CONTINUOUS ROD SCANNING USING LV-EMI™ PROPRIETARY TECHNOLOGY

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Rod pumping unconventional wells is becoming increasingly challenging due to unpredictable downhole environments. Many unconventional wells exhibit significant deviation accompanied with corrosion making them difficult to rod lift without exposing downhole equipment to unpredictable damage mechanisms – specifically the rod string.

Continuous rod is a proven technology in these deviated unconventional wells as it increases the mean time between failures through lack of connections and distributed side loads. Although continuous rod will increase the mean time between failures, all rod pumping systems will eventually require an intervention. Traditionally, when continuous rod is pulled during a workover, inspections have been done visually in the field by experienced rig crews. However, this method is imprecise and subject to human error. This can result in unexpectedly early failure after a satisfactory inspection or additional cost from replacing mechanically serviceable continuous rod strings.

The Low Voltage – Electromagnetic Inspection (LV-EMI™) unit will detect three-dimensional discontinuities and cross-sectional loss in semi-elliptical and round continuous rod strings. In this paper, the continued development of this new technology and the results from two semi-elliptical continuous rod string scans will be presented. Proposed future enhancements resulting from preliminary field tests will be identified.

INTRODUCTION

Rod pumping unconventional wells is becoming increasingly challenging due to unpredictable downhole environments. Advances in drilling and completions have yielded wells with higher dogleg severity throughout the drilling path. Unintentional deviations and planned, complex trajectories can make it difficult to rod pump these wells successfully when their production declines. Deviations can result in excessive side loading conditions and resultant wear. These side loads accompanied with corrosion can result in high failure rates – specifically on the sucker rod string.

The sucker rod string is used in the rod pump system to convey energy from the pumping unit at surface to the downhole pump to lift fluid to the surface. The sucker rod string typically consists of steel sucker rods connected by couplings every 25 feet or 30 feet. Unconventional wellbore trajectories increase the amount of wear on the downhole equipment, especially on the sucker rod string and tubing. Increased wear between the couplings/rods and tubing can result in failures including parted rods or tubing leaks. In a conventional sucker rod string, the side load or force is concentrated on the rod's couplings, increasing the pressure between the rod and tubing string. This leads to an increase in failure rates at the coupling in particular.

The most common solution is to add rod guides to increase the number of contact points and distribute the side load over a greater contact area, see [1]. However, depending on the material the rod guide is made from, and the number of guides added per rod, adding rod guides to the string can significantly increase both the absolute weight and the drag load of the string. These increased loads can result in higher stress on the rod string and higher tensile load at the pumping unit.

Using continuous rod is a viable solution for stress concentration at rod couplings in deviated wells as it eliminates couplings in the wellbore, see [2]. The force between the rod and the tubing string in the well is distributed over a much greater contact area reducing the contact pressures to acceptable levels, see [3]. This results in longer run times.

Unfortunately, even though continuous rod will increase the mean time between failures, all rod pumping systems will eventually require an intervention. Historically, a downside to continuous rod has been lack of EMI servicing to determine the condition of the rod string when it's pulled.

EMI technology has not been previously available for continuous rod inspection. Typically, when continuous rod is pulled, inspections of continuous sucker rods have been done visually in the field by experienced rig crews. Manual visual inspection, even by experienced personnel, is imprecise, dependent on the operator's expertise and diligence, and subject to human error. Additionally, it is difficult to obtain a 360° view of the rod during manual inspection. These challenges mean that defective rods may not be identified with a visual inspection and can be run back in the wellbore, resulting in premature failure. Conversely, if continuous rod is scrapped under a conservative use policy, the operator might incur a more expensive workover than necessary by prematurely replacing a serviceable rod string.

DEVELOPMENT OF LV-EMI™ UNIT

"Electromagnetic testing is a form of nondestructive testing and is the process of inducing electric currents or magnetic fields or both inside a test object and observing the electromagnetic response", see [4]. If the test is conducted properly, a defect inside the test object creates a measurable response.

Electromagnetic inspection of OCTG including drill pipe, casing, tubing, and conventional sucker rods utilizes a method that relies on magnetic flux leakage (MFL). However, with the availability of hall effect sensors, electromagnetic inspection practices have advanced to also monitor the magnetic flux density (MFD). Magnetic flux density (MFD) measurement changes are proportional to changes in cross-sectional area (e.g. from wear, corrosion, stretch, etc.), permeability (e.g. welds), and hard/soft spots resulting from cycle fatigue or manufacturing discontinuities. This enables a holistic assessment of continuous rod health through a non-destructive test.

Prior to the development of the Low Voltage-Electromagnetic Inspection (LV-EMI™) unit, the only way to inspect continuous rod in the field was visually.

Some of the challenges to overcome in the evaluation of continuous rod include the following:

1. Lack of physical space to place an EMI unit at wellhead.
2. Lack of guidance to control the rod prior to entering the unit.
3. Unauthorized to work at the wellhead due to safety concerns.
4. Continuous rod will always retain coiled shape to a certain degree.
5. Speed of pull varies based on well conditions.
6. Continuous rod will not be entirely clean when scanned out of hole.

To overcome the above-mentioned challenges, the LV-EMI™ unit was developed to operate like a tubing scanner.

The LV-EMI™ unit has a Class I, Div. I rating and utilizes magnets to induce magnetic fields to test the object and observe responses. This unit is compact, allowing for placement between the last guide arm and the rod spool. The unit consists of two components that clamp around the rod allowing it to be easily installed or removed at any time during operation.

