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An Electronic Attachment To Replace Mechanical Dynamometers Used To Record Torque In Mixers And Extruders

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AN ELECTRONIC ATTACHMENT TO REPLACE MECHANICAL DYNAMOMETERS USED TO RECORD TORQUE IN MIXERS AND EXTRUDERS

Peter W. Voisey

SUMMARY

An electronic dynamometer attachment is described to replace existing mechanical dynamometers used on laboratory instruments to record the torque required to operate mixers and extruders. The repeatability and accuracy of the new system is within ± 0.1% of the calibrated range. The design offers a number of advantages including simplified construction and increased versatility.

1. INTRODUCTION

It is a common requirement to record torque against time in laboratory mixers and extruders to evaluate the energy input into the test material. Applications of such instruments are found in a diverse range of industries such as food and plastics, both in research, product development and quality control. One of the first applications was probably the evaluation of the baking quality of wheat in 1889 by a Scottish miller.

Torque is traditionally measured by detecting the reaction torque of the motor driving the mixer or extruder using a mechanical scale made up of levers and weights. A pen attached to one of the levers in the scale mechanism then recorded torque on a chart moved past the pen at constant speed to provide a torque-time record. The versatility and accuracy of such a mechanical dynamometer is limited, particularly when dealing with small laboratory samples which generate small torques. This has been clearly demonstrated in the development of a series of small mixers, consistometers and viscometers by Engineering Research Service (see references in Section 6.0).

In recent years the reduction in costs of the electronic apparatus required to detect and record torque electronically has made it economic to convert any instrument from a mechanical to an electronic dynamometer. One approach to this was to use a position transducer connected to the scale linkage. This gives the advantages of electronic recording, but the problems inherent in the scale mechanism remain. The best approach to date has been to use a strain gage transducer to prevent the motor casing rotating. The transducer thus detects the torque and its output can be amplified and recorded in a number of ways. This technique offers a number of immediate advantages:

1. The dynamometer mechanism is greatly simplified reducing the cost of manufacture.
2. Wear of components and maintenance required is reduced.
3. The instrument is more compact.
4. The dynamometer is far less prone to damage and can be shipped in its operating configuration.
5. The operational flexibility of the system is greatly increased because the dynamometer can be easily adjusted over a wide range of sensitivities to record large and small torques on any scale merely by adjusting two knobs on the amplifier.
6. Analog records are obtained on rectilinear charts which are easier to interpret than the normal curvalinear charts.
7. The accuracy and resolution of measurement are greatly increased. Operating accuracy of ± 0.1% can be easily achieved, and by selecting different electronic recording apparatus, resolution is virtually unlimited.
8. By selecting electronic recording apparatus with an appropriate frequency response, high frequency torque changes can be recorded accurately.
9. Because the motor casing only rotates a negligable amount to record torque, shear rates in the mixer or extruder are constant throughout the test and depend only on the rotational speed of the motor.
10. The methods available to record torque can be selected from a wide range of readily available equipment such as:
    a) analog - on a strip-chart recorder
    b) analog to digital on a printer, punched tape or magnetic tape.
    c) digital peak detection to show maximum or minimum values throughout the test.

d) analog or digital integration to directly record energy inputs Vs. time or rate of energy input or total energy input during a test.

e) the torque signal can be used in a feedback loop to automatically control the process (e.g. RPM, Temperature, etc.).

11. The viscous damper used to limit the oscilations of the mechanical dynamometer scale is eliminated. Damping is accomplished electronically and is thus a constant not a variable factor in the measurement.

12. The electronic recording apparatus can be used (in turn) with any of a series of instruments where torque, force or displacement must be measured. All that is required is to install an appropriate transducer in the system. The electronic apparatus used is the same for any size instrument.

13. The effects of friction in the dynamometer mechanism are minimized.

14. Accurate repeatable calibrations can be accomplished rapidly with simple attachments.

15. Because an electronic dynamometer can operate at high sensitivity, the size of instrument (mixer, viscometer, consistometer, extruder, etc.) can be reduced to allow the testing of very small samples a distinct advantage in some laboratory procedures.

