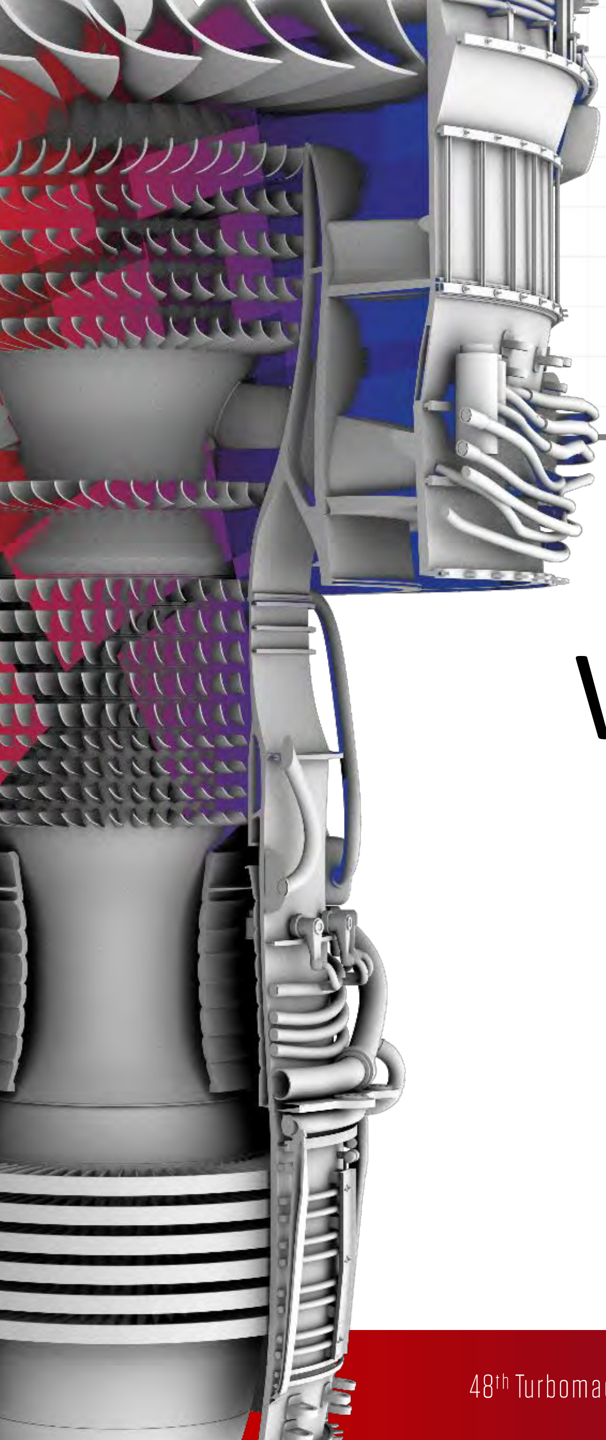

TURBOMACHINERY & PUMP SYMPOSIA

Morton Effect With Pedestal Support Influence

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Abstract

The Morton effect was encountered during a compressor rotor high speed balance. Morton effect for high speed balance configuration was not considered in the design phase analysis, and it was a unique experience. The high speed balance pedestal stiffness will be shown to have a significant influence on the Morton effect. This presentation will cover:

(1) Design phase screening & analysis of this case

(2) High speed balance & test floor Morton effect mitigation

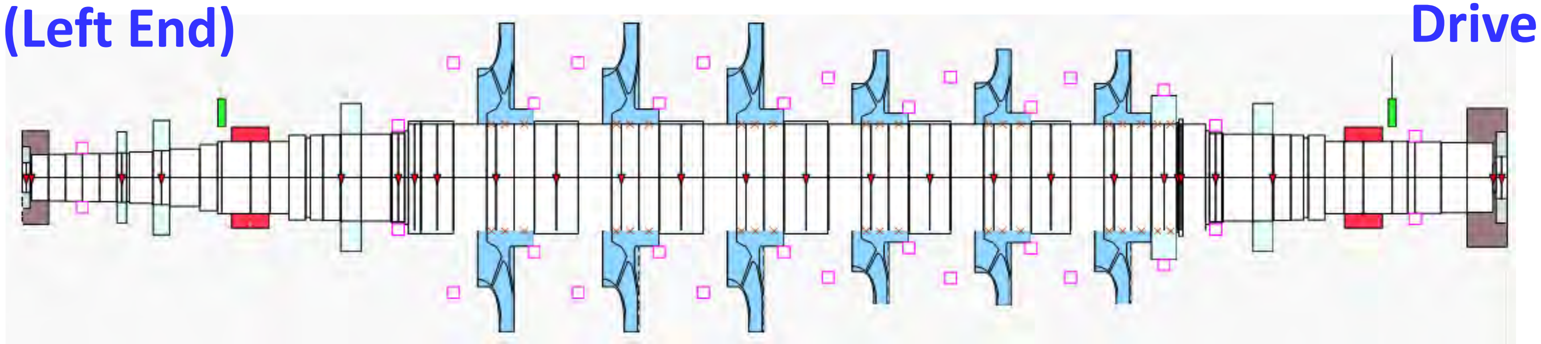
(3) Morton effect analysis & root cause analysis

(4) Conclusions

Rotor Configuration

Drive Through End (Left End)

Drive End (Right End)



Left Overhung Length: 18.1 in (45.97 cm)
Left Overhung Weight: 114.2 lb (51.8 Kg)
Left Coupling Weight: 58.4 lb (26.5 kg)

Right Overhung Length: 11.4 in (28.96 cm)
Right Overhung Weight: 91 lb (41.3 Kg)
Right Coupling Weight: 125.7 lb (57 Kg)

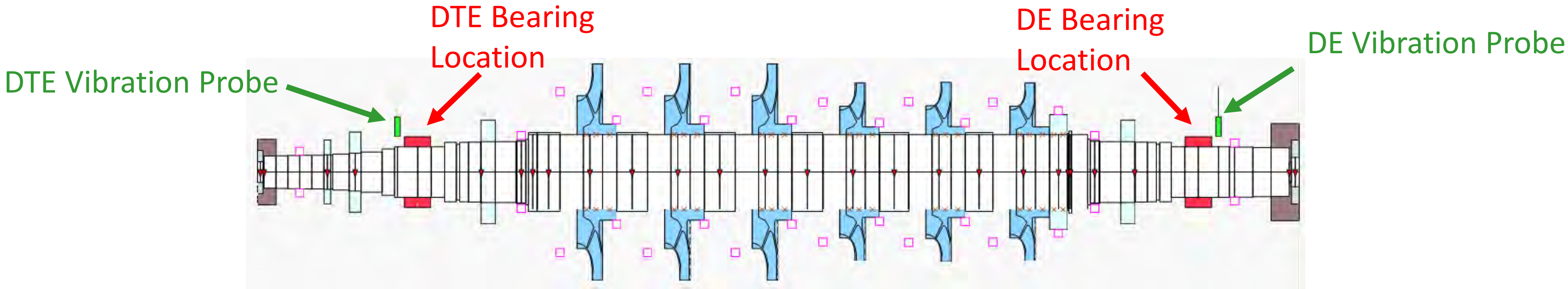
Rotor total weight: 2619.4 lb (1188 Kg)
Bearing span: 88.2 in (224.03 cm)

VFD driven:
Maximum continuous speed: 9086 rpm
Trip speed: 9540 rpm

Tilting Pad Bearing Configuration (Load Between Pads)

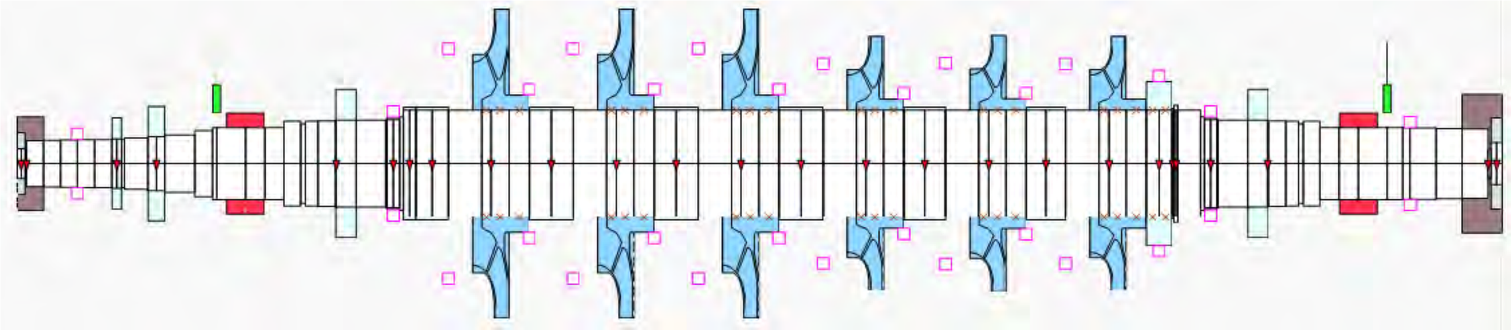
Bearing Location	Bearing type	Bearing Size (inches)	Min. Dia. Assembly Clr. (inches)	Avg. Dia. Assembly Clr. (inches)	Max. Dia. Assembly Clr. (inches)
Drive Through End (Left)	5 pads (spherical seat)	6 X 3	0.0067	0.0077	0.0087
Drive End (Right)	5 pads (spherical seat)	6 X 3	0.0067	0.0077	0.0087

Maximum bearing surface speed: 249.8 ft/sec (76.14 m/s)
Bearing oil type: VG32
Oil supply temperature: 115 F (46 C)



Initial Morton Effect Risk Screening

Drive Through End
(Left End)



Drive End
(Right End)

Morton effect screening rule: $\frac{(W_{oh} + W_{cplg})}{W}\frac{L_o}{L_b} < 0.01$ For VG32 oil at 105 F to 125 F inlet temperature

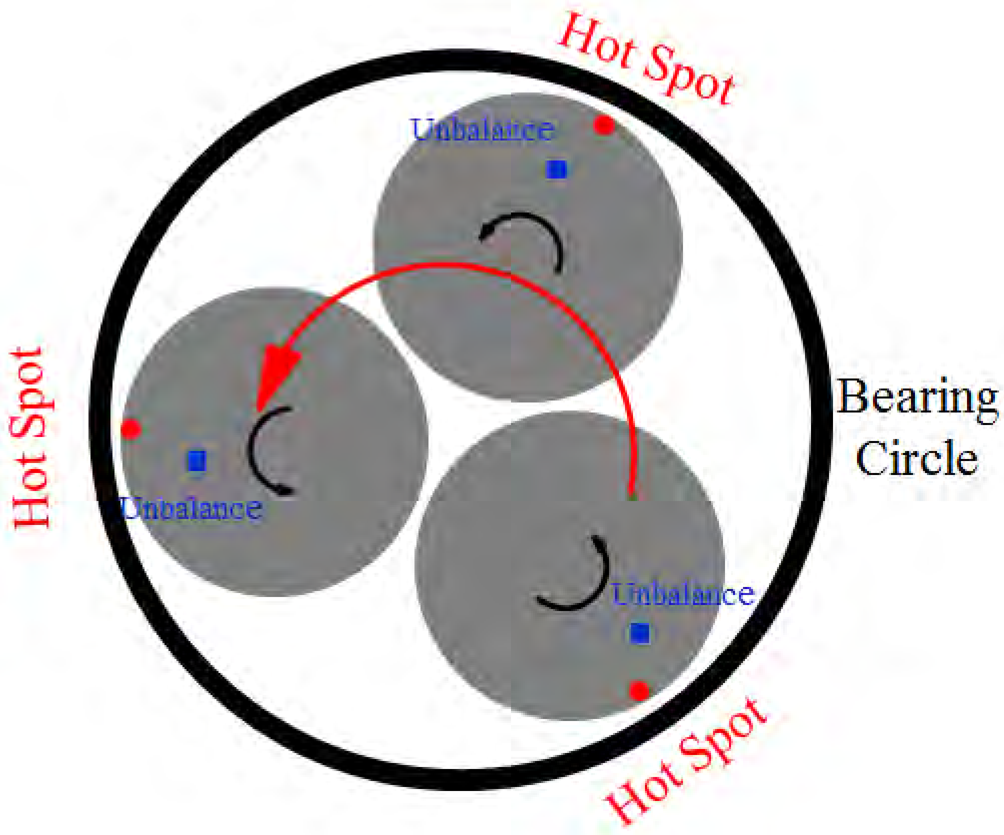
Left end failed the rule due to a long shaft overhung length,
Right end failed the rule due to a heavy coupling
The unit also has a high bearing surface speed

