THE RAILROAD DYNAMOMETER CAR
OF THE UNIVERSITY OF ILLINOIS AND
THE ILLINOIS CENTRAL RAILROAD

BY

JOHN K. TUTHILL
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# CONTENTS

## I. INTRODUCTION
1. Purpose and Scope of Circular .......................... 5
   2. Historical Development .................................. 5
   3. Dynamometer Car No. 609 .................................. 6
   4. Dynamometer Car No. 17 .................................. 7

## II. PRESENT CAR AND BASIC EQUIPMENT
5. Dynamometer Car No. 30 (1943) .......................... 11
6. Dynamometer ............................................... 13
7. Types of Cars ............................................ 16
8. Drawbar Pull Recorder .................................... 16
9. Calibration of Drawbar Pull Recorder ................. 17

## III. AUXILIARY EQUIPMENT
10. Recording Table ......................................... 19
11. Recording Table Drive .................................. 19
12. Recording Table Gear Box ............................... 20
13. Paper Travel ............................................ 20
14. Recording Pens ......................................... 21
15. Recorder Apparatus ..................................... 21
16. Recorder Chart Record .................................. 22
17. Time Record ............................................ 24
18. Water Record ............................................ 25
19. Coal Record ............................................. 25
20. Engine Data .............................................. 26
21. Telephone to Locomotive ................................ 27

## IV. WIND DIRECTION AND VELOCITY
22. Wind Direction .......................................... 28
23. Wind Velocity ........................................... 28
24. Determination of Absolute Direction and Velocity 28

## V. SPEED AND OTHER RECORDS
25. Speed Recorder .......................................... 30
26. Indicator Card Record .................................. 30
27. Mile Post Record ....................................... 30
28. Brake Cylinder Pressure Record ....................... 32
29. Integrator ................................................ 32
30. Direct-Current Selsyn Equipment ..................... 33
31. Recorder Paper and Ink ............................... 34
THE RAILROAD DYNAMOMETER CAR OF THE UNIVERSITY OF ILLINOIS AND THE ILLINOIS CENTRAL RAILROAD

I. INTRODUCTION

1. Purpose and Scope of Circular.—This Circular of the University of Illinois Engineering Experiment Station presents a history of the development of University of Illinois railway dynamometer cars over a period of nearly half a century from 1898 to 1947. In addition it describes many pieces of equipment and gives instructions for the care, operation, and calibration of most of these.

Intended in the first place to serve as a guide in training operators for car No. 30—the University's present dynamometer car—the Circular can with a few alterations be made to apply to any dynamometer car, whether used for obtaining data on train resistance values, on tonnage ratings, or on locomotive testing. The Circular contains a number of suggestions which will prove useful to anyone who contemplates the designing, building, renovating, and equipping of a railway dynamometer car.

A companion publication is Bulletin No. 376 of the University of Illinois Engineering Experiment Station. Scheduled for appearance soon after this Circular is issued, the Bulletin presents values of freight train resistance at train speeds of 40 to 70 mi. per hr. and also includes curves relating to lowspeed train resistance values. Since Bulletin No. 376 deals with results only, those interested also in the equipment and investigative methods will find the present Circular a necessary supplement to the bulletin.

2. Historical Development.—The study of train resistance dates back to at least 1836, when Pambour's *Locomotive Engines* described tests made to determine the pull necessary to move railroad trains. The dynamometer used, a separate piece of apparatus placed between the tender and the train, was a simple spring balance which gave a very poor indication of drawbar pull. In 1862 P. H. Dudley, a civil engineer and an authority on the economics of train operation, offered several fundamental suggestions regarding the efficiency of train operation at different speeds. To demonstrate and prove many of his theories, in 1874 he designed and built a dynamometer car which may be considered one of the first of its type. The recorder (Fig. 1), called a dynagraph, possessed many of the features of the most modern dynamometer cars.
In addition to the dynamometer an elaborate system of apparatus was installed to record conditions of the track.

The locomotive pull was registered on a chart, driven from one axle of the car, through a hydraulic cylinder attached to the underframe of the car. The cylinder was equipped with two pistons, one to measure buff and the other pull. Besides drawbar pull the graphic records made on the 30-in. chart were speed, work, time, coal, water, and condition of the track. Apparatus for making gas analysis was provided.

