

DESIGN AND CONSTRUCTION OF AN INSTRUMENTATION SYSTEM FOR MEASURING DRAUGHT ON MODEL TILLAGE TOOLS

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ABSTRACT

This paper describes the design and construction of an instrumentation system for measuring draught on model tillage tools. The instrumentation system was incorporated into a laboratory soil bin. The soil bin facility was used to measure draught on model chisel furrowers. Results obtained are reported in the paper.

KEYWORDS: Draught tillage tool, Instrumentation.

INTRODUCTION

In modern agricultural production, soils that are adjudged to be suitable for crop production are usually manipulated to cause some desired effect such as cutting, breaking or inversion. The manipulation is accomplished with a tillage tool by moving the tool through the soil. There are five design factors that define soil manipulation, namely, initial soil condition, shape of tillage tool, manner of moving the tool, forces required to move the tillage tool through the soil and the results of the soil manipulation which is usually referred to as the final soil condition (Gill and Vanden Berg, 1967). Two parameters that are commonly used to assess the performance of a tillage tool are the degree of soil manipulation and the magnitude of forces required to cause the manipulation (Gill and Vanden Berg, 1967). Tillage tool forces are, however, more difficult to measure than the degree of soil manipulation. This is because tillage forces relate directly to soil conditions, deformation resistance, tool geometry and working depth.

Several authors used different methods for measuring the forces on tillage tools and implements. Majewski (1983) measured the draught of model chisel ploughs in a laboratory soil bin. The model tools tested had vertical supports. Each of the chisel plough model tools was clamped on a frame of the carriage. Electric resistance wire strain gages were bonded to the vertical support of each model to measure the horizontal component of working resistance in the direction of

motion. Strain gage multi-channel bridges and ultraviolet loop oscillograph were used to record the measurements on tape. Reid et al. (1985) designed a dynamometer for measuring draught. The dynamometer used strain gages mounted on a vertically cantilevered aluminium beams to sense the implement loads including side draught. Owen (1989) conducted an experiment to determine under field conditions, in two compact soils, the effect of tool speed on the vertical, horizontal and total forces on a subsoiler tine. The effect of tool speed was also determined on the moment applied to the tine, soil areas heaved and disturbed, total soil area, specific resistance, and to compare the vertical, horizontal and total forces to values predicted by a three dimensional model of soil wedge failure. He used a vertical rigid tillage tool mounted on a trailed tool bar system. An instrumentation system was installed on the trailed tool bar system and was used to record several operating parameters of the tillage tool. The instrumentation system recorded the vertical force, horizontal force in the direction of travel and the moment in the plane of these forces as applied to the tine. These values were measured using an octagonal ring transducer rigidly mounted on the tool bar. Oni et al. (1992) determined the effects of design on the draught of undercutter-sweep tillage tools in a laboratory soil bin. The instrumentation system used for draught measurement included a rectangular tubing frame, a dynamometer and a tool holder. The tubing frame permitted lateral and vertical movements of the dynamometer in the soil bin through arrangements of stainless steel shafts, bearing blocks and mechanical actuators. There were six load cells on the dynamometer frame. Two of them were in the vertical plane, three oriented in the horizontal plane and one in the side plane to monitor side draught. Shirin et al. (1993) evaluated the effects of disc and working parameters on the performance of a disc plough in a clay soil. A three-point linkage dynamometer was used to sense the draught on disc plough. Each lower link transducer of the dynamometer had two bridge circuits to detect the draught and the vertical force. An LVDT, mounted on a three-point linkage of the tractor was used for the measurement of ploughing depth. A Massey Ferguson 4-cylinder diesel engine tractor with a rated power of 46 kW at 2000 rpm was used for testing. Shinnars et al. (1993) investigated the performance characteristics of a tillage machine similar to a chisel plough that uses active-passive components. They used a portable three-point linkage dynamometer to measure draught. The dynamometer was attached to the three-point linkage of the tractor used. Load cells were located at each of three hitch points which measured the vertical and horizontal reaction forces of the implement. The active-passive tillage machine was equipped with transducers to measure rotor speed, PTO torque and speed. Durairaj and Balasubramanian (1997) developed a dynamometer and used it to measure soil reactions of a bent leg plough. The dynamometer included six force transducers and an L-shaped tool