16. Data can be reported in basic units of mass, length and time and the instrument calibrated in any desired units by using appropriate calibration attachments (e.g. English or Metric).

17. The new attachment permits connection of the instrument directly to a computer to record and manipulate the data during testing.

18. The increased precision of measurement and sensitivity facilitiates interlaboratory standardization and the study of the effects of experimental treatments at lower concentrations.

All the above points have been demonstrated with a number of instruments including the Farinograph, the Mixograph, the Amylograph, the GRL Mixer, commercial mixers of various sizes and viscometers (see Section 6.0).

The purpose here is to describe a means of converting a commercially available motor drive-dynamometer system to record electronically by installing a strain-gage transducer in place of the mechanical dynamometer.

There are a great number of transducer designs that could be selected for the purpose. The simplest to construct and install is a beam type which also gives a high degree of operational flexibility. Other alternatives (see Section 6.0) are either more costly or more difficult to install.

2. DESCRIPTION

The following description is based on the conversion of Plasticorders manufactured by C.W. Brabender Instruments Inc., South Hackensack, New Jersey. The basic principles discussed are, however, applicable to any existing rotational drive mechanism equipped with a mechanical dynamometer or to install a dynamometer on any rotational machine.

All the components relating to the mechanical dynamometer are stripped from the machine and discarded. This leaves the motor supported on the base by its outer case in bearings at each end. The bearings should be thoroughly cleaned and lubricated with a low viscosity oil. Thus, the motor casing is free to rotate.

A plate (P, Fig. 1) is bolted (using existing motor bolts) to the end of the motor (M) to facilitate connection of the transducer. A cantilever beam (B) is bolted to the base positioned so that its free end is immediately below one corner of the plate. The beam is made of ground tool steel. A vertical link (L) with ball bearings at each end is connected between the plate and free end of the beam. The length of the link is adjustable (left and right hand threads) and the attachment point on the plate is at exactly 10 cm radius from the motor center of rotation. Thus, the motor is prevented from rotating by the beam since the reaction torque of the motor is transmitted to the beam.

To detect the forces four strain gages are bonded to the beam close to the clamps holding it on the base (Fig. 2A). Two strain gages are bonded to each side so that when the link is pulled up by the motor reaction torque the top gages (1 & 2) are placed in compression and the bottom (3 & 4) are placed in tension (Fig. 2B). The four strain gages are connected to form a Wheatstone bridge (Fig. 3A) so that the resistive change of each gage is additive to maximize the output. The strain gages are protected by waterproofing compounds and a sheet metal cover over the beam.

The transducer is connected to the input module (Type 93) (I, Fig. 3B) of a strain gage-conditioning-amplifier (M) (Model 300D with zero center meter and rack mounting brackets, Daytronic Inc., Dayton, Ohio). These connections are made by installing a 5 pin Winchester plug on the 4 wire shielded cable from the transducer. An extension cord (4 wire shielded), with a 5 pin Winchester plug on one end and a 6 pin MIL plug (supplied with amplifier) on the other, connects the transducer to the amplifier input module. All connections to the plugs are made according to the E.R.S. standard wiring code (Fig. 4).

The amplifier output is connected to a laboratory strip chart recorder (R, Fig. 3B) of the potentiometric type with an input range of about 10 mV. Most recorders are satisfactory for the purpose, but the general purpose multichart speed multi-input range with zero and span control is the best choice, as they offer operational flexibility at modest cost.

Thus, the transducer is installed on the base (Fig. 5), and when the motor is driving a load, the reaction torque is imposed on the beam. This changes the resistance of the strain gages which, in turn, is converted to a millivolt signal by the amplifier which can be recorded on the strip chart.

