COMPREHENSIVE STUDIES ON THE FACTORS AFFECTING SUCKER ROD-COUPLING MAKE-UP

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INTRODUCTION

Beam pumping systems are operated in challenging and hostile environments due to the ever increasing demand to produce oil in a fast and efficient manner. The goal of this project is to increase the efficiency of these beam pumping systems by studying and optimizing some of the critical factors affecting sucker rod–coupling make-up.

Customer feedback indicated failures due to over, under, and loss of displacement. There have been significant number of issues regarding the adequacy and accuracy of the current displacement values, the lubrication technique (dry or wet face) for sucker rod-coupling make-up process, and the life of a sucker rod or number of make-ups on a sucker rod for maximum efficiency and output. This paper describes the research & development project which addressed the following issues:

a. Achievable load carrying capabilities on a made-up rod string using current industry standards of circumferential displacement.
b. Updated Displacement values.
c. Comparative analysis between dry and wet face make-up.
d. The decrease in the sucker rod's load carrying capabilities after multiple make-ups.
e. Optimal number of make-ups on a sucker rod.

The project used the core engineering concepts of stress, strain, torque, and circumferential displacement. A comprehensive engineering analysis was conducted in a laboratory using an exclusive displacement testing machine. The entire project was divided into the following three phases, and each phase addressed different aspects of sucker rod-coupling make-up.

Phase II - Verification and re-establishment of current industry standards of displacement values.
Phase III - Comparison between dry and wet face make-up.
Phase IV - Decay of sucker rods.

BASIC THEORY

A. Normal and Shear Forces:

To understand the sucker rod-coupling joint, refer to figure 1 (attached). There are two major forces acting on the joint:

a. Normal forces
b. Shear forces

Normal forces act in a direction parallel to the axis of the rod body. The amount of clamping force (force which keeps the sucker rod-coupling joint together) is directly proportional to the amount of normal forces generated in the system, and is a very desirable attribute in the make-up process.

Shear forces act in a direction perpendicular to the axis of the rod body, and tends to aid in the bending moment of the rod which may result in premature failure. Shear forces are a very detrimental attribute in a sucker rod-coupling make-up. Normal and shear forces (Strain) can be measured by strain gauges.

B. Stress-Strain Relationship:

The most important scientific concept applied in this experiment was the stress-strain curve: stress is directly proportional to strain (in the elastic region of the stress-strain curve).

Stress / Strain = Modulus of Elasticity.
Modulus of elasticity (Elastic modulus) can be calculated using an in-house tensile test. Strain (normal and shear strain) can be measured using strain gauges. Using these known parameters, the amount of preload stress in the stress relief of the pin can be calculated.

DISPLACEMENT TESTING MACHINE

The tests were performed using a displacement testing machine (strain gauge testing apparatus) designed and built in-house. The machine has the torque capability to shear a 1 1/8" sucker rod pin. The normal and shear forces were measured by using strain gauges, and the torque applied on the system was captured by a load cell. The strain gauges were pasted on the stress relief of the sucker rod pin and were connected to the data acquisition system. The data acquisition system has a capability of capturing 10000 data points per second. Figures 2, 3 and 4 illustrate the strain gauges and displacement testing machine. The displacement testing machine has the capability to measure torque applied, normal strain and shear strain, which were the three critical parameters to conduct the project.

ANALYSIS AND TEST RESULTS

Verification of current circumferential displacement values

The scope or goal of this phase of the project was to calculate the achievable load carrying capabilities of a made-up rod string when compared to its design strength ratings (design yield of a sucker rod). In order to achieve this, each grade and size of sucker rod was made up to the respective displacement values and the amount of pin stretch was measured using the strain gauge testing apparatus. The amount of pin stretch was used in the stress-strain formula or relationship to calculate the amount of preload stress in the stress relief or undercut OD of the sucker rod pin. The preload stress was compared with the design yield of the respective grade of sucker rod which gave a numerical value (%) called as design rating. The design rating gave a measure of the effectiveness and adequacy of the current displacement values.

