COMPLETE ROD CONTROL PROVIDES UNMATCHED RELIABILITY IN ROD LIFT SYSTEMS

Jonathan Martin
Black Mamba Rod Lift

INTRODUCTION & HISTORY

Drilling technologies have continued to evolve over the last 30 years; these improvements have been wonderful for industry, however, as well production rates decline naturally over time, rod lift is most often deployed as the most economical form of artificial lift. Complicated wellbores bring their fair share of challenges with rod lift systems. Rod strings are being deployed in applications far more extreme than the standard vertical wells with sub-5000' pump depths that rod lift originated with. The mechanical linkage between the surface and down-hole pump has been extended to depths greater than 12,000 feet, navigating various drilling corrections and diverse deviation profiles both intentional and unintentionally so.

For decades sucker rod instability has long been understood as a significant driver of pre-mature failure in rod lift systems. Often masked by the definition *Compression*, compression by itself is not problematic to rod strings and sucker rods. However, compression *without* sucker rod stability leads to pre-mature failure.

Compression happens in wells for multiple reasons. The down-hole pump can be bound up with trash, sand, or other debris, sticking and requiring excess force to slide-in to collect more fluid for the up-stroke. Rod pumping deviated wells may have areas where rods cannot fall with ease, requiring a 'push' from the weight of the rods above them. Further, and most commonly, compression occurs by way of incomplete pump fillage, where there is inertia and velocity in the rod string on the downstroke and pump stroke-in velocity impacts the fluid in the pump chamber. This variant can also take the form of gas interference, a slightly dampened alternative. Pump tagging - the down-hole pump finds bottom and is 'stroked-in' before the sucker rod string achieves peak bottom of the downward sinusoidal motion from the surface pumping unit, creating violent compression. Even before the well is operational, rig operators must seat the pump which uses the weight of the rods to push the pump into the seating nipple, forcing the rods into compression.

Combining any source of compressive loads which are greater than the tensile load on the rods themselves can create sucker rod instability and in turn, bending moments. These bending moments will undeniably cause accelerated rod failure. Additionally, sucker rod instability can increase side-loads as the negative load (compression) is being applied outwardly to the point of contact between the rod string and its accessories (guides, centralizers, stabilizers) and the production tubing. Great harm is done when the side-loads are not well-distributed across larger surface area(s).

Compression increases its prevalence as the system increases in length. Incomplete pump fillage, gas interference, pump tagging, slug flow, inertia, acceleration and deceleration of the rod string, fluid-load transfer during the pumping cycle, all these instances create compression and can create sucker rod instability. This instability, when not managed, undoubtedly leads to a reduction in system up time and rod string product life.

INNOVATION

Bending moments are created when negative loading (compression) is applied to sucker rods and the long slender column become unstable. Euler math can be used to project negative loading and at what negative load would cause instability in the rod string. Countless papers and industry subject matter experts have studied this to understand how much compression a sucker rod can encounter safely. Again, because of so many variables in the system, the end-conditions, the size of couplings, buoyancy effects and dampening from the rod string immersed in liquid, the results vary from mathematical computation, lab and bench testing, and real-world application.

Eliminating any potential instability solves the fear of bending moments. This can be done 1 of 2 ways.

1) Remove compression loading from the system; or
2) Provide continual stability to the sucker rod

Understanding that compression is inevitable, impossible to always quantify accurately, and is simply part of the system, is imperative for operators to maintain systems which are truly reliable. Variable Frequency Drive ("VFD") controllers are reaction devices, not necessarily proactive devices. In a simple form, Polished Rod Load ("PRL") and the associated load cell observes a load reduction at certain points in time and the VFD and surface automation controller responds by slowing things down.

Other compression solutions or compression related products include sinker bars ("k-bars") which are often used to overcome compression tendencies. The logic and use of sinker bars is that the large diameter steel bars (1.250", 1.500", 1.625" round bar) are heavy, counter-acting and neutralizing compression forces at the bottom of the well, hoping to keep the remainder of the rod string (fiberglass, 1", 7/8", and 3/4" sucker rods) in tension, always. The use of sinker-bars has their place, however, localizing a large amount of weight at the bottom of the rod-string increases axial load on the up-stroke (similar to large bore pumps) AND down-stroke, increasing side-load throughout the rod string at all times.

Another option to assist in production efficiency and rod string reliability is gas separation. Gas separation and their associated designs and technologies continue to evolve, hoping to minimize gas interference and increase pump fillage. By doing so, the effects of fluid or gas pound are minimized which help the sucker rod string and its need for stability (minimize compression/negative loading).

Murphy's Law still applies: *Anything that can go wrong will go wrong.*

The industry has leaned on several products to help with rod-on-tubing wear which has a direct association with sucker rod compression, sucker rod buckling, and deviation throughout the well-bore.

