LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Friction measurements

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1 Introduction

Knowing the coefficients of friction of different materials in their clean state is essential for LIGO. Since only clean structures can enter the vacuum chambers, and the values of these friction coefficients are not widely known, I have conducted this experiment. Using my results and the more to come, engineers in LIGO can plan more precisely how many bolts are needed to hold each load.

2 Experimental Setup

The experiment is very simple and easy to repeat. It requires a torque wrench, a force sensor, class A clean washers (if the bolts are too long for the tested holes) and class A clean bolts and blocks according to the materials we want tested.

In this experiment the equipment I used was:

- 3/8'' dial torque wrench, 0 to 300 in lb scale 5718A46 MacMaster-Carr
- LBO-5K, 5,000 lbs, Transducer Techniques
- LC901-1/2-30K force sensor OMEGA
- DP41-S strain gage meter OMEGA
- Only 3/8" bolts were tested
- Nichrome Helicoils

In the oiled setting I have oiled the bolts before screwing them into the holes. Thereafter applying torques between 0 to 150 inch pound and recording the force applied on the sensor. Torque wrenches are not meant for loosening bolts; therefore, I loosened the bolts using an allen wrench. In the clean setting I have maintained a clean environment by wrapping the torque wrench, the clamp which holds the block and all other tooling which were in contact with the assembly in foil. Between measurements the bolts and blocks were stored according to class A regulations.

After plotting the torque-force graph for each measurement I used a least square fit in order to extract the coefficient of friction. Knowing the slope of the graph I was able to find the coefficient of friction: $k = \tau/(Df)$, k- friction of coefficient, f- force(lbs), D- diameter(inches) of bolt, τ – torque(in-lbs).

3 Results

3.1 Oiled Experiment

I started by examining the effect of a thrust bearing on the coefficient of friction. This was to test the assumption that by placing the thrust bearing between the sensor and the bolt I am able to reduce the friction between the head and the hole. After taking the data with and without the use of a thrust bearing and comparing the results, I have learned that there is no significant change of the coefficient of friction due to the bearing.

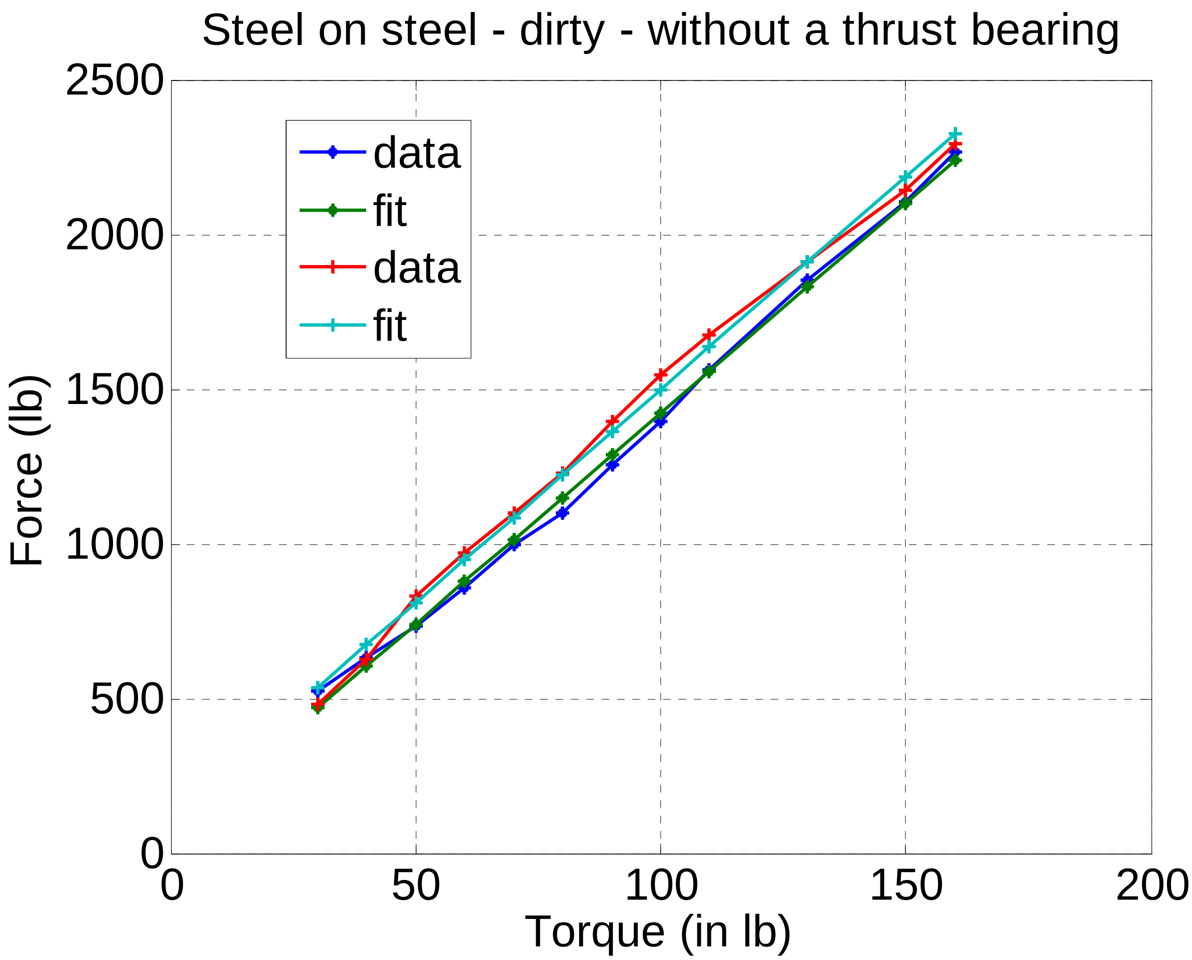

Figure 1: Steel on steel without a thrust bearing, oiled. Measured friction coefficient: 0.19. Expected friction coefficient:0.19