Continuous rod is pulled with a hydraulic injector. Prior to entering the guide arms, rubber strippers are used to eliminate excess oil and paraffin at the BOP. During operation, the rod travels through the guide arms, an additional set of rubber strippers, before entering the EMI unit and the collapsible service reel. The secondary rubber strippers are attached to the last guide arm and assist in keeping the rod steady to attain accurate data. With every scan, depth counters are used in tandem to determine where, in the rod string, defects are identified.

The LV-EMI™ unit consists of two sets of sensors: magnetic flux leakage (MFL) and magnetic flux density (MFD). Magnetic flux leakage (MFL) sensors are in contact with the rod covering the entire surface of rod and observe magnetic flux leakage (MFL) fields coming for metal discontinuities. Magnetic flux leakage (MFL) measures corrosion pitting and three-dimensional discontinuities. Magnetic flux density (MFD) consists of hall effect sensors that monitor the flux density around the rod. Magnetic flux density (MFD) measures loss of cross section and changes in the shape in the circumference of the rod.

Figure 1 displays a screenshot of what the EMI operator observes as the rod string is traveling through the unit. The top portion of the graph represents the magnetic flux leakage (MFL) readings, and the bottom portion represents the magnetic flux density (MFD) readings.

Current Thresholds:

Because there was not a previous solution for electromagnetic inspection of continuous rod, thresholds are continually being fined tuned. API 11BR standard for conventional sucker rods includes:

1. Any cracks shall be cause for rejection in all classes.
2. Mechanical damage that leaves sharp indications on the rod body shall be cause for rejection in all classes.
3. Loss of cross-sectional area due to corrosion, wear, defects, etc. greater than 0.020 in. shall be cause for downgrading to Class II or for rejection.
4. Wear between 20% and 30% reduction in cross-sectional area or corrosion pits of 0.040 in. to 0.060 in. shall be cause for rejection or downgrading to Class III, see [5].

Based on the above and current field trials, the current magnetic flux leakage (MFL) threshold for removal is set at 60 thousandths of the rod diameter for continuous rod. For magnetic flux density (MFD), the current threshold to remove sections is when cross-sectional loss is greater than 15% of the rod diameter. These thresholds can also be adjusted based on operator’s preferences.

Accelerometer:

The unit detects variations in the magnetic field induced by the permanent magnets installed in the housing. Material imperfections as well as relative motion between the rod string and the apparatus while scanning continuous rod out of a wellbore may both result in magnetic field variations. Variations caused by imperfections are defined as signal while variations caused by relative motion are defined as noise. To eliminate signal noise resulting from relative movement between the string and the sensors, an accelerometer was added to the unit. The accelerometer is 2G (gravitation of force of the planet, 9.8 m/s^2) with three axes and is compatible with a signal port available on the LV-EMI™ unit. The smaller the range of forces, the more sensitive the readings will be from the accelerometer. The unit graphs the signals from the accelerometer to monitor for noise created by an impact or movement.

The accelerometer is utilized with every continuous rod scan. Field scan results are shown in Figures 2, 3, and 4. The blue line in the bottom portion of the graph represents the accelerometer, the additional lines represent sensors on the EMI unit. The circled spots on Figures 2, 3, and 4 display that the accelerometer signal (blue) coincides with the EMI spikes indicating that the EMI signal is likely noisy (false signal) due to movement in the rod string and not due to a defect (true signal).

The next step in the development process is to regulate the electromagnetic signals with motion signals to automatically eliminate noise due to movement from the signal created by material flaw detection.

<u>RESULTS</u>

After the scan is complete, the EMI operator inputs their findings into a profile report, similar to a tubing scan profile report. The findings are from screenshots taken during operation (see Figure 1 for an example). Each screenshot represents an average of a fifty-five-foot section in the rod string. Each inspection screenshot is captured every thirty seconds so depending on the speed at which the rod string is pulled, the average section can slightly vary. Profile reports for magnetic flux leakage (MFL) can be seen in Figures 5 and 11. Profile reports for magnetic flux density (MFD) can be seen in Figures 6 and 12.

For the magnetic flux leakage (MFL) profile report, the yellow line in Figures 5 and 11 represents flaws up to .030 inches (30 thousandths) or 6% of the rod diameter. The blue line represents flaws greater than .030 inches (30 thousandths or 6% of the rod diameter) and up to .60 inches (60 thousandths or 15% of the rod diameter). The red line represents flaws above .60 inches (60 thousandths) of the rod diameter. These thresholds are valid for all diameters of continuous rod.

For the magnetic flux density (MFD) profile report, the yellow line in Figures 6 and 12 represents 6% cross-sectional loss of the rod diameter. The blue line represents cross-sectional loss greater than 6% and less than 15% of the rod diameter. The red line represents cross-sectional loss greater than 15% of the rod diameter. These thresholds are valid for all diameters of continuous rod.

Field trials were conducted in wells under enhanced recovery utilizing ¾" continuous rod strings and rod pumps in 2-⅞" tubing. Both wells are over 2000´ total measured depth including directional sections approximately 1000´ in length. Trial wells are located in the San Joaquin Valley of California, USA.

Well No. 1:

According to the magnetic flux leakage (MFL) chart in Figure 5, indications of 30 thousandths or 6% to 60 thousandths or 15% of the rod diameter were observed throughout most of the rod string. Visual inspection revealed what appeared to be moderate corrosion pitting throughout most of the rod string. Corrosion pitting of 60 thousandths of the rod diameter was observed between 150' to 300'. Photographs confirming this condition are given in Figures 7 and 8.