bar with a cross beam on it. Four of these six sensors were strain-gaged load cells. One of these four strain-gaged load cells measured the horizontal force, two measured the vertical forces and the remaining one measured the lateral force. Two of the four transducers measured the other two horizontal forces on the cross beam itself. Each of the six transducers had a separate instrumentation amplifier with necessary balancing circuits. The gain was made adjustable so that the output could be calibrated according to the capacity of the transducer. All the transducers were calibrated by applying the required load using a manually operated hydraulic press, with the load being monitored on its oil pressure gauge. The outputs of the instrumentation amplifiers were multiplexed by an analog multiplexer and led to a digital data logger for storing the information. Hann and Giessibl (1998) measured forces on driven discs. They used a triaxial dynamometer employing two extended octagonal rings and a torque tube mounted between the carrier frame and carriage in order to measure draught, vertical and side forces on the disc implement. Voltage outputs of the dynamometer strain gage circuits were fed through a d.c. differential amplifiers to a data logger. From the recorded parameters, disc performance variables such as draught, vertical and side forces, total power, specific total power and specific draught resistance were calculated. Al-Janobi and Al-Suhaibani (1998) measured the draught of primary tillage implements in a sandy loam soil. The instrumentation system consisted of a data logger, a three-point linkage dynamometer, a rotary position transducer, and a fifth wheel ground-speed sensor mounted on the tractor. The three-point linkage dynamometer that was used to measure implement draught was calibrated prior to the experiments using a specially built calibration rig. The fifth wheel used to measure tractor speed was calibrated on the soil surface at the beginning of the experiment.

Many more instrumentation systems have been designed and constructed for tillage studies (Wegscheid and Myers, 1967; Godwin, 1975; Johnson and Voorhees, 1979; Stafford, 1979; Godwin et al., 1980; Clark and Adsit, 1985; Green et al., 1985; Chaplin et al., 1987; Thomson and Shinnars, 1989). The selection or construction of an instrumentation system by researchers depended on the tool-soil interaction parameters that needed to be measured, accuracy of the measurement and convenience. Although several instrumentation systems have been constructed for tillage studies in different parts of the world, little information is available in Nigeria.

The objective of this study was therefore to design and construct an instrumentation system for measuring draught on model chisel furrowers in a laboratory soil bin.

THEORY

The measurement of strain is becoming an increasingly important area of stress analysis. Strain is the amount of deformation of a body due to an applied force. Strain measurement involves three main stages. These are sensing, transducer and signal conditioning stages. In practice, strain values are rarely larger than a few millistrain. If an electrical strain gage is used as a sensor, such a strain value will give rise to a very small change in strain gage resistance. To detect such a small change in resistance and compensate for temperature sensitivity, electrical resistance strain gages are usually used in a Wheatstone bridge configuration to form a transducer. In order to obtain a reasonable output to drive the indicating instrument, the output of the bridge circuit is conditioned by using an amplifier. Figure 1 shows a complete strain measuring system.

Bridge Configurations

Three types of bridge configurations are commonly used in strain measurements. These are quarter, half and full bridge circuits. In a quarter-bridge circuit, only one strain gage is used and the other three arms being fixed resistors. In a half-bridge circuit, two of the arms are strain gages and the other two being fixed resistors while in a full-bridge circuit, all four arms of the bridge are strain gages. To obtain a reasonable circuit with moderate sensitivity, linear output and negligible temperature effect, half-bridge circuit is usually used. In a half bridge circuit (Fig.2), one of the strain gages is placed on the tension side while the other is placed on the compression side. It is clear from Figure 2

$$\text{that voltage at point A, } V_A = \frac{V_i R_2}{R_1 + R_2} \dots\dots\dots(1)$$

$$\text{Also, voltage at point B, } V_B = V_i \frac{R_G - \Delta R}{R_G + \Delta R + R_G - \Delta R} \dots\dots\dots(2)$$

$$V_B = V_i \frac{R_G - \Delta R}{2R_G} \dots\dots\dots(3)$$

$$\text{But,} \\ V_0 = V_B - V_A \dots\dots\dots(4)$$

Therefore;

