UTILIZING SUB CYCLE SPEED OPTIMIZATION TO IMPROVE WELL PERFORMANCE

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INTRODUCTION

The oil and gas industry has used Variable Frequency Drives (VFDs) for decades to match production to inflow. In sucker rod pump applications, it is well understood that optimizing pumping speed dramatically improves pump efficiency and failure rate. The same technology provides the opportunity to make multiple speed changes in a pumping cycle.

The effects of speed changes within a pumping cycle were analyzed using predictive modeling, advanced rod stress and axial load calculations. In addition, a 5-year trial was conducted on a population of over 30 wells. As predicted by modeling software, a sizable majority of wells saw a fall in failure rate, many by impressive margins.

MOTIVATION

Long stroke pumping units operating at near the maximum allowable average speed, must slow down at the velocity reversal points to allow the weight box to smoothly transition. Wells operated by long stroke units had surprisingly low failure rates when compared to the rest of the field. It was speculated that the rod string would be exposed to lower compressive forces by reducing the speed through the top of stroke transition. An effort to investigate this theory began.

THEORETICAL RESULTS

Utilizing advanced predictive modeling software, a variety of speed profiles were evaluated. Pump off controllers in these fields are set to maintain a high pump fillage, therefore the profiles were compared assuming 96% fillage to mimic site conditions. Key metrics for comparison were estimated production, axial load and location of the neutral point. The neutral point is the location on the string which rods are no longer held in tension. Research has shown that the neutral point must be considered a dynamic rather than a static parameter [1]. However, to simplify our analysis, we will focus on the highest position in the string that is subject to 0 lbs of axial load at any point in the pumping cycle. Compression predicted in the ¾" taper has the most impact on fatigue life, since critical buckling loads are substantially lower for smaller diameter rods [2, 3].

Two wells were chosen as examples of sub cycle speed optimization. In each case, three different speed profiles were modeled (Table 1). The first profile is the status quo where the unit is running at a constant speed and meeting its production target. Profile two models the unit running at a constant speed that matches the average SPM of the optimized profile. Profile three is the optimized profile, reducing speed before the top of stroke and accelerating after the transition to downstroke.

For both Well A and Well B, the model predicted concerning compressive loads in the ¾" taper using constant speed profiles. The optimized profiles reduced max compressive load in the rod string and pushed the neutral point down to the bottom of the 1 5/8" sinker bars (Figure 1,2). In addition, optimized profile for Well A benefits from a notable increase in net stroke, allowing the production target to be achieved at a lower average SPM.

Table 1: Speed profile comparison

Well A									
Profile	AVG SPM	Speed Change (%)	Beginning of speed reduction (Upstroke)	End of speed reduction (Down Stroke)	Minimum Axial Load (lbs)	Neutral Point (ft)	Neutral Point Taper Diameter (in)	Structural Loading	Estimated Production (bbl/d)
1	6.9	0%	NA	NA	-1809	7375	3/4"	0.91	268
2	6.6	0%	NA	NA	-1486	7500	3/4"	0.91	247
3	6.6	30%	84"	143"	0	8800	Pump	0.89	268

Well B									
Profile	AVG SPM	Speed Change (%)	Beginning of speed reduction (Upstroke)	End of speed reduction (Down Stroke)	Minimum Axial Load (lbs)	Neutral Point (ft)	Neutral Point Taper Diameter (in)	Structural Loading	Estimated Production (bbl/d)
1	6.7	0%	NA	NA	-290	7300	3/4"	0.84	568
2	6.9	0%	NA	NA	-635	7020	3/4"	0.84	589
3	6.9	15%	179"	213"	0	8500	Pump	0.85	568

Well B: M1280-427-216				
Pump	2.00"	Tubing	3.5"	
Taper	Material	Length (ft)	Diameter (in)	Total Length (ft)
1	Steel	2597	1	2597
2	Steel	2825	0.875	5422
3	Steel	2775	0.75	8197
4	Steel	300	1.625	8497

Well A: M912-427-168				
Pump	1.75"	Tubing	3.5"	
Taper	Material	Length (ft)	Diameter (in)	Total Length (ft)
1	Steel	2000	1	2000
2	Steel	2400	0.875	4400
3	Steel	3850	0.75	8250
4	Steel	350	0.875	8600
5	Steel	200	1.625	8800

