Friction in Lines and Blocks—Plain Bearing Blocks give Ball Bearing Blocks a Run for Their Money

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Abstract

Measuring the force needed to pull a line loop through two blocks I find sheave and line diameter to be important but ball bearings do not reduce friction by any useful amount. The sheave-to-axle friction in the blocks is only a small part of the total friction in a tackle. Choosing line is important since the line dominates the losses.

1 Introduction

How much friction is there? How much does it depend on line and sheave diameter? What good are ball bearing blocks? The bearings of such blocks do after all look rather odd compared to bearings in other applications.

The measurement of friction in blocks and lines is described in this report. The results are discussed and the impact of friction on the performance of straight tackle and cascaded tackles is described.

2 Measurements

The measurements were done using line loops through block pairs. A simple representation of this is seen in Fig. 1. I used an electronic scale with an 0.2 N resolution to measure the force needed to overcome friction. All blocks and lines have seen use but only the smallest blocks may have seen abuse. Further details on the blocks and the lines are found in the Appendix.

All blocks and lines were washed, the blocks were lubricated with silicone oil and the lines were treated with fabric softener. This is my standard post-season treatment of all blocks and lines except for some Dyneema lines that have a waxy surface treatment.

Table 1 lists the complete parameter space of the friction measurements. All combinations except highest load plus thinnest line were tested. The measure-

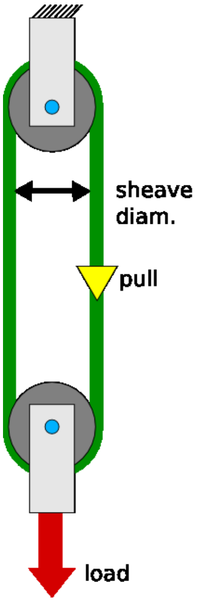

Figure 1: Measurement set-up.

Line diam. [mm]	Block type/sheave diam. [mm]	Load [N]
0.5	plain/19	13
2.5	plain/39	33
5	plain/40	93
6	plain/58	174
8	ball bearing/47	415
10		

Table 1: Measurement parameters.

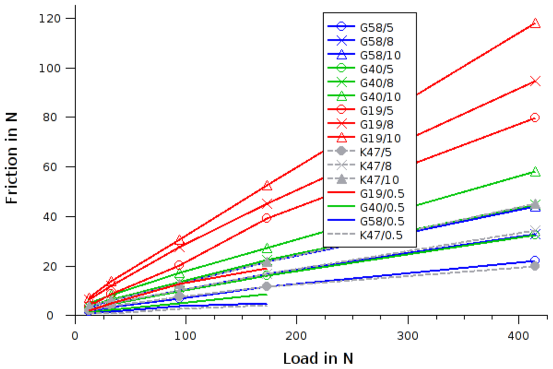

Figure 2: Measured friction for line + two blocks.

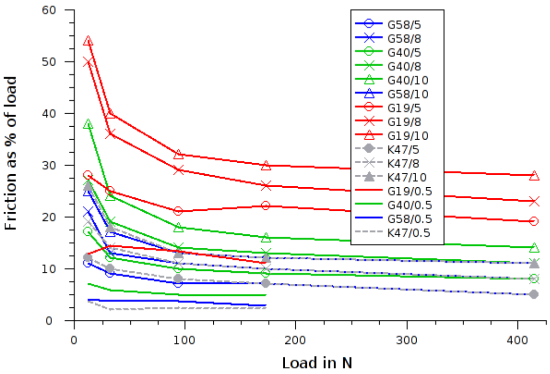

Figure 3: Measured friction divided by the load.

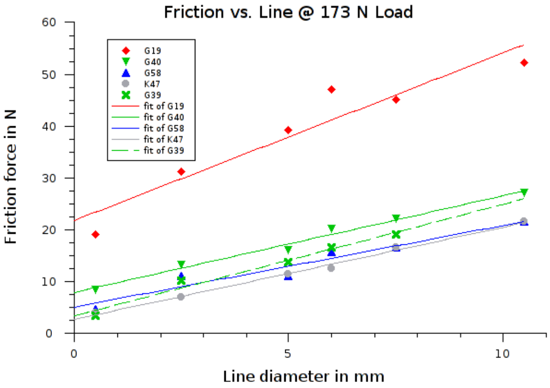

Figure 4: Friction force as a function of line diameter at 173 N load.