$$V_o = \left[\frac{R_G - \Delta R}{2R_G} - \frac{R_2}{R_1 + R_2} \right] V_i$$

Let $R_1 = R_2 = R_G$

$$V_o = \left[\frac{R_G - \Delta R - R_G}{2R_G} \right] V_i \quad \dots\dots\dots(6)$$

$$V_o = - \frac{\Delta R}{2R_G} V_i$$

$$\text{But } G.F \times \varepsilon = \frac{\Delta R}{R_G} \quad \dots\dots\dots(7)$$

where G.F is gage factor, ε is strain and R_G is strain gage initial resistance.
This implies that

$$V_o = - \frac{G.F \times \varepsilon}{2} V_i \quad \dots\dots\dots(8)$$

Equation (8) shows that for constant G.F and V_i , V_o is directly proportional to ε , which is a measure of the force on the strain gage.

Offset-nulling

The output of a bridge circuit is expected to be zero volts when no strain is applied to the strain gages, but in practice, zero output conditions is not attainable due to the strain induced by gage application, resistance tolerances, temperature effect and lead wire resistance effect. To take care of this initial offset voltage, offset nulling circuit is usually incorporated to adjust the resistance in the bridge arms to balance the output to zero volts. Figure 3 presents a bridge circuit with nulling circuit incorporated.

Signal Conditioning

Since small changes in strain leads to small changes in resistance of the strain gage in strain measurement, the output signal (voltage) will also be small. In order to get a reasonably high output from the small bridge output, and to improve resolution and signal to noise ratio, an amplifier is normally incorporated into the circuit. For the output impedance of the amplifier and the input impedance of

indicating instrument to match, the output of the amplifier is fed to the input of the indicating instrument through a buffer (Amplifier with unit gain). The buffer also reverses the direction of output of the amplifier which is already negative. Figure 4 is a circuit with buffer incorporated.

DESIGN AND CONSTRUCTION OF A STRAIN MEASURING DEVICE.

A device for measuring strain on model chisel furrowers was designed and constructed. In order to get a circuit with high reliability, repeatability and reasonable sensitivity, the components for the bridge and signal conditioning circuit were carefully determined and selected. The excitation voltage for the bridge circuit was also taken into consideration.

The strain measuring device constructed in this study was centered on a half bridge circuit. The resistances of the strain gages used were $120 \pm 0.5 \Omega$ and a gage factor of $2.05 \pm 1\%$. After mounting the strain gages on the specimen under test (tension and compression sides, respectively) and connecting to 6 m of lead wire, the resistances of the strain gages increased to 140Ω . One of the conditions for balancing is that the resistances of all the four arms of the bridge circuit as shown in Figure 3 be equal to R_G (strain gage resistance) which in this case was 140Ω . The rated current for 140Ω strain gage, I_g was 15 mA. From Figure 2,

$$V_i = I_g [R_G + \Delta R + R_G - \Delta R]$$

$$V_i = 2I_g R_G$$

Substituting the values, V_i is obtained as 4.2 volts

This excitation voltage was expected to be stable and accurate. To obtain this, a regulated power supply was used. Since there is no 4.2 volts regulator, the nearest to it is a 5 volts regulator and therefore, 5 volts d.c was used as the excitation voltage. A nulling circuit was selected such that it did not affect the sensitivity of the circuit. From Figure 3 and with $R_G = 140 \Omega$, R_n must be about 100Ω while R_p should be between $10 K\Omega$ and $50 K\Omega$. Figure 5 shows the resulting circuit. The signals obtained from the Wheatstone bridge were too small for meaningful interpretation. The output of the bridge circuit was amplified using a differential amplifier. The output of the amplifier was fed to a buffer (Fig. 4). From Figure 4, if the closed loop gain of the amplifier is given by

$R_i = 1000 \Omega$, then $R_f = 1000 \times 1000$

$R_f = 1000 K\Omega$.

Taking R to be $1 K\Omega$, the resulting circuit is as shown in Figure 6.