Since the torque input is most likely to fluctuate rapidly about some mean value, and generally the mean value is the reading of major interest, signal damping is required. This is accomplished by installing an electronic filter in the recorder input circuit (by the recorder manufacturer) to increase the pen response time. A full-scale response time of about 7 sec is generally satisfactory. The filter is arranged so that it can be switched out of the circuit if a fast response is required.

The dynamometer is calibrated with weights. A lever hooks on to pins in the plate to project horizontally on the opposite side of the motor to the transducer (Fig. 6). The radius of this lever is 50 cm (0.5M), thus, selected torques can be applied to the dynamometer by placing appropriate weights at this radius.

3. OPERATING INSTRUCTIONS

3.1 Setting up for Calibration

1. Disconnect the load (mixing bowl or extruder, etc.) from the motor drive.
2. Connect the transducer to the amplifier and the amplifier to the recorder.

3. Set the amplifier range switch to "standby" and switch on the amplifier and recorder. Allow a 20 min warm up time.
4. Level the machine and the level the calibration lever by adjusting the length of the link connecting the transducer to the plate on the motor. The link has lock nuts which should be tightened when levelling is completed.

3.2 Preliminary Amplifier Adjustments

Each time a transducer is connected to an amplifier the amplifier must be adjusted to compensate for the characteristics of the transducer and the wire connecting it to the amplifier. Once this procedure is completed, it need not be repeated except for occasional checks unless a different transducer is connected.

Note: The amplifier controls are 10 turn.

1. Set the sensitivity control to a minimum, i.e. full ccw and the R (zero) and C controls to their mid position.
2. Move the range switch to Null.
3. Adjust the R (zero) and C controls until the meter reading is minimized.
4. Continue this procedure while increasing sensitivity until the minimum meter reading (less than 2%) is obtained at maximum sensitivity.
5. Return sensitivity control to its mid position.

3.3 Calibrating Dynamometer

1. Install calibration lever (see Fig. 6)
2. Select the torque required for full-scale pen deflection. The calibration weight required in grammes is then twice this value in meter grammes, i.e.

$$\begin{aligned} \text{Torque} &= \text{force} \times \text{radius} \\ &= \text{Force (g)} \times 50 \text{ cm g} \\ &= \text{Force (g)} \times 0.5 \text{ Mg} \\ \text{or Force} &= 2 \text{ Torque Mg} \end{aligned}$$

3. Refer to Table 1 and set the recorder and amplifier range switch at the appropriate positions.
4. Adjust the amplifier zero control until the recorder reads zero.
5. Place the required weight on the end of the calibration lever.

Note: Positioning of the weight is critical as torque is proportional to radius.

6. Repeat steps 4 and 5 in an iterative process until the recorder reads correctly at zero and full-scale.

Note: If the recorder is also equipped with zero and sensitivity controls, these can be used as "fine" adjustments during the procedure.

7. Remove the calibration lever and readjust zero to compensate (i.e. tare) for this change in torque.
8. The dynamometer is now ready for operation.

Note: If insufficient weights are available, the calibration can be made at zero and some portion of the full scale reading (e.g. 50% or 25%). This will degrade the accuracy of calibration slightly.

3.4 Use of Zero Suppression

In some applications readings over the entire calibrated range may not be of interest, but it may be necessary to record the upper portion over full span of the recorder. For example, in a recorded range of 1000 Mg the portion of interest may lie in the 500 to 1000 Mg range which, to maximize resolution, should fill the chart span. This is accomplished as follows:

1. Calibrate the recorder so that the span equals the range that is to be recorded (e.g. R Mg) using the above procedure.
2. Select the torque that is to be the minimum of the recorded range (M, Mg) and set the amplifier zero suppression dial to this reading (e.g. 500 Mg = 500 units on the dial).
3. Place a weight on the lever to apply a torque of M Mg to the dynamometer. The pen will go up scale.
4. Move the suppression switch from off to + or - and leave it in the position which makes the pen come down scale.
5. Adjust the suppression span until the recorder reads zero.
6. The recorder range should then be checked by adding a weight to apply M + R Mg which should bring the pen to full scale.
7. Remove the weights and lever and move the suppression switch to off and readjust the zero control until the pen is at zero.
8. The system is now calibrated so that:

