

spindle point, in order to secure correct backing off. All the roller gearing is placed at the headstock ends of the roller beams. The change wheels are arranged in an improved manner, giving increased facilities for effecting the required changes, while the wheels themselves are of more convenient sizes than those commonly in use. The gain wheel contains 105 teeth, while the slubbing wheels have 50 and 25 respectively. The former enables the operator to make a very fine change. The rimband and carrier pulleys are of large size, which greatly diminishes friction and wear and tear of the bands. The in-taking and out-taking motions cannot by any chance be in gear and acting in opposition at the same time. The in-taking motion is withdrawn by the carriage in the event of the cam not withdrawing it. By a novel and simple arrangement of the gearing for the backing the cam off and the scroll shafts, no carrier pulleys are required for tightening the band from the countershaft that drives these motions. The connections from the front to the back are very simple in their construction and neat in their arrangement.

As we have observed previously, the mule, which we and hundreds of practical men have inspected during the past few weeks, contains 1,000 spindles, not being a small sample machine, but one that will form part of the plant of a large mill in the outskirts of Manchester. The spindles are $1\frac{1}{2}$ in. gauge, $17\frac{1}{2}$ in. long, and $8\frac{1}{2}$ in. out of the bolster. The mule was running 5 stretches of 64 in. in 64 seconds, with an 18 in. rim pulley and 12 in. pulley on tin roller, the tin roller being 6 in. diameter with a $\frac{1}{2}$ in. wharve on the spindle. The creel is made in two heights, and the rollers double bossed, single roving. The latter, however, are points of detail that can be varied to suit the taste or notions of purchasers.—*Textile Manufacturer.*

LUBRICATING OILS.

MEASUREMENTS OF FRICTION OF LUBRICATING OILS.*

By C. J. H. WOODBURY, Boston, Mass.

At the meeting of this society held in November, 1880, the writer presented a paper under the same title, giving the comparative results of some measurements of friction upon a variety of lubricating oils, submitted to a somewhat narrow range of conditions. On this occasion it is proposed to treat the subject from a different, but perhaps equally practical, point of view, and limit the subject to the examination of a single lubricant under a wide range of investigation.

In the course of some work on this subject for the Factory Mutual Insurance Companies, it became a matter of importance to know the coefficient of friction of a lubricant at a series of temperatures and pressures. These measurements were made upon another machine designed by the writer, similar in principle, but differing from the one used in the previous experiments in its general construction. The earlier machine was made for the specific purpose of testing spindle oils, and fulfilled conditions of high speeds and light pressures in a satisfactory manner, but was unsuited for work with heavy pressures upon the standard bearing where the friction was measured.

A standard brand of mineral oil, free from admixture of any animal oil, was selected for these experiments, because previous experience had shown that it was more uniform than any other lubricating oil, and duplicate samples could be obtained when desired. A test of this oil showed:

Flash..... 342 deg. Fahr.
Fire 410 "
Evaporation by exposure to 140
deg. Fahr. for twelve hours... 0.02
Specific gravity..... 0.888

The operation of the machine is based upon the principle of measuring the friction between two annular disks, and the whole designed for the purpose of observing this with precision.

The machine, shown in perspective in Fig. 1 and in elevations in Figs. 2 and 3, consists of a cast iron frame in the form of an arch, with a brace at the rear, and further stiffened with transverse webs arranged to present the utmost rigidity against the stresses liable to be applied to the machine.

The lower disk is secured upon the top of an upright shaft, its top being an annulus, ground to a true plane surface. Upon this rests the upper disk, which is in the form of a hollow ring based upon a flat plate, and is made of very hard composition, cast in one piece. The bottom of this disk is scraped to a true plane surface, so that the contact between these two disks is uniform.

A partition divides the interior of the hollow ring forming the upper disk, so that water can be introduced through the connecting tubes to control the temperature of the disks, and in some instances it is desired to use the water as a medium to retain the heat of friction. The sides and top of the other disk are surrounded by a case made of hard rubber, and the space filled with eider down.

In experimenting, ice water is generally used to reduce the temperature of the disks to nearly the freezing point of water, and then the friction is noted at each degree of the rise in temperature due to the heat of friction.

A tube of thin copper, closed at the bottom, reaches through to the bottom of the disk, and a thermometer with the bulb placed within this tube indicates the temperature of the frictional surface. A tube leading through the upper disk conducts the lubricant under trial to the recess in the middle of the lower disk. The upper end of this tube, being of glass, indicates the supply and rate of feeding of the oil. As the friction of a journal depends quite largely upon the method of lubrication, uniformity in the manner of supply is of the utmost importance.

Over the upper disk, a yoke with four arms rests upon four columns which extend through the upper disk to the middle of the frictional surfaces; these columns being cast as a portion of the disk. In the center of this yoke is a hole with hemispherical bottom. The lower end of the upper spindle is round, and fitting into this hole makes a ball and socket joint. This construction transmits the stress due to the weight applied

TABLE I.—RESISTANCE OF FRICTION OF A PARAFFIN OIL AT A VELOCITY OF 300 FT. PER MINUTE.