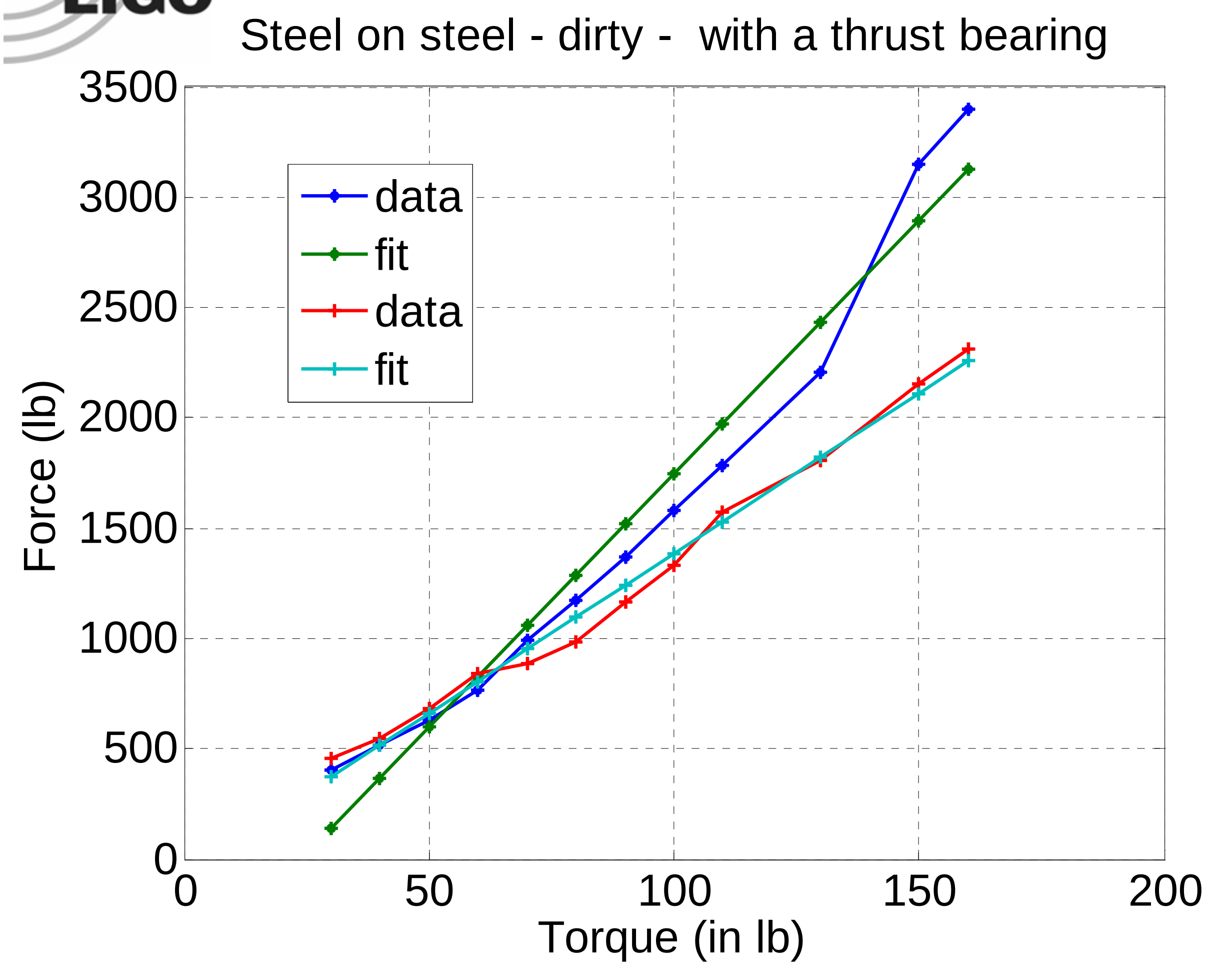

Figure 2: Steel on steel with a thrust bearing, oiled. Measured friction coefficient: 0.19. Expected friction coefficient:0.19.

During all oiled measurements the results were repeatable and did not depend on anything other than the materials themselves. The results also matched the expected available data.