Suppression Switch	Recorder Range Mg
Off	0 to R
On (+ or -)	M to R

<u>Note:</u> When the suppression switch is on and the torque is less than M, the recorder pen will be driven to the zero end the servo drive will keep attempting to drive it to less than zero. This condition should not be allowed to continue for long periods or the recorder will be damaged. Move the recorder range switch to "zero" or switch the suppression off until the torque exceeds M Mg.

3.5 Other Operating Adjustments

If the recorder pen moves in the wrong direction for increasing torque (either way can be selected as correct), the direction can be reversed by interchanging the green and white wires at one of the plugs in the transducer lead.

4. TYPICAL PERFORMANCE

Four machines have been converted as described. The performance of the dynamometers was evaluated as follows.

After calibration the linearity of the relationship between torque and recorder pen deflection was established by applying weights to the calibration lever from zero up to the maximum in increments. This was done for a number of ranges. The results (Table 1) indicate the linearity is within ± 0.1% of full-scale reading in the worst cases observed for full-scale torques ranging from 500 to 10,000 Mg. Similar results were obtained when operating with zero suppression. Some hysterisis was introduced under static conditions by friction in the bearings supporting the motor housing. This was eliminated during calibration by tapping the base of the machine. This problem does not occur when the motor is running as the vibration overcomes the friction.

It was concluded that calibration and repeatability of the dynamometer system could easily be maintained within ± 0.2% with careful techniques this could be reduced to ± 0.1%.

A typical record of the torque required to operate an extruder is shown (Fig. 7) to demonstrate the system.

5. CONCLUSIONS

The work described plus a number of years experience operating electronic dynamometers with Farinographs and extruders leads to the conclusion that the electronic dynamometer is superior. It is definitely more accurate, simpler to manufacture and easier to operate.

Cost savings are predictable as follows.

An amplifier costs $615 on a one off basis. O.E.M. discounts and bulk purchasing should reduce this by at least 20%, i.e. the amplifier would thus cost about $500.

Strip-chart recorders are available in many types at a wide range of prices. A suitable unit costs about $560 and with O.E.M. discounts etc. cost should be about $450. This cost could be further reduced if a recorder built specifically for the O.E.M. market with one millivolt range (10 mV), and a single chart speed for incorporation into the chassis of the dynamometer system was selected. Prices as low as $200 have been cited for such items.

The cost of the transducer ready to install on the machine and connect to the amplifier is estimated at $120.

Thus, the total cost of the electronic dynamometer components is about $1200 . One only has to see the large number of parts that are eliminated by discarding the mechanical dynamometer to realize that this cost is offset by savings in manufacturing costs.

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Table 1. Typical setting of amplifier (Daytronic 300D-93) and recorder (Riken Denshi SP5V) range controls to obtain different recording sensitivities showing maximum observed non-linearities in relationship between torque and pen reading. Test results for 2 machines, a type D3002 3 HP (FRI) and a type PL3S plasticorder.

Torque	Calibration weight at 50 cm radius	Range switch settings		Maximum observed non-linearity
		Daytronic	Recorder	
Mg	g	%	mV	± %
500	1,000	20	10	0.1
1,000	2,000	50	10	0.1
1,500	3,000	50	10	0.1
2,000	4,000	100	10	0.1
2,500	5,000	100	10	0.1
5,000	10,000	100	10	0.1
10,000	20,000	100	10	0.1