Table 1 gives complete design ratings on all grades and sizes of sucker rods. A summarized version of this Table is illustrated in Tables 2 and 3 respectively. Table 2 gives a summary of design ratings based on sucker rod grades and Table 3 gives a summary based on sucker rod sizes.

From the data analysis, it was experimentally proved that the average design rating on all new run displacement values was 9% less than design strength ratings. The average design ratings on all re-run displacement values were 18% less than design strength ratings.

Re-establishment of Displacement Values

The next step in this phase of the project was to re-establish the current displacement values and cards. End user failure data and experimental studies were used to re-establish the displacement cards. There were two critical aspects which needed to be addressed in this phase of the project.

a. The design ratings for grade C, and K do not look similar as can be seen in Table 1. The general industry practice today is to use the same displacement values/cards for both grades of sucker rods. The modulus of elasticity or the mechanical characteristics of these grades of sucker rods are unique and hence it is not a good practice to use the same displacement values for grades C, and K. The same reasoning can be applied to grades CD, AD, and KD grades (API grade D rods).
b. The design rating varies across the board as it can be seen in Table 1. The key question is what are some of the displacement values which need to be re-established?

Pin failures due to under displacement accounted for 70% of the pin failures in this industry. So, from the data analysis it was inferred that design ratings less than 100% needed to be addressed to minimize the pin failures. Experimental studies were conducted on design ratings which were less than nominal design rating and were matched to meet 85% of the design yield of the sucker rod. The new sets of displacement cards have unique displacement values for each grade of sucker rod.

Comparison between dry and wet face sucker rod coupling make up

There are two types of make-ups in this industry, namely dry face and wet face. A dry face make-up is a process where the thread lubricant is applied only on the threads of the sucker rod. A wet face make up is a process where the thread lubricant is applied on the threads and faces of sucker rod and coupling. The goal of this phase of the project is to scientifically study the performance between dry and wet face make-up and establish the best make-up practice.

A set of 7/8" HS (High Strength) sucker rods was subjected to an incremental displacement test. The torque, normal strain and shear strain were measured and analyzed at various stages of displacement as shown in fig. 5.

A set of high strength sucker rods were tested under two different of scenarios. In the first scenario (dry face make up), the thread lubricant was applied only on the threads. In the second scenario (wet face make up), the thread lubricant was applied on the threads and faces of sucker rod and coupling.

Torque: Graph 1 illustrates a direct comparison of torque values between wet and dry face make up. As it can be shown, the required torque on the dry face test was 41% higher when compared to wet face. In the case of a dry face, the amount of friction available at the joint is much higher than a wet face and as a result, the achievable torque is higher. The amount of friction available is responsible for a successful sucker rod coupling make-up and it can be inferred from the test results that the torque achievable with a wet face make-up is not sufficient to hold the sucker rod-coupling joint together.

Shear Strain: Graph 2 illustrates a direct comparison of shear strain values between wet and dry face make up. Shear strain acts in a direction perpendicular to the axis of the rod body and, as a result, is a very detrimental attribute in the application of sucker rod-coupling make-up. From the test results, the shear strain was 23% higher in the case of wet face when compared to dry face. The sucker rod-coupling joint with wet face lubrication yielded in shear before the maximum displacement during its first make up which is shown in graph 2. As a result of this, the load carrying capabilities of the sucker rod is compromised during the first make-up if wet face make-up/lubrication technique is used.

The amount of friction available in the case of a wet face is very limited because of the lubricated faces (sucker rod and coupling) and as a result, the applied torque goes into shearing the pin and not into the friction fit of the joint.

Normal Strain: Normal Strain acts in a direction parallel to the axis of the rod body and as a result is a very desirable attribute in the application of sucker rod coupling make-up. Normal Strain represents the load carrying capability of a sucker rod. The normal strain values were 9% higher in the case of a wet face when compared to dry face but this data is skewed because the sucker rod material (pin) yielded in shear during the first make-up.

Considering the torque, shear strain and normal strain values, dry face make-up is the best option or practice for the application of sucker rod-coupling make-up.