According to the magnetic flux density (MFD) chart in Figure 6, the rod string experienced mild to moderate wear throughout most of the rod string. Severe wear was seen between 1200' and 1300' with up to 25% cross-sectional loss. The minor side of the semi-elliptical rod string has worn to a knife-like edge. Photographs confirming this damage are given in Figures 9 and 10.

Well No. 2:

According to the magnetic flux leakage (MFL) chart in Figure 11, indications between approximately 30 thousandths or 6% to 60 thousandths or 15% of the rod diameter were observed throughout most of the rod string. Visual inspection revealed what appeared to be moderate corrosion pitting throughout most of the rod string. Examples are given in Figures 13 and 14.

According to the magnetic flux density (MFD) chart in Figure 12, the rod string experienced moderate wear. Up to 15% cross-sectional loss of the OD was seen near the top of the rod string from 100' to 300'. A weld can be seen in Figure 15 at 650'. At 1,145', a magnetic flux density (MFD) indication was observed on the magnetic flux density (MFD) chart, shown in Figure 16. It should also be noted that 175' of conventional stick rod with 4 guides per rod were run before the continuous rod section. Several of the guides were worn through, shown in Figure 17. The coupling in Figure 18 also experienced significant wall loss.

FUTURE WORK

At present, a trained operator must monitor signals to manually flag noise resulting from rod motion (vibrations or shocks). This has been partially mitigated by adding an accelerometer to the apparatus. Future work includes creating an algorithm to use motion signals from the accelerometer to automatically attenuate noise from the magnetic signal. This will reduce the potential for human error during flaw detection by reducing the tasks assigned to the operator during measurement scans.

Coiled tubing is a similar steel product to continuous rod. Both consist of a continuous string welded at some locations, susceptible to similar damage mechanisms (e.g. corrosion, cracking, wear), and handled similarly at the wellsite. The primary difference is that coiled tubing is hollow which precludes visual inspection of one surface. Additionally, visual inspection of the exterior surface at the wellhead presents safety concerns. Since the coil tubing is in tension when running into the well, personnel are typically excluded from the immediate area around the coil tubing. This leaves the operator to rely on pressure testing to detect flaws after they have resulted in a through-wall leak, see [6]. Modifying this EMI technology could enable a means of detecting both surface and internal flaws in coiled tubing in real-time at the wellsite before they grow to the size of a through-wall leak.

Assuming the system can be proven for hollow tubulars like coil tubing, additional OCTG applications become the next opportunity for future development. While some electromagnetic inspection methods are available for OCTG at the well site, all electromagnetic systems that require an external source are energized and present limitations on use in explosive gas environments. The LV-EMI™ system presents a simple alternative technology that also satisfies standard explosive environment requirements.

CONCLUSIONS

Fatigue failures are the most common reason continuous rods fail. Electromagnetic inspection can be used to check the integrity of the rod string and extend the useful life of the rods, minimizing both expensive repairs and deferred production from unpredictable failures.

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6. Stanley, R.K. “Development of and Results from a New Coiled Tubing Inspection System.” *Insight-Non-Destructive Testing and Condition Monitoring* 51, no. 12 (2009): 676-679.