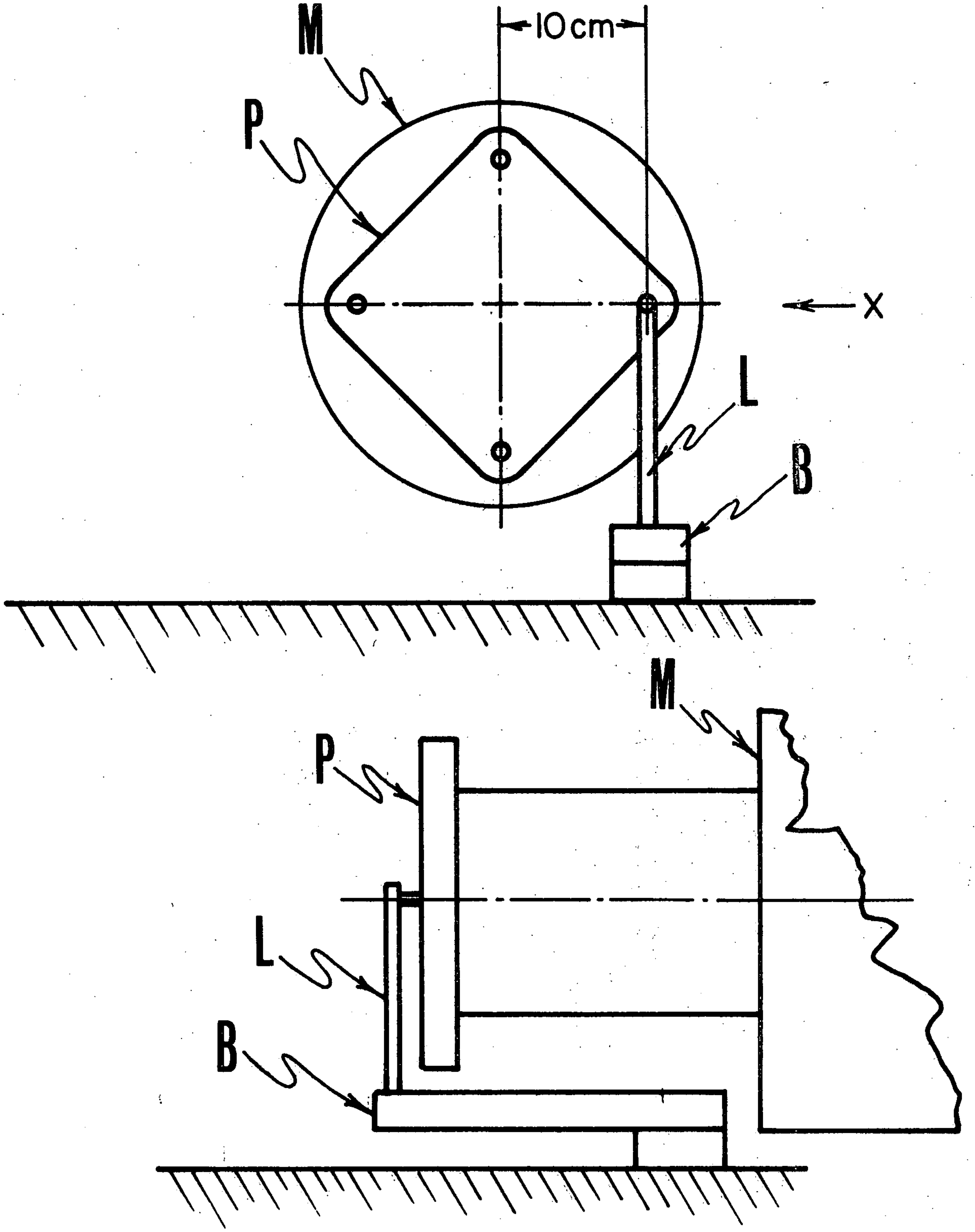


FIG. I

VIEW X

Figure 1. Diagram of dynamometer installation. B. tool steel beam forming transducer; L. link connecting transducer to plate; M. motor casing; P. plate bolted to end of motor.

