THE DESIGN, BUILDING AND TESTING

of

A NEW TYPE HYDRAULIC DYNAMOMETER

A THESIS SUBMITTED TO

THE FACULTY OF

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By

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Introduction -

In the testing of the draft developed by horses in connection with the use of various farm implements, the problem presents quite a wide range of conditions. The work required may be light, calling for one or two animals; or it may be fairly heavy, requiring a 4 or 6 horse team; or again, as out in the Palouse Country of Eastern Washington, the plowing is commonly done by an 8 or 10 horse team, while the combine harvester is usually pulled by a great outfit of 24 to 30 horses. These conditions call for a dynamometer of too wide a range for accurate results under all conditions of load.

The idea came to the writer that a small dynamometer might be built that could be easily handled and quickly connected at the one tug of a horse or a single tree. If the system of eveners were properly balanced, as they usually are, one could readily secure the average total power developed by the horses, no matter how many happened to be hitched together. By this arrangement, an instrument capable of testing the draft of one horse could with the multiple hitch give the total draft of all

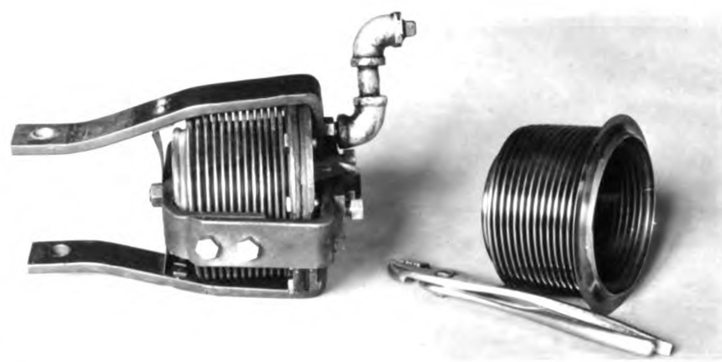


Figure 1

the horses pulling the load.

The Dynamometer -

It was decided that a hydraulic dynamometer with a recording gage carried beside the driver, might best meet the conditions of Eastern Washington. A bellows, such as is used for draught control on some types of steam furnaces, was selected as offering the most likely method of transferring the draft to liquid pressure, without loss of the liquid used. The dynamometer shown in the accompanying photograph, (Figure 1) has been completed, tested, and calibrated. All the work was done by the writer.

The dynamometer was so designed as to take up the minimum space between the evener and single tree. It dispenses with the usual ring between these two parts, so that the single tree connected to the instrument is moved ahead 2 or 2½ inches as compared to its usual position.

The bellows (B) is 4 3/8 inches outside diameter and 3 inches deep (Figure 2). The open end is tightly closed by a 5/16 by 5 3/16 inch circular steel cover plate, packing, and a flat ring an eighth of an inch thick; these parts being securely held together by 10 - 5/32 inch round head stove bolts. The circular plate is connected to the evener by two pieces of 5/16 by 1 1/4 strap iron 7 5/8 inches over all, swinging on a vertical steel bolt which passes through the hole in the end of the double-tree. A 5/16 cap screw and nut at the center of the closed end of the bellows supports a yoke of 5/16 by 1 1/4 strap iron which is made in two parts, fastened together by 2 - 5/16 inch cap screws on either side. To the side of this yoke farthest from the

