Friction Coefficient of Differently Treated Steel Surfaces

Email your question—along with your name, job title and company name (if you wish to remain anonymous, no problem) to: *jmcguinn@geartechnology.com*; or submit your question by visiting *geartechnology.com*.

QUESTION

My company designs and manufactures rotating machinery, and recently we adopted ion-nitride finish to our shafts. We have been led to believe that this process reduces the coefficient of friction used to calculate torque transmitted through a tapered hub interference fit.

Currently we use a friction coefficient of 0.15 per ANSI/AGMA 9003 for the calculation.

Do you know how much reduction, based on your knowledge of the finishing process and torque transmission?

Expert response provided by Dr. Hermann J. Stadtfeld. Ion-Nitride treatment is used to achieve an increase of surface hardness of mechanical components. Although the ion-nitride changes the color of the components from silver to a greenish gray, it is not a coating layer on top of the surface. The nitriding process creates a hard layer of only about 0.005mm at and underneath the surface. In order to investigate the reader's question, at first surface roughness measurements were conducted with parts which had a ground steel surface and parts of the same design which had been nitrided. In order to compare all results to a rather well known surface condition, the same part design had been REM super-finished. The next step was a laboratory experiment with the variety of different parts in order to gain individual friction coefficients. The goal of this work was not only to give a plain answer to the question, but to also present a simple and straightforward guideline for practical-oriented engineers for determining friction coefficients between different materials with different surface conditions. These guidelines are accurate enough for mechanical applications, as the interference fit connection between shaft and disk as described in the question.

The principle of friction determination is shown in Figure 1. In the example, the normal force is created by the weight, multiplied with the gravity constant g. At the left side in Figure 1 the friction exists between the flat block and the flat base surface. The problem with flat surfaces is that they are either not really flat, which could make the weight rock while it slides, or they are too flat, which could cause a surface bonding like that experienced with Jo blocks. In order to avoid those effects, cylinders are often used in friction investigations. The cylinders create line contact with the weight if their alignment is precise. At the right side in Figure 1, two cylinders locked in place with a stop are used to conduct the friction measurement. The following practical bench measurements have been conducted according to the right side principle in Figure 1.

The results from the surface roughness investigation, using a Zeiss surface tracer are summarized in Figure 2. The surface of the gage bar used in combination with all the different tested

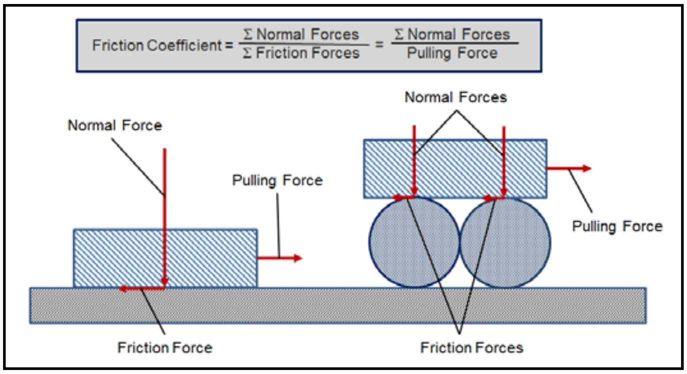

Figure 1 Theoretical principle of friction coefficient determination.

surfaces (No. 1, Fig. 2) shows very low roughness numbers, but exhibits some scratches that can be disregarded for the following friction measurements.

The surface roughness values of the ground steel specimen, the ion-nitrided specimen, and a super-finished specimen are shown respectively as the No. 2, No. 3 and No. 4 graphs in Figure 2. The ion-nitride treatment was applied to a ground steel ring, like the one represented in graph No. 2. One can observe that the ion-nitride, although it has the optical appear-

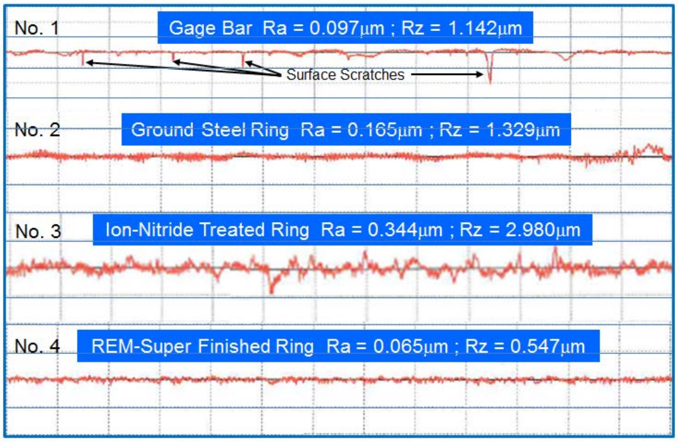

Figure 2 Surface roughness Comparison between ground steel, ion-nitrited steel and super-finished steel.

ance of a phosphate coating, does the opposite of what a phosphate coating would do to the surface roughness. The values of Ra and Rz more than doubled due to the nitriding. Another interesting surprise presents the result of the surface roughness measurement of the super-finished parts. The super-finishing generated a mirror surface finish on the treated rings, yet compared to the ground steel ring and gage bar, only a limited improvement can be seen.