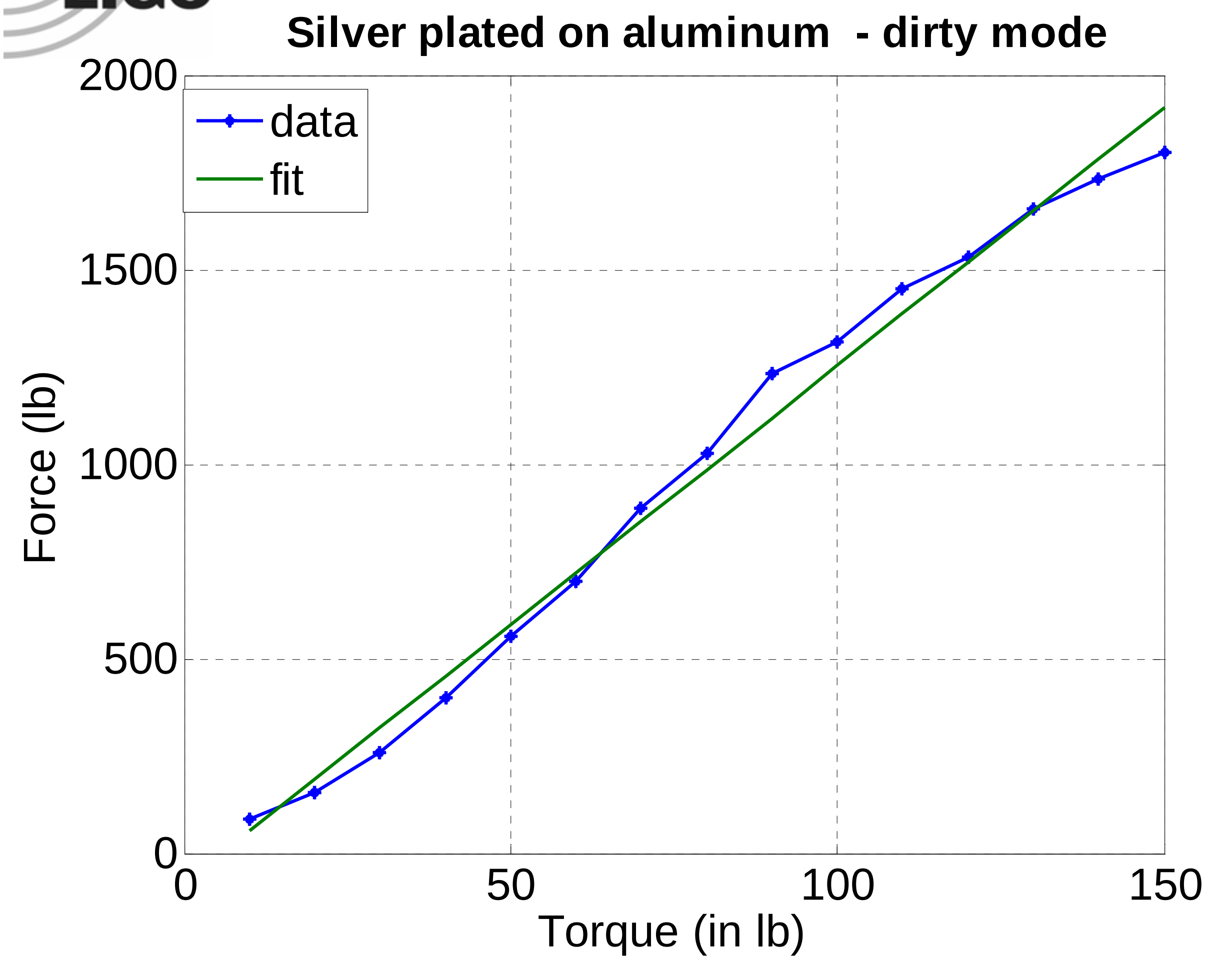

Figure 3: Silver plated on aluminum, oiled. Measured friction coefficient: 0.20.

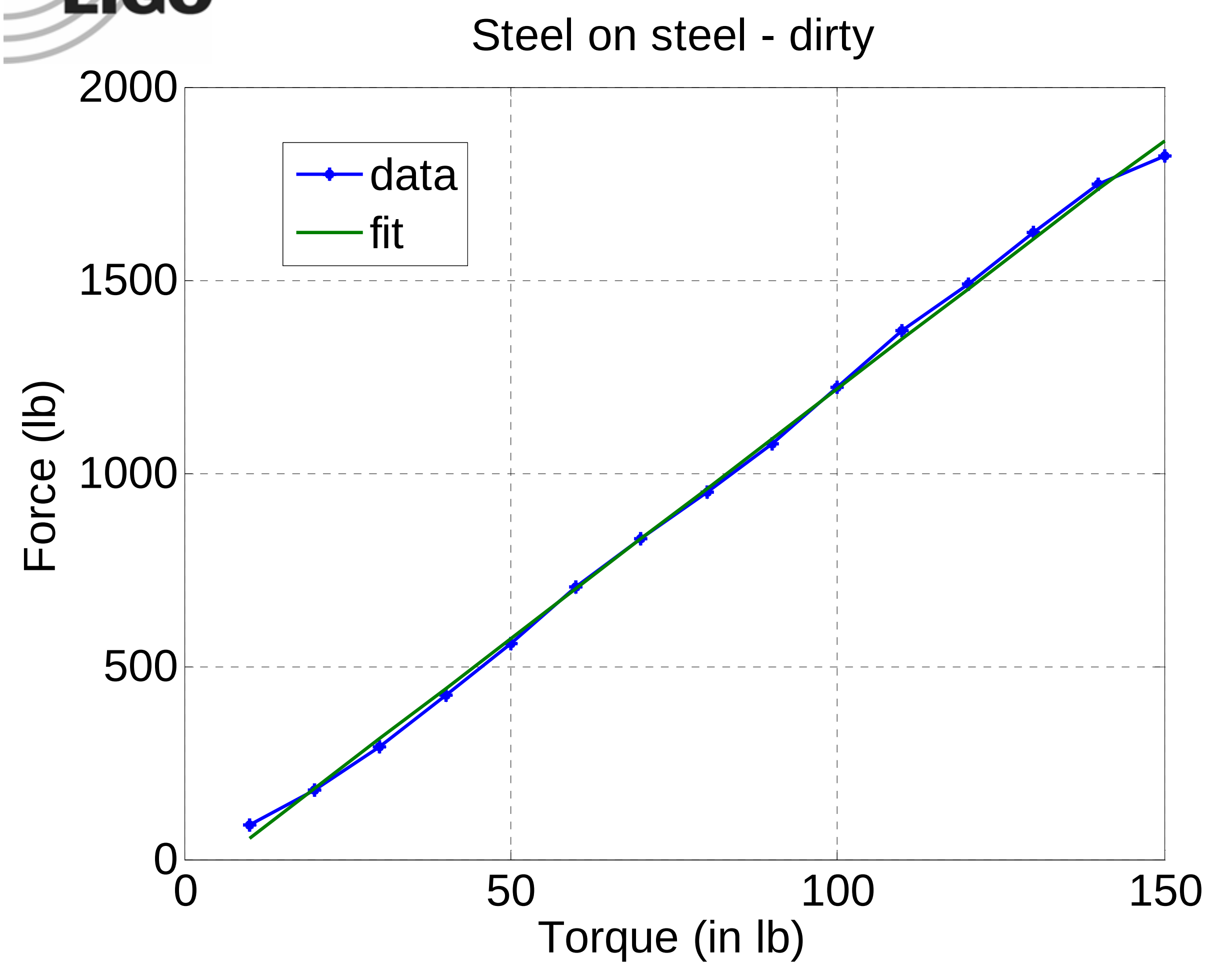

Figure 4: Steel on steel, oiled. Measured friction coefficient: 0.20. Expected friction coefficient: 0.19.