STUDYING THE MECHANICS

Sucker Rod Guide Standard Use

Sucker rod guides have been a common go-to solution for sucker rod failure, rod-on-tubing wear, and excessive deviation for decades. Sucker rod guides are typically used for addressing deviation and side-load throughout the well-bore, employing them as known sacrificial products between the sucker rod and tubing wall.

Side-load forces can be managed based on the selection of

- Real axial load (lbs-force) on the rods themselves)
    - Rod load + Fluid Load
- Bending-Stiffness (a combination of modulus and geometry)
    - Sucker rod size
        - Geometrical stiffness
    - Sucker rod material (glass or steel)
        - Material stiffness

More common as drilling technology and wellbore paths have become more complex, rod guides are still primarily for use in sucker rod **tension applications only**. Rod guide manufacturers have advised against using rod guides in compression applications. The bending moments and stresses created at the ends of legacy sucker rod guides when the free length(s) of sucker rod are able to deflect and buckle during compression will eventually create microfractures which propagate and lead to rod parts (Figures 2 and 3).

The rod is forced into the middle of the tubing at the centralizer or guide; however, the sucker rod buckles between the rod guides. Time and time again sucker rods fail at the edge of a sucker rod guide or at the start of the forged upset transition on the sucker rod (also a bending moment location).

A sucker rod may have longer life without the use of sucker rod guides if it is experiencing regular compressive loading which eclipses the critical buckling load for the long slender column – the sucker rod.

Verified by physics and engineering work, if the sucker rod is experiencing compressive loads greater than its mathematical allowance and is buckling between guides, more rod guides are needed to prevent sucker rod buckling, or the alternative, less or no rod guides, reducing the bending moment stress on the rod. If more guides are elected to be added to sucker rods, they must be able to eclipse the compressive loads the sucker rod is experiencing, otherwise the additional rod guides do more harm than good. Electing to use less or no sucker rod guides, the steel tubing and rod experience accelerated wear as there is no isolation or centralization of the sucker rod on the tension upstroke.

Surface Area

As it relates to sucker rod guides or centralizers, distribution of side-load and/or force across a larger surface area (bearing surface area of the “fins” of sucker rod guides – Figure 4) creates a reduction in the compressive stress on the inner surface of the production tubing (these can lead to tubing splits) and on the bearing surface area of the guide’s fin itself. By minimizing the stress and distributing the sideload throughout the sucker rod across a greater surface area in a balanced and predictable fashion, the system continues to gain reliability and minimizes system complications. This is the very reason why large sucker rod guides which have larger fin contact area last much longer than ‘low-turbulence’ rod guides with thin, low bearing surface area fins. Not only is there more plastic available, but the surface area and compressive stress on the plastic from the side load is also reduced.

Drag and Friction

Engineers sometimes question greater contact and surface area as it relates to drag and friction. Recall that in physics, the block-on-incline-plane example never questions surface area, it is irrelevant to basic physics (Figure 5). Factors which compute drag forces are limited to load (side-load, for rod lift applications) and coefficient of friction between the guide(s) and tubing. Leslie Malone’s *Rod Guide Strategy for Unconventional Beam Pumped Wells in the Eagle Ford Shale* paper from Southwest Petroleum Short Course, 2017, analyzed heavily guided sucker rod strings with large fin rod guides, finding no drawbacks to the increase in plastic-on-tubing contact.

Predicting Wear Rates in the Lab

For years and years sucker rod guide manufacturers and material/resin compounders have studied the wear of plastic materials on steel in controlled lab environments on custom or derivative based ASTM testing machines. ASTM D3702 and ASTM G-133 are common methods which are respected across a variety of industries, including oil and gas. Rod guide manufacturers have individually built machines of their own, too, logging plastic wear over time under a variety of loads and conditions, lubricated or dry.

Wear rates are extremely dynamic and very difficult to compute. Dr. Ahmed Abdelbary, a colleague and plastic industry friend, published the book *Wear of Polymers and Composites* in 2015 which dives into the complexities associated with predicting wear of plastics in varying conditions.

For rod lift systems, the complexities are even greater. Understanding the exact dynamics 2 miles beneath the surface of the earth is quite a challenge. Rod pumped wells are in a continually varying lubricated environment, with water, oil, gas, temperature, pressure, bubble points, dynamic loading between up-stroke and down-stroke (axial load differential), and even the dynamic loading changes throughout the cycle and from cycle-to-cycle as it relates to duration, time, acceleration, and deceleration. Additionally, the complexities continue as there is varying surface finish of rod guides, production tubing internal surface finish, the use of a tubing or rod rotator and their success rates at rotating rod-strings 2-miles long (torque capacity of clutch is a factor); all this to say, prediction of performance is incredibly hard.