3. Dynamometer Car No. 609.—The University of Illinois became interested in the railroad dynamometer car and in locomotive testing when in 1898 car No. 609 (Fig. 2) was built by the Peoria and Eastern Railway (now a part of the New York Central System) and equipped by the University. Like Dudley’s dynamometer car, No. 609 was equipped with hydraulic apparatus — entirely separate from instruments for train resistance measurements — for inspecting track conditions. It autographically recorded the character of the surface and of the joints of each rail, the deviation from gauge, and the supereleva-

4. Dynamometer Car No. 17.—This car (Fig. 3) was built in 1900 by the Illinois Central at its Burnside Shops and was equipped by the University. In 1907 it was rebuilt, steel girders were added to reinforce the wooden center sills, and a new set of recording apparatus was provided.

Fig. 1. Dudley’s Dynagraph

Fig. 2 (Above). Dynamometer Car No. 609
Fig. 3. Dynamometer Car No. 17 (1900)
designed, built, and installed. At this time, also, an auxiliary truck (Fig. 4) was mounted under the car body, the wheels of which when lowered to the rails would cause the record chart to move proportionally to the speed of the train or, to speak more accurately, to the distance traveled. The car number was changed in 1922 to No. 22 and later to No. 30, by which the car is now designated. In 1937, just before the beginning of the tests reported in Bulletin 376 of this Station, the car was again overhauled. The underframe was heavily reinforced with steel, the auxiliary truck removed, and the recorder driven by an axle-gear assembly applied to one of the car axles. The wheels of the driving axle were given a cylindrical tread. Figure 5 is an exterior and Fig. 6 an interior view of the car; Fig. 6 shows the Leeds and Northrup Micromax potentiometer-type speed recorder installed in 1937.

The old car is described in Bulletin 43 of this Station. The changes made in 1907— including methods of strengthening the underframe— were set forth in detail by F. W. Marquis in the Railway Age Gazette of February 19, 1909. A report on the car and equipment built in 1907 as well as on car No. 609 is in the Proceedings of the Pacific Coast Railway Club for November 16, 1901, under the title "The Dynamometer Car and Its Uses."
II. Present Car and Basic Equipment

5. Dynamometer Car No. 30 (1943).—The new car (Fig. 7), built by the Illinois Central at its Burnside Shops, is 60 ft. long and 8 1/2 ft. wide and weighs 62 1/2 tons. Of heavy steel construction, it is built and equipped to operate in any type of train service. The interior is divided into three sections, shown in Fig. 8. At the front a 21-ft. operating room contains the recording table and all testing apparatus, desk, tool bench, supply cabinet, and an electrical locker (Fig. 9). This
locker, behind the recorder operators, contains in turn all electrical circuit terminals, control switches, and protective circuit breakers and fuses. All circuits from the recording table, cable running to the locomotive, and wire connections to other parts of the car terminate on panel boards in this locker—an arrangement that permits quick and easy shifting from one piece of apparatus, or one circuit, to another.

A specially built locker for holding a supply of recording paper and the completed charts is shown in Fig. 10. The top of this locker is used as working space on which to unroll the record charts when data are to be obtained from them. It also serves as a place to put indicating and recording equipment for special tests. In Fig. 10, furthermore, is given a view of the front of the operating room. Some special equipment is shown, consisting of a 12-element magnetic coil type of oscillograph, 100-ohm decade resistance box for the oscillograph galvanometers, a power unit, and a cathode ray oscilloscope. All are mounted on a 2-in. shock-absorbing cushion of hair felt and are used in connection with General Electric electric pressure gauges for measurement of pressures in the cylinders of a steam locomotive, from which engine indicator cards are constructed.

Behind the operating room and connected to it by a passageway are two staterooms, each equipped with sleeping accommodations for four men, with overhead lockers for bedding and lower space for the crew's personal effects. Removable tables permit the staterooms to be used as workrooms.

Ample clothes lockers for the personnel of the car, a shower bath, lavatories, and a toilet room occupy the next section, above which are five gravity water storage tanks whose combined capacity, 600 gal., suffices for all needs.