Table 2: Sucker rod design

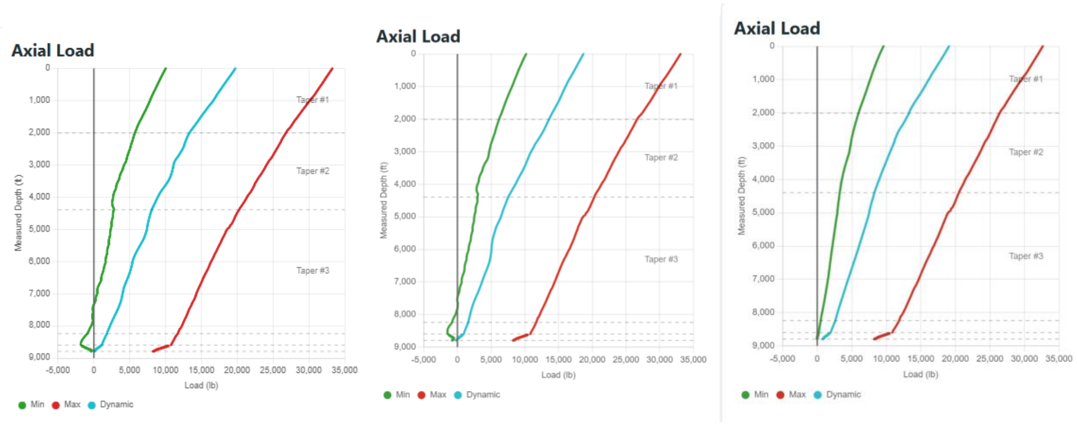

Figure 1: Well A axial load charts for profile 1,2 and 3 respectively

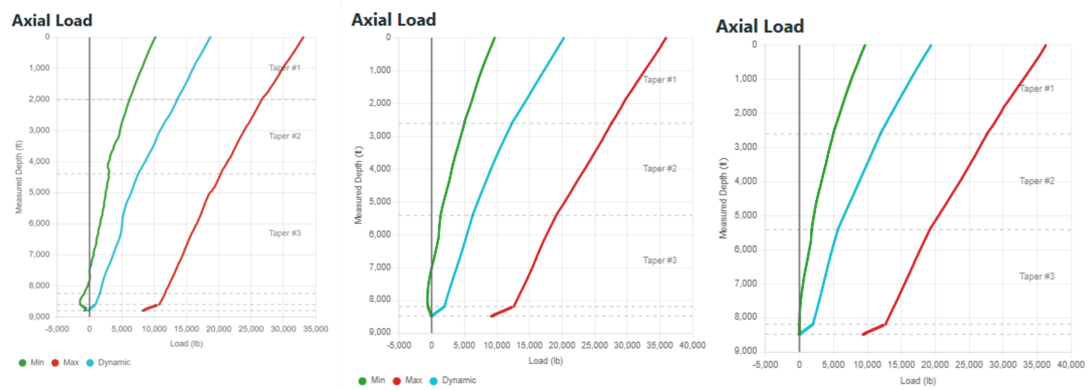

Figure 2: Well B axial load charts for profile 1, 2 and 3 respectively

FIELD OBSERVATIONS

Field data was collected to compare constant speed operation to the optimized speed profile at the same average SPM. While a method of measuring the neutral point or compressive force directly is not available, several data points were compared to understand the effects of an optimized speed profile. Excellent research has been conducting showing a strong relationship between polished rod velocity (PRV) and failure rate [4]. In our case, PRV is no longer strictly governed by pumping unit geometry, so the peak polished rod velocity (PPRV) of the upstroke and downstroke were compared. In addition, since the rod string may be more vulnerable at different parts of the stroke, the position in the downstroke that the PPRV is achieved was recorded. To help understand the magnitude of the force applied to the rod string, peak polished rod acceleration (PPRA) is compared. Finally, net stroke is compared to understand the impact of the profile on pump efficiency. The observational data is summarized in table 3.

Well	Profile	Upstroke PPRV	Downstroke PPRV	Upstroke PPRA	Downstroke PPRA	Downstroke PPRA Position	Net Stroke Length
Well A	Constant	53.3	70.8	36.2	64.9	104"	118"
Well A	Optimized	65.4	56.4	40.9	37.6	74"	127"
Well B	Constant	73.8	97.4	55.7	92.6	125"	205"
Well B	Optimized	78.4	96.2	54.1	83.1	119"	200"

Table 3: Summary of field observations

Several things stand out the field data from Well A running at a constant motor RPM (Figure 5). Governed by the Mark II pumping unit geometry, both the PPRA and PRV are significantly higher on the downstroke. The polished rod hits its maximum velocity while the plunger velocity is essentially 0, this is a perfect recipe for the buckling conditions predicted in the model.