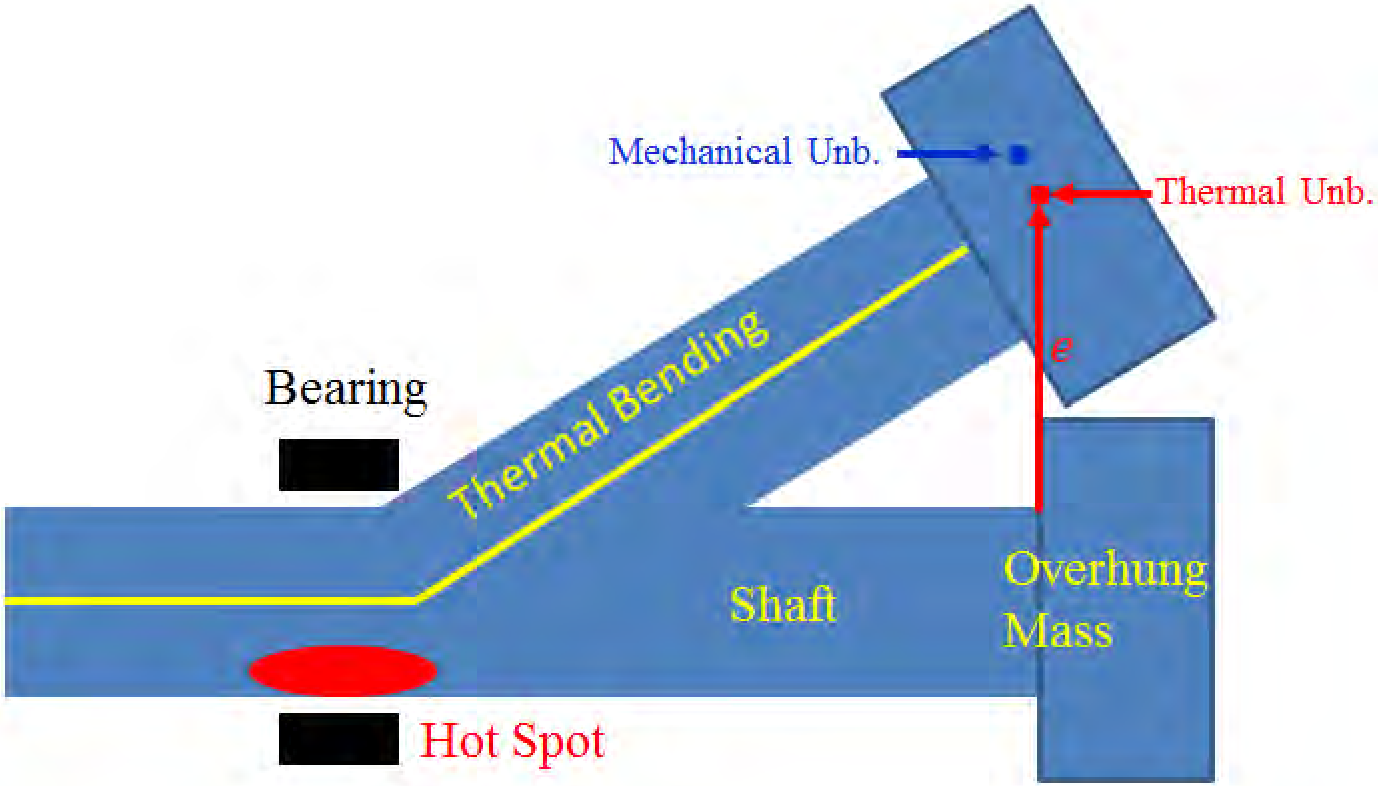
→ **Detailed Morton effect analysis required**

The screening is conservative:
passing units need no further analysis

W_{oh} is the overhung weight excluding the coupling weight
W_{cplg} is the overhung coupling weight
W is the total rotor weight
L_o is the overhung length
L_b is the bearing span

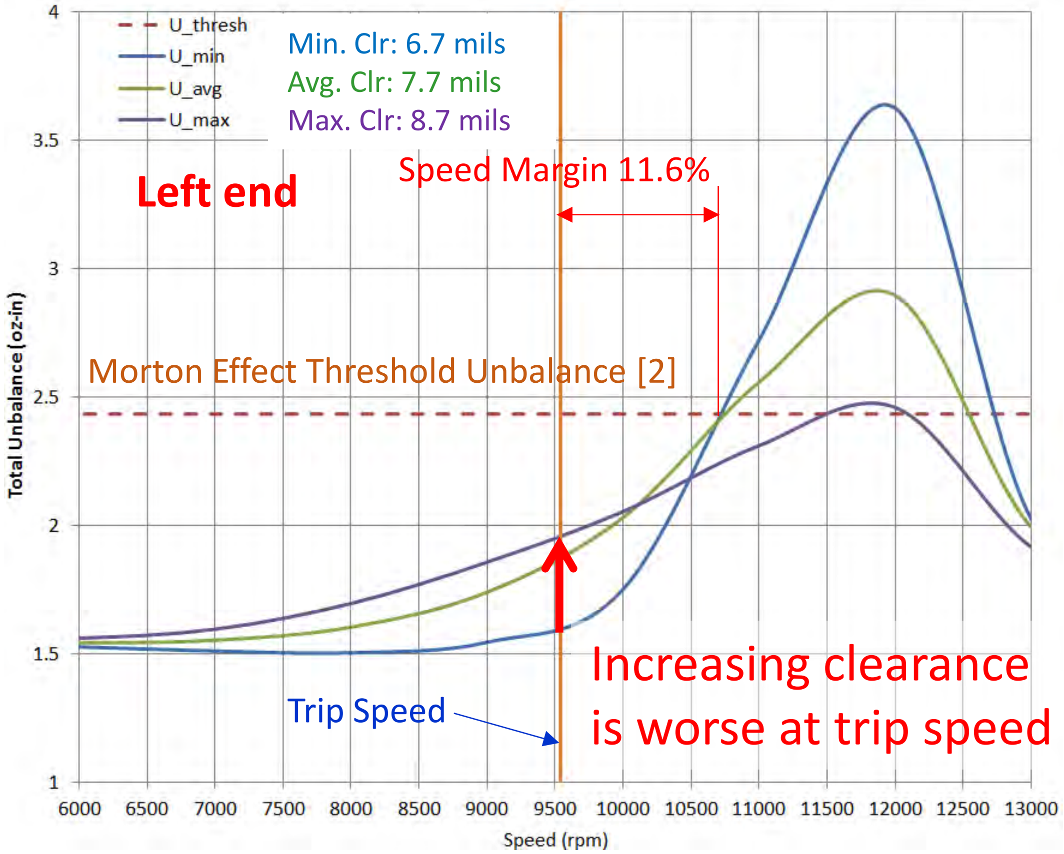
Morton Effect Description [2]

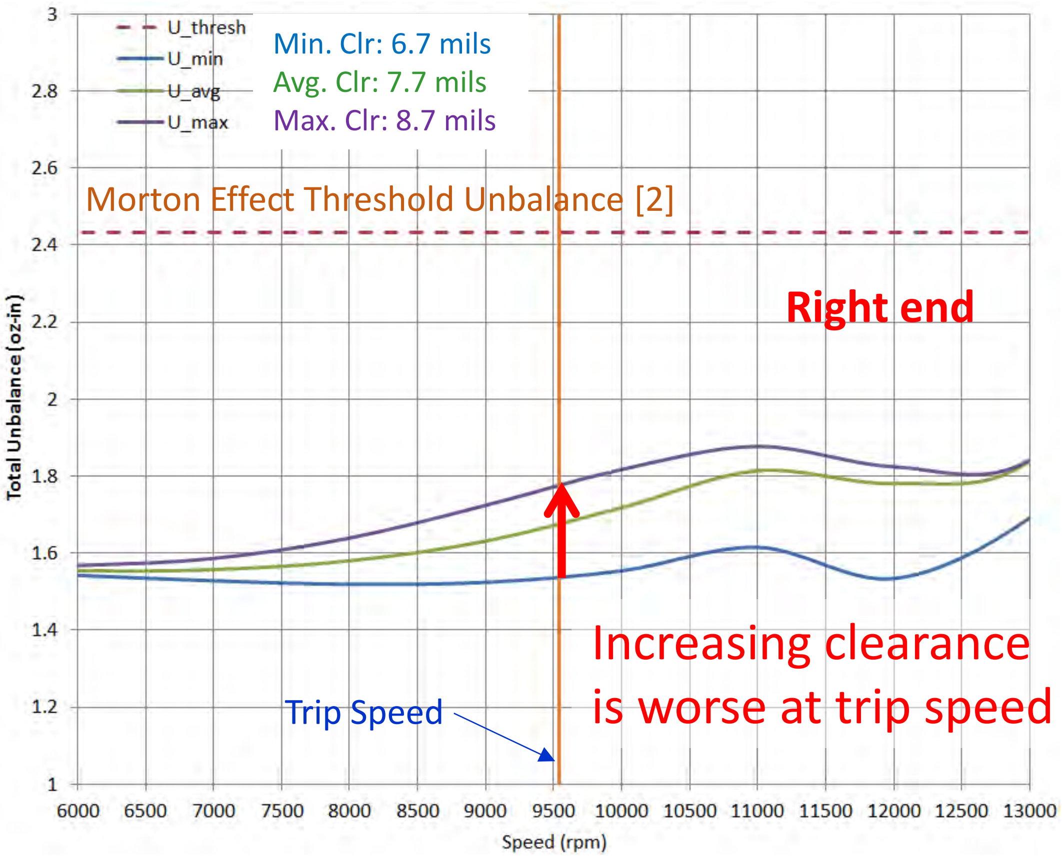




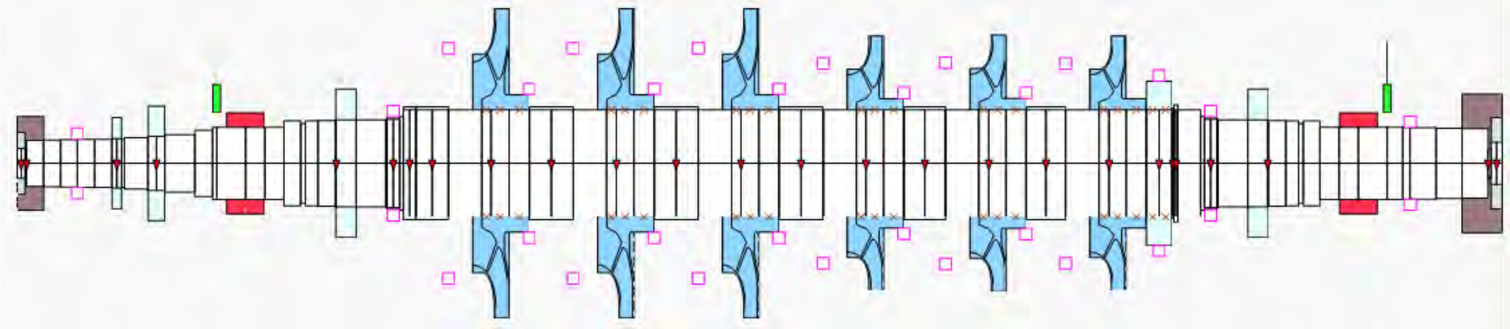
Design Morton effect analysis (pedestal influence not considered) [2]

Morton effect results are below the threshold. Therefore, we expect this to be good.