Sucker rod products are most often generally projected to perform relative to other products on the market, not necessarily projected with a computed life to specific down-hole conditions.

A new patented product, apparatus and use, Black Mamba®, is introduced to industry in 2019. The primary focus: extended length **sucker rod stabilization** and centralization. Continuous reinforcement and stability are provided from the helical sucker rod stabilizer as it can circumferentially wrap and extend along the entire sucker rod body in 7-per configuration (Figure 1).

COMMON ROD LIFT FAILURE MODES

Pump Failure

Down-hole pump failures can occur in compression environments. The pull-rod or pull-tube may arc and buckle as it is transitioning from stroked-out to stroked-in. Fluid pounding provides direct, abusive compression tendency into the pull-rod. Stabilizer bars are helpful at centralizing the pumping action on the upstroke, but do not necessarily address the potential buckling nature of the pull-rod as it is stroked in. Products are in development to address buckling of pull-rods and pull-tubes for down-hole pumps, as this is a pain point for industry.

Tubing Splits

Tubing splits are common, costly failure modes of the rod lift system. Often sucker rod couplings or rod bodies grind into the inner surface of the tubing due to side-load and deviation. This grinding action can also be exacerbated by instability in the sucker rod string, the buckling action taking compressive loading and pushing it outward into the tubing in an uncontrolled and non-distributed fashion.

Rod Failure

Rods fail by *corrosion-fatigue* almost always. This description is technically accurate as there are components in a known-corrosive environment (water, oil, H_2S, CO_2, pressure, temperature, chemical treatments) with fatigue involved in the cyclic loading of the sucker rod string and the rod pumping system. These corrosion fatigue failures are most often influenced by stress raisers (i.e.: pit origin, stress-corrosion cracking, bending moments at rigid points along the sucker rod – forged upsets or rod guides) which pinpoint where the fatigue failure will occur.

Pin Failure

Proper coupling torque is critical especially in dynamic, repetitive cycling. Consistent and reliable coupling-to-pin pre-load has been a proven focal point of preventative measures for increasing reliability in the sucker rod string. When loss of coupling torque occurs, pin failure is a result.

ROD STRING DYNAMICS

Rod String Velocity

Lufkin advises *Maximum Stroke Per Minute (based on free fall speed of the rod)* with basic formulas specific to Conventional Units, Air-Balanced Units, and Mark II Units. Values are in Table 1. These rates are most often **not** approached as instability in the sucker rod string is feared and most often the compression-induced sucker rod buckling makes operations unbearable. In other words, sucker rod instability has long been the limiting factor of pumping unit operational speeds.

A common metric for rod pump system design is taking *Strokes Per Minute* multiplied by *Stroke Length* and keeping this result below approximately 1400 inches-of-stroke/min. The goal is to not induce compression along the rod string from inertia effects of up-to-down transitions in the rods. Removing the limiting factor, the pumping unit and rod string can operate at higher rates with absolute reliability, approaching 2000 inches-of-stroke/min, a +40% increase over standard practices.

By Lufkin's recommendations:

$$L = Stroke\ Length = 216$$

$$SPM = Max\ Strokes\ per\ Minute$$

$$SPM = 0.7\sqrt{\frac{60000}{L}}$$

$$SPM = 0.7\sqrt{\frac{60000}{216}}$$

$$\boldsymbol{SPM = 11.67}$$

Applications of Complete Rod Control™ have been deployed with Conventional pumping units operating at 8.5 SPM and 216" stroke lengths. Operating a *Lufkin Conventional 1280-427-216* at 8.5 SPM is considered safe, cycling with 25% buffer to Lufkin Max SPM Recommendation.

Industry history tells us stability in the sucker rod string must be maintained to do this with any meaningful run life.

PRODUCT DEVELOPMENT

Complete Rod Control™ has been developed using a single helical fin design which wraps and bonds to the sucker rod body over an extended length (36" on a 3/4" sucker rod – Figure 6). Material selection is important, as the plastic material must flow, properly filling, packing, and curing or cooling with adequate bonding strength to the sucker rod, but also do so with molecular integrity in its final form. More important than material selection is the geometrical design of the product itself.

DESIGN

A stabilizer for a sucker rod has a continuous vane with helical profile which is attached along a length of the sucker rod body, between forged upsets for steel sucker rods or between end connections for composite sucker rods. The stabilizer extends from the sucker rod body to near the inner diameter surface of the production tubing. The helical profile continuously reinforces and stabilizes the sucker rod, constraining the central longitudinal axis of the sucker rods to be coaxial with the central axis of the production tubing. This helical profile affixed to the sucker rod centralizes and stabilizes the sucker rod in both tension and compression moments, preventing the buckling of the sucker rod due to the constant reinforcement of the sucker rod. The stabilizer is preferably corrosion resistant, strong and rigid, yet lightweight and affordable.