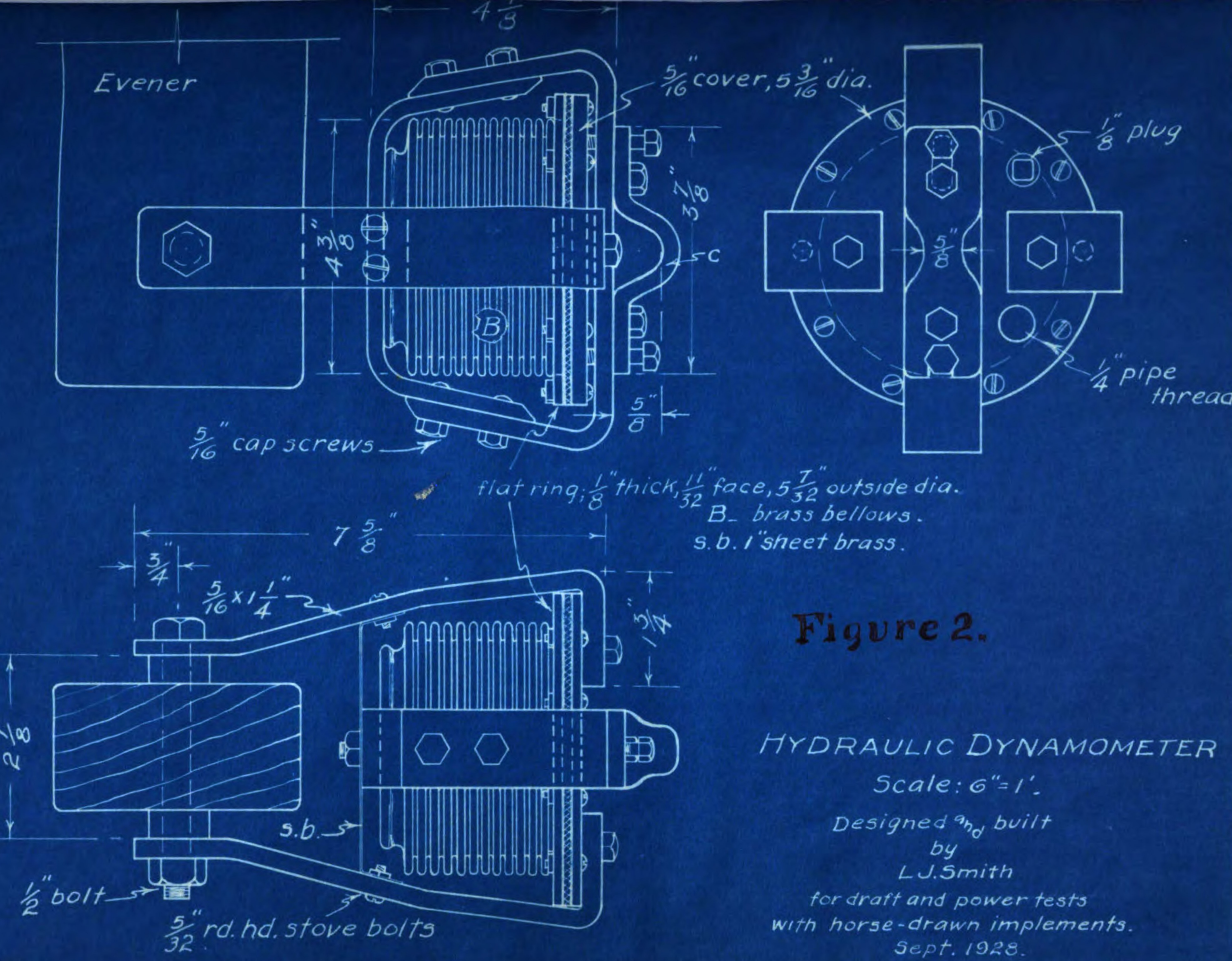


Figure 2.

HYDRAULIC DYNAMOMETER

Scale: 6" = 1'.

Designed and built
by
L.J. Smith
for draft and power tests
with horse-drawn implements.
Sept. 1928.

evener, is fastened a stirrup 3 7/8 inches long. The two inner cap screws hold the stirrup in place. The single tree is connected to the stirrup where it narrows down to 5/8 inches in the center. The two outer cap screws pass loosely through the ends of the stirrup and are screwed into the 5/16 inch circular cover. They act as stops, preventing the bellows from being compressed so far as to bring the gage pressure above its maximum of 25 pounds per square inch.

In preliminary tests, it was found that the left end of the bellows sagged when under a horizontal pull and threw the corrugations of the bellows out of line, thus producing a strain on it. To overcome this lack of alignment, a light piece of sheet brass, an inch in width (s-b), was fastened to the left end of the yoke and also to the strap irons connecting to the eveners, with enough curve at each end so that the arrangement did not affect the free movement of the bellows.

Two holes were drilled and tapped in the 5/16 inch cover plate, - one for filling with oil, and the other for attaching the flexible tube to the pressure recording device. A Bristol Recording Pressure Gauge was used for this purpose. The chart is graduated to half pounds, the maximum pressure being 25 pounds per square inch. The gage clock was ordered to be geared to make the chart turn once an hour, but no chart was available with that type of graduations; so a 24 hour chart had to be used. A one hour period on the chart is, therefore, equal to a 2½ minute period, a very satisfactory speed for draft tests.

Preliminary Tests

A wooden frame weighing 27½ pounds was built to hang underneath the dynamometer for supporting the weights used in testing and calibrating the instrument. The weights used were whole and half concrete building blocks.

For the first trial, the bellows of the dynamometer and the connections to the recording pressure gage were filled with kerosene with about 25% No. 5 Zerolene. It was found difficult to retain this liquid under pressure. The leaks though small, eventually caused the frame of the bellows to come up against the two stop cap screws.

The kerosene solution was, therefore, removed and extra heavy Shell Oil (a Western oil) was used in its place. A good deal of care was exercised in order to remove all the air. Then the dynamometer was loaded and corresponding records made on the chart as shown in Figure 3. During these tests the needle valve was wide open. The temperature of the room where the tests were made was 80½°F. Record "a" shows the first test. The chart makes one complete revolution in one hour instead of 24, so that a 1 hour interval as shown on the chart represents 2½ minutes. The dynamometer was loaded 17½ pounds, then 61 and finally a 62 pound block was added, making a total load of 140½ pounds. It will be noted at once that there was a considerable resistance to a rapid transfer of the pressure from the dynamometer to the gage. The record shows that it took at least 2½ minutes (4 divisions) for the pointer to cease its outward movement. On the 61 pound increase, the period was still longer, -- about 7 divisions or nearly 4½ minutes. With the 62 pound increase in load, the time was at least 7½ divisions or nearly 5 minutes. Another test immediately following the first showed time intervals of 5, 8, and 5½ minutes. Obviously, this arrangement takes too long to record the changes in pressure for a draft recording instrument for farm implement test. Such an instrument, however, should