The rear end section contains a kitchen with charcoal range, sinks, icebox, and food lockers. Metal surfaces are of stainless steel. Overhead lockers hold extra dishes, food, and supplies. Also located in the kitchen section is an oil heater to heat the car and provide hot water for dishwashing and toilet use. Beside the heater, and enclosed in a semi-airtight and soundproof compartment, is a Diesel-driven 32-volt d-c. generator which furnishes power when the car is on a siding or operating in such slow-speed service that the axle light generator cannot keep the 32-volt car lighting battery charged, or when a constant voltage is desired during special tests. Two sets of louvers are provided in the engine generator cabinet whereby air is drawn in from the outside, forced over the engine, and exhausted to the outside of the car. The louvers are kept closed when the engine is not operating.

While the car is not air-conditioned at present, it is heavily insulated and is provided with numerous electric fans and ventilators which make for comfortable operation except in the hottest weather. Plans have been discussed for installing an air-conditioning system on the car or placing small cooling units in the staterooms and perhaps the operating room.

6. Dynamometer.—The dynamometer, or apparatus for measuring the pull of the locomotive, is the most important piece of equipment on the car. The new car, like the old one, uses a volume of oil to transmit the drawbar pull to the recording instruments. In fact, the hydraulic cylinder from the old car was removed and was riveted to the heavy underframing of the new, immediately behind the drawbar yoke and in line with it.

The details of the cylinder are shown in Fig. 11. Its inside diameter is 10 in., its piston length 7½ in. Both piston and cylinder
are ground to an exact fit and no piston packing or rings are used. The pull is transmitted from the drawbar yoke to the piston through a heavy roller-borne yoke, and the whole device is practically frictionless. A slight leakage of oil does take place around the piston, but it serves to properly lubricate the surface between cylinder and piston and proceeds so slowly as to be no inconvenience, even under maximum drawbar pull. The leakage oil flows to a driptank and later is returned to a supply tank by air pressure. Oil from the supply tank is returned to the hydraulic system by means of a hand pump when the train is at rest or when moving downgrade and exerting no drawbar pull. However, the cylinder may be refilled while the car is in operation without impairing the accuracy of the record. The oil in the hydraulic system varies from S.A.E. 20 for cold weather use to S.A.E. 50 for operation in the hottest summer weather.

Figure 12 is a schematic diagram of the drawbar pull apparatus with the valves controlling the movement of oil throughout the system. Once a season or when weather conditions require change in oil, the oil supply tank is filled from an opening on the roof of the car. The whole oil system may be drained from the driptank; the oil from other parts of the drawbar pull apparatus either drains by gravity to the driptank or is forced into it by air pressure.
7. Types of Cars.—The main difference between the University-Illinois Central car and most others of the same kind that are used on American railroads is in the manner of transmitting locomotive pull to the recording instruments. As mentioned, car No. 30 has an oil cylinder attached rigidly to the underframe and in line with the drawbar. When pull takes place on the drawbar, a piston is forced into the oil-filled cylinder, and the oil pressure is transmitted to the small cylinder of the drawbar pull recorder. No arrangements have been made to record buff or shock. When backing up, the yoke connected to the draft gear moves backwards over the pull rod, thereby relieving piston and cylinders of unwanted shock. Most other dynamometer cars have a vertical lever whose fulcrum consists of bearings rigidly fixed to the car frame. The lower end of the lever is attached to the drawbar draft gear, the upper end to two pistons—one for measuring drawbar pull, the other buff. Oil transmits pressures to pull and buff recorders.

8. Drawbar Pull Recorder.—Because of a drawbar pull the pressure of the oil in the cylinder underneath the car is transmitted to a small cylinder of a special indicator attached to the recording table in the operating room. In design the indicator is identical with one of the modern types of outside-spring steam engine indicators, though larger and heavier throughout. Figure 13 shows the recorder and springs.

![Fig. 13. Drawbar Pull Recorder and Springs](image)

Three sizes of cylinder bushings are used in order to adapt the recorder to various types of locomotives and different train weights. The bushings are provided with pistons ground to an exact fit, and are 3/8, 1, and 1 1/2 sq. in. in area. Five springs, available and easily applied to the recorder, are rated at 100, 150, 300, 500, and 700 lb. The spring ratings mean that a dead weight of 700 lb. suspended from the 700-lb. spring would elongate it 1 in. A 1-in. movement of the small piston and spring of the recorder would cause a 6-in. movement of the drawbar pull recording pen.