By continuously reinforcing and stabilizing the rod throughout each coil section, the area-moment of inertia ("AMOI") as an assembly is increased. This forces the full length of the rod to stay within the central axis of the tubing during compressive loading. The ideal pitch of the profile is calculated by evaluating an extreme circumstance in beam-lifted wells, the maximum compressive loading possible (the weight of the rod string above the bottom-most sucker rod).

The singular vane helically wrapping around the sucker rod allows for more efficient fluid flow patterns, reducing drag loads in comparison to standard sucker rod guides. The reduction in fluid drag through the helical efficient design allows for more efficient energy consumption for the pumping unit on the surface, as well as reduces the chance of solid and gas erosion and corrosion on the sucker rod body due to momentary pressure changes made by the surface of standard sucker rod guides which can lead to a swirling effect at the edges of the sucker rod centralizer, eroding the steel sucker rod body away over time.

Additionally, the singular vane of the invention has a greatly reduced AMOI in comparison to traditional molded centralizers, allowing for geometric flexibility of the plastic profile which exceeds the flexibility of the sucker rod in all directions along the spine of the coil, and where the wrap around pad is on the helical profile, profile flexibility is approximately equivalent to the 3/4" sucker rod flexibility.

Larger diameter steel sucker rods are far more rigid than the composite coil profile. The polymeric profile is more flexible than other common rod guides, which allows for the rod, if it does buckle or flex, to not impose additional stress and bending moments along the rod body like that of large body legacy sucker rod guides.

Engineering math to calculate the necessary sucker rod reinforcement to best prevent buckling along the sucker rod is shown below:

$$E = sucker\ rod\ modulus\ of\ elasticity = 29{,}700{,}000\ psi$$

$$I = moment\ of\ inertia\ (round\ bar) = \frac{\pi D^4}{64}$$

$$L = length\ of\ reinforcement, helical\ pitch\ (inches)$$

$$F = load\ (lbs)$$

$$n = boundary\ condition$$

(See Figure 7)

Euler’s Column Formula:

$$F = \frac{n\pi^2 EI}{L^2}$$

Solving for helical pitch:

$$L = \sqrt{\frac{n\pi^2 EI}{F}}$$

Results are computed and provided in Table 2. A 3/4" rod with a pivot end condition n=1 (Figure 7), would require approximately a 15-inch helical pitch to safely stabilize the rod section. Sucker rod behavior in-well and linked together with sucker rod couplings is more reflective of an n=2 scenario, where there is a fair amount of rigidity at the coupling due to the increased diameter of the steel coupling profile (Figure 8). Euler boundary condition n=2 is the most conservative pitch spacing and could be considered for the above to provide maximum rod stabilization; however, sucker rods are linked together and often reflect a scenario much closer to that of Fixed End condition, n=4 (Figure 7).

In observance of Table 2 data, it is obvious that as load decreases and rod diameter increases, the sucker rod becomes more stable, and less likely to buckle. This is somewhat common sense. In a well with a full fluid column, the compressive load potential reduces greatly due to buoyancy forces.

MANUFACTURING

Specialized manufacturing equipment has been produced to mold helical stabilizers around the sucker rod. Through learning lessons in application after studying deployed product, Black Mamba Rod Lift has continued to iterate its product lines to tune in desirable material properties and product behaviors. A constant refinement of manufacturing parameters, material composition, and geometrical modifications have been made to better the product after understanding its limitations and receiving feedback from end-users. Countless operators and industry as a whole has collectively been incredibly supportive of developing Complete Rod Control™.

> Version 1.0 did not make commercialization after internal testing for handling and flexing of the molded profile on sucker rods in certain orientations.
>
> Version 1.1 launched to market in 2019 and has performed incredibly well. Limitations observed include a cosmetic cracking similar to polyphathalamide (PPA) immersion products. Product function has performed beautifully. Wear rates in application are promising. Operators are understanding as the product is new to market, new design, new equipment, and solving problems in a new way.
>
> Version 1.2 launched in early 2020 for the high-temperature market. Supply chain restrictions were found necessary; a secondary supplier was incapable of providing reliable product during COVID market down-turn and complications. This lesson was learned through rapid deterioration of product in customer wells. Black Mamba Rod Lift addressed these with the customer who was understanding. A second batch of product (Version 1.3) was deployed with this customer and is operating as intended.
>
> Version 1.3 was a material modification to Version 1.1 for enhanced elongation, addressing early concerns of cracking in the long, floating fin-profile of the helical stabilizer. This has been a noticeable improvement. Certain large operators have had very promising results and comment on fantastic wear performance – some cracking still has been observed. It should be noted that these products have never come off down-hole and trashed a well or caused a stripping job (that we know of).
>
> Version 2.0 and 2.1 have launched as of April 2022, eliminating the risk of problematic cracks in a floating fin profile. Complete Rod Control™ is now actively pushed to the market without reservation, as the products flaws and sins have been addressed and engineered out.
>
> > Version 2.0 is a thermoplastic variant of the original optimized geometry.
> >
> > Version 2.1 is a geometrical change which allows for material Version 1.3 to be utilized without concerns for cracking in high temperature environments.

