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Correction of High Vibration on a Vertical Turbine Deep Well Pump with a Dynamic Vibration Absorber

Benjamin Bryant
Matthew Moll

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TEXAS A&M UNIVERSITY

TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

Authors

Benjamin Bryant

Benjamin Bryant is a Production Manager of the Baling and Warehouse units for Celanese Corporation in Narrows, VA. Previous to this role, Ben was a Mechanical Integrity Engineer supporting the entire Narrows facility. Ben received his BS in Mechanical Engineering from North Carolina State University in 2014.

Matthew Moll

Matthew D. Moll is a Principal Rotating Equipment Engineer in the Core Technology Group for Celanese Corporation, based from Narrows VA. Previous to Celanese, Matthew was a Rotating Equipment Engineer for E. I. du Pont de Nemours and Company. Matthew received his BS in Mechanical Engineering from Virginia Polytechnic Institute and State University in 2003.

Case study on the correction of chronic high vibration on a Vertical Turbine Deep Well Pump with a Dynamic Vibration Absorber

A vertical turbine pump called #12 Well had a history of reoccurring high vibration despite multiple pump rebuilds and motor replacements. The problem was identified as a structural resonance of the motor and discharge head assembly. It was determined that a dynamic vibration absorber (DVA) would be the most effective solution. This case study presents the technique of diagnosing the resonance and the methodology of designing and calibrating a dynamic vibration absorber. Installation of the DVA reduced the overall vibration velocity amplitude by a factor of 16.

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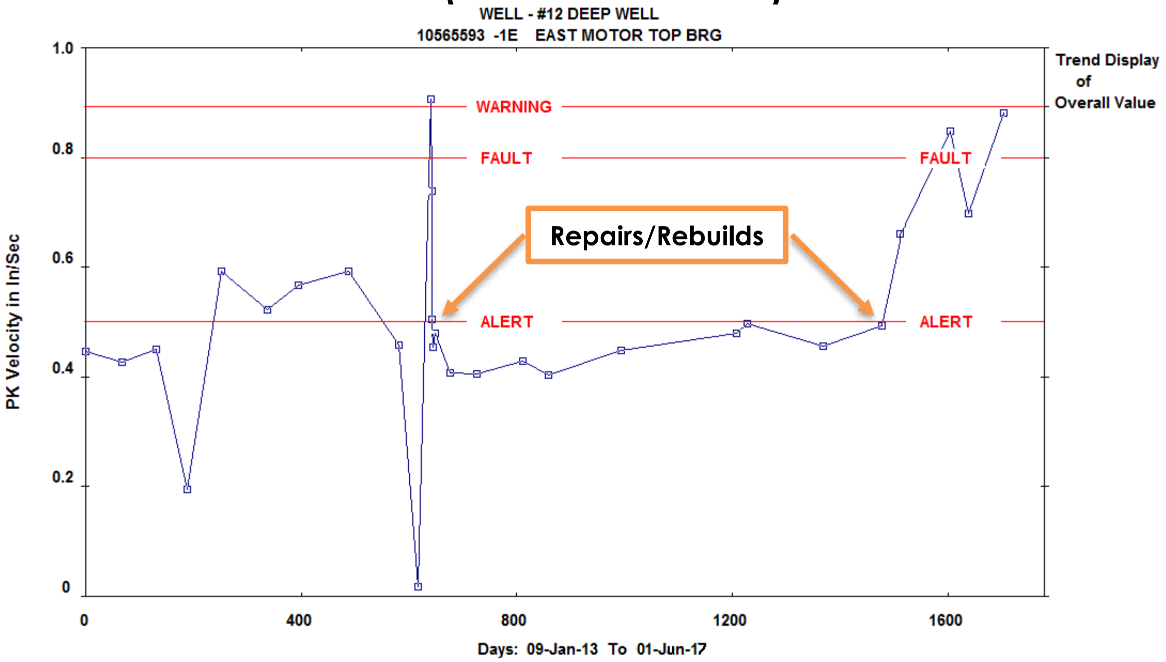
Problem Statement

- A 100hp, 1780 RPM, 180 ft. deep well vertical turbine pump experienced chronic recurring high vibration.
- Despite multiple repair and rebuild attempts to the pump, motor, and foundation the issue would return within a few months of operation.
- This pump was rebuilt in early March, 2017 and experienced alert and fault level alarms (> 0.8 ips velocity overall) by late April.

