BALL MILL GEARBOX PROBLEM

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BACKGROUND INFORMATION & OBSERVATIONS:

- Concern was expressed over the gearbox and Ball Mill at a power plant.
- Black grease was noticed at the coupling-end pillow block bearing as well as a loose bearing nut.
- Unusual noises were also reported from the machine.
- The gearbox between motor & ball mill had been recently rebuilt.
- Two identical ball mills were in place at the plant (1A & 1B).
- These machines are used to pulverize or crush lime into small particles (dust) that is then made into a slurry and injected into the flue gases to reduce pollution. Hundreds of steel balls rolling with the slow turning mill act to effectively crush the lime.

Photo Of Ball Mill

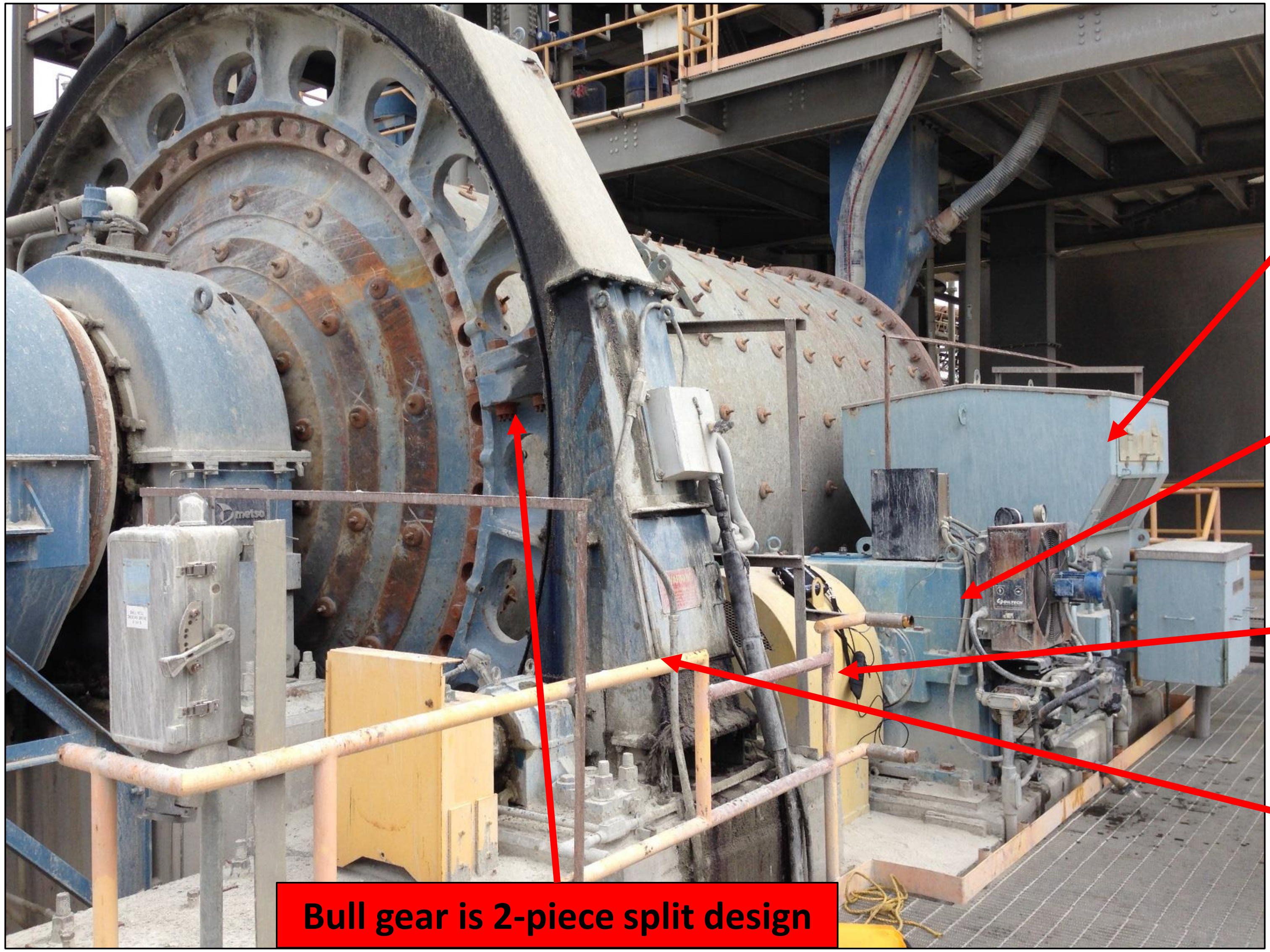


TABLE 1 - BALL MILL SHAFT SPEEDS, EXPECTED FORCING & FAULT FREQUENCIES

BALL MILLS, FORCING FREQUENCIES (CPM)						
SHAFT SPEEDS	1X RPM					
MOTOR SPEED	1,191					
BALL MILL PINION SPEED	226					
BALL MILL GEAR SPEED	18					
GEARBOX (Between Motor & Ball Mill)	NB	FTF	BSF	2X BSF	BPFO	BPFI
INPUT BRGS, SKF#22330	15	491	3,192	6,384	7,358	10,507
OUTPUT BRGS, SKF#22240	19	97	783	1,566	1,848	2,446
GEARBOX GEARMESH FREQ	22,629	19				
Gearbox Pinion Tooth Count	19					
Gearbox Bull Tooth Count	100					
BALL MILL						
PILLOW BLOCK BEARINGS, SKF#23240	19	98	803	1,607	1,858	2,436
BALL MILL GEARMESH	4,068					
Ball Mill Pinion Tooth Count	18					
Ball Mill Bull Tooth Count	226					

EVALUATE GEAR RATIOS (A REVIEW OF FACTORING)

From “The Gear Analysis Handbook” by Mr. James Taylor we read the following:

- “Evaluation of the gear tooth ratios can be accomplished by factoring the number of teeth on each gear and determining the greatest common factor” (GCF).
- “An ideal set of gears does not have any common factor other than 1”.
- “When one is the only common factor between the two gears, a tooth on one gear must mesh with all of the teeth on the other gear before the same two teeth mesh again. This ensures relatively even wear on each tooth”.
- “When the number of teeth on each gear has a common factor other than 1 (improper gear set), a tooth on one gear will mesh with every Nth tooth on the other gear where N is the greatest common factor. When this occurs, every Nth tooth can become worn differently, the time signal of gearmesh frequency can be distorted and an FFT on the signal can produce fractional gearmesh frequencies”.
- *For an improper gear set, the negative effects from any defect or imperfection on any tooth of either gear will be focused on a fraction of the teeth on the meshing gear (negative effects not equally shared between all teeth).*

EVALUATE GEAR RATIOS (REVIEW FACTORING)

Prime numbers are numbers that are only divisible by themselves and one. Examples of prime numbers are as follows:

1, 3, 5, 7, 11, 13, 17, 19, 23, 29, etc.

Our **Gearbox** between the motor & ball mill has the following tooth counts:

Pinion 19 teeth → 1 x 19 (19 is a prime number)

Bull 100 teeth → 1 x 2 x 2 x 5 x 5

Thus, the factor common to both of these gears is only 1 (proper set).

EVALUATE GEAR RATIOS (REVIEW FACTORING)

Our **Ball Mill** has the following tooth counts:

Pinion 18 teeth → 1 x 2 x 3 x 3

Bull 226 teeth → 1 x 2 x 113 (113 is prime).

Thus, the factor common to both of these gears is 2 (improper set).

Since we have a common factor other than one between the two gears on the ball mill we can expect to see the appearance of fractional gearmesh frequency and harmonics in our vibration data.

In this case since the common factor is 2, we expect to see the appearance of 1/2x gearmesh and harmonics in our vibration data.

RELATING GEAR COMMON FACTORS TO EXPECTED GEAR LIFE

From “The Gear Analysis Handbook” by Mr. James Taylor we also read the following table relating gear common factors to gear life:

COMMON FACTOR	% OF LIFE EXPECTED
1	100
2	50
3	33
4	25
5	20
6	16
7	14

This table follows the formula as follows: % Gear Life Expected = 100/GCF

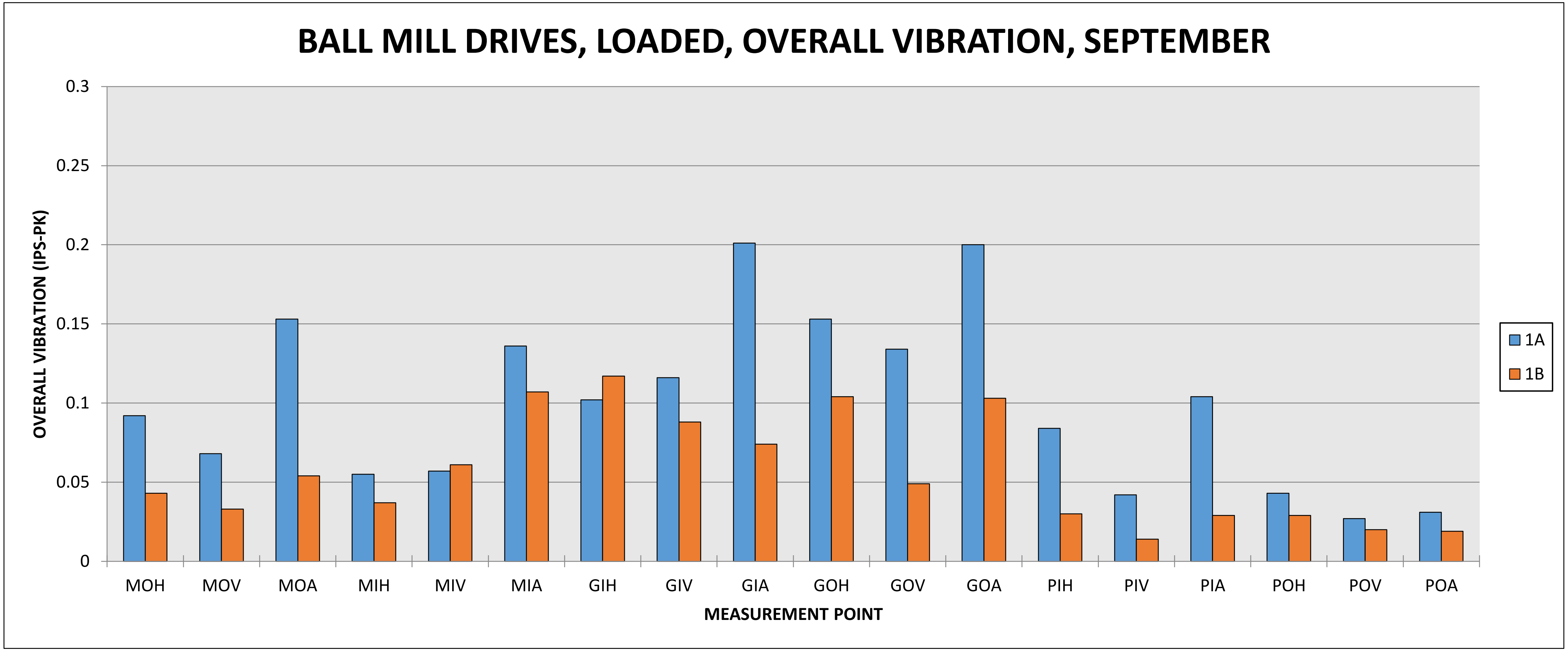
VIBRATION DATA:

- Vibration data was first collected from both 1A & 1B Ball Mill Drives under normal load (route vibration data).
- Additional vibration data was collected from the motor & gearbox of the 1A Ball Mill Drive under no load.
- To determine what problems (if any) existed with the drive, a comparison of the route vibration data between 1A & 1B Ball Mills was made as well as between loaded & unloaded data at 1A Ball Mill.
- Table 2 below shows the symbols & descriptions of each measurement point taken.