INSTALLATION, CARE, AND HANDLING

The industry has long used sets of 60 1”, 80 7/8” or ~100 3/4" rods as standard counts for palletizing bundles based on weight and dimension of the rods. Standard palletizing spacers are recycled and reused with every bundle as the helical profiles can nest together, producing no waste or scrap for palletizing boards and spacers.

Complete Rod Control™ bundles require 1 set of additional boards, creating 6-board pallets.

Installation in well is just like any other sucker rod. Follow *Recommended Practice for the Care and Handling of Sucker Rods* [6], tailing in sucker rods, keeping them flat. Most often sucker rods are abused, flexed, and stressed from greater deflection outside of tubing than within tubing, in application.

A NEW APPROACH TO ROD LIFT

At face value, there is obvious benefit to the removal of bending moments in an engineered system. In all aspects, it will only help the system increase in reliability.

Black Mamba® and Complete Rod ControlTM has been deployed in a variety of wells and conditions

Black Mamba® is also used as standard rod guide replacement (4-per), but ultimately, the system's true benefits are not realized unless there is Complete Rod ControlTM through 7-per configuration.

Case 1 – Rod String Reliability

A Bakken operator approaches Black Mamba Rod Lift for a meeting, string design, and quote on a problem well. Operator had 8 failures in a row at 3-month intervals. Issues stem from gas interference, fluid pound, and incomplete pump fillage. The operator attempted to control the situation with VFD and switching from conventional pumping unit to a Rotaflex style long stroke unit. Issues persisted.

Region: Bakken
Depth: 12,075 feet
Bottom Hole Temperature: 240 F
Surface Unit: Rotaflex 320-500-306, 305" stroke @ 2.4 SPM
Production: 128bfpd, 1.5" plunger
Install date: January 2021

> "Hey Jon! Things are going well. Here's the latest data on the _____. Pretty steady, on curve, and so far the longest run times we've seen in a long time from the well."
>
> "[Black Mamba]… I have to gripe a bit. I want to change the BHA on this well because of our gas issues… but your damn rods WILL NOT BREAK, so I can't justify it just yet. **You** guys have absolutely proven yourselves to our organization."

Results: 13 months of operation with no failures. At month 13, the well failed in the only section that was not protected with helical sucker rod stabilizers. Operator swapped all legacy rod guides for Black Mamba® CRC rods and put the well back online. All 3/4" and 7/8" original rods were re-run after inspection.

Operator defaults to CRC pumping for its problem wells.

Case 2 – High Volume Pumping A

Black Mamba® has proven itself with this operator after ~25 rod strings with positive and promising results. Black Mamba Rod Lift approaches an engineer with a 'wild' idea, really pushing the limits of Complete Rod ControlTM. Operator accepts the challenge and the risk.

Region: Permian
Depth: 8,200 feet
Bottom Hole Temperature: 180 F
Surface Unit: Conventional 1280-365-240, Hole 2: 205" stroke @ 8.7 SPM (1783 in/min)
Production: 800bfpd, 2" insert pump
Install date: January 2022

String Design:

- 4,200 feet 1-1/4" Fiberglass Sucker Rod
- 2,000 feet 7/8" Norris N96 w/ 7-per Black Mamba® Complete Rod Control
- 2,000 feet 1" w/ 3/4" Pin Sinker Rod, Norris N90 w/ 7-per Black Mamba® Complete Rod Control

Results: Operator and engineer continue more traditional installations of Black Mamba® product for compression control. 2 months after rod up of *High Volume Pumping A*, the engineer emails:

"Attached is the ____________ design for a request for another Black Mamba CRC design. We are going to be pushing the envelope again on this one like we did on the last design.

The last design [High Volume Pumping A] we are yielding great fluid rates so far: 700-720 bbls total fluid at 8.4 SPM [1722 in/min]"

Case 3 – High Volume Pumping B

Based on the results of Case 2, this operator goes at it again.

Region: Permian
Depth: 8,700 feet
Bottom Hole Temperature: 180 F
Surface Unit: Conventional 1280-365-240, Hole 2: 205" stroke @ 9 SPM (1845 in/min)
Production: 798bfpd, 2" insert pump
Install date: March 2022

String Design:

- 4,500 feet 1-1/4" Fiberglass Sucker Rod
- 2,050 feet 7/8" Norris N96 w/ 7-per Black Mamba® Complete Rod Control
- 2,150 feet 1" w/ 3/4" Pin Sinker Rod, Norris N90 w/ 7-per Black Mamba® Complete Rod Control

Results: Actively pumping as expected. Other engineers begin practicing this same approach. Under standard string design where bending moments are possible, these wells would fail in days.

