load increases. This is because of increases slip and higher current flow.

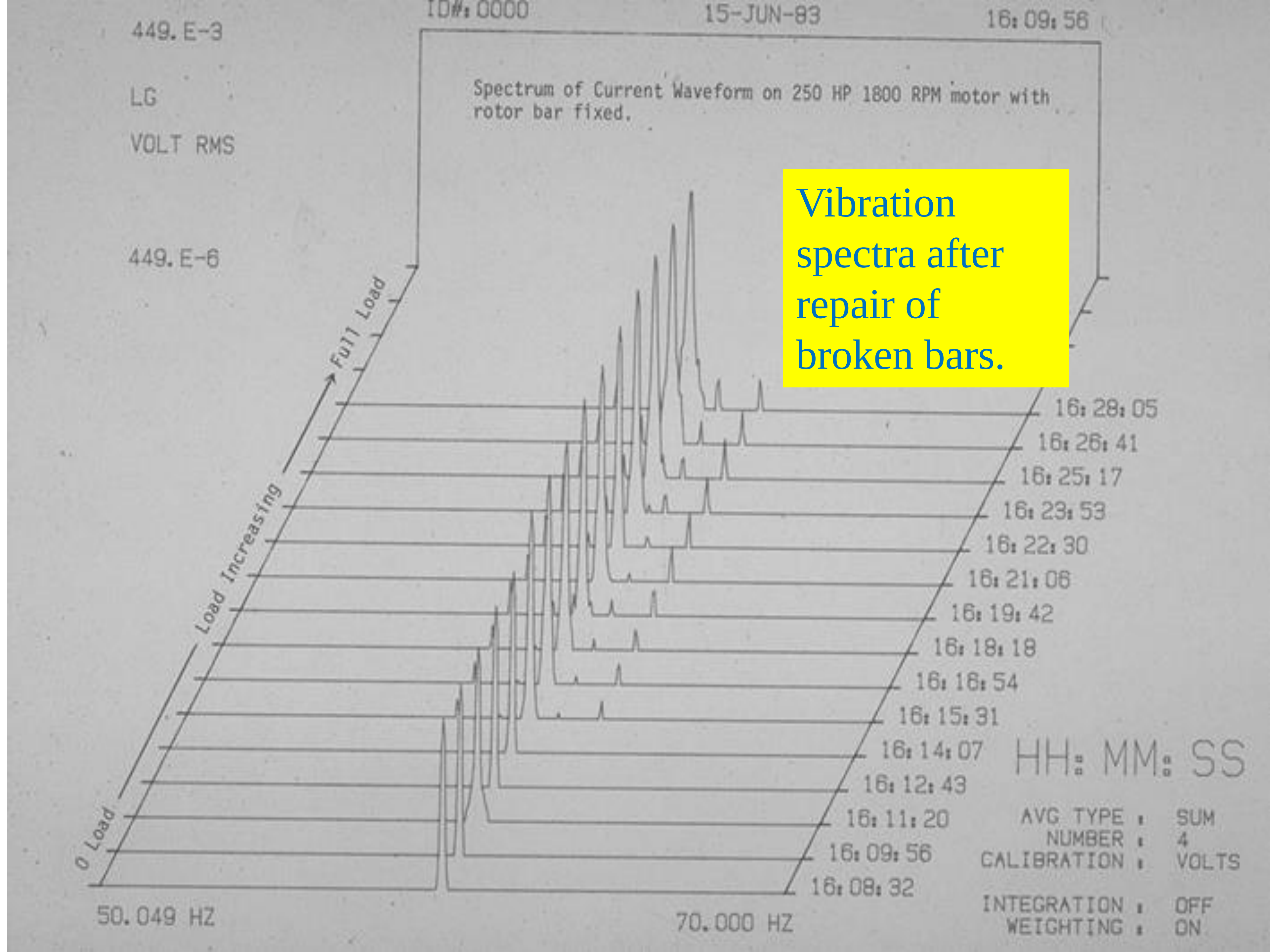



Vibration Spectra. In some cases, the no. poles X slip modulation will also show up in the vibration spectra.


Cracks usually occur here where the rotor bar is connected to the end ring.




ID#:0000
16-JUN-83
09:03:42
47.6E-3
LG
INCH P-P
47.6E-6
250 HP motor with broken rotor bar fixed vibration spectrum.
Current spectra after repair of broken rotor bars.
Full Load
Load Increasing
0 Load
09:22:09
09:20:44
09:19:18
09:17:53
09:16:28
09:15:03
09:13:38
09:12:13
09:10:48
09:09:22
09:07:57
09:06:32
09:05:07
09:03:42
09:02:16
HH:MM:SS
AVG TYPE : SUM
NUMBER : 4
CALIBRATION : 100mV/G
INTEGRATION : 2
WEIGHTING : ON
1203.0 CPM
2400.0 CPM

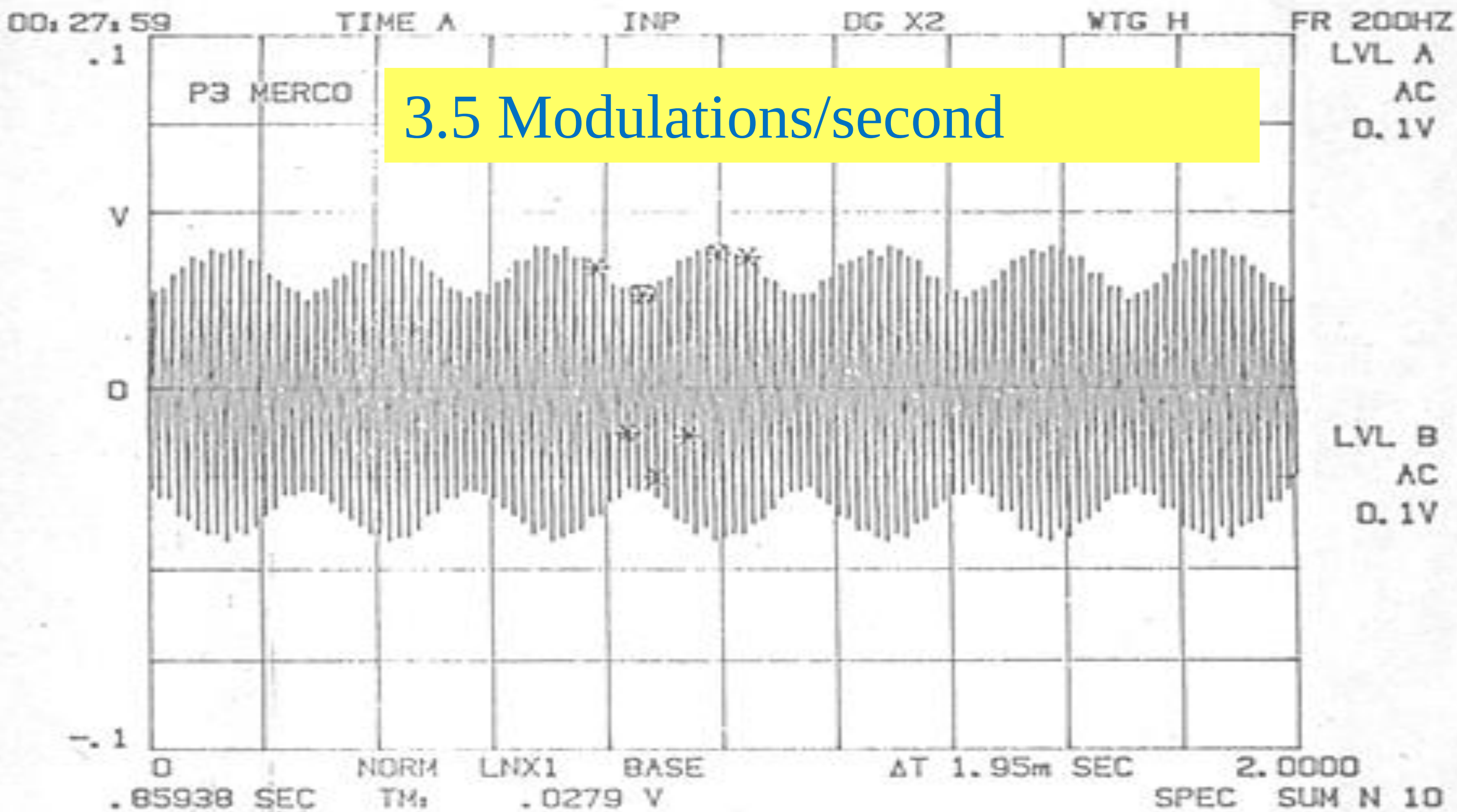


ID#: 0000
15-JUN-83
16: 09: 56
449. E-3
LG
VOLT RMS
449. E-6
Spectrum of Current Waveform on 250 HP 1800 RPM motor with rotor bar fixed.
Vibration spectra after repair of broken bars.
Full Load
Load Increasing
0 Load
16: 28: 05
16: 26: 41
16: 25: 17
16: 23: 53
16: 22: 30
16: 21: 06
16: 19: 42
16: 18: 18
16: 16: 54
16: 15: 31
16: 14: 07
16: 12: 43
16: 11: 20
16: 09: 56
16: 08: 32
HH: MM: SS
AVG TYPE : SUM
NUMBER : 4
CALIBRATION : VOLTS
INTEGRATION : OFF
WEIGHTING : ON
50.049 HZ
70.000 HZ

# CRACKED END RINGS

FIGURE 1

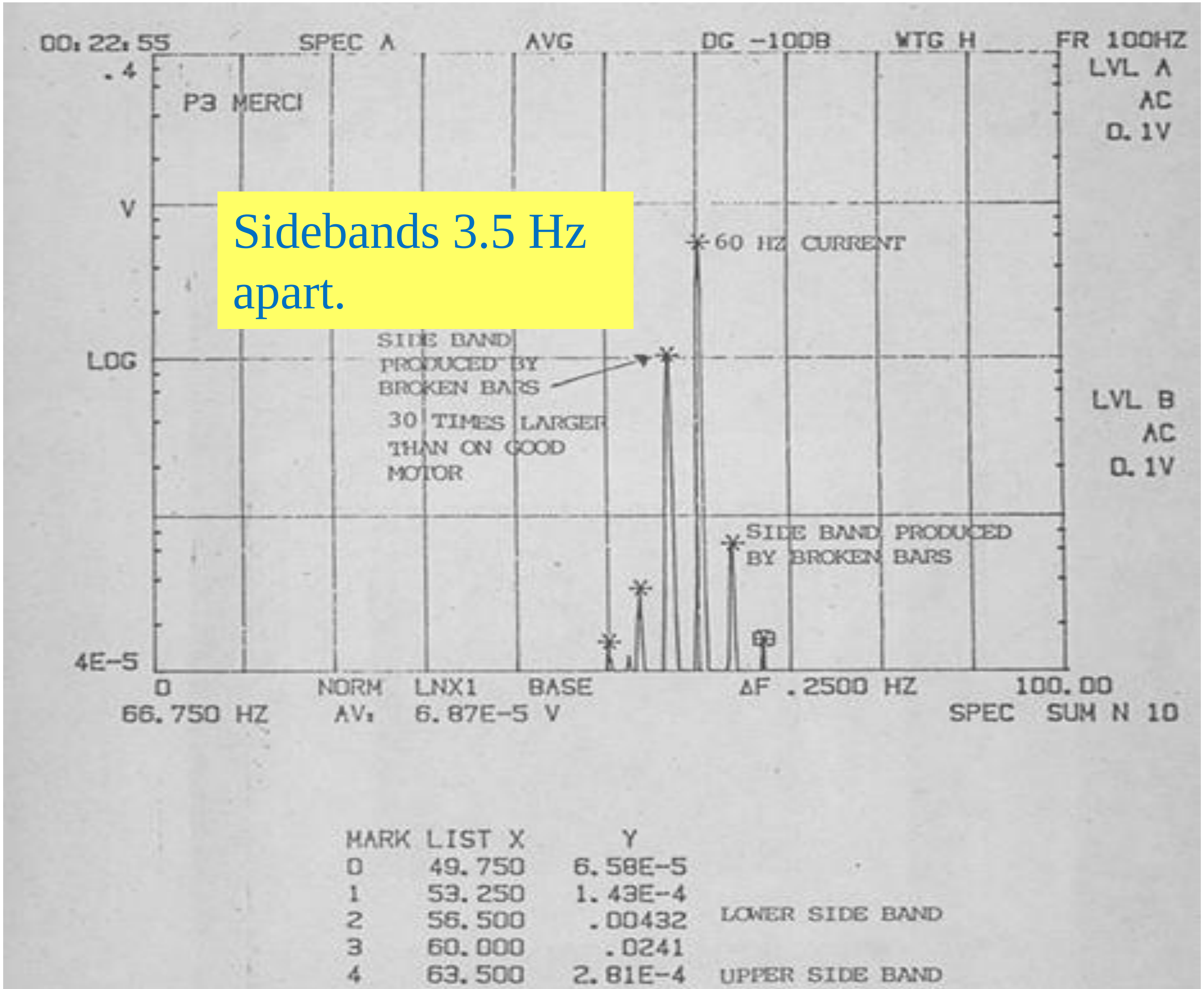
3.5 Modulations/second



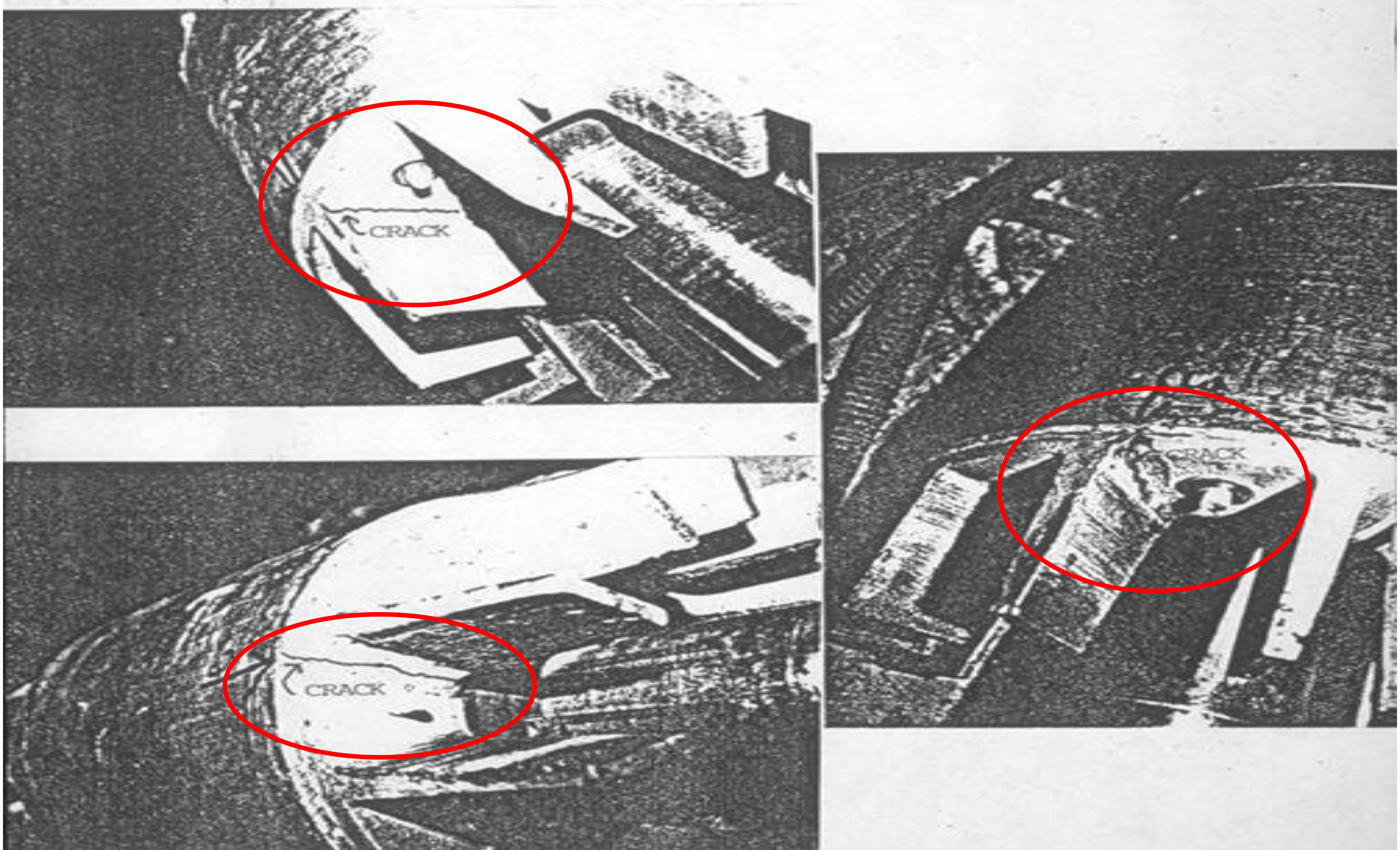

MARK LIST X Y
0 .77734

THIS FIGURE SHOWS THE MODULATION OF THE CURRENT GOING TO THE P-3 MERCO MOTOR. FOR A HEALTHY MOTOR, THE CURRENT WILL FLOW STEADILLY. WHEN BROKEN BARS ARE PRESENT, THE IMPEDENCE VARIES AS THE MAGNETIC POLES GO PAST THE BROKEN BARS. THIS CAUSES THE VARIATIONS IN MOTOR CURRENT. THE POLES PASS AT THE RATE OF THE NUMBER OF POLES TIMES THE SLIP FREQUENCY.

Sidebands 3.5 Hz apart.



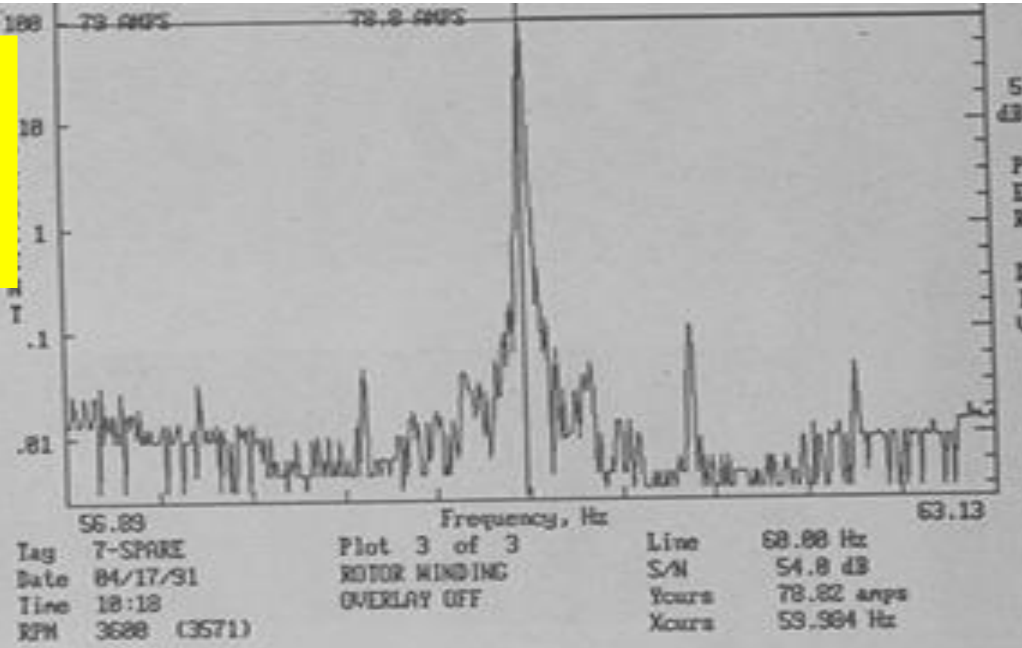
# PHOTOGRAPHS OF DAMAGE TO P-3 MERCO MOTOR ROTOR



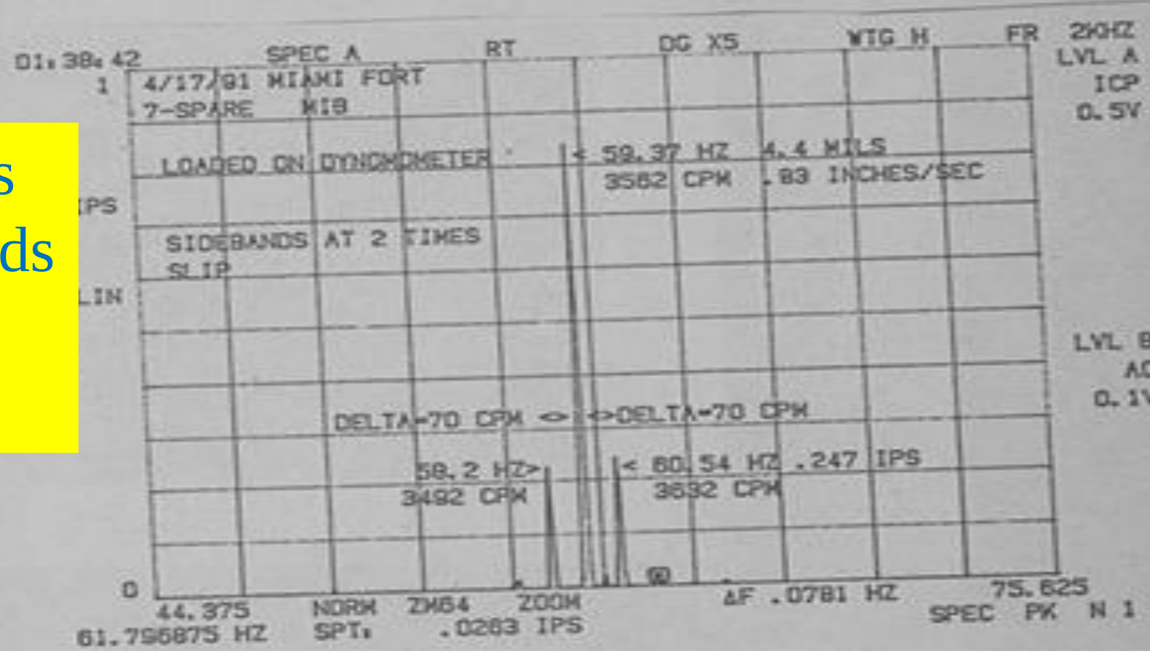
# ECCENTRIC ROTOR

- A motor had a distinctive wa wa sound
- It was suspected that it had a broken rotor bar.
- However, current spectra did not show anything unusual.
- Vibration spectra did show significant side bands at the no. poles X slip.