Drive Through End Has Morton Risk



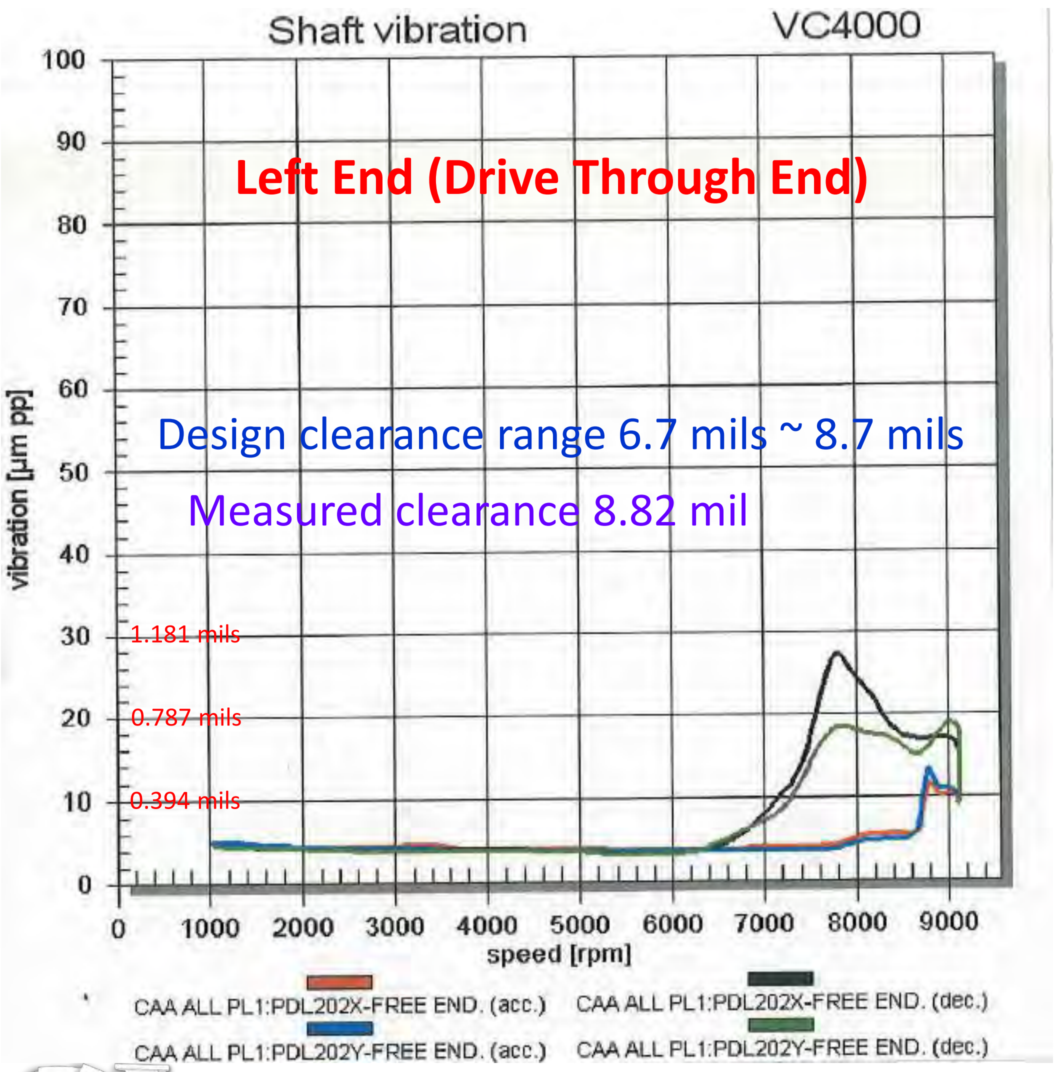
Drive End Risk Free

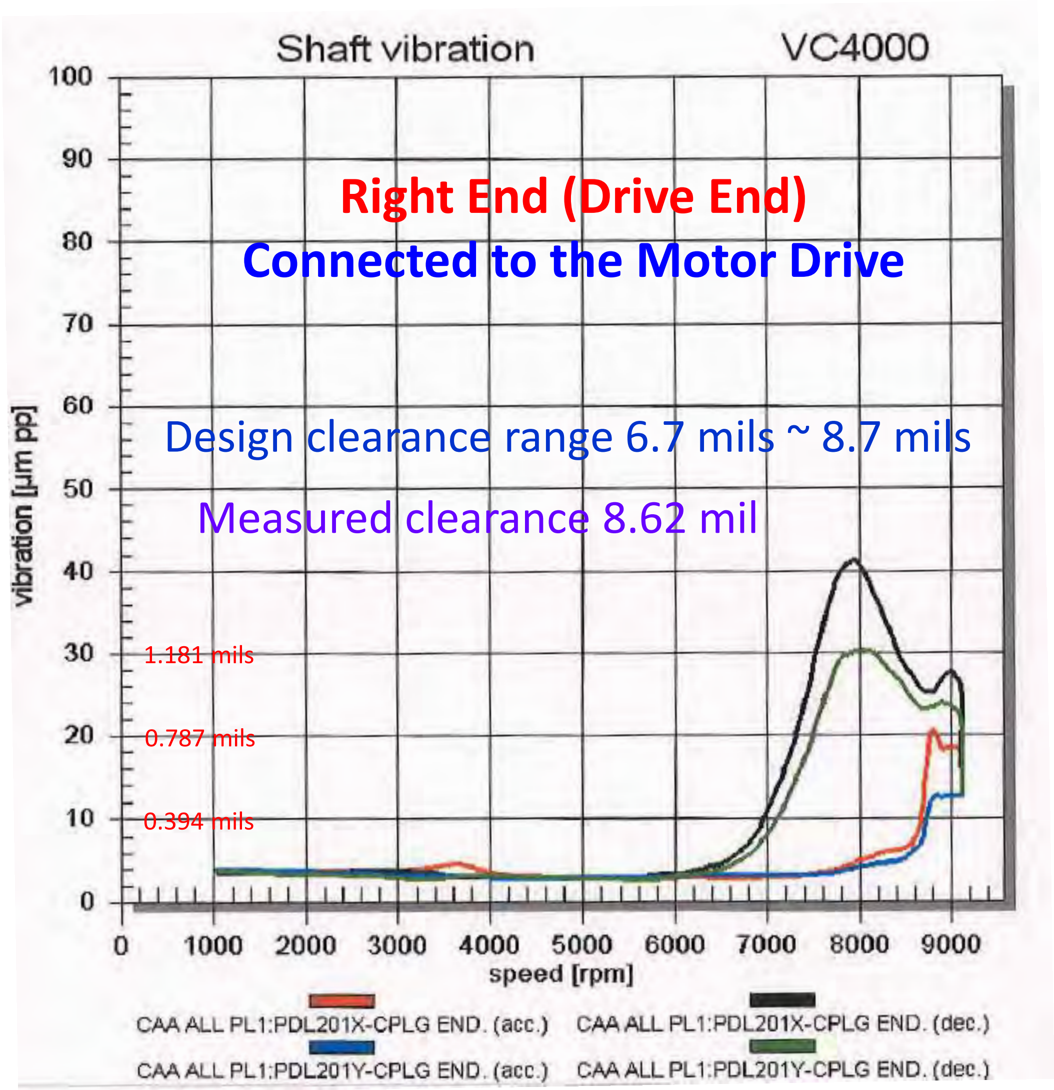
High Speed Balancing

1st High speed balance test

Pedestal to bearing support stiffness ratio less than 3.5

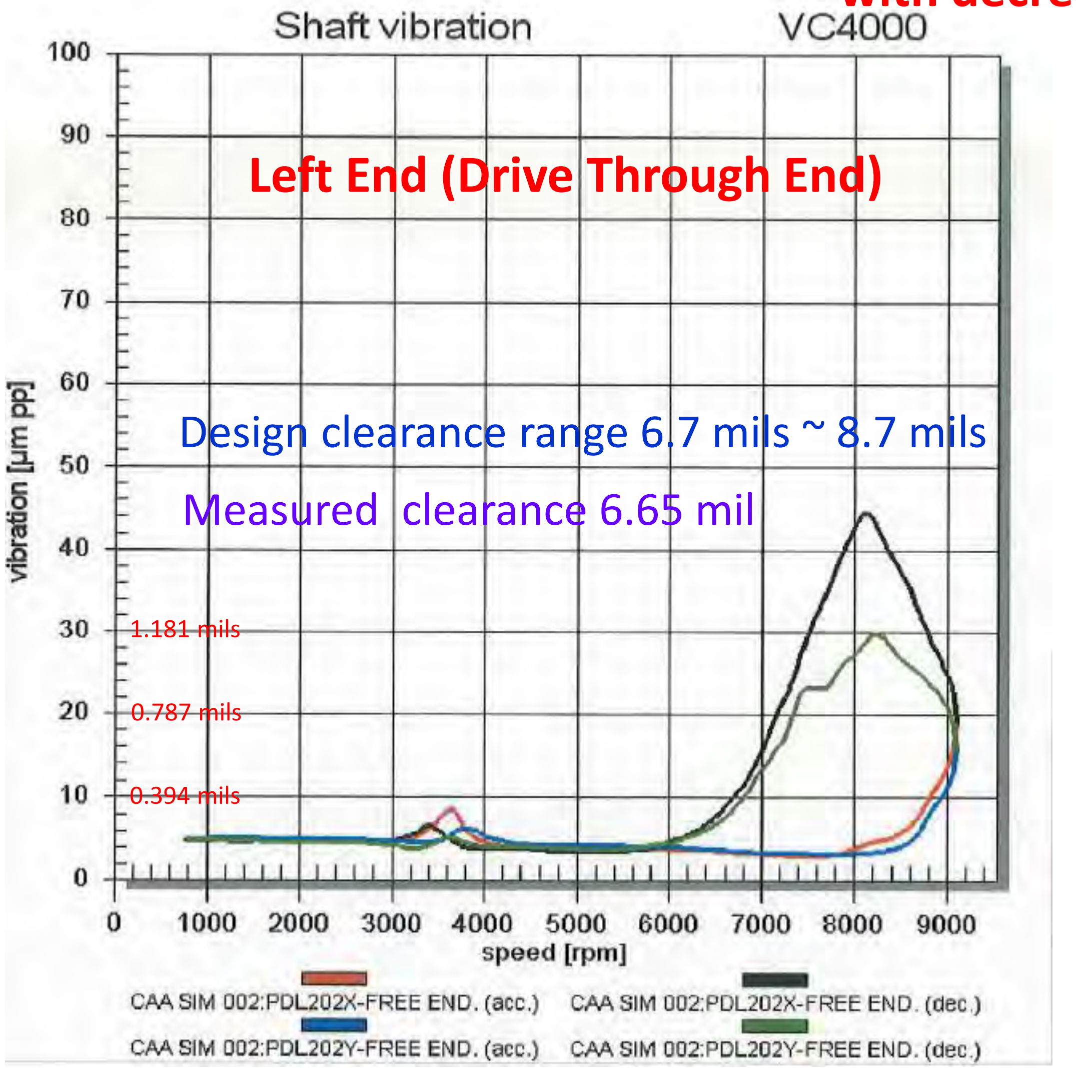
Unexpected Morton effect on both ends

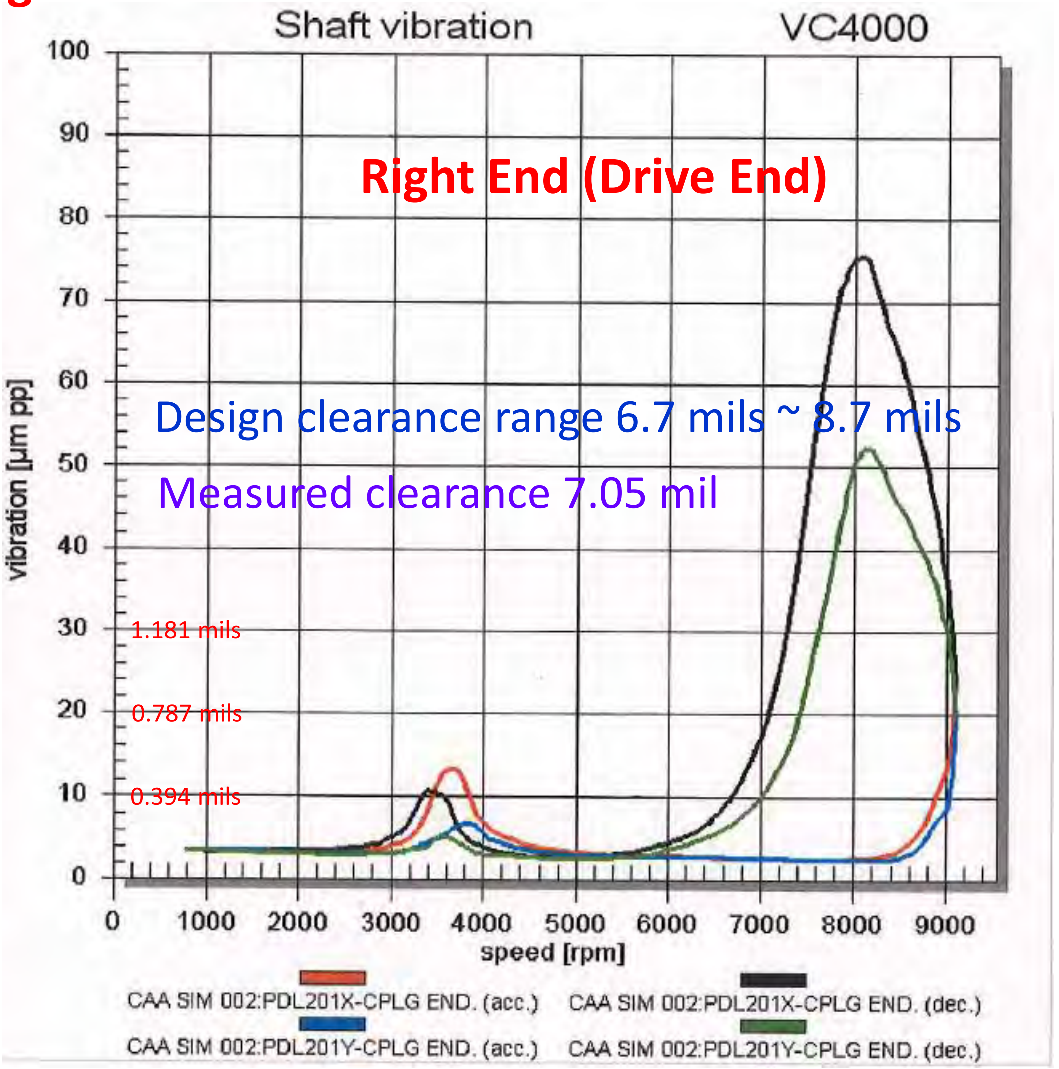




2nd High speed balance test

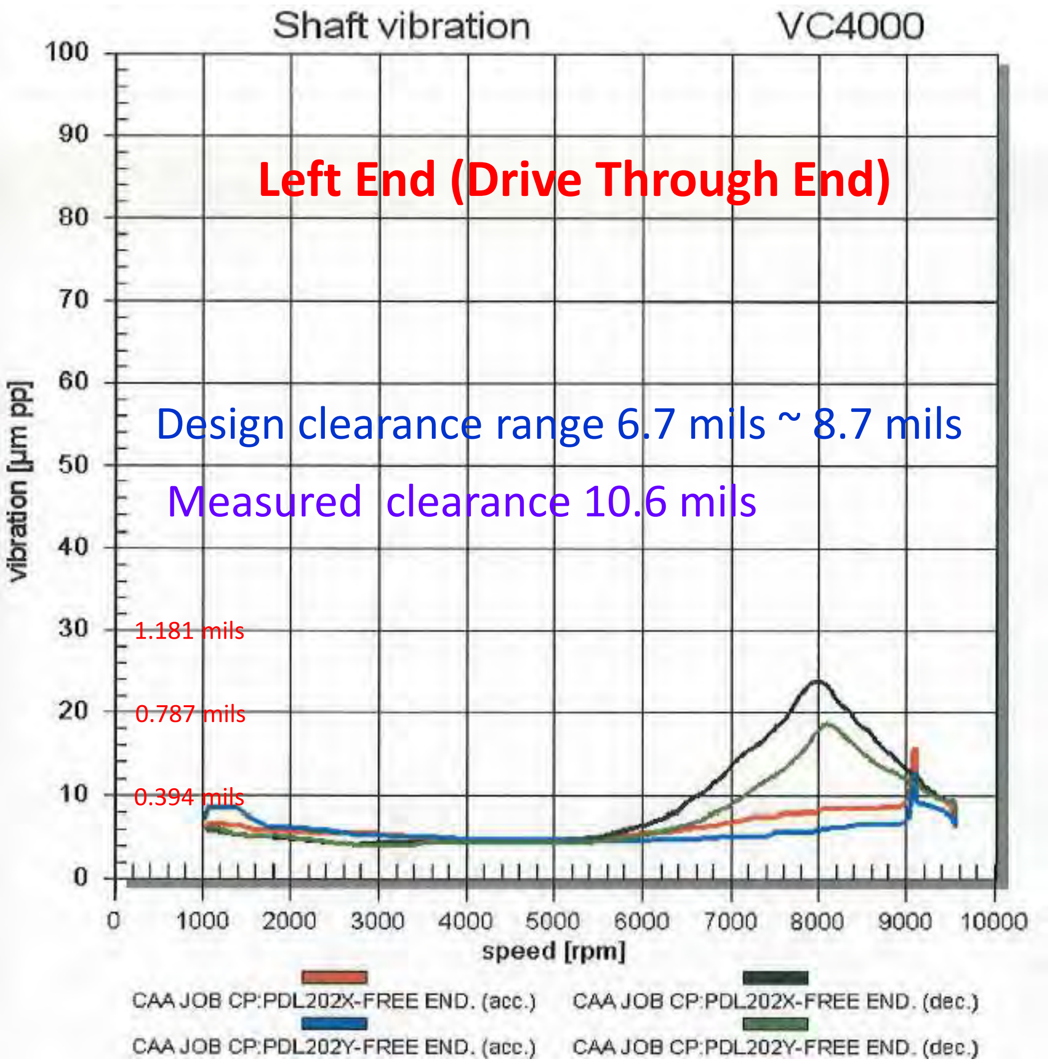
Morton effect worse on both ends with decreased bearing clearance