| Pressure in Pounds per Square Inch. | TEMPERATURES. | | | | | | | | | | | | | |
|---|-------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-------------|--|
| | deg. 40 | deg. 45 | deg. 50 | deg. 55 | deg. 60 | deg. 65 | deg. 70 | deg. 75 | deg. 80 | deg. 85 | deg. 90 | deg. 95 | deg. 100 | |
| | RESISTANCE OF FRICTION. | | | | | | | | | | | | | |
| 1 | 2.69 | 2.39 | 2.13 | 1.91 | 1.70 | 1.51 | 1.34 | 1.19 | 1.06 | .95 | .85 | .75 | .69 | |
| 2 | 2.99 | 2.61 | 2.32 | 2.08 | 1.86 | 1.66 | 1.50 | 1.34 | 1.21 | 1.09 | .99 | .89 | .80 | |
| 3 | 3.16 | 2.78 | 2.49 | 2.23 | 2.00 | 1.80 | 1.62 | 1.47 | 1.32 | 1.20 | 1.10 | .99 | .90 | |
| 4 | 3.34 | 2.95 | 2.65 | 2.35 | 2.12 | 1.92 | 1.74 | 1.59 | 1.45 | 1.33 | 1.21 | 1.10 | .99 | |
| 5 | 3.50 | 3.08 | 2.76 | 2.49 | 2.25 | 2.04 | 1.85 | 1.69 | 1.55 | 1.43 | 1.30 | 1.19 | 1.09 | |
| 6 | 3.65 | 3.20 | 2.88 | 2.61 | 2.36 | 2.15 | 1.96 | 1.79 | 1.65 | 1.51 | 1.39 | 1.28 | 1.17 | |
| 7 | 3.79 | 3.32 | 3.00 | 2.71 | 2.47 | 2.25 | 2.06 | 1.89 | 1.74 | 1.61 | 1.48 | 1.36 | 1.24 | |
| 8 | 3.91 | 3.43 | 3.10 | 2.82 | 2.57 | 2.34 | 2.16 | 1.99 | 1.83 | 1.69 | 1.56 | 1.45 | 1.34 | |
| 9 | 4.05 | 3.56 | 3.22 | 2.93 | 2.67 | 2.45 | 2.25 | 2.07 | 1.92 | 1.78 | 1.65 | 1.53 | 1.42 | |
| 10 | 4.18 | 3.68 | 3.33 | 3.03 | 2.77 | 2.54 | 2.34 | 2.17 | 2.01 | 1.86 | 1.74 | 1.62 | 1.51 | |
| 11 | 4.30 | 3.79 | 3.43 | 3.14 | 2.88 | 2.65 | 2.45 | 2.28 | 2.11 | 1.96 | 1.83 | 1.70 | 1.59 | |
| 12 | 4.41 | 3.89 | 3.55 | 3.25 | 2.99 | 2.75 | 2.54 | 2.36 | 2.19 | 2.04 | 1.91 | 1.78 | 1.66 | |
| 13 | 4.52 | 4.00 | 3.65 | 3.35 | 3.08 | 2.84 | 2.63 | 2.44 | 2.27 | 2.13 | 1.99 | 1.85 | 1.73 | |
| 14 | 4.64 | 4.10 | 3.75 | 3.44 | 3.16 | 2.92 | 2.72 | 2.53 | 2.36 | 2.22 | 2.07 | 1.94 | 1.81 | |
| 15 | 4.75 | 4.21 | 3.85 | 3.55 | 3.26 | 3.02 | 2.80 | 2.61 | 2.44 | 2.29 | 2.15 | 2.01 | 1.88 | |
| 16 | 4.85 | 4.32 | 3.95 | 3.64 | 3.36 | 3.12 | 2.90 | 2.70 | 2.53 | 2.38 | 2.23 | 2.09 | 1.95 | |
| 17 | 4.95 | 4.42 | 4.06 | 3.75 | 3.46 | 3.22 | 3.00 | 2.79 | 2.62 | 2.46 | 2.31 | 2.17 | 2.04 | |
| 18 | 5.08 | 4.54 | 4.16 | 3.84 | 3.56 | 3.30 | 3.08 | 2.89 | 2.71 | 2.54 | 2.40 | 2.25 | 2.13 | |
| 19 | 5.18 | 4.63 | 4.26 | 3.93 | 3.65 | 3.40 | 3.18 | 2.98 | 2.80 | 2.64 | 2.49 | 2.34 | 2.21 | |
| 20 | 5.28 | 4.73 | 4.35 | 4.03 | 3.75 | 3.49 | 3.27 | 3.07 | 2.89 | 2.73 | 2.57 | 2.41 | 2.27 | |
| 21 | 5.38 | 4.84 | 4.44 | 4.13 | 3.83 | 3.59 | 3.36 | 3.10 | 2.98 | 2.82 | 2.65 | 2.49 | 2.35 | |
| 22 | 5.46 | 4.94 | 4.56 | 4.23 | 3.94 | 3.68 | 3.45 | 3.25 | 3.07 | 2.90 | 2.73 | 2.57 | 2.42 | |
| 23 | 5.55 | 5.05 | 4.65 | 4.32 | 4.03 | 3.76 | 3.54 | 3.33 | 3.15 | 2.97 | 2.81 | 2.64 | 2.49 | |
| 24 | 5.65 | 5.13 | 4.74 | 4.41 | 4.10 | 3.81 | 3.62 | 3.42 | 3.23 | 3.05 | 2.89 | 2.72 | 2.56 | |
| 25 | 5.75 | 5.22 | 4.83 | 4.50 | 4.19 | 3.93 | 3.70 | 3.49 | 3.31 | 3.13 | 2.95 | 2.79 | 2.63 | |
| 26 | 5.83 | 5.31 | 4.92 | 4.58 | 4.28 | 4.01 | 3.78 | 3.57 | 3.39 | 3.21 | 3.03 | 2.86 | 2.71 | |
| 27 | 5.93 | 5.41 | 5.01 | 4.67 | 4.35 | 4.09 | 3.86 | 3.65 | 3.46 | 3.29 | 3.11 | 2.94 | 2.78 | |
| 28 | 6.03 | 5.50 | 5.10 | 4.75 | 4.45 | 4.18 | 3.95 | 3.73 | 3.54 | 3.36 | 3.18 | 3.02 | 2.85 | |
| 29 | 6.10 | 5.59 | 5.19 | 4.84 | 4.54 | 4.26 | 4.02 | 3.81 | 3.62 | 3.44 | 3.26 | 3.09 | 2.92 | |
| 30 | 6.19 | 5.67 | 5.28 | 4.92 | 4.61 | 4.33 | 4.10 | 3.88 | 3.69 | 3.51 | 3.34 | 3.15 | 2.99 | |
| 31 | 6.26 | 5.75 | 5.35 | 5.01 | 4.69 | 4.41 | 4.16 | 3.95 | 3.76 | 3.58 | 3.40 | 3.23 | 3.05 | |
| 32 | 6.35 | 5.83 | 5.43 | 5.09 | 4.77 | 4.49 | 4.24 | 4.04 | 3.84 | 3.65 | 3.46 | 3.29 | 3.12 | |
| 33 | 6.43 | 5.91 | 5.52 | 5.16 | 4.85 | 4.57 | 4.33 | 4.11 | 3.91 | 3.72 | 3.54 | 3.35 | 3.19 | |
| 34 | 6.50 | 6.00 | 5.60 | 5.25 | 4.93 | 4.65 | 4.41 | 4.19 | 3.99 | 3.80 | 3.61 | 3.43 | 3.24 | |
| 35 | 6.58 | 6.08 | 5.69 | 5.32 | 5.01 | 4.73 | 4.48 | 4.26 | 4.05 | 3.86 | 3.68 | 3.50 | 3.32 | |
| 36 | 6.65 | 6.15 | 5.75 | 5.40 | 5.09 | 4.81 | 4.57 | 4.34 | 4.13 | 3.93 | 3.75 | 3.56 | 3.38 | |
| 37 | 6.73 | 6.22 | 5.83 | 5.49 | 5.17 | 4.88 | 4.64 | 4.41 | 4.21 | 4.01 | 3.82 | 3.63 | 3.45 | |
| 38 | 6.80 | 6.31 | 5.92 | 5.57 | 5.25 | 4.97 | 4.72 | 4.49 | 4.29 | 4.09 | 3.89 | 3.70 | 3.52 | |
| 39 | 6.88 | 6.39 | 6.00 | 5.65 | 5.34 | 5.04 | 4.79 | 4.56 | 4.35 | 4.15 | 3.95 | 3.76 | 3.57 | |
| 40 | 6.97 | 6.46 | 6.06 | 5.73 | 5.41 | 5.12 | 4.86 | 4.63 | 4.42 | 4.21 | 4.02 | 3.83 | 3.63 | |