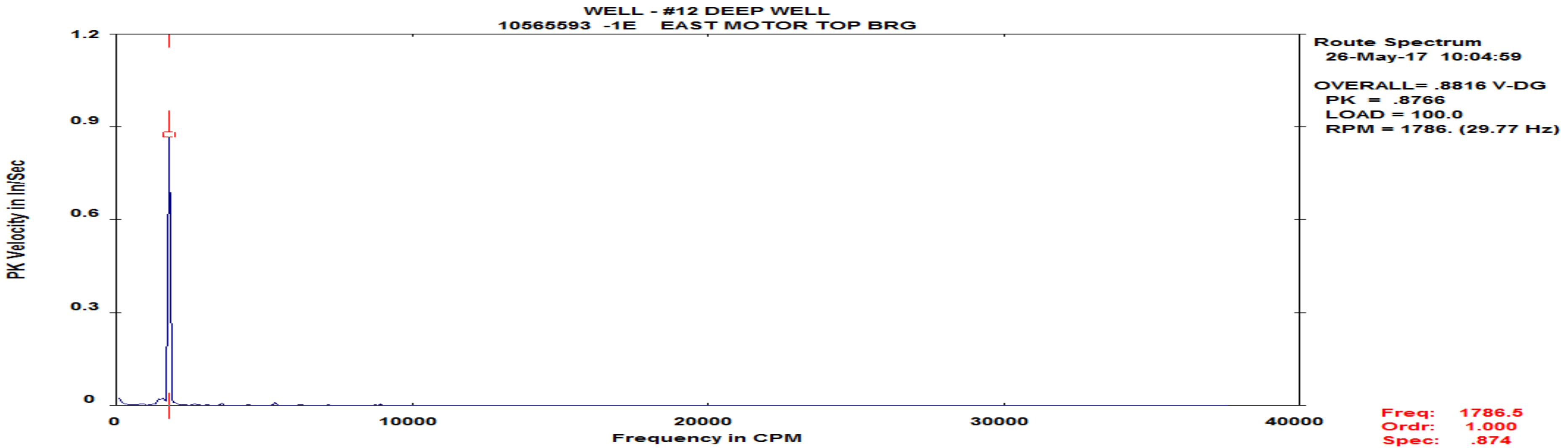
Diagnosis

- Consistently recurring high vibration despite multiple repairs and rebuilds (2013-2017)



Diagnosis

- The velocity amplitude at 1x RPM was significantly higher than any other peak.



Diagnosis

- Reviewing the vibration data with the understanding that this pump underwent a partial rebuild only a few months prior led to the investigation of a potential resonance.
- Imbalance was ruled out for two primary reasons
  1. Tightening loose bolts in the body flange to concrete base increased vibration from ~0.75 ips to ~1.0 ips
  2. Motor was replaced at this time due to brass (cage material) found in the oil. The 2nd motor was solo run on rubber pads and produced ~0.05 ips however once mounted (uncoupled) ran ~0.75 ips

Diagnosis

- Using a portable vibration analyzer, impact testing was conducted on the pump's motor when the pump was down. Natural frequencies detected at 1781CPM and 2200 CPM in both planes
- Having natural frequencies within 20% of the operating range allowed a small forcing frequency to be significantly amplified.
  - The closer a natural frequency is to the forcing frequency, the larger the resonating effect.

Solutions

- Moving the system's natural frequency far enough away from the pumps operating speed will drastically reduce the amplification factor.
- Since the natural frequency of a system is a function of it's stiffness and it's mass, the only way to resolve the resonating motor was to either change it's mass, or change it's stiffness.
- Increasing the mass or lowering the stiffness will lower the natural frequency while reducing mass or increasing stiffness will increase natural frequency.

Solutions Considered

- Replace pump and foundation to resolve the underlying vibration source
- Install stiffening members (e.g. I-beams)
- Add mass to the pump
- Design and install a Dynamic Vibration Absorber (DVA)

Dynamic Vibration Absorber Design

- Dynamic absorber chosen for practicality and for proximity to a second natural frequency
- A design routine published in 1998 November Edition of Sound and Vibration Magazine authored by Richard Smith "Dynamic Vibration Absorbers" was utilized for absorber engineering
- Cardboard templating came in handy too