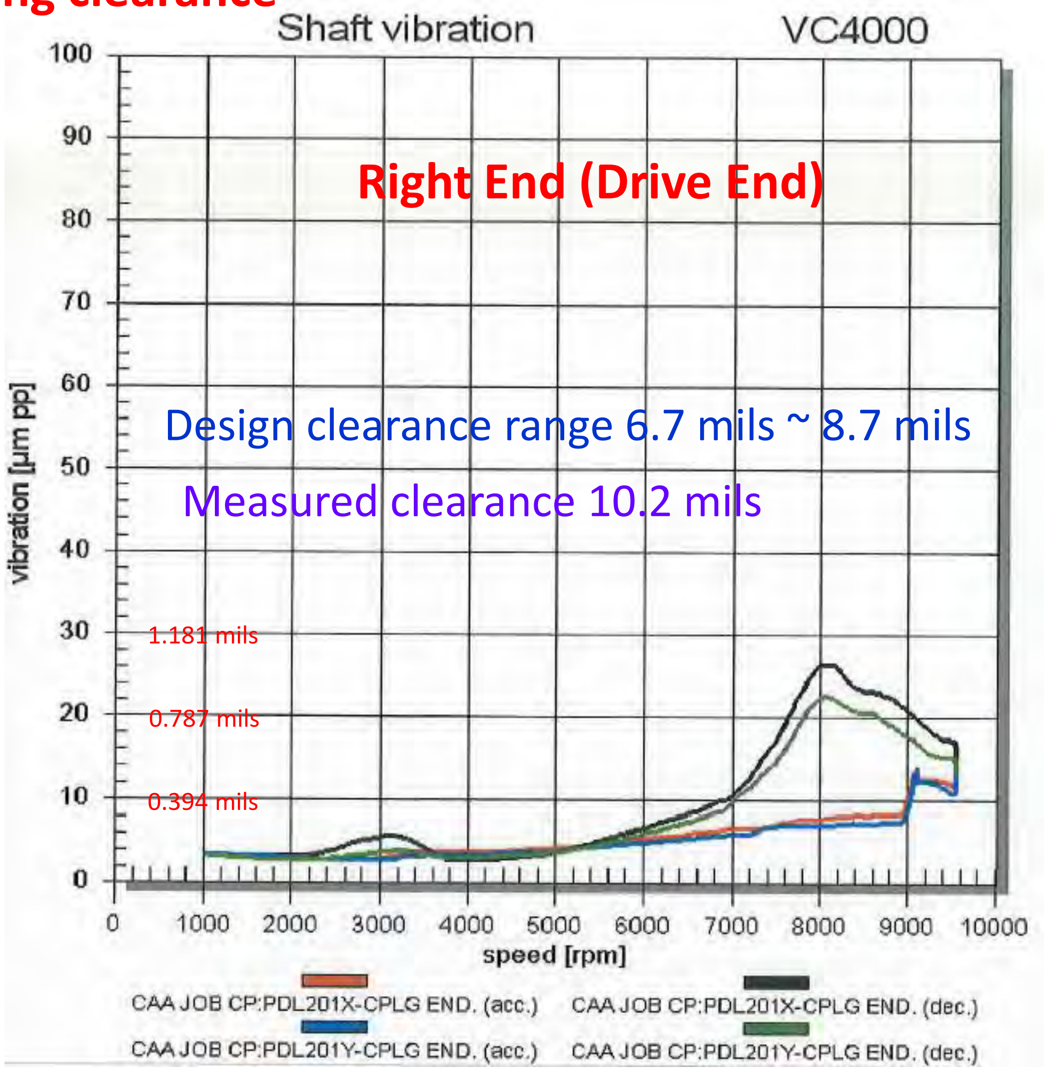




3rd High speed balance test

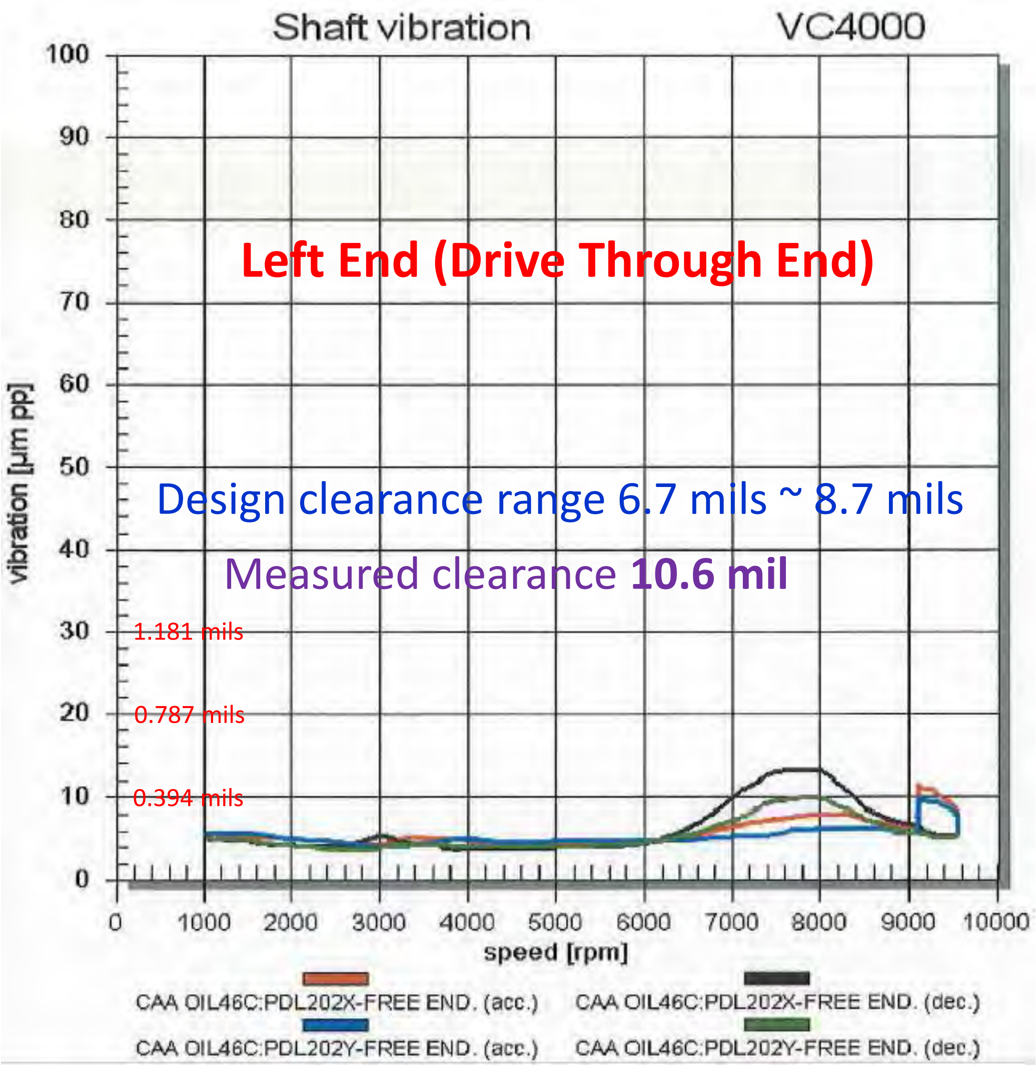
Morton effect getting better with increased bearing clearance

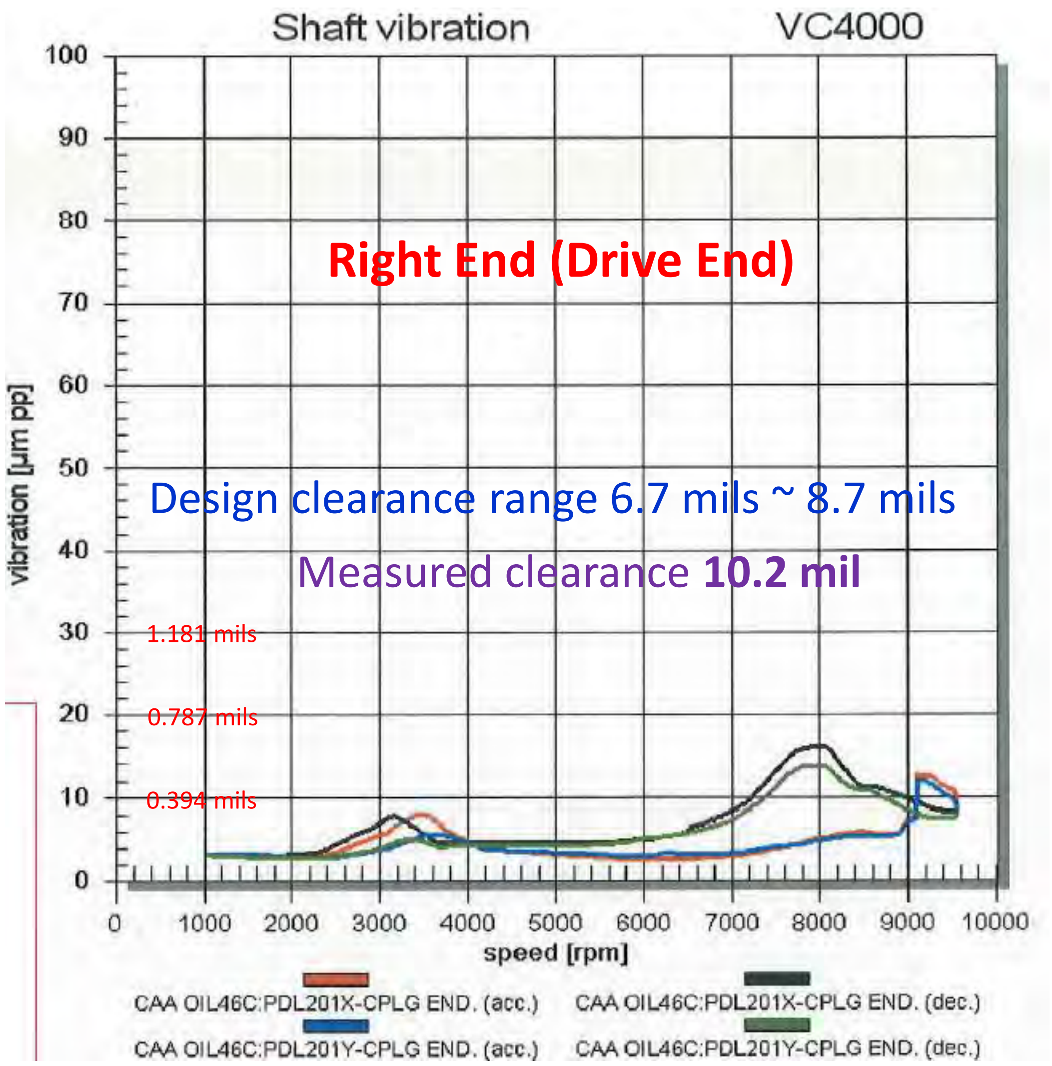




4th High speed balance test

Morton effect becomes acceptable
with increased clearance and balancing both coupling hubs