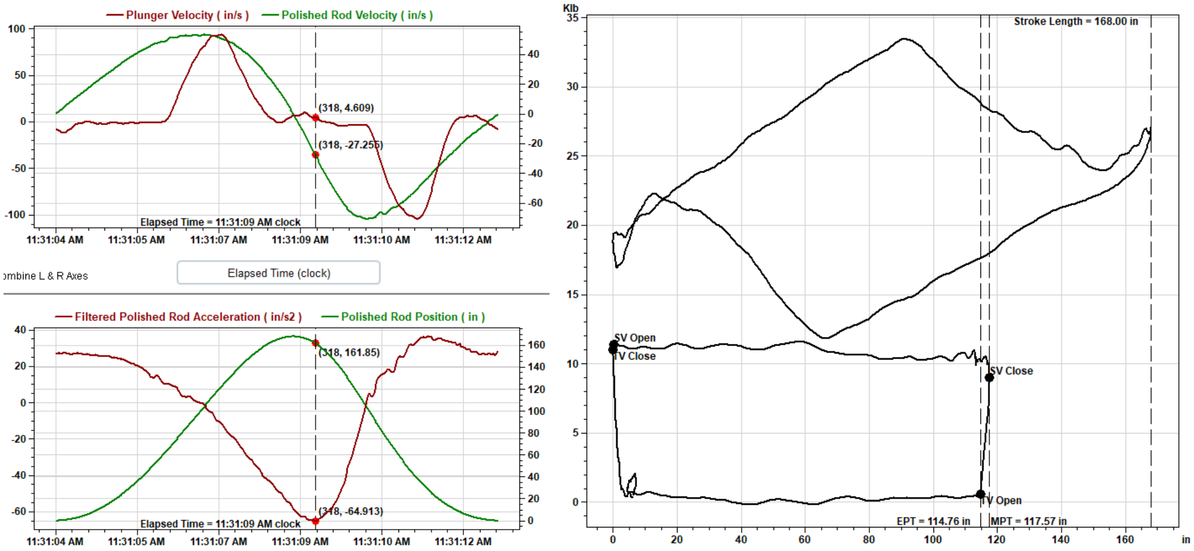

Figure 5: Well A Field Data – Constant Speed Profile

The optimized profile provides a 9” gain in net stroke, as predicted by the model (Figure 6). Further, Downstroke PPRA is reduced by 42%, and downstroke PRV 20%. This injects significantly less energy into the string as it decends on the pump. The PRV is achieved after plunger movement has started, indicating productive work, rather than distructive buckling.