PERFORMANCE EVALUATION OF THE INSTRUMENTATION SYSTEM

The instrumentation system was incorporated into a laboratory soil bin constructed in the Department of Agricultural Engineering, University of Ilorin, Nigeria. The soil bin consists of a stationary soil bin and a single-axle tractor served as the carriage for both the soil processing and model tools. The soil processing unit consists of a rotary tiller, a soil leveller and a roller compactor. The model tool unit has a tool bar frame and a tool bar. Thirty-six geometrically similar model tools were fabricated and tested at 4 levels each of soil depth and travel speed.

The soil bin was filled with an artificial soil for the performance evaluation of the instrumentation system. Soil preparation involved rotary tilling, levelling and compaction to a uniform density along, across and down the soil profile. Six passes of a 39.5 kg roller gave an average uniform density of 1.76 Mg/m^3 . Six roller passes were required for each soil preparation. The common carriage was powered by a 3.73 kW, three-phase electric motor. The tool bar was bolted to the tool bar frame and the model tool was mounted on the tool bar. The two strain gages that formed the two arms of the Wheatstone bridge (Fig. 5) were mounted on the tool bar. One of the strain gages was mounted on one face of the tool bar in direction of travel (tension) and the other one was mounted on the opposite face of the tool bar (compression). Figure 7 shows the tool bar with the model tool and strain gages mounted. The draught on the tool bar was picked in form of signals by the electrical resistance strain gages. The signals were conditioned and an S-T plotter recorded them on a chart. Figure 8 shows the assembly of the instrumentation system.

The instrumentation system was calibrated in terms of force. A static load calibration procedure was used. This was done by mounting the tool bar on a laboratory clamp in the same configuration as it will be used in the actual experiment. A load hanger was fixed to the tool bar at the point of tool attachment. The load hanger was used to subject the tool bar to known weights. The tool bar was loaded in steps and at each step, the pen of the S-T plotter moved a distance corresponding to the load on the hanger. The same procedure was used for unloading.

After the soil preparation, the tool bar which carried the model tool and the strain gages was mounted on the carriage and pulled through the soil. The signals recorded by the S-T plotter were interpreted and computed. The mean values of draught obtained were analyzed statistically.

RESULTS AND DISCUSSION

Calibration

The values obtained from the calibration indicated a linear response within the load range. There was no hysteresis in any of the outputs.

The data was fitted to a linear regression model. The regression equation for the calibration was found to be:

$$Y = 4.905 + 9.81X \quad \dots\dots\dots(10)$$

Where Y is load (kN) and X is the distance moved by the pen of the S-T plotter. The equation of the calibration was then used to compute the draught recorded by the S-T plotter for each of the model tools tested. Figure 9 shows the calibration graph of the instrumentation system. Some samples of the signals recorded by the S-T plotter at different speeds are presented in Figure 10.

Draught of Model Tools.

The draught of the model tools varied with variations in tool (cutting edge height, nose and slide angles), operational (soil depth and travel speed) and mechanical properties of the soil. Draught increased with increase in soil depth and speed. Draught also increased with increase in nose and slide angles. The results obtained in this study are similar to those reported by other researchers who used different instrumentation systems for measuring draught on model tools.

CONCLUSIONS

An instrumentation system was designed and constructed for measuring draught on model tools. The output of the instrumentation system was linear and there was no hysteresis. The instrumentation system is suitable for measuring draught on model tools in a laboratory soil bin.

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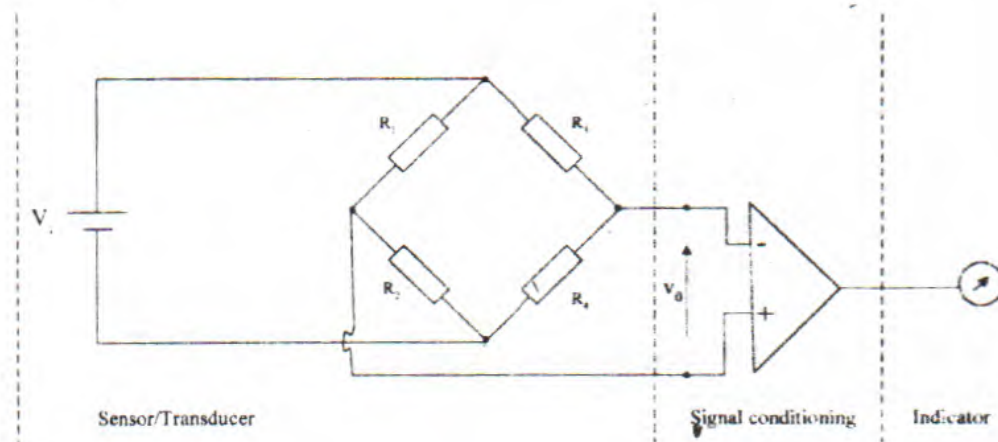


Figure 1: Schematic diagram of stages involved in strain measurement.