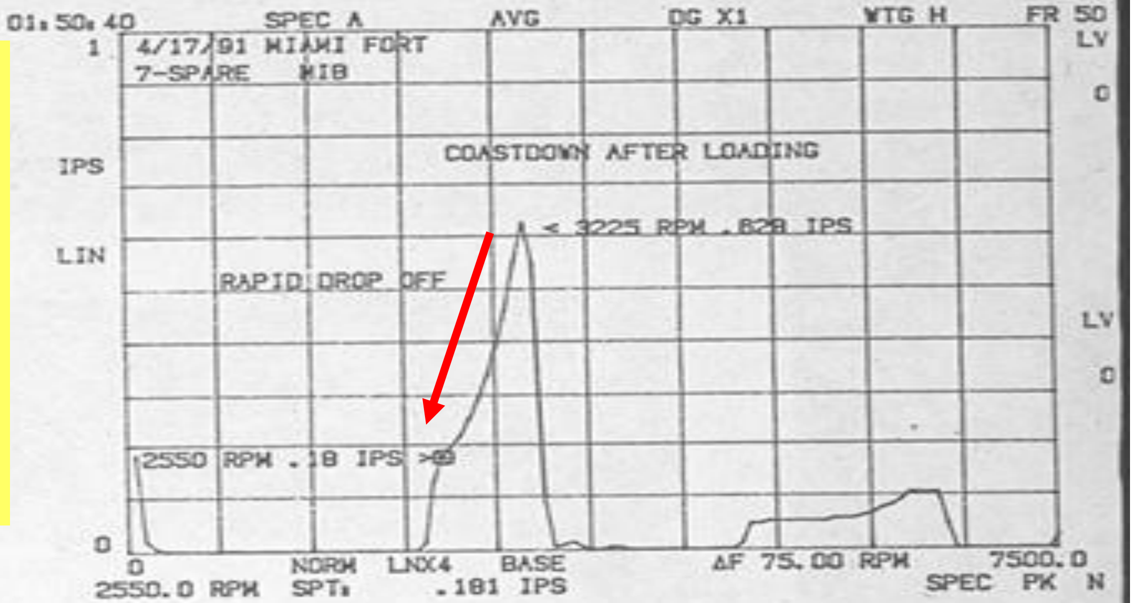
Current spectrum side bands were low



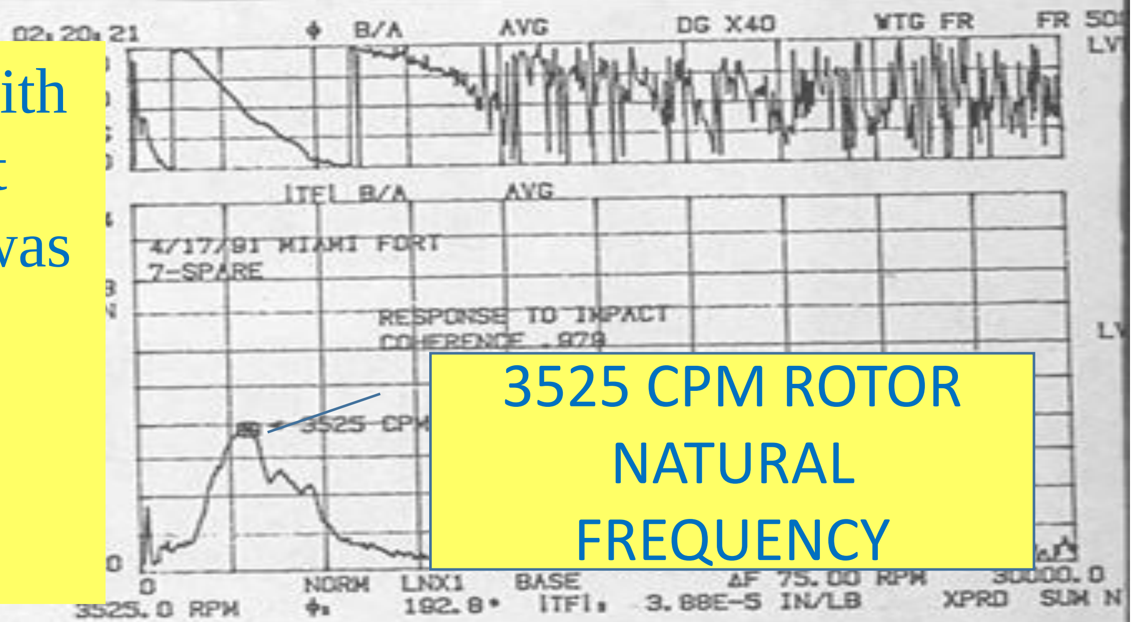

Vibration sidebands were high. Sidebands were at no. poles X slip frequency.



Coast down data was taken on the motor and is showed that it was operating near a natural frequency.




An accelerometer with a long cable was put on the rotor which was slowly turned to get shaft up on oil film while an impact test was performed.




3525 CPM ROTOR NATURAL FREQUENCY

# What caused this problem to occur

- Motor had originally had an aluminum cast rotor
- Owner decided to have someone build a copper bar steel lamination rotor.
- The change in mass resulted in pulling the rotor natural frequency down close to the operating speed.
- This caused the rotor to bow introducing rotating eccentricity.
- The rotating narrow air gap then interacted with the rotating stator's magnetic field. The interaction rate just like a broken rotor bar is no. poles times slip. This causes the vibration to modulate, but has no effect on current flow.
- By doing a precision field balance, the amount of rotor bow was reduced and the modulation was significantly lower.

# MOTOR CURRENT SPECIAL CONSIDERATIONS

- Eccentricity versus broken rotor bars
- Beware cast aluminum rotors
- Pole modulation
- Mechanical Modulation causing low frequency side bands
- Higher speed motors and low inertia loads(high speed pumps) versus low speed motors and high inertia loads (fans).

1: Rotor eccentricity- An eccentric rotor will of course result in unbalance. If the rotor is balanced, there can still be a problem of a rotating deviation in the air gap. This causes unequal pull on the rotor as the magnetic poles pass the rotating gap deviation. This occurs at the number of poles times the slip frequency, which is the same frequency that is generated by a broken rotor bar. Note that in neither case will this low (usually less than 1.5 HZ) frequency show up in the spectrum, but they can both appear as side bands of running speed in the vibration spectrum. The way to tell the difference between an eccentric rotor and broken rotor bars is to obtain a current spectrum. A broken rotor bar will generate no. poles times slip frequency around the line frequency in the current spectrum where as the eccentric rotor will not.

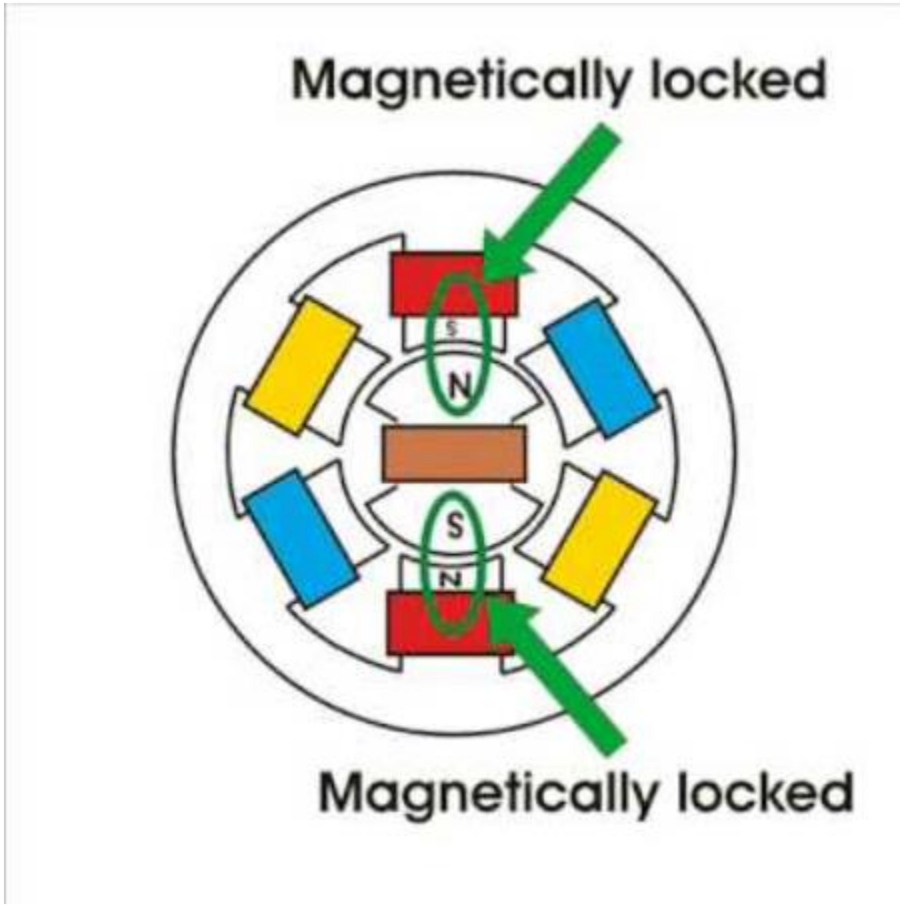
2: Beware of cast aluminum rotors. Cast aluminum rotors will sometimes have voids that will cause false positives of the above described side band test. When in doubt, test the motor over several starting cycles to determine if the level is stable or getting worse.

3: Pole modulation- If the number of spiders in the rotor equals the number of poles, the current will modulate and look just like a broken rotor bar is present. The way to tell if this is the case is to vary the load on the motor. If it is pole modulation, then the side band ratio will be higher at low load. If there is an actual broken bar problem, the opposite will be true. When a broken bar is present the degree of modulation will increase at higher loads. Case History- A power plant had 8 pole motors on its FD fans. Every year a current spectrum test was performed to identify broken rotor bars. It was noted both FD fan motors had indications of what appeared to be broken rotor bars. The interesting thing was that the modulation was less at high loads than at low loads. The cause of the modulation turned out to be pole modulation. The motors ran for many years and never had any problems, even though an expert system program kept calling them out as having broken rotor bars.

4: Mechanical Modulation- Beware of motor current testing, if there is a speed reduction gearbox coupled to the motor. Low speed mechanical modulation will sometimes cause the current to modulate thereby mimicking a rotor problem. Always determine the motor speed to within 1 RPM, then calculate the number of poles times slip frequency side band frequency. If there is any variation in the calculated versus the actual frequency, then suspect mechanical modulation. Examples: Case 1: Coal barge unloader. The rate at which the buckets dug into the barge of coal was exactly the number of motor poles times the slip frequency making it impossible to perform an accurate rotor bar analysis. Case 2- In large coal mills, the rate at which the rolls pass over the rotating table is very close to the number of poles times the slip frequency. This has resulted in several mill motors being falsely called out as having bad rotor bars. Case 3- A coal conveyor motor was called out as having rotor problems. It was discovered that the speed of the output gear was close to the number of poles times the slip frequency. The problem was with the gear instead of with the motor rotor. Very accurately determining the speed of the motor allowed a calculation to be made that determined that the modulating frequency was a match with the gear instead of the number of poles times the slip frequency.

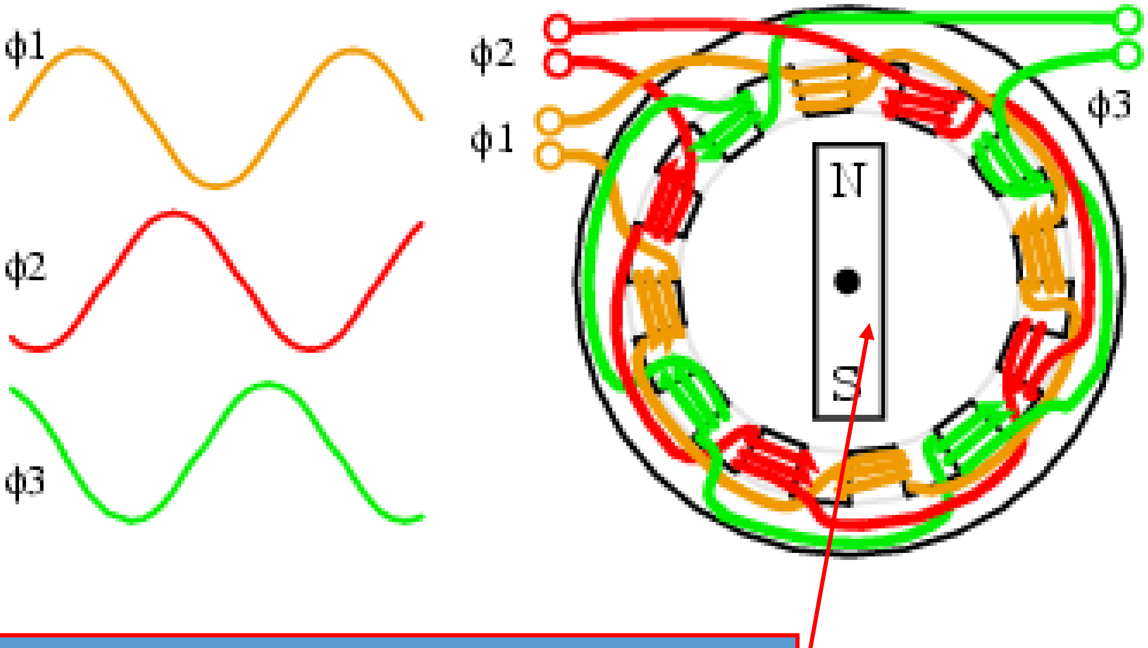
5: Two pole and four pole motors with broken rotor bars will often cause number of poles times slip frequency side bands in both the current and vibration spectra. Higher pole lower speed motors, particularly those driving high inertia loads will create number of poles times slip side bands in the current spectra, but will in many cases not cause them to appear at all in the vibration spectra.

# Synchronous Motors



- Synchronous motors have a rotating magnetic field just like induction motors.
- Unlike the induction motor, the rotor is magnetically locked to the stator’s magnetic field.
- As the name suggests, the rotor speed is synchronously locked to the stator field. Thus, a synchronous motor has no slip.
- The magnetic field in a synchronous motor is established by sending current into the rotor though slip rings.
- When the breaker is closed to start a synchronous motor, there is a strong 120 HZ torsional stimulus.  This is due to the stators rotating poles passing by the rotors stationary poles.  This torsional stimulus goes to zero at full speed once to poles become magnetically locked.
- By adjusting the field current, the power factor can be changed.

# Synchronous Motor Case History- Case 1

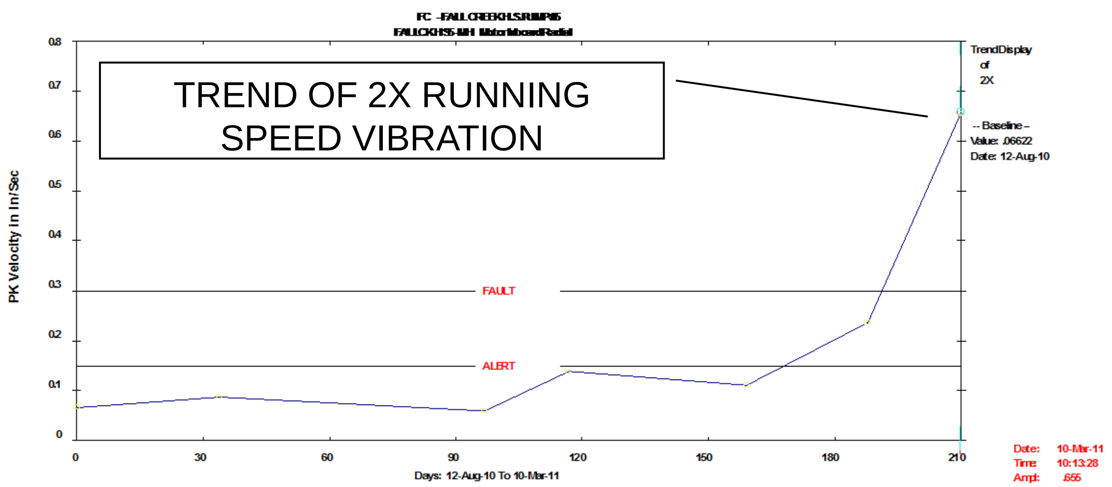



DC Current is supplied through a commutater to coils to produce north-south poles. These poles lock on to (synchronize) to the rotating field in the stator.

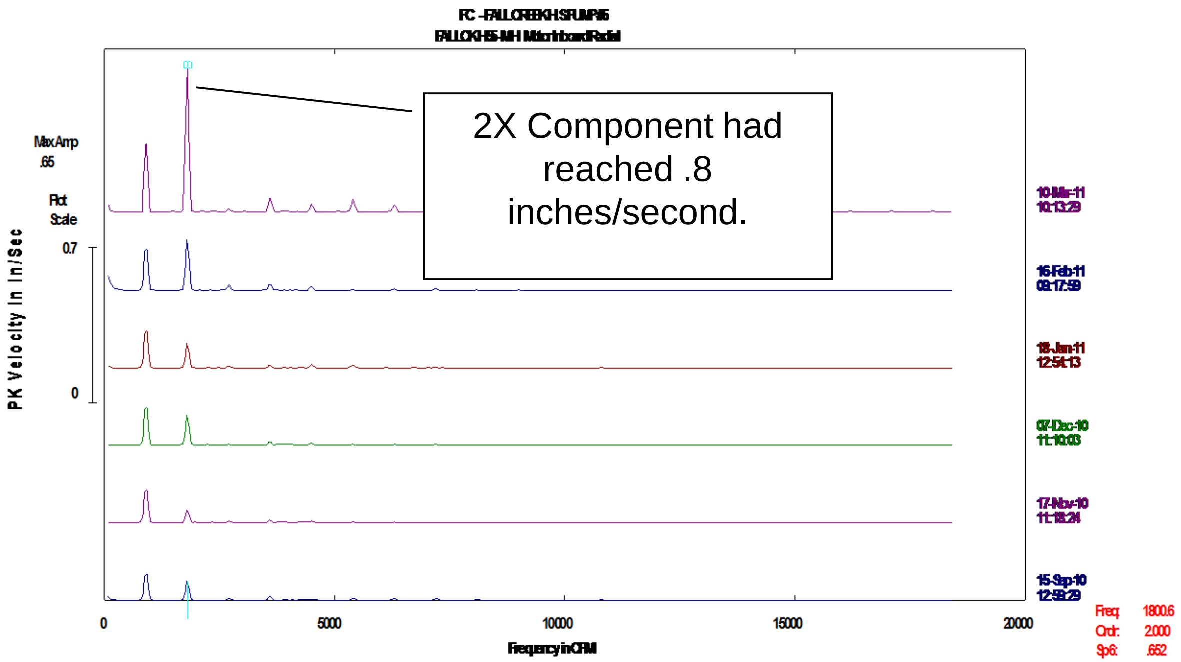
# SYNCHRONOUS MOTOR
# Mystery High 2X

# Case History Back Ground

- Vibration had been trending up. Most of the vibration was at 2X running speed.



# Spectral History



# Test Procedure

- IOTECH test instrument was put into mode to rapidly capture and store data from tach, DC amp probe, accelerometers and Proximity Probes.
- The area of most interest was to look closely at the vibration as DC current was supplied to field coils.
- Was this a locked coupling, cracked shaft or electrically induced?