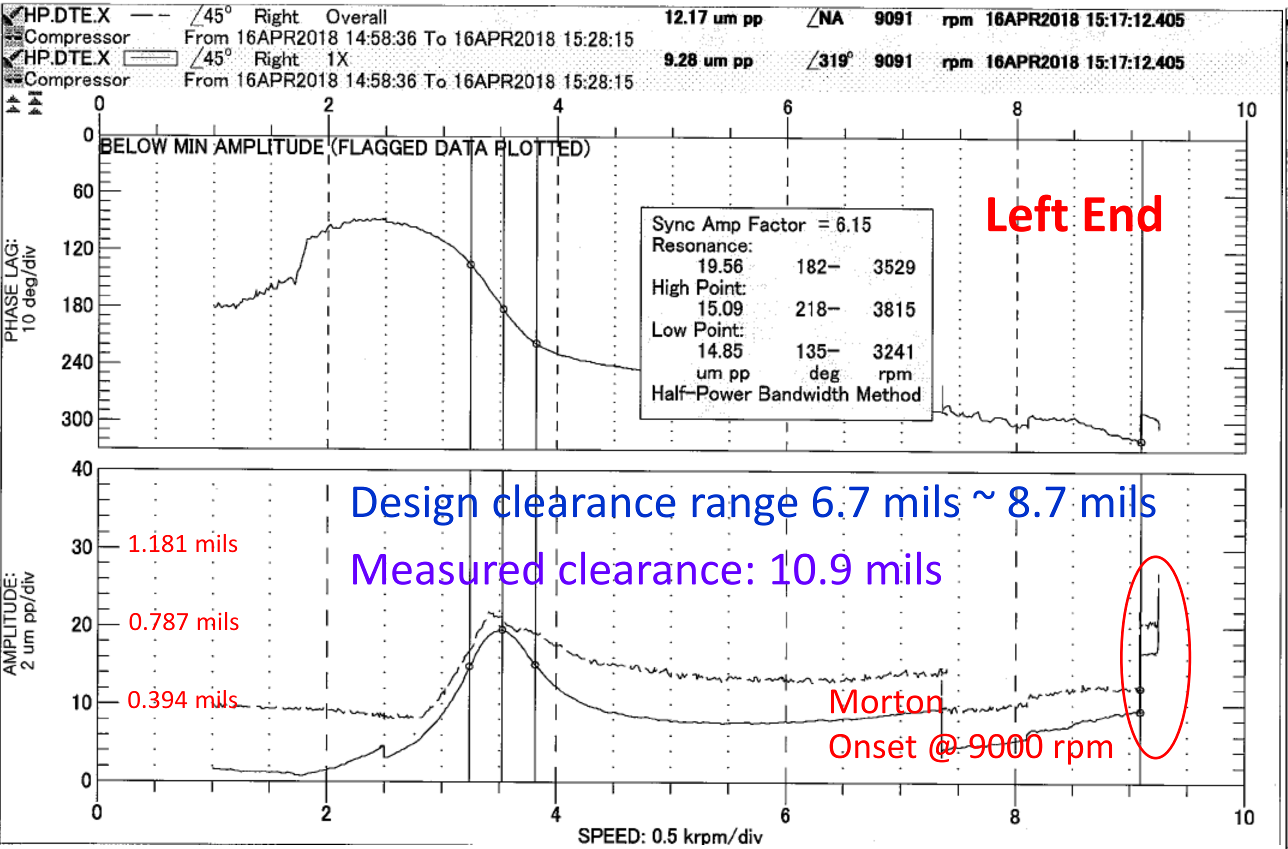
Left End Coupling Correction Unbalance: 0.167 oz-in

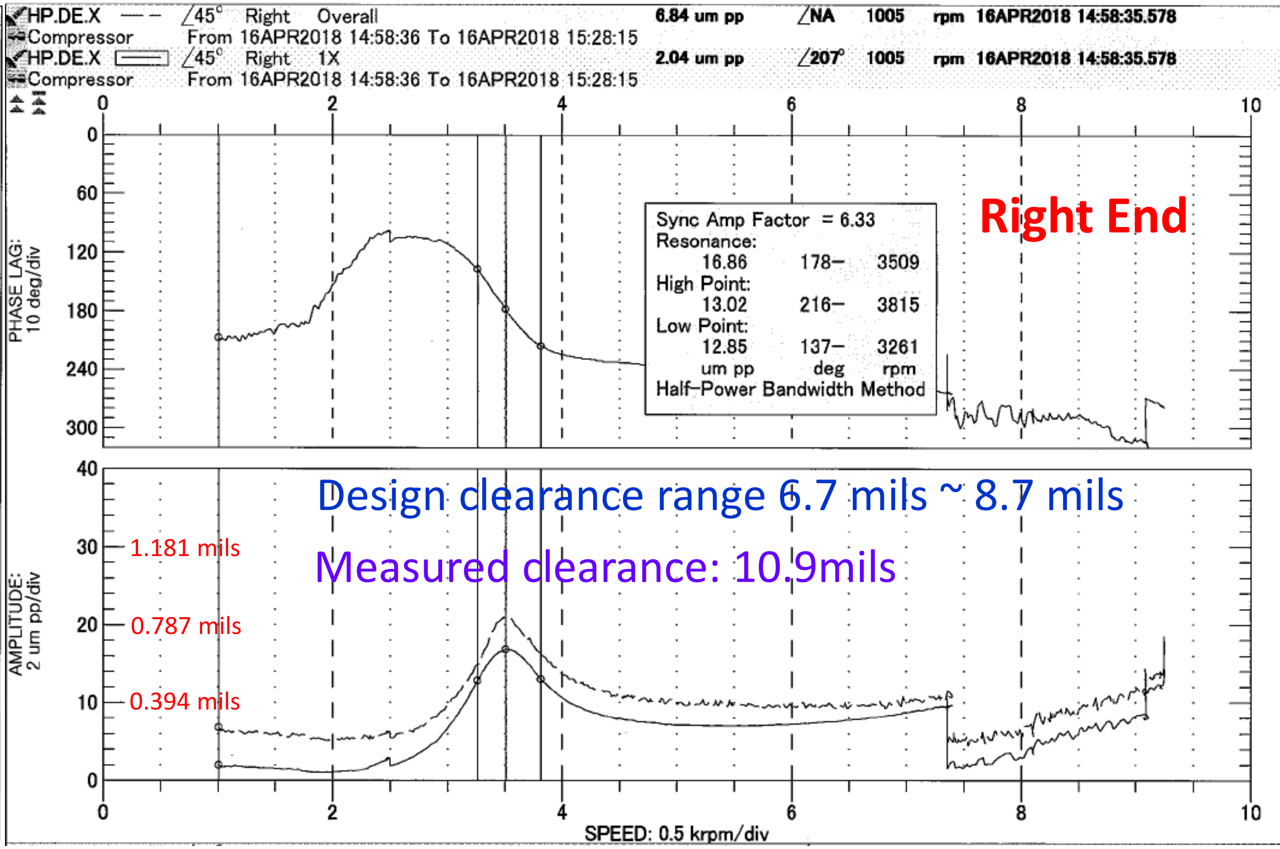
Right End Coupling Correction Unbalance: 0.502 oz-in

Mechanical Test

1st test floor mechanical test

Unexpected Morton effect

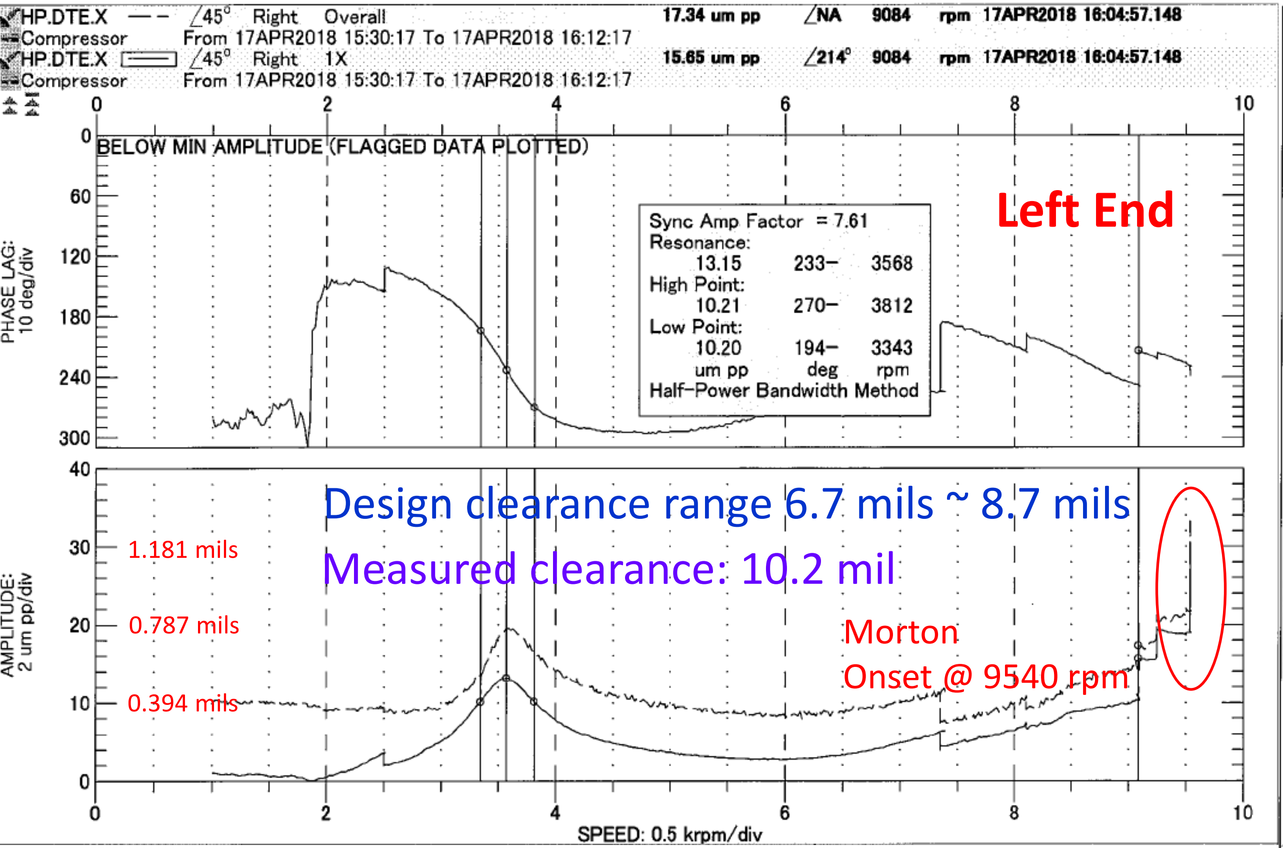


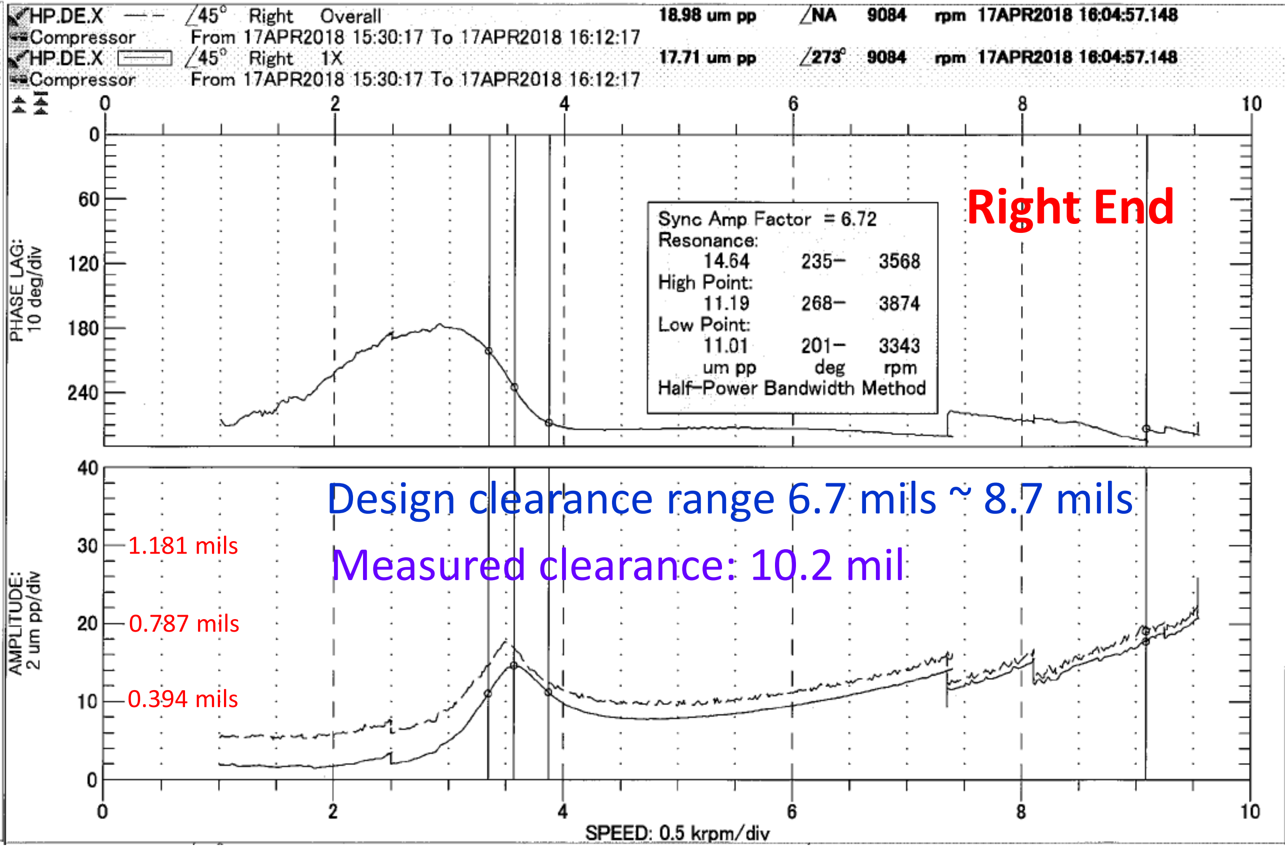


Compressor bearing support stiffness is more than 3.5 times the journal bearing film stiffness.
Bearings are the same as used during high speed balancing.
Slightly different measured clearance compared to high speed balancing due to assembly

2nd test floor mechanical test

A slight decrease in the bearing clearance gave a slightly better Morton effect response.