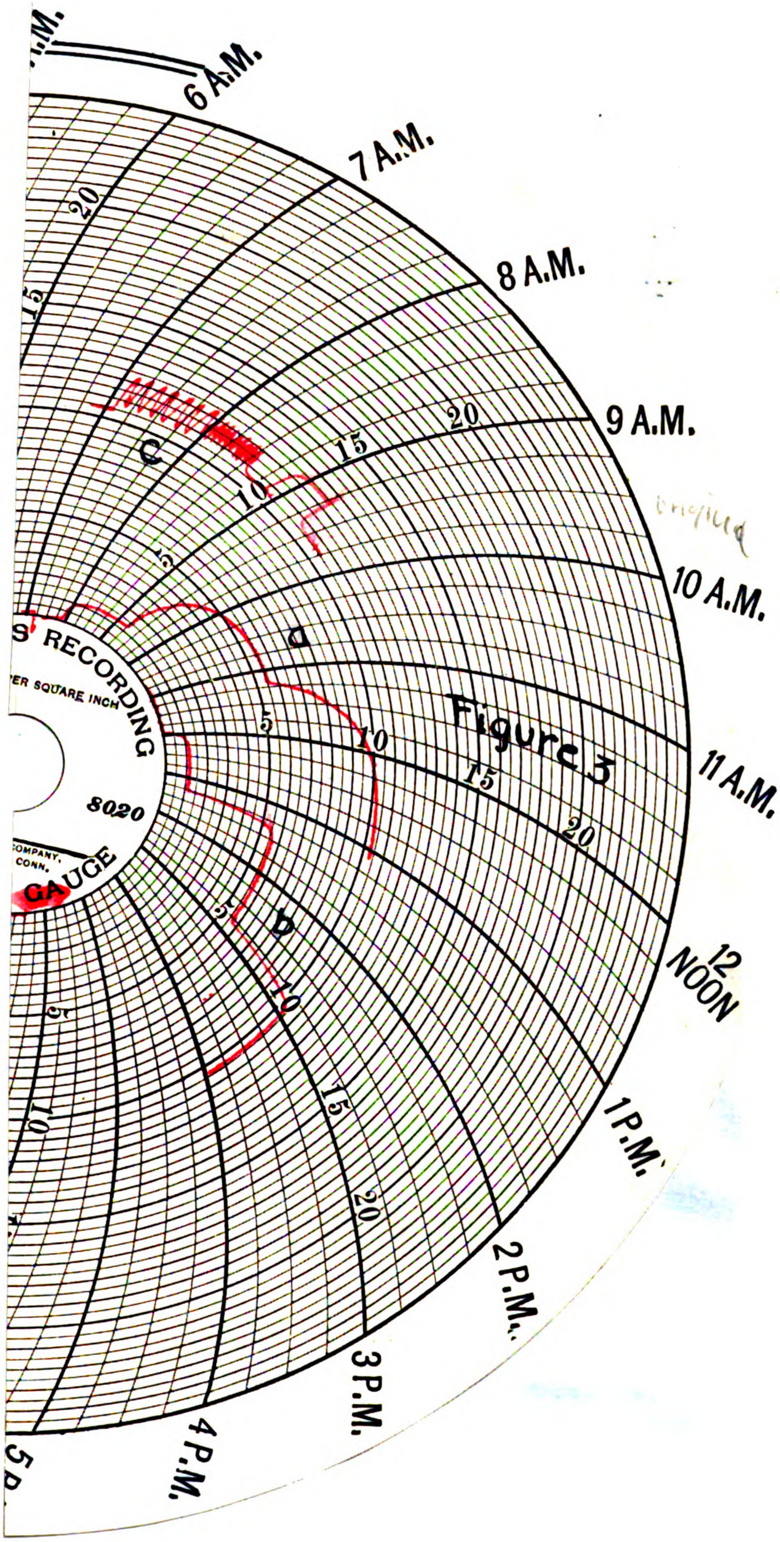

6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
S' RECORDING
PER SQUARE INCH
8020
GAUGE
Figure 3
a
b
c

Figure 3.

have a considerable "lag" in order to smooth out the excessive vibrations, because of the momentum of the moving parts of the recording device.

The 6 inch Bristol flexible damping coil, which was just below the needle valve, was next removed, leaving only the 6 feet of flexible alemite armored hose between the dynamometer and the needle valve next the recording gage. Then another series of tests were made as shown by "b" with increments of 17½, 61, and 62 pounds as before. The action of the ink pen was much more rapid. The successive increases were recorded in about one division each, or possibly less or in 35 or 40 seconds, but 2/3 of the resultant movement took place in about 1/5 of a division or 7 or 8 seconds.

Then an additional weight of 25 pounds was used, increasing the load for approximately 10 seconds, then taking the weight off for 10 seconds; continuing this process a number of times as shown at "C". It will be interesting to note that the outer points came almost to the same height as that shown later when the 25 pound load was left on continuously; but the inner points lacked about ½ of a division from coming down to the line recorded when the 25 pound weight was removed.

Then the 25 pound weight was put on for 5 seconds and removed for intervals of about 5 seconds. With the shorter interval of fluctuation, the movement of the recording pen was cut down to a little over 2 divisions or a variation of about 14 pounds pressure. It would appear, therefore, that the resistance to the rapid flow of this grade of oil in the alemite tubing is sufficient to satisfactorily cut down undue fluctuations at the recording pen so that a quite accurate record of widely and rapidly fluctuating loads could be made. The needle