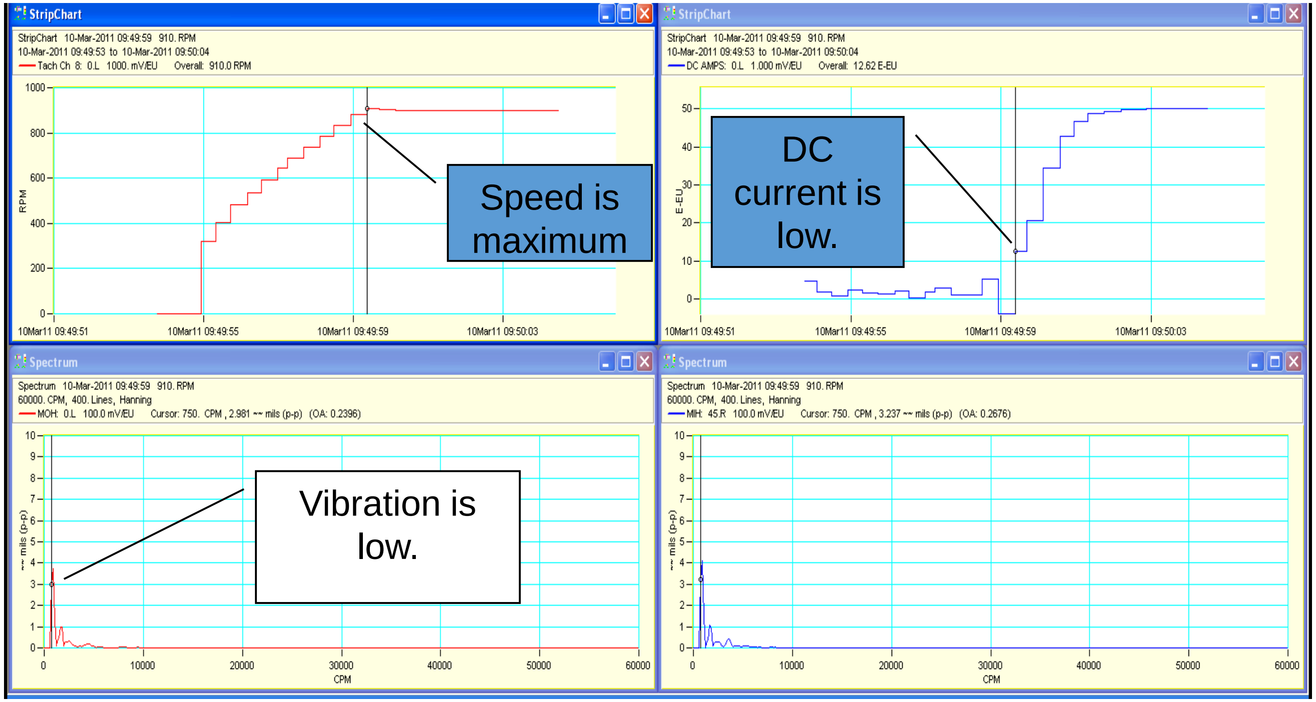
# Test Setup

| 20 Channel IOTECH | HALL EFFECT DC PROBE | TACH SETUP |
|---|---|---|

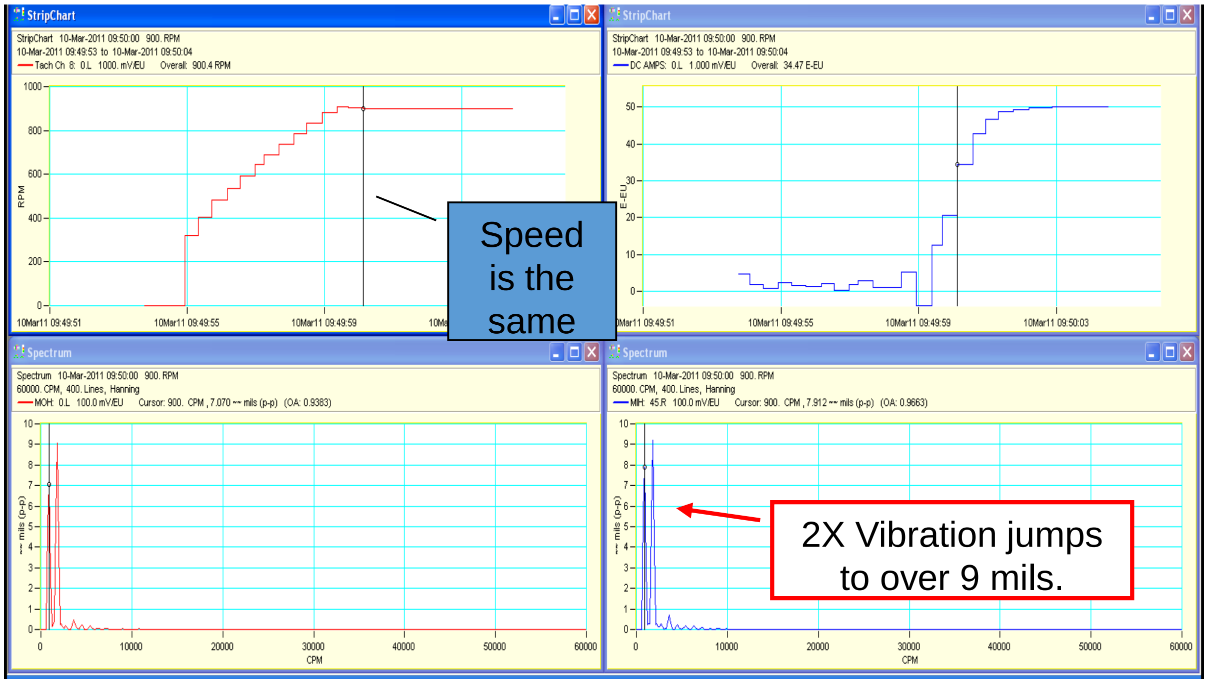

Accelerometers

Proximity Probe

# Test Results- At full speed, initially there was not problem.



# DC CURRENT IS APPLIED
# .4 seconds later high vibration

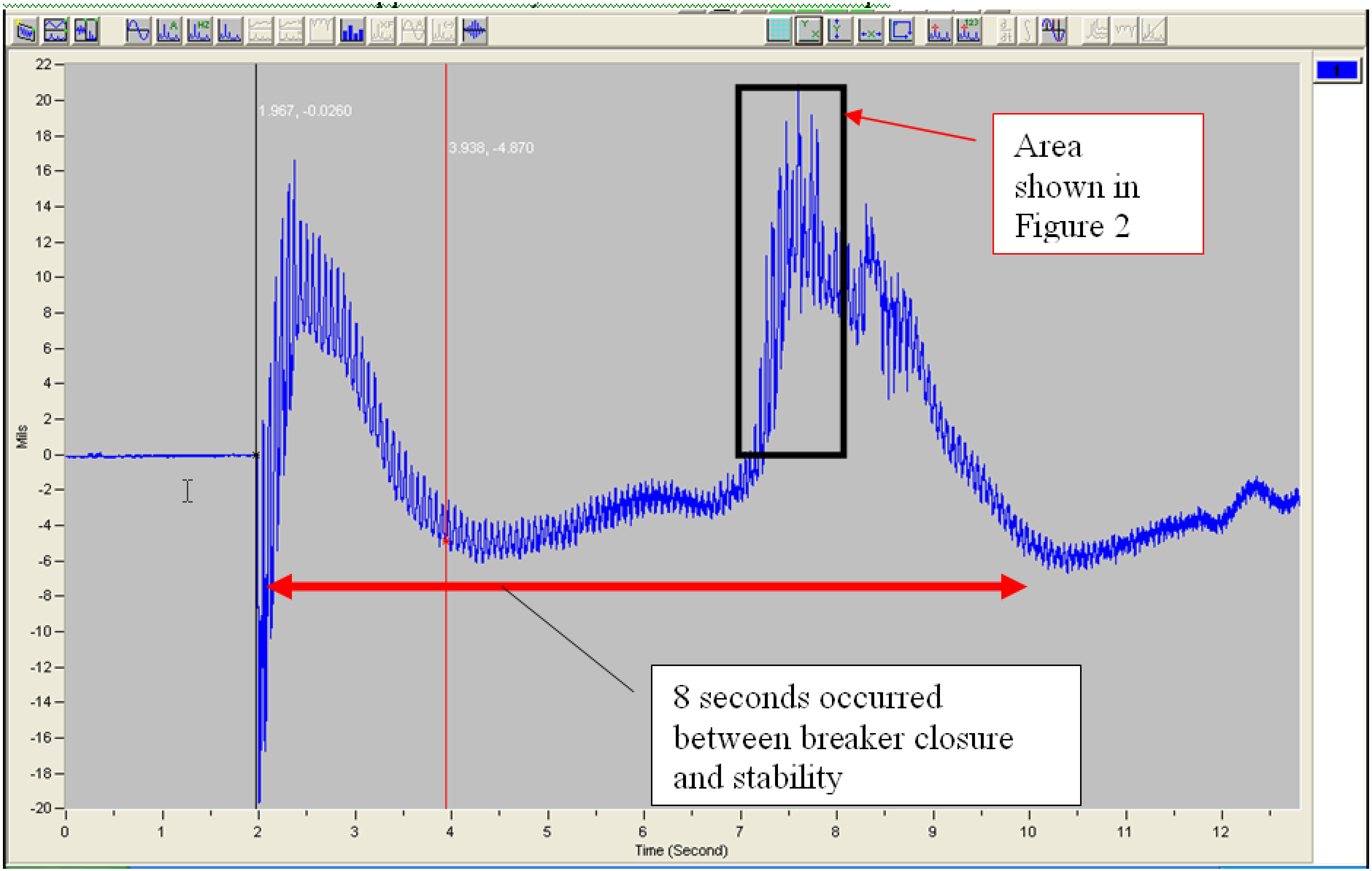



Problem was a shorted field coil that caused uneven magnetic field.

# Synchronous Motor Case 2 -Large 5000 HP compressor wipes seals & destroys rotor in startup after overhaul

- This machine had a history of high vibration during the 6-8 second run up period.
- This was a newly overhauled unit. The aluminum seals rubbed. The aluminum built up on the shaft forcing the impeller into the scroll resulting in complete destruction of the impeller.

# 8 SECOND STARTUP



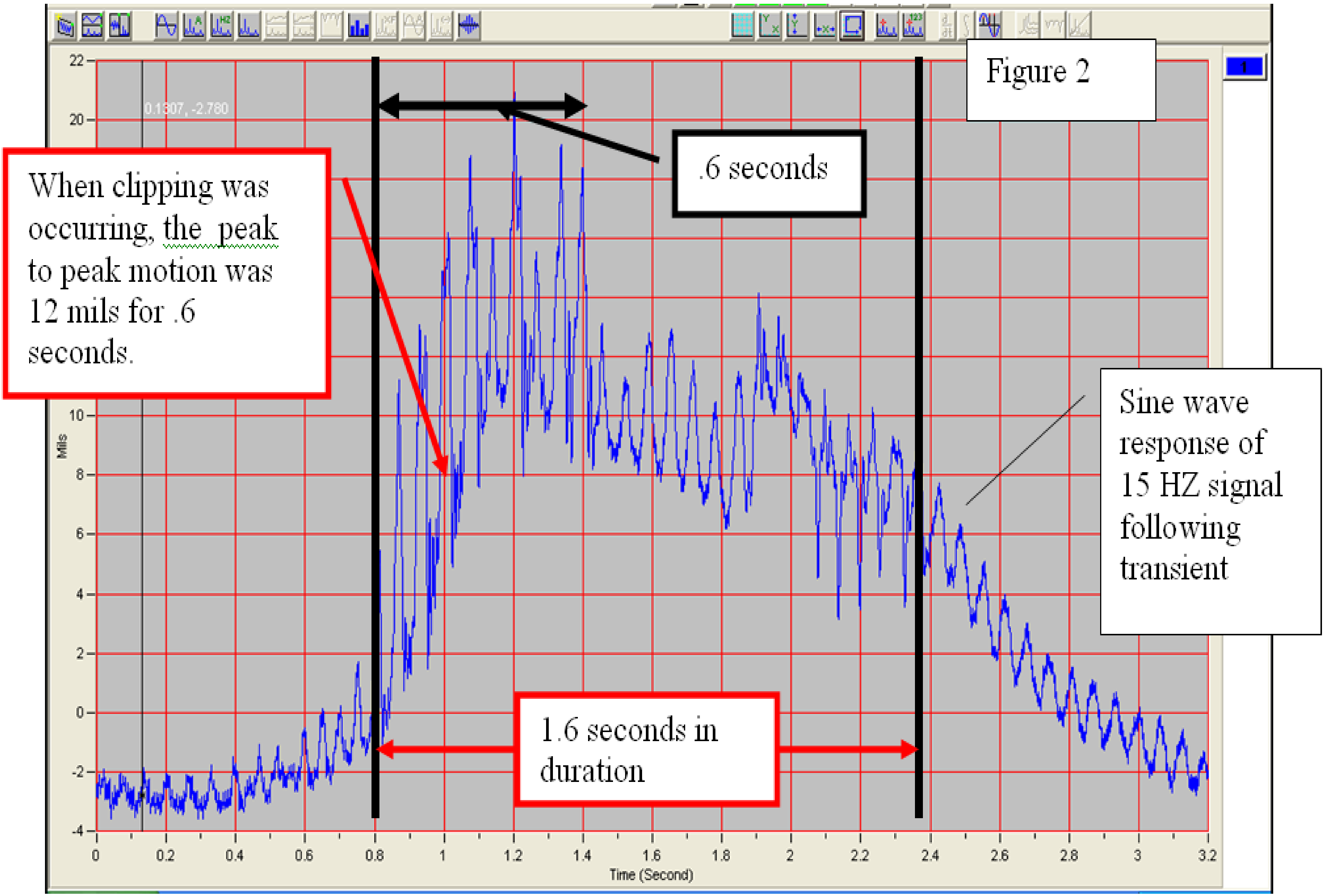
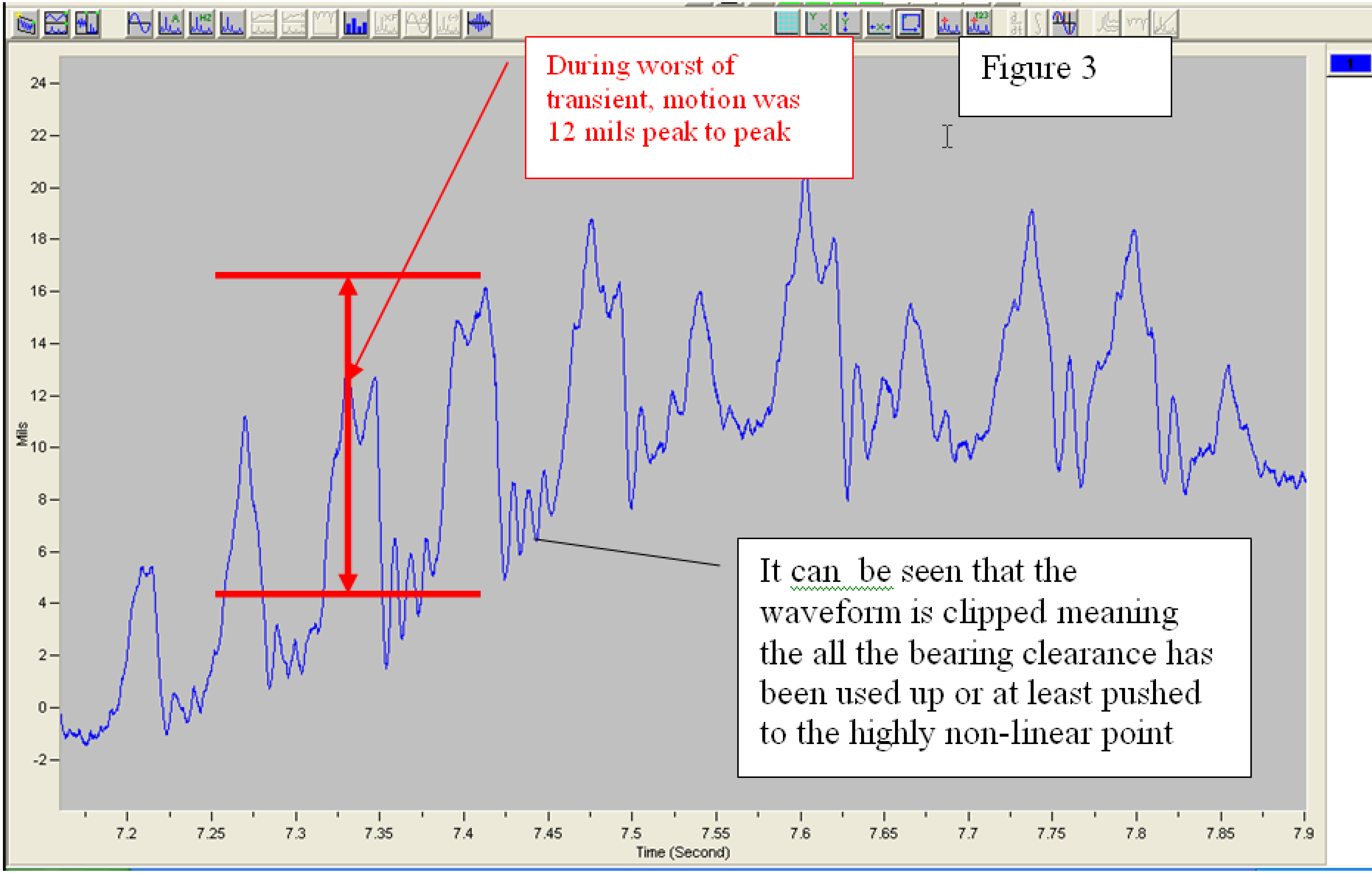
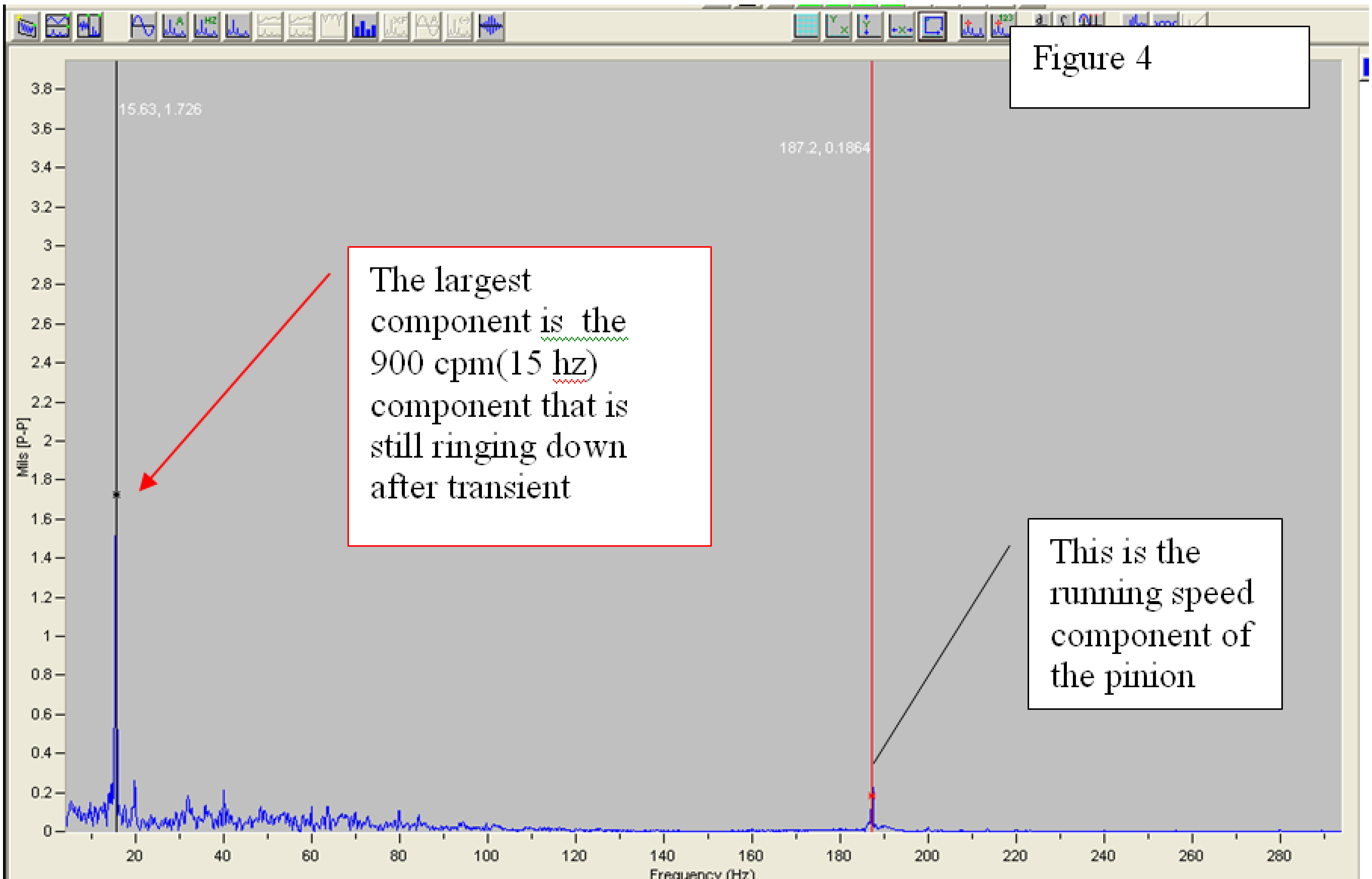


Figure 2
When clipping was occurring, the peak to peak motion was 12 mils for .6 seconds.
.6 seconds
1.6 seconds in duration
Sine wave response of 15 HZ signal following transient
0.1307, -2.780
Mils
Time (Second)
22
20
10
8
6
4
2
0
-2
-4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2