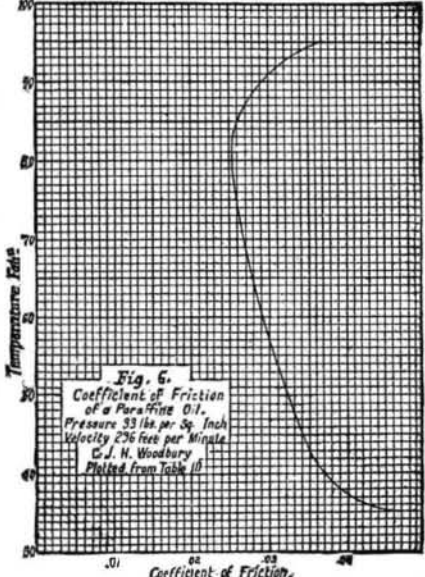
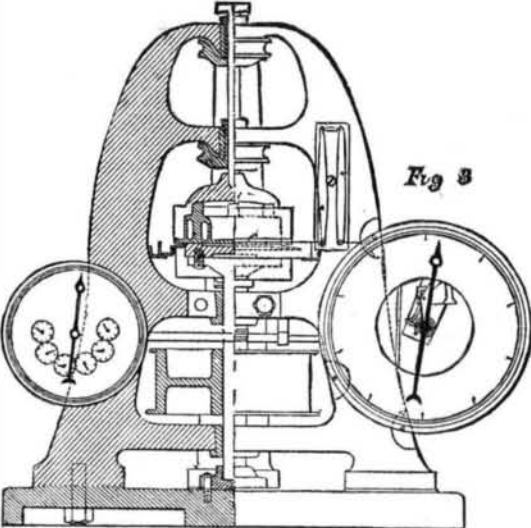
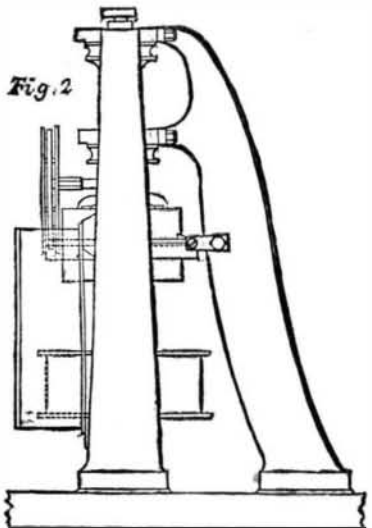
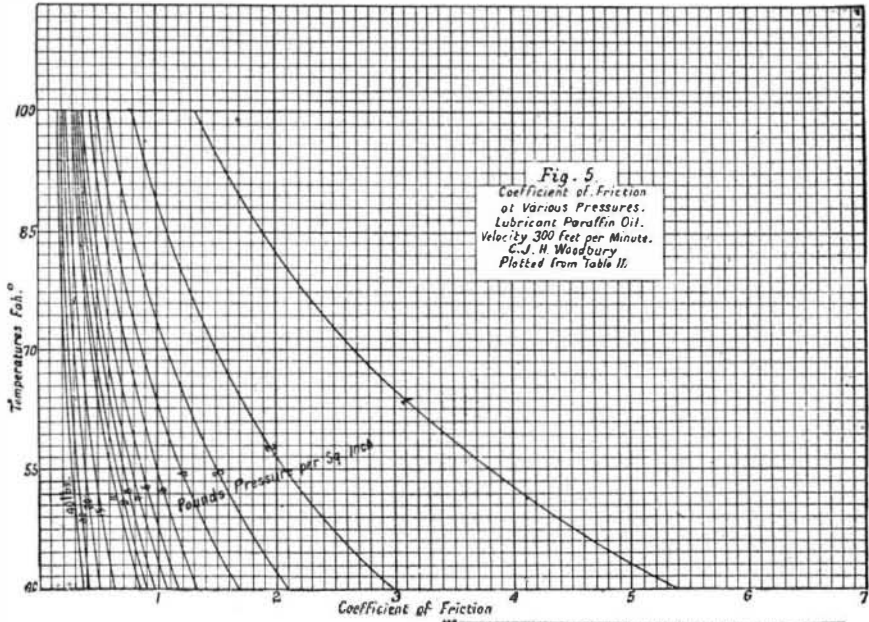
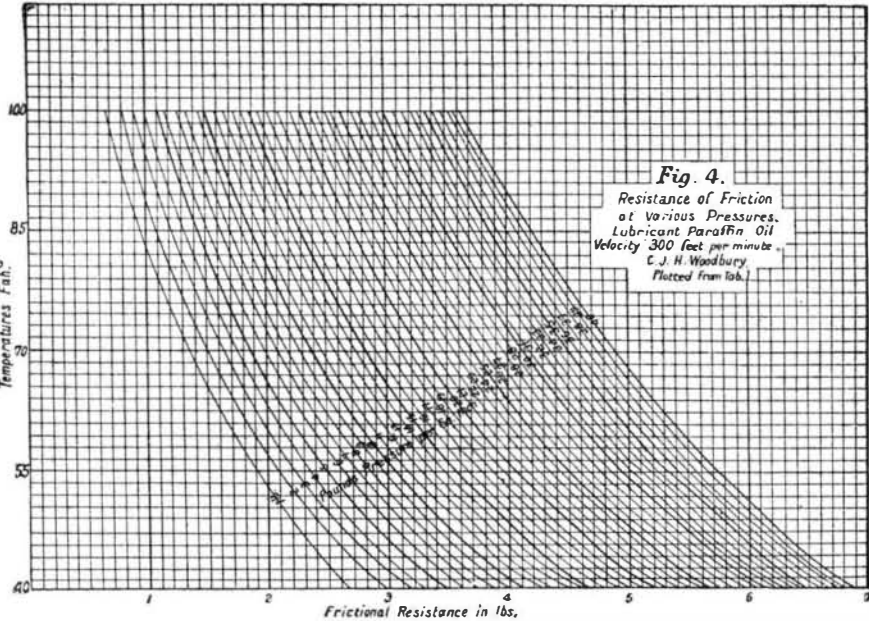
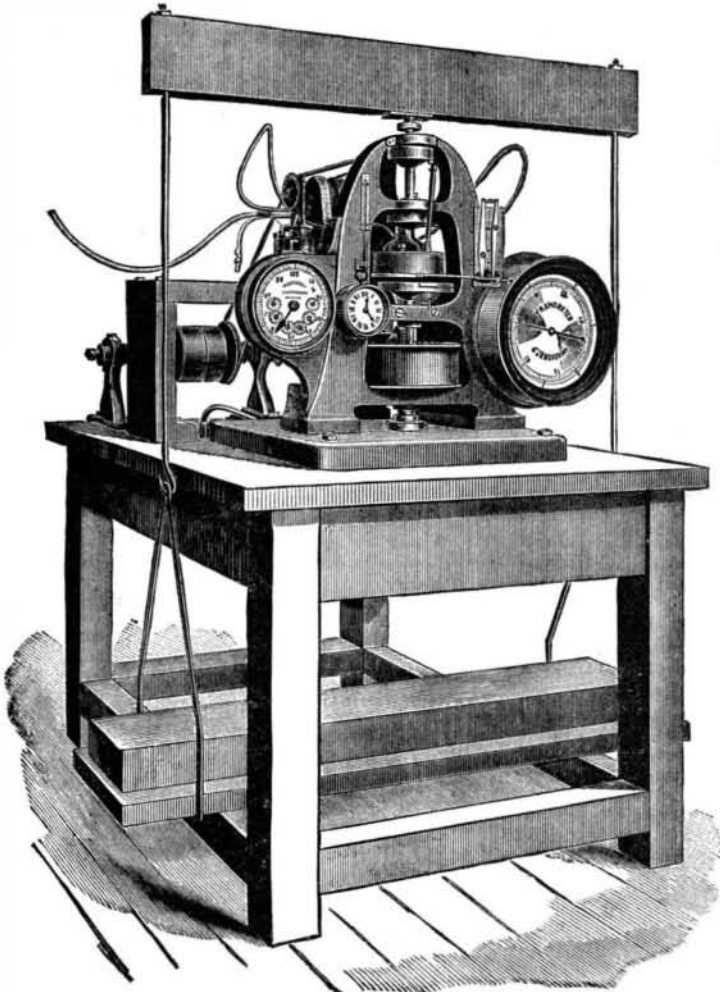
TABLE II.—COEFFICIENT OF FRICTION OF A PARAFFIN OIL AT A VELOCITY OF 300 FT. PER MINUTE.

