

The Six Sigma Approach to Improving Tribology Measurements and Methodologies, Including the Use of Laboratory Equipment at the Rig Site

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Abstract

Process improvement entails a methodology that refines the proper application of products, procedures, and equipment to achieve a desired result. While applying Six Sigma methods, a device that can be used at the rig site is optimized through both technological and process improvements. As drilling optimization pushes boundaries with deeper wells and longer laterals, friction forces incurred can limit lateral length and performance. Accordingly, field testing of the drilling fluid for its ability to impact potential frictional forces is critical.

Drilling fluid tribology is measured by an extreme pressure and lubricity tester. The resulting lubricity coefficients potentially lead to fluid modifications to reduce torque and drag. However, because changing wellsite conditions affect fluid lubricity, analyzing the lubricity at a lab—later and remotely—provides little benefit. Taking this equipment to the field enables scheduled, real-time performance characterization of the drilling fluid.

This tribology tester uses a rotating ring and stationary block of known and fixed contact forces. This equipment is trusted throughout the industry to be used as an indicator of the nature of the lubriciousness of the fluid; however, direct correlations between the results from the tribology tester and drilling fluid performance have never been formally applied. By using statistical analysis and Six Sigma principles, techniques are explored to increase the reliability and utility of the data from the extreme pressure and lubricity tester. After validation of the process, the manufacturer of the instrument makes suggested product modifications that allow for higher levels of reliability, which can be translated into higher levels of drilling fluid performance.

Introduction

Drilling operations continue to push boundaries by drilling longer laterals in both conventional and unconventional plays. Monitoring well-site trends is necessary for timely operating decisions. When drilling long, horizontal laterals with a high-performance water-based drilling fluid (HPWBF), a lubricity meter is used in the field¹. The drilling industry uses the

Model 212 lubricity meter, a block on ring tester^{2,3}, as the standard tool for measuring drilling fluid lubricity. It is common, affordable, and transportable, making it a viable option as a field instrument. However, the meter is designed for the laboratory, where it is used by a specialist under controlled conditions. Lubricity measurements taken at the rigsite are more variable than those taken in the laboratory. A certified Six Sigma Black Belt conducts a study.

Variability and Six Sigma

The objective of this study is to develop a capable lubricity measurement system for the field. Capability, in this context, represents the amount of error in the measurement process. A capable system is one that has an acceptable amount of variability. The variability thresholds, according to AIAG⁴, are listed below. The thresholds are derived from the measurement system and are equal to an estimated process variation seen within the study based on the tolerance of a measurement.

Defined Standard	System variability
Acceptable	<10%
Marginal	10-30%
Unacceptable	>30%

The main variable of interest in the study is the fluid's lubricity. Lubricity is on target if it meets the expectation as outlined in the drilling program. Lubricity has acceptable variability if the reading obtained by the field personnel from the lubricity meter is below 10%, as per the chart above.

Potential measurement variability sources include:

- The lubricity gauge and operator
- The fluids being measured
- The procedures
- The environment

Measurement Systems Analysis

The Six Sigma methodology incorporates Measurement Systems Analysis (MSA) to assess the capability of the measurement system, which is a function of precision (repeatability and reproducibility).⁵

Assumptions

The measurement system should be able to differentiate between fluids of different lubricities. If it cannot, the system variation may be so large that system variation is not acceptable. If the process performance is acceptable, then the variation between readings and between operators is analyzed for acceptance. In addition, the measurement system should be stable (in control) over time, provide accuracy throughout a full range of fluid types and lubricities, be accurate or unbiased, demonstrate linearity, and illustrate an appropriate amount of resolution.

The potential study focuses on variability attributable to the interaction between the gauge and the operator. Repeatability is the variability of readings within a single operator. Reproducibility is the variability of readings between operators. Each individual study focuses one potential variable based on finding from previous studies.

Software Analysis

Figures 1-6 and 8-9 are sample output from the statistical software that performs the Gauge R&R calculations. The output includes both Variation Reports and Summary Reports. The Variation Report breaks down sources of variation while the Summary Report states conclusions.

To calculate Gauge R&R, the statistical software uses the ANOVA method to break down the sources of variability, differentiating between fluid-to-fluid variation and the Gauge R&R variation. The Gauge R&R variation is further split between repeatability and, reproducibility (both from operator to operator and within the operator). The variation breakdowns are located on the lower right hand corner of the Variation Reports. Also included on this report are graphical descriptions of repeatability and reproducibility.

To determine process performance, the tolerance of deionized (DI) water assesses the system's capability⁶. On the Summary Report, the top graph describes process performance and the bottom graph describes the variation reported on the Variation Report. For the measurement system to be deemed capable, both graphs must be below 10%.

The Gauge and Operator

The lubricity meter operator takes and records visual lubricity readings off an analog or digital display. Two operators measure the lubricity of the same fluids using the same first generation lubricity meter. For each fluid, the operators measure the fluid and record the data three times. The data is then inputted into statistical software, which calculates the Gauge R&R output and states conclusions.

The Fluids Being Measured

In each Gauge R&R study, the operators measure ten fluids of varying compositions and repeat the measurements, for each of the ten different fluids, three times. The compositions offer the range of lubricity typical of drilling

fluids. Measurement systems analysis requires that all the fluid samples are kept as one homogenous sample and separated only for each individual study. After a sample is used for a measurement, it is disposed of to eliminate contamination to the homogenous mixture. One of the ten fluids in each study is DI water, for which the lubricity specification is well known and established to be 0.32-0.38.^{6,7} This is done to validate that the instrument is calibrated and operational.

The Procedures

In order to minimize variation between operators, it is critical to establish calibration and measurement procedures for each Gauge study. Calibration is part of the procedural setup for these studies.⁵ Incremental improvements are made through the study. The procedures are detailed in Appendix 1.

The Environment

Conditions in the field tend to vary. To minimize variability introduced into this study by the environment, each Gauge R&R application was conducted in a laboratory environment. However, the third R&R application aims to reduce environmental variability in the field.

Initial Gauge R&R Study

The purpose of the initial Gauge R&R study is to set a baseline for subsequent studies. One of the individuals is an experienced user of the lubricity meter and the other operator has no experience.