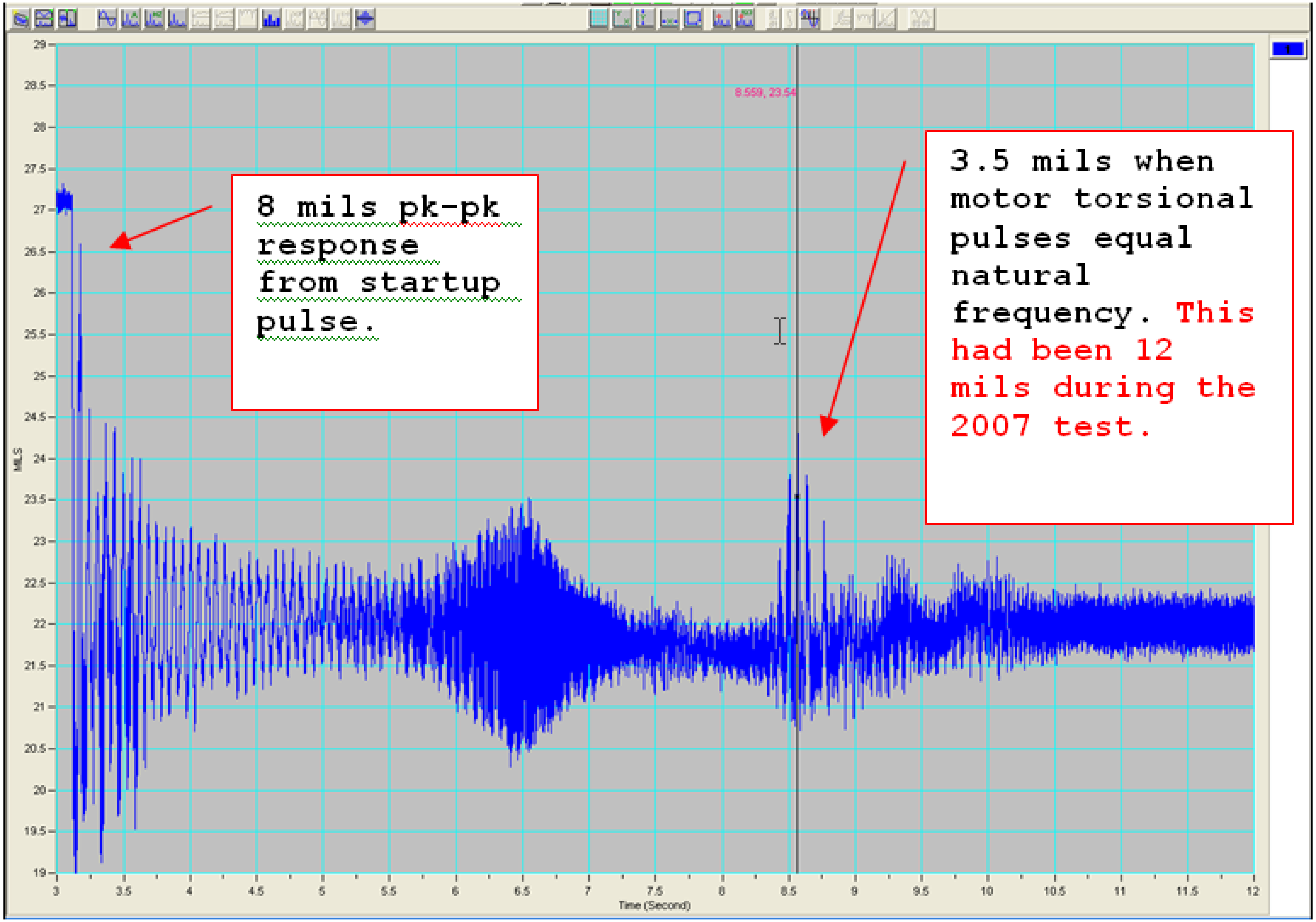
# Vibration just prior to synchronization



# At Synchronization 900 CPM is still ringing down



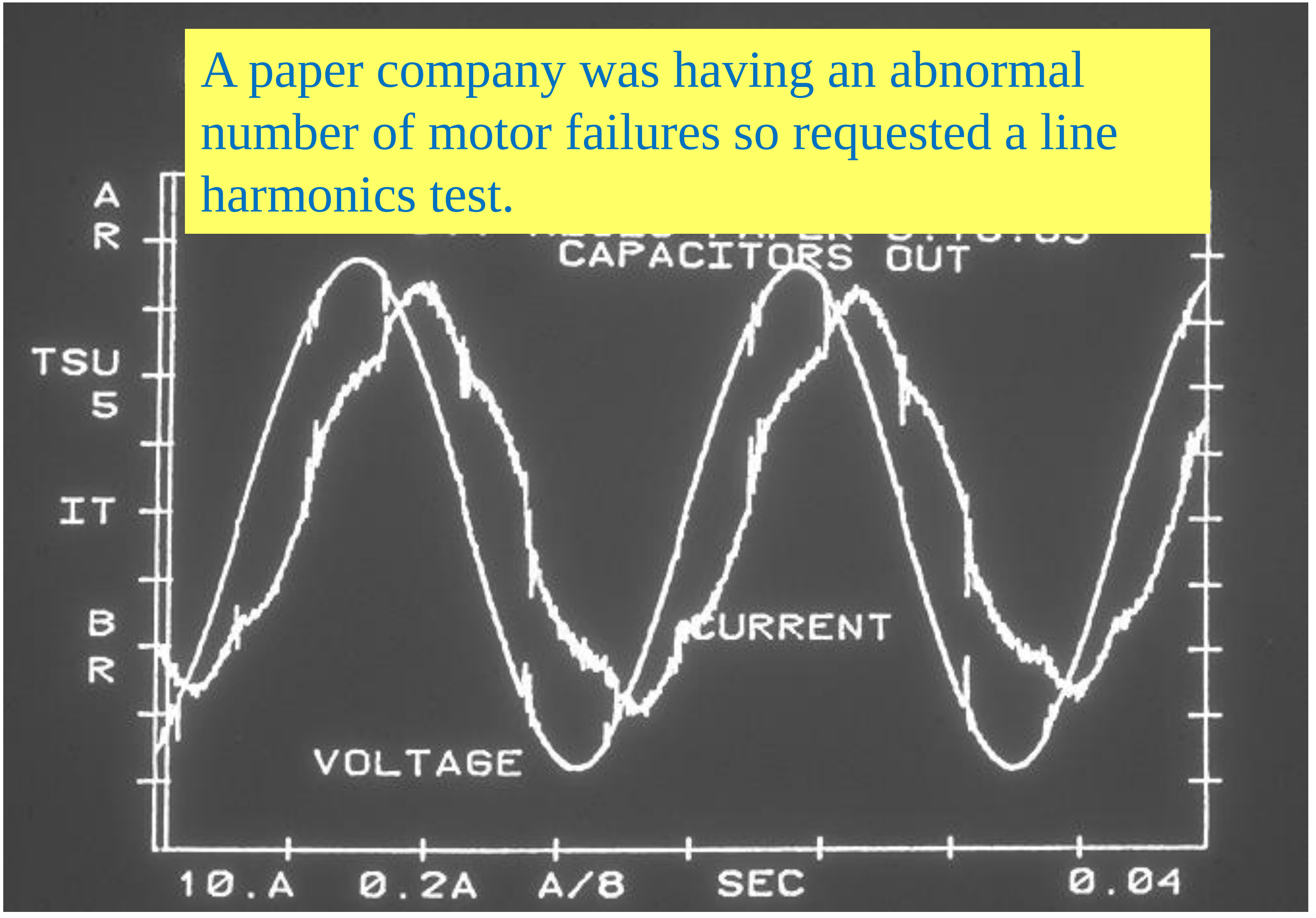
Coupling was badly worn. When it was replaced response dropped significantly. The 915 cpm component was still present, but at much lower levels.



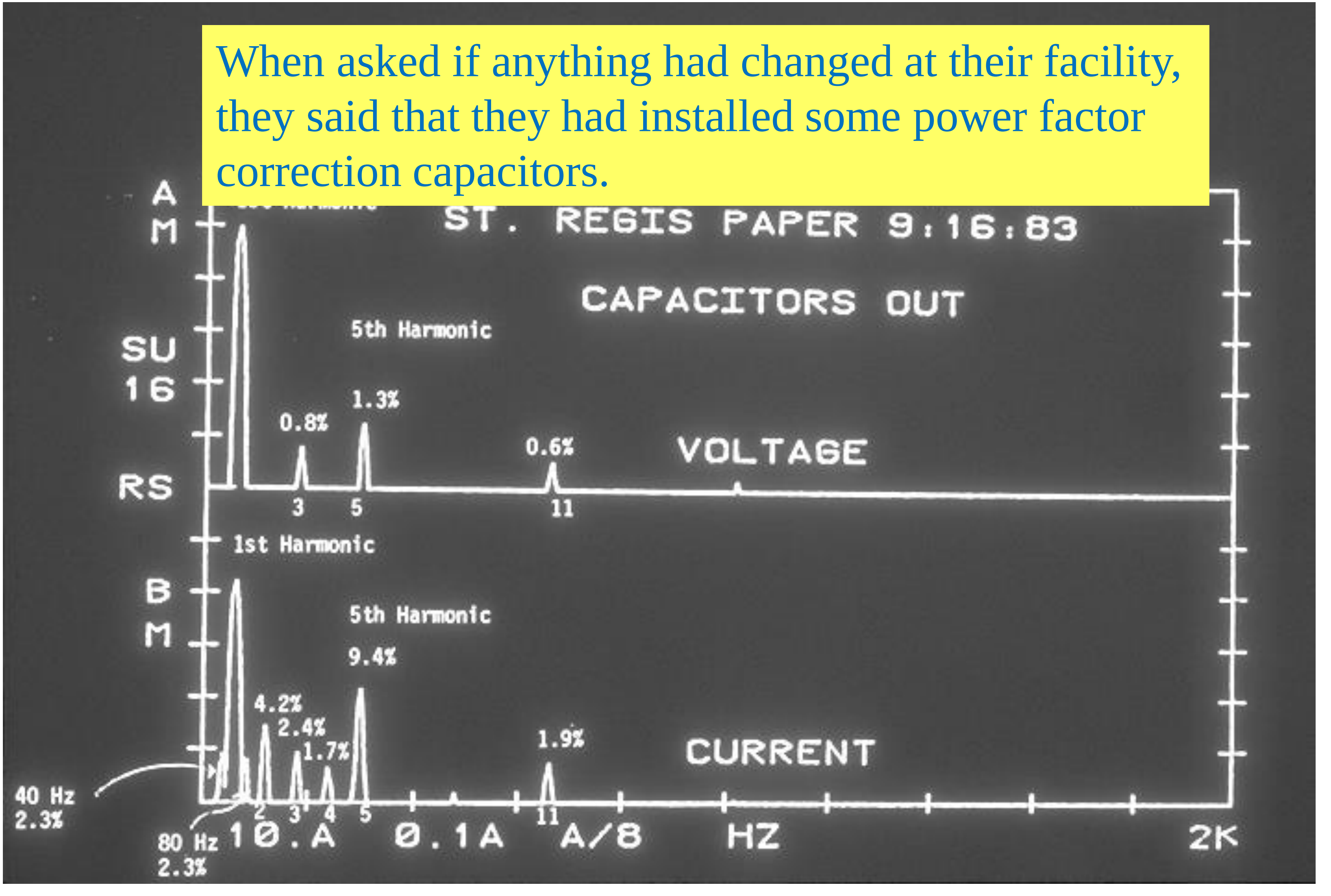
# LINE HARMONICS

- In an ideal situation, all current being fed to motors, transformers and power supplies would be at exactly 60 HZ (50 HZ in some countries).
- The pure 60 HZ pure sine wave energy can, however be distorted thereby producing harmonics of 60 HZ. These harmonics are dissipated in heat and can therefore cause pre-mature failure in motors and electronic devices.
- The most common harmonics generated are the odd harmonics that are not divisible by 3. They are the 5$^{th}$, 7$^{th}$ and 11$^{th}$ harmonics.
- These harmonics are generated by VFD drives and even battery chargers.
- Line harmonics can be transferred through transformers so can contaminate power to areas beyond where they were created.

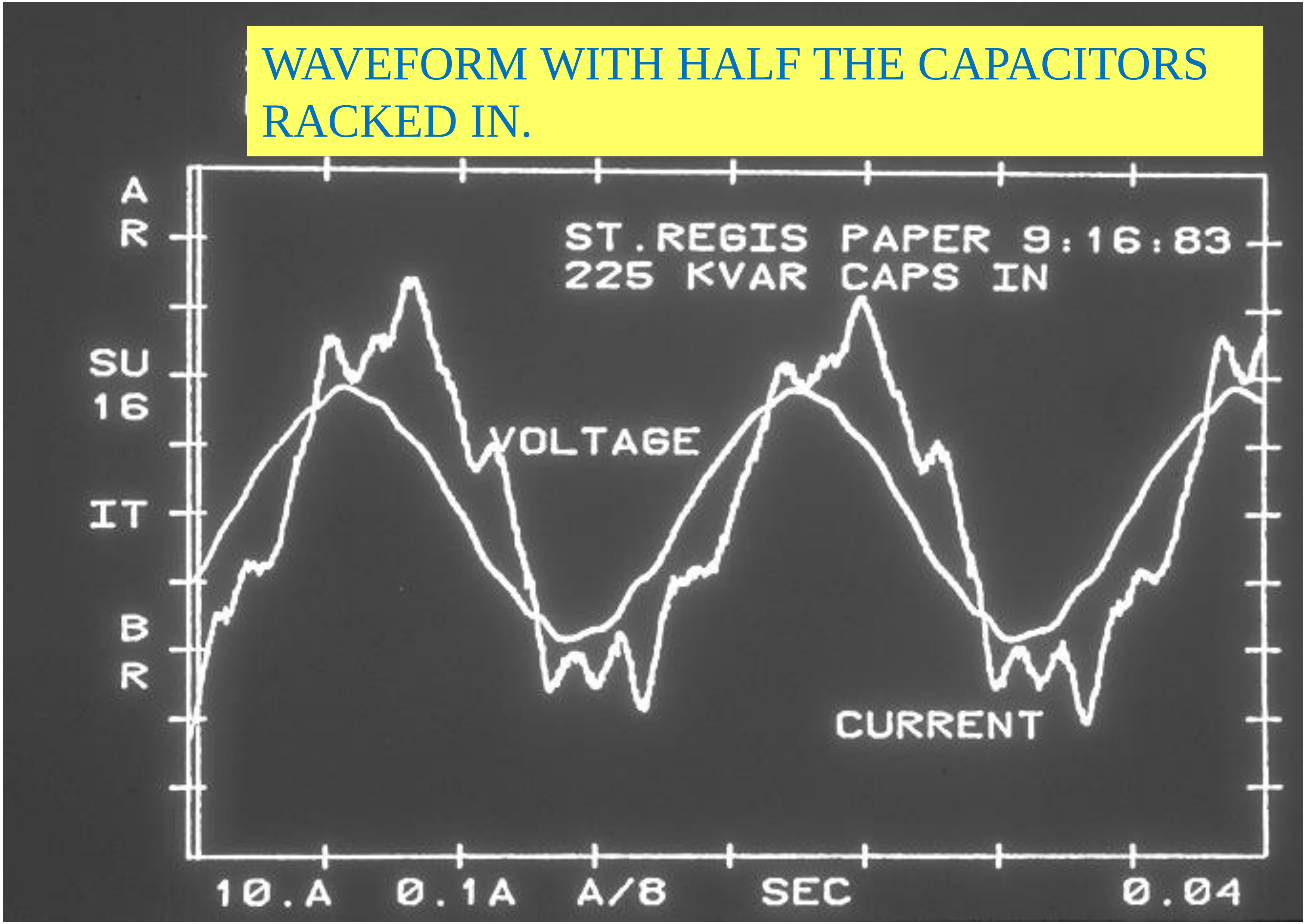
A paper company was having an abnormal number of motor failures so requested a line harmonics test.

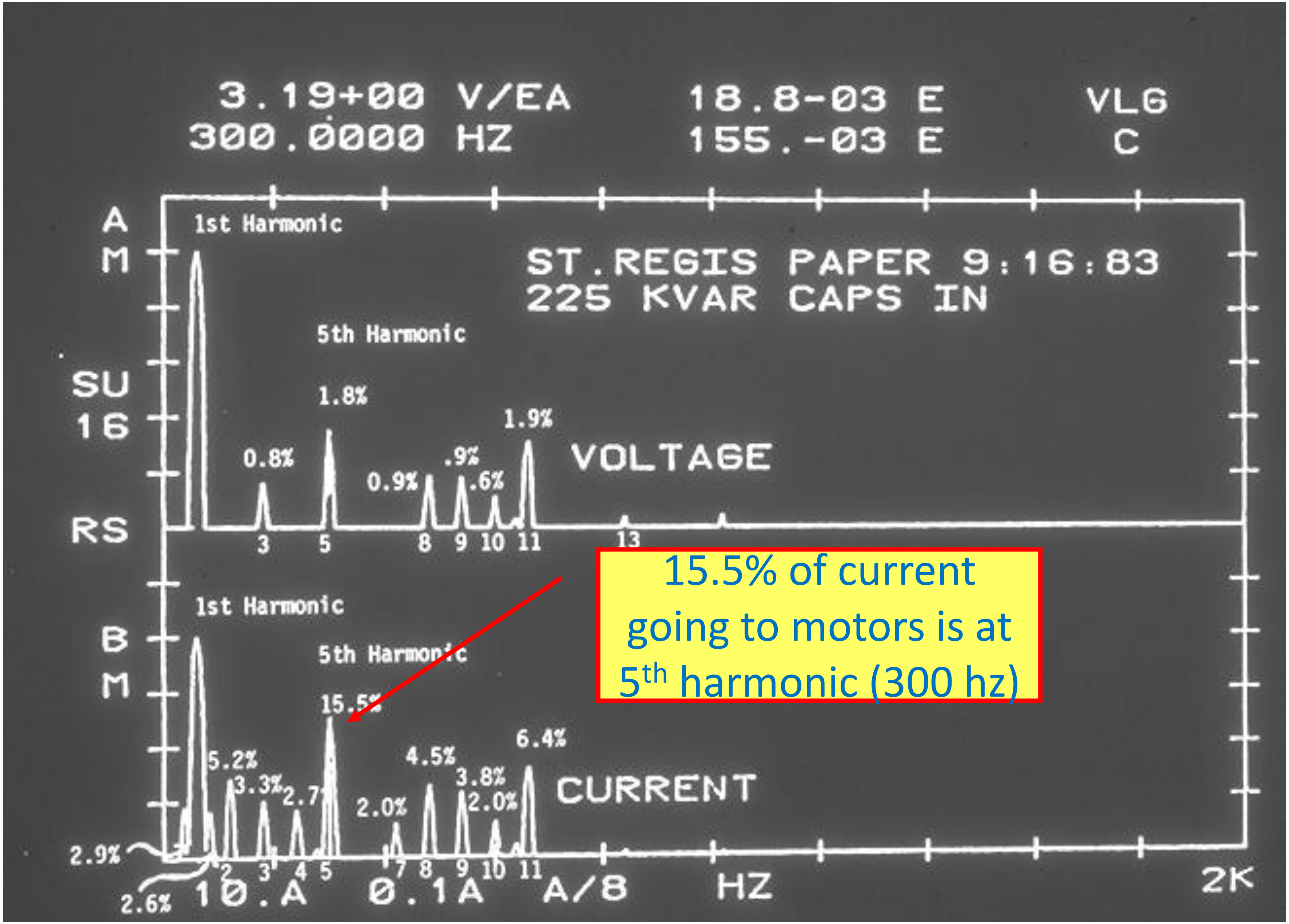


When asked if anything had changed at their facility, they said that they had installed some power factor correction capacitors.