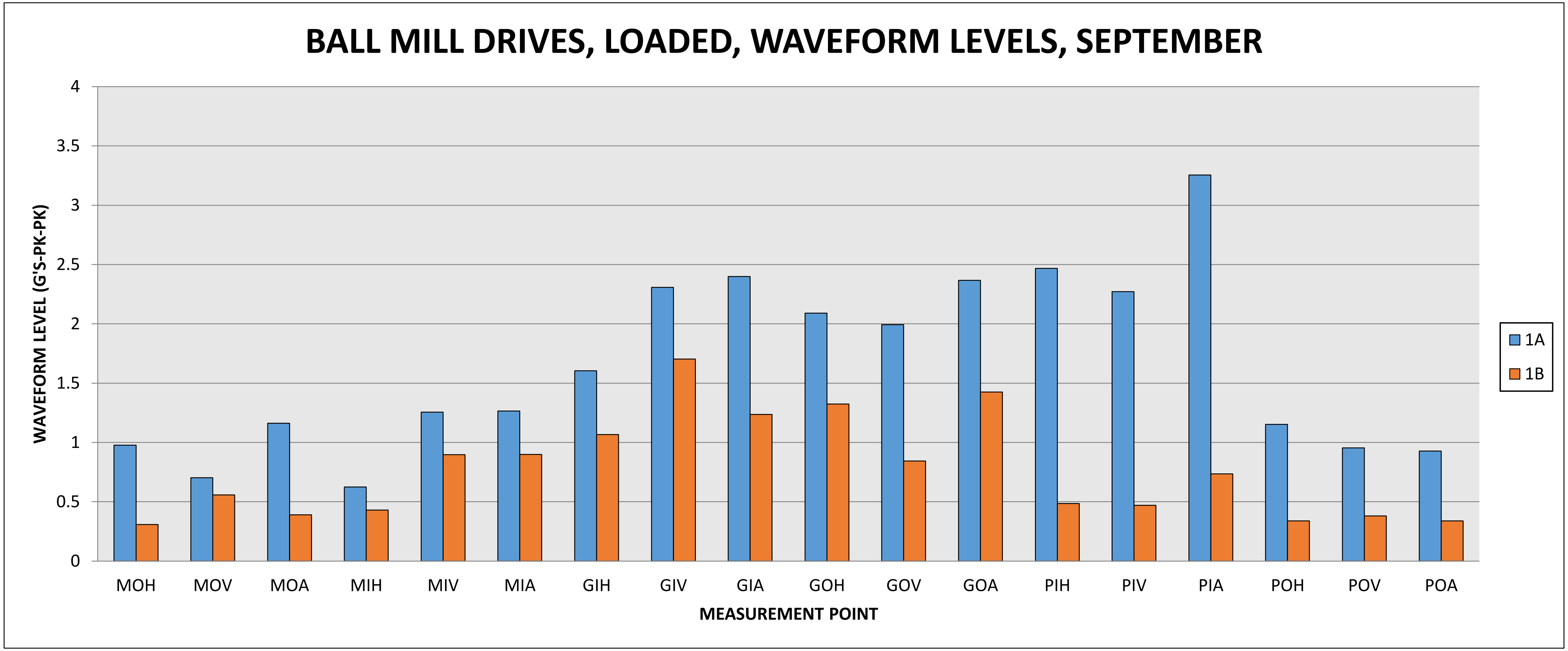
TABLE 2: MEASUREMENT POINT DESCRIPTIONS & SYMBOLS

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
MOH	MOTOR, OUTBOARD, HORIZONTAL	GOH	GEARBOX, OUTPUT, HORIZONTAL
MOK	MOTOR, OUTBOARD, PEAKVUE	GOK	GEARBOX, OUTPUT, PEAKVUE
MOV	MOTOR, OUTBOARD, VERTICAL	GOV	GEARBOX, OUTPUT, VERTICAL
MOA	MOTOR, OUTBOARD, AXIAL	GOA	GEARBOX, OUTPUT, AXIAL
MIH	MOTOR, INBOARD, HORIZONTAL	PIH	PILLOW BLOCK BEARING, INBOARD, HORIZONTAL
MIK	MOTOR, INBOARD, PEAKVUE	PIK	PILLOW BLOCK BEARING, INBOARD, PEAKVUE
MIV	MOTOR, INBOARD, VERTICAL	PIV	PILLOW BLOCK BEARING, INBOARD, VERTICAL
MIA	MOTOR, INBOARD, AXIAL	PIA	PILLOW BLOCK BEARING, INBOARD, AXIAL
GIH	GEARBOX, INPUT, HORIZONTAL	POH	PILLOW BLOCK BEARING, OUTBOARD, HORIZONTAL
GIK	GEARBOX, INPUT, PEAKVUE	POK	PILLOW BLOCK BEARING, OUTBOARD, PEAKVUE
GIV	GEARBOX, INPUT, VERTICAL	POV	PILLOW BLOCK BEARING, OUTBOARD, VERTICAL
GIA	GEARBOX, INPUT, AXIAL	POA	PILLOW BLOCK BEARING, OUTBOARD, AXIAL

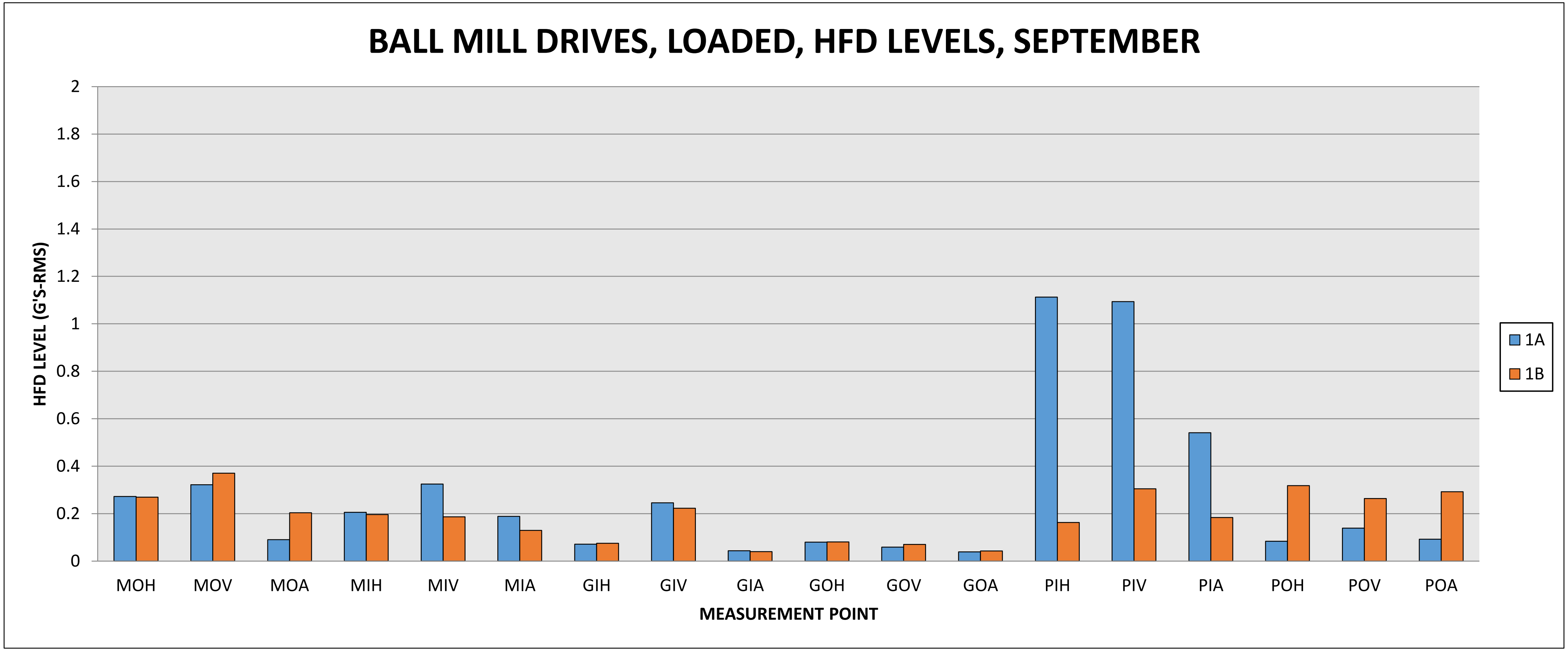
1A & 1B BALL MILLS,
COMPARE ROUTE VIBRATION DATA,
LOADED



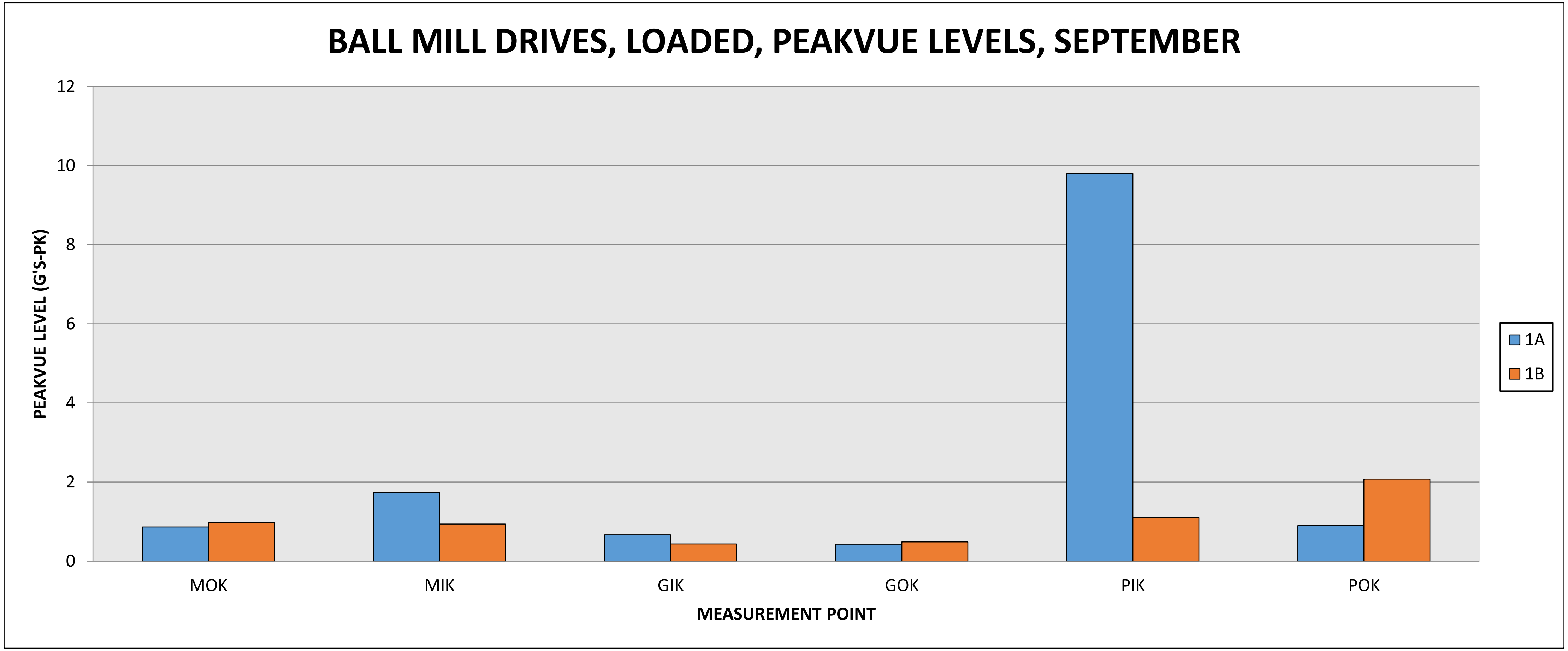
- Above is a plot of the overall vibration levels at both the 1A & 1B ball mills when loaded.
- Note how levels at 1A ball mill are higher than that at 1B ball mill for nearly every measurement.



- Above is a plot of the waveform vibration levels at both the 1A & 1B ball mills when loaded (acceleration).
- Note how waveform levels at 1A ball mill are higher than that at 1B ball mill for every measurement and especially at points PIH → PIA (pillow block, coupling-end bearing).