Initial calibration and measurement are provided to the two meter operators. The two operators perform the measurements and calculate the Coefficient of Friction (CoF) as per the instructions from the manufacturer:

$$\text{CoF} = (\text{Meter Reading} \times \text{Correction Factor}) / 100$$

The corrected reading takes into account the reading of DI Water before running the sample.⁸ The operator's reading is multiplied by the DI standard (34) divided by the operator's reading of DI water.

The Fluids Being Measured

1. Base Oil 1
2. Base Oil 2
3. Base Oil 3
4. Drilling Fluid 1- LSND1
5. Drilling Fluid 2- LSND2
6. Drilling Fluid 3- LSND3 + 1% Lubricant
7. Drilling Fluid 4 -HPWBF + 2% Lubricant
8. Drilling Fluid 5- Diesel OBF
9. Drilling Fluid 6 – LSND3 + 2% Lubricant
10. Tap Water

Discussion

The initial study confirms that the meter is capable of distinguishing between fluids of different lubricities. Therefore it has acceptable process performance. However, as seen in Figure 1, MSA shows over 119% measurement system variability.

As concluded in Figure 2, the current lubricity measurement system is not capable. A variability of 119% exceeds 10%. It is noted that meter operators in this study have varying levels of experience using the lubricity meter.

Second Gauge R&R Study

The purpose of the second Gauge R&R study is to reduce variation caused by differences in methodologies of the equipment operators and to evaluate the effect of the equipment manufacturer's suggested correction factor.

To reduce variation caused by the operator, a certification course is developed and implemented to guide an lubricity meter operator and provide procedural documentation. The course trains the operators to validate and monitor the lubricity meter appropriately in order to control and verify experiment variation.

To evaluate the effect of the equipment manufacturer's suggested correction factor, the meter operator calculates the CoF both with and without the correction factor. The Gauge R&R analysis is run on both sets of data and variability results are compared.

The Fluids Being Measured

1. Lubricant-HPDE
2. 10.5 ppg CaCl₂ Brine
3. Polyglycerol Additive
4. DI Water
5. 12.8 ppg Diesel OBF
6. GoM Reference SBF
7. Un-weighted MMO fluid
8. 11.7 ppg High Performance WBF
9. Red Dye Diesel
10. C16- C18

Discussion

Figure 3 shows the results of the Gauge R&R study on the CoF as calculated with the correction factor. Figure 4 shows the results on the CoF as calculated without the correction factor. The variability with the correction factor is similar to the initial Gauge R&R study (118% vs. 119%). The variability when the correction factor is not applied is reduced by 30% to 85%.

It is concluded that the correction factor adds variability. The calibration and measurement procedures are modified to eliminate it:

$$\text{CoF} = (\text{Meter Reading})/100.$$

The measurement system is still not capable as a variability of 85% exceeds 10%.

Third Gauge R&R Study

The purpose of the third Gauge R&R study is to evaluate the effect of temperature variation of the fluid sample. The

inability of the testing method to maintain a precise and constant temperature is resolved by testing the sample directly in an electronic thermal cell, which maintains a fluid temperature of 120°F.

The study continues with the same ten fluid samples and the same equipment operators as the second study.

The Fluids Being Measured

1. Lubricant-HPDE
2. 10.5 ppg CaCl₂ Brine
3. Polyglycerol Additive
4. DI Water
5. 12.8 ppg Diesel OBF
6. GoM Reference SBF
7. Un-weighted MMO fluid
8. 11.7 ppg High Performance WBF
9. Red Dye Diesel
10. C16- C18

Discussion

In Figure 5 and 6, the CoF is calculated without the correction factor as per the new procedures. The Gauge R&R study shows 60% variability.

Using the MSA to reduce variability caused by the operator, the procedures and the environment reduces the overall variability by almost 50% compared to the initial study (60% vs 119%). Even so, the measurement system still is not acceptable as it has greater than 10% error.

Fourth Gauge R&R Study

Formal assessment of the meter concludes that the analog or digital display oscillates between a range of values rather than remaining stable at one value. The oscillation, inherent to the block on ring mechanism, occurs when measuring either the DI water standard or the fluid sample. Reading lubricity values accurately is difficult.

One possible solution is to use an alternate mechanism for measuring lubricity other than the block on ring tester. More advanced technology is more expensive and not appropriate as field equipment. Another possible solution is to average a large sample of output data, thereby minimizing error. Upon request, the final output of the instrument is modified by a manufacturer of the instrument. The instrument records the readings in real time at a rate of the operator's choosing. An example of the data output by the improved lubricity meter is seen in Figure 7. After the first five minutes, the values oscillate around a stable average value. The lubricity meter captures the data points for an additional five minutes and then calculates an average value as the fluid's lubricity.

The purpose of the fourth Gauge R&R study is to evaluate the variability when the operator uses the improved lubricity meter. The test is run at 10 minute durations per sample and

the data is recorded every second. The final reading is the average starting at the 5 minute mark to the end of the test. All process improvements from prior tests are implemented.

The Fluids Being Measured

1. DI Water
2. High Performance Field Sample
3. Lubricant 1
4. Red Dye Diesel
5. C16-C18
6. 28% CaCl₂ Brine Drilling Fluid
7. 28% CaCl₂ Brine
8. 19% NaCl Brine
9. WBF Lab Sample
10. Bentonite/Lignite 9.5 ppg WBF

Discussion

Figures 8 and 9 display the results of the Gauge R&R study using the averaged data. Variability is less than 1%.

In summary, Gauge R&R measures the size of the noise relative to the total data variation. The variability is acceptable because it is below 10%. This criterion meets the desired target within the scope of the project, and so the measurement system is deemed capable.

Conclusions

- This study illustrates that a sample's lubricity may be successfully assessed when implementing the lubricity Meter as a field instrument.
- The measurement system may be better understood and improved by utilizing statistical methods.
- There is potential for further technical development for measuring drilling fluids tribology.