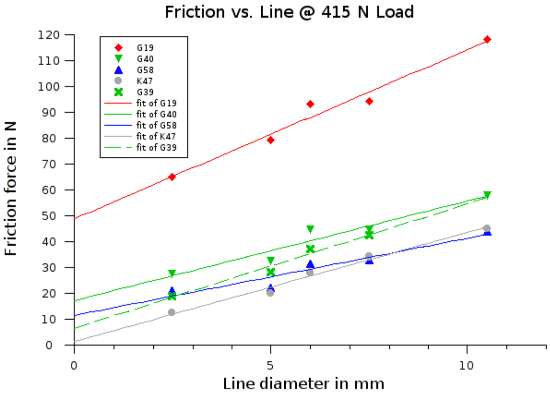

Figure 5: Friction force as a function of line diameter at 415 N load.

ments were done by pulling on the line using the electronic scale. The hook of the scale was attached to a knot on the line for the four thinnest lines and and a thin line was used to attach the hook to the two thickest lines. I made sure I pulled parallel to the line at all times and no swinging of the measurement set-up was tolerated. Measurements were repeated five times for each parameter combination and the average of these five readings was used to create the graphs in Section 3.

Various weights and gravity were used to generate the load. My current equipment limits the maximum load to 415 N and I have no reliable way of measuring line speed. All measurements have been done at a steady but fairly low line speed.

3 Results

Figures 2 through 7 offer different views of the measured data. The axes information should be self explanatory. What may be somewhat cryptic is the designations in the legends. "G58/5" should be interpreted as plain bearing blocks with 58 mm sheave combined with 5 mm line. "G40/10" is the 40 mm plain bearing blocks combined with the 10 mm line and so on. "K" stands for ball bearing. The "G" and the "K" come from the Swedish for plain bearing and ball bearing.

Fig. 2 is a straight forward graphical representation of the measured data. I have not included all data as I realized the graph was becoming very cluttered and this way of presenting the data is not very revealing anyway. I find it more educative to plot the friction force divided by the load. Fig. 3 shows the data in Fig. 2 processed in this way. It is clearly seen how the relative friction levels

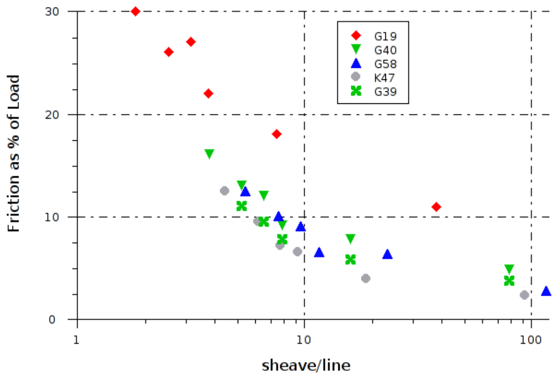

Figure 6: Measured friction divided by the load vs. sheave diameter divided by line diameter. The load is 173 N.

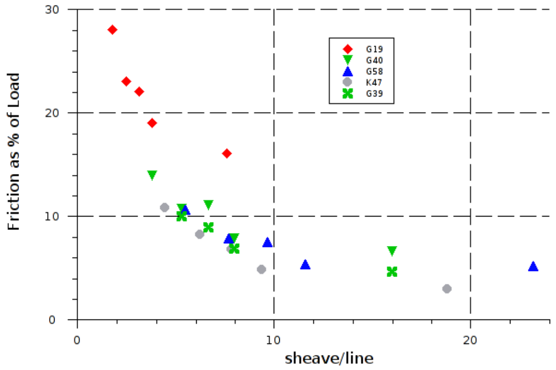

Figure 7: Measured friction divided by the load vs. sheave diameter divided by line diameter. The load is 415 N.

out as the tackle is loaded up. The higher numbers at low load levels come from the fact that bending even an unloaded line takes some effort.