Decay of sucker rods

Decay is the process of decrease in the load carrying capabilities of a sucker rod after multiple make-ups. The goal of this phase of the project is to study the decrease in load carrying capabilities of a sucker rod and to establish the optimal number of make ups on a sucker rod (life of sucker rod). In order to achieve this, a set of 7/8", 3/4" and 1" sucker rod samples were repeatedly made up with the coupling until failure or 16 make-ups. The torque, normal and shear strain values were measured for each make-up/test on all samples.

Torque Decay Curve: There are three types of decay curves generated using the torque, normal strain and shear strain values respectively. Graph 3 illustrates the decay curve generated for a 1" sucker rod sample using the torque values. As it can be observed, the torque values are on an upward trend or in other words, the amount of torque required to make-up a sucker rod increases as the usage increases. It is also important to note the fact that the torque or amount of work required to make up a sucker rod with the coupling decreases for the few initial make-ups (initial 4 make-ups) and increases for the subsequent make-ups.

There was an average increase of 23% in torque values when the sucker rod was subjected to multiple make-ups. There is an inherent variation of torque values in the sucker rod-coupling make-up process, and as result of this, torque providing devices should not be adjusted based upon the torque values; circumferential displacement values must be used, instead.

Normal Strain Decay Curve: Graph 4 illustrates a decay curve for a 1”sucker rod sample based on normal strain values. The normal strain or load carrying capability of the sucker rod decreases after multiple make-ups. It is important to note that the normal strain increases for a few initial make ups and is on a downward trend for the subsequent make-ups. The threads of the sucker rod tend to burnish and smooth out for the initial make ups and as a result, the load carrying capabilities or normal strain increases and the torque required decreases on the first few make-ups. However, after the few initial make-ups, a saturation level on the burnishing of the threads is reached and is converted to friction. This conversion of burnish to friction of sucker rod threads is responsible for the overall decrease in the load carrying capability of the sucker rod.

There was an average decrease of 14% in the load carrying capability of the sucker rod after multiple make-ups. This is the main justification for the fact that there has to be two different types of displacement values or cards used for the new run and re-run make-ups.

Optimal number of make-ups on a sucker rod: The 1”, 7/8” and 3/4” sucker rod samples completed 11, 15 and 16 make ups respectively. However, there was face deformation and thread gulling on all the samples after the 10th and 11th make-up. Considering the facts and observation during the test, the optimal number of make-ups on a sucker rod for maximum efficiency was experimentally determined to be 9.

CONCLUSION

The technology in the manufacturing of sucker rods and quality of raw material has improved to a large extent over the past several years. As a result of this, the current industry standards of circumferential displacement values are not adequate for a successful make-up and compensation in the service factor of the rod string design needs to be considered.

There are two types of make-up in the sucker rod industry namely the dry and wet face make up. From the test results, dry face make-up is proved to be the best option for the application of sucker rod coupling make-up process.

The optimal number of make-ups on a sucker rod was experimentally determined to be 9.

The maximum number of failures in the sucker rod pumping industry is attributed to pin failures, which constitute 60 -70 % of the failures. The combination of best field practices and the comprehensive studies conducted in this project will help minimize the majority of failures.

Table 1
Design Ratings of All Grades and Sizes of Sucker Rods

		5/8	3/4	7/8	1	1 1/8
C	New	51%	63%	124%	54%	
	Re-run	89%	59%	66%	43%	
K	New		113%	69%	67%	110%
	Re-run		81%	91%	52%	98%
CD	New	104%	78%	103%	56%	
	Re-run	86%	74%	99%	54%	
AD	New	108%	104%	114%	53%	107%
	Re-run	35%	94%	92%	60%	98%
KD	New		106%	90%	67%	98%
	Re-run		63%	100%	52%	91%
HS	New		148%	99%	88%	102%
	Re-run		103%	103%	67%	104%