Acknowledgments

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Nomenclature

<i>EP</i>	= <i>Extreme Pressure</i>
<i>SOP</i>	= <i>Standard Operating Procedure</i>
<i>WBF</i>	= <i>Water Based Fluid</i>
<i>OBf</i>	= <i>Oil Based Fluid</i>
<i>MSA</i>	= <i>Measurement Systems Analysis</i>
<i>HPDE</i>	= <i>High Performing Drilling Enhancer</i>
<i>GoM</i>	= <i>Gulf of Mexico</i>
<i>DI</i>	= <i>Deionized</i>
<i>LSND</i>	= <i>Low solids-non-dispersed</i>
<i>ppg</i>	= <i>pounds per gallon</i>

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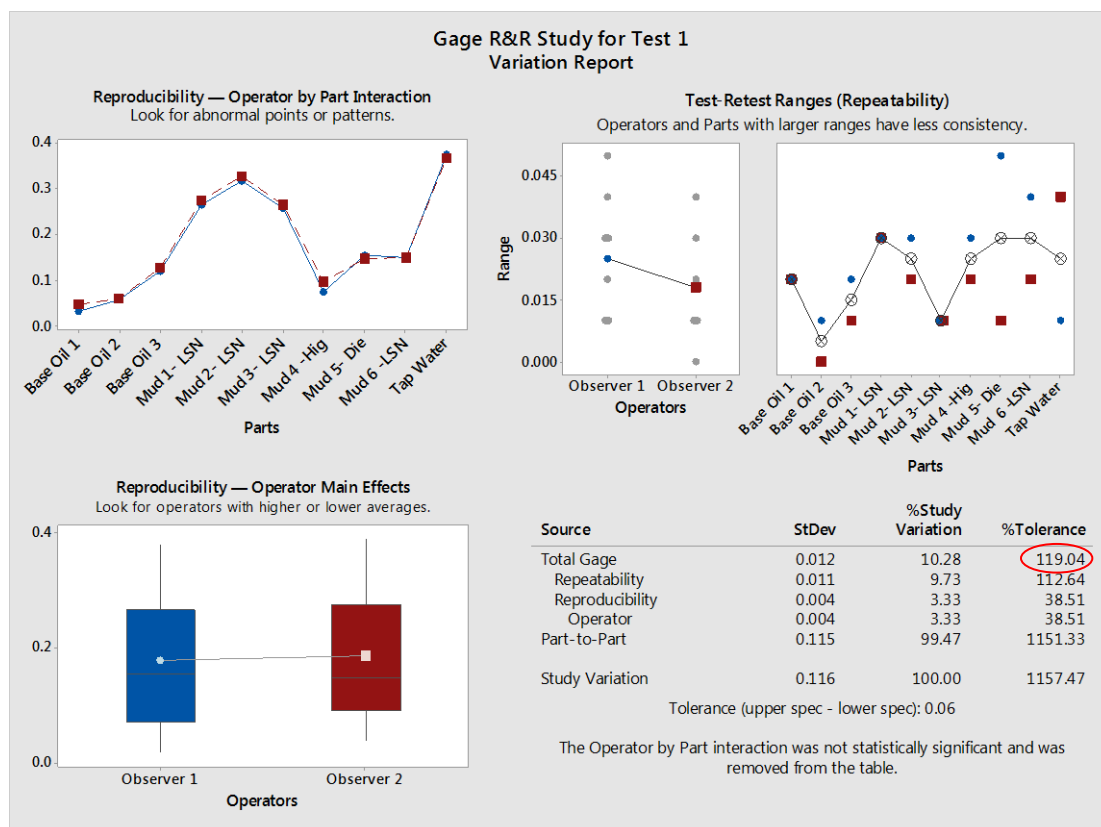


Figure 1: Initial Gauge R&R study to set baseline variability.

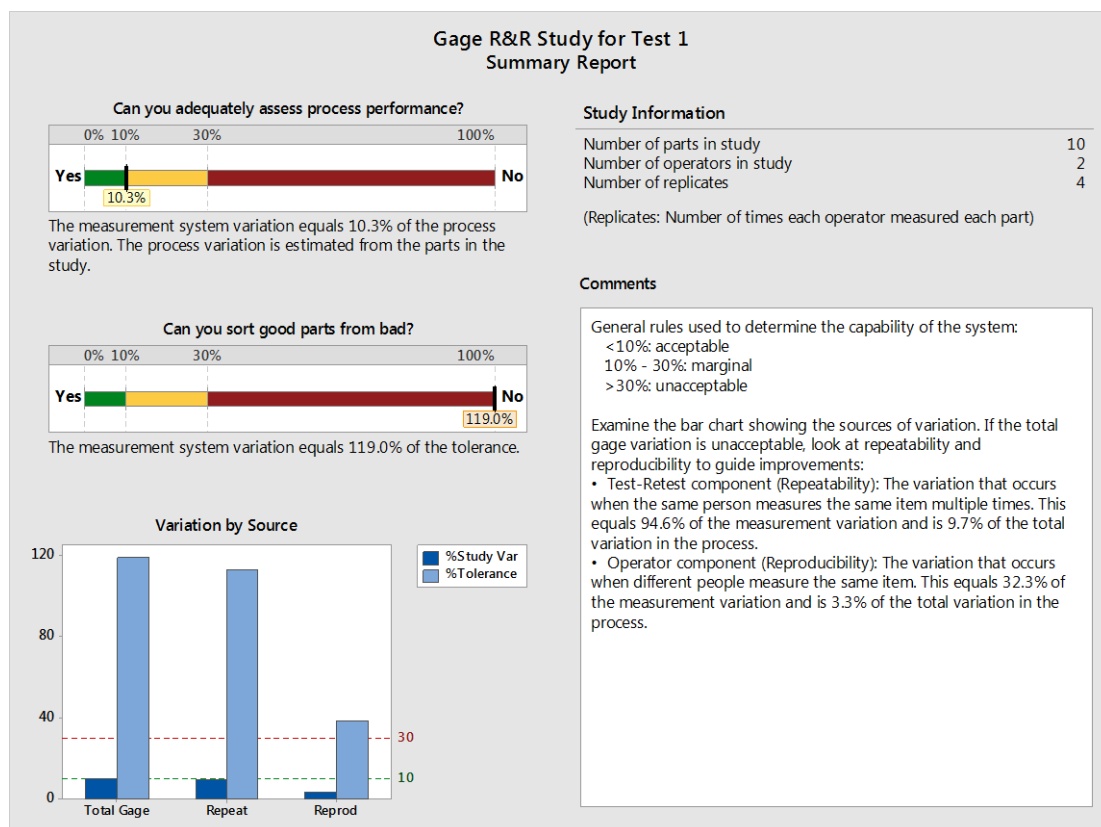


Figure 2: Initial Gauge R&R study conclusion that system has 119% variability, which is not acceptable.