By the use of different combinations of springs and cylinders it is possible to obtain a long ordinate of drawbar pull whether the train consists of one car or 200 loaded coal cars.

9. Calibration of Drawbar Pull Recorder.—The accuracy of the drawbar pull recorder depends greatly upon the calibration of the recorder, a detailed account of which follows.

Valve no. 7 (Fig. 12), under the front end of the car, is first closed. This cuts off the oil line between the recorder and the hydraulic cylinder underneath the car. A dead weight gauge tester is properly set up and a flexible copper tube is attached to valve no. 9. A flow of oil expels any air from the tube, and the other end of the tube is attached to the dead weight tester, where the gauge is usually mounted. The record chart is slowly moved by means of the electric motor, and the zero setting of the recording pen is made with reference to the datum-line pen provided for the drawbar pull record. The paper movement is stopped. Any pressure on the volume of oil between the dead weight tester and the drawbar pull recorder will cause the recorder pen to move proportionally to the pressure exerted, exactly as if it were caused by a locomotive pulling a train. A dead weight tester capable of exerting a pressure of 2000 p.s.i. is adequate for calibrating most drawbar pull recorders.

When a weight is placed on the dead weight tester, whirled slowly to reduce friction, and pushed down slightly to take up any lost motion in the record-pen moving mechanism, the chart is moved about an inch and thereby a permanent record of the calibration is made. Each time that an additional weight is placed on the tester this process is repeated, until a maximum pen deflection is obtained for the weight of spring used in the drawbar pull recorder. Without removal of any of the weights they are again whirled slowly, and then pushed up slightly to take care of any lost motion in the down direction, and the paper chart is moved. This process is continued till only one weight
remains on the dead weight tester. To obtain the drawbar pull in pounds the average pen movements up and down for the same weight on the tester are multiplied by the area of the hydraulic cylinder underneath the car, 78.54 sq. in. Figure 14 shows a calibration curve from which the drawbar pull may be determined for any length of pen movement. This method of calibrating the drawbar pull recorder does not depend on the area of the recorder cylinder, nor does it require that the spring used shall itself have any definite calibration.

III. Auxiliary Equipment

10. Recording Table.—For use in the new car an entirely new recording table was designed and built by the University of Illinois. It is near the rear of the operating room and is so placed that operators, observers, railway officials, and others interested in any test which is being conducted can move freely around the table.

11. Recording Table Drive.—The moving parts of the recording table are driven through a horizontal and vertical shaft and a gear box which is welded to the underframe of the car. The horizontal shaft connects to an axle-mounted Spicer gear drive—a standard piece of equipment on the Illinois Central Railroad System—through two universal joints and a sleeve joint to the gear box. On an extension of the horizontal shaft through the gear box is mounted a multiple V-pulley which drives the car lighting generator. The upper end of the vertical shaft extends through the car floor and drives the recording table by means of a square-jawed clutch which is controlled by the first lever shown at the side of the table in Fig. 15.

Fig. 14. Calibration Curve, Drawbar Pull Recorder

Fig. 15. Rear View of Recording Machine
12. Recording Table Gear Box.—To reduce noise and to promote safety, nearly all gears and highspeed moving parts are mounted in a central gear case (Fig. 16) on the base of the recorder, and all are run in oil. The clutch-controlled vertical shaft terminates within the gear case, in a horizontal bevel gear meshed with two similar gears on a horizontal shaft and so arranged that this shaft always turns in the same direction, regardless of the direction of motion of the car. An extension of this shaft projects through the gear case; on it is mounted a circuit-closing device to give a record of distance traveled on the chart. Two gear wheels of different diameters are mounted on the opposite ends of the horizontal shaft and, by means of the outside control lever, govern the speed of two electric tachometer generators, one of which is for the speed recorder and the other for a speed indicator.

On this same end of the shaft is also a square-tooth clutch which permits the movement of the paper chart to be made on a distance basis or a time basis — by distance when geared to the car wheels and by time when driven by an electric motor. Shifting from the distance, time, or neutral position is controlled by the middle operating lever. Most tests are made on a distance basis; but special tests — especially certain braking or acceleration tests — often require a fast paper speed when the train speed is low.