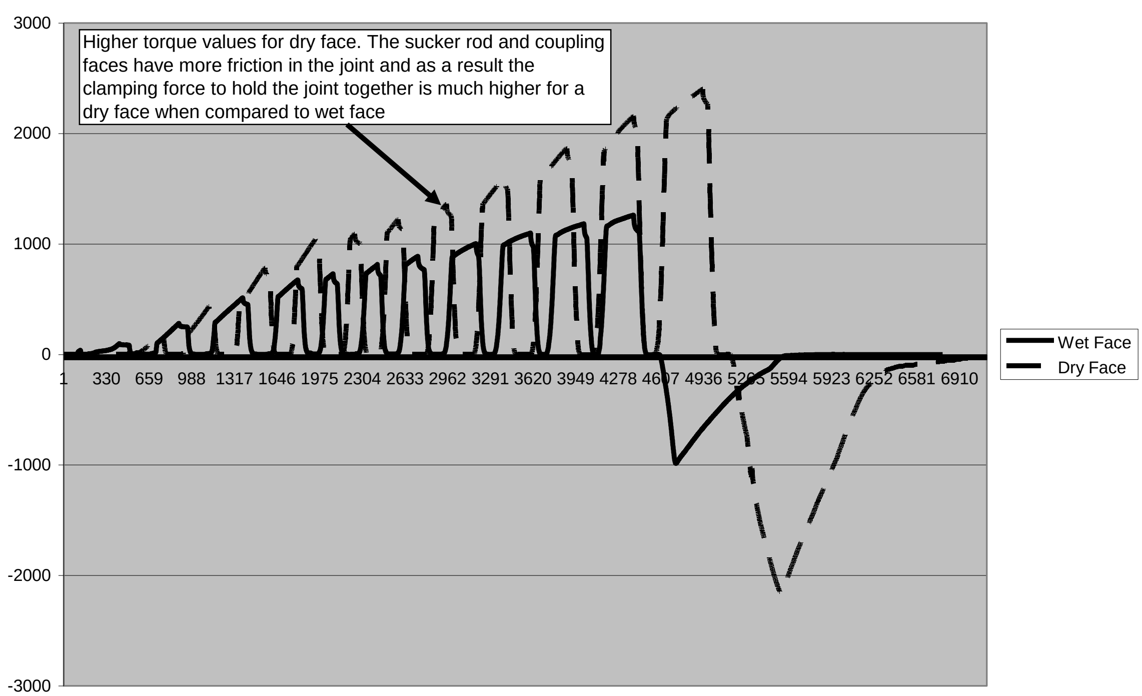
Table 2
Summary of Design Ratings Based On Sucker Rod Grades

Grade	Run	Design rating %
HS	New	112%
	Re-run	91%
AD	New	95%
	Re-run	86%
CD	New	85%
	Re-run	78%
KD	New	88%
	Re-run	72%
K	New	83%
	Re-run	75%
C	New	73%
	Re-run	64%