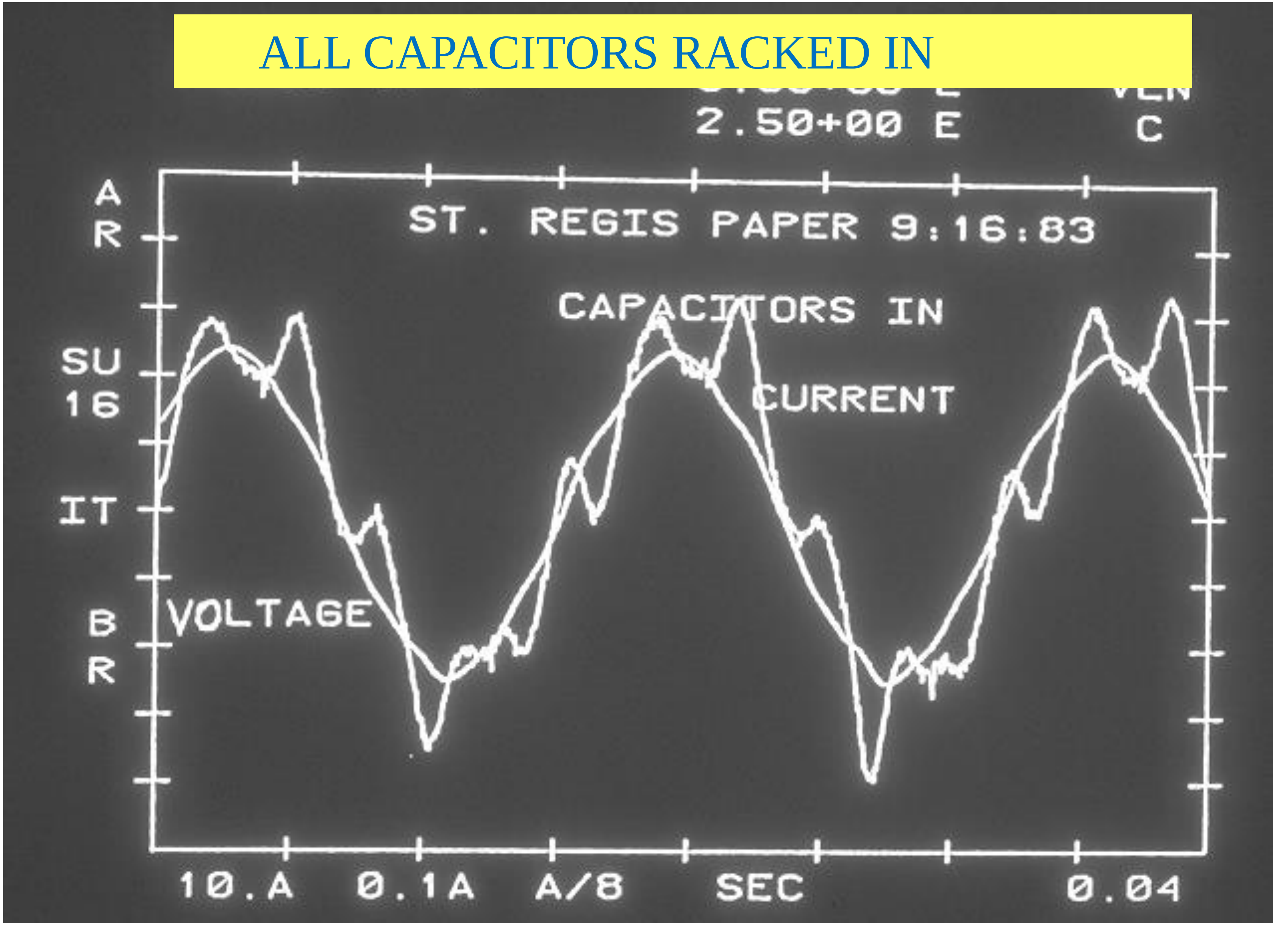


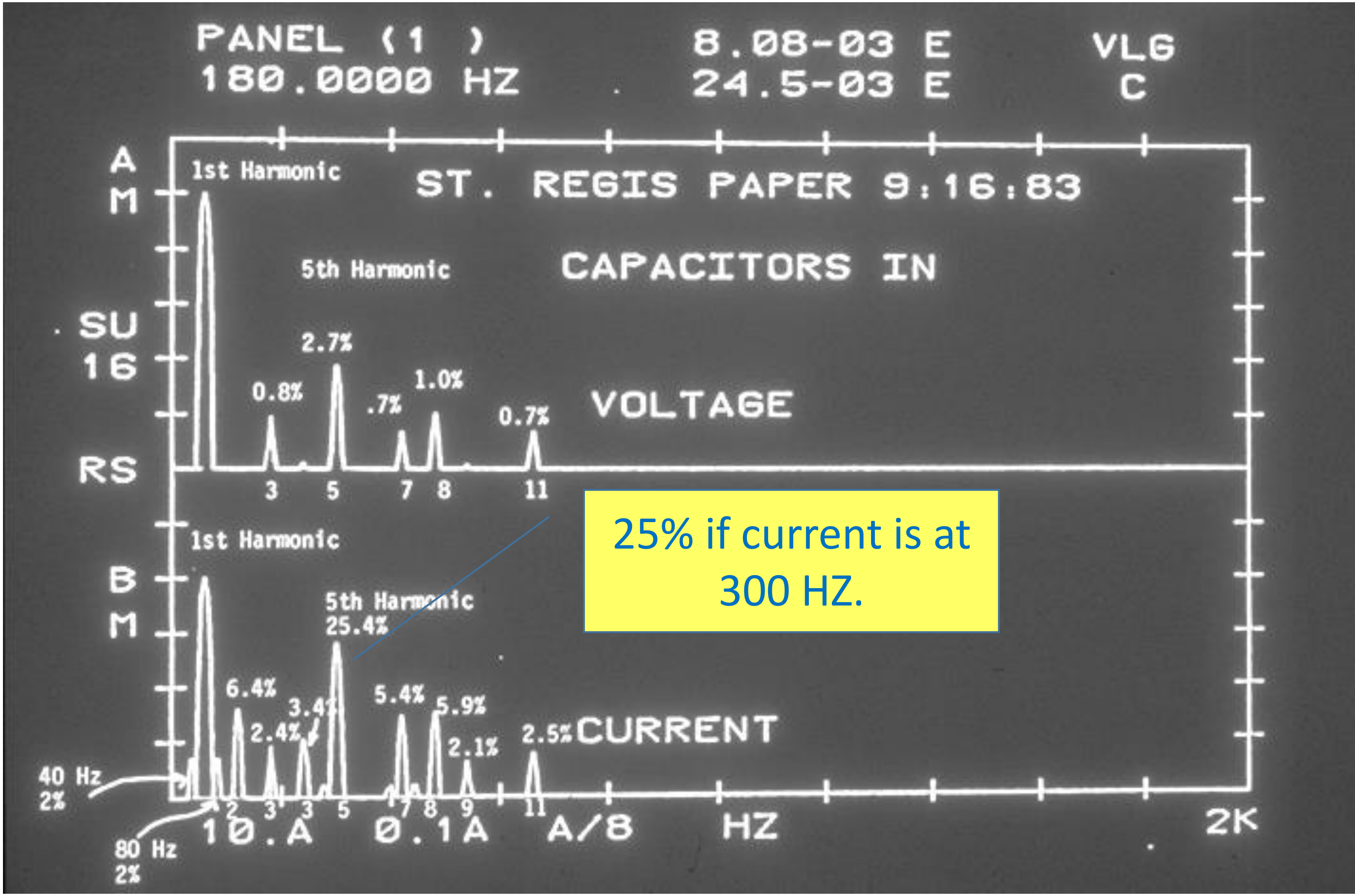
# WAVEFORM WITH HALF THE CAPACITORS RACKED IN.




3.19+00 V/EA
300.0000 HZ
18.8-03 E
155.-03 E
VLG
C
A
M
SU
16
RS
B
M
1st Harmonic
5th Harmonic
ST.REGIS PAPER 9:16:83
225 KVAR CAPS IN
1.8%
0.8%
0.9%
.9%
.6%
1.9%
VOLTAGE
3
5
8
9
10
11
13
1st Harmonic
5th Harmonic
15.5%
5.2%
3.3%
2.7
2.0%
4.5%
3.8%
2.0%
6.4%
CURRENT
2.9%
2.6%
2
3
4
5
7
8
9
10
11
10.A
0.1A
A/8
HZ
2K
15.5% of current going to motors is at 5th harmonic (300 hz)

# ALL CAPACITORS RACKED IN

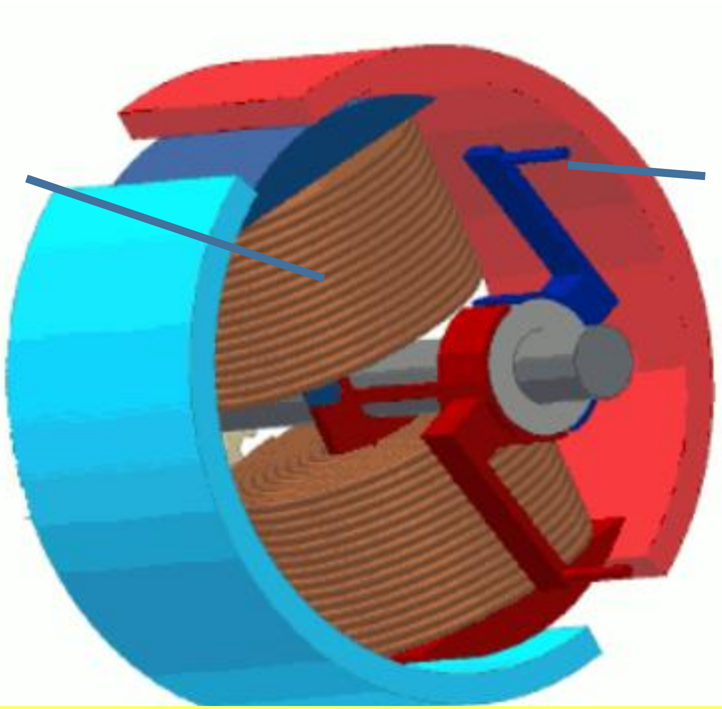



PANEL (1 )
180.0000 HZ
8.08-03 E
24.5-03 E
VLG
C
ST. REGIS PAPER 9:16:83
CAPACITORS IN
VOLTAGE
1st Harmonic
5th Harmonic
2.7%
0.8%
.7%
1.0%
0.7%
3
5
7
8
11
CURRENT
1st Harmonic
5th Harmonic
25.4%
6.4%
3.4%
2.4%
5.4%
5.9%
2.1%
2.5%
40 Hz
2%
80 Hz
2%
10.A
0.1A
A/8
HZ
2K
AM
SU
16
RS
BM
25% if current is at 300 HZ.

# ANALYSIS

- Excessive current at the 5th harmonic of line frequency was detected at this facility.
- The amplitude of the 5th harmonic nearly tripled when all the power factor correction capacitors were racked in.
- The 5th harmonic is a counter rotating field, so it was trying to drive the motor backwards are 5 times the operating speed.  That energy was thus turned to heat.
- The 5th harmonic was most likely produced by some on site variable frequency drives.
- Electrical circuits can have resonances, just like mechanical system.
- Electrical circuits resistance to current flow (impedance) is a function of the resistance, capacitance and inductance.
- Recommendation: Have an expert in electrical power circuits model system and try to reduce harmonics with filters or alter system impedance.

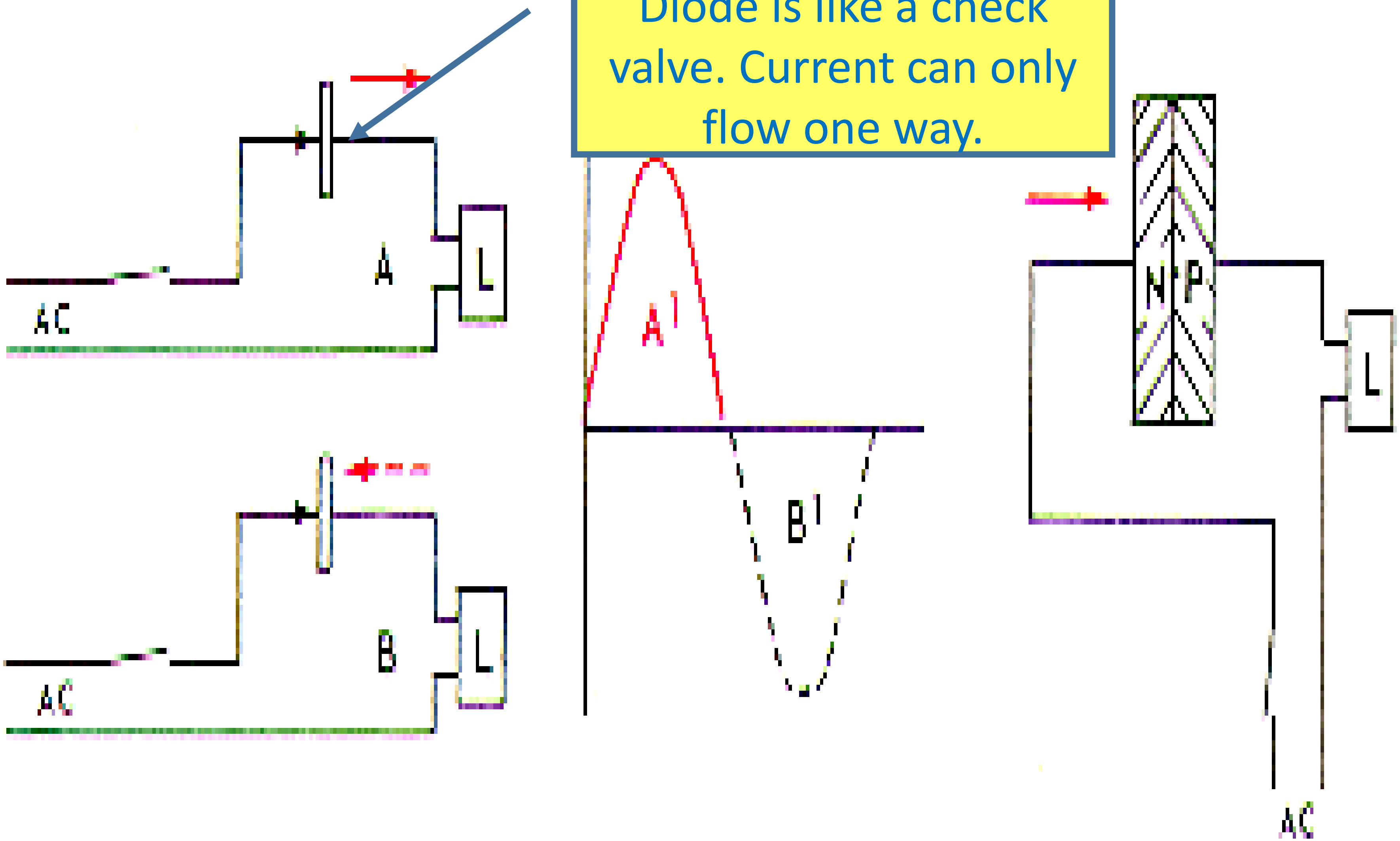
# DC MOTORS



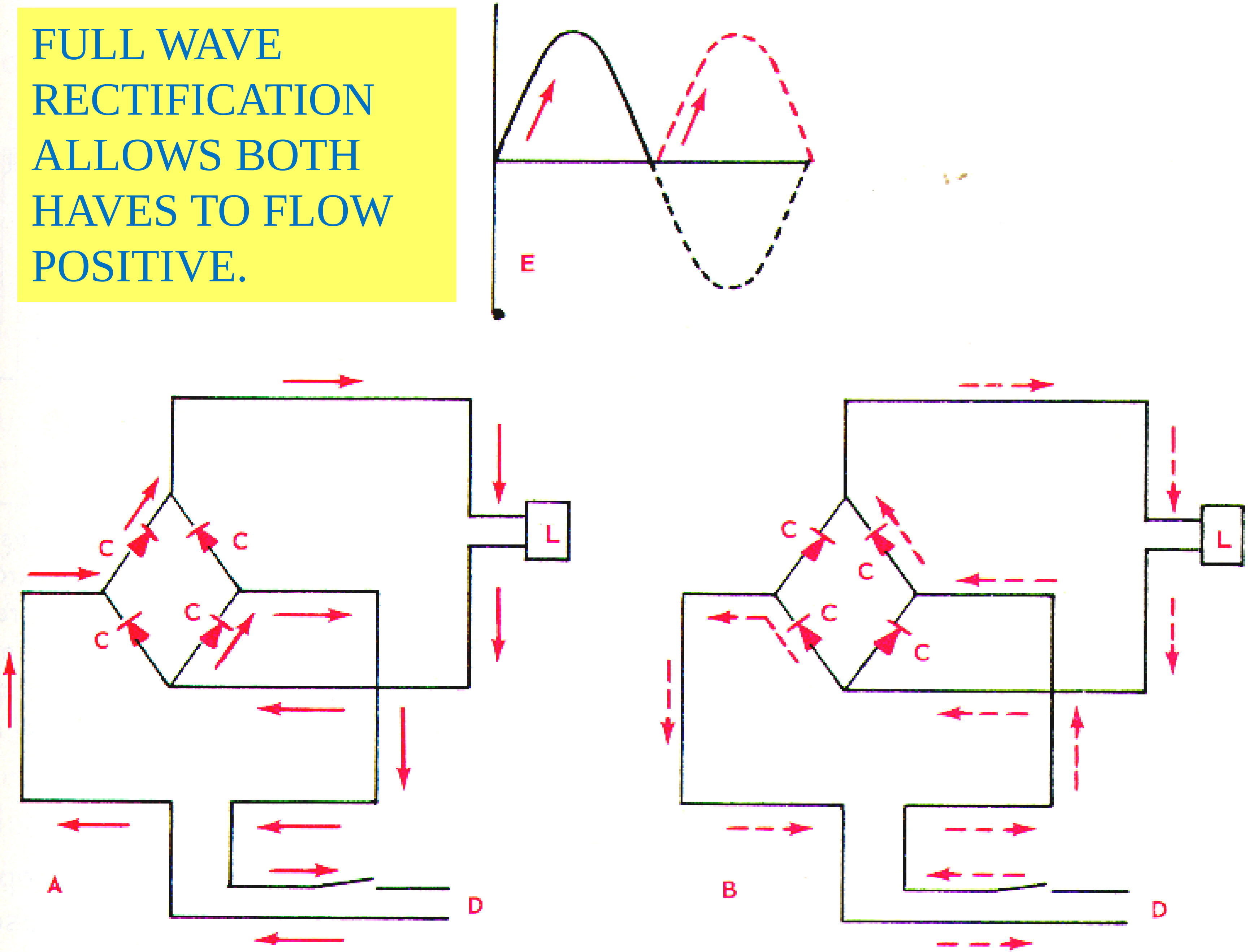

The magnetic field generated in the rotor coils are attracted to the opposite poles of the stator. This causes the shaft to rotate. As the poles start to line up, the commutator sends the current to the opposite coil keeping the rotor in continuous motion.

# The current to most DC motors is rectified AC current. Below is a ½ HALF WAVE RECTIFIER

Diode is like a check valve. Current can only flow one way.



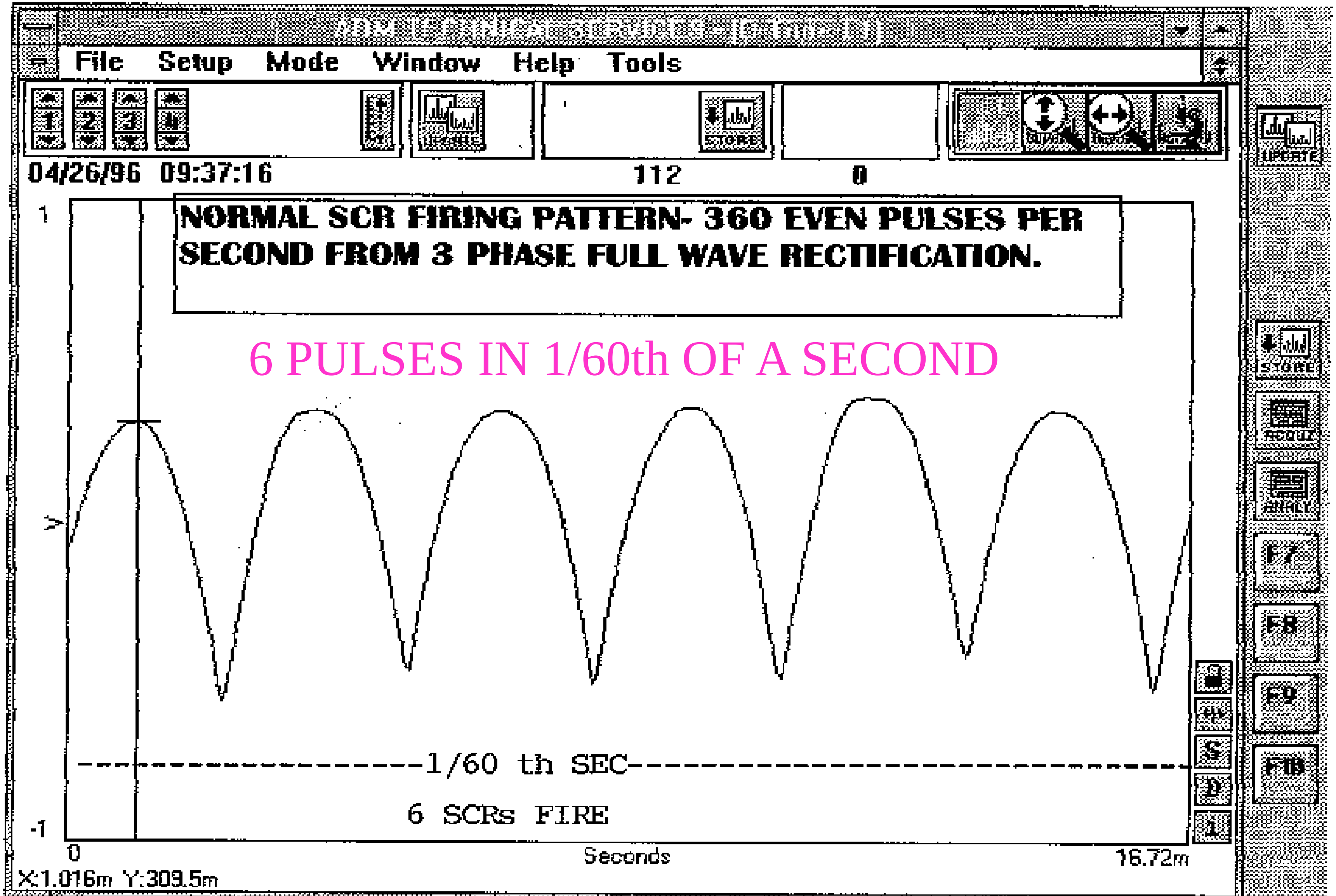
FULL WAVE RECTIFICATION ALLOWS BOTH HAVES TO FLOW POSITIVE.