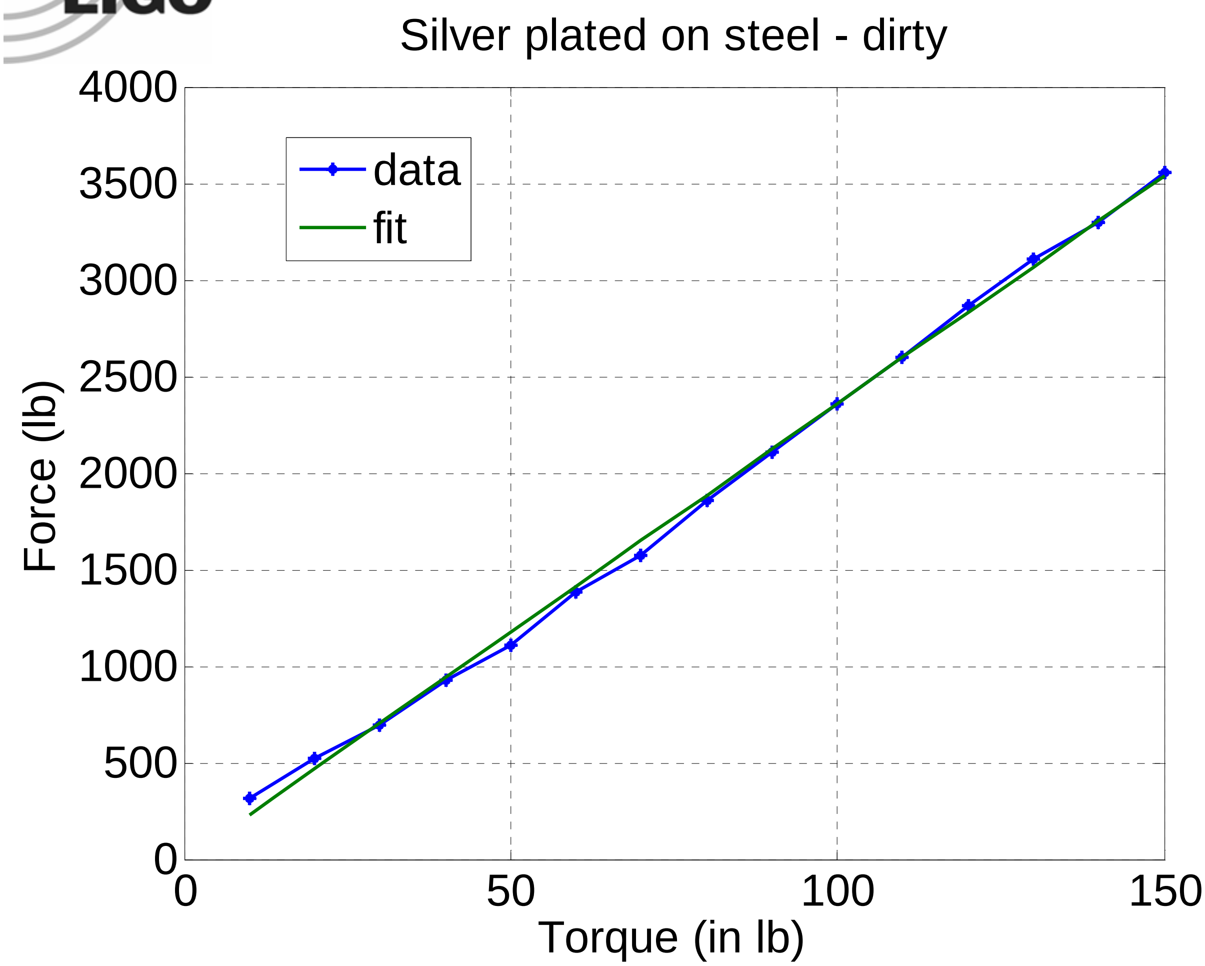

Figure 5: Silver plated on steel, oiled. Measured friction coefficient: 0.11.