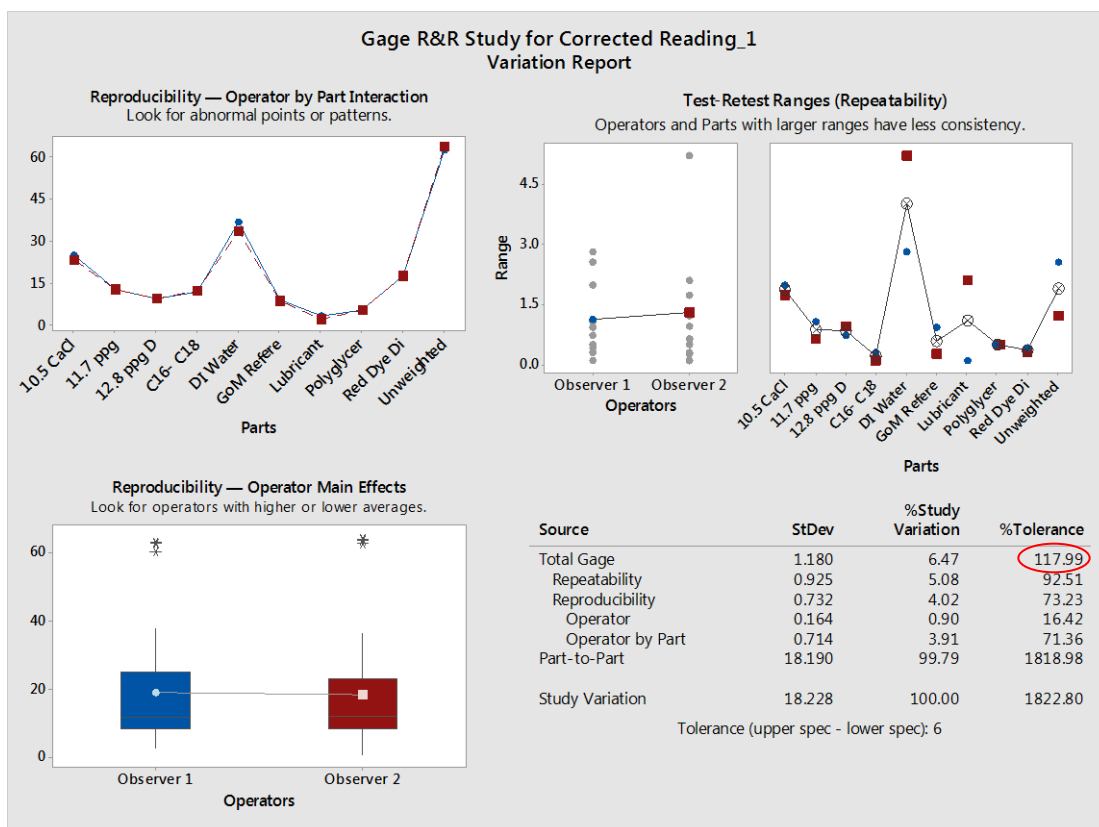


Figure 3: Second Gauge R&R study to reduce operator induced variability and evaluate correction factor (with the correction factor).

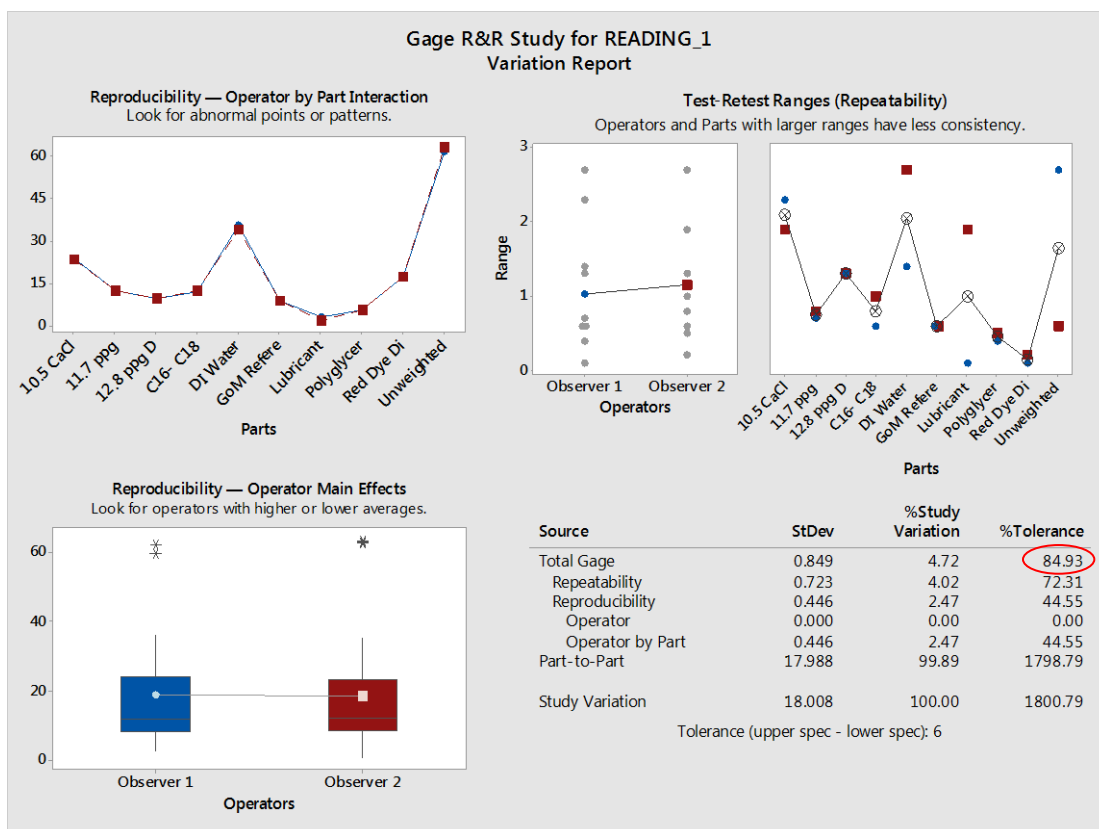


Figure 4: Second Gauge R&R study to reduce operator induced variability and evaluate correction factor (without the correction factor).