13. Paper Travel.—The rate of paper travel across the top of the recorder is controlled by the lever on the left-hand side of the table top, as shown in Fig. 17. The most convenient paper speeds have been found to be 3.3, 13.2, and 52.8 in. of paper per mile of track. However, the gears in the box underneath the car may be changed for any other paper travel or to allow for different diameters of car wheels. The car wheels driving the recorder were turned to a cylindrical tread, and no brake shoes are used on them.

14. Recording Pens.—The pens used on the record chart are Ink-O-Graphs. They have proved very satisfactory. They are mounted in a vertical position, may be raised from the paper without blotting, and are easily filled, cleaned, and maintained. Using the medium paper speed, one filling of the pens will usually record the test over 500 to 600 miles of track, the sole exception being the drawbar pull recorder pen.

15. Recorder Apparatus.—Figure 17 shows the operator’s side of the recording table and the panel board mounted on the table top directly in front of him and in line with his vision. This arrangement makes it possible for one man to operate the table in an emergency or...
during simple tests that require a minimum amount of data. Generally the recorder is operated by two men, one of whom is continually in telephone communication with an observer on the locomotive.

At the left on the panel board is the Micromax speed recorder which was removed from the old car. Under normal operation it gives a speed ordinate of 10 mi. per hr. per inch of pen travel up to 100 mi. per hr. Next is a vertical rod ending in a bell crank on its lower end. This rod goes through the roof of the car and is attached to a wind vane which gives a record on the chart of wind direction with respect to the car. Next is an electric type of speed indicator which is connected in series with one placed in the cab of the locomotive. A toggle switch to the left of the indicator changes from a high to a low reading scale. The eight gang switches control the operation of various pieces of apparatus used in making different tests. The single switch above the “eight group” operates the paper-driving motor.

The General Electric timer operates the two outside pens, through a relay, to give a record of time in 1/2-sec., 1-sec., or 5-sec. intervals. On the right side are shown two of four electric counters which are used in connection with pens on the table to indicate the number of times a circuit has been closed. One may be employed in connection with the integrator to indicate work units or area under the drawbar pull curve; another is operated by a stoker contactor to show coal consumption; the other two, when operated by electric watermeters and properly calibrated, give water used.

16. Recorder Chart Record.—Directly beneath the panel board are shown ten of the twelve 32-volt electromagnets (only nine have ever been used in making a test) which make the important records on the chart. As shown in Fig. 18, the pens are arranged to record the following data (starting at the left side):

1. Time in 5-sec. intervals
2. Water, left injector
3. Water, right injector
4. Coal
5. Engine data, cutoff, throttle position, boiler pressure, steam chest pressure, back pressure, and steam temperature
6. Wind direction
7. Speed
8. Indicator cards
9. Mile posts
10. Wind velocity

11. Brake cylinder pressure
12. Integrator or work indicator
13. Operator’s information
14. Drawbar pull
15. Time in 5-sec. intervals.

Four datum-line pens are mounted in front of the wind direction, speed, brake cylinder pressure, and drawbar pull pens, are easily adjusted to positions with respect to their recording pens, and may be raised from the table by a separate lever. Enough electromagnets are available to make records on the chart from which can be computed the amount of water used in the “blow down” of the boiler or when the safety valve opens.

Fig. 18. A Section of the Record Chart
17. **Time Record.**—An accurate time record on the chart is imperative. For ordinary use a 5-sec. interval suffices, though the General Electric timer gives an additional ½- and 1-sec. record. This timer is very accurate, deriving its exactness from the manner in which an electric circuit is closed on each oscillation of the clock balance wheel. A sensitive relay operates a second relay to make the ½-, 1-, or 5-sec. offsets on the record chart. A pen on each side of the chart, the two being connected by a pen rod, makes offsets which serve as a guide for drawing lines across the chart for references in working up the test results and also for checking pen alignment, so that all will be in one straight line across the chart. For special tests, especially those having to do with accelerations, two other timing devices are available. One is a Jaquet chronometer which closes an electric circuit every ½ sec. and thereby operates a relay which in turn causes one of the extra magnets to move a pen. The other is a 4-pen chronograph which makes a record on a separate tape but is easily correlated with the record chart. This chronograph is operated by an electric tuning fork having a fundamental frequency of 50 cycles per second. A time interval of ½ sec. is easily obtained and read from this instrument.