Dynamic Vibration Absorber Design

	Units	
Weight of Motor	lb	1200
Mass Effectiveness Ratio		0.9
Mass Effectiveness Ratio	in*lb/sec^2	2.797927461
Resonance Frequency	CPM	1780
Measured Velocity	in/sec	1
Elapse Time - dT (1/4 Cycle)	sec	0.008426966
average acceleration	in/sec^2	118.6666667
peak acceleration	in/sec^2	186.3066667
Weight (Force)	lb	521.2725389
Length of Spring (Rod)	in	12
Number of Springs	qty	4
Spring Moment	in*lb/# of springs	1563.817617
Spring Radius (Assume Round Rod)	in	0.697
Spring (Inertia for Rod)	in^4	0.185361966
Peak Stress in Rod	lb/in^2	23521.13333
Resonance Frequency In Radians	Rad	186.4010067
Spring Constant (Rod)	lb/in	9654.26906
Mass Effective of Absorber	lb / per absorber	107.2531845

$$M_{eff} = \frac{W \times (MER)}{g}$$

$$dt = \left(\frac{1}{RPM}\right)\left(60\frac{Sec}{Min}\right)\left(\frac{1R}{4}\right)$$

$$a_{ave} = \frac{v\,\frac{inch}{sec}}{Time\ sec}$$

$$a_{Peak} = 1.57 \times a_{ave}$$

$$F = M \times A$$

$$\text{Moment} = \frac{F \times L}{\#\ of\ Springs}$$

$$I = \frac{\pi}{4}r^4$$

$$\sigma = S\frac{Mc}{I}$$

$$\omega_f = \left(\frac{R}{Min}\right)\left(\frac{1\ Min}{60\ Sec}\right)\left(2\pi\frac{rad}{R}\right)$$