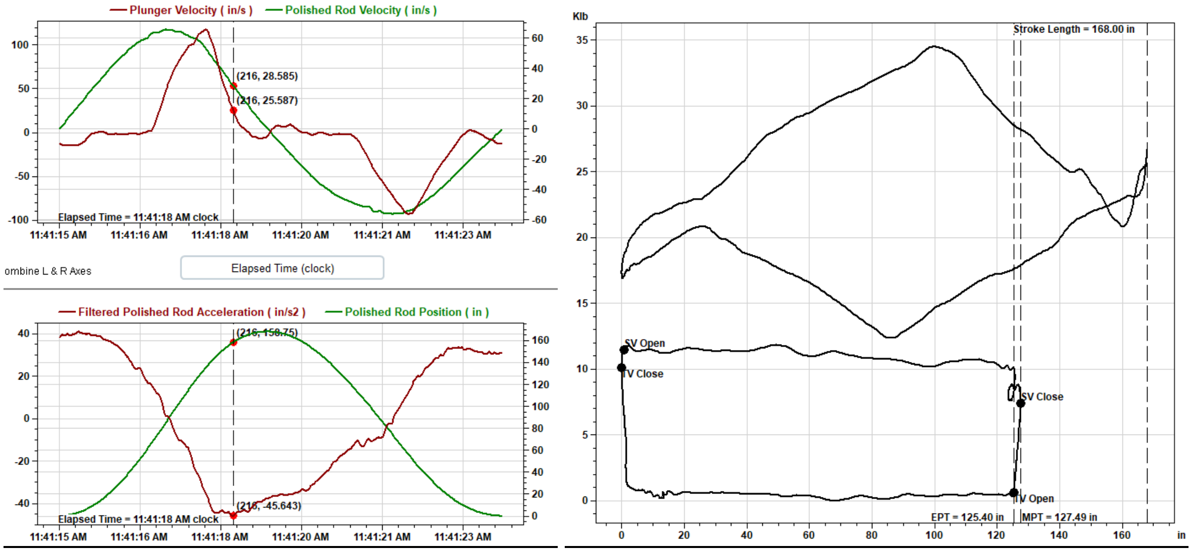

Figure 6: Well A field data – optimized speed profile

Although the profile is less aggressive than Well A, the field data collected at Well B is similar. In the constant speed profile, violent acceleration and a high downstroke PPRV are present before plunger movement begins (Figure 7). Unfortunately, the small loss in plunger movement predicted by the model was observed. Even running at a slightly higher average SPM, the optimized profile better aligned plunger and polished rod movement and provided a lower downstroke PPRA (Figure 8).