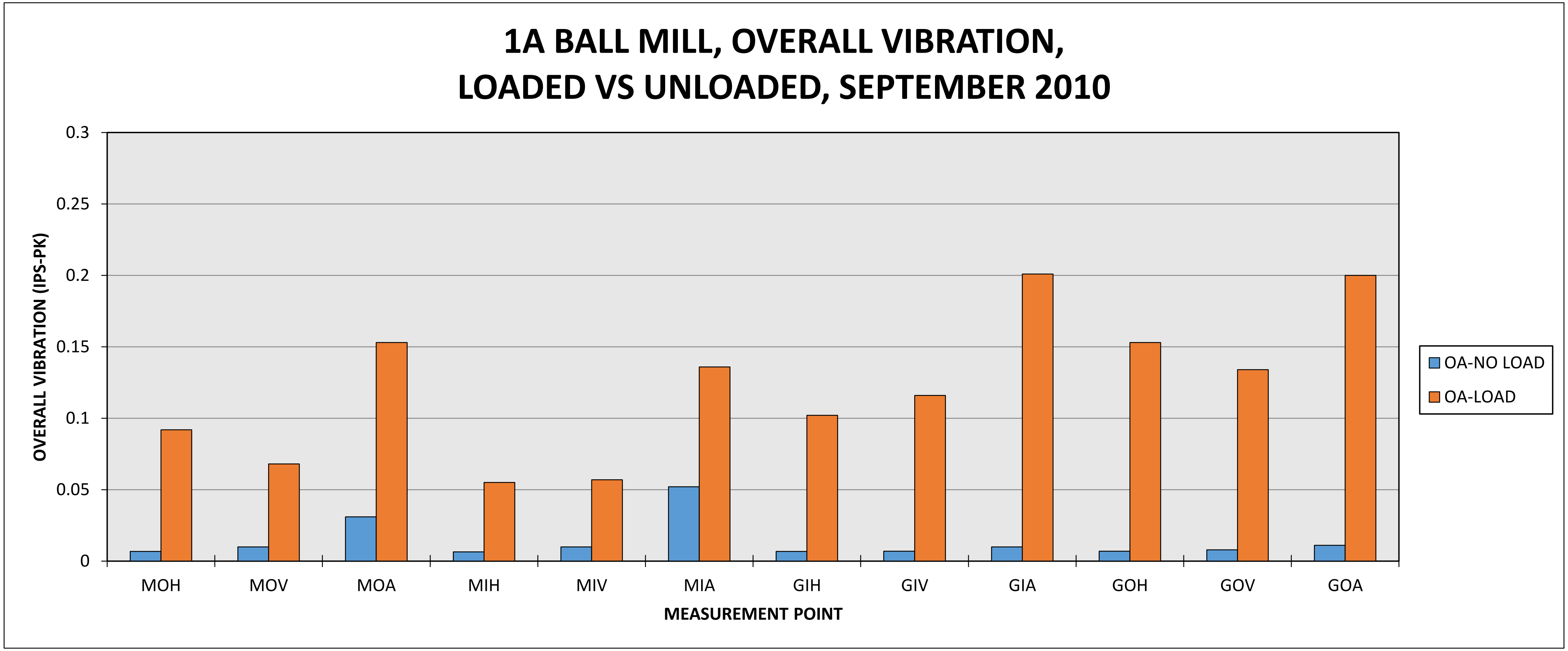


- Above is a plot of the high frequency HFD vibration levels at both the 1A & 1B ball mills when loaded (acceleration energy band from 2 to 20 kHz).
- Note how HFD levels at 1A ball mill coupling-end pillow block bearing (PIH → PIA) are much higher than that at 1B ball mill.

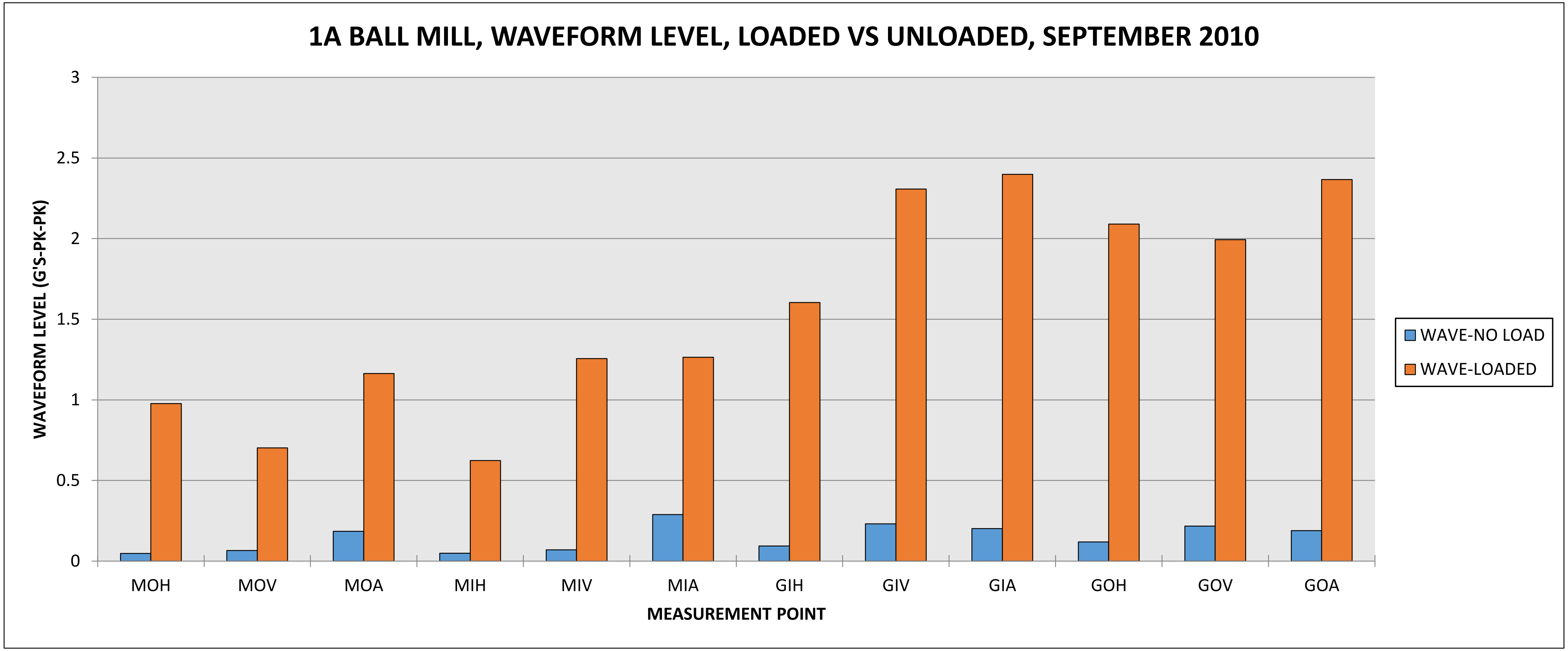


- Above is a plot of the high frequency Peakvue levels at both the 1A & 1B ball mills when loaded.
- Like the earlier HFD levels, note how the Peakvue levels at 1A ball mill coupling-end pillow block bearing (PIK) are much higher than that at 1B ball mill.

1A BALL MILL,
VIBRATION DATA,
LOADED .VS. UNLOADED

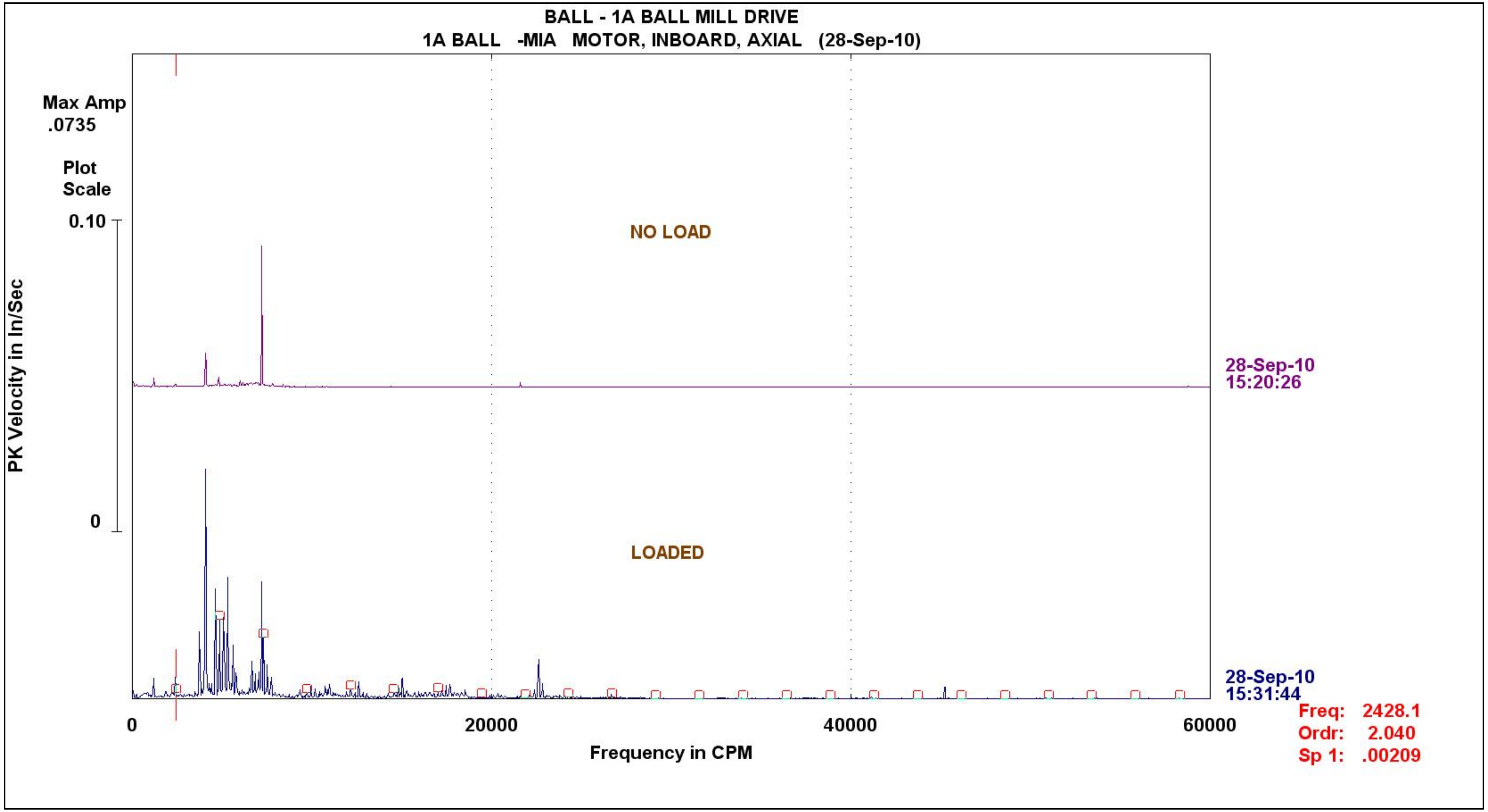


- Above is a plot of the overall vibration levels at 1A ball mill when loaded & unloaded.
- Note the significant difference that loading makes on vibration levels at this machine.
- The presence and absence of vibration at the ball mill gear-mesh frequency and multiples explain most of this difference between loaded & unloaded levels.