1: D.C. MOTORS- The spectrum of the current to a D.C. Motor can be used to find problems with SCRs or firing circuits. The rectifier input supply frequency (50 or 60 HZ) times 6 for 3 phase full wave rectifiers will normally be present in the current spectrum. When 1/3 or 2/3 of the firing frequency is present, it indicates failed SCRs or firing circuits. It is much simpler to look at the current spectrum or current waveform than to try to see the problem with vibration. Vibration is a secondary effect reflecting the problem which is actually of electrical origin.

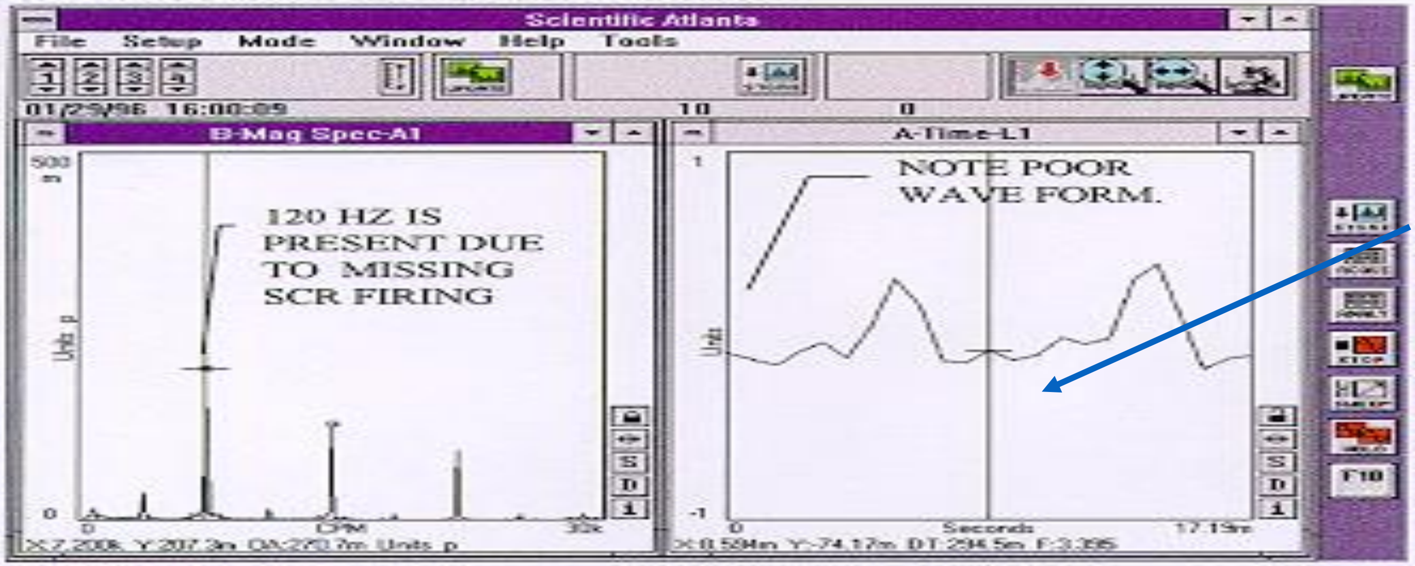
# WHAT DOES THE CURRENT PATTERN OF A NORMAL DRIVER LOOK LIKE

**CURRENT WAVEFORM FROM FAN PUMP DRIVE**
**NORMAL PATTERN**
**FOLLOWING REPLACEMENT OF FIEL SCR**



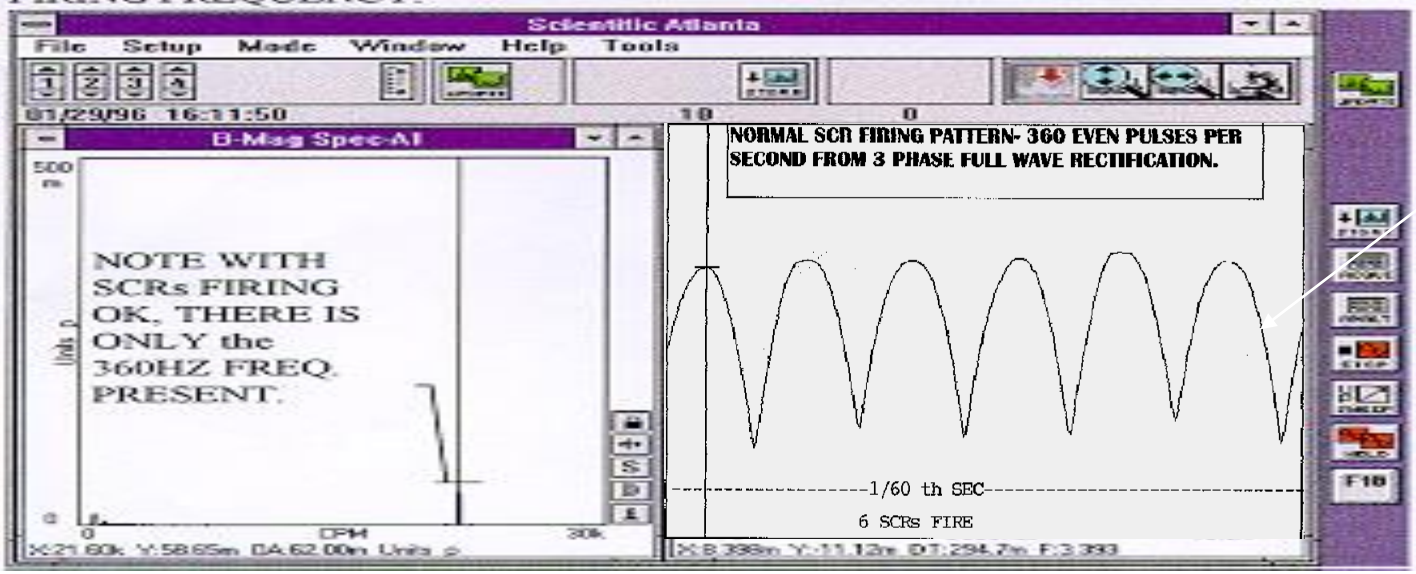
# WHAT DOES THE WAVEFORM OF A BAD DRIVE LOOK LIKE ?

THIS IS AN EXAMPLE OF 2 SCRs NOT FIRING IN A FULL WAVE RECTIFIED DC DRIVE
FILE IS STORED UNDER SCRMISS.WAV




BAD

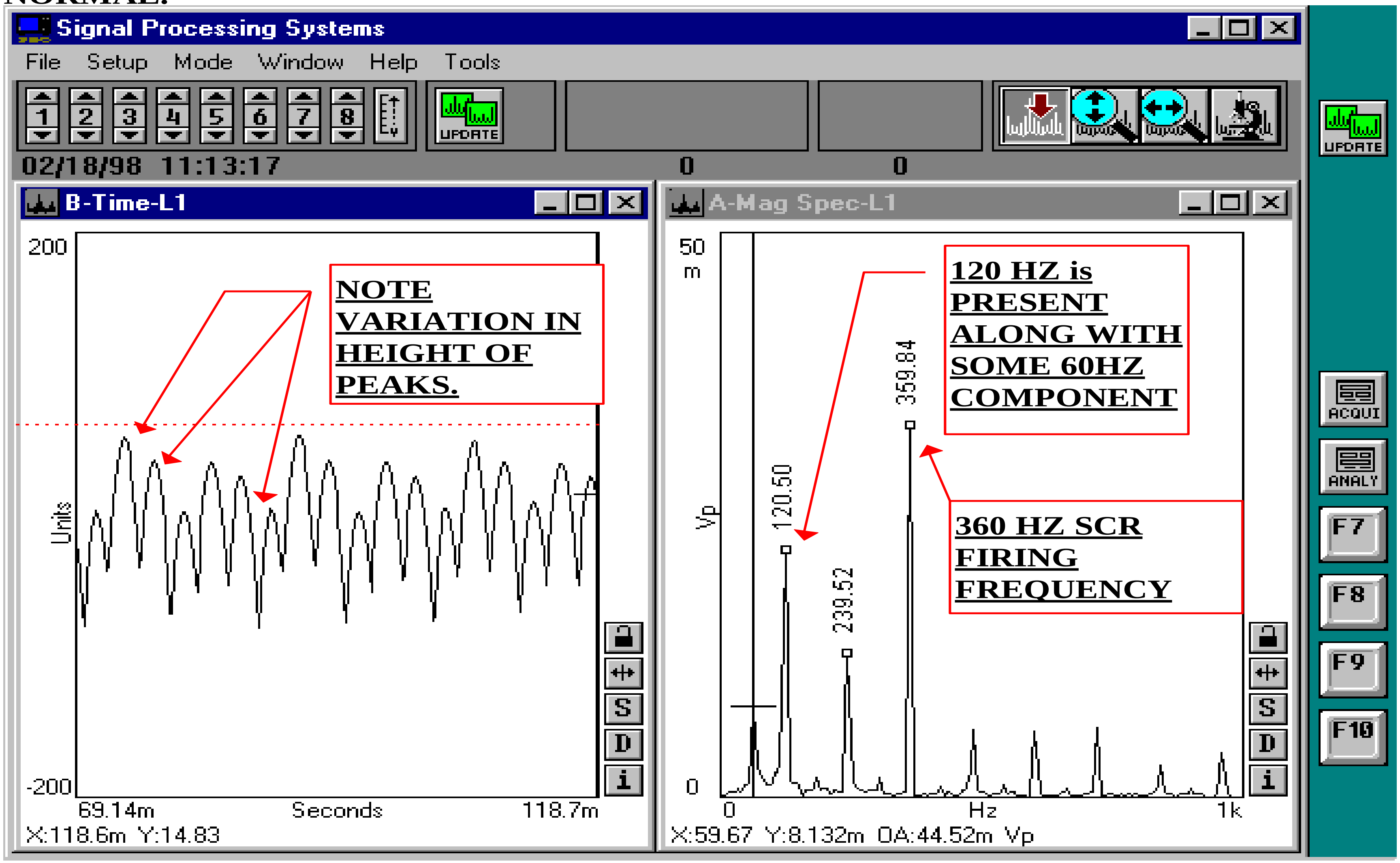
BELOW IS WHAT A PROPER WAVE FORM WITH ALL SCRs FIRING NOTE SIX PULSES IN 16 MSEC. PERIOD= 6 X 60 CYCLES/SEC WHICH IS PROPER FULL WAVE 3 PHASE SCR FIRING FREQUENCY.




GOOD

**FEBRUARY 18, 1998**
**VISY   FAN PUMP DRIVE**
**250 AMP LOAD**

**WHEN SCR'S WERE REPLACED,   THE WAVEFORM AND SPECTRUM RETURNED TO NORMAL.**



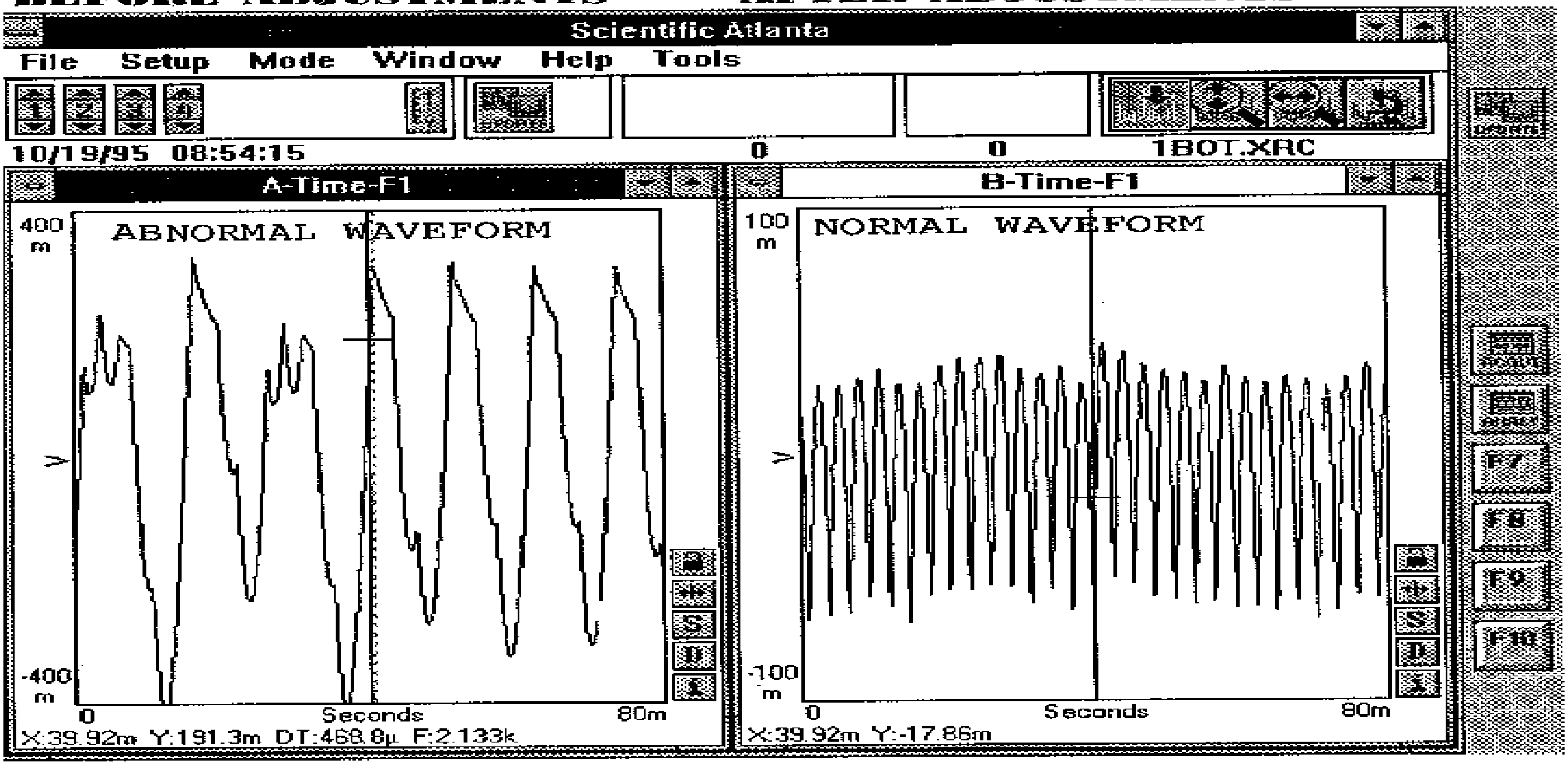
2: D.C. MOTORS- The current spectrum from a D.C. Motor can also be used to find tuning problems with D.C. Drives. Improperly tuned drives will produce frequencies at the oscillation rate of the instability. These frequencies can also appear in the vibration spectra and are very difficult to analyze since they do not have a mechanical origin. These oscillation frequencies are unpredictable. They are a result of the interaction between the rotating inertias of the mechanical components, the torsional stiffness of the shafts and the tuning of the electrical control system. If a completely unexplainable frequency appears on a drive, then it may well be due to this complex interaction.

BAD TUNING, WHERE SPEED IS CONSTANTLY MOVING UP AND DOWN.

## CURRENT WAVE FORMS FROM MAIN POWER CABLES TO PRESS DC DRIVE MOTORS.

### 2nd PRESS CURRENT WAVEFORMS

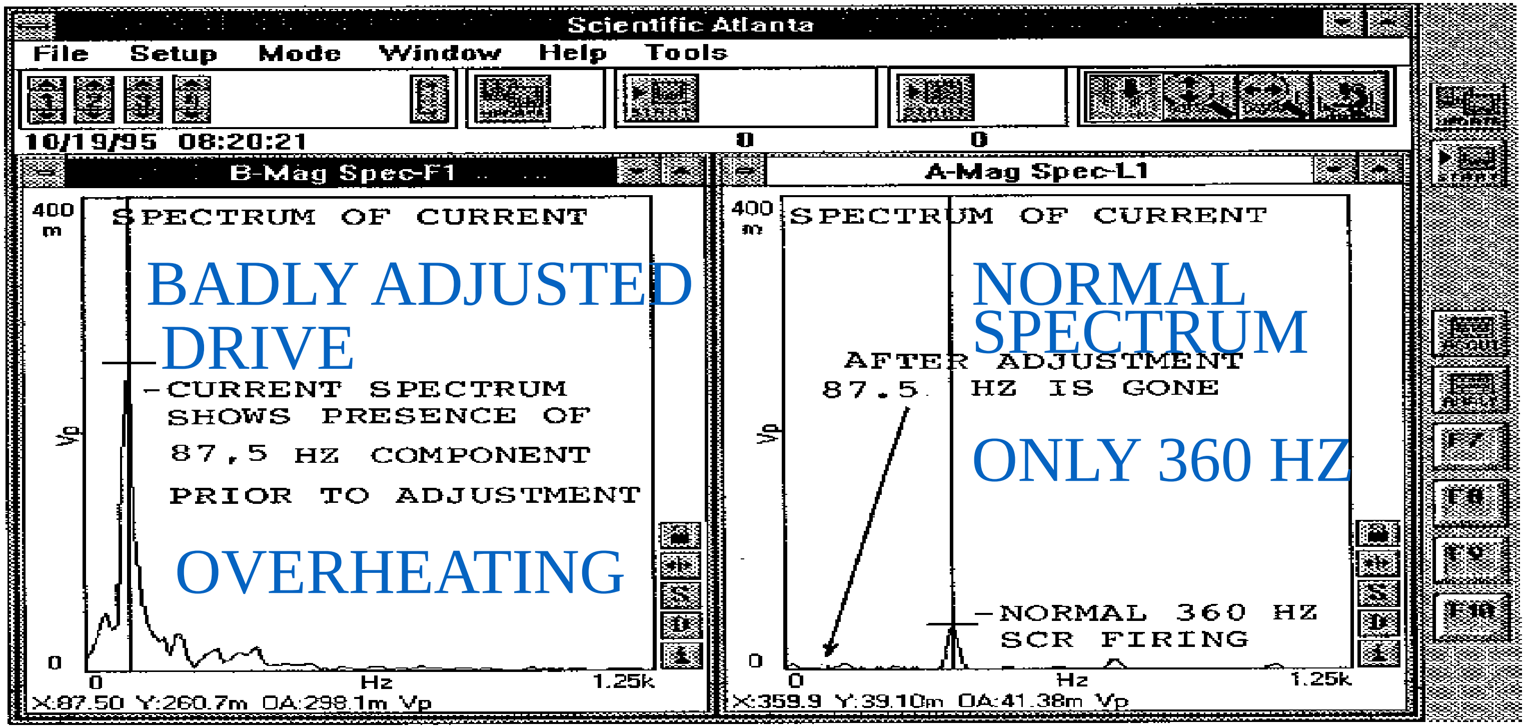
BEFORE ADJUSTMENTS — AFTER ADJUSTMENTS




The upper left time plot of the motor current shows what was present on the 2nd press bottom drive prior to making adjustments to the drive. The figure to the right is from the 1st press bottom drive. The next page shows the FFT transform of the above data.

