DIRECT INDICATION OF TRACTOR-WHEEL SLIP

by

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INTRODUCTION

An important criterion of farm tractor performance is the amount of travel reduction or slip of the drive wheels for a given drawbar load. Generally maximum tractive efficiency occurs when the driving wheels slip between 10 and 15 percent (1). The tractive efficiency drops when slip is greater than 15 percent, and part of the fuel consumed is wasted by unnecessary soil disturbance.

Excessive slip, in addition to wasting power, also causes rapid tire wear which has an economic significance for large tractors. The rate of tire wear which occurs between 10 and 15 percent slip is usually acceptable, particularly in view of the higher tractive efficiency obtained. The operator should add weight to the rear (or driving) axle to reduce the slip to below 15 percent.

Measurements of drive-wheel slip were made on 300 tractors at work in southern Ontario during the spring and fall of 1961 and 1962 (5). The readings obtained show that drive-wheel slip ranged from one percent to 36 percent, the average being 8.4 percent. These measurements indicate that a travel reduction of greater than 15 percent is not uncommon for some tillage operations. Similar tests were conducted in various parts of Saskatchewan in 1964 on 30 tractors (3). Draft and slip measurements were made under typical operating conditions during summerfallowing. A plot of slip versus percentage of tractors tested, showed a curve peak at about eight percent slip. Slip values ranged from 3.5 percent to 11.5 percent.

It is difficult for a farmer to estimate the amount of wheel slip taking place on his tractor during field work. The conventional method of measuring drive-wheel slip is cumbersome and time consuming. It requires at least one man in addition to the tractor operator. This method gives an average slip for the length of run used. An indication of instantaneous slip would be valuable in many instances where implement draft is being measured. A direct-reading slip indicator would be a valuable instrument for manufacturers, testing agencies, implement dealers and farmers. This paper describes the design and operation of such an instrument.

METHOD

Methods of Slip Measurements

The conventional method of measuring tractor drive-wheel slip consists of measuring the base (unloaded) distance for a given number of drive wheel revolutions, and then measuring the loaded distance for the same number of wheel revolutions. Percent slip is given by the relation:

Percent slip = 100 \frac{(B - L)}{B}

where B = base distance

L = loaded distance

This equation is also part of the Agricultural Tractor Test Code (A.S.A.E. S309.2).

Several experimental methods have been developed for measurement of drive-wheel slip. Reznicek et al (4) mounted electrical resistance strain gauges on rear tire tread bars. A relationship was obtained between tire slip and the force transmitted, by measurement of the bending strain of the tread bars of the tire and the compressive peripheral deformation of the tire when rolling on a firm surface.

A method of measuring the slip coefficient of ground-wheel drives on agricultural machines was described by Boroshek (2). A crank attached to the ground wheel of the machine under test operated a guide-mounted slider, which was fitted with a recording pen. The trace was made on a disc whose angular speed was synchronized with the forward movement of the machine. The disc was driven by friction from a piece of cord, one end of which was anchored to the ground. The cord was unwound as a result of the forward travel of the machine. The pen traces a symmetrical curve when no slip occurs, but when slip occurs the traced curve becomes flattened as well as asymmetrical.

Principle of Operation of Slip Indicator

The slip indicator was designed to read percent slip at any instant during a drawbar test. The unit consisted of

![Diagram of slip indicator circuit]

The conventional method of measuring the slip consists of:

1. Driving the tractor on a firm surface in a standardized manner.
2. Measuring the ground travel distance for the same number of wheel revolutions.
4. Calculating the percent slip using the formula:

\[ \text{Percent slip} = 100 \times \left(\frac{B - L}{B}\right) \]

where:

- \( B \) = base distance
- \( L \) = loaded distance

TABLE 1. GROUND SPEED RANGES FOR CART DRIVE RATIOS

<table>
<thead>
<tr>
<th>Cart Speed Range</th>
<th>Cart Gear Ratio</th>
<th>Ground Speed, mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>19.4</td>
<td>0.85</td>
</tr>
<tr>
<td>Second</td>
<td>10.8</td>
<td>1.34</td>
</tr>
<tr>
<td>Third</td>
<td>6.5</td>
<td>2.53</td>
</tr>
<tr>
<td>Fourth</td>
<td>3.9</td>
<td>4.22</td>
</tr>
</tbody>
</table>

Figure 1. (a) Vector representation of generator voltages, and (b) simple potentiometer circuit.
the two identical Barber-Coleman (BYLM) tachometer generators coupled to a potentiometer circuit. One tachometer generator was driven by the PTO shaft and produced a voltage (Ep) proportional to power-take-off shaft speed. This voltage represented a value proportional to the average speed of the two drive wheels. The second generator was driven through a two-wheeled cart and therefore developed a voltage proportional to ground speed. The two-wheeled cart was pulled behind the tillage implement.