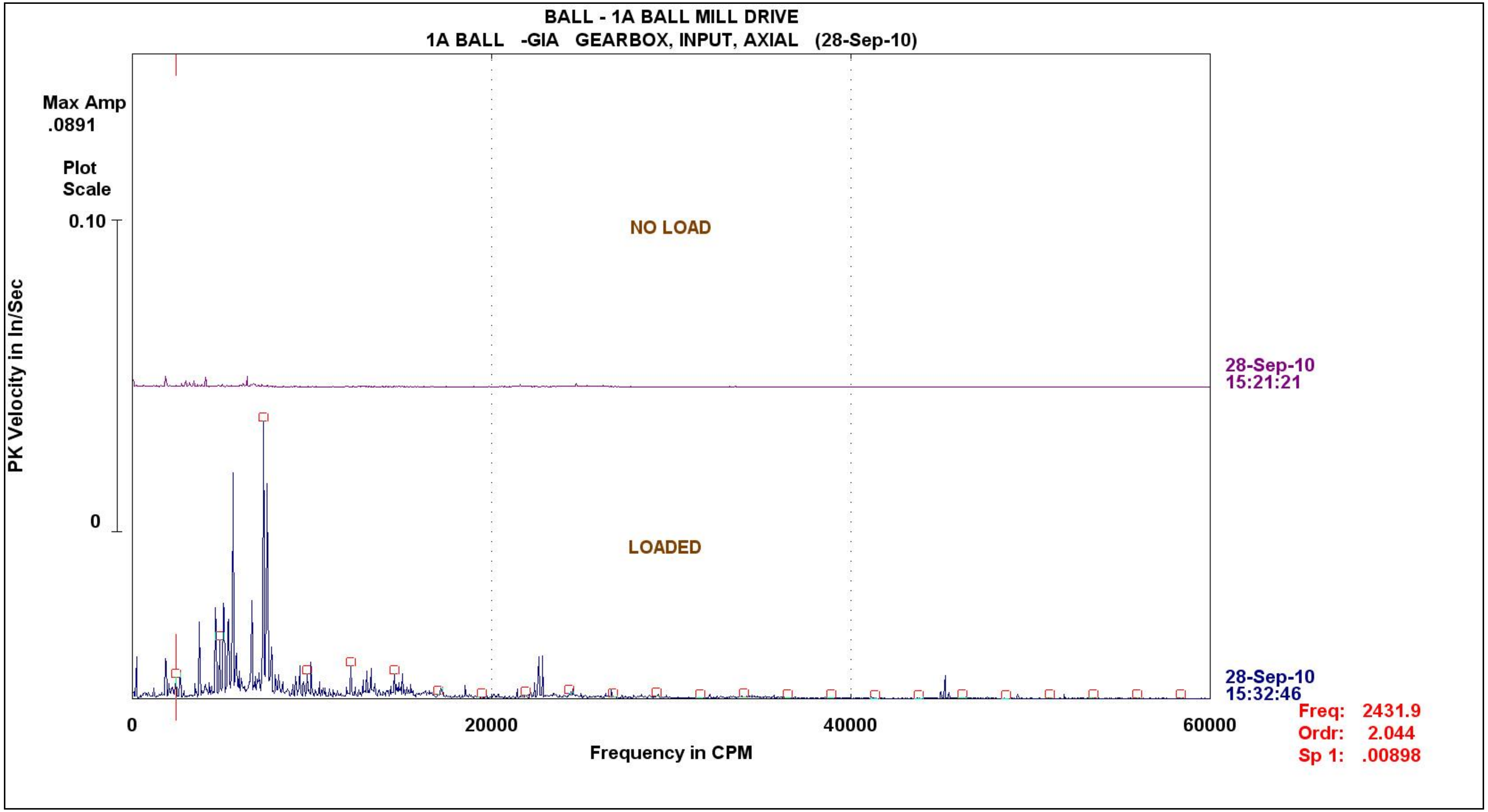
- Above is a plot of the waveform vibration levels at 1A ball mill when loaded & unloaded.
- Note the significant difference that loading makes on vibration levels at this machine.
- The presence and absence of vibration at the ball mill gear-mesh frequency and multiples explain most of this difference between loaded & unloaded levels.

BALL MILLS,
VIBRATION SPECTRAL DATA



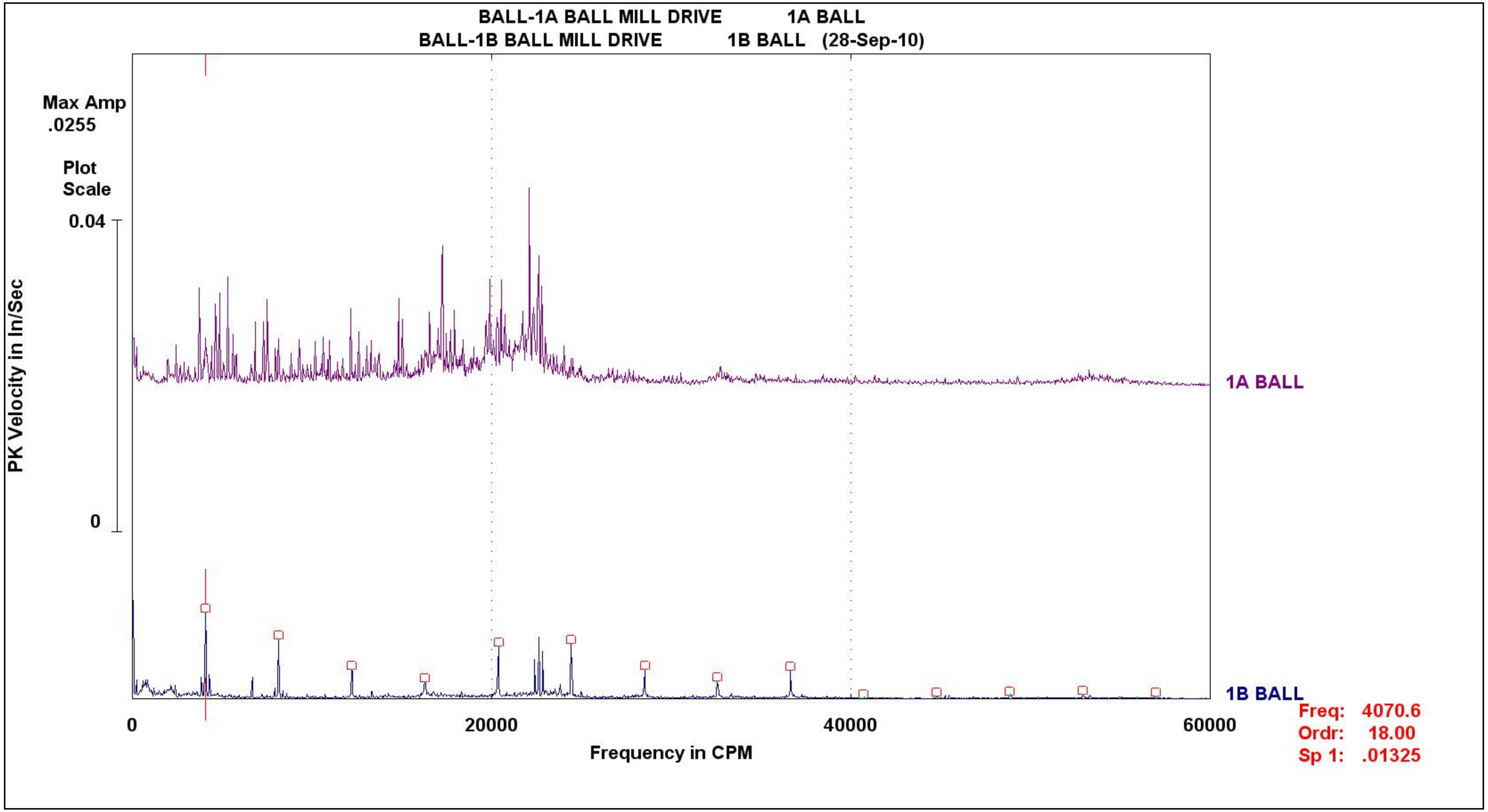
- As this motor operates on sleeve bearings, it is very doubtful that this vibration originates from the motor. It is much more likely being transmitted to the motor from the ball mill pillow block bearings.

- Above is spectral data from 1A ball mill when loaded & unloaded (motor, inboard, axial).
- Note how loading introduced much higher vibration levels composed of multiples of vibration at 2,428 cpm which is 10.74x the output speed of the gearbox (226 rpm) which is a perfect match for the inner race defect frequency of the pillow block spherical roller bearings.



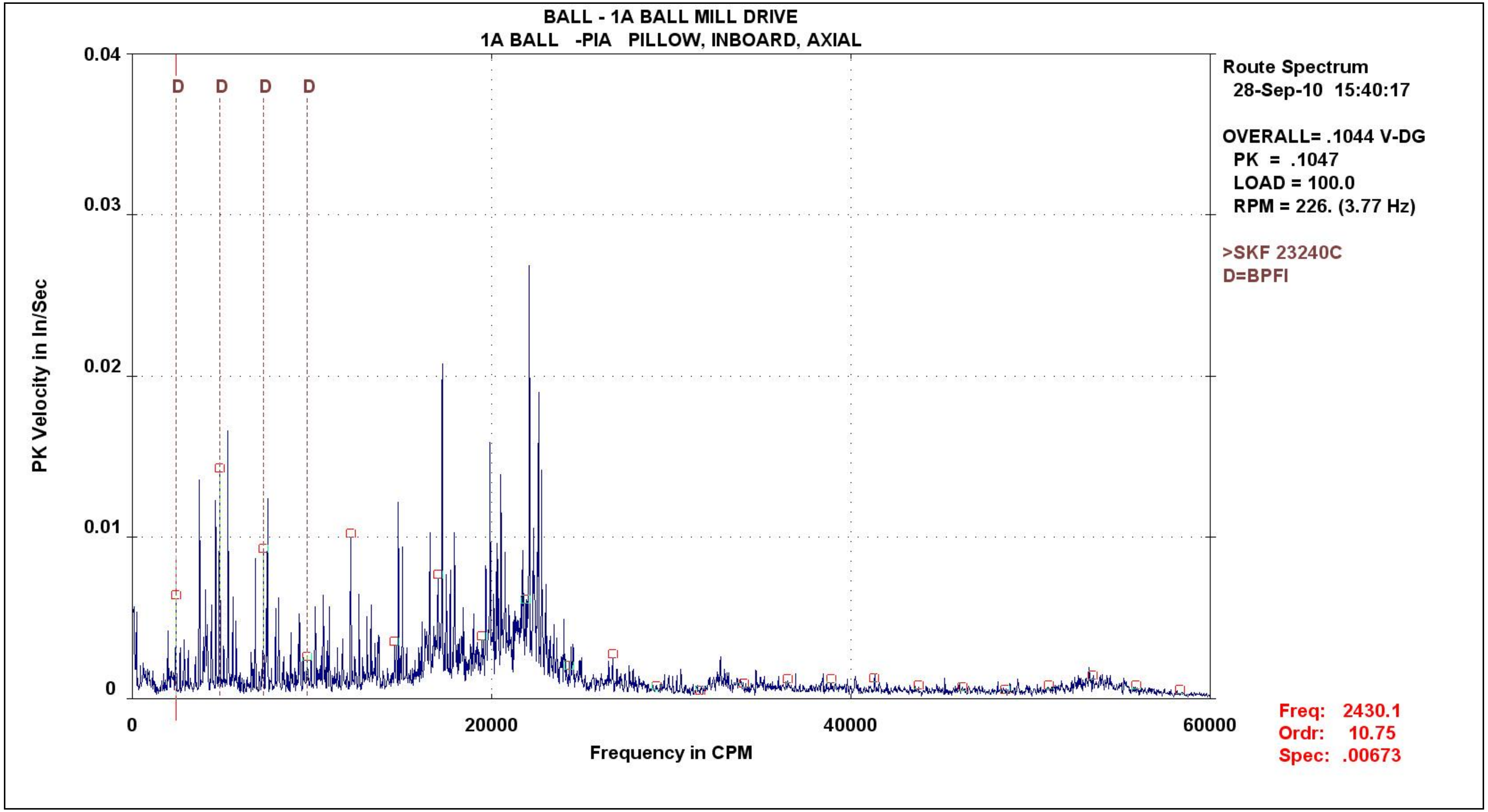
If this vibration originated from the gearbox, some level of vibration at these frequencies would be expected even from unloaded data. It is likely being transmitted from the inboard pillow block bearing thru the clutch & base to the gearbox.