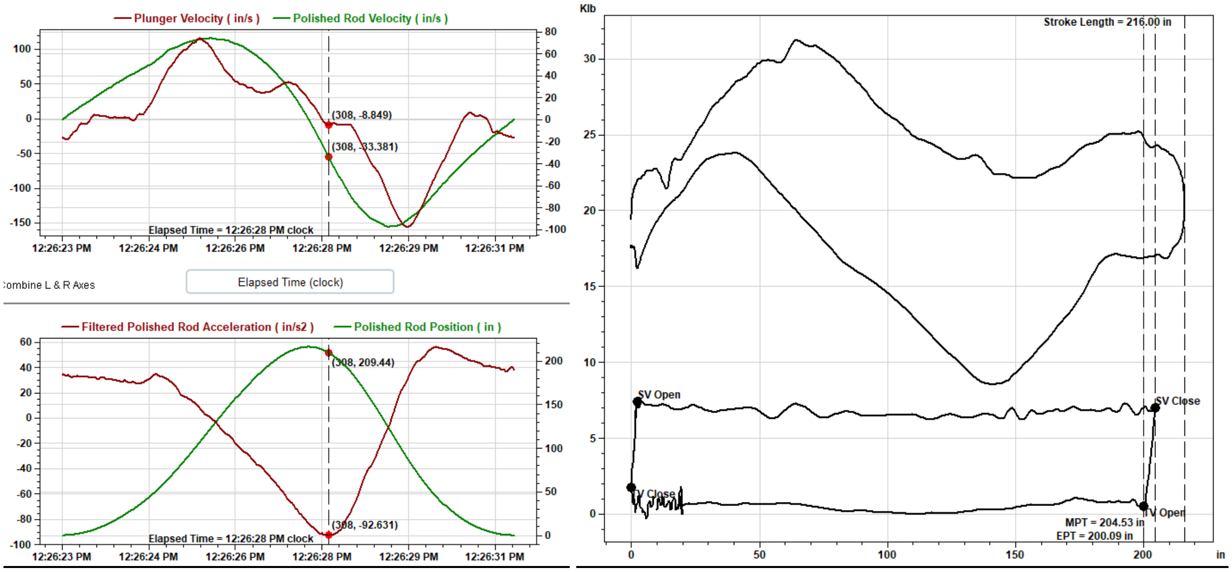

Figure 7: Well B field data – constant speed profile

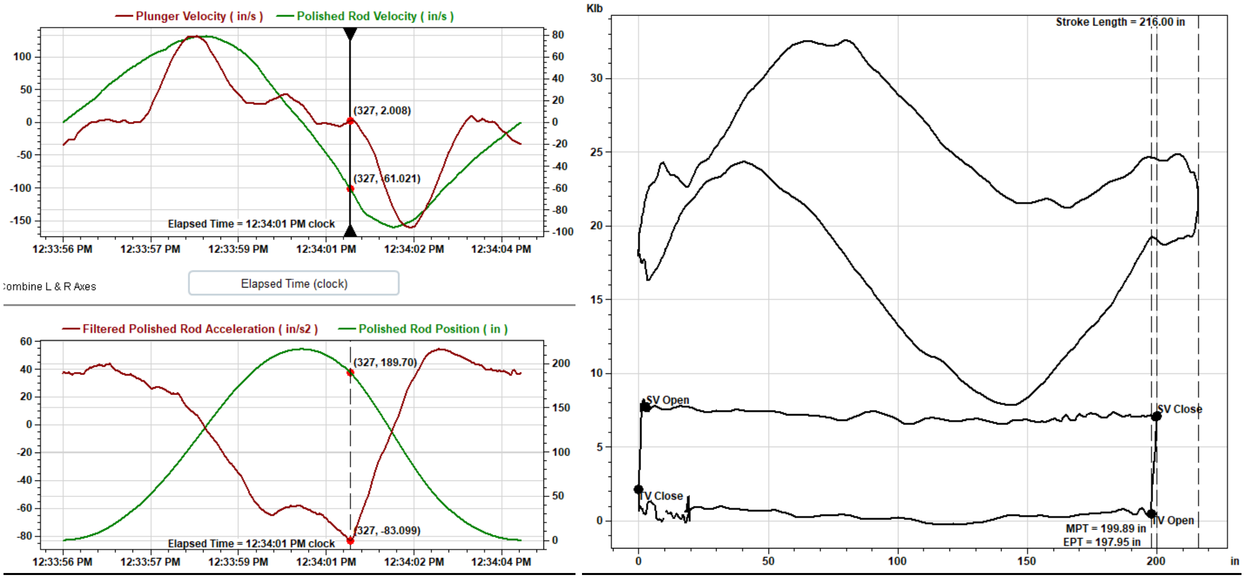

Figure 8: Well B field data – optimized speed profile

EXPERIMENTAL RESULTS

Beginning in 2019, intra-stroke speed reductions were applied to a population of 31 wells in MT and ND. 8 wells were set to run at a reduced speed on the downstroke, half of which improved their failure rate. The change in failure rate was also negligible, leading the authors to conclude that there was no benefit gained by reducing speed exclusively on the down stroke. 23 wells were set up with a speed reduction prior to top of stroke and through the transition. 18 wells improved their run times, with the groups average failure rate moving from 2.06 to 1.30.

As for the two wells analyzed in this paper, a significant improvement in rod life was observed in both cases. Each nearly doubling their respective record run times.

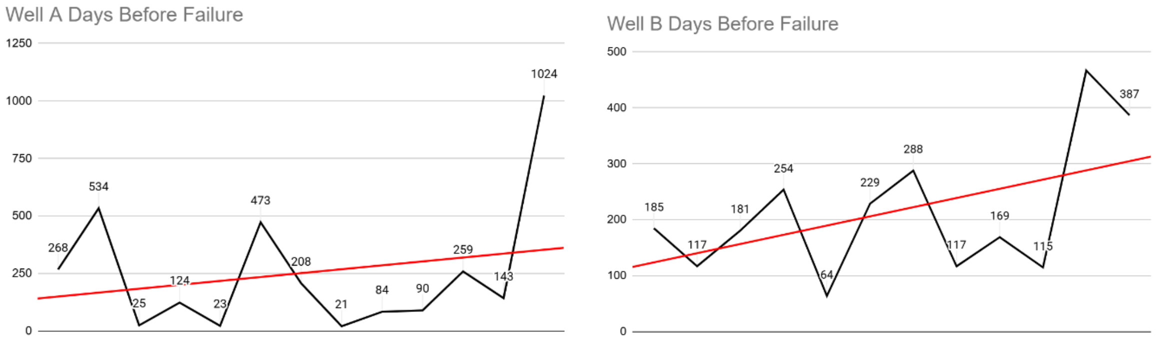

Figure 9: Run time plots (Days)

CONCLUSION

As pump off controllers and VFDs have become common components of modern sucker rod pumping systems, sub cycle speed optimization is highly economical and scalable. In this instance, the speed profile was optimized to move the neutral point and reduce compressive forces applied to the rod string. This approach provided a consistent improvement across a large population of wells, without impacting production. The combination of predictive modeling and wellsite automation provides operators with the opportunity to dramatically reduce operating costs through analysis and optimization at the sub cycle level.

REFERENCES

[1] Mendenhall, Greg L., Ott, R.E., “SOLVING ROD BUCKLING”, Southwestern Petroleum Short Course, 2015.

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