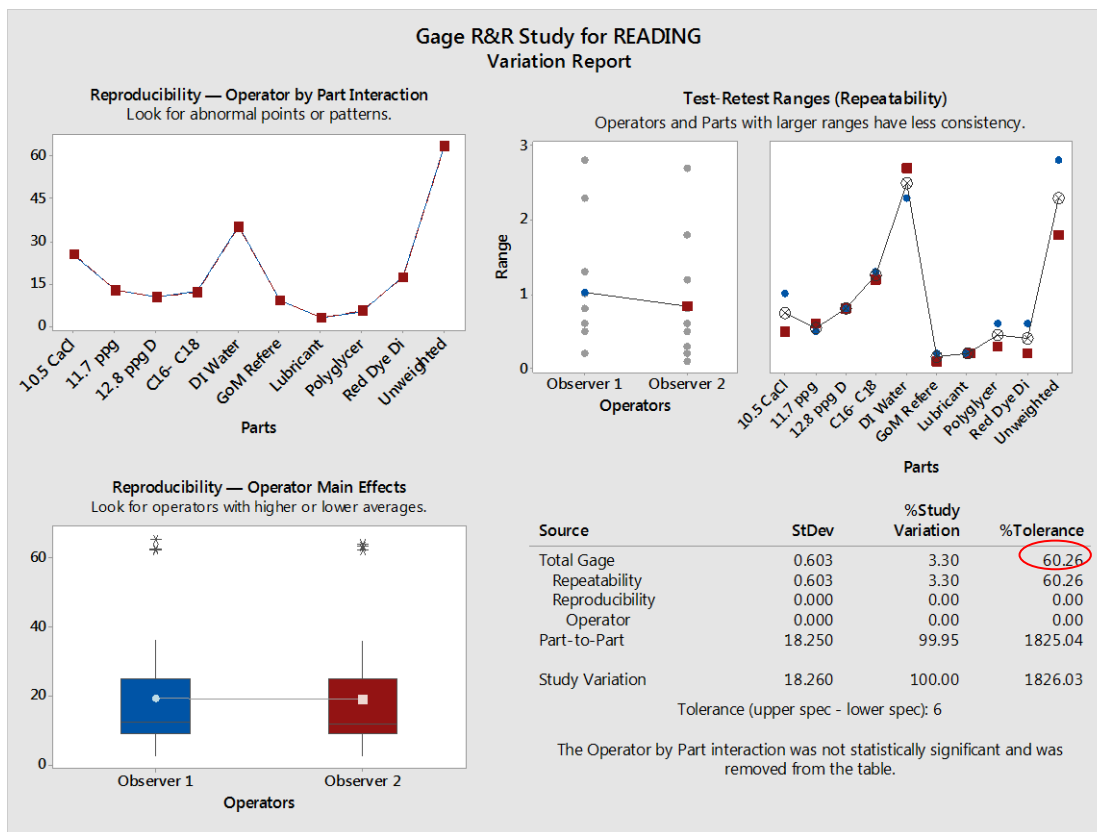


Figure 5: Third Gauge R&R study to reduce environmental variation.

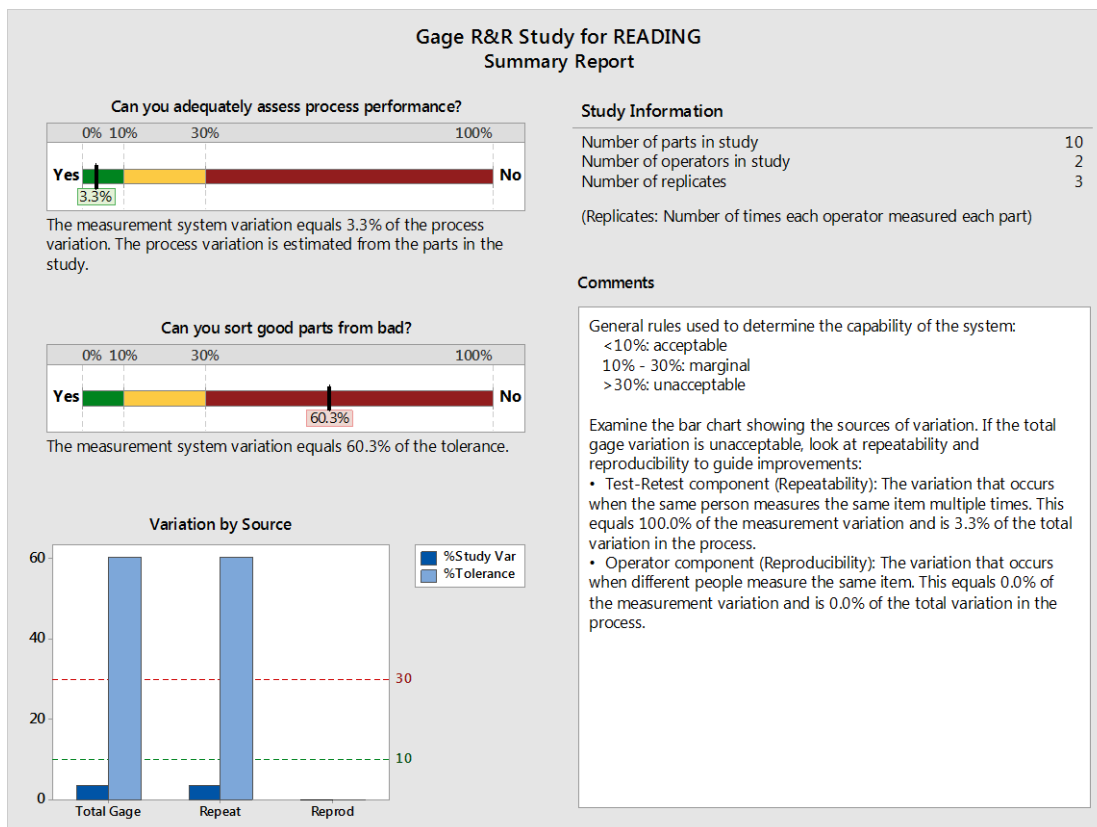


Figure 6: Third Gauge R&R study conclusion that variability has dropped from 119% to 60%, but is still not acceptable.

