A GEARBOX STORY

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ABSTRACT

• This story is about a mixer gearbox problem. The full story of:
  • what happened,
  • what we knew,
  • what we did not know
  • what we learned,
  • what we said was wrong
  • what was actually wrong
  • the probable root cause are all included.
The Beginning

• Abnormal low pitched sound coming from the agitator was reported by the department operator.
• This agitator (maybe 30 years old) had been relocated from another plant.
• It was not yet included in the machine health process but it soon was included.
• So no pervious measurements & no machine anatomy details were available.
• The complaint is abnormal noise.
• The first thing to do is to hear this abnormal noise.
• In hind sight – we should have recorded the noise.
• The relationship be airborne noise and vibration is not always straightforward.
SEE & HEAR

• The gearbox was mounted on top of an agitator tank about 18 feet from the floor.
• After climbing the ladder we step onto a small platform. Access to the gearbox is limited to the motor, input area, and a part of the right side. The output shaft area is not accessible.
• The abnormal noise was a bit scary.
The gearbox is up the ladder.
WHAT WE KNEW

• The photos show almost all we knew at this point.
• AC motor at “constant speed” (nominal 1770 RPM) drives the gearbox via a “LOVEJOY” coupling.
• The nameplate data on the gearbox gave the ratio as 31.4:1.
WHAT WE KNEW ABOUT THE GEARBOX AT THIS STAGE
First Measurements 10/8/2003

- P1H Motor opp end Horizontal
- P2V Motor drive end Vertical
- P2A Motor drive end Axial
- P3A Gearbox input Axial
- P3V Gearbox input Vertical
- P4H Top of Gearbox Horizontal on the side
P1H Motor opp end Horizontal

CURSOR @ 1770 CPM

LEGEND SPEED: 1789 FROM LATER MEASUREMENTS
P2V Motor drive end Vertical

Highest peak @ 5370 CPM (which we now know was 3X motor)
1. Alignment is bad on the motor gearbox. To be safe and thorough, the motor and coupling will be replaced, then aligned on 10/11. Cursor resolution = 7.5 CPM.

P2A Motor drive end Axial
P2A Motor drive end Axial
CURSOR @ 3532.5 CPM
• P4H Top of Gearbox Horizontal on the side
1= P1H, 2= P2V, 3= P2A, 4= P3A, 5= P3V, 6= P4H

CURSOR @ “2X”
“First Repair”

• First measurements were on Thursday.
• Next maintenance window was that weekend, and maintenance was booked.
• Based on the unknown machine history & indication of misalignment, the maintenance manager decided to have the motor changed and a laser alignment performed, by Dusty.
P2 AXIAL BEFORE
MOTOR REPLACEMENT & ALIGNMENT

PEAK @ 5370 CPM is
ALMOST GONE

“2X” is STILL THERE
Now What?

- Assume the new motor is good & we know the alignment is good- Dusty did it.
- The problem noise is still with us.
- Another similar machine was tested & exhibited none of these problems.
- When the motor was changed, tape was put on the gearbox input shaft. So now we have “exact” shaft speed.
Was it “2X”? 

- The exact speed showed it was close to “2x” but no cigar.
- Examination of the spectra with the exact speed with the frequency axis in orders shows how close it was.
- Was there a 1X or just close to 1X?
ORDERS SHOWN ON PEAKS ARE INTERPOLATED VALUES
INSIDE THE GEARBOX

• The parts book for the gearbox contained a lot of useful information BUT not the number of teeth on the gears.
• The gearbox ratio is 31.4:1.
• Input of 1789 rpm = 56.97 rpm output.
• There are two gear sets: input pinion & gear and output pinion & ring gear.
• The output shaft is connected to the ring gear.
NOTE: BEFORE INSTALLATION CHECK INSTALLATION AND SERVICE INSTRUCTIONS MAILED UNDER SEPARATE COVER FOR FURTHER INFORMATION.
GEAR TEETH

• Two of the gears were in plant spares.
• Another gear was located in storage.
• The teeth were counted.
• A call to the gearbox distributor yielded the “number of teeth” on the remaining gear.
• Calculation of the ratio using these numbers DID NOT match the gearbox ratio.
Gear Teeth Calculation

- Using the gearbox ratio from the nameplate (31.4:1) and tooth count from the gears on hand, the teeth on the remaining gear was calculated.
- A mechanical schematic was drawn.
GEAR FREQUENCIES