18. **Water Record.**—Two special watermeters built, tested, and calibrated by the writer are placed in the water lines between injectors and water tender. They operate on the principle of a streamflow meter, and an electric circuit is closed every time the moving element makes a certain number of revolutions. Figure 19 shows one of the meters in test position, and Table 1 gives the calibration test results. If the flow of water to the boiler is constant, as it usually is when the injector is wide open, it is necessary only to determine the average time between offsets on the water records on the chart and to multiply the gallons per contact by the number of contacts made by the watermeters. The number of contacts at any time may be read on the electric counters connected to the watermeters, and the readings may be periodically written on the chart by the recorder operators. Since the two meters are not made exactly alike, a different calibration must be applied to each.

19. **Coal Record.**—One of the hardest records to get in locomotive testing is that of coal consumption. To weigh the coal that is to be used is a time-consuming task, and if additional coal should be needed out on the road where no weighing devices are available, the amount of coal actually used can be only approximated. At the end of the test, all remaining coal would have to be weighed. The method used on car No. 30 has proved very accurate and convenient. A worm gear was mounted on the engine shaft driving the

![Figure 19: Watermeter Mounted at Left Side of Locomotive](image-url)

**Table 1**

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18. Water Record.—Two special watermeters built, tested, and calibrated by the writer are placed in the water lines between injectors and water tender. They operate on the principle of a streamflow meter, and an electric circuit is closed every time the moving element makes a certain number of revolutions. Figure 19 shows one of the meters in test position, and Table 1 gives the calibration test results. If the flow of water to the boiler is constant, as it usually is when the injector is wide open, it is necessary only to determine the average time between offsets on the water records on the chart and to multiply the gallons per contact by the number of contacts made by the watermeters. The number of contacts at any time may be read on the electric counters connected to the watermeters, and the readings may be periodically written on the chart by the recorder operators. Since the two meters are not made exactly alike, a different calibration must be applied to each.

19. Coal Record.—One of the hardest records to get in locomotive testing is that of coal consumption. To weigh the coal that is to be used is a time-consuming task, and if additional coal should be needed out on the road where no weighing devices are available, the amount of coal actually used can be only approximated. At the end of the test, all remaining coal would have to be weighed. The method used on car No. 30 has proved very accurate and convenient. A worm gear was mounted on the engine shaft driving the
locomotive stoker. The stoker counter was calibrated by placing the
tender loaded with coal on the scales and weighing it. Then the stoker
was set in operation and the number of contacts made by the stoker
contactor was determined for the amount of coal passing through the
stoker. The constant for each offset on the coal record of the test car
chart is 21.8 lb. of coal for a Type B Standard stoker.

20. Engine Data.—An observer on the locomotive is in continuous
communication with one of the recorder operators whenever a test is
in progress. The receptacle to which a cable plug is inserted that
connects test car and locomotive is shown in Fig. 20. When any change
occurs in boiler pressure, steam chest pressure, back pressure, throttle
position, or cutoff, the observer pushes a button that makes an offset
in the locomotive data line and announces the information, which is
written directly on the chart.

![Figure 20. Front End of Car No. 30](image)

The locomotive observer is also able to transmit to the test car any
train order received by the train crew, especially if plans for the test
have to be changed unexpectedly. When a long series of freight train
tests is to be made over the same railroad division it is convenient to
have train orders prepared in triplicate so that a set may go to the
test car crew as well as to the trainmen in locomotive and caboose.
Besides the test car observer on the locomotive, the presence of a
traveling engineer, road foreman of engines, or someone else with
authority to take over the operation of the locomotive should its per­
formance not be up to standard is advantageous.