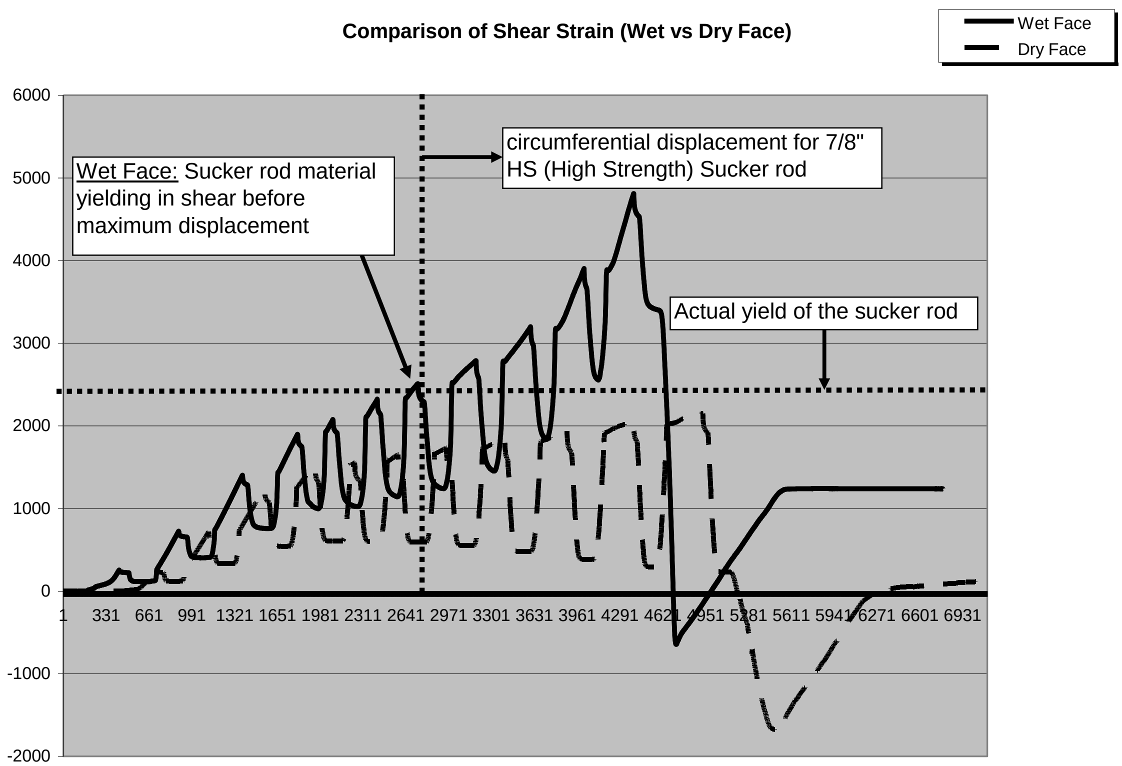
Table 3
Summary of Design Ratings Based On Sucker Rod Sizes

Size	Run	Design rating %
1 1/8	New	104%
	Re-run	98%
7/8	New	104%
	Re-run	94%
3/4	New	100%
	Re-run	83%
5/8	New	88%
	Re-run	88%
1	New	65%
	Re-run	56%