The bench test setup is shown in Figure 3. Two ring gears with a ground steel surface are the artifacts. Defined surface contact was created with a precision ground steel gage bar. In order to achieve sufficient surface contact a second bar was placed on top of the first one. The photo in Figure 3 shows the arrangement with a pull scale. The scale was pulled gently until the gage bars broke loose. The drag pointer feature allowed capturing the maximal value of pulling force, which was then used to calculate the static friction factor. The surface combination was cleaned with a solvent in order to use conditions that are representative for friction between dry surfaces as present with interference fits (no lubrication present). The friction coefficient calculated from the breaking loose pulling force resulted in 0.145. It is interesting to mention that this experimentally obtained value is very close to the coefficient found in ANSI/AGMA 9003, which is 0.15.

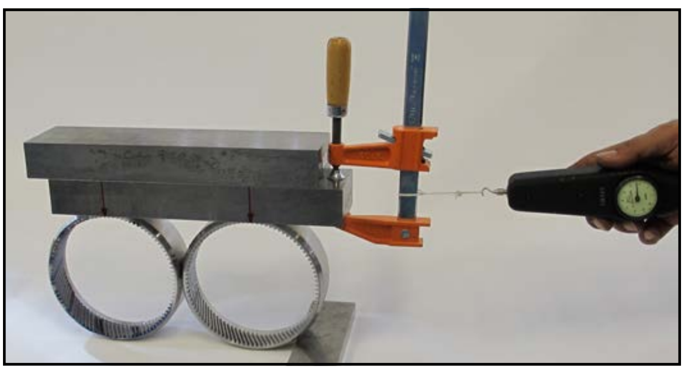

Figure 3 Bench setup for friction determination pull test: ground steel on ground steel.

Figure 4 shows the pull test conducted for the surface combination ground steel versus nitrided surfaces. The test conditions were the same as mentioned with the first test of Figure 3. Although the pulling force seemed to be slightly higher in some of the tests, the average friction coefficient calculated are identical to the steel versus steel combination.

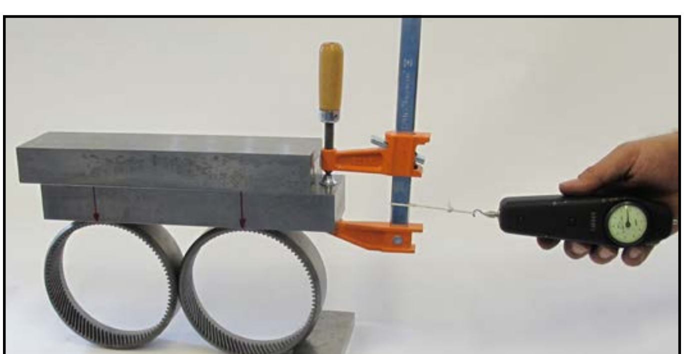

Figure 4 Bench set-up for friction determination pull test - Ion-Nitride treated surfaces on ground steel

Figure 5 shows the setup for the ground steel versus REM super-finished steel. Readers who expected a significant reduction of the friction coefficient will be disappointed with a resulting average value of 0.138. Although the super-finishing might enhance hydrodynamic conditions, there is only a very small friction reduction in the dry stage.

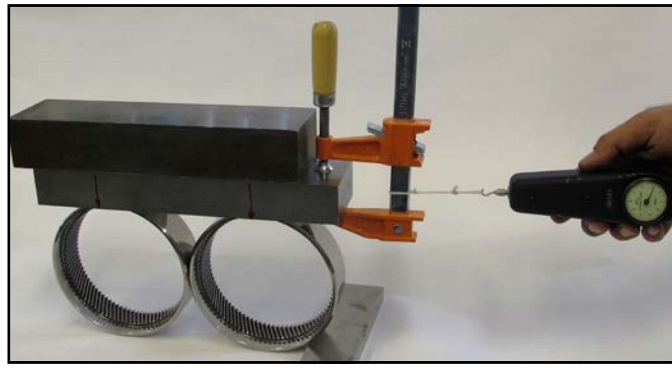

Figure 5 Bench setup for friction determination pull test: super finished surfaces on ground steel.

The conclusions of the experiments are summarized in the table shown in Figure 6. With the documented results, the reader's question can be answered favorably. The press fit with the combination of a ground or hard-turned tapered bore and a ground or hard-turned nitrided shaft will result in the same torque transmission capability as the previous components, which consisted of a steel versus steel combination.

Material	Steel-on-Steel	Steel-on-Nitrided Steel	Steel-on-Superfinished Nitrided Steel
Ring Roughness, Ra [μm]	0.165	0.344	0.065
Bar Roughness, Ra [μm]	0.097	0.097	0.097
Normal Force [N]	161.09	161709	164109
Average Pulling Force [N]	23.26	23.16	22.15
Mean Coefficient of Friction	0.145	0.145	0.138
Mean - 3σ	.125	0.129	0.122
Mean + 3σ	.165	0.160	0.155

Figure 6 Friction coefficient test evaluation results.

Test Articles/ Ra	Static Coefficient of Friction
Steel-on-steel,a=0.16S prn	0.14S
Steel-on-Nitrided Steel, Ra=0.344	0.14S
Steel-on-Superfinished Nitrided Steel, Ra= 0.065	0.138

Figure 7 Friction coefficient result summary.

The table in Figure 7 is a management summary for fast readers; it contains the resulting friction coefficients of the three investigated friction combinations.

References

1. Ligata, H. and H.J. Stadtfeld. "Friction Coefficient Evaluation between Differently Treated Steel," Engineering Report, The Gleason Works, Rochester, New York, Sept. 2017.
2. Carsetad, H. and S. Khorsandijon. "Effect of Surface Roughness on Steel-Steel Dry Friction Coefficient," *Journal of Mechanical Research and Application*, Vol. 4, No. 3, 2012.

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