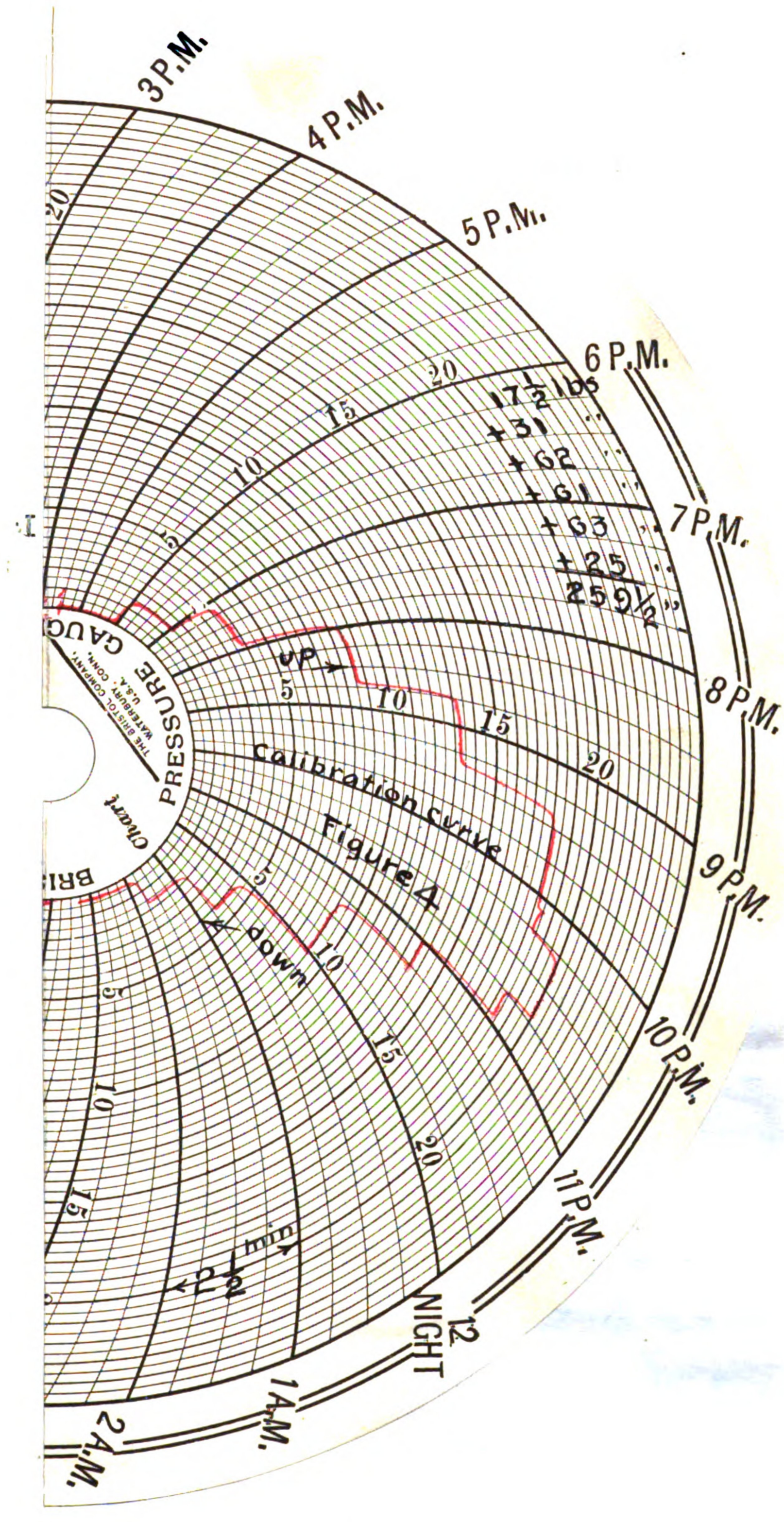

3P.M.
4P.M.
5P.M.
6P.M.
7P.M.
8P.M.
9P.M.
10P.M.
11P.M.
12 NIGHT
1A.M.
2A.M.
PRESSURE GAUG
Chart
17½ lbs
+31
+62
+61
+63
+25
259½"
Up
down
Calibration curve
Figure 4
2½ min

Figure 4.

valve still can be used in cases of extreme fluctuations. It should also be noted that the average of the 5 second fluctuations records a little higher than the average between the curves when the 25 pound load was on and off,--but not more than 1/3 of one division or 2 pounds, at the greatest, on the draft. These variation load tests show that as the load fluctuates more rapidly the pen movement becomes smaller, a desirable condition tending to the securing of more accurate records of draft tests of farm implements.

Calibration of Dynamometer

Using in succession the weights, - 17½, 51, 62, 63, and 25 pounds the calibration curve was secured as shown on the chart, Figure 4. The total of 259½ pounds gave just 20 pounds per square inch on the recording gage, or a draft of practically 13 pounds draft per pound pressure as recorded on the gage chart. Then the weights were taken off one at a time in the reverse order to that in which they were put on. It will be noted that there is a "lag" as the pen does down, averaging one quarter of a pound, gage pressure. This is due to the fact that increased pressure at the bellows acts quickly, while the bellows and light brass spring have a lighter pull tending to bring the pen toward the zero line. The resistance of the oil to the return to normal on the part of the bellows causes a uniform lag on the part of the recording pen. The calibration curve (Figure 5) is taken from the upward record on the chart (Figure 4). The temperature of the room was similar to that when the preliminary tests were made, a little over 80°F. The plotted curve is almost a straight line, showing that all air had been removed when the oil was put in the dynamometer and connecting parts;