| Pressure in Pounds per Square Inch. | TEMPERATURES. | | | | | | | | | | | | | |
|-------------------------------------|---------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|--|
| | deg. 40 | deg. 45 | deg. 50 | deg. 55 | deg. 60 | deg. 65 | deg. 70 | deg. 75 | deg. 80 | deg. 85 | deg. 90 | deg. 95 | deg. 100 | |
| | COEFFICIENTS. | | | | | | | | | | | | | |
| 1 | .5330 | .4760 | .4260 | .3820 | .3400 | .3020 | .2680 | .2380 | .2120 | .1900 | .1700 | .1500 | .1330 | |
| 2 | .2990 | .2610 | .2320 | .2080 | .1860 | .1660 | .1500 | .1340 | .1210 | .1090 | .0990 | .0900 | .0800 | |
| 3 | .2107 | .1853 | .1660 | .1487 | .1335 | .1200 | .1080 | .0980 | .0880 | .0800 | .0733 | .0675 | .0600 | |
| 4 | .1670 | .1465 | .1310 | .1173 | .1060 | .0960 | .0870 | .0795 | .0725 | .0665 | .0605 | .0550 | .0495 | |
| 5 | .1400 | .1232 | .1104 | .0986 | .0900 | .0816 | .0740 | .0670 | .0620 | .0560 | .0500 | .0445 | .0390 | |
| 6 | .1217 | .1067 | .0960 | .0870 | .0787 | .0717 | .0653 | .0597 | .0550 | .0503 | .0453 | .0407 | .0360 | |
| 7 | .1089 | .0949 | .0847 | .0774 | .0706 | .0642 | .0583 | .0540 | .0497 | .0450 | .0403 | .0359 | .0310 | |
| 8 | .0978 | .0858 | .0755 | .0705 | .0642 | .0585 | .0540 | .0498 | .0458 | .0423 | .0385 | .0349 | .0300 | |
| 9 | .0900 | .0791 | .0715 | .0657 | .0593 | .0544 | .0500 | .0460 | .0427 | .0395 | .0367 | .0340 | .0300 | |
| 10 | .0836 | .0732 | .0666 | .0606 | .0554 | .0508 | .0468 | .0434 | .0402 | .0372 | .0348 | .0324 | .0280 | |
| 11 | .0782 | .0687 | .0624 | .0571 | .0524 | .0482 | .0445 | .0411 | .0382 | .0356 | .0330 | .0304 | .0260 | |
| 12 | .0735 | .0648 | .0592 | .0542 | .0498 | .0458 | .0423 | .0390 | .0365 | .0340 | .0315 | .0290 | .0245 | |
| 13 | .0695 | .0615 | .0561 | .0515 | .0474 | .0437 | .0405 | .0375 | .0349 | .0325 | .0300 | .0275 | .0230 | |
| 14 | .0663 | .0586 | .0533 | .0491 | .0451 | .0419 | .0389 | .0361 | .0337 | .0317 | .0294 | .0270 | .0225 | |
| 15 | .0633 | .0561 | .0513 | .0475 | .0436 | .0403 | .0375 | .0349 | .0325 | .0305 | .0280 | .0260 | .0215 | |
| 16 | .0608 | .0540 | .0494 | .0456 | .0420 | .0390 | .0363 | .0338 | .0316 | .0295 | .0273 | .0250 | .0205 | |
| 17 | .0582 | .0520 | .0477 | .0441 | .0407 | .0378 | .0353 | .0328 | .0309 | .0288 | .0267 | .0245 | .0199 | |
| 18 | .0564 | .0504 | .0462 | .0426 | .0396 | .0364 | .0342 | .0314 | .0296 | .0275 | .0254 | .0232 | .0186 | |
| 19 | .0545 | .0487 | .0448 | .0414 | .0384 | .0358 | .0335 | .0314 | .0292 | .0271 | .0250 | .0228 | .0182 | |
| 20 | .0528 | .0473 | .0435 | .0403 | .0375 | .0349 | .0327 | .0307 | .0289 | .0273 | .0257 | .0241 | .0195 | |
| 21 | .0510 | .0460 | .0424 | .0394 | .0364 | .0342 | .0320 | .0302 | .0284 | .0269 | .0252 | .0238 | .0192 | |
| 22 | .0498 | .0450 | .0414 | .0384 | .0358 | .0334 | .0314 | .0296 | .0280 | .0266 | .0248 | .0234 | .0188 | |
| 23 | .0483 | .0439 | .0404 | .0374 | .0350 | .0327 | .0308 | .0290 | .0274 | .0258 | .0244 | .0230 | .0184 | |
| 24 | .0471 | .0436 | .0398 | .0368 | .0342 | .0320 | .0302 | .0285 | .0269 | .0254 | .0241 | .0226 | .0180 | |
| 25 | .0460 | .0428 | .0388 | .0358 | .0336 | .0314 | .0296 | .0279 | .0263 | .0242 | .0220 | .0198 | .0152 | |
| 26 | .0448 | .0418 | .0378 | .0348 | .0326 | .0308 | .0290 | .0274 | .0258 | .0246 | .0233 | .0218 | .0172 | |
| 27 | .0439 | .0408 | .0368 | .0338 | .0316 | .0298 | .0280 | .0264 | .0248 | .0236 | .0223 | .0208 | .0162 | |
| 28 | .0430 | .0399 | .0359 | .0329 | .0306 | .0288 | .0270 | .0254 | .0238 | .0226 | .0213 | .0198 | .0152 | |
| 29 | .0421 | .0389 | .0349 | .0319 | .0296 | .0278 | .0260 | .0244 | .0228 | .0216 | .0203 | .0188 | .0142 | |
| 30 | .0413 | .0378 | .0338 | .0308 | .0284 | .0266 | .0248 | .0232 | .0216 | .0204 | .0191 | .0176 | .0130 | |
| 31 | .0404 | .0371 | .0331 | .0301 | .0277 | .0259 | .0242 | .0226 | .0210 | .0198 | .0184 | .0170 | .0124 | |
| 32 | .0397 | .0364 | .0324 | .0294 | .0270 | .0252 | .0235 | .0219 | .0203 | .0191 | .0177 | .0163 | .0117 | |
| 33 | .0390 | .0358 | .0318 | .0288 | .0264 | .0246 | .0229 | .0213 | .0197 | .0185 | .0171 | .0157 | .0111 | |
| 34 | .0382 | .0353 | .0313 | .0283 | .0259 | .0240 | .0223 | .0207 | .0191 | .0179 | .0165 | .0151 | .0105 | |
| 35 | .0376 | .0347 | .0307 | .0277 | .0253 | .0234 | .0217 | .0201 | .0185 | .0173 | .0159 | .0145 | .0099 | |
| 36 | .0370 | .0342 | .0302 | .0272 | .0248 | .0229 | .0212 | .0196 | .0180 | .0168 | .0154 | .0140 | .0094 | |
| 37 | .0364 | .0336 | .0296 | .0266 | .0242 | .0223 | .0206 | .0190 | .0174 | .0162 | .0148 | .0134 | .0088 | |
| 38 | .0358 | .0332 | .0292 | .0262 | .0238 | .0219 | .0202 | .0186 | .0170 | .0158 | .0144 | .0130 | .0084 | |
| 39 | .0353 | .0328 | .0288 | .0258 | .0234 | .0215 | .0198 | .0182 | .0166 | .0154 | .0140 | .0126 | .0080 | |
| 40 | .0349 | .0323 | .0283 | .0253 | .0229 | .0210 | .0193 | .0177 | .0161 | .0149 | .0135 | .0121 | .0075 | |