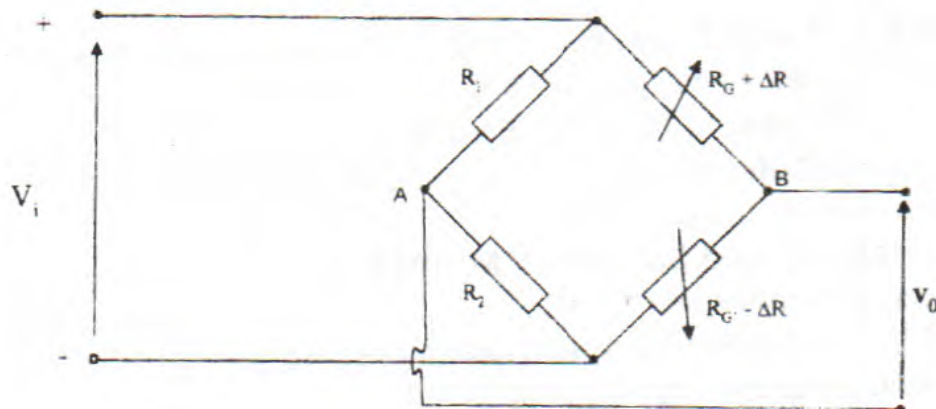


Figure 2: Half bridge circuit configuration.

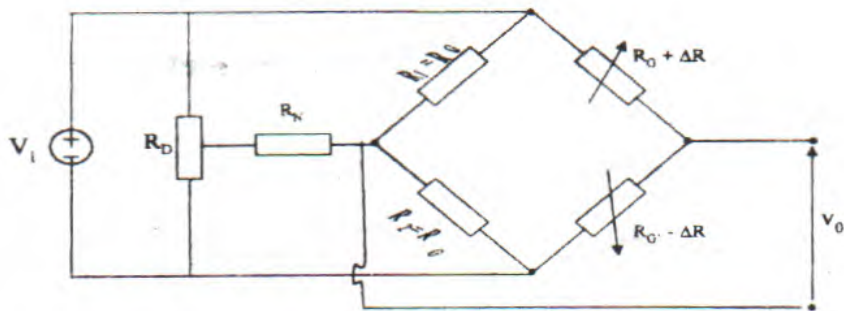


Figure 3: **Circuit diagram of a half bridge circuit with nulling circuit incorporated**

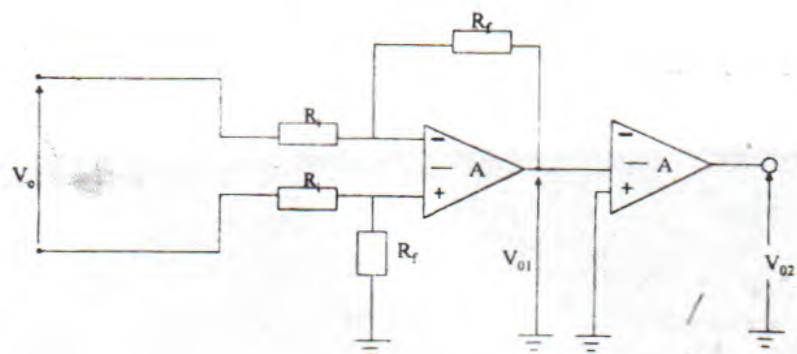


Figure 4. **Circuit diagram for signal conditioning unit.**
(R_f -feedback resistance, $-A$ = Open loop gain).