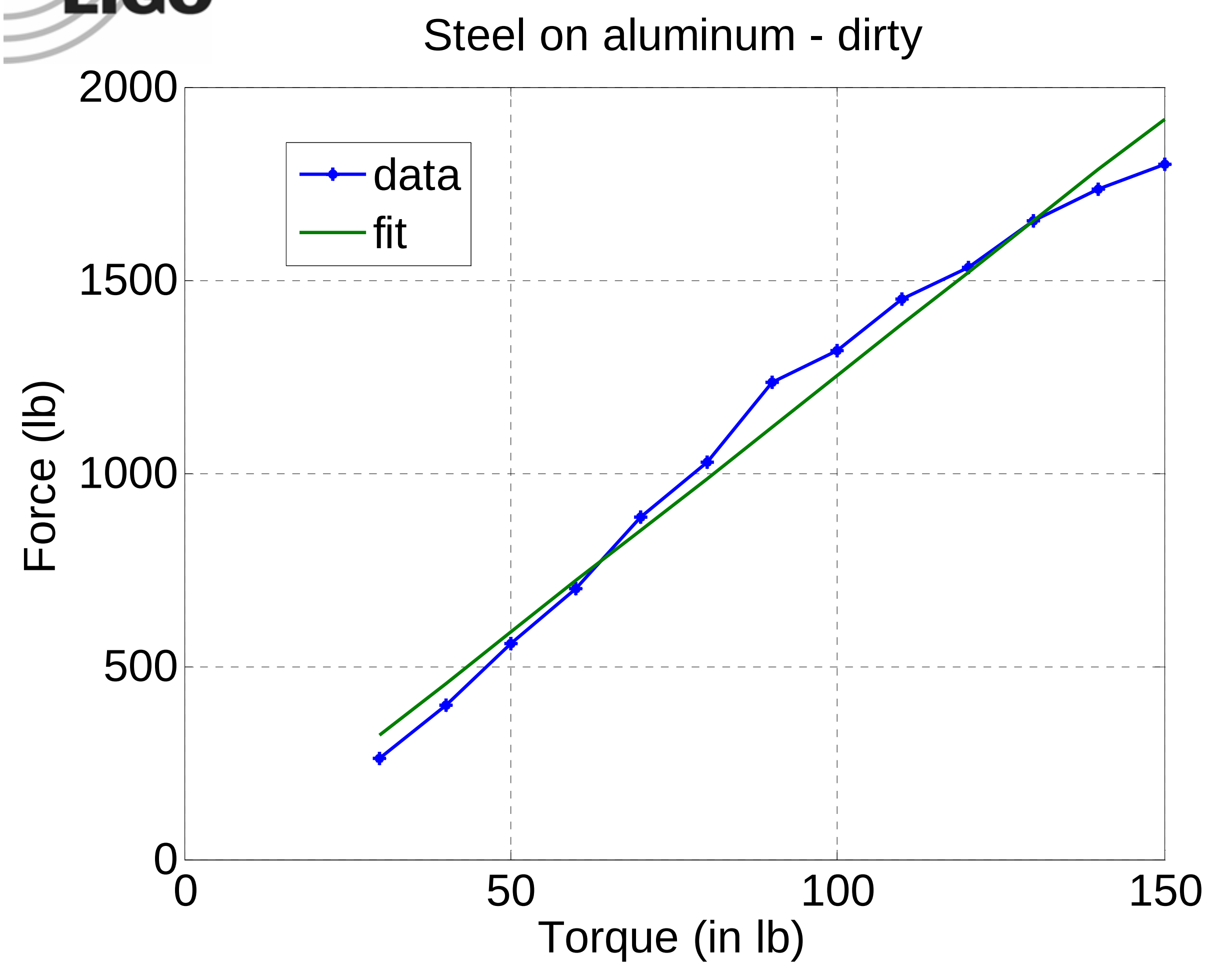

Figure 6: Steel on aluminum, oiled. Measured friction coefficient: 0.20.

3.2 Clean Experiment

The measurements were taken with two different sensors. The first measurements were taken with a sensor that had a range of 0 to 30,000 lbs and the second of 0 to 5,000 lbs. When taking the measurements with the first sensor, I noticed the significance of using different bolts in different holes. Therefore, before retaking the data with the second sensor I retapped the aluminum and steel holes and used new steel bolts. It is easy to notice that the second sensor yields better results. This is since my measurements did not exceed 2,500 lbs and therefore used a wider range of the second sensor which contributes to the accuracy level of the sensor. When I measured the coefficient of friction for the same bolt in the same hole I received a maximum measurement error of 2%.

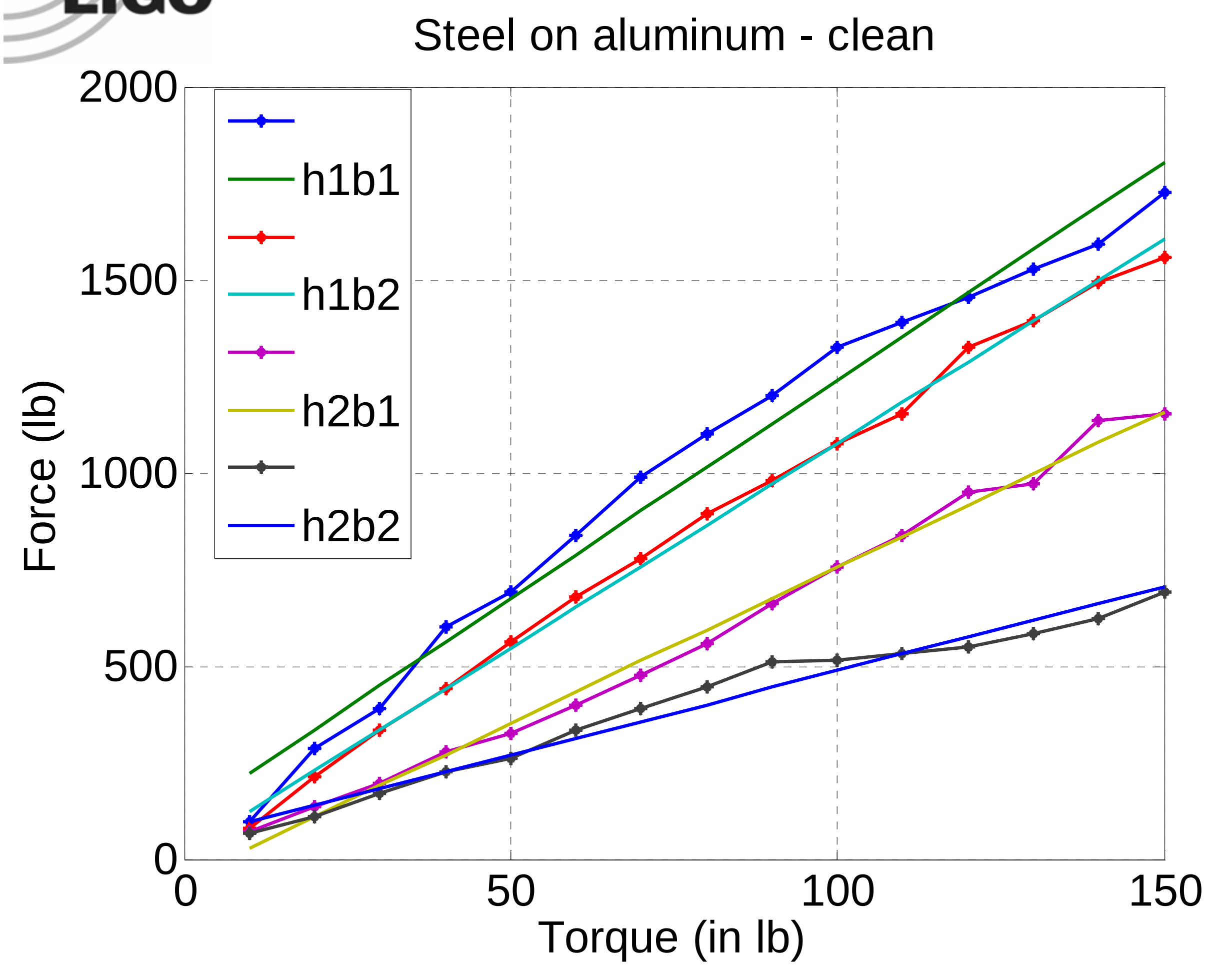

Figure 7: Steel on aluminum, clean. Using the first sensor (range 0 to 30,000 lb). Measured friction coefficient: 0.23 to 0.61. Expected friction coefficient: 0.61 (engineershandbook.com).