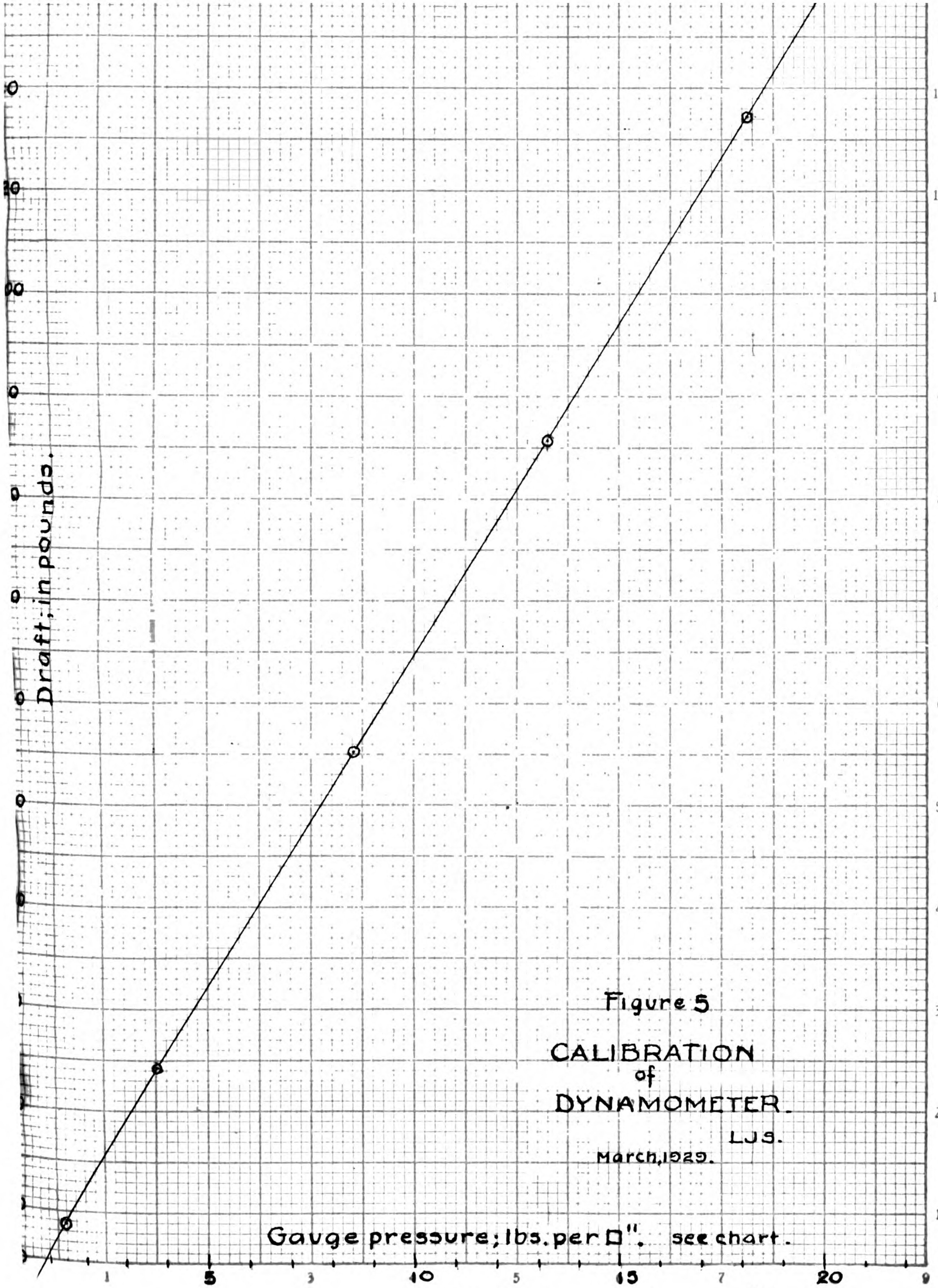


Figure 5

CALIBRATION of DYNAMOMETER.

LJS.

March, 1929.

and that the bellows did not spring out radially. This latter point was also checked at the time of the calibration test by holding a straight edge across the corrugations of the bellows.

In view of the fact that there was an average downward "lag" of 1/4 of a pound per square inch, a reduction should be made from the calibration curve. Since when there is constant vibration of the pen point with the upper end of these vibrations reading accurately, and the lower end of the vibration 1/4 of a pound high, the average of these upward and downward movements would be 1/8 of one pound pressure per square inch too high, or 1 5/8 pounds on the draft. It seems sufficiently accurate to call this 1 1/2 pounds and deduct this amount from the average pull as taken off the calibration curve.

<u>Draft Test on Seeder</u>

The first actual test of the dynamometer under field conditions was with an 8 ft. I.H.C. double Disk Drill with two tongues and the standard I.H.C. 4 horse hitch. The equipment was new and the evener parts unworn. The writer had not seen the drill before going to the field,--in fact did not know the make; but in a little less than six minutes after the machine was stopped, it was ready to make the draft test, the teamster helping. A one inch oak upright 30 inches long was fastened to the side of one of the tongues with 2 - 3/8 inch lag screws. A clamping device was also provided for emergency use in case the upright had to be fastened to metal. The recording gage (weight 15½ lbs.) was swung a few inches clear of the upright, being suspended by a quite flexible spring 1 inch in diameter and 3½ inches long. Another smaller horizontal spring was attached to the upright lower down, and fastened to