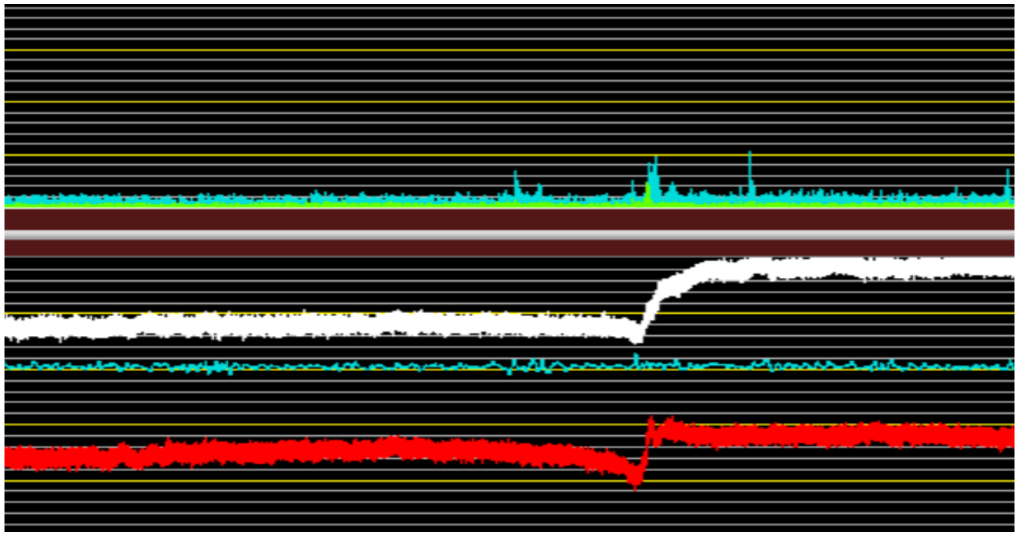

Figure 1: EMI Indications for Rod String Scan

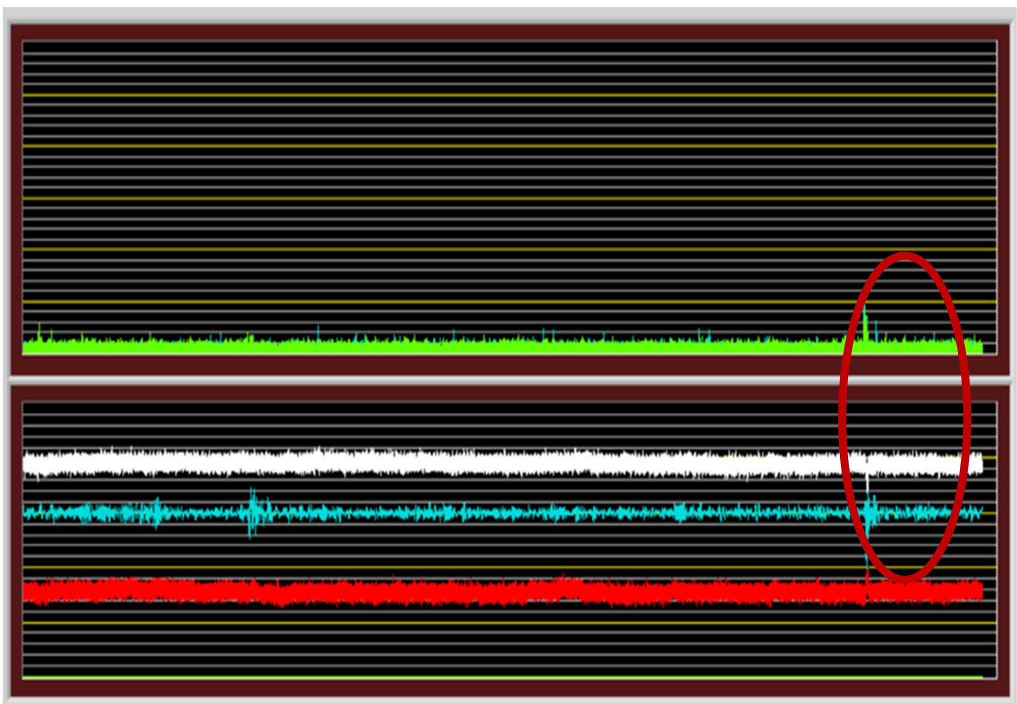

Figure 2: Accelerometer Display Field Results (blue signal)

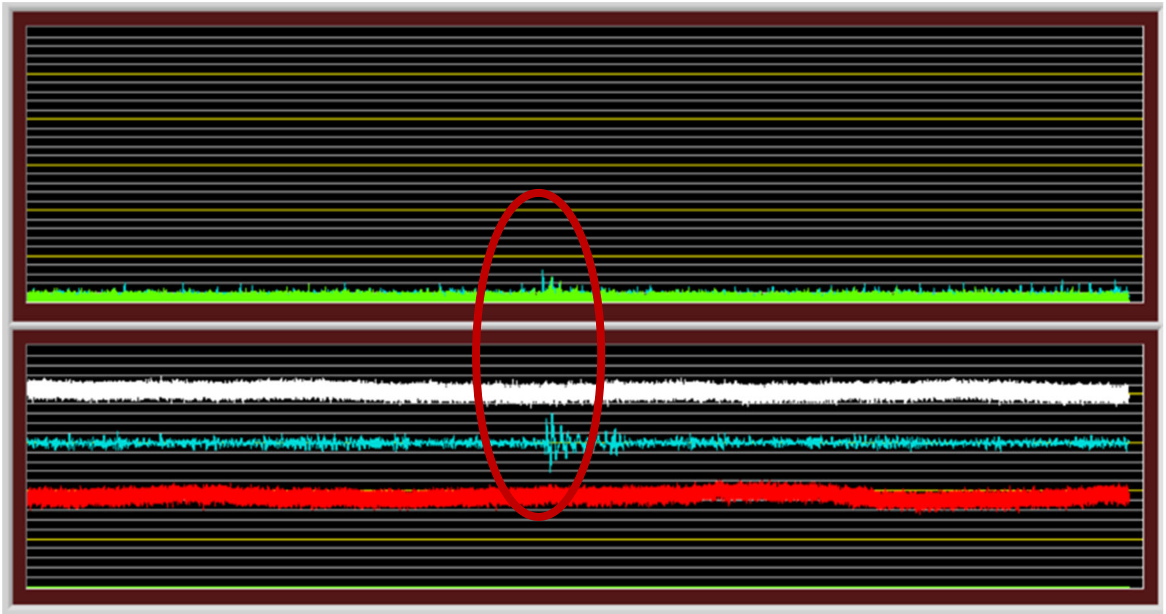

Figure 3: Accelerometer Display Field Results (blue signal)