21. Telephone to Locomotive.—Three sets of telephone apparatus
are available for communication between test car and locomotive.
The set to be used at any one time depends on the personnel and on
the type of test to be conducted. A loudspeaker system is not recom­
manded. When noise is not excessive the ordinary breast-type trans­
mitter and headphones are used, but a Laryngaphone throat set and
Electrovoice lip microphone and receiver set are also available in case
the noise level increases.
IV. Wind Direction and Velocity

22. Wind Direction.—The wind direction record is made by a wind vane supported 2 ft. above the car roof. The shaft from the vane projects down into the car, carrying at its lower end a crank that is parallel to the vane and points in the same direction as the arrow on the vane. The end of this crank rides in a slot in a bar fastened to the pen rod, as shown in Fig. 17. The datum or zero pen is so set that the line drawn by it and that drawn by the wind direction pen coincide when the vane is pointing in a direction parallel to the axis of the car. Since the car travels in only one direction during a test, the crank will always point toward the front of the car, either on the datum line or to the right or left of it.

23. Wind Velocity.—The wind velocity record is made by means of a Robinson cup anemometer, of the standard Weather Bureau type, supported on a mounting about 2 ft. above the car roof. This anemometer is so constructed that an electric circuit is closed and an offset made on the record chart by the wind velocity pen every time it registers 0.1 mi. of wind—that is, every time one tenth of a mile of wind has passed the car. This record, then, consists of a line having offsets in it at intervals which represent 0.1 mi. of wind. The time interval between offsets, which may be obtained from the time record on both sides of the chart, is a measure of the wind velocity relative to the car. This velocity, \( V_w \), may be determined as follows:

\[
V_w = \frac{3600}{10t} = \frac{360}{t}, \tag{1}
\]

where \( t \) is the time in seconds between any two offsets in the wind velocity record. This gives the average velocity of the wind relative to the car during the time \( t \).

24. Determination of Absolute Direction and Velocity.—If it is desired to find the absolute direction and velocity of the wind at a point \( x-y \) of Fig. 21a, then from \( O \) as a center with a radius of \( \frac{3}{4} \) in. (which is the length of the crank at the bottom of the wind vane shaft) an arc is described intersecting the datum line at \( d \). The direction of the wind relative to the car is \( o-d \), and the wind vane was pointing in the same direction as the crank.

The relative direction of the wind having been determined, its relative velocity is found by counting the seconds between two offsets on the wind velocity record, nearest the point \( x-y \), and applying the formula for \( V_w \) as given in Equation (1). The line \( h-e \) in Fig. 21c is drawn parallel to \( o-d \) and of such length that it will represent to some scale the relative velocity found from Equation (1). The speed of the car is next found from the speed record on the chart. A line \( e-f \) is drawn parallel in direction to the motion of the train and of such length that its length represents, to the selected scale, the speed of the train.

Care must be taken to have this line so drawn that the arrows representing the direction of motion shall follow around from \( h \) to \( f \).

The closing side of the triangle, \( h-f \), will then represent both direction and magnitude the absolute direction and velocity of the wind, the direction being as shown by the arrow.

Figure 21b shows the method adopted for designating the absolute wind direction. Thus, in the case set forth above, if the angle \( h-f-g \) is 60 deg., the designation will be \(-60^\circ\) L.
V. Speed and Other Records

25. Speed Recorder.—One of the most difficult records to get on the test car chart is that of speed. The instrument must be kept in perfect calibration, must withstand the severe shocks encountered in freight train operation, and must give a readable indication at low speed. The Leeds and Northrup potentiometer type recorder fulfills these requirements satisfactorily. It is mounted on the panel board, so that the recording mechanism operates one of the regular test car pens and is in line with all other pens on the chart.

The variable voltage applied to the recorder is furnished by a Model 44 magneto generator geared to the wheels of the car through a shaft extending from the recorder gear box. The calibration is simple, since a magneto speed of 2000 rev. per min. will generate 12 volts, causing a full 10-in. movement of the speed pen, which represents a car speed of 100 mi. per hr. Since the voltage generated by the magneto is directly proportional to the speed, any ruler graduated in inches and tenths of inches may be used to read speeds on the chart. The cam speed of the recorder has been increased from that of the ordinary potentiometer so that the pen will make a full-scale deflection from 0 to 100 mi. per hr. in 10 sec., which is faster than any train will accelerate. Because the movement of the speed pen is made in small steps, some care must be exercised in taking readings, in order to get an average between two or more steps. The speed recorder may be calibrated at any time, even when the car is at a standstill, by applying any voltage between 0 and 12 and checking the pen movement.