Case 4 – High Volume Pumping C

Region: Permian
Depth: 8,700 feet
Bottom Hole Temperature: 180 F
Surface Unit: Conventional 1280-427-216, Hole 1: 216" stroke @ 8.3 SPM (1793 in/min)
Production: 750bfpd, 2" insert pump
Install date: March 2022

String Design:

- 4,300 feet 1-1/4" Fiberglass Sucker Rod
- 2,300 feet 7/8" Norris N96 w/ 7-per Black Mamba® Complete Rod Control
- 2,100 feet 1" w/ 3/4" Pin Sinker Rod, Norris N90 w/ 7-per Black Mamba® Complete Rod Control

Results: Actively pumping as expected.

Case 5 – Fearless Pumping

Region: International
Depth: 6,040 feet
Bottom Hole Temperature: 150 F
Surface Unit: Conventional 912-365-192, Hole 2: 165" stroke @ 8.5 SPM (1402 in/min)
Production: 490 bfpd, 2" tubing pump
Install date: August 2021

String Design:

- 1,800 feet 7/8" US Rod DXS w/ 7-per Black Mamba® Complete Rod Control

- 2,550 feet 3/4” US Rod DXS w/ 7-per Black Mamba® Complete Rod Control
- 1,700 feet 7/8” US Rod DXS w/ 7-per Black Mamba® Complete Rod Control

Commentary: This well is considered a ‘banana-drill’. Surface to 1,000 feet ramps to 40-degree inclination. This inclination continues to about 6,000 feet; the pump is landed at 30-degrees inclination. Preliminary pull for inspection is scheduled for next month. Production is on target.

SUMMARY

Complete Rod Control™ and Black Mamba® allows for a new wave in rod pumping, changing standard practices and what is considered safe. We as engineers must continue to ask “Why?” when perceived, prior, long-time historical limitations continue to be relied upon. The industry is evolving with new technologies daily; Complete Rod Control™ is a powerful tool which forces reliability and predictability into the rod string.

Sucker rods no longer operate as long slender columns which are highly sensitive to negative loading and compression.

- Pumping units can operate faster - 1,000 bfpd wells on rod pump is no longer *crazy*
- String design becomes simpler, cookie cutter operation.
- Side-load computation becomes secondary as Complete Rod Control™ full centralized and protected sucker rod strings.
- Incomplete pump-fillage is not something to be fearful of. The rod string takes no negative impact.

Buckle-proof rod strings allow for compression in the rod string with no negative effects. With instability eliminated under any event, whether the rod string sees compression or not is now irrelevant as there is no bending moments, further, no unaccounted-for stress not reflected in the predictive string and system design.

For minimal expense (Table 3), sucker rod pumping can truly be predictable and reliable, this reliability paid back in mere days. Complete Rod Control™ reduces costs of expensive sinker bars on a 3:1 basis, completely isolating the rod string from the tubing and preventing all sucker rod buckling.

This patented, economical solution provides perfect sucker rod reliability in a well-engineered and validated design and system. Multiple operators big and small have tested and validated the effectiveness of Complete Rod Control™ (CRC) since 2019. A typical application for CRC rod pumping implementation begins at the pump, working upward.

The methodology of Compete Rod Control™ is simple – compression cannot be avoided. Address it head on.

REFERENCES

[1] L. Malone. *Rod Guide Strategy for Unconventional Beam Pumped Wells in the Eagle Ford Shale*. Southwestern Petroleum Short Course, 2016.

[2] *Standard Test Method for Wear Rate and Coefficient of Friction of Materials in Self-Lubricated Rubbing Contact Using a Thrust Washer Testing Machine.* ASTM D3702-94, 2019.

[3] *Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear.* ASTM G133-05, 2016.

[4] Dr. Ahmed Abdelbary. *Wear of Polymers and Composites.* Woodhead Publishing, 2015.

[5] Lufkin. *Artificial Lift Nomenclature and Application Formulas – Oilfield Products.*

[6] API. *API RP 11B - Recommended Practice for the Care and Handling of Sucker Rods.* American Petroleum Institute, 9th Edition, 2008.