- Above is spectral data from 1A ball mill when loaded & unloaded (gearbox, input, axial).
- Note how loading introduced much higher vibration levels composed of multiples of vibration at 2,428 cpm which is 10.74x the output speed of the gearbox (226 rpm) which is a perfect match for the inner race defect frequency of the pillow block spherical roller bearings.



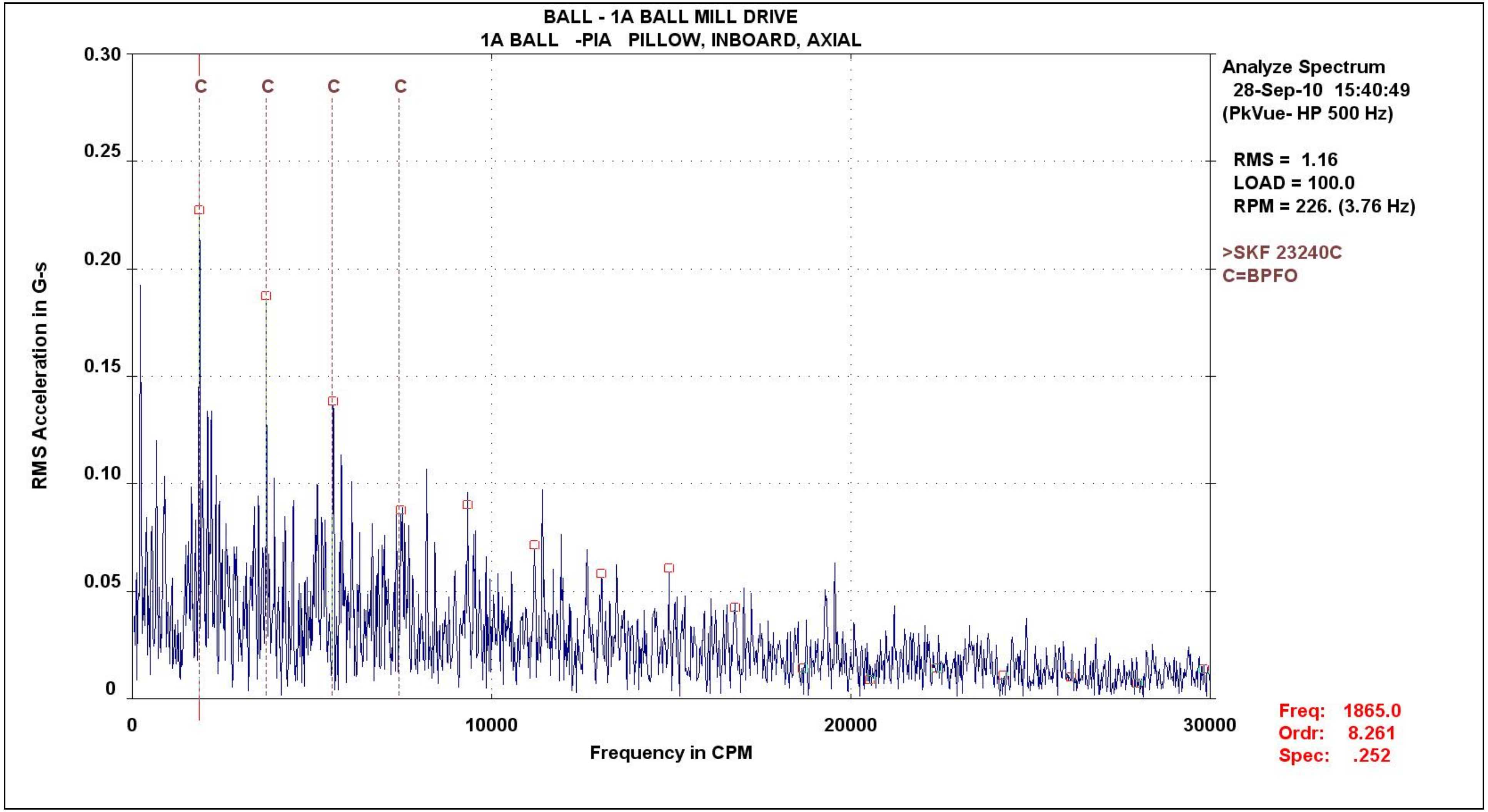
- Data from 1A shows a great amount of noise & low frequency peaks, while data from 1B shows the expected vibration at the ball mill gearmesh frequency & multiples (18x rpm).

- Above is spectral data from both 1A & 1B ball mills when loaded (ball mill pillow block bearing, inboard, axial).
- Note the great difference in spectral pattern between these two data sets. As they were taken from similar machines under similar conditions of speed & load, we would expect similar spectral patterns – this is not the case.

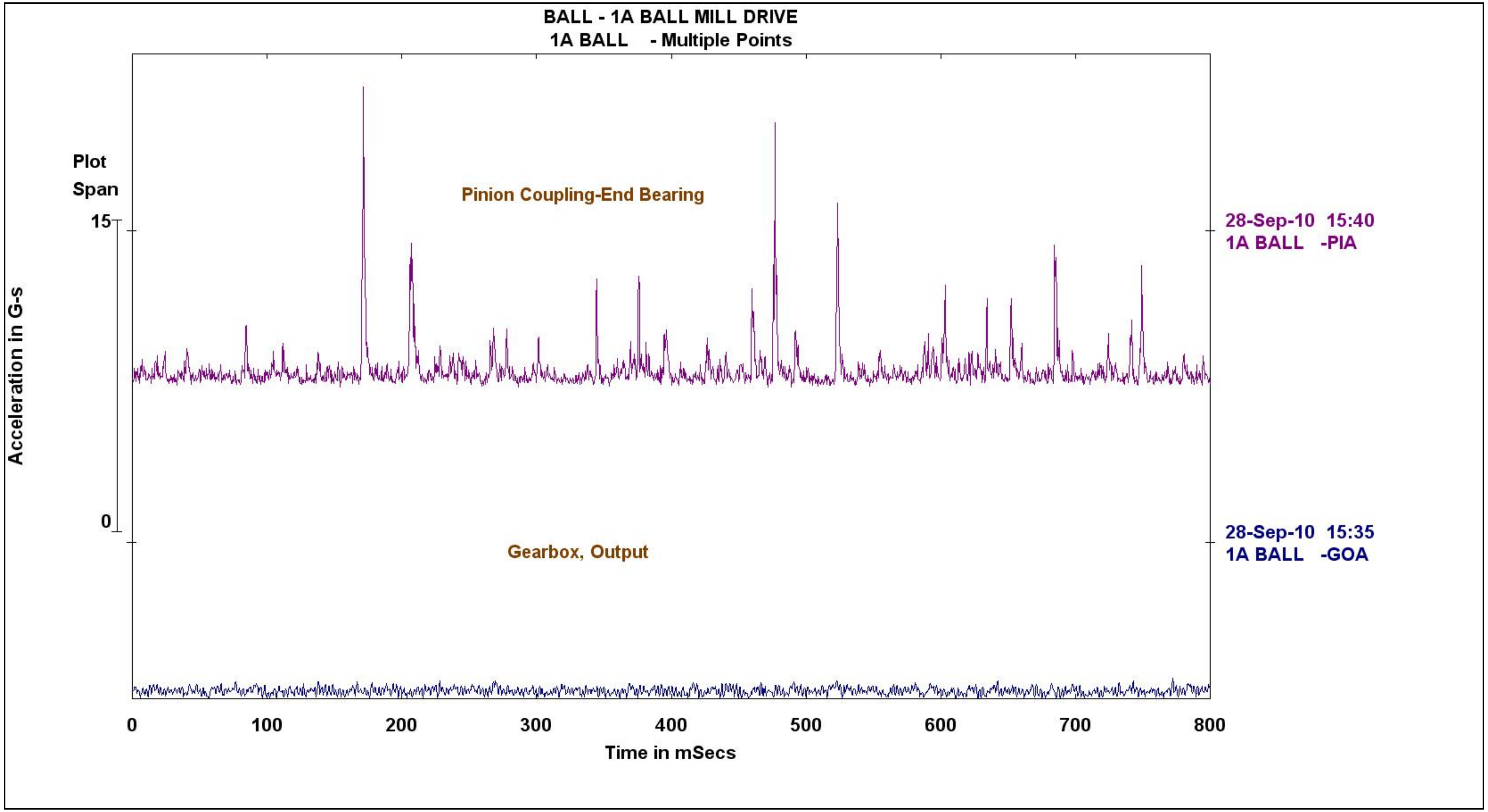


- Above is spectral data from 1A ball mill when loaded (ball mill pillow block bearing, inboard, axial).
- Note that dominant vibration occurs at multiples of the inner race defect frequency (2,430 cpm) for this SKF#23240 spherical roller bearing (19 rollers). Vibration at multiples of the outer race defect frequency (1,865 cpm) were also seen in the data.

BALL MILLS,
PEAKVUE DATA



- Above is Peakvue spectral data from 1A ball mill when loaded (ball mill pillow block bearing, inboard, axial).
- Note the vibration appearing at multiples of the outer race defect frequency (1,865 cpm) for this SKF#23240 spherical roller bearing (19 rollers). High levels of 1.16 g's-rms were also noted as well as a high noise floor.



- Compare high frequency Peakvue vibration waveform data from 1A Ball Mill, measurement points PIA (pillow block, inboard, axial) and GOA (gearbox, output, axial).
- Note how levels at the pillow block are significantly higher than those seen at the gearbox. This data is telling us the source of the problem is most likely at the inboard pillow block bearing, not the gearbox.

PEAKVUE DATA:

- Peakvue measurements are very sensitive to machinery faults involving metal to metal contact or impacting such as lubrication problems, bearing faults, or mechanical looseness.
- Peakvue’s emphasis on high frequency vibration also means its levels increase rapidly as we move to the source of the problem and dissipate rapidly as we move away from the source of the problem.
- Low frequency vibration typically transmits much better through materials than high frequency vibration does.

CONCLUSIONS (SEPTEMBER 2010)

1) As high frequency vibration levels were much higher at the inboard pillow block bearing of 1A versus 1B Ball Mill, a problem of some sort is expected at 1A inboard bearing.
2) As vibration spectra from 1A inboard pillow block bearing showed dominant vibration occurring at multiples of both the inner and outer race defect frequencies expected from that SKF#23240 spherical roller bearing, a significant fault is expected at that bearing.
3) As high frequency Peakvue vibration measurements are a clear maximum at 1A inboard pillow block bearing and drop off dramatically when we move to either the gearbox output or outboard pillow block bearing, no significant problems are expected at either the gearbox or outboard pillow block bearings at this time.
4) The unloaded versus loaded vibration data suggest the source of the problem does not lie at either the motor or gearbox.

RECOMMENDATIONS (SEPTEMBER 2010)

1) To avoid unscheduled downtime and further damage to the machinery, have both pinion pillow block bearings changed ASAP. Although vibration shows no significant problems at the outboard pillow block bearing at this time, due to their common installation date, and thus common operating hours, changing both bearings would be wise.
2) Conduct follow-up vibration & temperature measurements after work is completed to ensure no installation problems occurred as well as to double-check against any smaller problems at the gearbox or motor.

1A BALL MILL REPAIRS (OCTOBER 2010)

Following the September 2010 vibration analysis of 1A ball mill, repairs were performed at the machine as follows:

1) Both 1A ball mill pillow block bearings were changed.
2) The ball mill gears were inspected (see photos below).
3) The shaft alignment between the gearbox & ball mill pinion shaft was checked & minor corrections were made as needed by moving the gearbox only.
4) Following these repairs, a baseline vibration analysis of the machine was requested and later performed in November 2010.