X = motor speed
Gear set 1: GT1=16 GT2=81
GMF1 = GT1x X = 16X
GS1 = X   GS2 = GMF1/GT2 = 16X/81
Na1 = 1 (common factor for gear set 1)
GAPF1 = GMF1/Na1 = GMF1
Fht1 = ((16X)x(1))/((16)x(81)) = X/81
Tht1 = 1/Fht1 = 81/X
Gear Set 2

- GT3 = 10 teeth GT4 = 62 teeth
- GS3 = GS2 = X/81
- GMF2 = \((16X/81) \times 10) = 160X/81 \approx 1.97531X\) close to 2X!
- GS4 = GMF2/GT4 = \((160X)/(81 \times 62)\)
- GS4 \approx 0.03186 X
- Na2 = 2
Gear Set 2 Cont 1

- GAPF2 = GMF2/Na2
- GAPF2 = ((160X/81)/2) = 80X/81
- GAPF2 = 0.98765X close to 1X!
- 2GAPF = 1.9752X
- Fht2 = 16X/(81x31) ~ 0.00627X
- Tht2 = 1/Fht2 = (81x31)/16X ~ 159.468/X
Bearings

• We did not forget the bearings.
• The bearings were identified
• Bearing fault frequencies were included in the frequency set up in the software.
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PLOT INDICATES THE PROBLEM IS GEAR SET 2
Gear Set 2

- The plot shows “alignment” of major peaks with gear set 2 frequencies.
- GAPF2 and harmonics are evident.
- \[ \text{GMF2} = \left(\frac{16X}{81}\right) \times 10 = \frac{160X}{81} \approx 1.97531X \text{ close to } 2X! \]
- \[ \text{GAPF2} = 0.98765X \text{ close to } 1X! \]
- \[ 2\text{GAPF} = 1.9752X \]
- Note 2\text{GAPF} \sim \text{GMF2}
So We Said

• Gear set 2 (ring & pinion) have excessive wear.
• Change the gearbox.
• The gearbox was changed.
BEFORE GBX CHANGE

MMA-14004 LF
GEARBOX OUTPUT
4top/gb
Horizontal
ips
21.6vd
Band Overall: 11456
Peak Amp: 0.9656975
Sync: 0.9930253
SubSync: 0.98656087
NonSync: 0.954405

AFTER GBX CHANGE

MMA-14004 LF
GEARBOX OUTPUT
4top/gb
Horizontal
ips
21.6vd
Band Overall: 0.3777181
Peak Amp: 0.0122427
Sync: 0.9258173
SubSync: 0.0084341
NonSync: 0.0281724

BEFORE GBX CHANGE

REFINING
MMA-14004 LF
Position: 4top/gb
Speed: 56.
Direction: Horizontal
10/15/2003 12:11:04 PM

AFTER GBX CHANGE

REFINING
MMA-14004 LF
Position: 4top/gb
Direction: Horizontal
10/22/2003 12:25 PM

P 4 H
Results 1

- The gearbox change solved the original problem. So the recommended maintenance action was correct.
- The gearbox was indeed bad – it was not economical to repair & was scrapped.
- BUT the gears appeared to be OK.
- The lower output shaft bearing rotating parts were rusty – they had not been in contact for some time.
Results 1 Cont

• When the rotating parts in a bearing do not contact, they can not generate the bearing frequencies.

• Over time the lack of lubrication caused the bearing components to wear so they lost contact.

• This bearing is grease lubricated and the shaft seals are supposed to protect the bearing.
Digging Deeper

• This unit had a small trapped air space between the bottom of the gearbox and the top of the mixer tank. Apparently, hot vapors from the tank caused the bottom gearbox seal to fail exposing the lower output shaft bearing to hot vapor. The result was deterioration of the grease (assuming there was grease to start with).
What we should have said

• 1. Gear set 2 has a severe meshing problem.
• 2. Replace the gearbox.
• Well we got number 2 right.
The Second Gearbox

- The first replacement gearbox lower output shaft bearing was not greased prior to installation on 10/18/2003 (this was a surplus gearbox from another plant).
- This lack of grease was discovered on 2/2/2004 and the bearing was greased.
- On 2/9/2004 this gearbox was replaced because it had run 3 months without grease in the lower bearing.
Support Structure Modification

• During the 2/9/2004 work the support structure under the gearbox was opened to allow the hot vapors to vent.