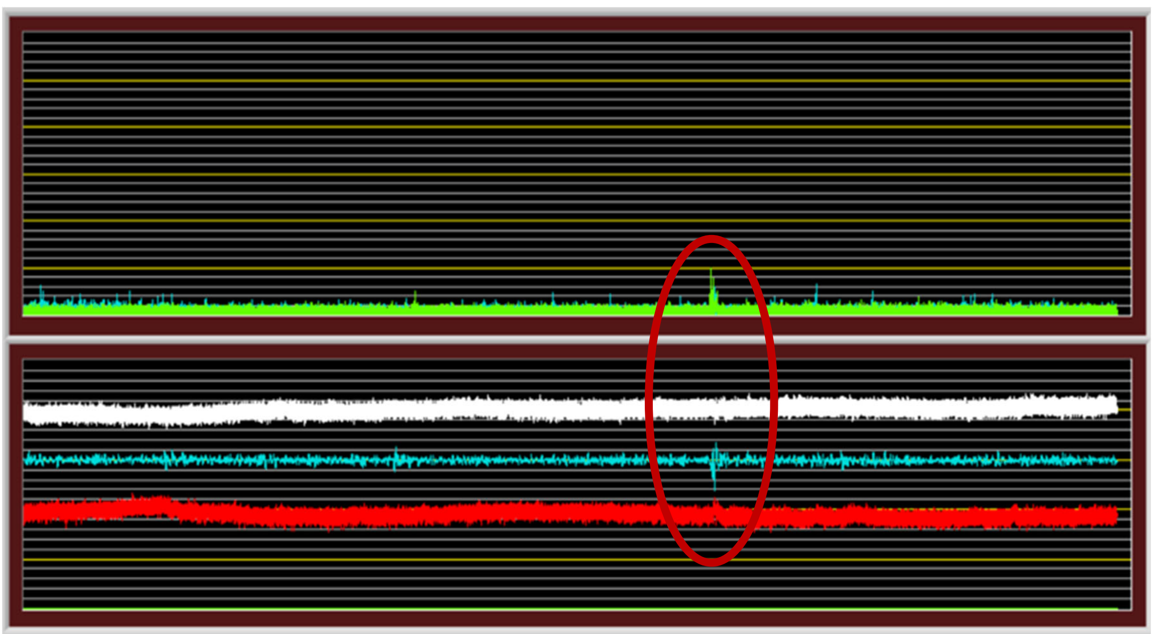

Figure 4: Accelerometer Display Field Results (blue signal)