26. Indicator Card Record.—This record is simply a pen record with an offset, made every time an indicator card is made, with the card number written beside the offset. In this way, train operating data may be correlated with indicator cards.

27. Mile Post Record.—Projecting windows, shown in Fig. 7, are placed on each side of the car, where an observer notes the location of the mile posts along the right-of-way. Pressing a button makes an offset on the mile post record, and the table operator writes the number on the record chart opposite the offset. This record permits the location of the car to be determined accurately when working up the test.

Trainmen use the observation windows to look over their train, especially when moving around curves. The glass in the windows is shatterproof. As shown in Fig. 22, the windows are close to the recorder so that the operators may observe the mile post location in case the test car crew is short-handed. At night, powerful spotlights are turned on the mile posts so that these may be located and the numbers read. As soon as a mile post is passed, the spotlights are turned off.

The observation windows and the mile post push-button have been used, in making curve resistance and operation tests, to note the times (and place on the chart) at which the train enters and leaves a section of curved track.
28. **Brake Cylinder Pressure Record.**—A small recorder mounted on the right side of the table has its cylinder connected to the brake cylinder of the test car. The piston rod is attached directly to the pen, and no reducing motion is required. In working up the record charts, this record is used to point out the places where brake applications were made and to show how the brakes were applied.

29. **Integrator.**—The integrator, or work recorder, is a special instrument designed by the University. It is shown in Fig. 23; Fig. 22 and Fig. 15 show it mounted on the recording table.

![Fig. 23. Integrator (Work Recorder)](image)

The integrator causes offsets to be made in a line, the distance between offsets being proportional to the pulling force at the drawbar and the distance traveled, which in turn represents work done. When no drawbar pull is being exerted and the cylinder is on the part of the sphere directly in line with the traveling shaft and at an angle of 90 deg. with it, even though the sphere is turning because of the movement of the car, the cylinder will not turn — indicating that no work is being done. The same condition will exist when the car is standing still but the locomotive is exerting a drawbar pull.

The integrator indications, together with the time record on the chart, permit calculation of the rate at which work is done; this figure gives the horsepower developed by the locomotive.

The integrator is calibrated by removing the spring from the drawbar pull recorder, setting the drawbar pull pen at different ordinates from the datum line, and driving the record chart across the table. Rectangular areas result for a certain number of offsets, the length representing the distance traveled per inch of paper travel, and the width the drawbar pull; the unit depends on the size of spring and area of cylinder used in the drawbar pull recorder. The area in square inches per offset gives a working constant for the integrator and should be the same for all ordinate settings of the drawbar pull pen. If a slight difference exists, an average of all areas should be taken.

When properly maintained and calibrated the integrator saves a great amount of work and time in the making of comparative tests. It is necessary only to set the electric counter at zero when the test starts and to read the number of offsets recorded when the test is completed. If excessive brake applications have been made during the tests, it may be necessary to subtract the number of offsets made during the time that the brakes were applied and the locomotive throttle was partly opened.

30. **Direct-Current Selsyn Equipment.**—After considerable experimentation d-c. Selsyn transmitters have been applied to the water tender to show the height of the water at all times, and to reverse lever, throttle, and boiler steam gauge with appropriate indicators mounted on the panel board of the recording table and in the locomotive cab. These instruments relieve the cab observer of much work.

Five special indicators have been built, to be mounted on the right side of the table, for recording boiler pressure, steam chest pressure, back pressure, and any other pressures in case it should be desired to study and compare the continuous records thus made.
31. Recorder Paper and Ink.—Paper for the recorder is ordered in rolls 30 in. long, 10 in. in outside diameter, and wound on a stiff cardboard or fiber cylinder whose inside diameter is 2 in. This will fit over a wooden cylinder that is expanded in the paper roll, holding it fast to a steel axle. Two steel rolls pull the paper across the face of the recording table, and as it unrolls the finished chart is wound on another 3-in. wooden roller. An adjustable friction clutch controls the tension that is put on the finished chart.

A white utility sulphite paper gives good results in the making of dynamometer car tests. Special or high-price ink is not necessary; a good grade of fountain pen ink has proved most satisfactory. The ink should not run on the paper, and it should dry rapidly, so that it will not be moist when it reaches the front of the table.


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