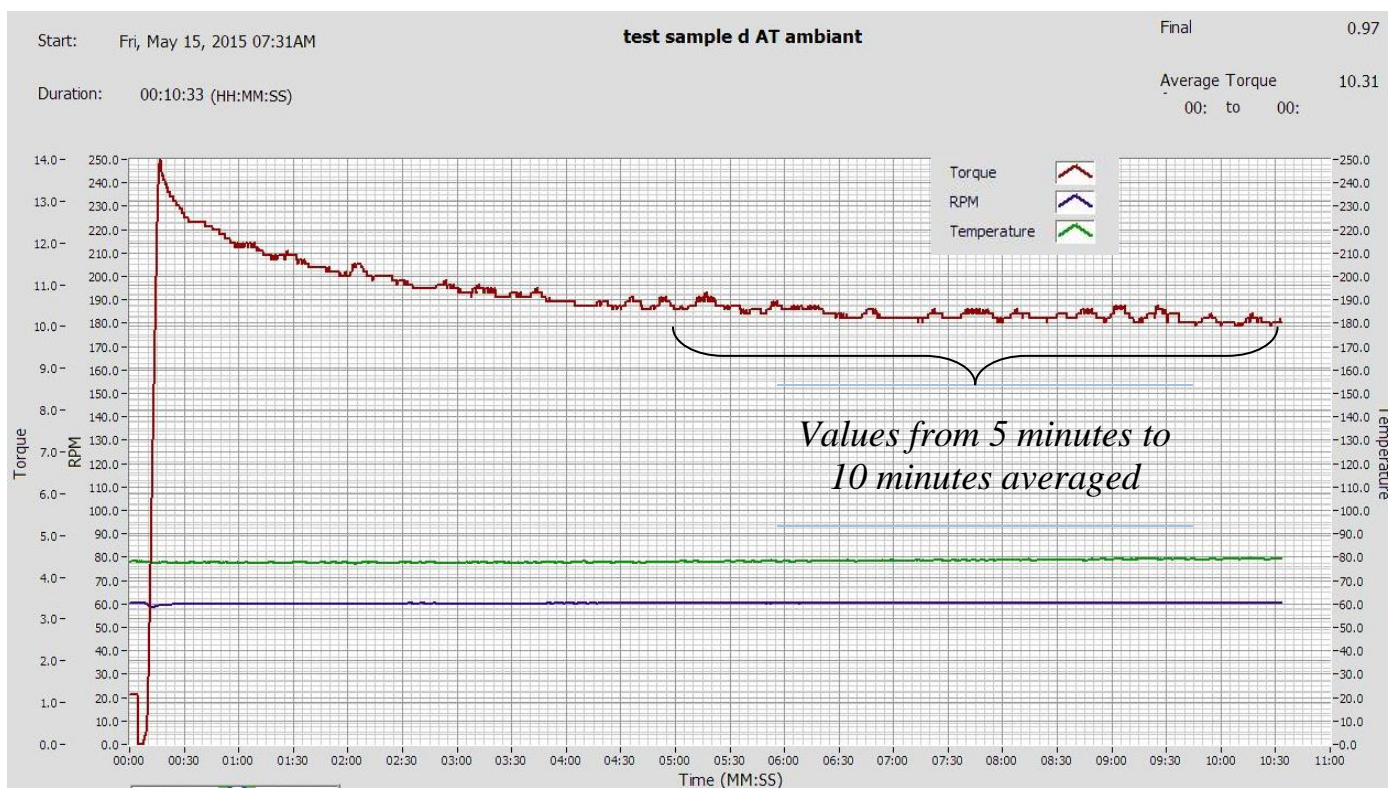


Figure 7: Output generated by lubricity meter showing oscillation, but stabilization of torque reading around average value after 5 minutes.