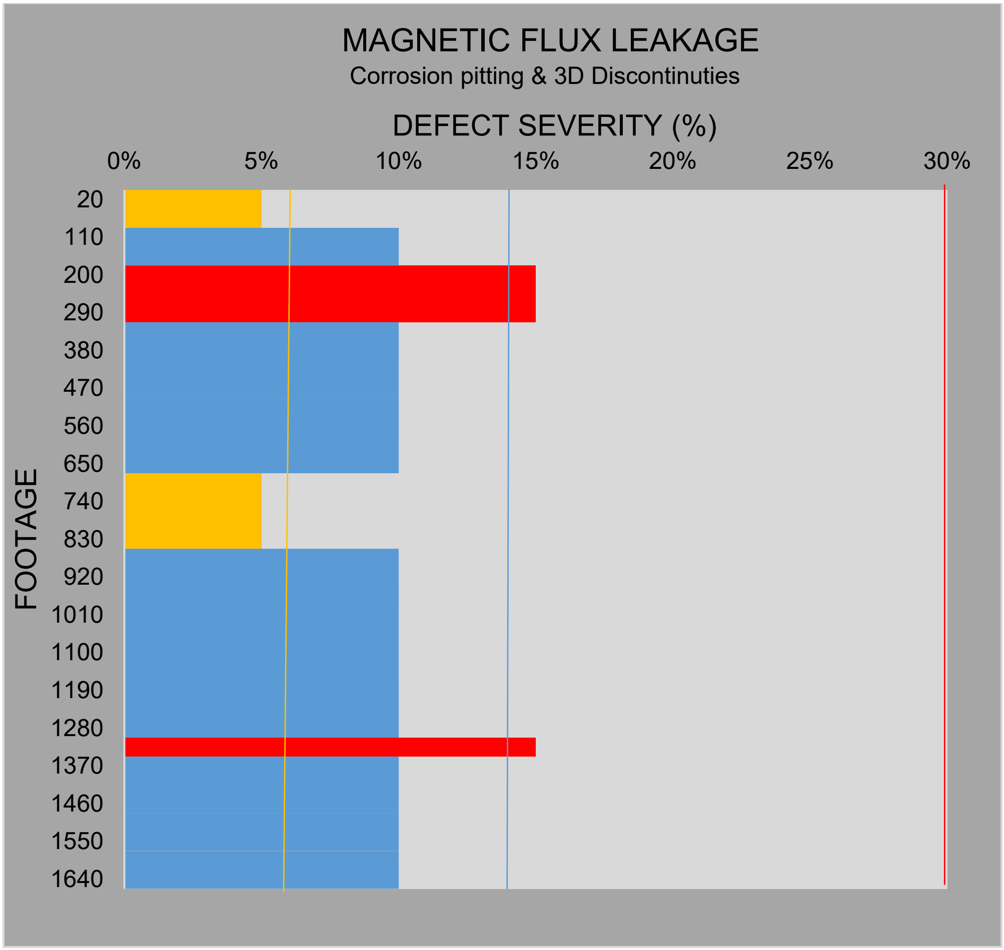

Figure 5: Magnetic Flux Leakage (MFL) Indications for Well No. 1

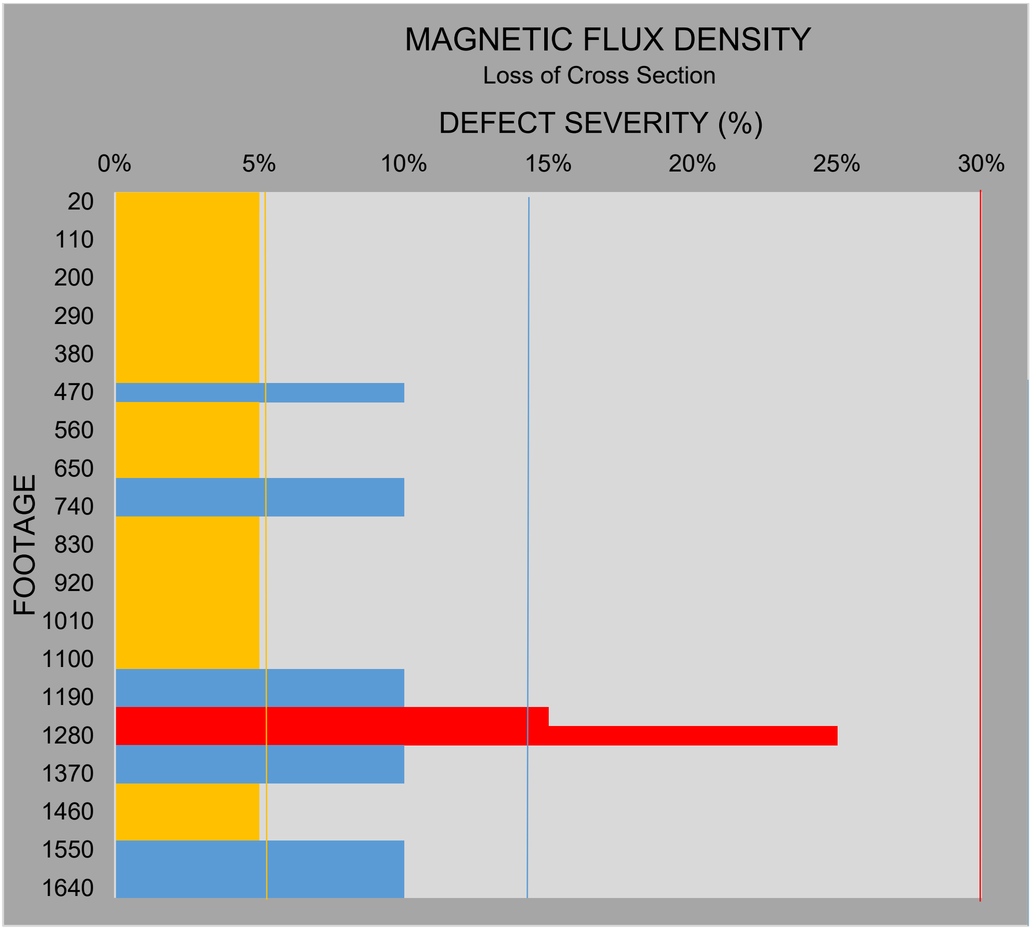

Figure 6: Magnetic flux density (MFD) Indications for Well No. 1

Figure 7: Appears to be corrosion pitting – Well No. 1

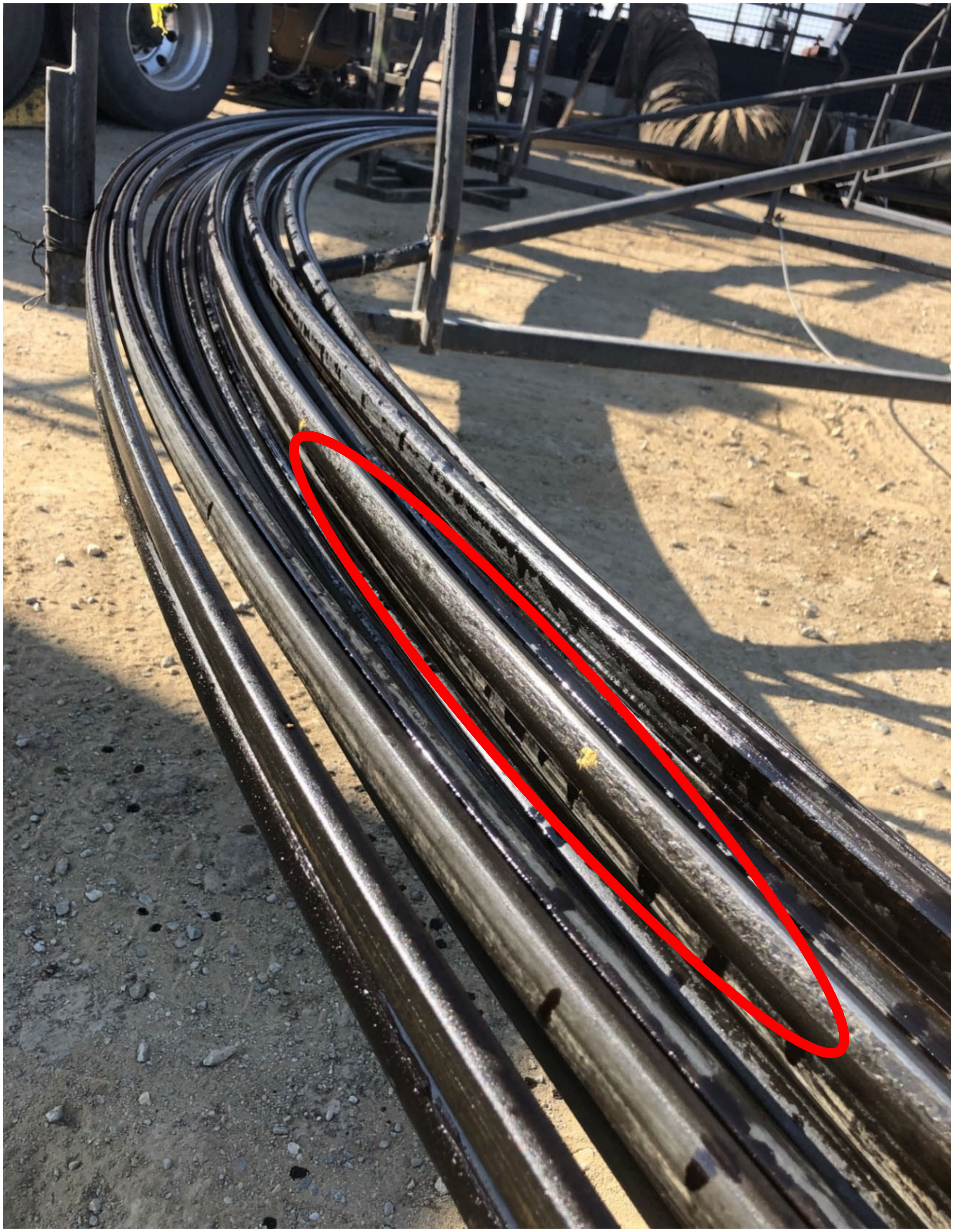

Figure 8: Appears to be corrosion pitting – Well No. 1

Figure 9: Worn to a knife-like edge on minor side – Well No. 1

Figure 10: Worn to a knife-like edge on minor side between 1200’ – 1300’ – Well No. 1