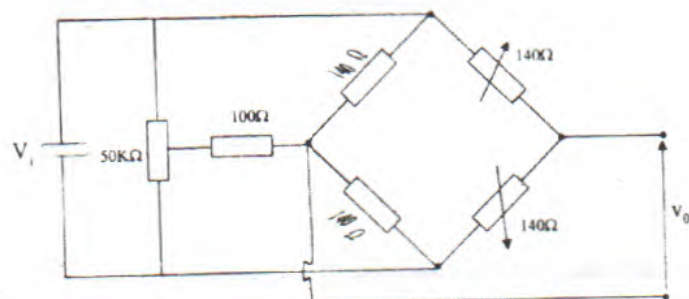


Figure 5. **Circuit diagram of the transducer.**

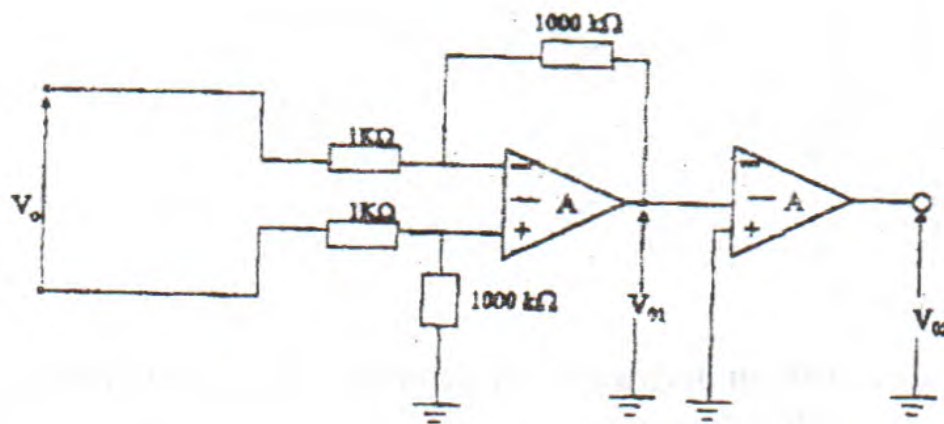


Figure 6: Circuit Diagram of the signal conditioning unit.



Figure 7: Strain gaged tool bar with a model tool attached. A—Model tool;
B—Tool bar clamp.