Another way of looking at the data is to look at friction force as a function of line diameter. In Figs. 4 and 5 I have plotted the friction vs. line dimension data for the two highest loads. The lines fitted to the data points should not be regarded as a modeling attempt. I merely added the lines as eye-balling guides.

Plotting the relative friction against sheave diameter divided by line diameter is perhaps the best way of studying the measured data if one is interested in the relative merits of the block technologies since sheave diameter is taken out of the picture. You find this view of the data in Figs. 6 and 7. Once again I have only plotted the data for the two highest loads. In Fig. 6 I use a logarithmic scale for the x-axis to make the figure easier to read. If you are not used to logarithmic scales it helps to realize that the tick mark following 10 is 20 and not 11, the next one is 30 and so on.

4 Observations and Discussion

- Large sheaves are better than small sheaves.
- Thin lines are better than thick lines.
- The sheave-to-axle friction is much smaller than the friction in any reasonably thick line.
- There is hardly any difference between good plain bearing blocks and ball bearing blocks.

The two first results were expected. The third and fourth were what I was curious about. I suspected internal friction of the lines to be important but I had not expected it to be this dominating. Those lines feel very flexible and easy-moving when handled but bending them over the radius of a sheave must cause quite a bit of internal fiber-to-fiber movement.

In Figs. 4 through 7 the smallest and worst block is the only one that stands out from the crowd. The ball bearing block is only just the best of the good blocks and it is very clearly rivaled by the best plain bearing block.

The reason for the missing advantage of the ball bearing block is the fact that the sheave-to-axle friction of the plain bearing block is just a small part of the total friction.

Are fancy, brand-name, ball bearing blocks just a waste of money? Yes, if you are trying to reduce friction they are! In defense of ball bearing blocks I must

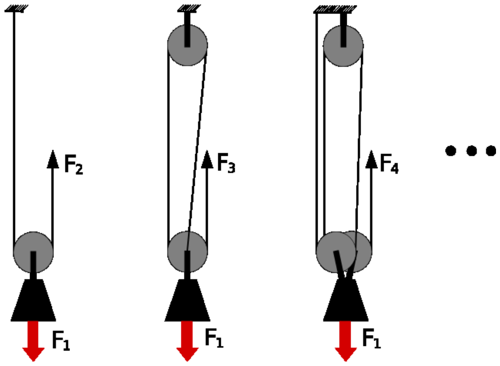

Figure 8: Schematic drawing of tackles.

point out that they are usually much lighter than similarly sized plain bearing blocks. If you aim for the same safe working load the weight advantage disappears but then the sheave diameter of the ball bearing block is usually bigger so it will deliver lower total friction.

The obvious choice from an engineering perspective is weight optimized plain bearing blocks with large diameter sheaves. They won't spin their sheaves quite as nicely as ball bearing blocks do when you stand there in the marine equipment shop though.

5 The Performance of Tackle Including Friction

How bad is this level of friction to the performance of tackle? With the help of Fig. 8 I derive the force needed on a tackle's tail to both move the load and overcome friction. Here is the basic math:

$$
\begin{aligned}
F_2 &= F_1/2 + \text{friction} \\
F_3 &= F_1/3 + \text{friction} \\
F_4 &= F_1/4 + \text{friction} \\
&\vdots
\end{aligned}
$$