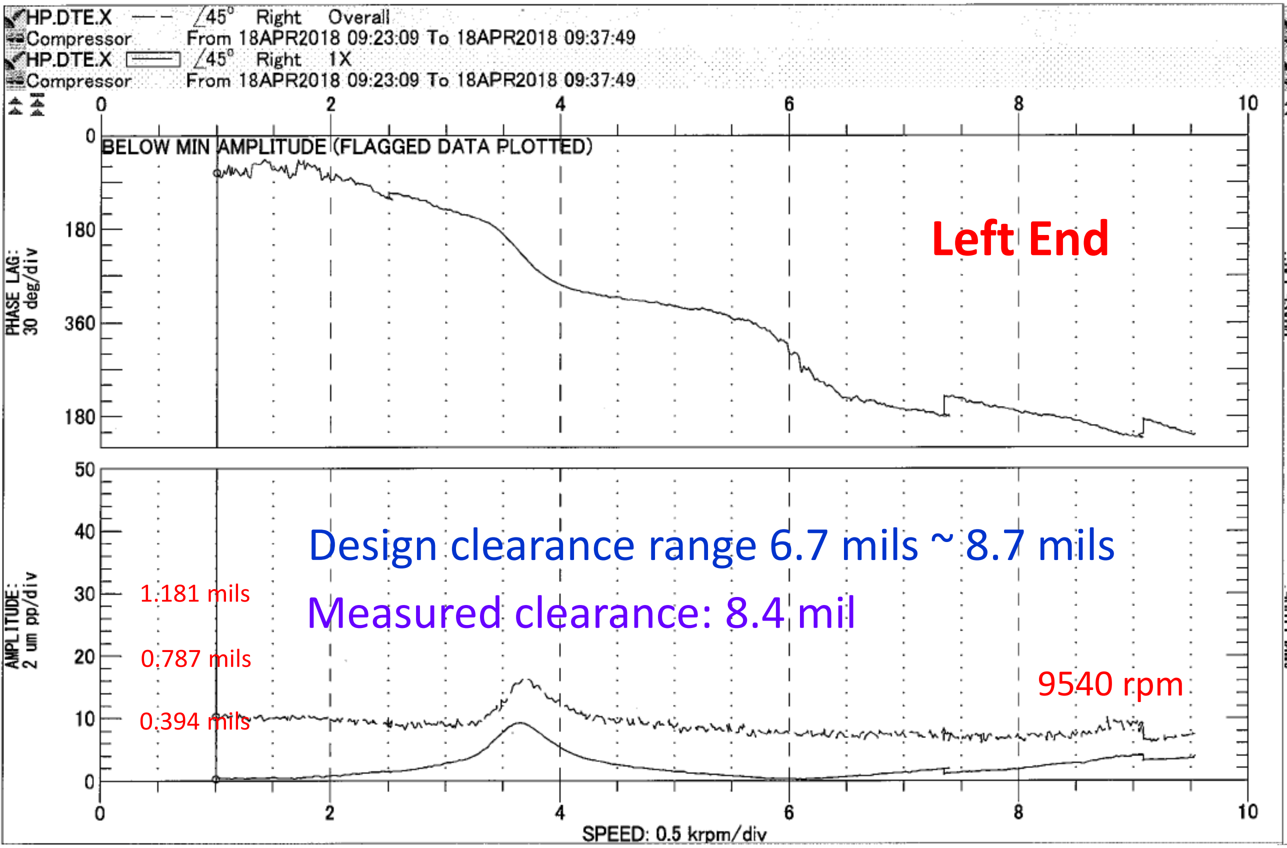


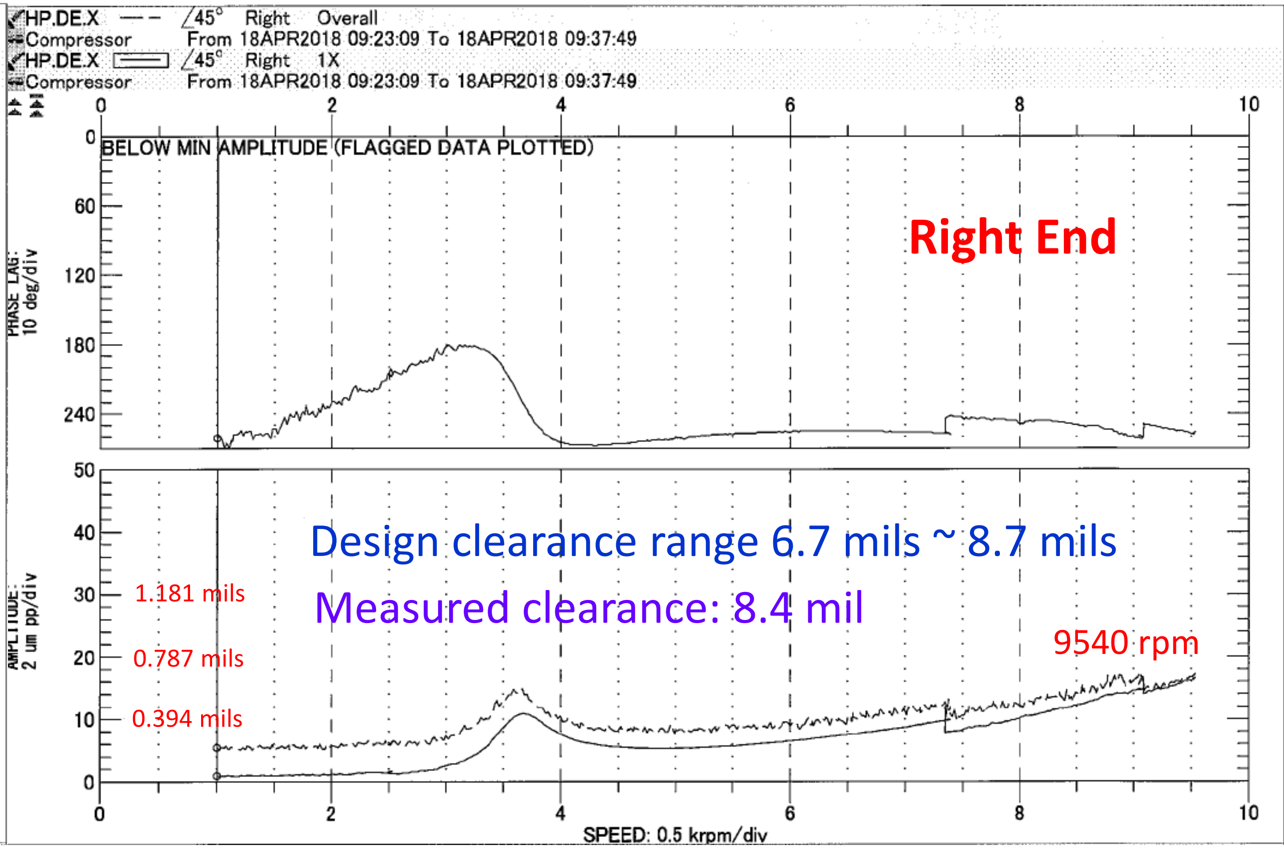


Change allows a higher speed (from 9000 to 9540 rpm)

3rd test floor mechanical test

Morton effect problem is solved





Decreasing the bearing clearance back into the original design range solved the Morton effect problem

Test Summary:

(1) Original design clearance got unexpected Morton effect during the high speed balance.

(2) The solution for the high speed balance was increasing the bearing clearance above 10 mils which was not indicated by the original design analysis which didn't include the pedestal effect.

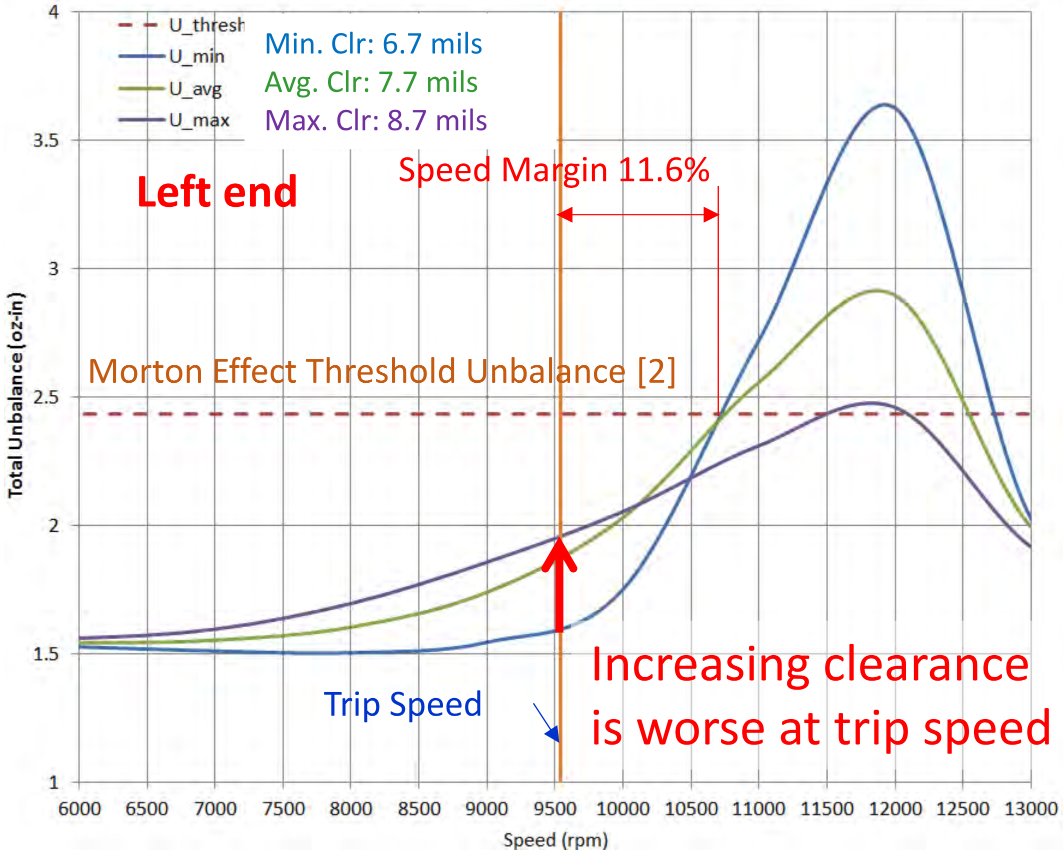
(3) When the unit was back to the test floor, Morton effect came up again and the solution was totally opposite to the high speed balance as decreasing the bearing clearance back to the original design clearance range of 6.7~8.7 mils solving the Morton effect.

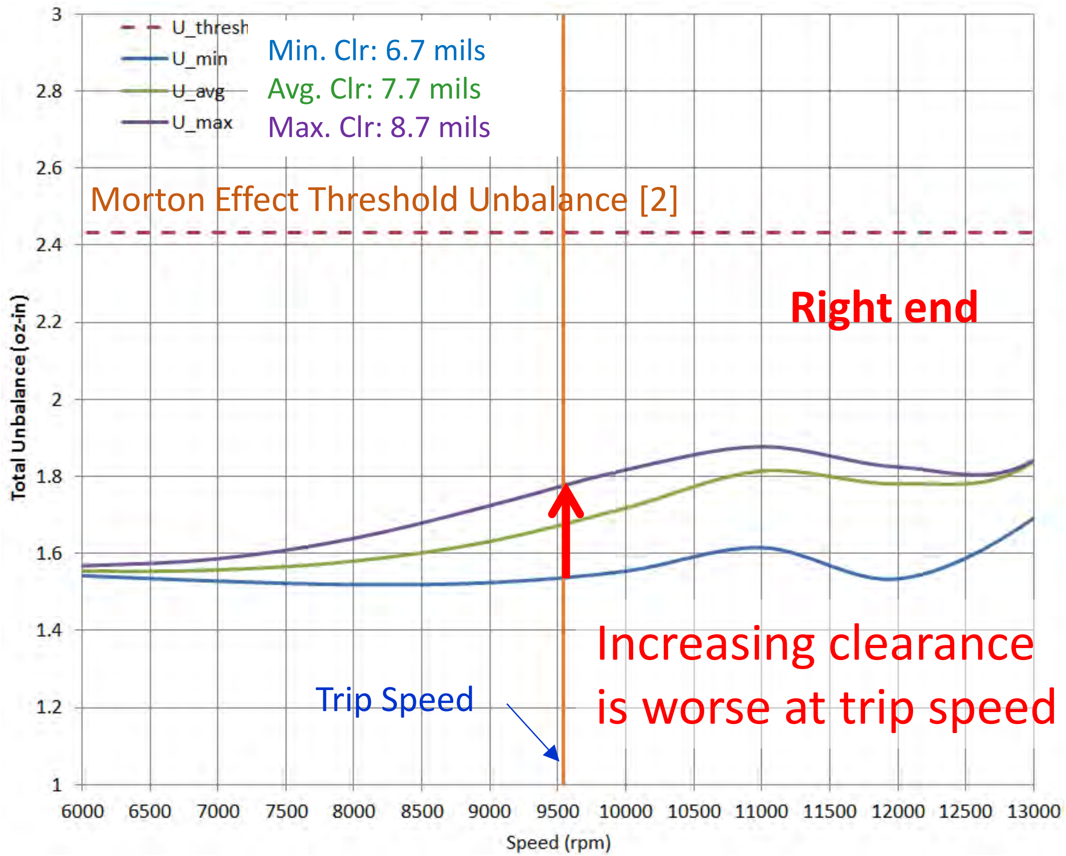
(4) We have had approximately 100 units that have required further Morton effect analysis, but only this unit has encountered such a Morton effect problem.