TABLES

Table 1. Lufkin's Stroke Per Minute, Maximum Recommendation

Stroke Length, in.	*Conventional*	*Air Balanced*	*Mark II*
144	14.3	12.9	11.4
168	13.2	11.9	10.6
192	12.4	11.1	9.9
216	11.7	10.5	9.3
240	11.1	10.0	8.9
300	9.9	8.9	7.9

Table 2. Results of Euler Critical Load To Derive Helical Pitch

Rod Size	Depth from Surface	Compressive Load Potential	Helical Pitch (n=1)	Helical Pitch (n=2)	Helical Pitch (n=4)
3/4".	10,000 feet	20,000 lbf	15.1"	21.3"	30.2"
7/8"	5,000 feet	10,000 lbf	26.5"	37.5"	53.0"
1".	2,000 feet	5500 lbf	51.0"	72.2"	102"

Table 3. Complete Rod ControlTM economics, WTI = $100/bbl

Payback	*25 bopd*	*50 bopd*	*100 bopd*	*200 bopd*	*400 bopd*
5,000 ft.	10 days	5 days	2.5 days	1.25 days	0.625 days
7,500 ft.	15 days	7.5 days	3.75 days	1.875 days	1 day
10,000 ft.	20 days	10 days	5 days	2.5 days	1.25 days

FIGURES

Figure 1. Complete Rod Control^{TM} through 7-per Configuration.

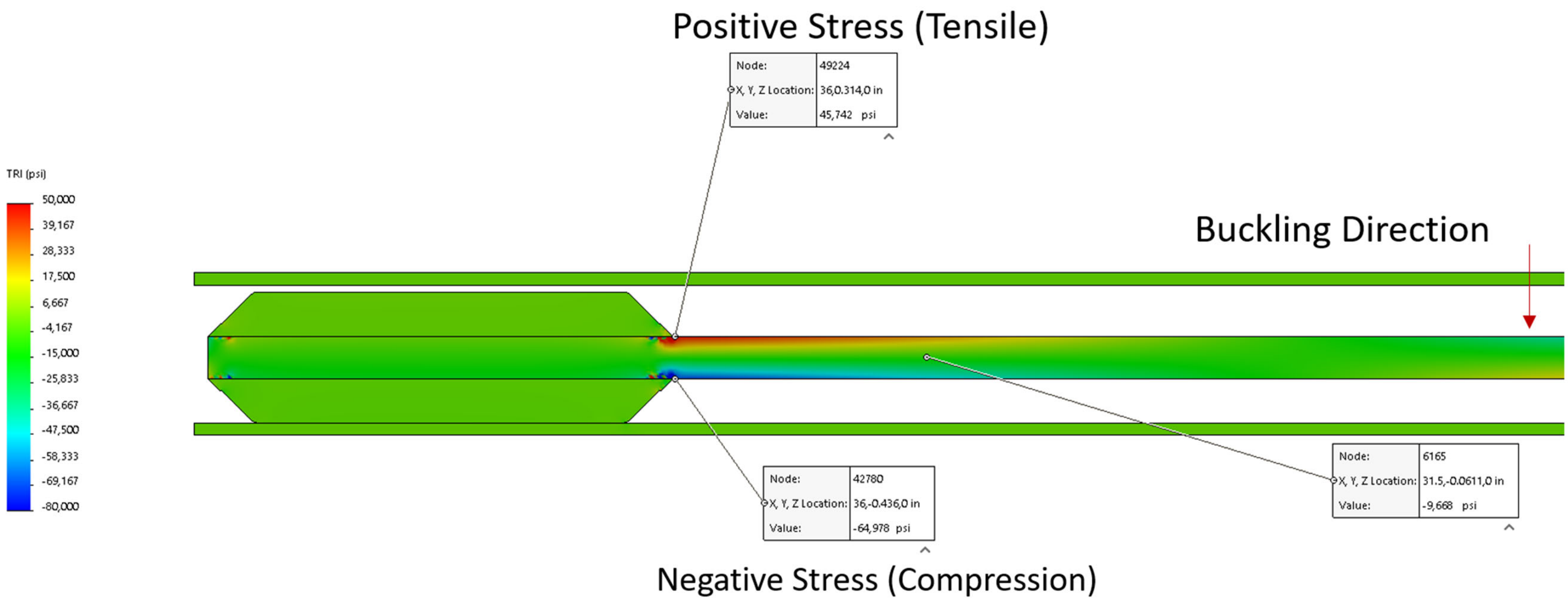

Figure 2. Bending Moment FEA.

Figure 3. Rod Part at Rod Guide.

Figure 4. Bearing Surface Area and Erodible Wear Volume of Various Rod Guide Designs.