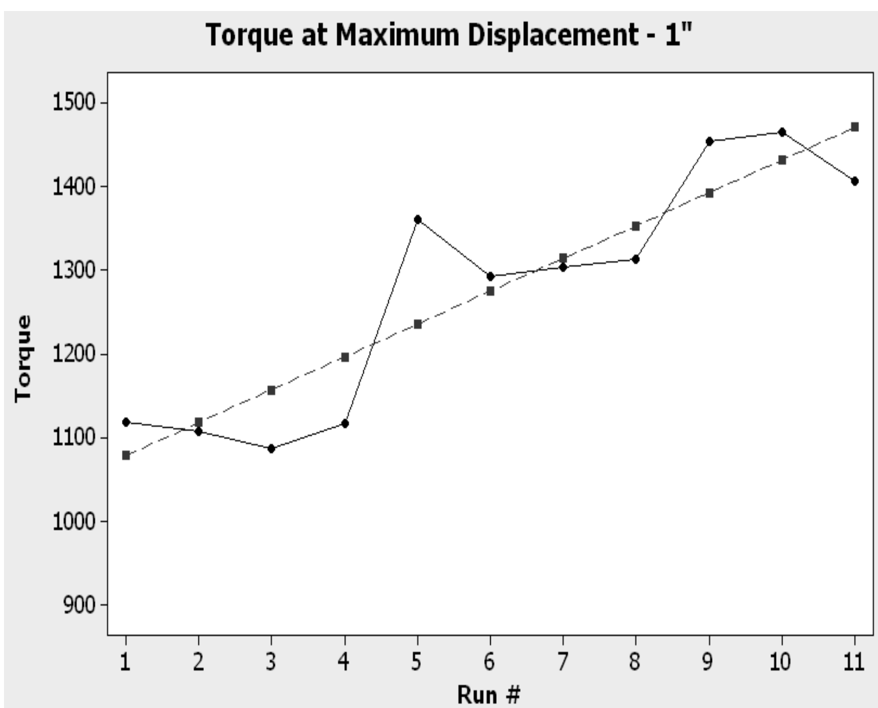
Comparison of torque - Dry vs Wet Face



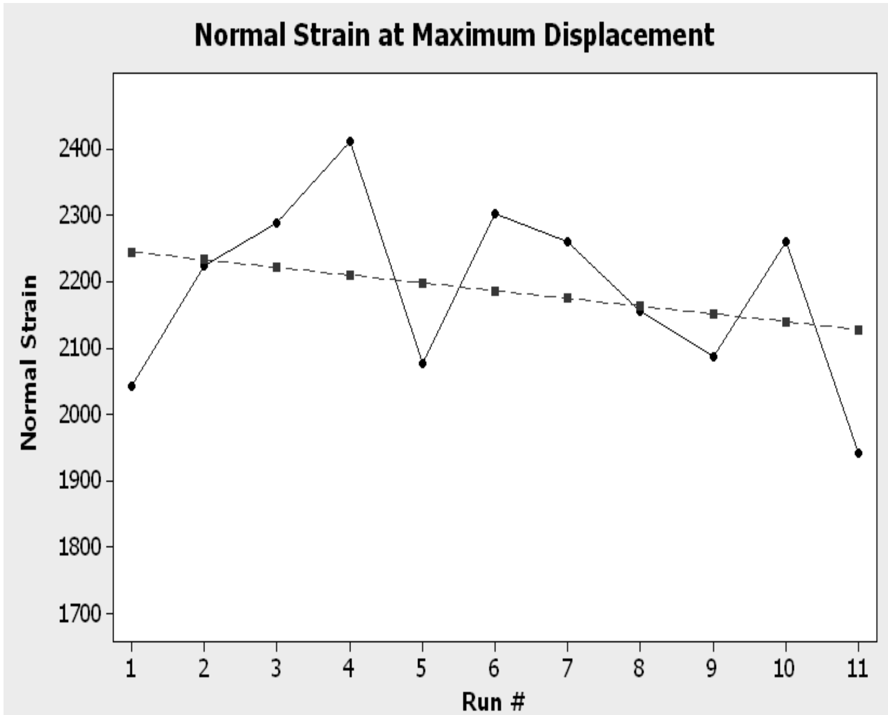
Graph 1



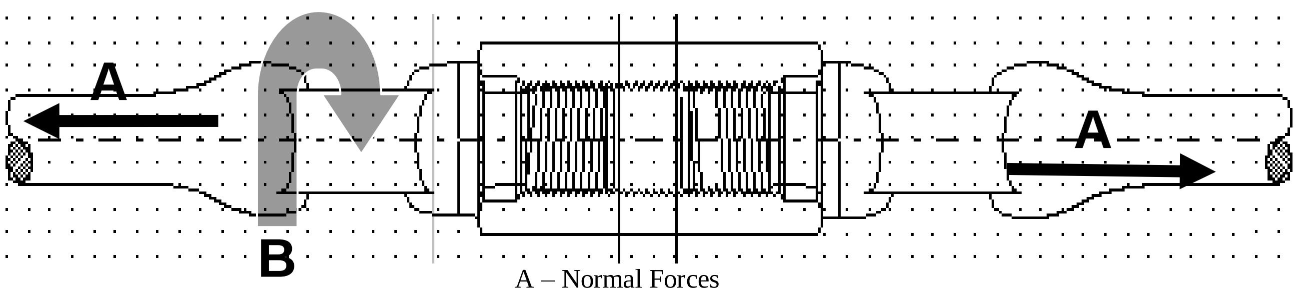
Graph 2



Graph 3



Graph 4



A – Normal Forces
B – Shear Forces

Figure 1

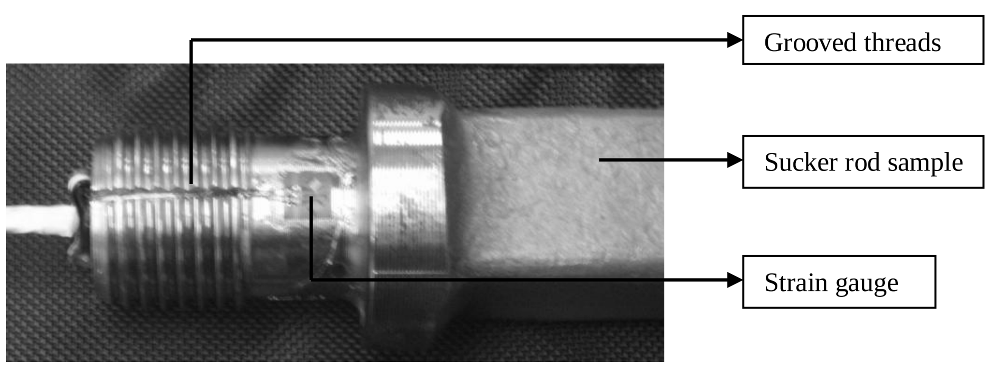