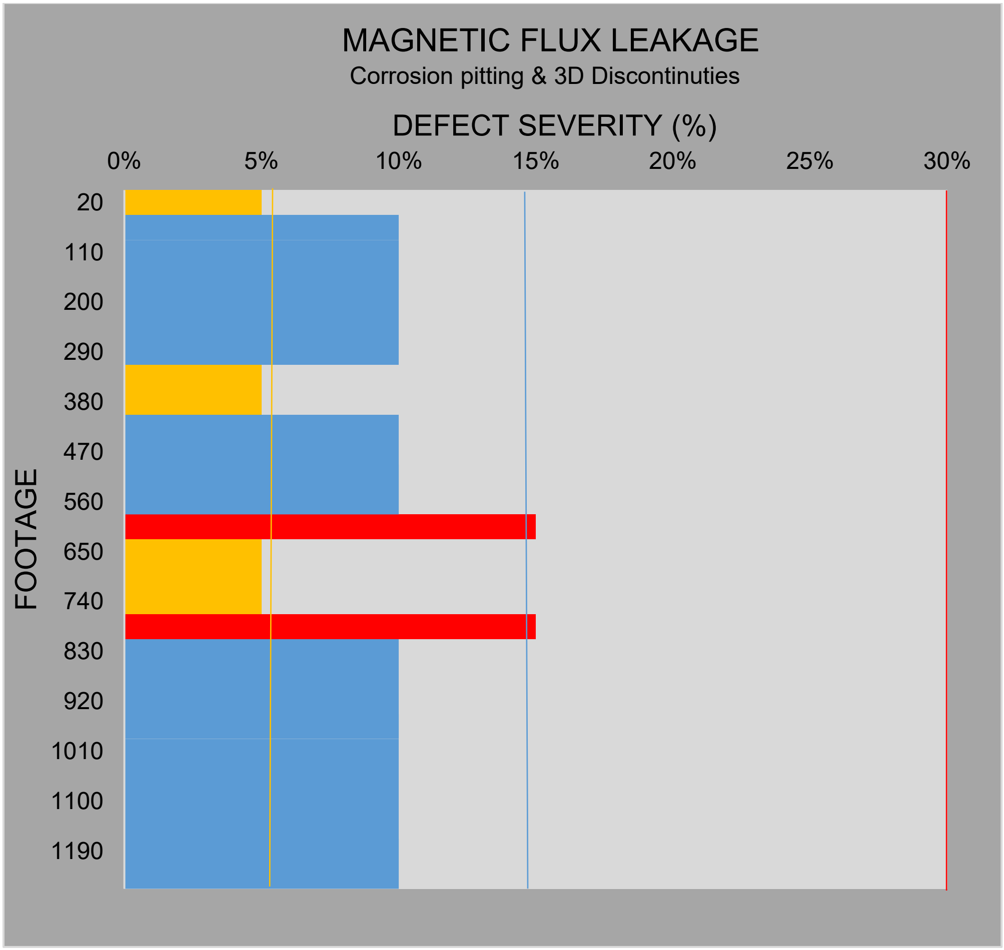

Figure 11: Magnetic Flux Leakage (MFL) Indications for Well No. 2

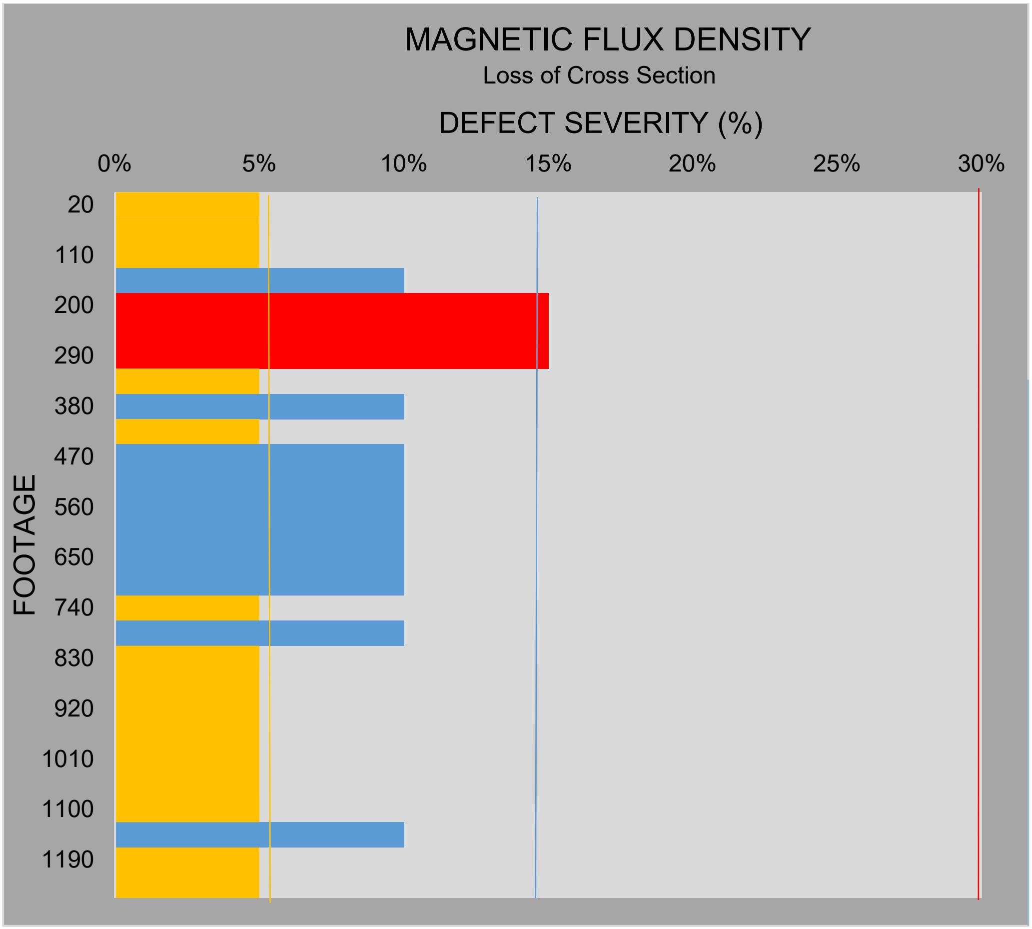

Figure 12: Magnetic Flux Density (MFD) Indications for Well No. 2

Figure 13: Appears to be corrosion pitting – Well No. 2