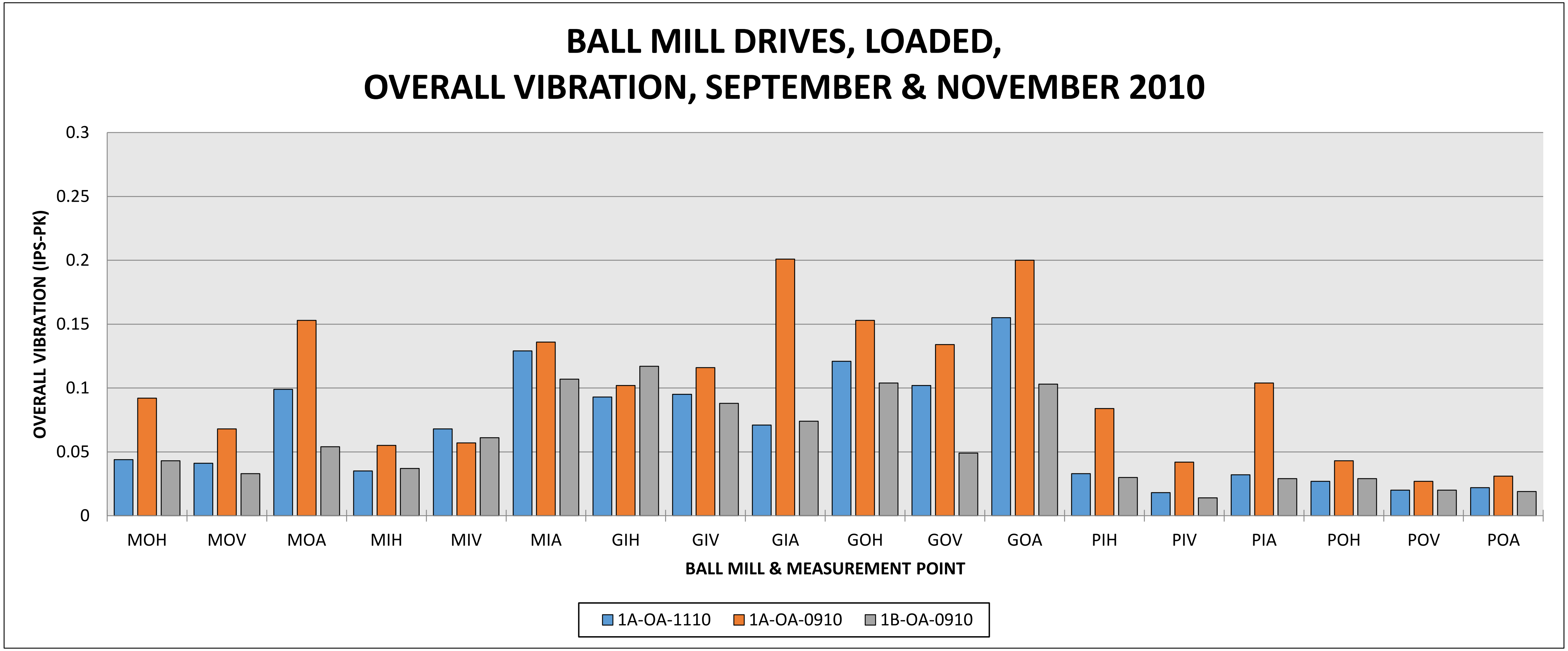
PHOTOS FROM BALL MILL GEAR INSPECTION

- Some wear on gear teeth observed, but no major problems noted even when both gears rotated thru 360 deg.
- Wear marks compared well from left to right of gear teeth (alignment probably ok).
- No broken or cracked gear teeth found.
- Plenty of oil present with lube appearing in good condition.
- No abnormal coloring of gears or excessive varnish, etc seen.

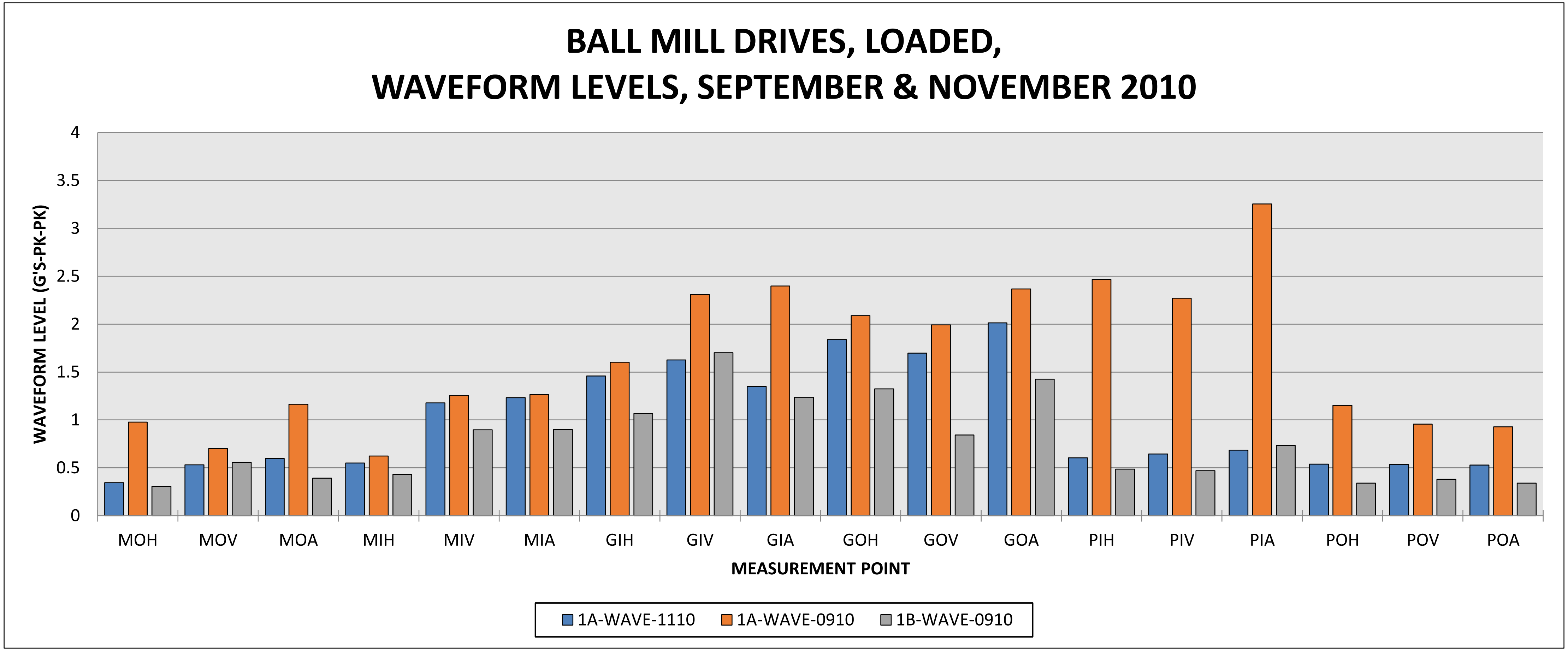
VIBRATION DATA (NOVEMBER 2010):

- Following repairs in October 2010, baseline vibration data was collected in November 2010 from 1A Ball Mill Drive under normal load.
- To determine what remaining problems (if any) existed with this drive, a comparison was made of vibration data before & after the recent bearing change.
- Vibration data collected in September at the nearby 1B Ball Mill was also used as a reference point in the analysis.

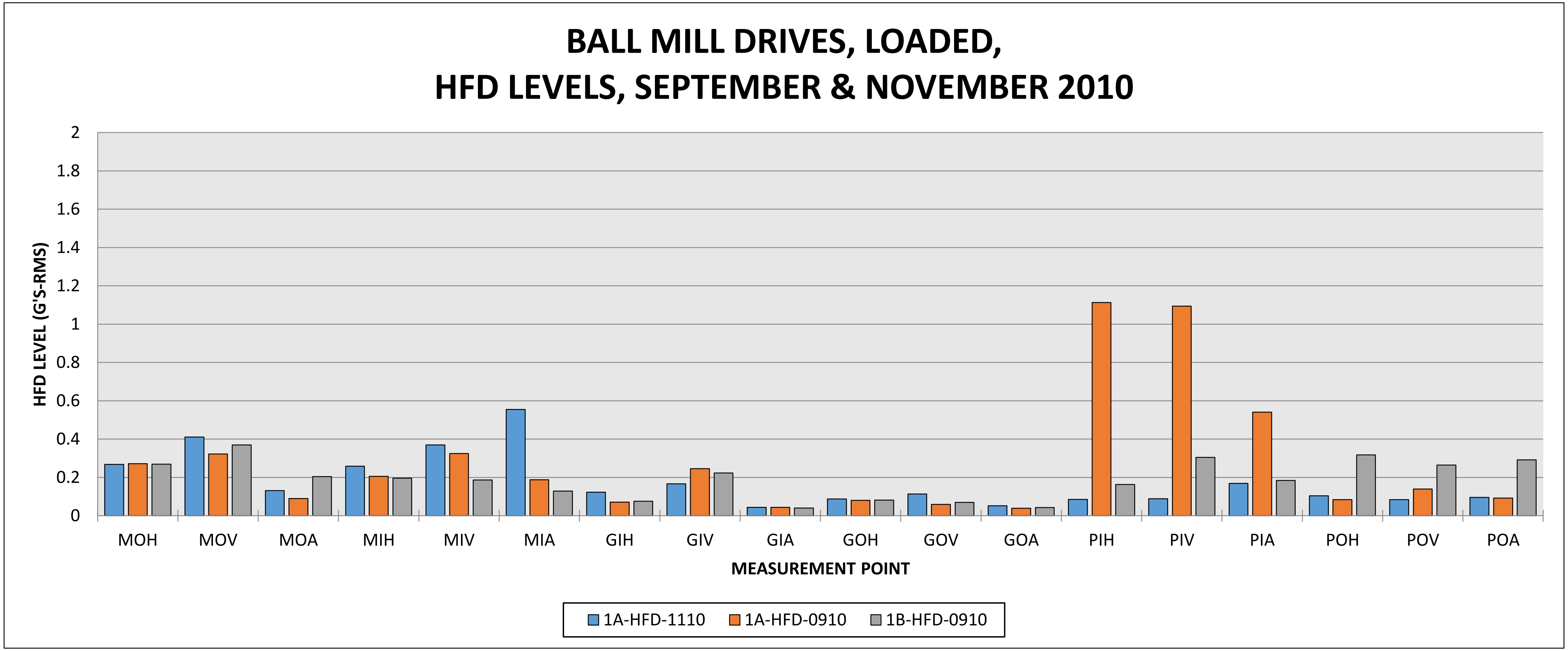
BALL MILLS,
VIBRATION DATA,
BEFORE & AFTER REPAIRS