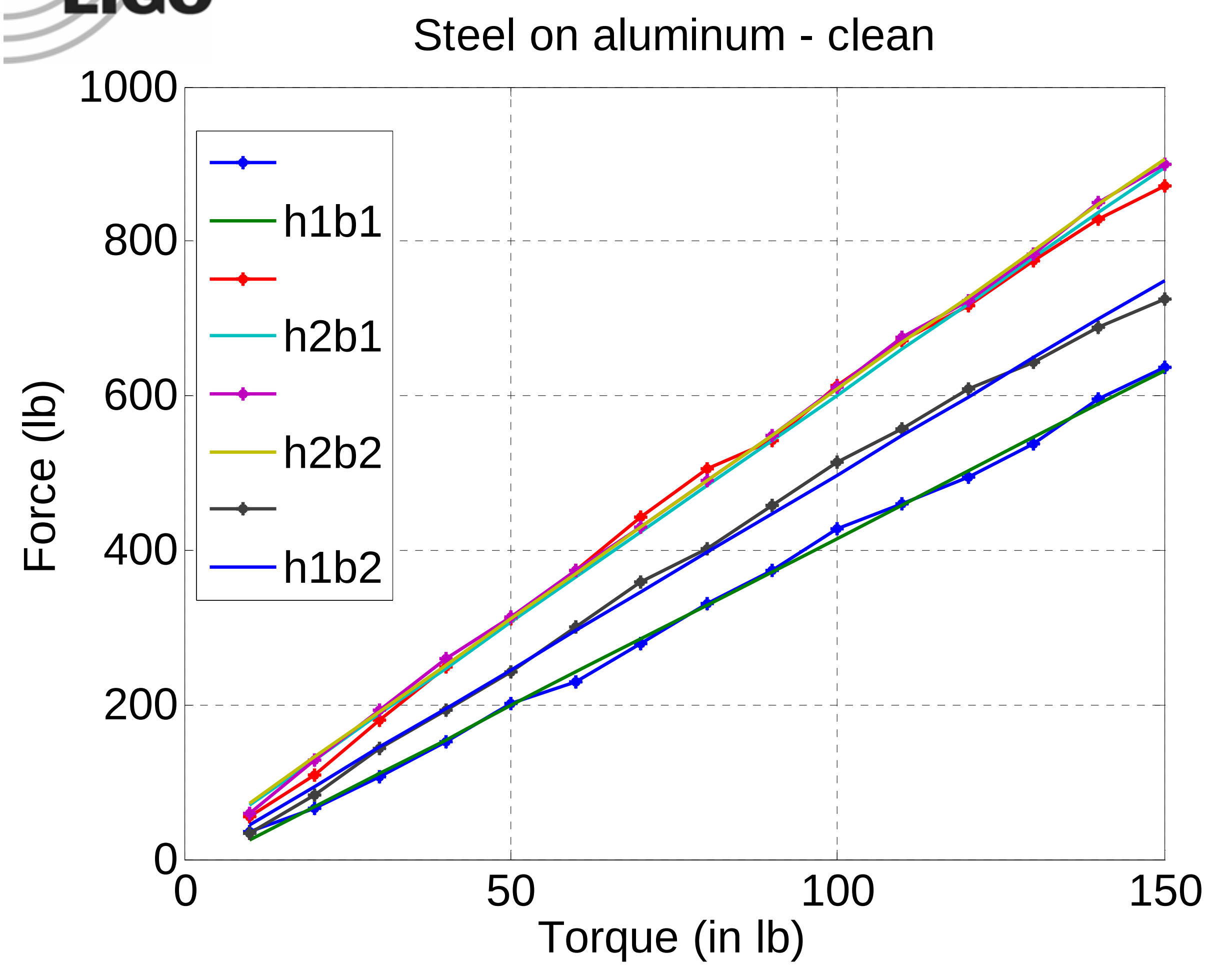

Figure 8: Steel on aluminum, clean. Using the second sensor (range 0 to 5,000 lb). Measured friction coefficient: 0.44 to 0.61. Expected friction coefficient: 0.61 (engineershandbook.com).