Investigation

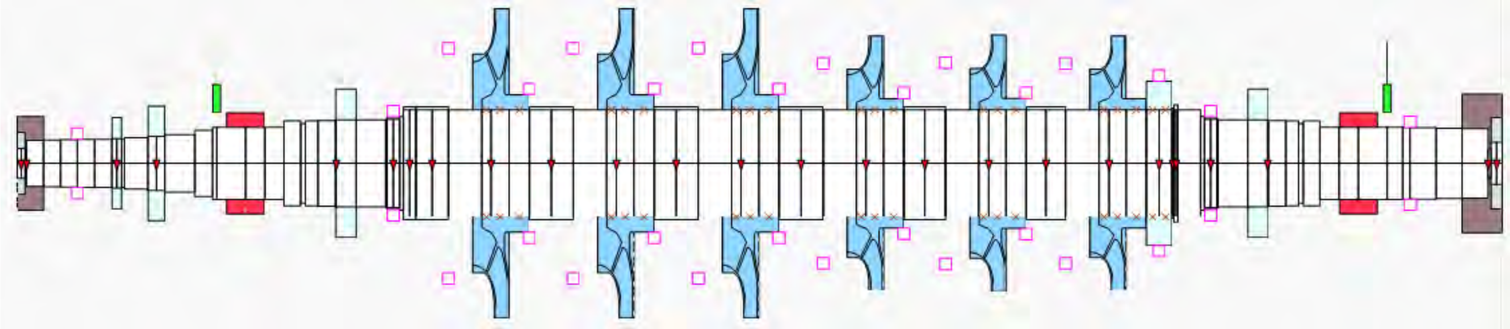
Recall: Design Morton effect analysis (pedestal influence not considered)

Morton effect results are below the threshold. Therefore, we expect this to be good.





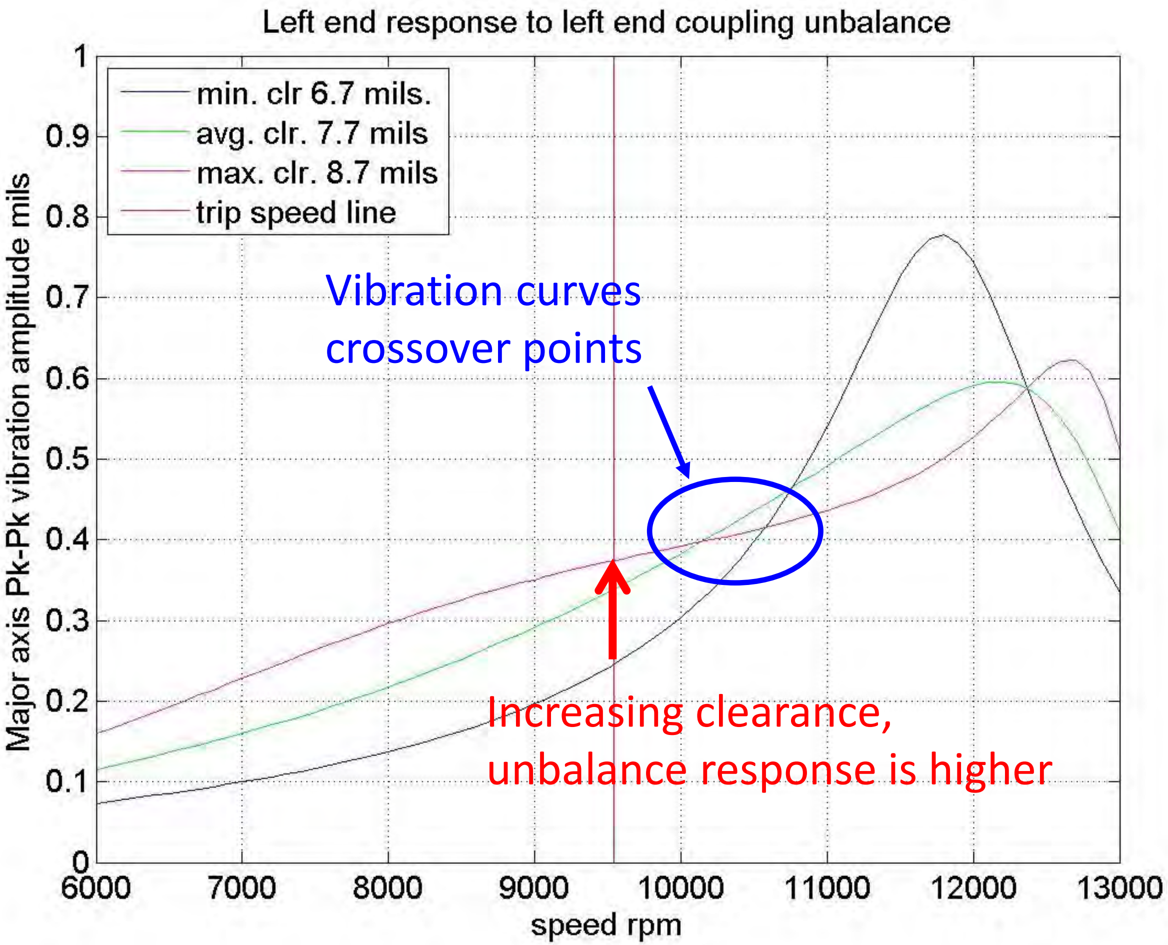
Drive Through End Has Morton Risk

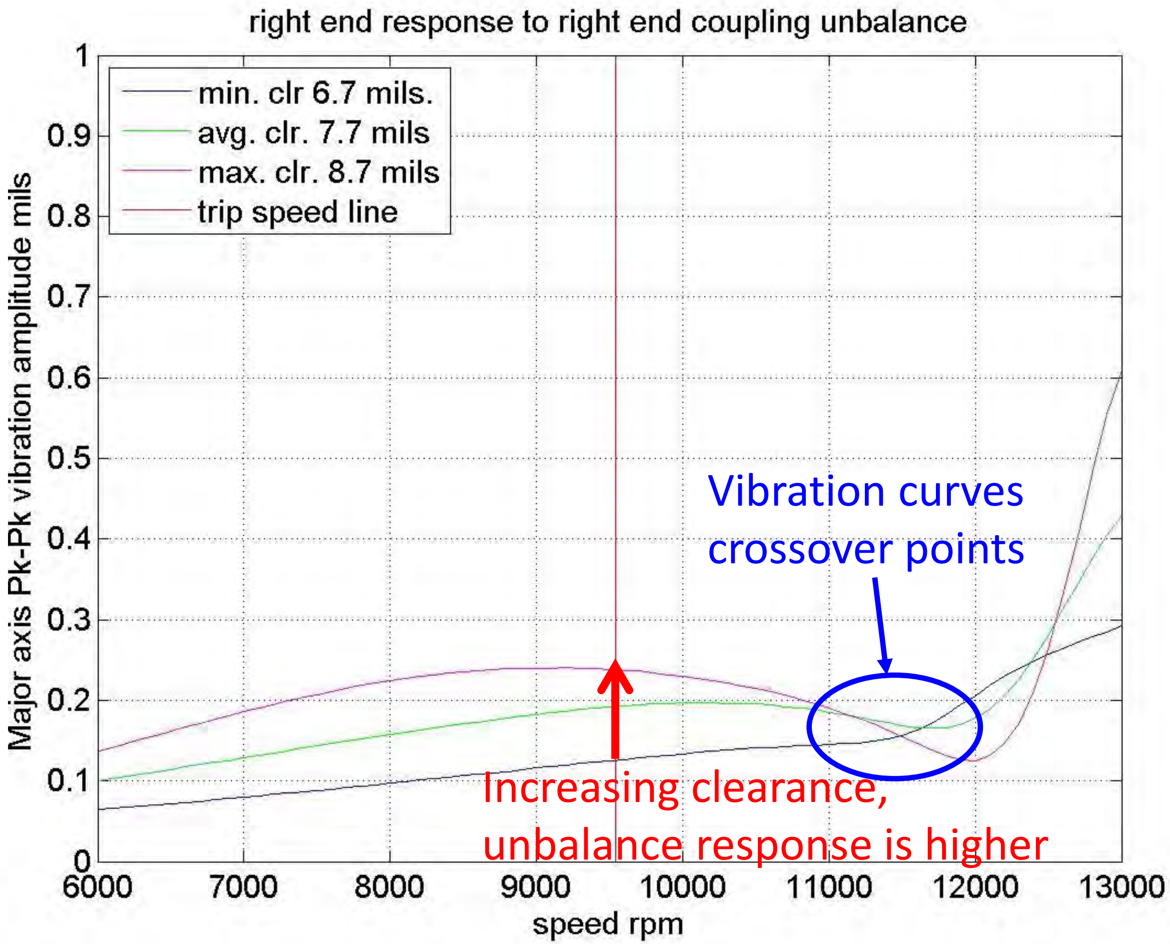


Drive End Risk Free

Design unbalance response analysis (pedestal influence not considered)

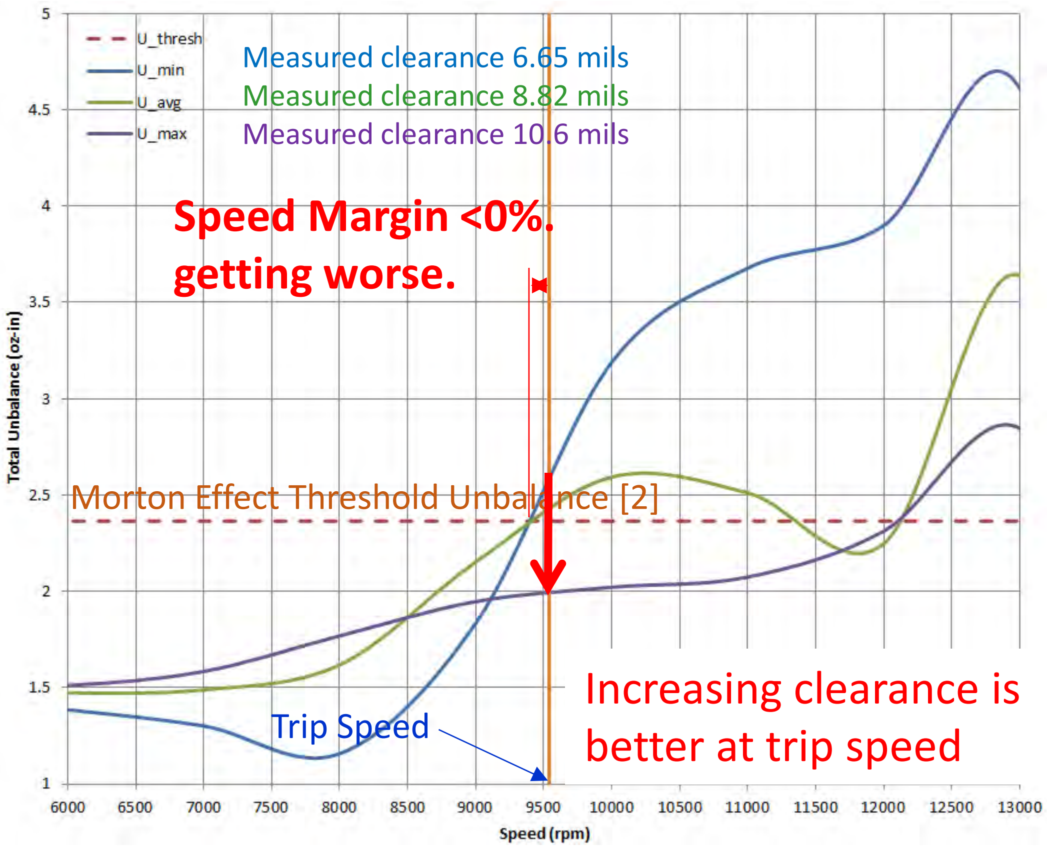
The unbalance response curves follow the Morton effect trend for this case:
Increasing clearance increases the unbalance response therefore feeding into the Morton effect.