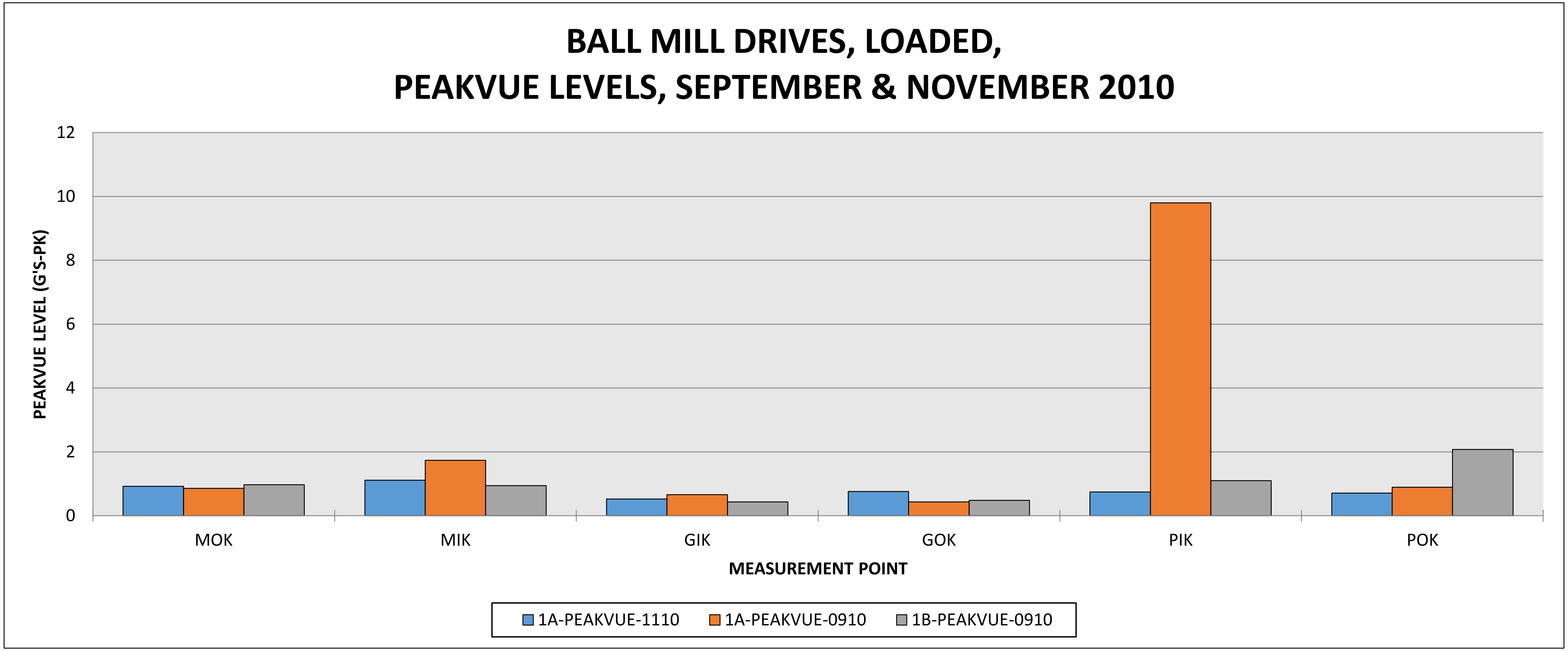
- Above is a plot of the overall vibration levels at both the 1A & 1B ball mills when loaded.
- Data from 1A ball mill is shown from both September & November 2010 (before & after repairs).
- Note how levels at 1A ball mill are lower following repairs.
- Note also how following 1A repairs, levels at the ball mill pillow block bearings now agree with one another.



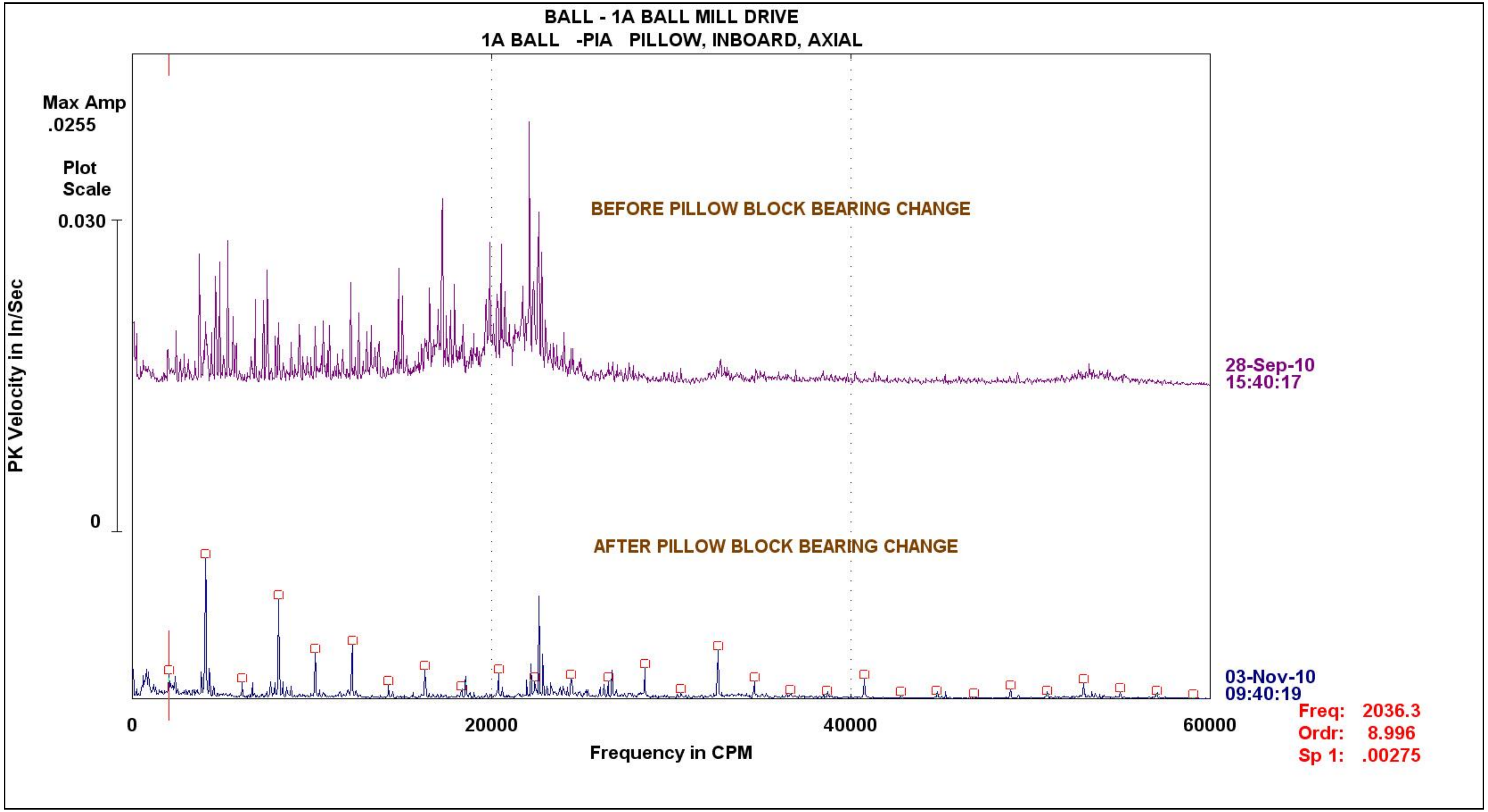
- Above is a plot of the waveform vibration levels at both the 1A & 1B ball mills when loaded (acceleration).
- Data from 1A ball mill is shown from both September & November 2010 (before & after repairs).
- Note how levels at 1A ball mill are lower following repairs especially at the ball mill inboard bearing points.
- Note also how following 1A repairs, levels at the ball mill pillow block bearings now agree with one another.



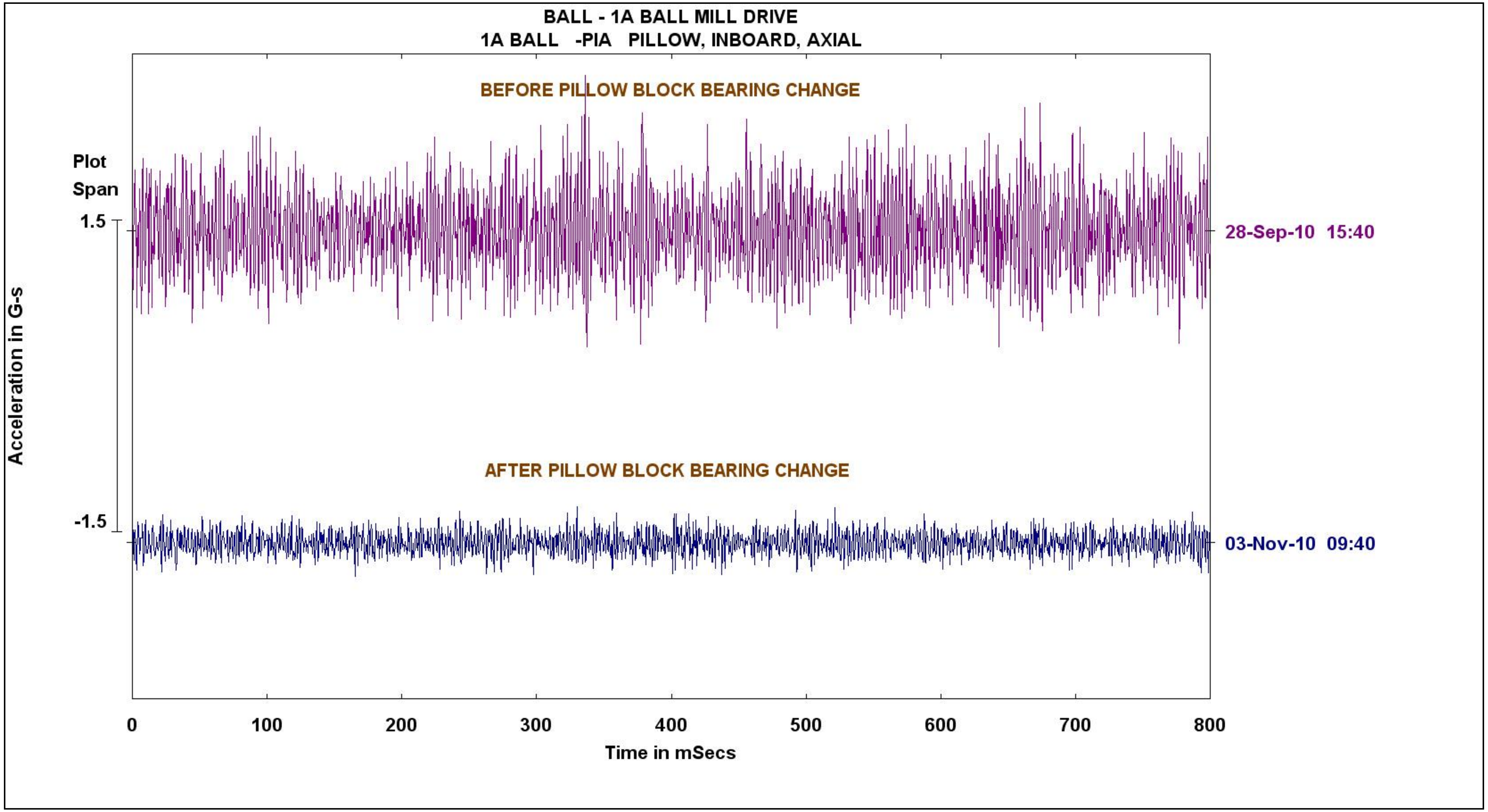
- Above is a plot of the high frequency HFD vibration energy levels at both the 1A & 1B ball mills when loaded (acceleration energy band, 2kHz to 20kHz).
- Data from 1A ball mill is shown from both September & November 2010 (before & after repairs).
- Note how levels at 1A ball mill ball mill inboard bearing (PIH → PIA) levels following repairs are much lower and now agree with those at 1B.