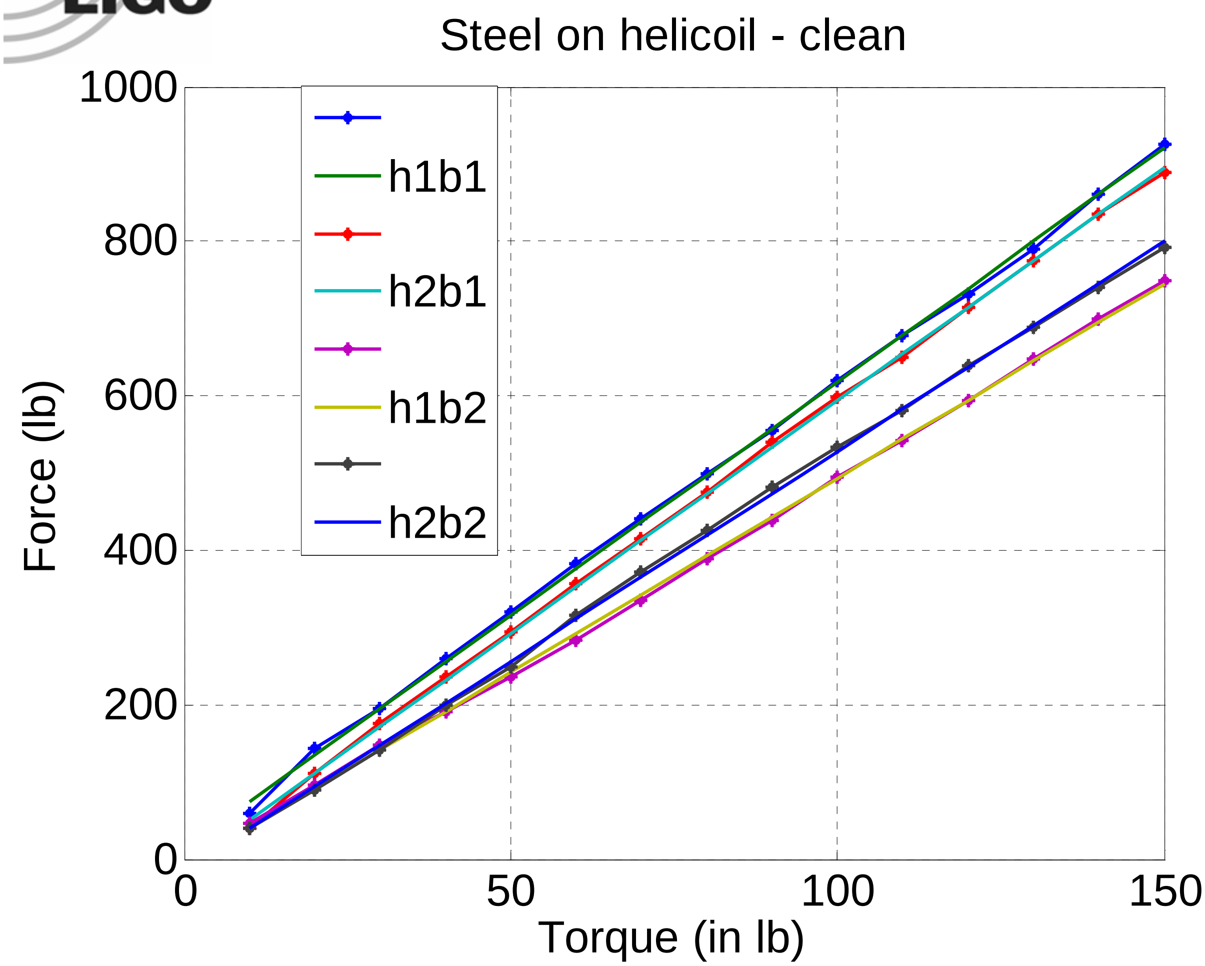

Figure 9: Steel on helicoil, clean. Using the second sensor (range 0 to 5,000 lb). Measured friction coefficient: 0.44 to 0.52.