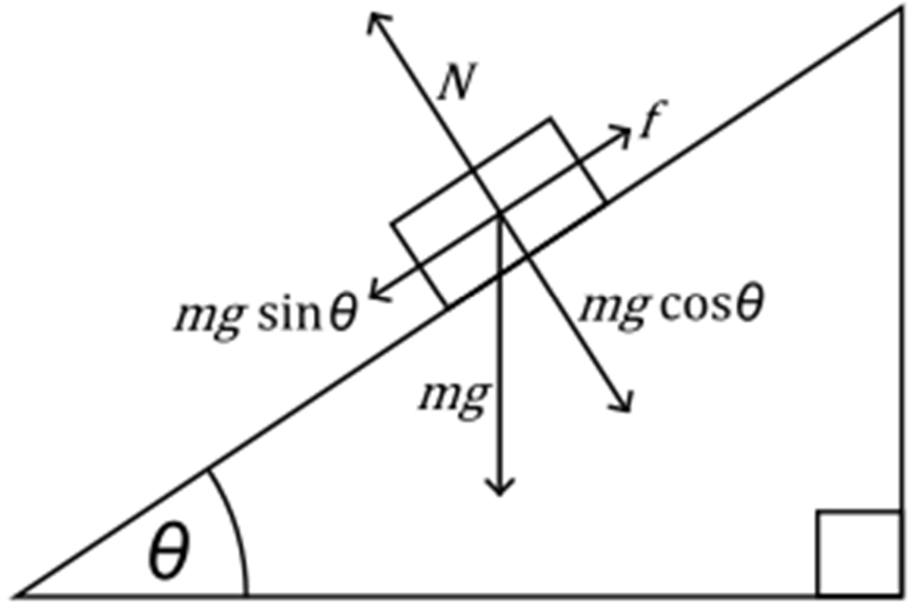

Figure 5. Block on Plane, Friction.

Figure 6. Black Mamba® on 3/4" Sucker Rod.

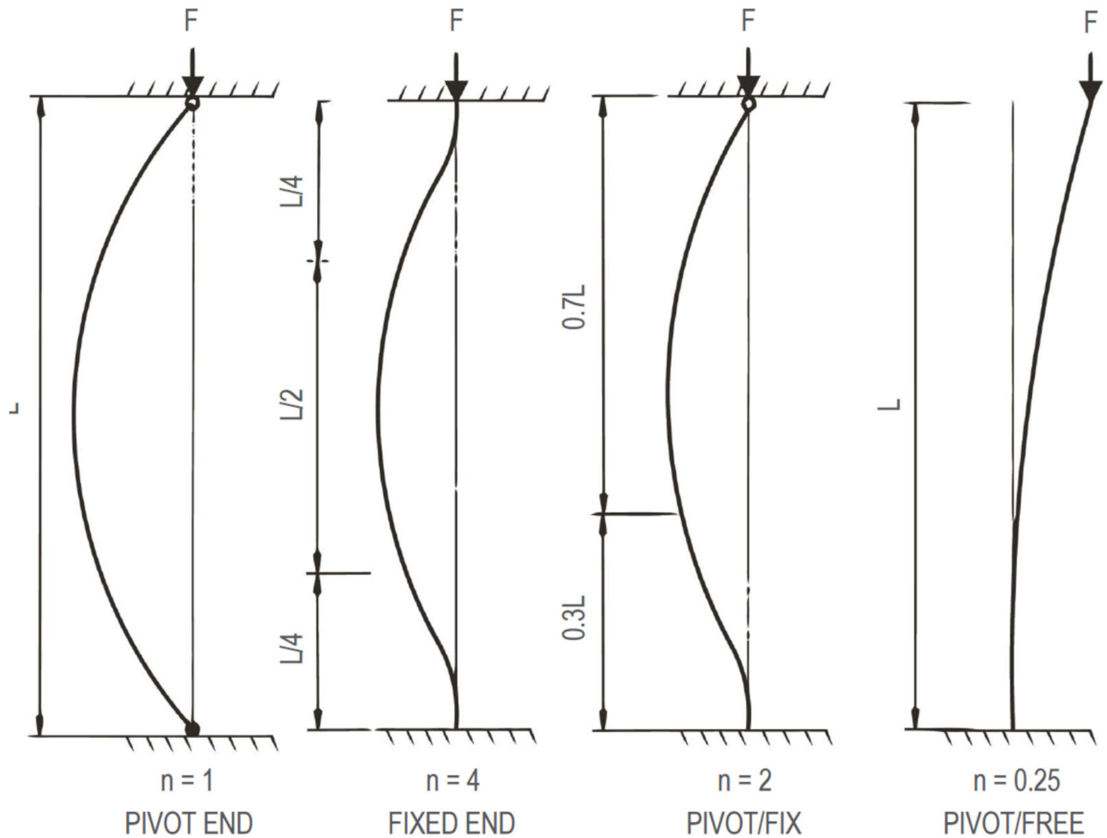

Figure 7. Euler Column Formula End Conditions

Figure 8. 2 Sucker Rods Connected with a Coupling.

Figure 9. Palletized Rods with Black Mamba® Complete Rod Control™