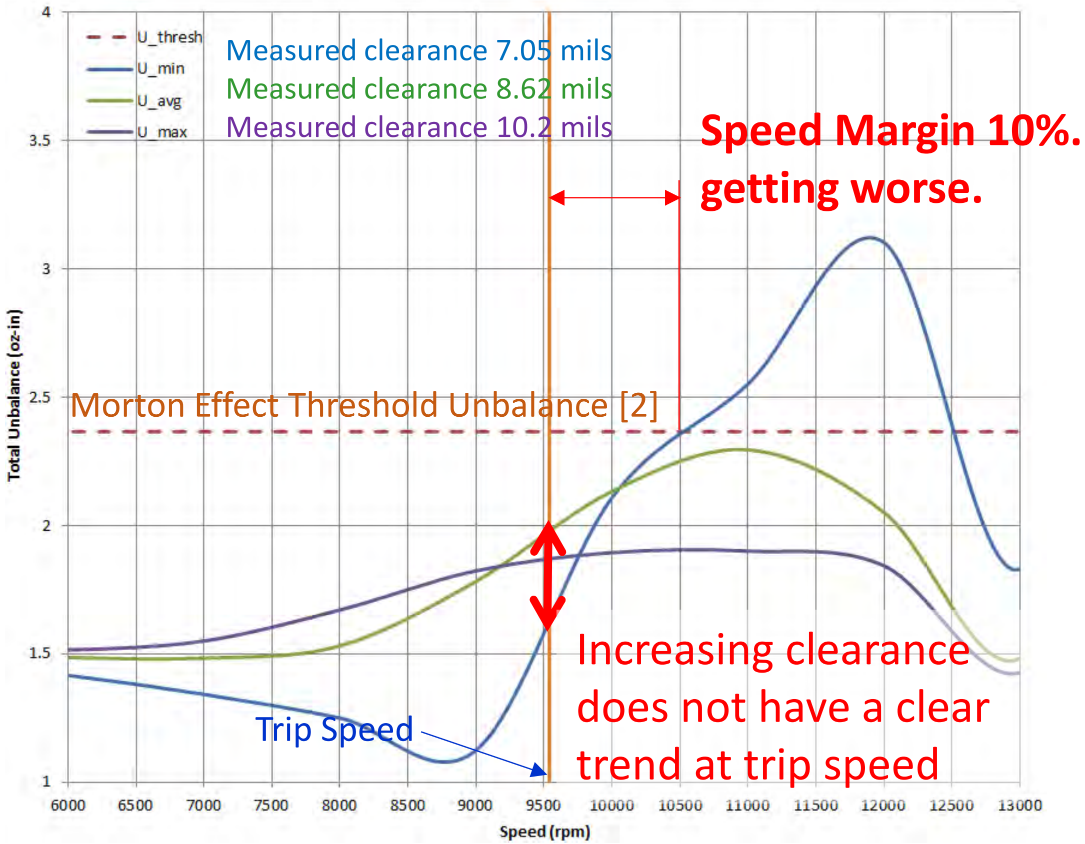




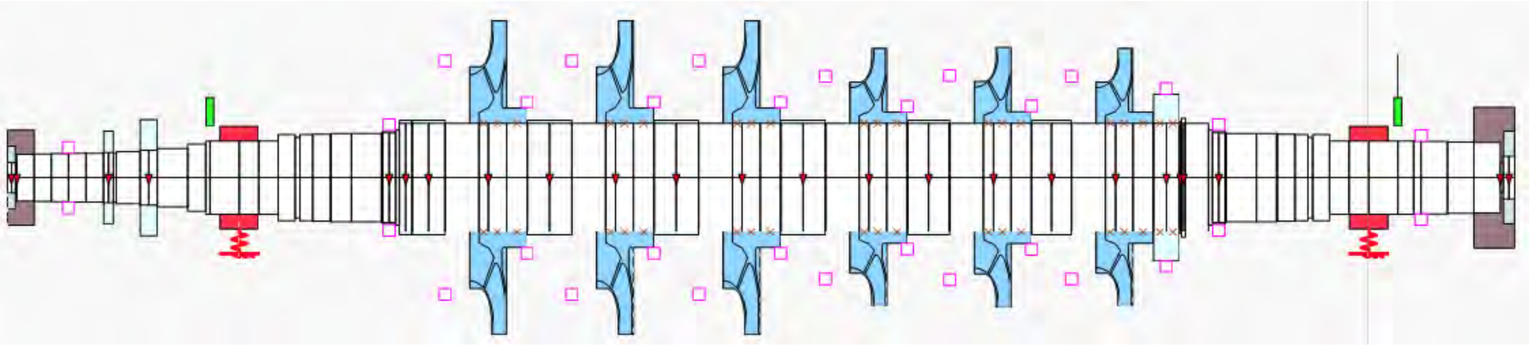
Morton effect analysis considering high speed balance pedestal influence

Morton effect risk on both ends increased due to the pedestal influence





Drive Through End Has Morton Risk



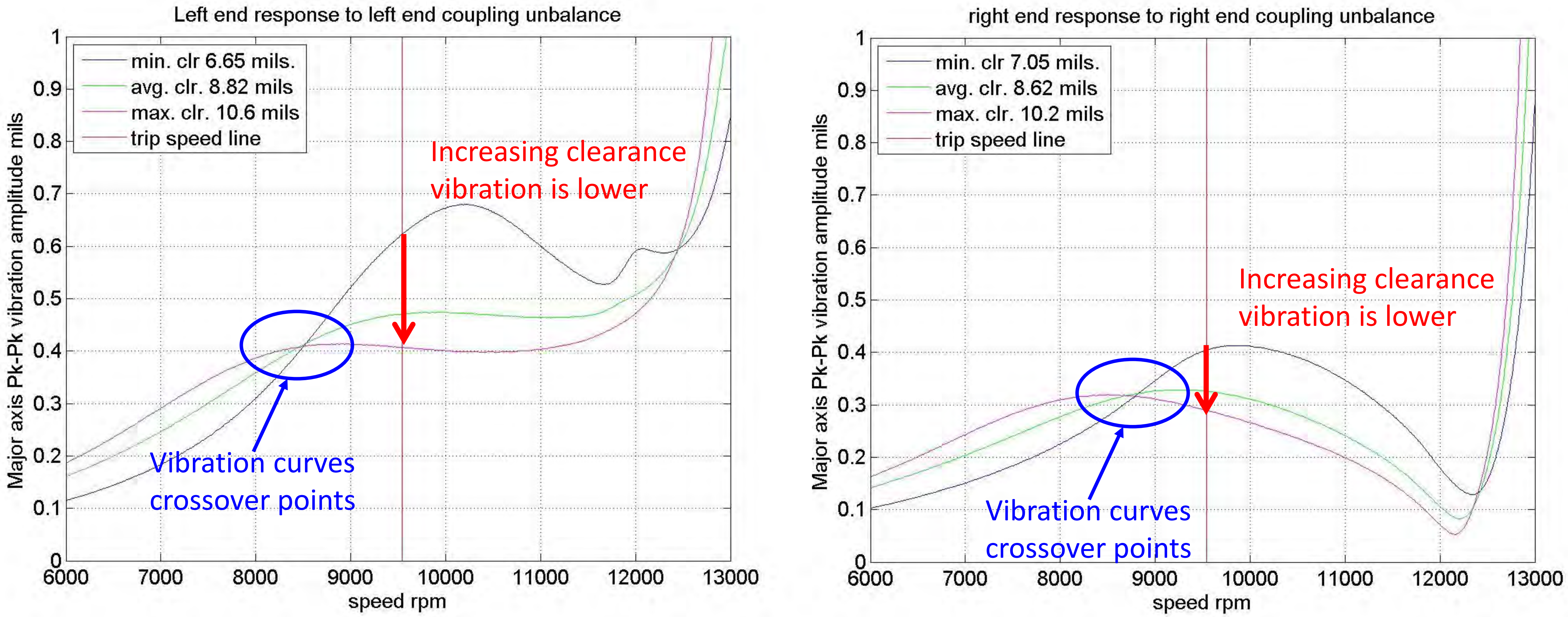
Drive End Has Morton Risk

Unbalance response analysis considering high speed balance pedestal influence

The unbalance response curves follow the Morton effect trend again on balancing pedestals

BUT the trend is the opposite direction of the stiff support analysis:

Increasing clearance decreases the unbalance response therefore suppressing the Morton effect.



Morton Effect Analysis Summary:

(1) Morton effect analyses and unbalance response are aligned following the same trends with respect to bearing clearance for both pedestal stiffness cases.

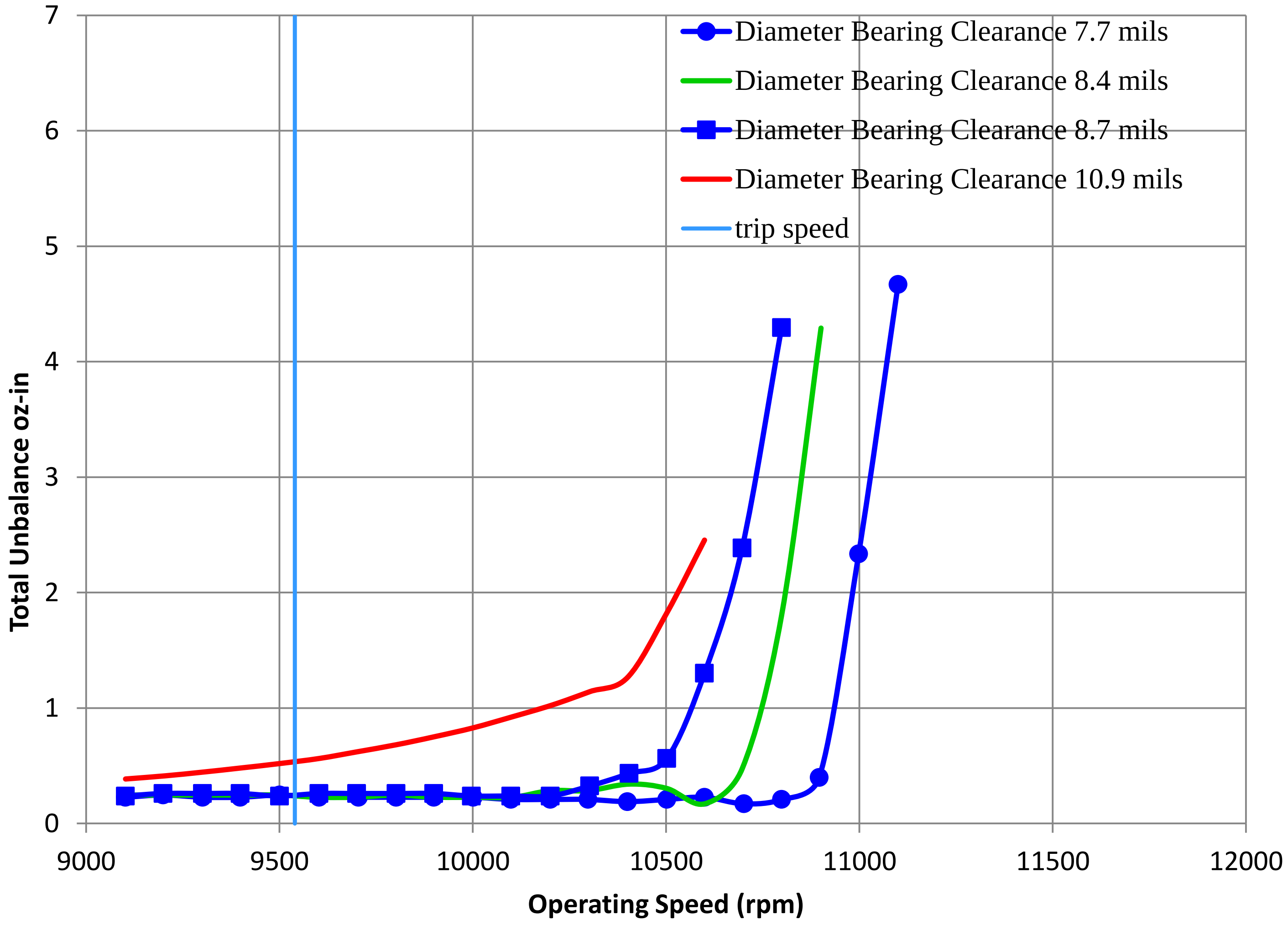
(2) Soft pedestal support of the high speed balance unit shifted the crossover points of the unbalance response curves and thus change the problem mitigation direction
  - increasing bearing clearance is better when supported on balancing pedestals.
  - decreasing bearing clearance is better when supported in the machine.

(3) Morton effect software requires benchmarking to tests to establish confidence levels.

(4) Current Morton effect code sometimes doesn’t converge. For this case, Morton effect analysis for the test floor is not convergent when using 10.9 mils clearance .

Morton effect analysis with alternative software [3-4]

Second code also indicates that high bearing clearance (10.9 mils) is worse than the design clearance range for stiff support condition.



Conclusion

(1) Screening method, which is benchmarked to the entire fleet, correctly identified Morton effect risk for this case therefore requiring further analysis.

(2) Morton effect was observed in the at-speed balance facility where the pedestal vs. bearing stiffness ratio is less than 3.5 (API standard). Morton effect was not observed on the test floor where the pedestal vs. bearing stiffness ratio is greater than 3.5.

(3) Current Morton effect prediction method did not predict the Morton effect behavior adequately for this case. A conservative acceptance criterion is needed for the method and this has been added into procedures.

(4) Morton effect during the high speed balance with pedestal influence indicated a solution (increasing clearance) which was different from the test floor Morton effect mitigation (decreasing clearance).

(5) Adjusting the bearing clearance was an effective way of mitigating Morton effect.

References

[1] Qingyu Wang, Brian Hantz and Brian C. Pettinato, 2018, "API High Speed Balancing Acceptance Criteria And Pedestal Dynamics", 47th Turbo Machinery & 34th Pump Symposia

[2] Avinash C. Balbahadur and R. Gordon Kirk 2004, "Part I Theroretical Model for a Synchronous Thermal Instability Operating in Overhung Rotors", International J. of Rotating Machinery, 10 (6)

[3] Palazzolo, A., " Junho Suh and Alan Palazzolo, 2014, "3D Nonlinear Transient Morton Effect Simulation: Theoretical Model and Parametric Studies – 3D Dynamic Model of TEHD Cylindrical – Pivot Tilting – Pad Journal Bearing: Theoretical Model and Parametric Studies", Turbomachinery Research Consortium Annual Report

[4] Tong, X and Palazzolo, A., 2017 "Double Overhung Disk and Parameter Effect on Rotordynamics Synchronous Instability-Morton Effect: Part I: Theory and Modeling", ASME J. Tribol. 139 (1)