N =Number of revolutions per minute.
 W =Reading on dynamometer, pounds.
 l =Length of arm on upper disk, feet.
 ϕ =Coefficient of friction.
Suppose that the annular surfaces of the disk be divided into an infinite number of elementary areas by equidistant circles and radial lines, then will—
Width of band = $d\rho$(1)
Angle between two successive radial lines = $d\theta$(2)
Length of arc between two radii = $\rho d\theta$(3)
Elementary area = $\rho d\rho d\theta$(4)
Area of annulus = $\pi(R^2-r^2)$(5)
Pressure per unit of area = $\frac{P}{\pi(R^2-r^2)}$(6)
Pressure on elementary area = $\frac{P \rho d\rho d\theta}{\pi(R^2-r^2)}$(7)
Friction on elementary area = $\frac{\phi P \rho d\rho d\theta}{\pi(R^2-r^2)}$(8)
Moment of friction on elementary area = $\frac{\phi P \rho^2 d\rho d\theta}{\pi(R^2-r^2)}$(9)
Moment of friction on entire disk = $\frac{\phi P}{\pi(R^2-r^2)} \int_r^R \int_0^{2\pi} \rho^2 d\rho d\theta$ (10)
Integrating = $\frac{2\phi P}{\pi(R^2-r^2)} \left\{ \frac{\rho^3}{3} \right\}_r^R$(11)
Substituting the limits = $\frac{2\phi P(R^3-r^3)}{3(R^2-r^2)}$(12)