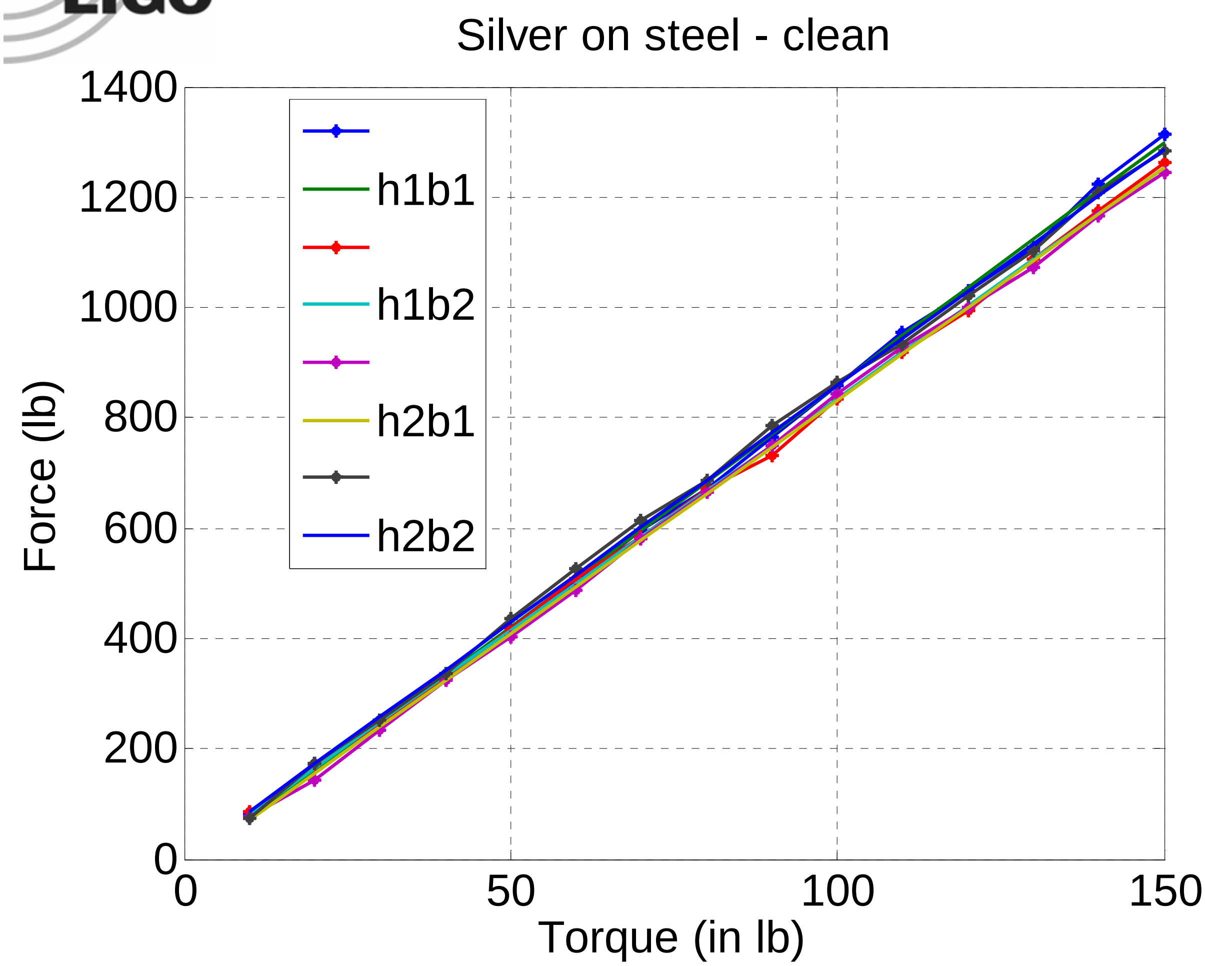

Figure 10: Steel on helicoil, clean. Using the second sensor (range 0 to 5,000 lb). Measured friction coefficient: 0.30 to 0.31.

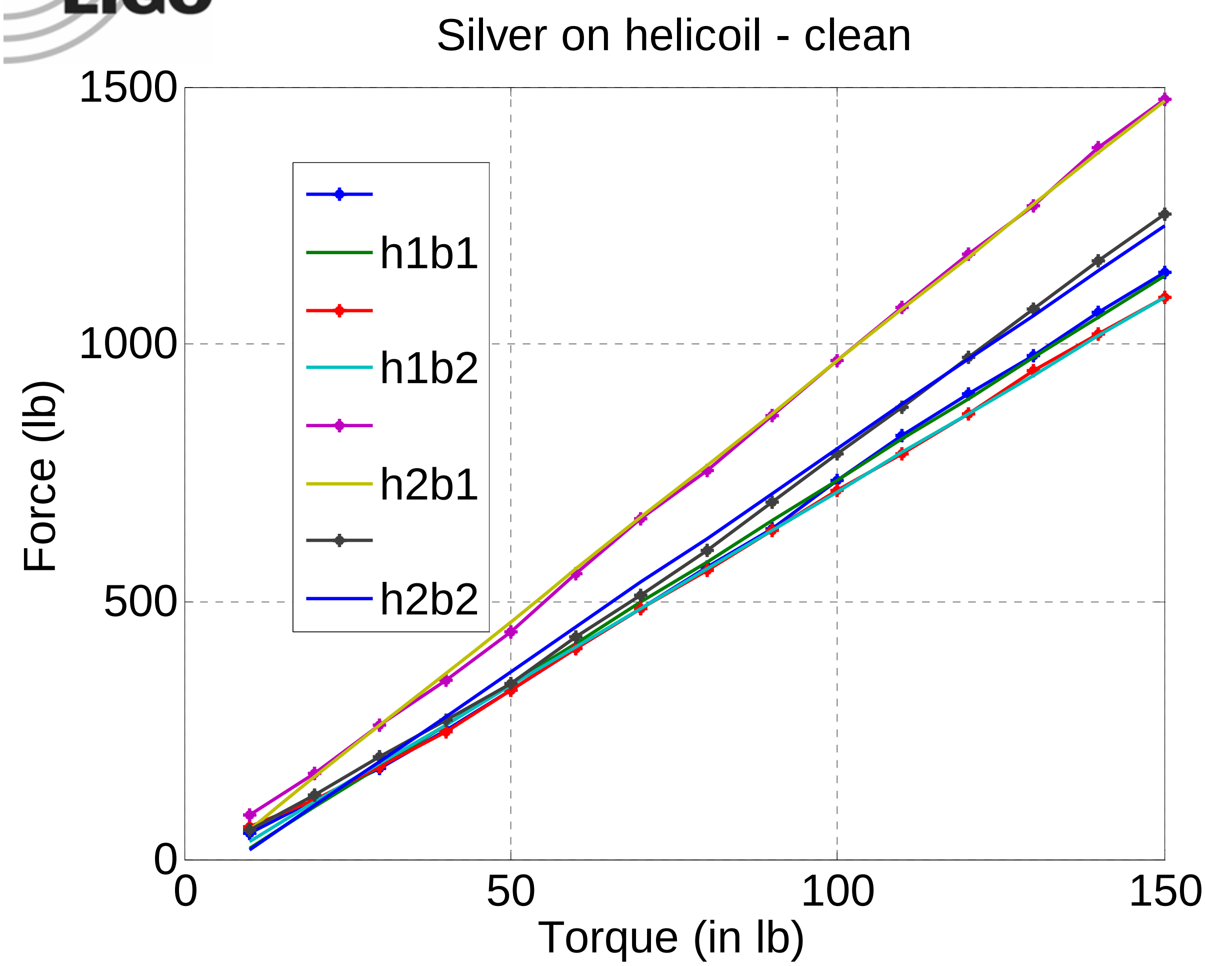

Figure 11: Steel on helicoil, clean. Using the second sensor (range 0 to 5,000 lb). Measured friction coefficient: 0.26 to 0.35.

4 Conclusions

Bolt	Hole	Measured Coefficient	Expected coefficient
Silver plated	Steel	0.30-0.31	---
Silver plated	Helicoil	0.26-0.35	---
Steel	Helicoil	0.44-0.52	---
Steel	Aluminum	0.44-0.61	0.61*

The friction coefficients for clean surfaces depend both on the specific bolt and holes (bare holes and helicoils). Silver plated on steel gave the most stable and repeatable results. I believe the results of the steel in aluminum yield a wide range since aluminum is soft. When taking the measurements I have noticed a slow decrease in the force with time. This decrease was not too significant however it might imply that it is hard to obtain a high degree of accuracy. Therefore, more investigation needs to be done on steel in aluminum. I will next increase the range of my measurements by measuring until 300 inch pounds, and search for non linearity due to the stretching of the bolt. Moreover, I will measure the breaking points of all the types of bolts I have been using.

*** engineershandbook.com**