Figure 14: Appears to be corrosion pitting - Well No. 2

Figure 15: Weld at 650’ – Well No. 2

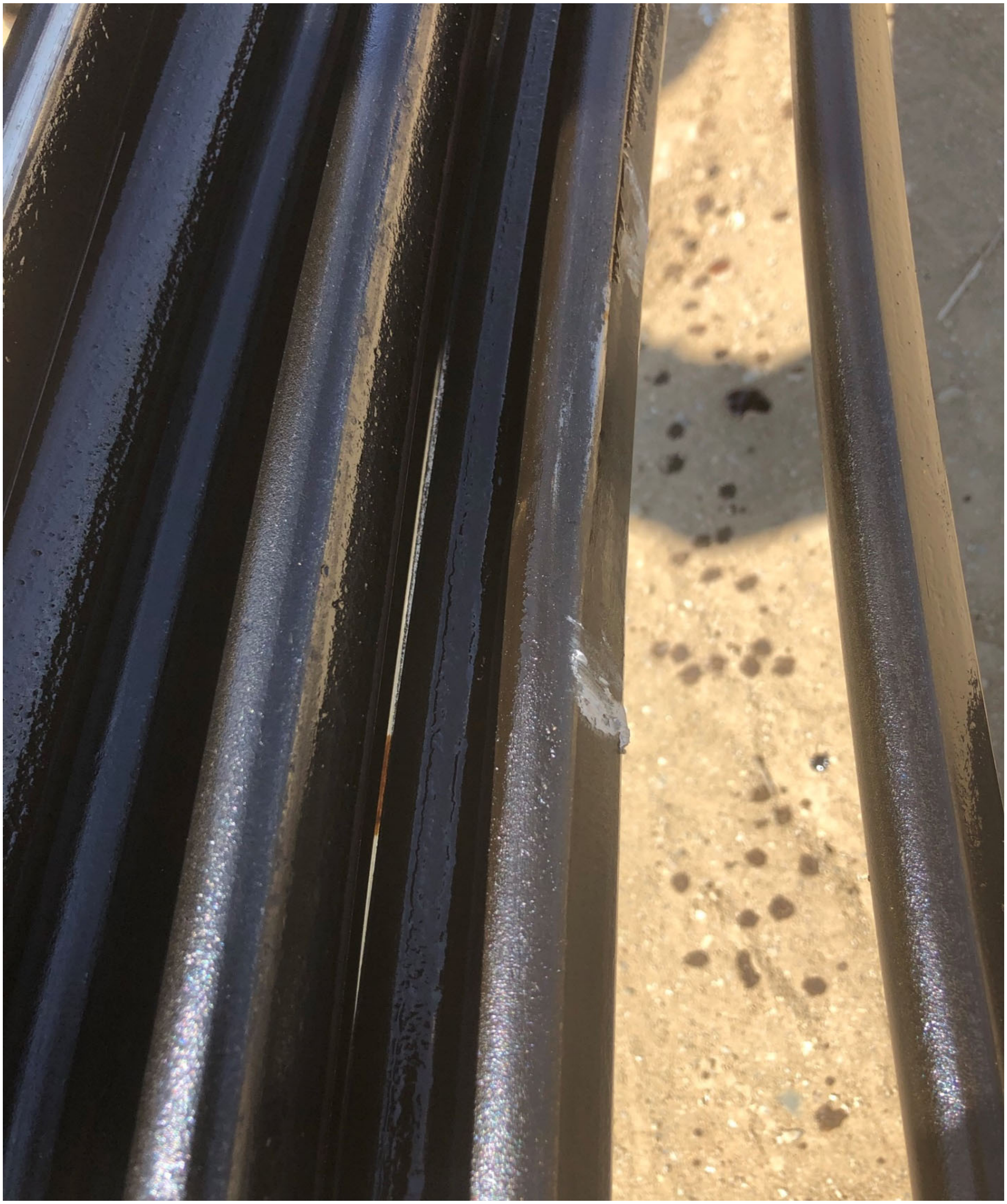

Figure 16: Magnetic Flux Density (MFD) indication at 1,145’ – Well No. 2

Figure 17: Worn Guide - Well No. 2

Figure 18: Wall Loss on Coupling