$$K = \frac{3EI}{L^3}$$

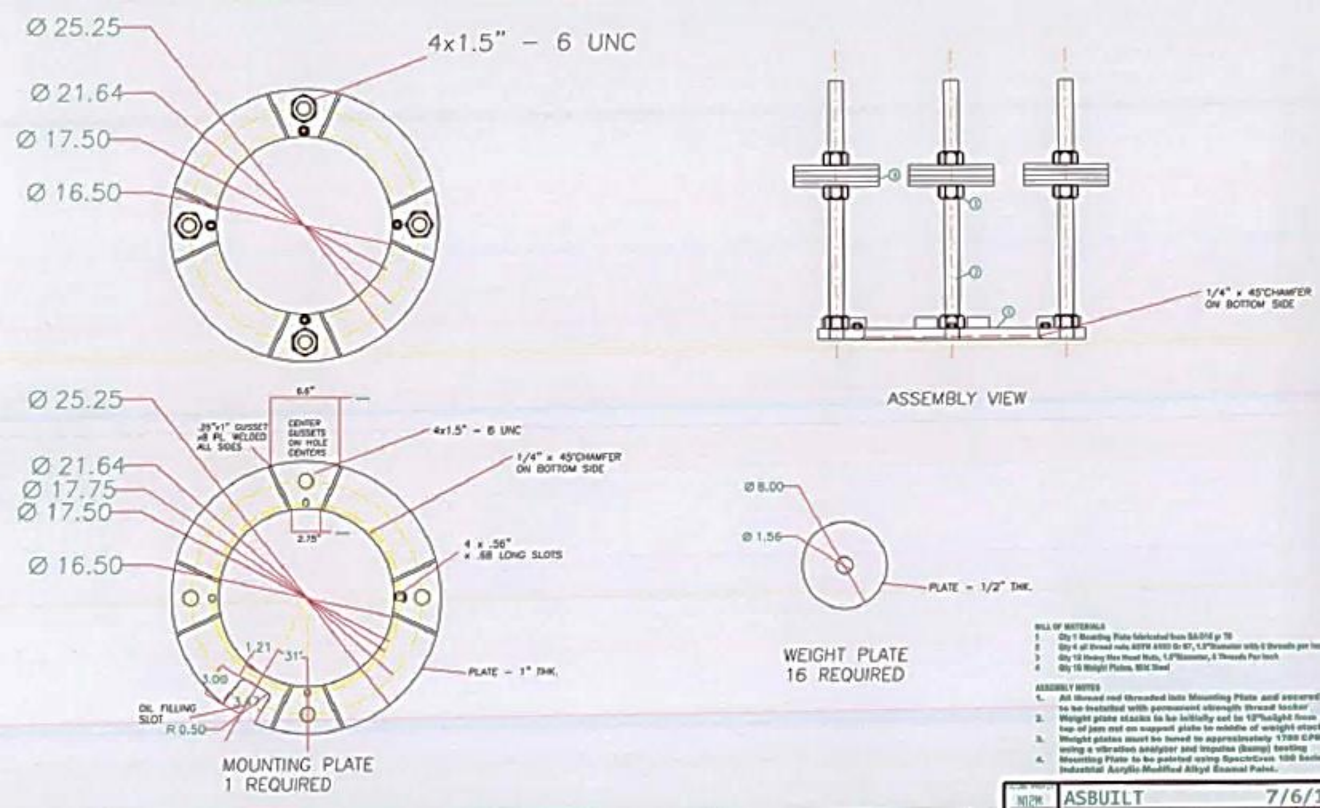
$$M_{eff} = \frac{K}{\omega^2}$$

Weight Per Foot of Rod	lb /in of 1.5" all t.	0.462
Weight of spring	lb	22.176
Mass Effective Correction	lb	102.1527045
Mass Per Spring		25.53817613

Support Plate		
Plate Thickness	in	0.75
Plate Inner Diameter	in	16.5
Plate Otter Diameter	in	25.25
Plate Volume	in^3	215.1866432
Weight Per Volume	lb/in^3	0.284
Weight of Plate	lb	61.11300666

Weight Plates		
Plate Thickness	in	0.5
Plate Inner Diameter	in	1.56
Plate Otter Diameter	in	8
Plate Volume	in^3	24.17704832
Weight Per Volume	lb/in^3	0.284
Weight of Plate	lb	6.866281723

Dynamic Vibration Absorber Design



Dynamic Vibration Absorber Design

- The initial design to use one weight plate supported by four threaded rods was impractical due to the difficulty of tuning.
- To solve this, the weight was divided in four and individual weight plates were placed on each of the four threaded rods. This method was much easier to install and tuning was predictable with length.

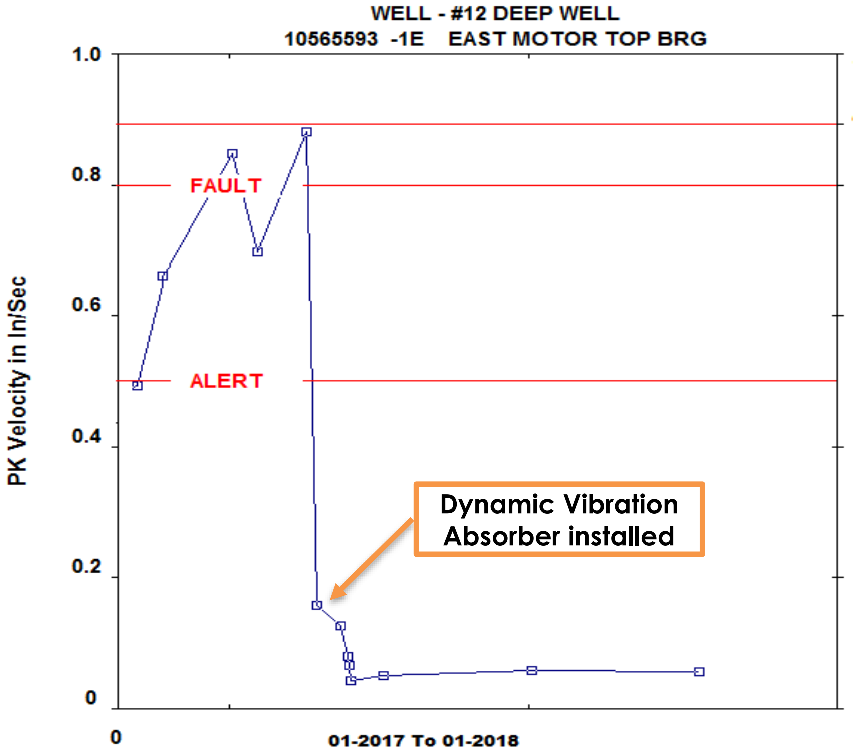
Calibration

- Initial calibration was performed in the shop. An impact test was performed on each set of weights. The weights were then adjusted up or down to resonate at the frequency intended to absorb 1780 CPM.
- Final calibration was performed in the field. Using the same techniques as in the shop, the DVA required more fine tuning once installed to ensure the natural frequencies of the weights matched that at which the vibration was occurring.

Results

- Overall vibration was reduced from 0.947 inches per second to 0.058 inches per second peak velocity.
- 9 months run-time (to date) with no failures or significant changes in overall vibration

Results



WELL - #12 DEEP WELL
10565593 -1E EAST MOTOR TOP BRG
PK Velocity in In/Sec
1.0
0.8
0.6
0.4
0.2
0
FAULT
ALERT
Dynamic Vibration Absorber installed
0
01-2017 To 01-2018