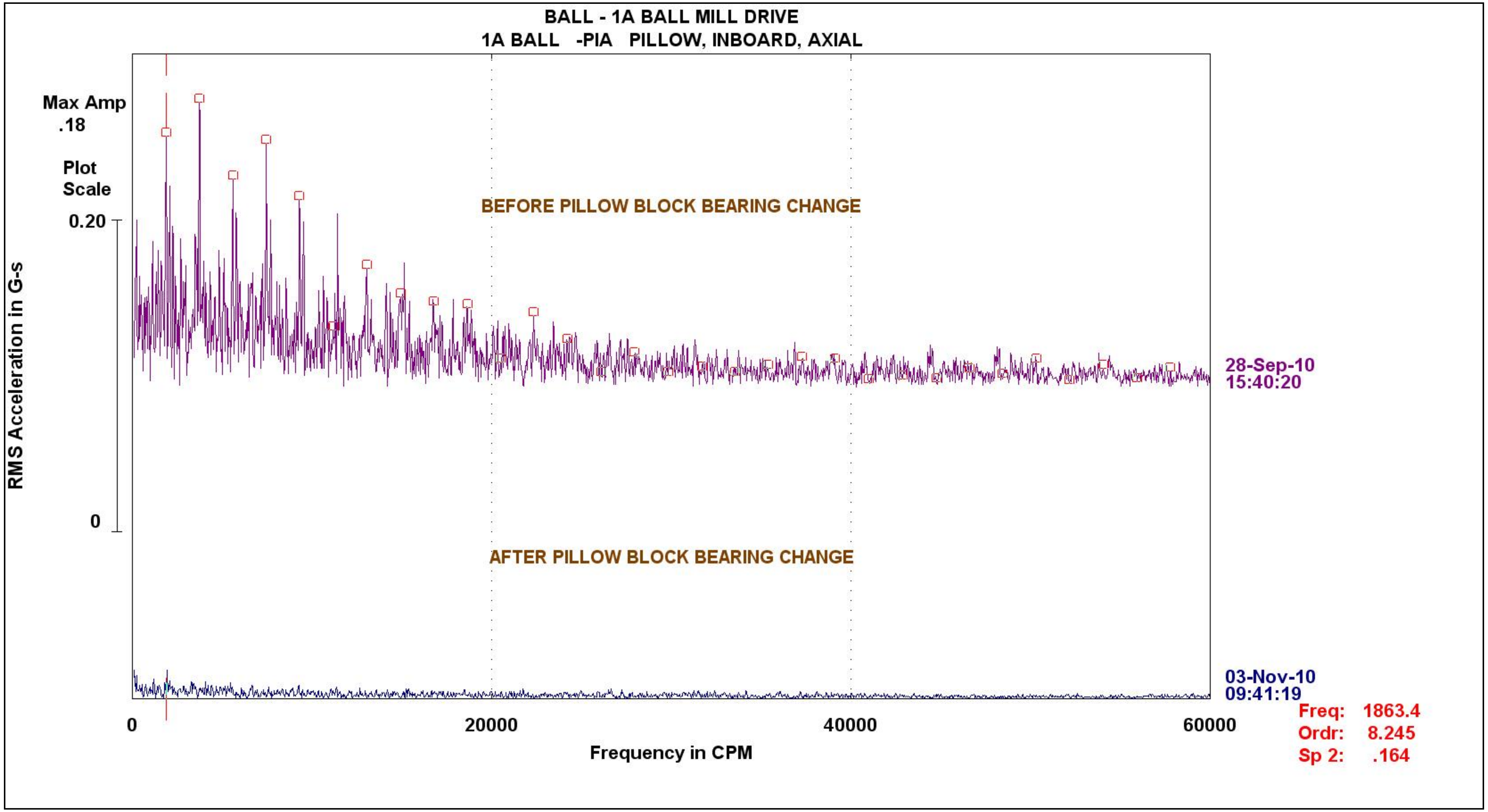
- Above is a plot of the high frequency Peakvue levels at both the 1A & 1B ball mills when loaded.
- Data from 1A ball mill is shown from both September & November 2010 (before & after repairs).
- Note how levels at 1A ball mill ball mill inboard bearing (PIK) following repairs are significantly lower and now agree with those at 1B.



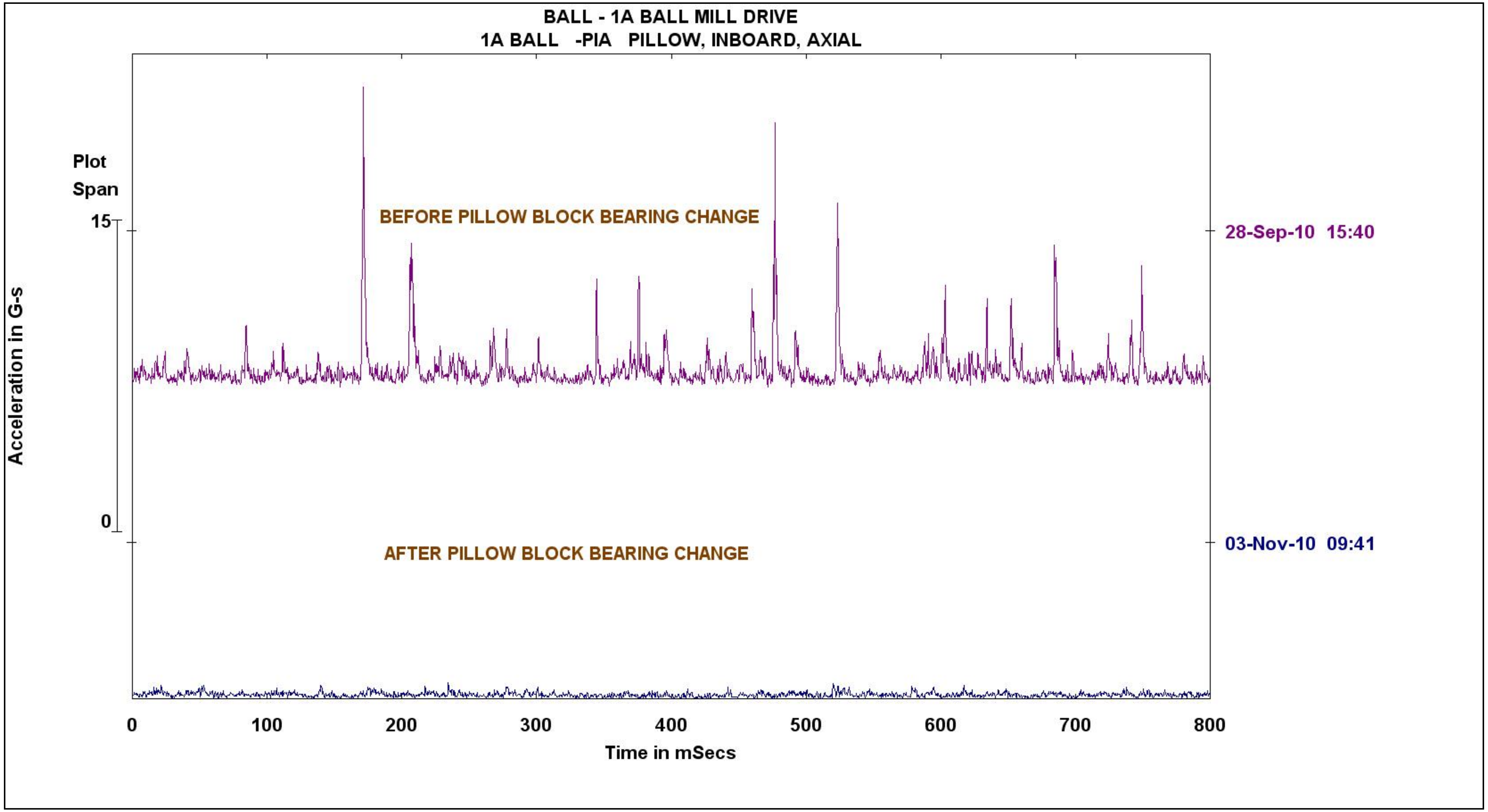
- Above is spectral data from 1A ball mill when loaded both before & after October repairs (ball mill inboard bearing).
- The multiples of vibration at 9x pinion speed seen in current data (1/2x gear-mesh frequency) are thought due to the common factor of 2 between the pinion & bull gears at the ball mill and/or the 2-part bull gear construction (gear assembly phase issue?).



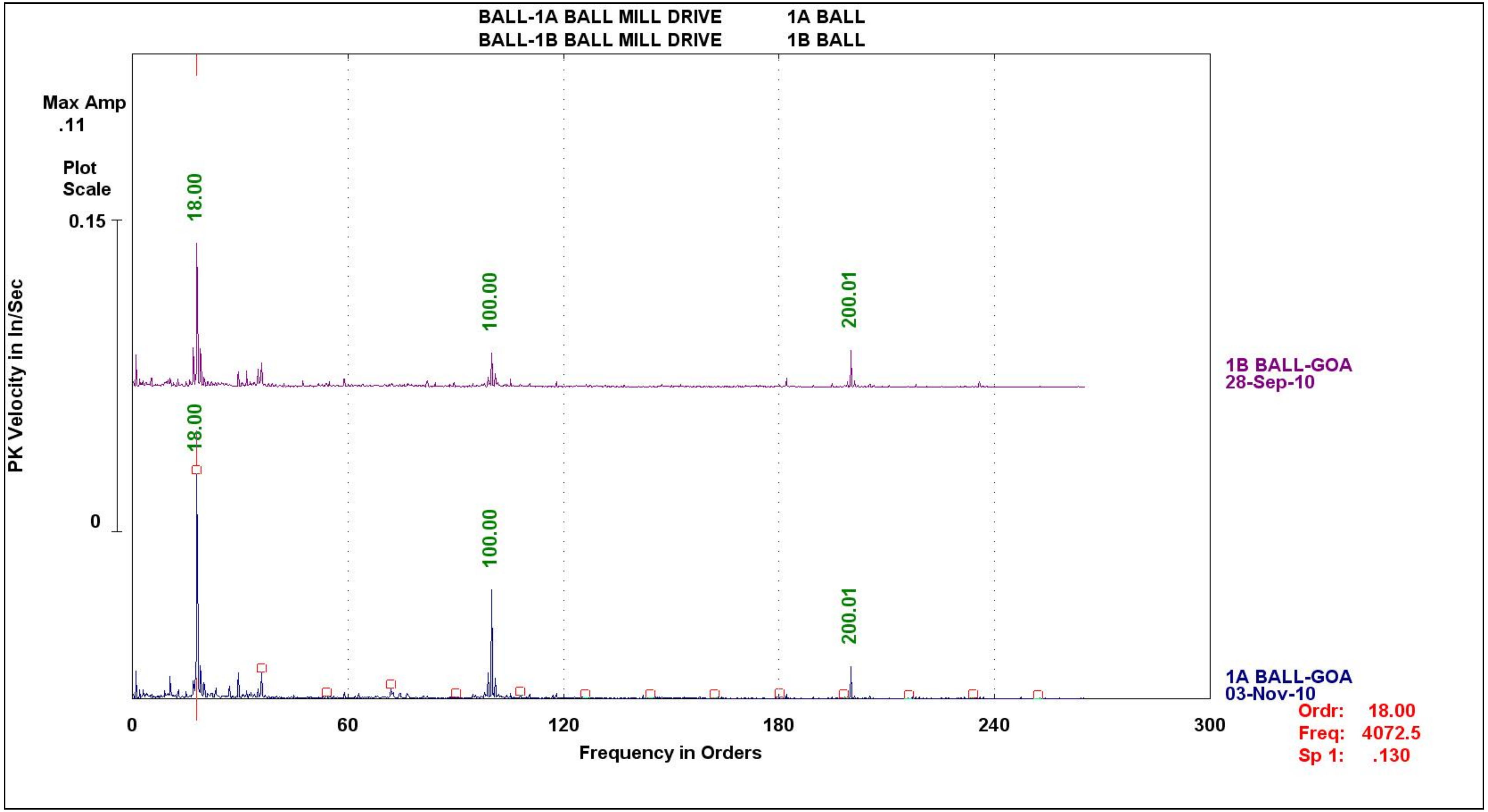
- Above is waveform data from 1A ball mill when loaded both before & after October repairs (ball mill inboard bearing).
- Note the significant drop in levels following the October repairs.



- High frequency Peakvue vibration spectra from 1A Ball Mill, measurement point PIA (pillow block, inboard, axial) both before & after recent bearing change.
- Note the disappearance of the bearing fault frequencies seen before repairs and much lower noise floor.



- High frequency Peakvue waveform data from 1A Ball Mill, measurement point PIA (pillow block, inboard, axial) both before & after recent bearing change.
- Note the significant reduction in levels and absence of significant impacting following the recent bearing change.



- Compare vibration spectra from the gearbox, output, axial measurements (GOA) from both 1A & 1B Ball Mills.
- Note how the dominant frequencies of vibration in both cases are identical (18, 100 & 200 orders) and are associated with gearbox & ball mill gear-mesh frequencies which in my view pose no significant threat to the condition of either machine at this time.

FINAL CONCLUSIONS, BALL MILL GEARBOX:

1) Recent change of the 1A Ball Mill inboard pillow block bearing resulted in significantly reduced vibration levels there and no signs of any significant problems at this time.
2) A minor bearing fault may exist at the gearbox output, but current vibration data indicate the problem is very small and of no great concern at this time. Current data from 1A gearbox is similar to that seen from 1B gearbox which is further evidence that no significant problem exists at 1A gearbox at this time.