The contribution from friction depends on the number of sheaves involved and the load on each sheave. The load on a sheave is closely related to the load on the line wrapped around it. I assume it is proportional to the load on the line:

$$F_2 = F_1/2 + C_f * F_1/2$$

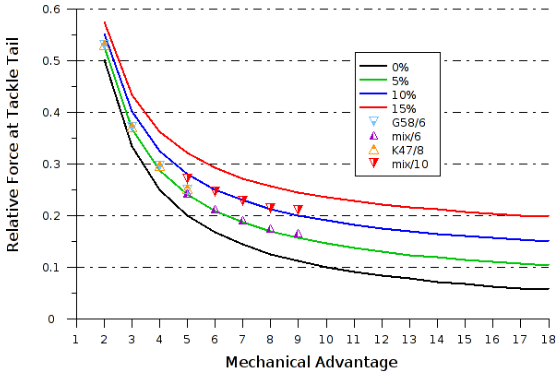

Figure 9: Tackle performance including friction.

where C_f is the friction coefficient. Two sheaves results in two times friction but the force is down since the mechanical advantage of the tackle has increased:

$$F_3 = F_1/3 + 2 * C_f * F_1/3$$

4x tackle with three sheaves:

$$F_4 = F_1/4 + 3 * C_f * F_1/4$$

Generalized to n times mechanical advantage and $n-1$ sheaves:

$$F_n = \frac{F_1}{n}\left(1 + C_f\,(n-1)\right)$$

This does not hold water if the friction coefficient is not constant but depends on the load and/or the speed of the line. I ignore this problem for now and in Fig. 9 I have plotted F_n as a function of n and for different values on C_f. I have also plotted some measured data. The lines in Fig. 9 represent calculated results and the discrete points represent measured data.

F_1 was equal to 174 N throughout these measurements. The use of tackles with mixed block technology is a matter of availability. I used the Harken ball bearing blocks and the OH plain bearing blocks since these were the block types that were most closely matched in my first measurements session.

Fig. 9 demonstrates how bad friction is to powerful tackles. Even with just 5 % friction per sheave the total friction of an 18x tackle stands for almost half the pulling force needed on the tail. With 10 % friction this is the case for a 10x tackle.

Measured data line up well with the curves. The reason for measured data leveling out at a higher level is the

Figure 10: Healthy sheave to line ratio on maxi trimaran IDEC. Photo: J. Paul Riou.

low load on the line when the tackle becomes powerful. We have moved to the far left of Fig. 3 and the assumption that C_f is constant has been violated. Note that I used a 6 mm line in blocks designed to accept 10 mm and 12 mm lines to get a C_f close to 5 %. Those blocks are usually used with 8–10 mm lines!

6 Cascading Tackles

What about cascading tackles? I could assemble a 12x tackle as a straight forward 12x tackle or by cascading a 6x tackle with a 2x tackle or a 4x tackle with a 3x tackle. If there was no friction they would all perform the same. Once friction enter the picture things become more complicated and more interesting.

Cascading tackles is the same as multiplication in the mathematical model. Hence, the resulting force on the tail of two cascaded tackles becomes

$$F_{nm} = F_1 \frac{1 + C_{fn}(n-1)}{n} * \frac{1 + C_{fm}(m-1)}{m}$$

where n and m are the mechanical advantages of the two tackles that are cascaded. $n*m$ is the total mechanical advantage when there is no friction. C_{fn} and C_{fm} are the friction coefficients for the two tackles. Re-arranging the equation above helps clarifying what makes cascaded tackles interesting.

n,m	12,1	6,2	4,3	3,4	2,6	1,12
% of F_1	12.9	12.0	12.5	13.3	15.3	22.1

Table 2: Resulting tail force for two cascaded tackles with friction.

$$\begin{aligned} F_{nm} = {} & \tfrac{F_1}{nm}(1 + C_{fn}(n-1) + C_{fm}(m-1) \\ & + C_{fn}C_{fm}(n-1)(m-1)) \end{aligned}$$

The first term—the lonely 1—in the parenthesis represents the friction-less performance of the cascaded tackles. The second and third terms are the friction contribution of each part tackle. Note that both these are divided by $n*m$. The friction contribution of tackle one is reduced by the mechanical advantage of tackle two and vice verse! The last term is the product of the two friction contributions. This term should be quite small for all useful tackles since both C_{fn} and C_{fm} are significantly smaller than 1.