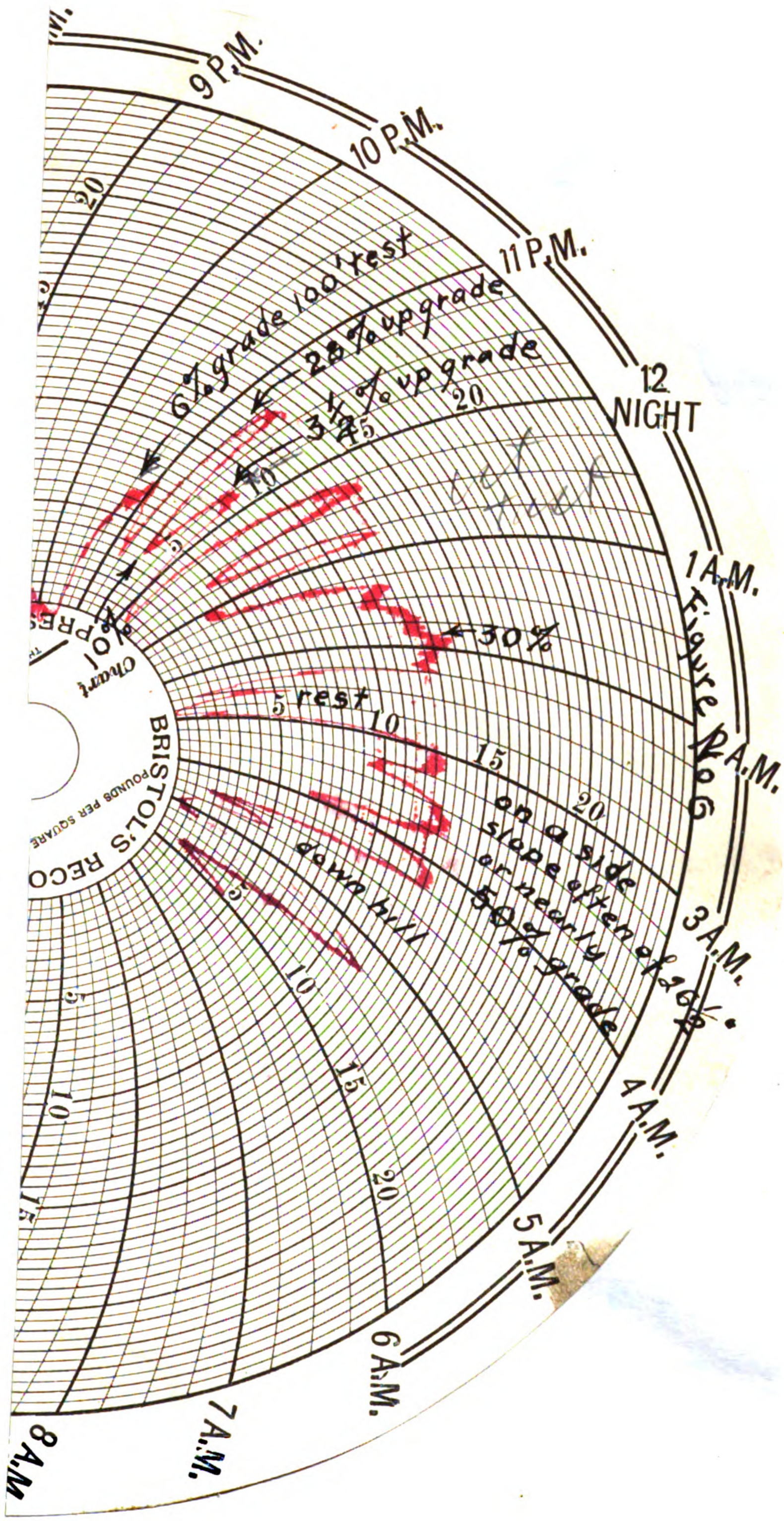

9 P.M.
10 P.M.
11 P.M.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
BRISTOL'S RECO
POUNDS PER SQUARE
6% grade 100' rest
28% upgrade
14% upgrade
30%
rest
on a side slope often of 36%
or nearly 50% grade
down hill
Figure No 6
10% Chart

Figure 6.

the back of the gage to prevent its bumping and swinging unduly. By this arrangement, the instrument moved freely with the movements of the drill, so that the pen was not disturbed in its accurate function by outside influences.

The ground which was being sown to wheat, was very irregular, and therefore not given to the securing of a uniform record of draft. The conditions made a rather severe test on the apparatus. There were no level stretches; but 2 - 100 ft. runs were laid off, both of quite uniform slopes, the first having a 6% downward grade, and the other a 3½% upgrade. Between these two runs was a short knoll whose maximum upward slope was a bit over 28% grade, and whose greatest downward slope was 10% grade. Farther on the upgrade was a little over 30%.

On the 6% down grade the draft on the one horse in front of the dynamometer was around 6 pounds gage pressure or only 78 pounds per horse. (Figure 6) On the 28% upgrade, it was a maximum of 12 3/4, or about 166 pounds draft. The 3½% upgrade gave 8 1/4 or about 107 pounds on the single tree. On the level, the draft would have been a little under 100 pounds per horse, but there is not much level land in the famous Palouse Country. The maximum draft on the 30% upgrade was 14 x 13 or 182 pounds, — a good load where the horses are lifting themselves up a 30% grade, — and on loose land.

On the steep side slope, where the team partly followed the contours, the side supporting spring was not sufficient to keep the recording device away from the upright support. Here the writer was forced to walk just to the right and in front of the high drill wheel, and with a stiff wire keep the gage away from the standard, — a rather difficult job, so that on the 2nd. test around (used in the 2nd. copy of the thesis) because of bumps the pen arm shifted slightly at its joint and lowered the zero reading nearly one pound. A better horizontal spring support for the gage, will overcome this little difficulty. The day was warm (about 70°F) and windy.

The oil and the 6 ft. alemite connection ironed out the extreme vibrations at the bellows so that the curve on the chart was not a widely fluctuating one. The needle valve was wide open.

<u>Draft Test on Plow</u>

The test plots of the Agricultural Experiment Station are on one of the few fields where a fairly uniform slope is to be had. It was here, therefore, that the writer wished to make the plow test; but this had to wait the finish of the spring seeding on the College farm.

The plow used in the test was a two-way 14 inch John Deere plow. The furrows were all turned down the slope, while the plowing was done across the slope. Two horses were used to pull the plow. Figure 7 shows the dynamometer and recording gage in position. The ground was not level with the furrows, but had about a 6% upgrade at the beginning (going west), then it was flatter and in two places nearly level, while the far end of the furrow was a longer up-slope nearly as steep as at the beginning. The furrows were 380 feet long.

Figure 8 shows the second chart taken. The first few rounds showed too much ink in the pen. The plowing was on wheat stubble land. It will be noted that the draft records of all of the plowing towards the west were higher than when the plowing was toward the east, which was on the average down slope.

The lower draft records, between the east and the west records were taken while the horses were turning at the ends of the furrows.