Work of friction = $\frac{4\phi P N (R^3-r^3)}{2(R^2-r^2)}$(13)
per minute
Resistance of the dynamometer = $2\pi l W N$(14)
The friction equals the resistance, hence
 $\frac{4\phi P N (R^3-r^3)}{2(R^2-r^2)} = 2\pi l W N$(15)
 $\phi = \frac{3 W l (R^2-r^2)}{2\pi (R^3-r^3)}$(16)
This is not in a form convenient for continual use, and is susceptible of much simplification, if the proper dimensions are used for the various parts in connection with the frictional surfaces and the dynamometer arm. It is also important for the sake of simplicity that the length of the line of mean area of the disk be 1 ft., so that the number of revolutions per minute is equivalent to the frictional velocity in feet per minute. For convenience, it was desirable that the area of the disks be 10 square inches.
If c = radius of circle whose circumference is 12 in., then—
 $2\pi c = 12$(17)
 $c = \frac{12}{2\pi} = 1.909$ in.....(18)
Area within this circumference,
 $\pi c^2 = 11.46$ square inches.....(19)
If this circumference divide the annulus of 10 square inches area into two equal parts, then the outer rim of the annulus will circumscribe an area of $11.46+5 = 16.46$

square inches. The radii corresponding to these circles are:
 $R = \sqrt{\frac{A}{\pi}} = 2.289$ in. = 0.1907 ft.....(20)
 $r = \sqrt{\frac{a}{\pi}} = 1.434$ in. = 0.1195 ft.....(21)
 $R^2-r^2 = 0.0221$ ft.; $R^3-r^3 = 0.00523$ ft.....(22)
Substituting the values in equation (16)
 $\phi = \frac{6.338 W l}{P}$(23)
This equation can be made still more simple if the length of the arm l is of such length that
 $\phi = \frac{2 W}{P}$(24)
Substituting this value of ϕ in equation 23, we have
 $l = 0.3156$ ft. = 0.3787 in.
Generally the weight on the disks is referred to in pounds to the square inch, then
 $\phi = \frac{W}{5P}$(25)
If the reducing levers which have been referred to are used, the reading on the dynamometer is one-fifth of the pull on the arm, and when the machine is used with this attachment
 $\phi = \frac{W}{P}$(26)
The blank used in taking notes of the observations



THE MEASUREMENT OF FRICTION OF LUBRICATING OILS.

made upon the work with the machine is shown in Table III.

After the temperature of the disks has been reduced by a current of ice water, the circulation of the water is stopped, the machine started, and the reading of the dynamometer noted at each degree of temperature.

As the machine is generally used without the compound levers, the column of coefficient of friction is obtained by dividing the dynamometer reading by five times the pressure in pounds per square inch.

Table I. contains the record of the dynamometer readings, and shows the resistance of friction of a paraffin oil tested in the machine, at a series of pressures of 1 lb. to 40 lb. per square inch, and temperatures from 40 deg. to 100 deg. Fahr. Readings were noted at each degree, but a tabulation of the friction at every fifth degree answers all required purposes.

The results are clearer expressed by the diagram, which shows in a graphical manner the relations of these measurements to each other within the limits of the data (Fig. 4).

As the temperature rises, the increasing fluidity of the oil diminishes the friction within the limits of free lubrication.

It is also seen that the resistance does not increase proportionately with the pressure, nor at a uniform rate. The lubricant, while separating the surfaces of a journal, and protecting them from injury, also introduces the resistance of its own cohesion; and at

TABLE III.—Boston Manufacturers' Mutual Fire Insurance Company, March 12, 1883.

Frictional Tests of No. 58 Unknown Mineral Oil.

| | | | | | |
|-------------|-------------|-------|------------------------|-----------|---------|
| Temp. Disc. | Ending.. | 95 | Duration of experiment | .. | 21 |
| " | Beginning.. | 35 | Counter .. | Ending .. | 910,882 |
| Temp. Room | Ending.. | 60 | " | Beginning | 904,162 |
| " | Beginning.. | 62 | Total revolutions | .. | 6220 |
| Time .. | Ending.. | 10.31 | Rev. per minute | .. | 290 |
| " | Beginning.. | 10.10 | " | " | " |

Pressure on Frictional Surfaces 33 lb. per Square Inch.

| Temperature. | Dynamometer. | Coefficient of Friction. | Temperature. | Dynamometer. | Coefficient of Friction. | Temperature. | Dynamometer. | Coefficient of Friction. |
|--------------|--------------|--------------------------|--------------|--------------|--------------------------|--------------|--------------|--------------------------|
| 33 | 8.00 | .0485 | 64 | 4.80 | | 93 | 5.45 | |
| 34 | 7.00 | | 65 | 4.75 | .0258 | 94 | 5.80 | |
| 35 | 6.65 | | 66 | 4.70 | | 95 | 6.10 | .0370 |
| 36 | 6.45 | | 67 | 4.66 | | | | |
| 37 | 6.30 | | 68 | 4.60 | | | | |
| 38 | 6.12 | .0371 | 69 | 4.57 | | | | |
| 39 | 6.02 | | 70 | 4.54 | .0375 | | | |
| 40 | 5.90 | | 71 | 4.49 | | | | |
| 41 | 5.82 | | 72 | 4.45 | | | | |
| 42 | 5.75 | | 73 | 4.42 | | | | |
| 43 | 5.68 | .0344 | 74 | 4.39 | | | | |
| 44 | 5.61 | | 75 | 4.37 | .0265 | | | |
| 45 | 5.55 | | 76 | 4.36 | | | | |
| 46 | 5.49 | | 77 | 4.35 | | | | |
| 47 | 5.42 | | 78 | 4.32 | | | | |
| 48 | 5.36 | .0325 | 79 | 4.30 | | | | |
| 49 | 5.32 | | 80 | 4.29 | .0260 | | | |
| 50 | 5.28 | | 81 | 4.27 | | | | |
| 51 | 5.22 | | 82 | 4.25 | | | | |
| 52 | 5.17 | .0310 | 83 | 4.25 | | | | |
| 53 | 5.12 | | 84 | 4.28 | | | | |
| 54 | 5.09 | | 85 | 4.31 | .0261 | | | |
| 55 | 5.06 | | 86 | 4.41 | | | | |
| 56 | 5.03 | | 87 | 4.51 | | | | |
| 57 | 4.99 | | 88 | 4.64 | | | | |
| 58 | 4.95 | .0300 | 89 | 4.75 | | | | |
| 59 | 4.91 | | 90 | 4.90 | | | | |
| 60 | 4.88 | | 91 | 5.05 | .0297 | | | |
| 61 | 4.84 | | 92 | 5.22 | | | | |

small pressures the film of oil is thicker and the resistance due to viscosity of the oil exceeds that at high pressures, when a smaller amount of oil lies between the surfaces.