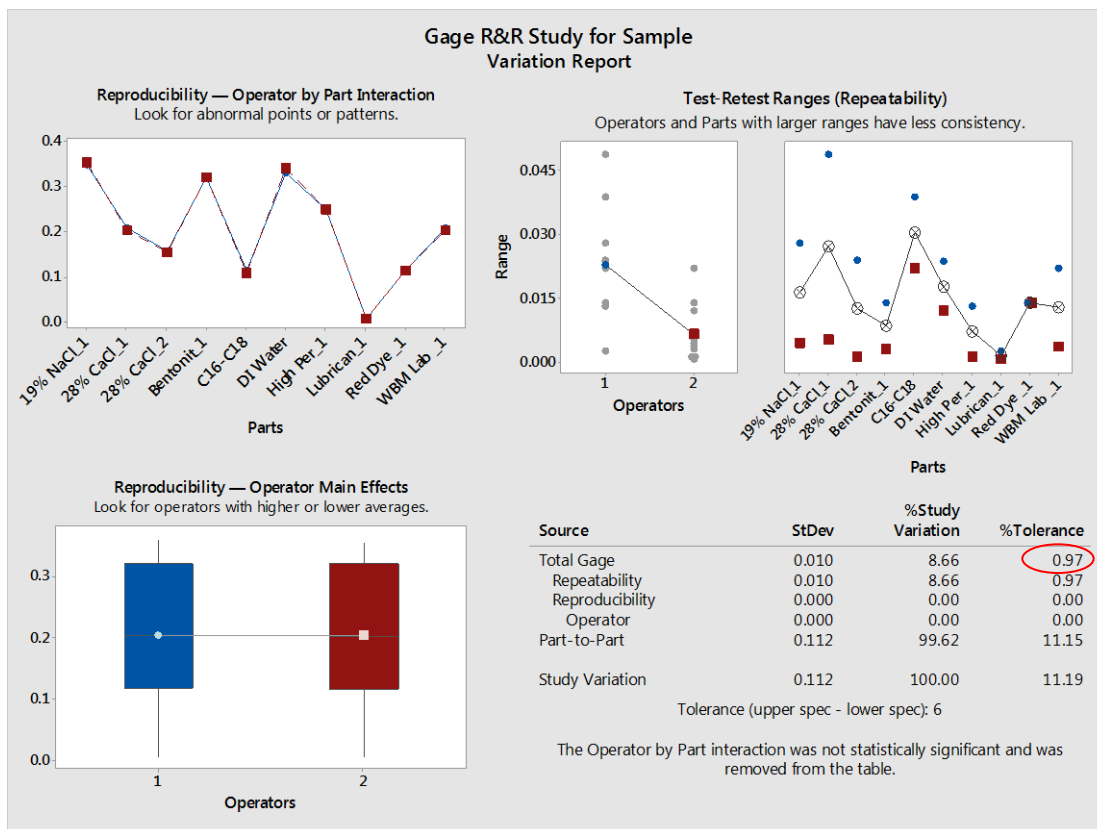


Figure 8: Fourth Gauge R&R study to determine variation with improved lubricity meter which averages readings from 5 minutes to 10 minutes

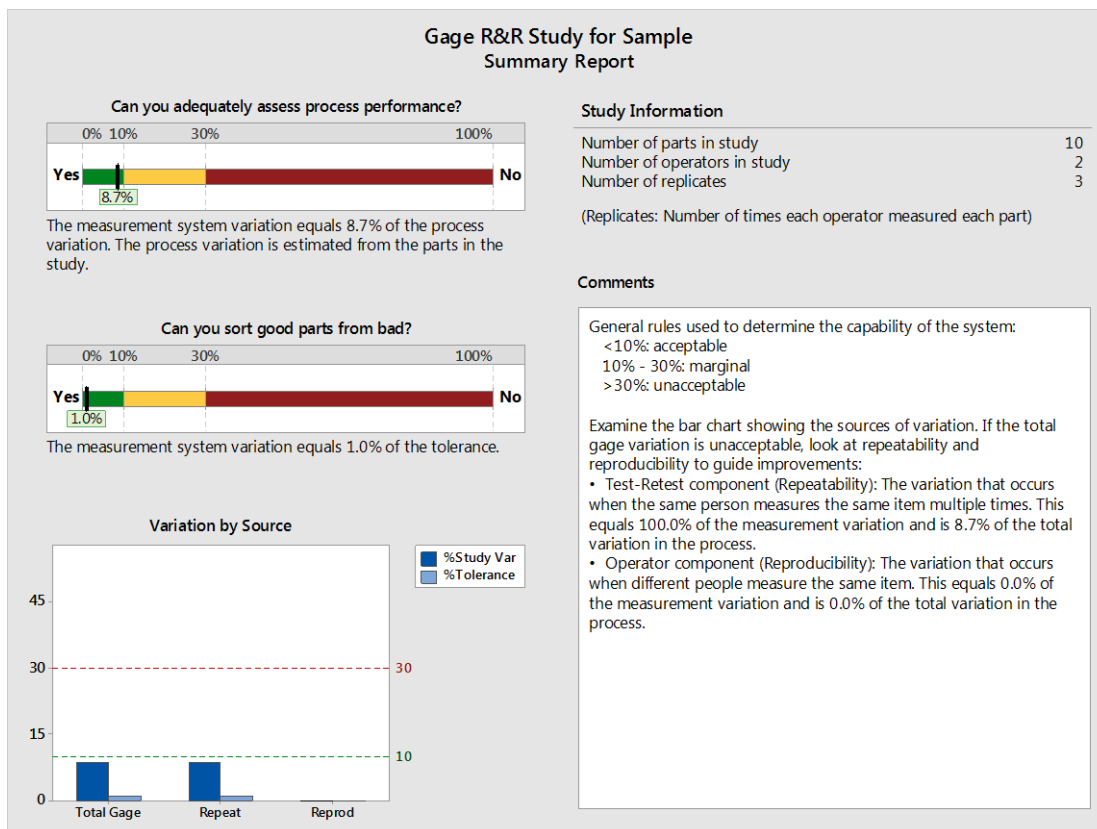


Figure 9: Fourth Gauge R&R study conclusion that system has 1% variability, which is acceptable. The improved lubricity meter allows for a capable system.

Appendix 1

Initial Procedure is as follows

Before running a test, the Coefficient of Friction of water should be 34 ± 2 at 60 RPM and 150 inch-pounds.⁸ (see note below)

1. Thoroughly clean all parts of the machine sampling area and the ring and block.
2. Turn on the power and let the machine run for 15 minutes.
3. Place the test block in the holder. Do not let the ring and block touch.
4. Mix the test fluid for at least ten minutes.
5. Set the motor speed to 60 rpm.
6. Zero the torque reading on the control panel.
7. Fill the cup with fluid. Place it on the stand.
8. Raise the cup until the ring and block assembly are fully submerged. Tighten the thumb screw.
9. Zero the torque reading.
10. Position the torque arm so it is inside the torque arm clamp.
11. Turn the torque adjust handle so the gauge reads 150 in-pounds.
12. Zero the time on the control panel.
13. Let the machine run for 5 minutes.
14. Record the torque reading from the display screen.
15. Lower the cup and discard the fluid.
16. Thoroughly clean the cup, the block holder and ring and block.
17. Calculate the Lubricity Coefficient = (Meter Reading \times Correction Factor)/100

Note: The CoF of DI water ranges between 0.32-0.38. The meter reading of water is 34, which is 100x the CoF.