The PTO speed may be represented by vector Ep, and the ground speed by vector Eg in figure 1(a). The voltages were adjusted so they were equal when there was no slip. The ground speed decreased and hence Eg decreased proportionately when drive-wheel slip occurs. The slip (as a decimal) was then given by, \( \frac{E_g}{E_p} = \frac{E_s}{E_p} \) where

\[ \text{slip} = \frac{E_g}{E_p} = \frac{E_s}{E_p}. \]

The sensitivity of the slip indicator may be determined for any setting of tractor gear ratios. The multiple V-belt drive on the cart allowed the speed of the ground driven generator to be changed in steps as indicated in table 1. Resistance \( R_1 \), was chosen with a range (0-5000 ohms) so that \( I_1(R_2 + R_3) \) could be made equal to Eg for any tractor gear ratio from 0.85 to 8.33 mph. Since the sensitivity of the slip indicator is highest when \( R_1 = 0 \), a chart gear ratio should be selected so that \( R_1 \) is as small as possible. For example, if a test is conducted at 2.5% mph, the second speed range should be used rather than the first range. The ground drive cart is shown in figure 4.

The generators produced 24 volts per 1000 rpm into an infinite load. Thus for a PTO speed of 540 rpm, \( E_p = 24 \times \frac{540}{1000} = 12.95 \) volts. With \( R_1 = 0 \), \( E_g = 12.95 \times \frac{4505}{5119} = 11.40 \) volts. At 10 percent slip, for example, \( E_g = 11.40 \times (0.1 \times 11.40) = 10.26 \) volts. Similarly with \( E_p = 12.95 \) and \( R_2 = 5000 \), \( E_g = 5.76 \) volts.

The sensitivity of the slip indicator could be made equal to \( I_3(R_2 + R_3) \) lying in the lower branch of the circuit. For the most sensitive case \( (R_1 = 9) \), with the circuit values given in figure 2, the sensitivity was 88 \( \mu \)amps per percent slip. The galvanometer had a 500-5000 ua scale. In the least sensitive situation, i.e., when \( R_1 = 5000 \) ohms, the sensitivity was 19 \( \mu \)amps per percent slip. Circuit components can be chosen to provide greater sensitivity, but galvanometer needle oscillation, caused by instantaneous voltage variation, becomes a problem. It was necessary to make a compromise between sensitivity and damping.

Satisfactory circuit damping was obtained by use of capacitors \( C_p \) and \( C_g \). The RC network around each generator was made equal. The time constants were \( T = RC = C_p(r + R_2) = C_g(r + R_2) = 1.23 \) sec. Cart bounce was reduced by filling the tires with liquid to further reduce the instantaneous variation in \( E_g \).

Laboratory and Field Tests

The slip indicator circuit was checked in the laboratory for linearity and sensitivity by substitution of power supplies for the two generators. Various settings of \( E_g \) were used to simulate different amounts of slip. Nonlinearity could not be detected on the scribed instrument dial. Sensitivity readings agreed with the values calculated by equations 3, 4 and 5.

The slip indicator was simple to operate during a field test. The implement and cart are first pulled without slip (zero slip), that is, without the tools engaging the soil, with the tractor transmission in the gear to be used during the test. Potentiometer \( R_1 \), was adjusted until the galvanometer indicated a null with switch \( S \) closed. The instrument was now calibrated. The galvanometer deflects as slip increases when the load is applied. It was brought to the null position by adjusting \( R_2 \) with \( S \) closed, and percent slip was read on the instrument dial (figure 3).

The accuracy of the slip indicator depended on the linearity of the tachometer, on the linearity of potentialmeter \( R_1 \), and on the relative amount of decrease in effective radius of the drive wheels from the no-load to the loaded condition. The generators were found to be linear to within less than one percent. The amount of error involved as a result of a decrease in the effective drive-wheel radius was equal to that involved during the conventional method of slip measurement. This error was not evaluated.

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The sensitivity of the slip indicator, depended on the setting of \( R_1 \), the least sensitive case, a slip change of 0.5 percent could be detected. Since the drive-wheel slip varied due to changes in soil conditions during a test, the operator must mentally "integrate" the reading to get an average value for the test run. The slip may vary by 5 to 10% in a typical test run. The error involved in making this decision was, no doubt, of more significance than any other error.

Extension of the Simple Slip Indicator

The drive wheel slip could be recorded by making a simple addition to the circuit if field recording equipment was available. The control knob which adjusted \( R_2 \) could control a potentiometer. This potentiometer would operate with a constant auxiliary voltage supply to act as a position transducer. The position of its wiper would coincide with the wiper of \( R_2 \) and the output voltage would be recorded as percent slip.

5. Southwell, P. H. and Jackson, D. J. 1965. Tractor Slippage. Undergraduate Thesis, Department of Agricultural Engineering, University of Saskatchewan, Saskatoon, Canada.