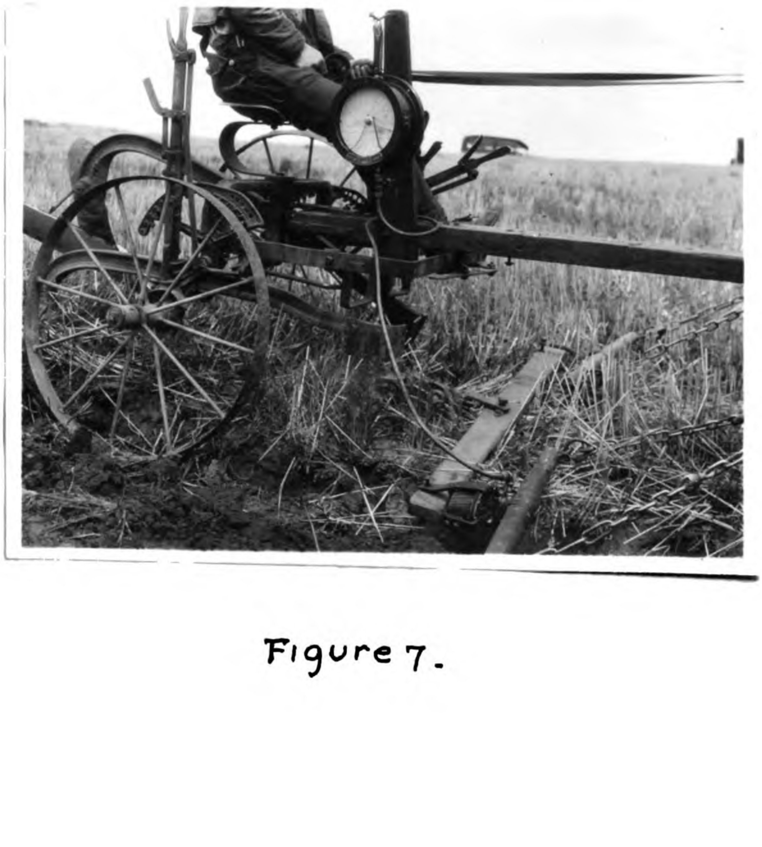


Figure 7.

Not often did the pen get down to the zero reading.

Beginning with the west record between 3:00 and 4:00 P.M., and continuing on through the test, the dynamometer was taken from the upright and carried by hand to see if this would make any difference in the vibration registered on the chart. It appears that the amount of ink in the pen is the greatest factor. Keeping the pen partly filled and adding more ink at frequent intervals gave the best results. This is well illustrated in the 4:00 - 6:00 P.M. records and in the 10:00 - 12:00 P.M. records. The dynamometer gave a very satisfactory record of plow draft, as compared to the records taken with the Schaffer & Budenberg Dynamometer, a sample of which (taken by the writer in Manitoba, Canada) is shown. In this test two compression springs were used to help flatten out the vibrations. With the Schaffer & Budenberg instrument the distance between the maximum and minimum draft vibrations was often as great as one-third of the total average draft recorded.

Other Possible Uses

While the dynamometer was designed primarily for draft tests with farm implements, and will be used in experiments along these lines at the State College of Washington, it would appear that a modification of the principle might have a wider range of usefulness. It could be employed to record the time and amount of quite a variety of movements. These movements would not necessarily have to be accompanied by a corresponding variation in pressure. Two of these bellows, or smaller diameter bellows might be bolted together in order to secure a wider movement. One end could be held stationary and the other attached directly to the fluctuating part or to a reducing or increasing lever