A film of the lubricant adheres to each of the frictional surfaces, and that portion which lies between these two films is pulled in one direction upon one side, and in the other direction upon the other side, and as a resultant, the movement of this center layer is a rolling motion, whose rate of progression varies with the difference between the adhesion of oil between the two frictional surfaces.

Nearly five years ago I stated,* as a result of some early work on this subject, that "friction exists at the surface of the two disks between the film of oil acting as a washer and the particles of oil partially embedded within the pores of the metal," and the result of all subsequent investigation has tended to confirm this view of the subject.

Table II. shows the coefficient of friction as computed from the first table of resistances by the formula previously given.

$$\phi = \frac{W}{5p}$$

ϕ = coefficient of friction.

W = resistance of friction as shown as by dynamometer, in pounds.

p = pressure upon frictional surfaces in pounds per square inch.

It does not seem feasible to deduce a formula which will meet the limitations of this table; and if such an equation were given, it could serve no practical use either in practice or theory, because it would be bound to these specific results, and unsuited for application elsewhere; but from these results one can observe certain generalities capable of wide application.

It will be observed that, in a general way, the coefficient of friction diminishes inversely with the pressure, and directly with the fluidity of the oil, as indicated by the temperature; and that the rate of these differences diminishes with the increase of pressure. The reason for this is that the resistance due to the viscosity of oil is greater at low than at high temperature, and that with heavier pressures the film of oil is actually thinner, besides being relatively smaller in proportion to the pressure.

On this account, the frictional difference between lubricants is much less at high than at low pressure during continuous lubrication, although the differences in regard to endurance are more widely marked at high pressure.

It is almost universally asserted to be a general prin-

ciple that the coefficient of friction is independent of the pressure, regardless alike of the actual facts in the matter and of the limitations of Morin's experiments,* which form the common source of authority on the subject.

The coefficient of friction between any two solids is accepted to be a constant ratio; but when a lubricating medium is interposed, then the frictional relation between these three substances becomes variable, according to the effect of temperature, pressure, and velocity upon the lubricant, and the problem bears certain analogies to those of hydrodynamics relative to the efflux of a fluid through a narrow orifice. When the pressures are great, these variables form such a small ratio to the whole frictional resistance that they escape observation unless the measurements of friction are taken in an accurate manner.

If the lubricant is not used, the variables disappear altogether, and then the coefficient of friction becomes reduced to a constant ratio. This latter class of friction is rarely considered, except for the friction of repose, in matters pertaining to the stability of structures; while the problems of mediate friction enter into the operation of the moving parts of every machine.

This is not the place to enter into a criticism of the work of Morin, but it should be observed that his investigations were devoted to measurements of a sled upon tracks in the interests of the Ordnance Corps; and although he made some experiments upon friction of oil bearings, they were not subjected to the frictional conditions of lubricated journals under conditions analogous to those in machines.

In a letter† written March 15, 1879, Gen. A. Morin said [translation]: "The results furnished by my experiments as to the relations between pressure, surface, and speed, on the one hand, and sliding friction on the other, have always been regarded by myself, not as mathematical laws, but as close approximations to the truth within the limits of the data of the experiments themselves."

Considerations of safety have fixed the minimum limit of the flashing point of a lubricating oil at 300 deg. Fahr., with a proportion of volatile matter not exceeding five per cent. thrown off by exposure to 140 deg. Fahr. for twelve consecutive hours. With the saving clause of proper limits of pressure, a fluid oil offers less frictional resistance than a viscous one.

Although the data in Table II. show that the coefficient of friction diminishes with the increase of fluidity, it does not warrant any extreme position in respect to the use of thin oils, except for light pressures, because, under all circumstances, the film of oil must be thick enough to keep the surfaces of a journal from actual metallic contact. In the severe work of heavy pressure a viscous oil must be used in order to retain its place upon the bearing surfaces in sufficient thickness to protect the inequalities upon the journal from colliding. In some places, it has been found that the use of an extremely thin oil resulted in a diminution of the friction of the machines at the expense of more rapid wear of the journals. Such results are not apt to occur upon journals of light pressure, such as spindles, where a thin oil is used with good judgment.

Table III. shows the record of a test of a very limpid mineral oil which reached, in the frictional machine, its limit of lubrication at 82 deg. Fahrenheit, under a pressure of 33 lb. to the square inch; beyond that point, the oil became so fluid that the pressure reduced the thickness of the sheet of oil, until portions of the surfaces met in actual contact.

At lower temperatures the greater resistance shows a large coefficient of friction on account of the viscosity of the oil, while the rise in friction at higher temperatures, as shown in the upper part of the curve, indicates a resistance produced by the collision of portions of the disks, and the diagram illustrates a graphical representation of the beginning of a hot bearing.

These results have been submitted in the hope of presenting facts which will add somewhat to the means for a fuller treatment of the problem of lubrication. The several economies pertaining to lubrication operate at the expense of each other. An economy of oil may represent an extravagance in motive power; a liberal allowance of limpid oil may save motive power at the expense of the repair account, and above all the final result must show the greatest amount of lubrication for a dollar. Lubricants are wasted, not worn out by attrition, and it is of more importance to know how to use oil than what oil to use. The problem of lubrication seeks to know what combination of oil casks, coal pile, and wear and tear will represent the fewest dollars; and in its broad sense it cannot be solved on any experimental basis, nor settled by a final dictum from any one source, but it will reach its solution through the practical experience of intelligent observation, aided by the resources of technical science.

PHOTOGRAPHIC SURFACES MORE SENSITIVE FOR THE GREEN, YELLOW, AND RED RAYS.