Let us return to the 12x tackle example. Let us assume we have blocks and lines that allows us to build rather good tackles with a friction coefficient close to 5 % and less good tackles with a friction coefficient of some 15 %. We don't have enough of the good stuff to build any combination of cascades using only the good stuff so we must mix. What are the alternatives and how do they perform relative to each other? A bit of number-crunching provides the answer summarized in Table 2.

The superiority of the low friction straight 12x tackle over the straight high friction tackle is expected. More of a surprise is maybe that combining a low friction 6x tackle with a 2x high friction tackle results in less friction than the straight low friction 12x tackle. The cascade composed of a 4x low friction and a 3x high friction tackle is also better.

One candidate for the 12x tackle has been left out above: the 2x+2x+3x cascade. I leave it to the interested reader to calculate how such a cascade performs.

7 Future Work

I hope to do measurements at higher load levels in a not too distant future.

Comparing different types of lines—double braid against single braid et cetera—should be interesting given the dominating role of the line.

8 Conclusions

The data presented here clearly show how the internal friction in the line dominates the total friction of a tackle. It follows that the design focus should be on line and block dimensions. Cascaded tackles should be considered as they have favorable friction properties. Choosing between plain bearing and ball bearing blocks is a distant third on the priority list.

Appendix

Blocks

First a note on sheave diameter. The diameter I use is the one the line is forced to bend over but manufacturers use the maximum diameter of the sheave.

- The 19 mm blocks are Ronstan RF 469s. This is a small, basic plain bearing block. The sheave is of Nylon and the axle is stainless steel. The safe working load is said to be 432 kg. Each RF 469 weighs 41 g.
- The 40 mm blocks are Rutgerson 50s. This is the original Rutgerson block design from the 1980s. They don't look fancy but are strong and built from high quality Delrin and stainless steel. I don't know the safe working load but they weigh 131 g each. Current, similar blocks from Rutgerson are claimed to weigh 116 g and have a 772 kg safe working load.
- The 39 mm blocks are Lewmar Synchro 50s. They actually have 40 mm sheaves using my definition but to distinguish them from the Rutgerson blocks described above I labeled them 39 mm blocks. These blocks are supposed to have a safe working load of 450 kg and a weight of 67 g (I measure 74 g). I included these blocks since they are a little different. The sheaves are noticeably thinner than usual forcing you to a bigger sheave for a given line size. Also, Lewmar claims there is some special design to the bearing and they do feel a little 'better' in terms of play and free spinning of sheaves when you play around with them.
- The 58 mm blocks are from Danish O.H. The model no. is 00403. OH's classic plain bearing blocks are not unlike Ronstan's bigger plain bearing blocks but the cheeks are aluminum rather than steel. The sheave is Delrin and the axle is stainless steel. The safe working load is said to be 950 kg. The weight is 216 g.
- The 47 mm blocks are Harken 2607s. These are made from glass fiber reinforced Nylon (PA66?). The weight is 75 g (68 g according to Harken) and the published safe working load is 360 kg.

Lines

- Both the 8 mm line and the 10 mm line are polyester double braids by Gleistein. This particular model is called Tasmania. The Tasmania is a fairly flexible, easy-moving sheet line. The 8 mm line is actually 7.5 mm and the 10 mm line is 10.5 mm in diameter.
- The 6 mm line is a Dyneema-cored halyard by Gleistein. The cover is polyester and both core and cover are braids. This line is almost as flexible as the Tasmania.
- The 5 mm line is of a different build: parallel fiber core and a braided cover. This is an all-polyester line. I don't know the make since this is the remains of a spool bought back in 1986.
- I added a 2.5 mm line to be able to do thin-line experiments at higher loads than the 0.5 mm line can handle. The 2.5 mm line is a Dyneema core/Polyester cover double braid from Seilflechter.
- The 0.5 mm line is Marlow's No. 4 Whipping Twine.

Revisions

Dec. 3, 2007 First release.

Jan. 12, 2008 Corrected graphs, some new measured data and three additional graphs. Sections 2, 3 and 4 have seen some re-work.