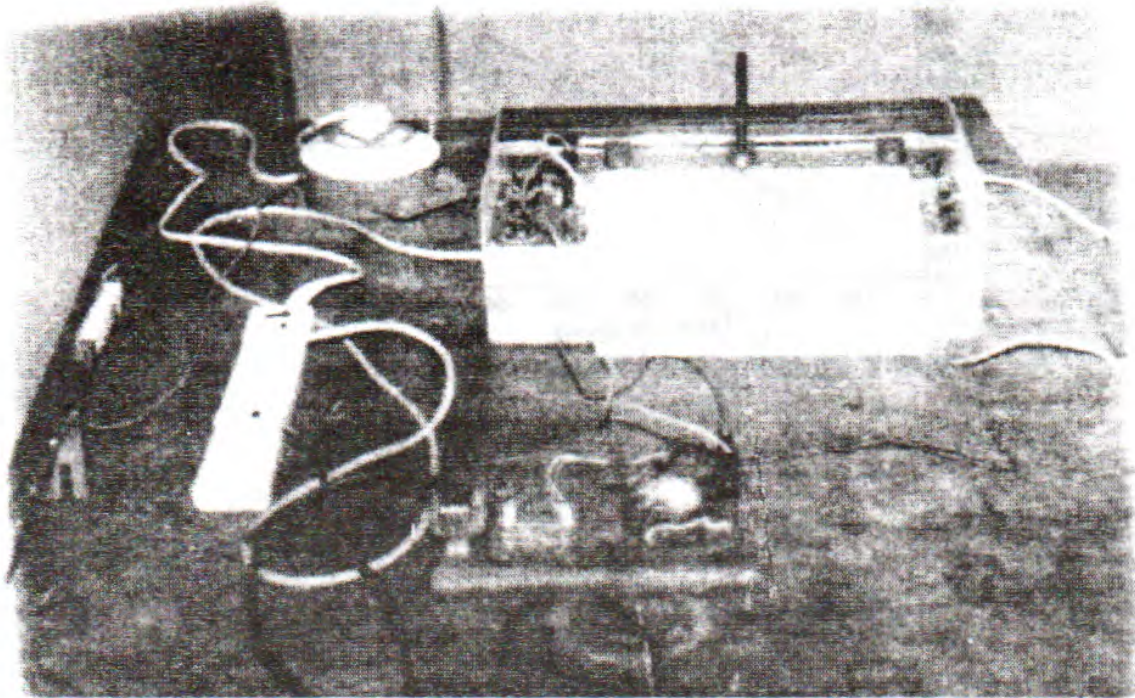


Figure 8: Assembly of instrumentation and recording system showing strain gaged tool bar, amplifier with signal conditioning and S-T plotter.

A = Tool bar clamp; B = Strain gage protection; C = Lead wire;
D = Amplifier; E = S-T plotter paper; F = S-T plotter; G = Recording pen.

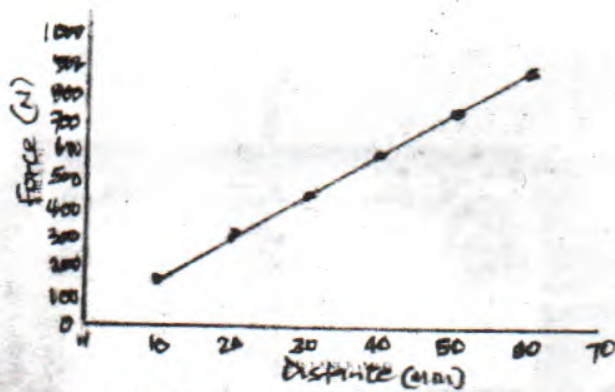


Figure 9. S-T Plotter pen calibration graph.

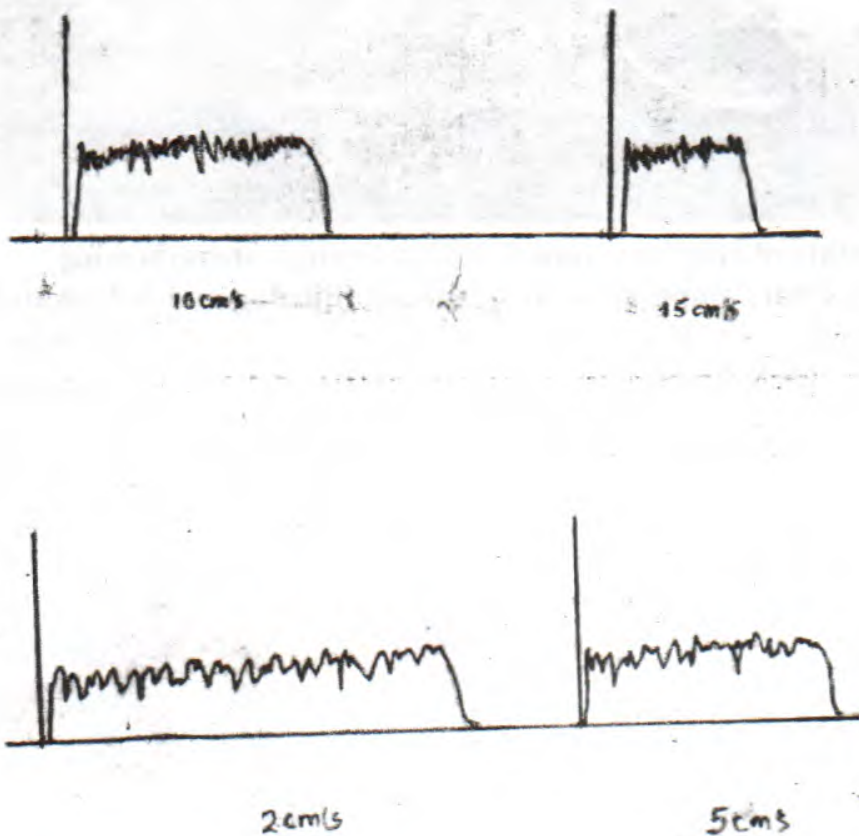


Figure 10. Sample output of S-T plotter recorded signals at different speeds.