By H. W. VOGEL.

IN this memoir, which is taken from the *Berichte der Deutsch. Chem. Gesell.*, the author speaks of the substances which, when added to silver bromide, render it sensitive to all rays. He finds that one and the same coloring matter acts in very different manners upon different surfaces. Paris violet used with dry silver bromide collodion is as sensitive for the orange rays as for the blue, while with gelatino-bromide the sensitivity for the orange rays is scarcely 1-50 of that for the blue rays. Moist collodion is still less favorable. Eosine behaves in an opposite manner; if a solution containing 1-400 of this color is added to gelatino-bromide in the proportion of 2 per cent., the yellow of the spectrum has one-third of the sensibility of the blue. With dry collodion the yellow and the blue are equally sensitive to light; and moist collodion containing eosine is 8 to 10 times more sensitive for the yellow than for the blue.

* *Nouvelles Expériences sur le Frottement, Faites à Metz*, 1831. Par Arthur Morin, Capitaine d'Artillerie. 128 pp., 4to. Plates. Second Mémoire. 1832. 103 pp., 4to. Plates. Troisième Mémoire. 1833. 142 pp., 4to. Plates.

† Transactions Institution Mechanical Engineers of Great Britain, 1883, p. 666.

COPYING MAPS AND PLANS.*

THERE are various methods by which maps, plans, tracings, etc., may be copied. There is that of producing black lines on a white ground, but I shall confine myself to two: First—The ferro-prussiate process, by which may be produced either white lines on a blue ground, or blue lines on a white ground. Second—The obtaining of copies with white lines on a blue ground. The face of the drawing is placed against the glass of the printing-frame, and the prepared paper is then placed on the drawing (the prepared side on the back of the drawing). It is advisable that the paper should be somewhat larger than the drawing, so as to leave a margin exposed to show the action of light upon it. The exposure required in very bright sunshine varies from five to fifteen minutes; but in the very dull days of winter it may require two or three hours, or even a whole day. During the exposure to light, the paper assumes various tints, from a greenish-blue to an olive tint. The print, when properly exposed, is taken from the printing-frame and immersed in clean water (which can be effected in any room) until the lines become purely white. The time required for washing occupies from five to ten minutes; but if warm water be used, the result is obtained much more quickly. Over-washing reduces the intensity of the blue ground. I find, from experience, the copies darken considerably while drying. If the prints are very large, say four or five feet in length, and three feet wide or more, great care is required in taking them out of the washing water to prevent them from tearing. To prevent this I generally get an assistant to hold along wooden roller near, upon which the copy is placed. If a line or figure has been left out by mistake on the original drawing before being copied, the same can be produced upon the printed copy by using a solution of soda and water. To obtain blue lines on a white ground by this process, a negative must first be made, which is accomplished by placing in the printing-frame the drawing, with the back against the glass; then place over the drawing a piece of special ferro-prussiate paper (thin) prepared for the purpose, with the smooth surface against the face of the drawing, close the frame, and expose to the light. The process of the negative print is rather difficult to verify and check; therefore, in this process the use of a second frame as a test frame will be found very useful. The negative print should be exposed at least three or four times as long as that by which white lines on blue ground are produced. The negative print, after proper exposure, should be washed in clean water, and dried as before mentioned. If this be properly done, the print when finished should show a clear dark blue on being held up to the light.

The negative print is then placed in the printing-frame with the rough side against the glass, and thereon a piece of ferro-prussiate paper (the same as used for producing white lines on blue ground), with the prepared side against the negative—the exposure and operation to be the same as if producing white lines on blue ground. The copy thus treated will, when finished, have blue lines on white ground. I may also say the special negative paper can be used for producing white lines on blue ground by the following procedure as in the first instance.

Very pleasing pictures can be made by printing from negatives with this paper, which can be obtained ready prepared. If any one choose to prepare his own paper, he can do so by the use of the following formula:

| | Parts. |
|-----------------------------------|--------|
| Ammonia citrate of iron | 1 |
| Water | 5 |
| Ferricyanidine of potassium | 1 |
| Water | 4 |

Mix together in equal quantities.

I now come to the process for producing dark blue lines on a white ground. The advantages of this process are many. It can be worked in all weathers, and requires no dark room. Copies can be colored and varnished, altered and corrected, and last, but not least, they do not fade.

There are five distinct operations, viz.: 1st, exposure in the printing-frame; 2d, developing of copy in yellow prussiate solution; 3d, washing in first water tray; 4th, bleaching in acidulated bath; 5th, brushing and flushing in second water tray, and finally drying.

The glass in the printing-frame should be very clean and bright. Place the drawing to be copied in the printing-frame, and upon it a sheet of the sensitized paper, put the felt over all, and smooth outwards from the center with both hands, close the frame, and expose to the light. The time of exposure varies with the seasons of the year, state of the atmosphere, and quality and intensity of the light. In the sunlight in summer it only requires a few seconds, in the shade a few minutes, but in foggy and dull weather in winter half to three-quarters of an hour. The exposure can only be determined by constant practice and test slips. The test slips should be placed in the printing-frame alongside the tracing being copied. These small test slips are inserted so as to be about two-thirds inside and one-third outside the frame at the back. They can then be conveniently drawn out without opening or disturbing the print. The frame must be exposed to the direct action of the light, and no shadow allowed to fall on it. After a time, one of the test slips is drawn out and dipped in the prussiate solution, and its chemical action watched for from 40 to 50 seconds. Should the background remain perfectly yellow, and the lines come out blue, the exposure has been sufficient. During the testing the frame must be turned face downward, or otherwise screened from the light.

It is not necessary to develop the copies immediately after exposure, therefore all the printing might be done while the light is strongest, leaving the development until the evening or the following day. After exposure, the copy should be placed face downward on a board, and the edges turned up carefully, so as to form a sort of tray, three-quarter inch in depth. This renders the sheet more easy of manipulation, and leaves the back white when developed in the prussiate bath. The copy is now placed face downward, and floating on the prussiate bath for about thirty seconds. The operator should see that uniform contact takes place everywhere while in the solution; raise the copy,

* By Mr. T. Scotton. Abstract of a paper read before the Derby Photographic Society.

* Transactions New England Cotton Manufacturers' Association, Fifteenth Annual Meeting, p. 61.