Revised Procedure for a Lubricity Test

Before running a test, the Coefficient of Friction of water should be 34 ± 2 at 60 RPM and 150 inch-pounds.^{7,8}

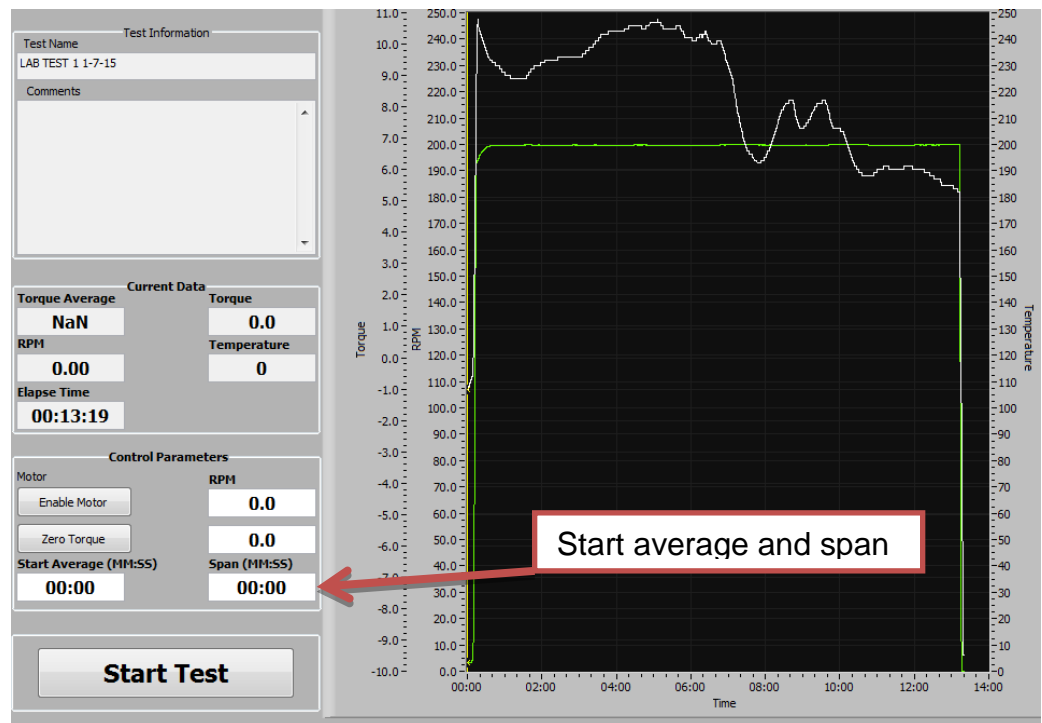
1. Remove the lubricity test ring (#111-02 with a flat outer surface) and the lubricity test block (#111-08 with a concave groove on one side) from the meter. You must remove the bottom nut below the test ring to remove the test ring. Place the nut, the test block, and the test ring in the ultra-sonic cleaner with 1 tablespoon of ultrasonic cleaner or hard soap (Ajax). Run for 15 minutes with DI water and approved cleaner for ultrasonic devices. Ultra sonic devices should be supplied with the lubricity meter and should be 160 watts or greater.
2. Remove the test block ring and nut from the cleaner and rinse with DI water. You will need to press pin to lock the shaft in order to remove and replace nut.
3. Clean the lubricity test ring (#111-02 with a flat outer surface) and the lubricity test block (#111-08 with a concave groove on one side) with acetone and rinse them thoroughly with deionized water. All parts of the machine in the sample area must be clean before starting a test.
Do not touch the metal contact areas with bare hands.
4. Place the lubricity test ring squarely onto the tapered portion of the main shaft. Using a 15/16" wrench, secure the test ring retainer nut. Make sure the ring seats squarely on the taper of the shaft.
5. Turn on the power and let the machine run for approximately 15 minutes.
6. Turn on the computer software where applicable. Right click the Ofite icon and run as an administrator.
7. Place the lubricity test block in the block holder with the concave side facing out and align it with the test ring.
8. Clean with acetone to be sure no fingerprints are present while reinstalling the block and ring. Be sure all components are dry by wiping with a paper towel.
9. Rotate the speed control knob until the indicator registers 60 RPM or if running the computer software, enable the motor to 60 rpm's.
10. After the unit has been running for 15 minutes, rotate the torque zero adjustment knob until the torque registers zero, or zero out the torque. Run the unit approximately 5 more minutes and adjust again if required.
11. Fill the stainless sample cup with ambient deionized water (260 - 280 mL) and place it on the lowered cup stand. Raise the cup stand until the test ring, test block, and block holder are fully submerged. Tighten the thumbscrew to secure the cup stand.
12. Position the torque arm so that it fits inside the concave portion of the torque arm clamp. Turn the torque adjust handle clockwise until the torque gauge on the arm reads 150 inch-pounds. If necessary, readjust the rotational speed to 60 RPM.
Never apply torque to the test ring unless it is submerged in a fluid.
13. Click "Start Test" in software
14. Let the machine run for 5 minutes and then record the torque reading. The torque reading should be 34 (between 32 and 36 are acceptable). If the torque reading is outside this range, see "Standardizing the Test Block" in the lubricity meter manual. Once standardization has been done return to step #1. Or if running the computer software click "run test" and fill out

appropriate label for test procedure. Let run for 7-10 minutes. At the bottom of the screen where it states “Start average” and “Span”. Enter “start Average” of 3-5 minutes and “Span” of 3-5 minutes.

15. Click “Stop Test” be sure the torque or torque average is in the 32-36 reading window

16. When test is done, rotate the torque wrench adjustment handle counter-clockwise until the torque registers zero. Lower the cup stand and discard the fluid. Wipe any remaining fluid from the sample cup, block, block holder, and test ring. Clean with acetone and rinse with DI water

17. Mix your test fluid (260 - 280 mL) for at least ten minutes. Pour the test fluid into the Heated Sample cup. Bring temperature of fluid up to a consistent 120 Degree Fahrenheit.



18. Place the cup on the stand and raise it until the block holder and test ring are fully immersed in the fluid. Secure the stand in place with the thumbscrew.

19. Turn the motor on to 60 rpm this can be done either by turning the speed control knob until the indicator registers 60 RPM, dialing in the knob to 60 rpm, or on the Software program enable motor and input 60 rpm

20. Turn the torque adjustment handle clockwise until 150 inch-pounds of torque have been applied to the test block. Let the machine run for 5 minutes. Or if running the computer software click run test fill out appropriate label for test procedure. Let run for 7-10 minutes. At the bottom of the screen where it states “Start average” and “Span”. Enter “Start Average” of 3-5 minutes and “Span” of 3-5 minutes.

21. Do not use a correction factor read the torque reading as is. If you are using the software this reading should be the Torque Average

22. Record the reading divided by 100 and record this on your report as Lubricity Coefficient.