Figure 2 - Strain Gauge Pasted On the Stress Relief of the Sucker Rod Pin

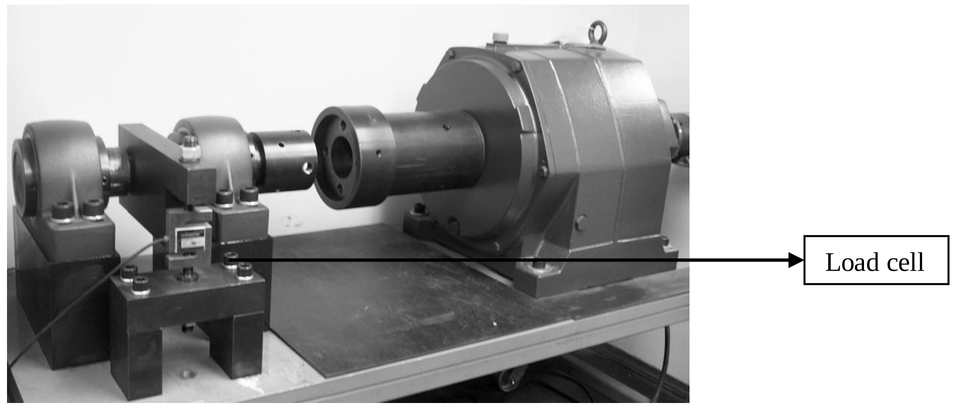


Figure 3 - Displacement Testing Machine with the Load Cell

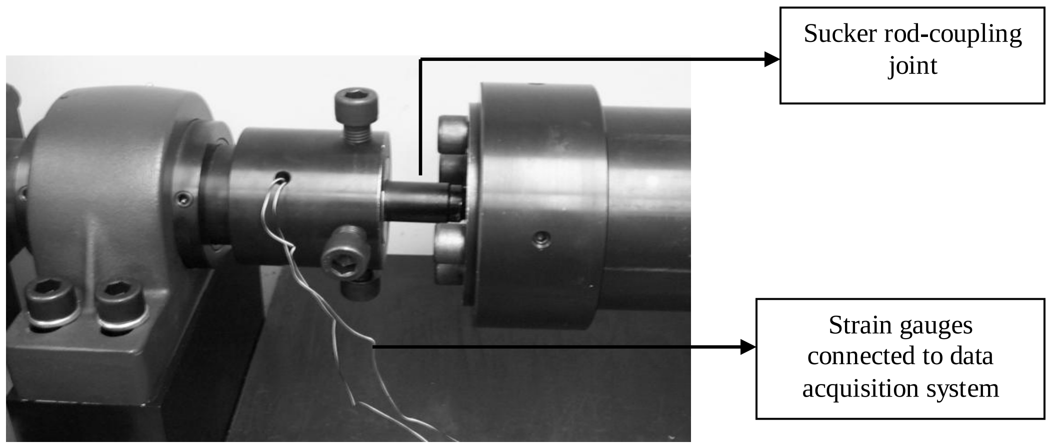


Figure 4 - Sample with Strain Gauges Connected to the Data Acquisition System

FIGURE 5 – INCREMENTAL DISPLACEMENT TEST