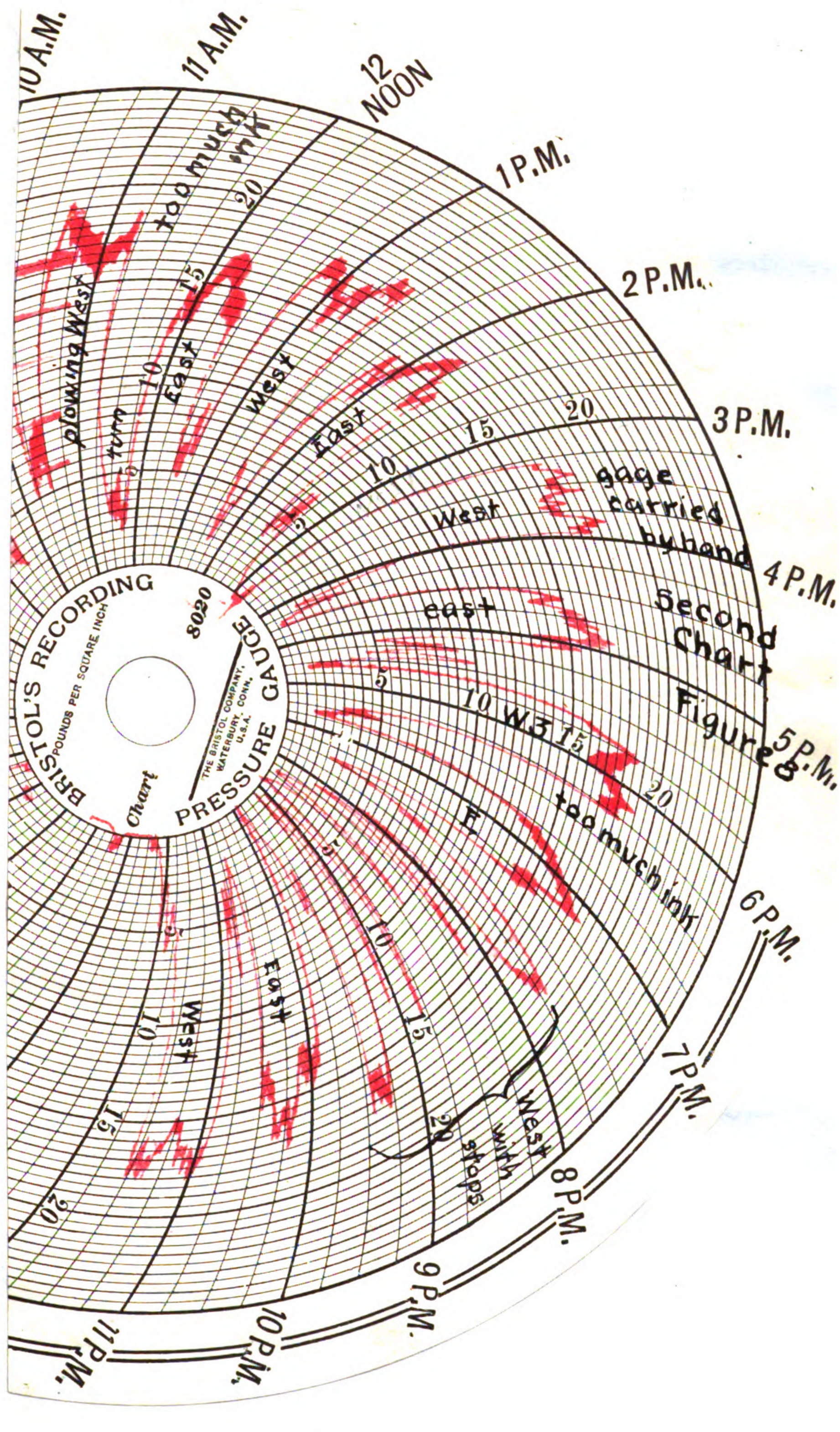
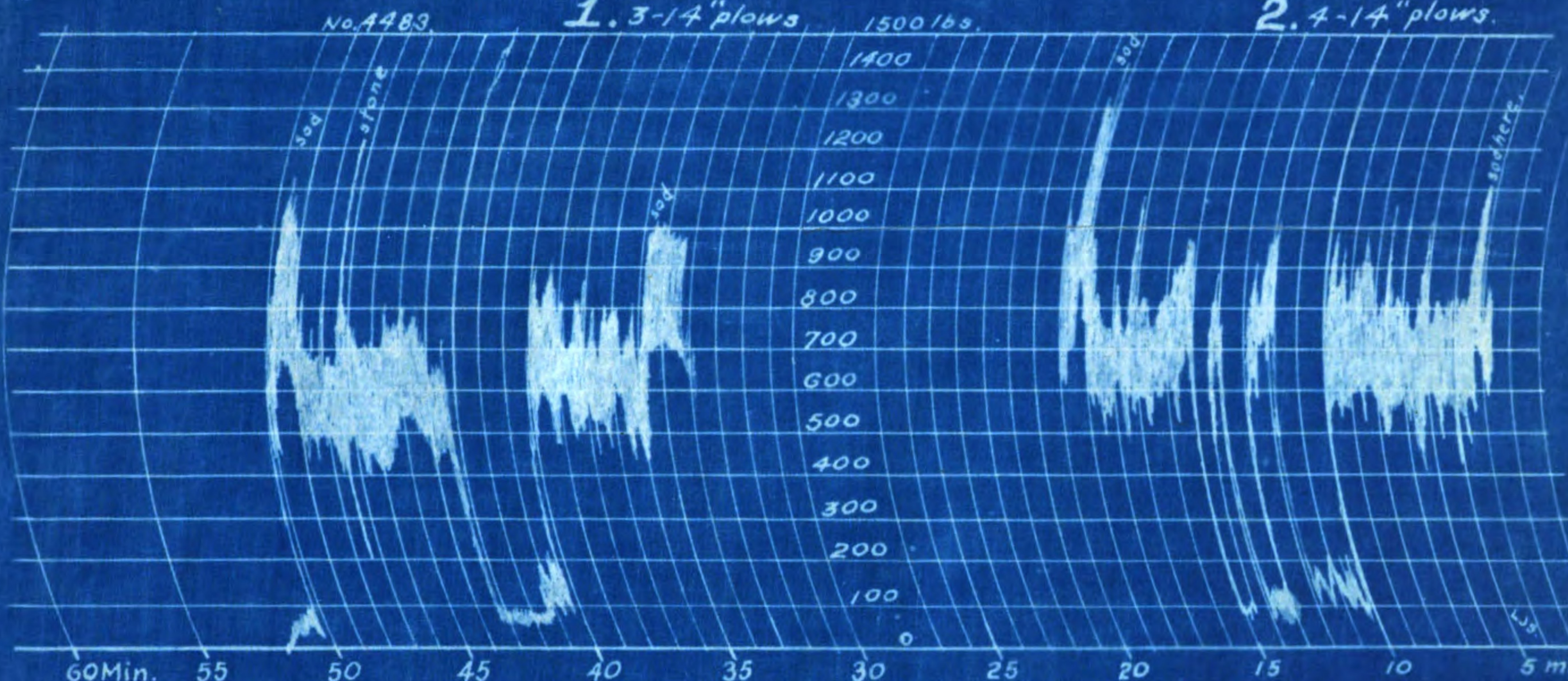

10 A.M.
11 A.M.
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
BRISTOL'S RECORDING PRESSURE GAUGE
POUNDS PER SQUARE INCH
8020
THE BRISTOL COMPANY, WATERBURY, CONN. U.S.A.
Chart
too much ink
plowing West
turn
East
West
East
West
gage carried by hand
east
Second Chart
Figure 8
W3
E
too much ink
West
East
West with stops

Figure 8.

arrangement attached to the moving part or resting against it. Any movement (within limits) could be recorded, both as to time and amount. Such an arrangement might, for example, be used to record the times that a platform scales was used to weigh objects, and the amount of each weighing.



Note: This chart shows half the draft for the plows.

Schaffer & Budenberg Dynamometer Chart of plowing on stubble land in Manitoba, shewing fluctuations where 3 & 4 plows are tractor drawn. Springs of two different strengths were also used to help reduce pencil variations.

L.J.S.

Figure 9