• The gearbox has *purred* ever since.
What we learned

• Grease the bearings.
• Make sure you have enough frequency resolution to sort out frequencies.
• Take the time to build a machine anatomy database.
• Dig deep until the “real” problem is found.
• Replacing heavy gearboxes located high off the floor should not be a habit.
LAST PLANNED SLIDE

• Thank you for your patience.

• Are there any questions?
GEAR FREQUENCIES

• Let $X =$ input shaft speed (motor speed in this case)
• Gear set 1:
  • $G_1$(input gear has 16 Teeth) $GT_1=16$
  • $G_2$(output gear has 81 Teeth) $GT_2=81$
  • $GMF_1= GT_1 \times X= 16X$
  • $GS_1= X \quad GS_2 = GMF_1/GT_2 = 16X/81$
Gear Set 1 cont 1

- $16 = 2 \times 2 \times 2 \times 2$
- $81 = 3 \times 3 \times 3 \times 3$
- $Na_1 = 1$ (common factor for gear set 1)
- $\text{GAPF}_1 = \frac{\text{GMF}_1}{Na_1} = \text{GMF}_1$
- $F_{ht1}$ = hunting tooth frequency of set 1
- $F_{ht1} = \frac{((\text{GMF}_1)\times(\text{Na}_1))/((\text{GT}_1)\times(\text{GT}_2))}{(16X)\times(1))/((16)\times(81)) = X/81}$
• Tht1 = period of the hunting tooth
• Tht1 = 1/Fht1 = 81/X
• Tooth matching occurs every 81 revs of GT1 (16 tooth gear) and every 16 revs of GT2 (81 tooth gear)
• 81 x 16 = 1296
• So tooth matching occurs as every 1296 teeth pass
Gear Set 2

- GT3 = 10 teeth
- GT4 = 62 teeth
- GS3 = GS2 = X/81
- GMF2 = ((16X/81)x(10)) = 160X/81 ~ 1.97531X close to 2X!
- 10 = 2 x 5
- 62 = 2 x 31
- Na2 = 2
• $Tht_2 = \frac{1}{Fht_2}$
• $Tht_2 = \frac{81 \times 31}{16X} \approx \frac{159.468}{X}$
• Recall the factoring of the gear teeth #’s
• $10 = 2 \times 5$
• $62 = 2 \times 31$ The common factor is 2.
• Tooth matching can be found by multiplying the uncommon of one gear by the number of teeth on the other gear.
• GAPF2 = GMF2/Na2
• GAPF2 = ((160X/81)/2) = 80X/81
• GAPF2 = 0.98765X close to 1X!
• 2GAPF = 1.9752X
• Fht2 = ((GMF2)x(Na2))/((GT3)x(GT4))
• Fht2 = ((160X/81)x(2))/((10)x(62))
• Fht2 = 16X/(81x31) ~ 0.00627X
Gear Set 2 Cont 3

• $10 = 2 \times 5 \quad 62 = 2 \times 31$
• $10 \times 31 = 310 = 62 \times 5$
• So tooth matching occurs at the passing of 310 teeth or
• 31 revs of the 10 tooth gear
• 5 revs of the 62 tooth gear
Gear Set 2 Cont 1

- \( \text{GAPF2} = \frac{\text{GMF2}}{\text{Na2}} \)
- \( \text{GAPF2} = \frac{((160X/81)/2)}{} = \frac{80X}{81} \)
- \( \text{GAPF2} = 0.98765X \) close to 1X!
- \( 2\text{GAPF} = 1.9752X \)
- \( \text{Fht2} = \frac{((\text{GMF2})\times(\text{Na2}))}{((\text{GT3})\times(\text{GT4}))} \)
- \( \text{Fht2} = \frac{((160X/81)\times(2))}{((10)\times(62))} \)
- \( \text{Fht2} = \frac{16X}{(81\times31)} \sim 0.00627X \)
Gear Set 2 Cont 3

- $10 = 2 \times 5 \quad 62 = 2 \times 31$
- $10 \times 31 = 310 = 62 \times 5$
- So tooth matching occurs at the passing of 310 teeth or
- 31 revs of the 10 tooth gear
- 5 revs of the 62 tooth gear
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