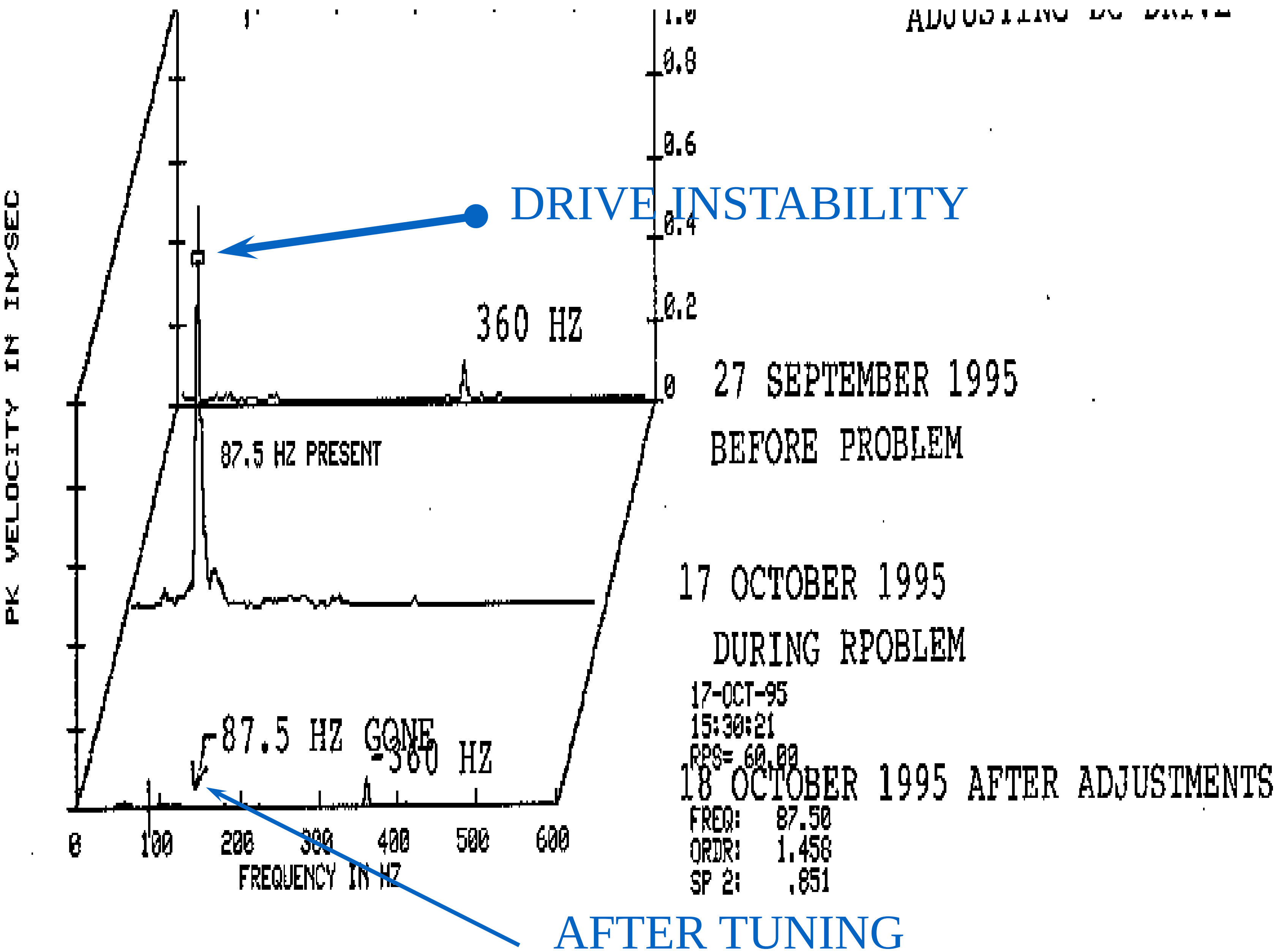
**COMPARISON BETWEEN ABNORMAL CURRENT SPECTRUM FROM POORLY ADJUSTED DC DRIVE AND WELL TUNED DRIVE.**

**2nd BOTTOM DRIVE BEFORE ADJUSTMENTS** | **2nd BOTTOM DRIVE AFTER ADJUSTMENTS**




**The spectrum on the left was taken from a current probe located on the 2nd bottom drive when the motor was vibrating at 1 inch\second and was operating at 180 degrees. The vibration signature showed a very high level of a 87.5 HZ frequency component, which is the identical frequency in the upper left spectrum.**

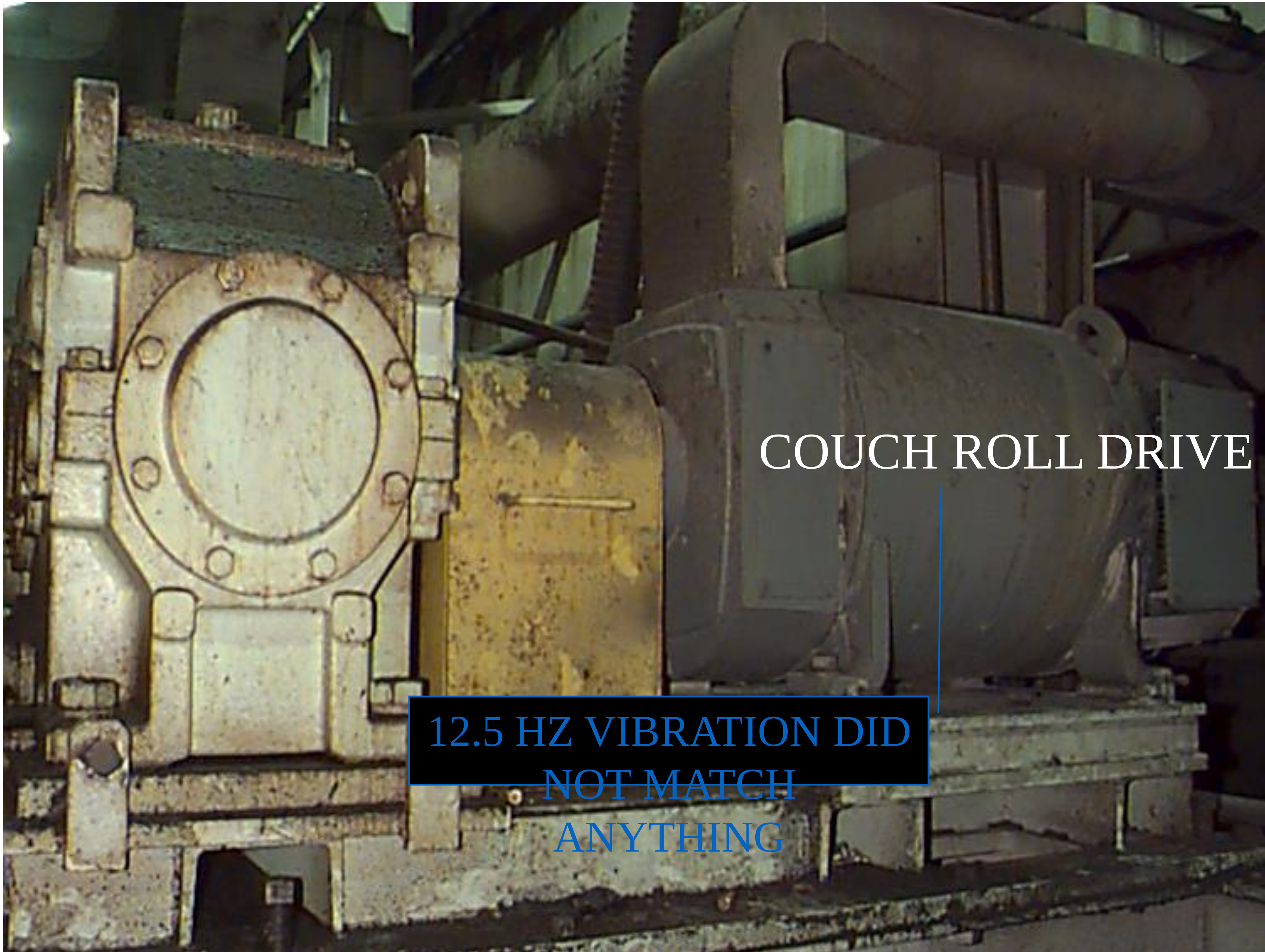
**The upper right spectrum was taken on the same motor after the drive controls were adjusted properly. Note that the only frequency which is present is the normal 360 HZ SCR firing frequency. The vibration on the motor dropped to below .1 in\sec and the 87.5 HZ component was no longer present after the drive was tuned properly.**



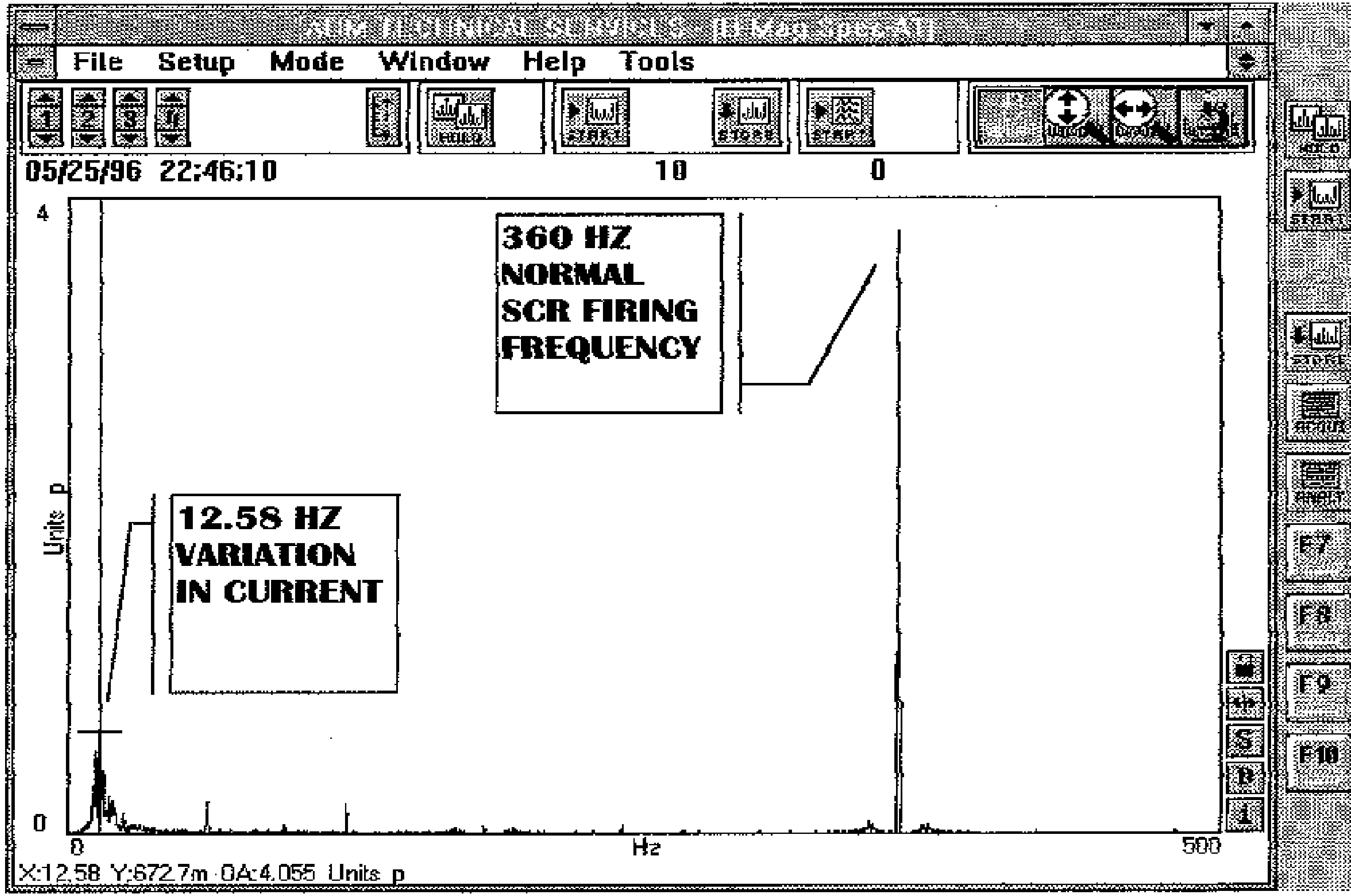
ADJUSTING DC DRIVE
PK VELOCITY IN IN/SEC
1.0
0.8
0.6
0.4
0.2
0
DRIVE INSTABILITY
360 HZ
27 SEPTEMBER 1995
BEFORE PROBLEM
87.5 HZ PRESENT
17 OCTOBER 1995
DURING RPOBLEM
17-OCT-95
15:30:21
RPS= 60.00
87.5 HZ GONE
360 HZ
18 OCTOBER 1995 AFTER ADJUSTMENTS
FREQ: 87.50
ORDR: 1.458
SP 2: .851
0
100
200
300
400
500
600
FREQUENCY IN HZ
AFTER TUNING

3: DC MOTORS- Unknown frequencies in the spectrum of the current going to a DC drive can originate from other mechanical equipment in the drive train. Case History- The current on a couch roll of a paper machine had an unknown component in its spectrum. It turned out to be the vane pass frequency of the fan pump located several yards away in the basement. The fan pump was causing pressure pulsations in the head box that caused the paper to be deposited in varying thicknesses. As the thicker material passed over the vacuum rolls, this caused the tension to increase which changed the tangential force on the couch roll which in turn caused the current draw to the couch roll to modulate at that rate.

SOMETIMES THE PROCESS CAN CAUSE THE DRIVE TO APPEAR UNSTABLE

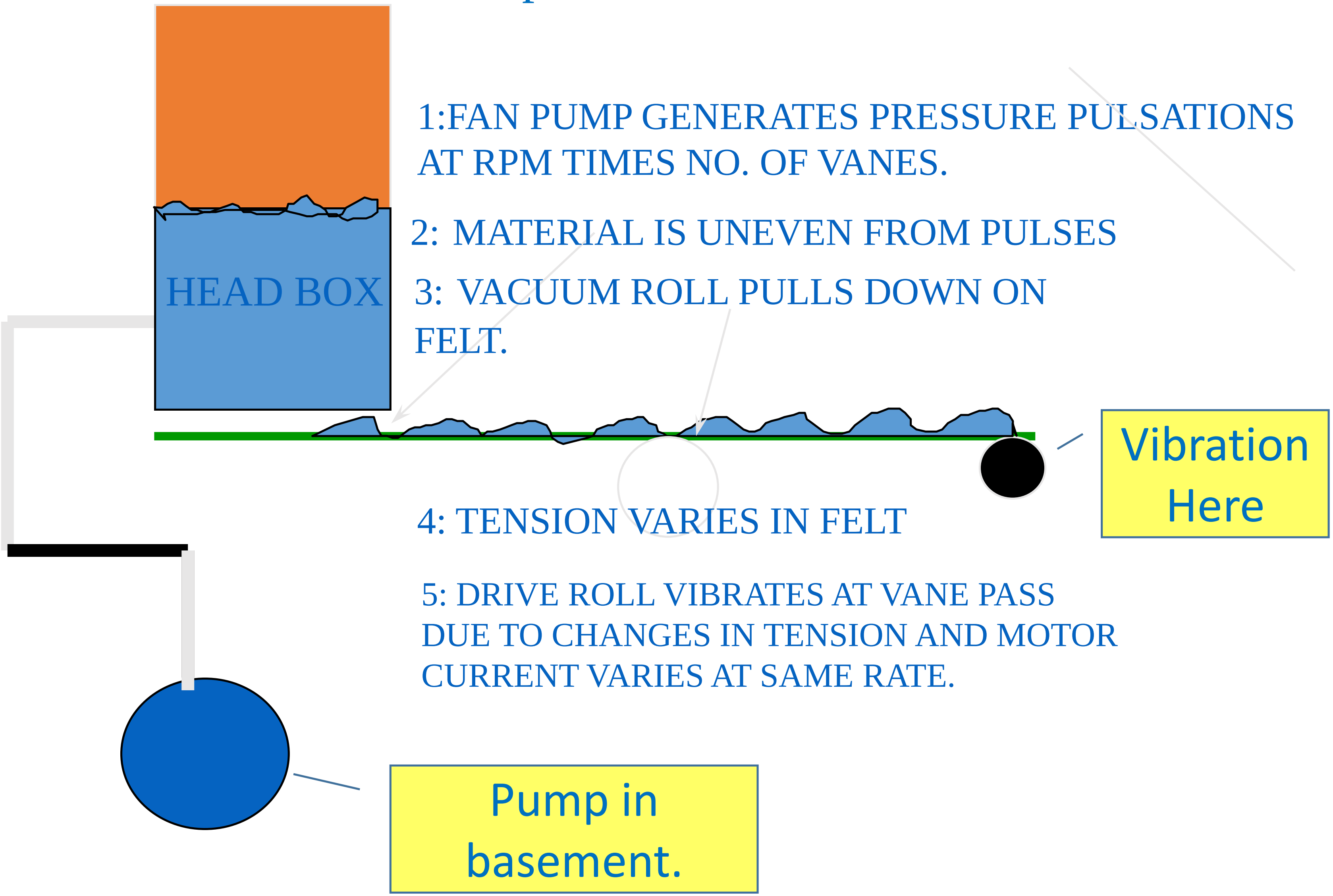

COUCH ROLL DRIVE
12.5 HZ VIBRATION DID NOT MATCH ANYTHING

MAY 25, 1996 COUCH ROLL DRIVE A1 LEAD CURRENT




12.58 HZ SIGNAL MATCHES VANEPASS OF FAN PUMP

# How does vanepass vibration on pump in basement show up on roll on 1st floor?




1:FAN PUMP GENERATES PRESSURE PULSATIONS AT RPM TIMES NO. OF VANES.

2: MATERIAL IS UNEVEN FROM PULSES

3: VACUUM ROLL PULLS DOWN ON FELT.

4: TENSION VARIES IN FELT

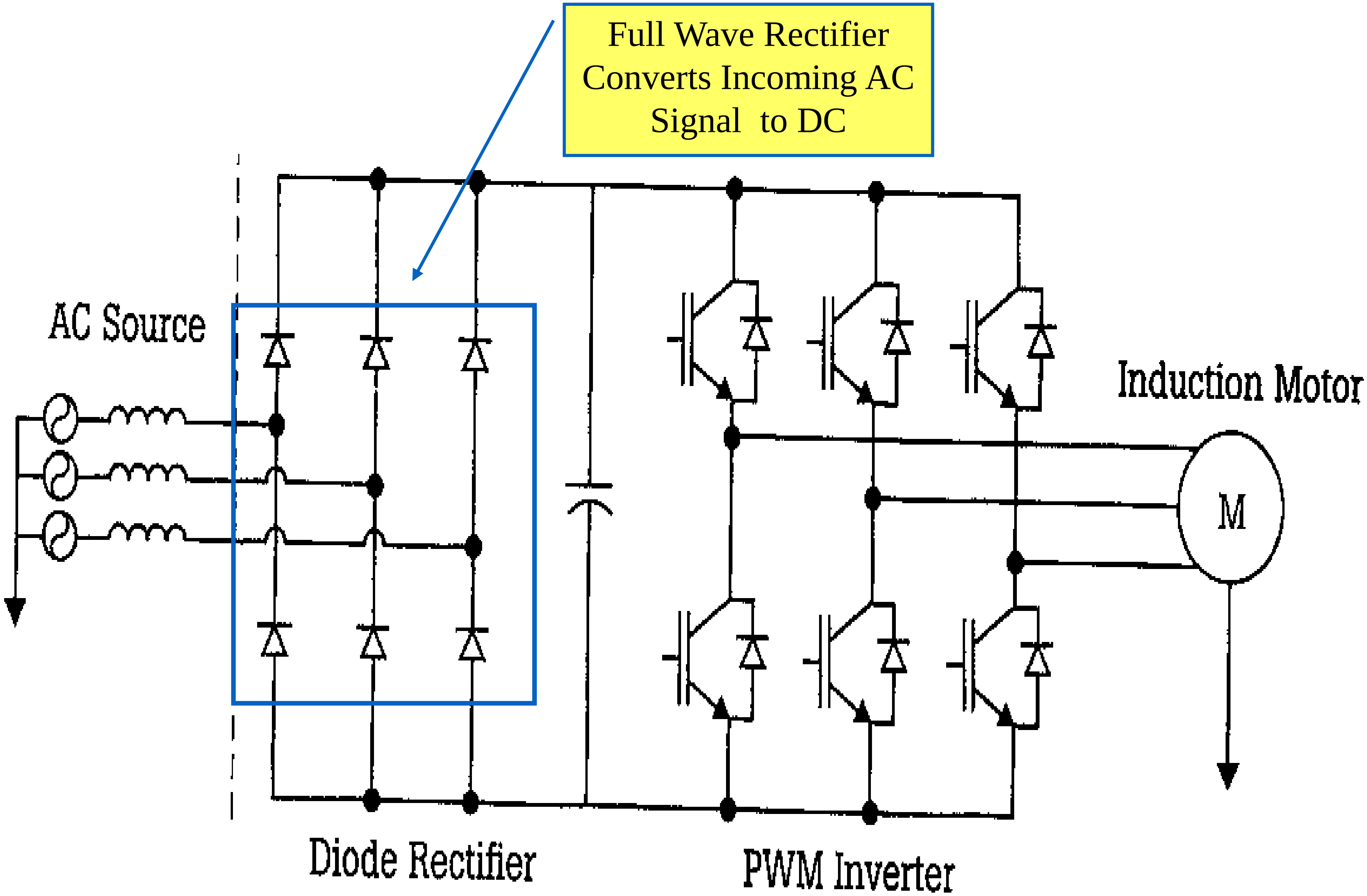
5: DRIVE ROLL VIBRATES AT VANE PASS DUE TO CHANGES IN TENSION AND MOTOR CURRENT VARIES AT SAME RATE.

# Variable Frequency Drives

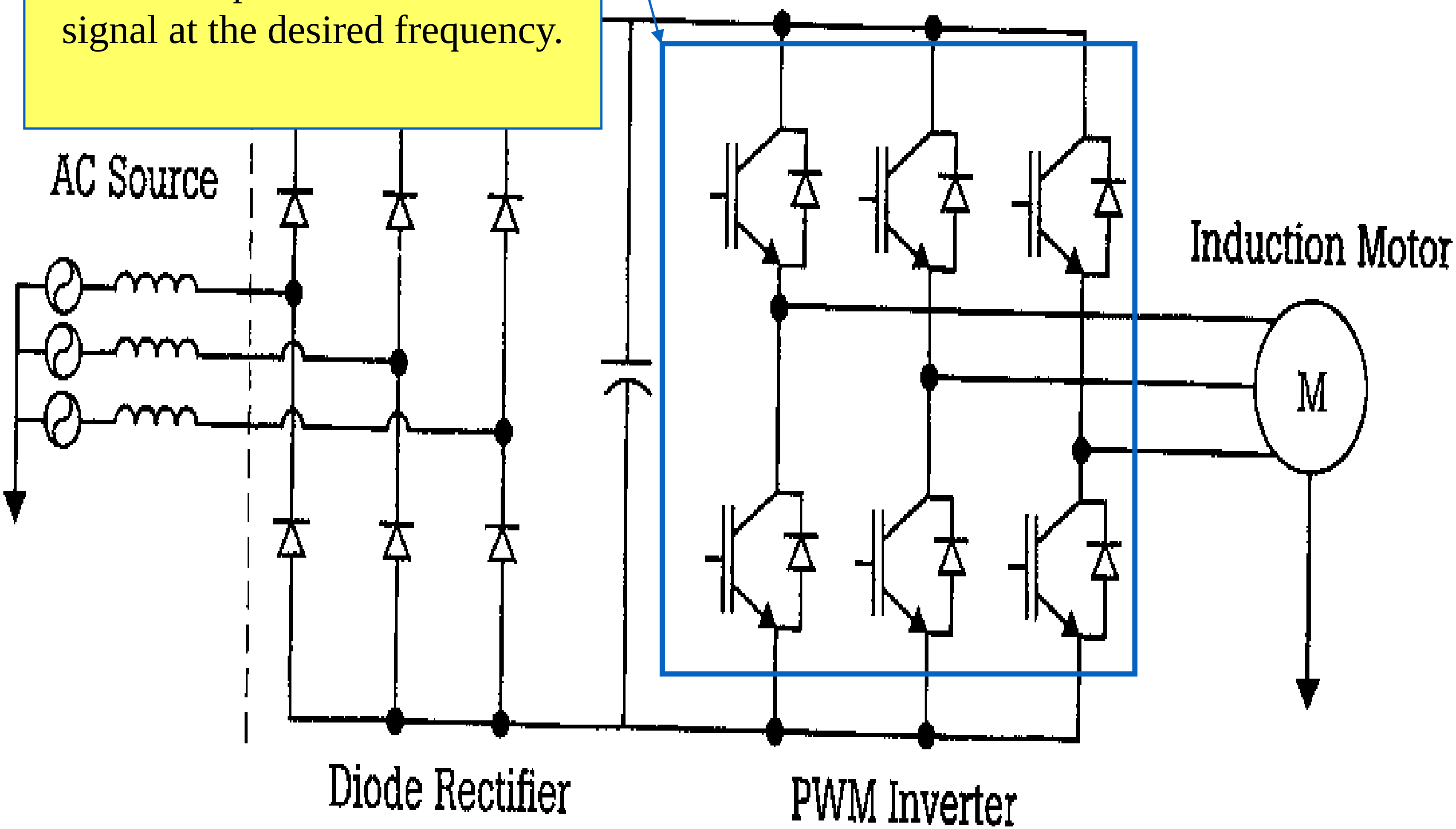
Variable Frequency Drives Control the speed by Varying the Frequency

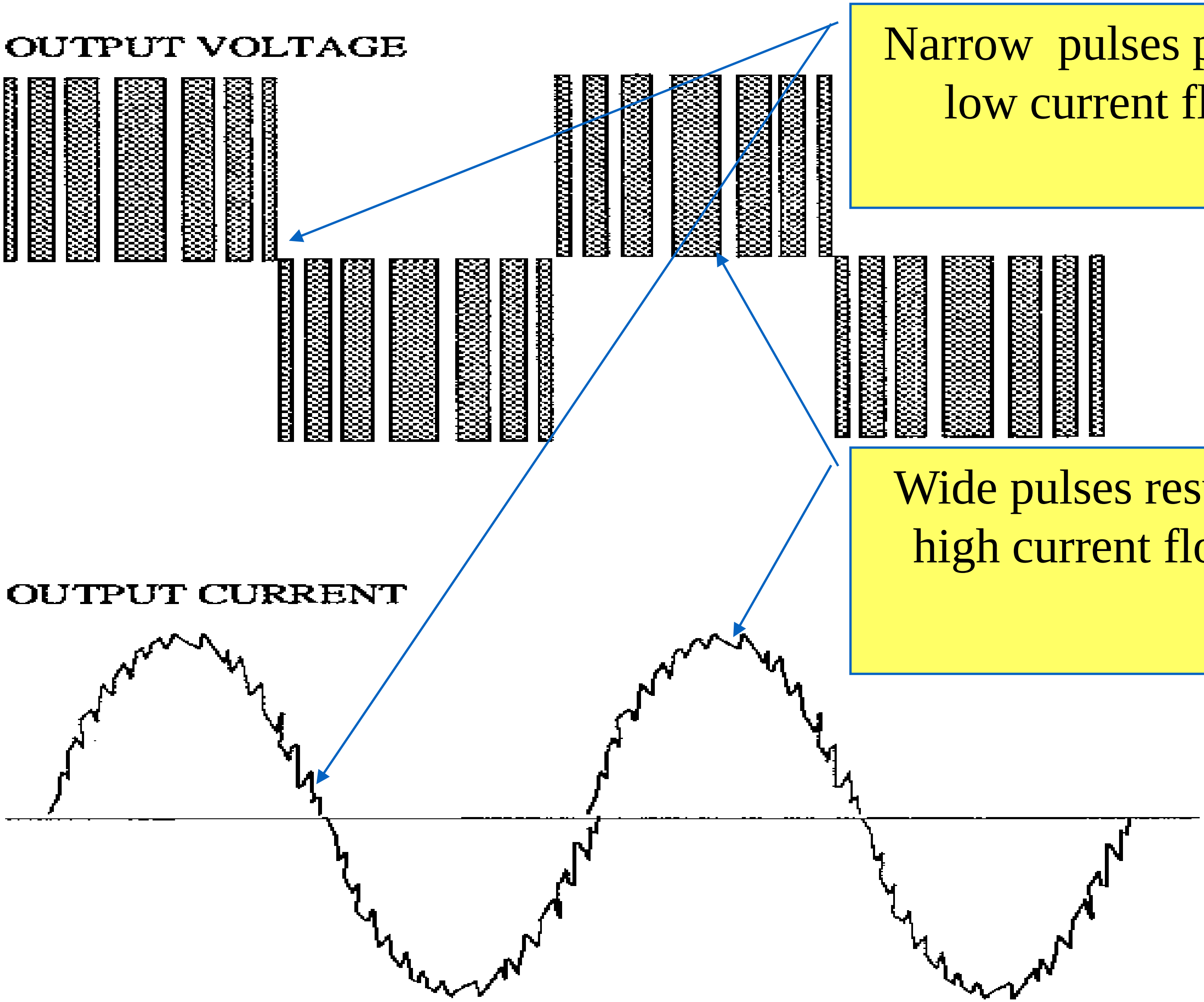
The RPM=120 X Frequency/No. Poles

# How Does a VFD (Variable Frequency Drive Work?


Full Wave Rectifier
Converts Incoming AC
Signal to DC
AC Source
Induction Motor
M
Diode Rectifier
PWM Inverter

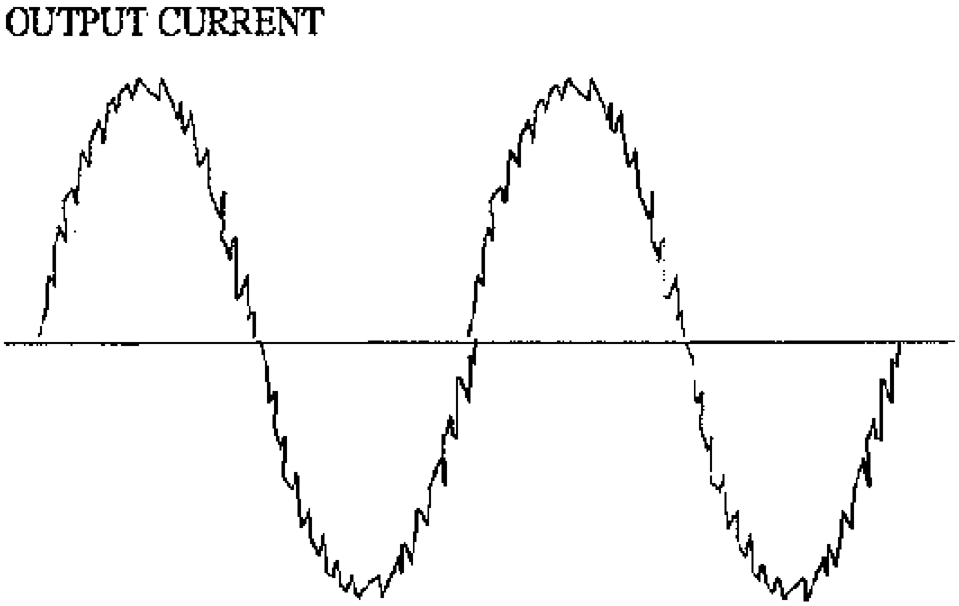
The Inverter section of the VFD by rapidly switching the current on an off produces a new AC signal at the desired frequency.




OUTPUT VOLTAGE
Narrow pulses produce low current flows
Wide pulses result in high current flows.
OUTPUT CURRENT

From the previous slide it can be seen that a variation (Modulation ) in the amount of time the signal is left on
(Pulse Width) is what produces the AC signal. This type of frequency converter is therefore referred to as a Pulse Width Modulated (PWM) inverter.

Note that the output current is not a pure sine wave.



With higher switching speeds and filters, the output signal from an inverter can be made to more closely approximate a Sine wave. This results in quieter and more efficient operation.

Herein lies a contradictory problem.
Faster switching speeds increase efficiency and lower noise. However, the down side to faster switching speeds is the increased likelihood of producing voltage spikes.

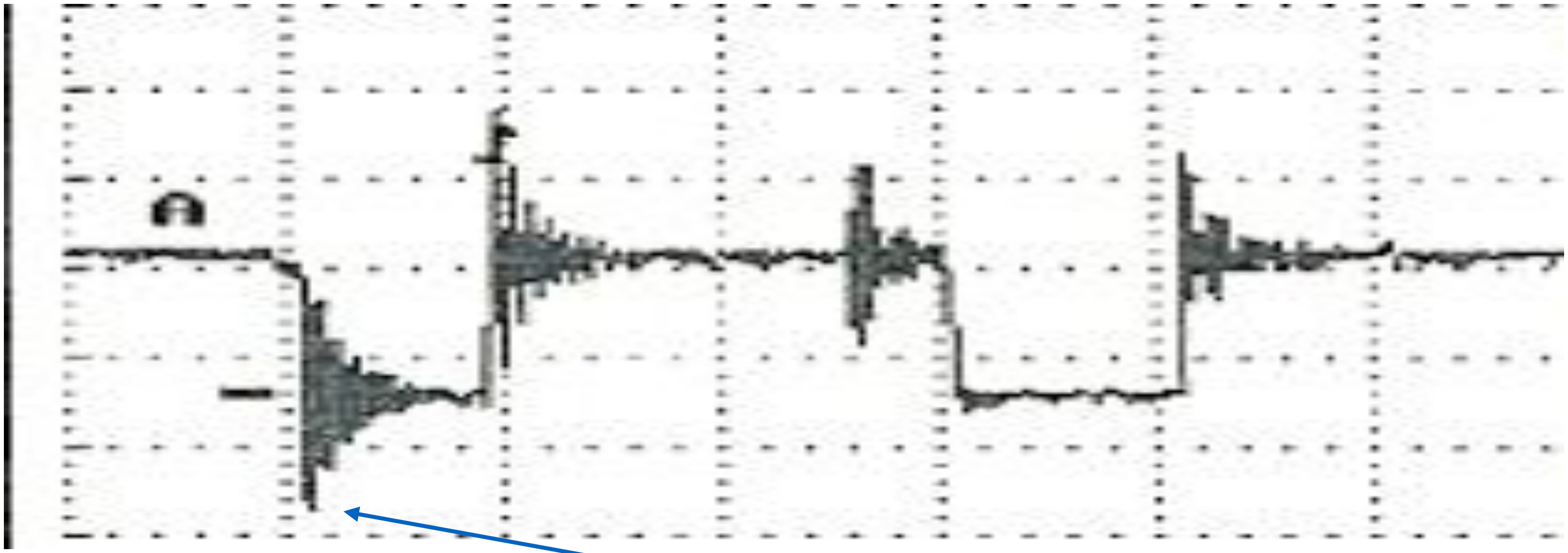
These voltage spikes produce levels much higher than what are seen on an ordinary across the line motor. Even a small nick in the insulation can cause failure in a VFD application.

## The voltage produced is described by the following equation.

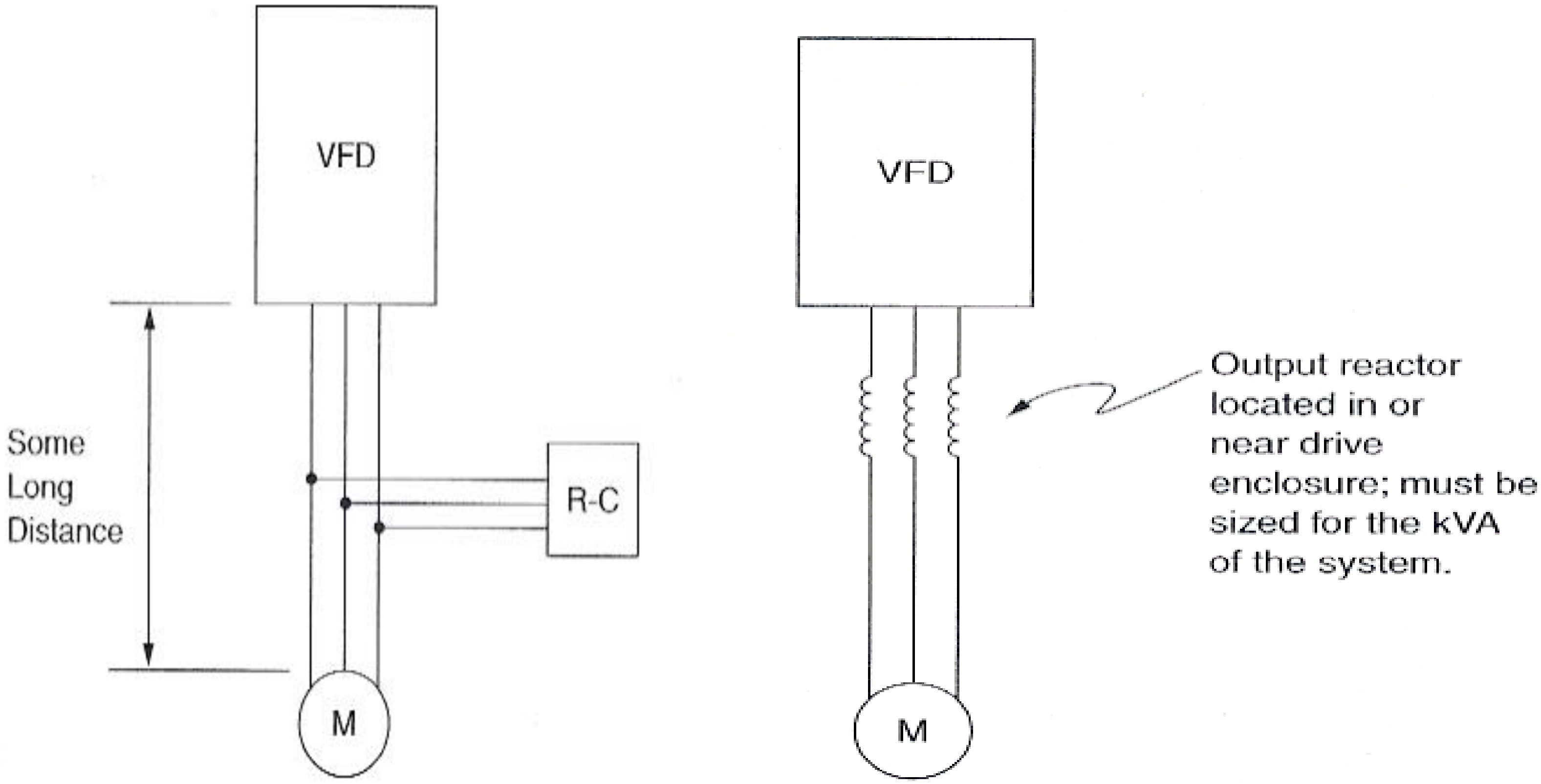
$$V = L\frac{d\Phi}{dt}$$

L is the inductance and is dependent upon the length of the line between the VFD and the motor. The other component is dependent upon the rate of the switching speed.

# The plot below shows the overshoot of a reflected signal.



Note that reflected voltage is nearly twice the amplitude of original square wave.




Either an RC circuit or a reactor can be utilized to reduce the aforementioned voltage spikes.

Damage to motor windings is just one of the problems that can be introduced by Variable Frequency Drives.

1: Line length is a factor in voltage spikes. Rapid switching of inverters causes voltage spikes that can be amplified by longer line lengths

2: Solutions to minimize bearing failures that result from VFD problems.

A: Lower the firing frequency of the inverter The switching speed is a critical factor in regards to VFD drive problems. "When VFD drives were first introduced in the eighties, there were few field problems. The carrier frequencies were generally below 2.5 kHz. As the switching frequencies increased, the number of problems also went up

B: Keep the line length between the inverter and the motor as short as possible.

C: Insulate bearings- Both bearings need to be insulated. In addition, the coupling must also be insulated or the current can travel through the coupling to the driven unit's bearings and then to ground.

D: Shaft Grounding- Grounding the shaft with carbon brushes allows the potential to travel to ground. The problem with this approach is that brushes need to be maintained. If the brushes wear out, then the current will again start flowing through the bearings.

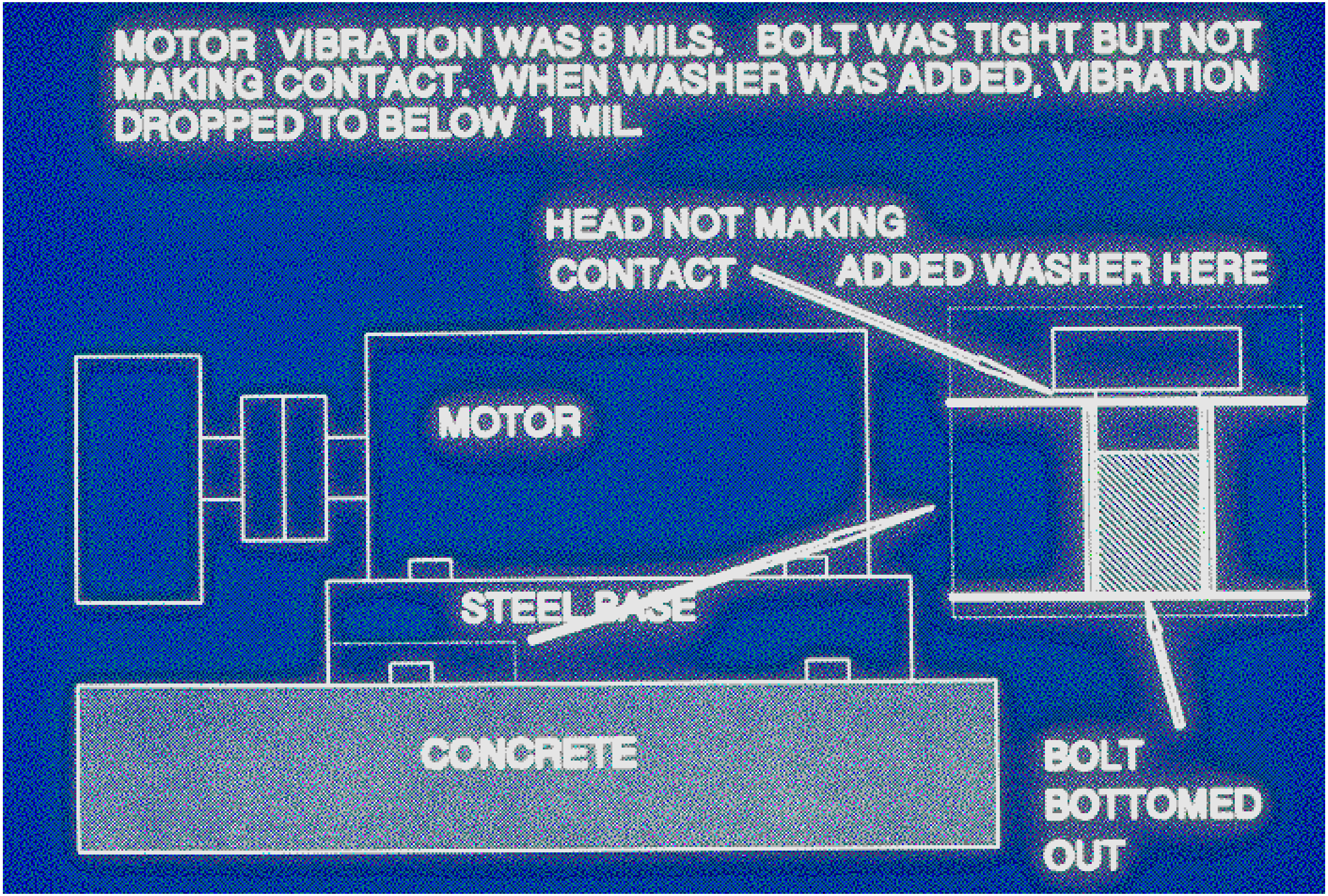
E: Conductive grease- Conductive grease allows the current to drain off rather than building up to a destructive potential. The downside to conductive grease is that it has been reported that bearing life is not as long as with standard grease.

F: Ceramic Bearings- Since ceramic bearings are nonconductive, they are another method of achieving electrical isolation between the rotor and the frame. Do not forget to insulate the coupling.

G: Output filters- These devices filter out the unwanted high order harmonics.

H: Isolation Transformers- "An isolation transformer with a delta primary and a wye secondary will greatly reduce common mode voltages within a drive and motor system.

# MOTORS DON’T FORGET COMMON SENSE


MOTOR VIBRATION WAS 8 MILS. BOLT WAS TIGHT BUT NOT MAKING CONTACT. WHEN WASHER WAS ADDED, VIBRATION DROPPED TO BELOW 1 MIL
HEAD NOT MAKING CONTACT
ADDED WASHER HERE
MOTOR
STEEL BASE
CONCRETE
BOLT BOTTOMED OUT