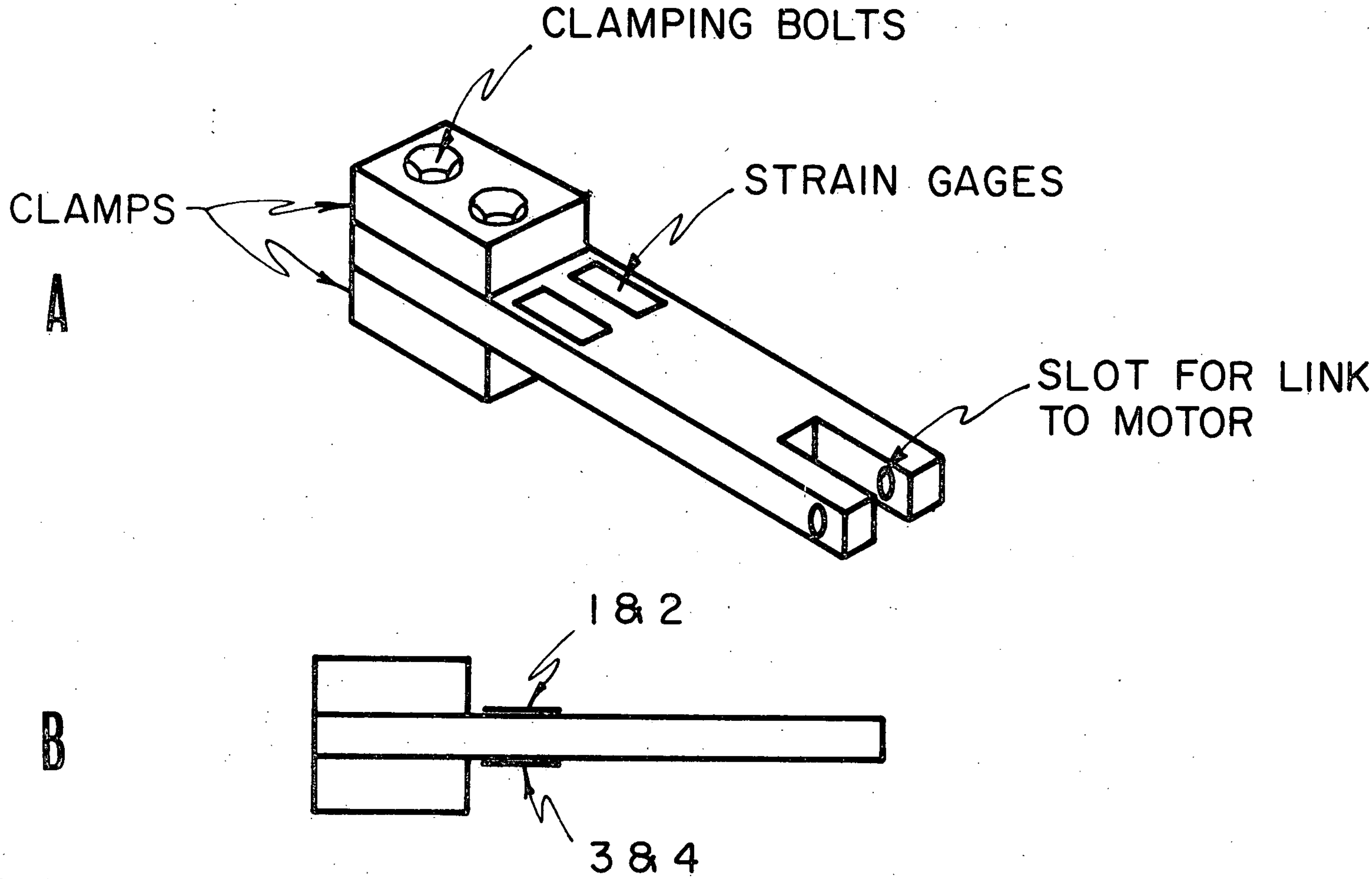


FIG. 2

Figure 2. Strain gage installation.

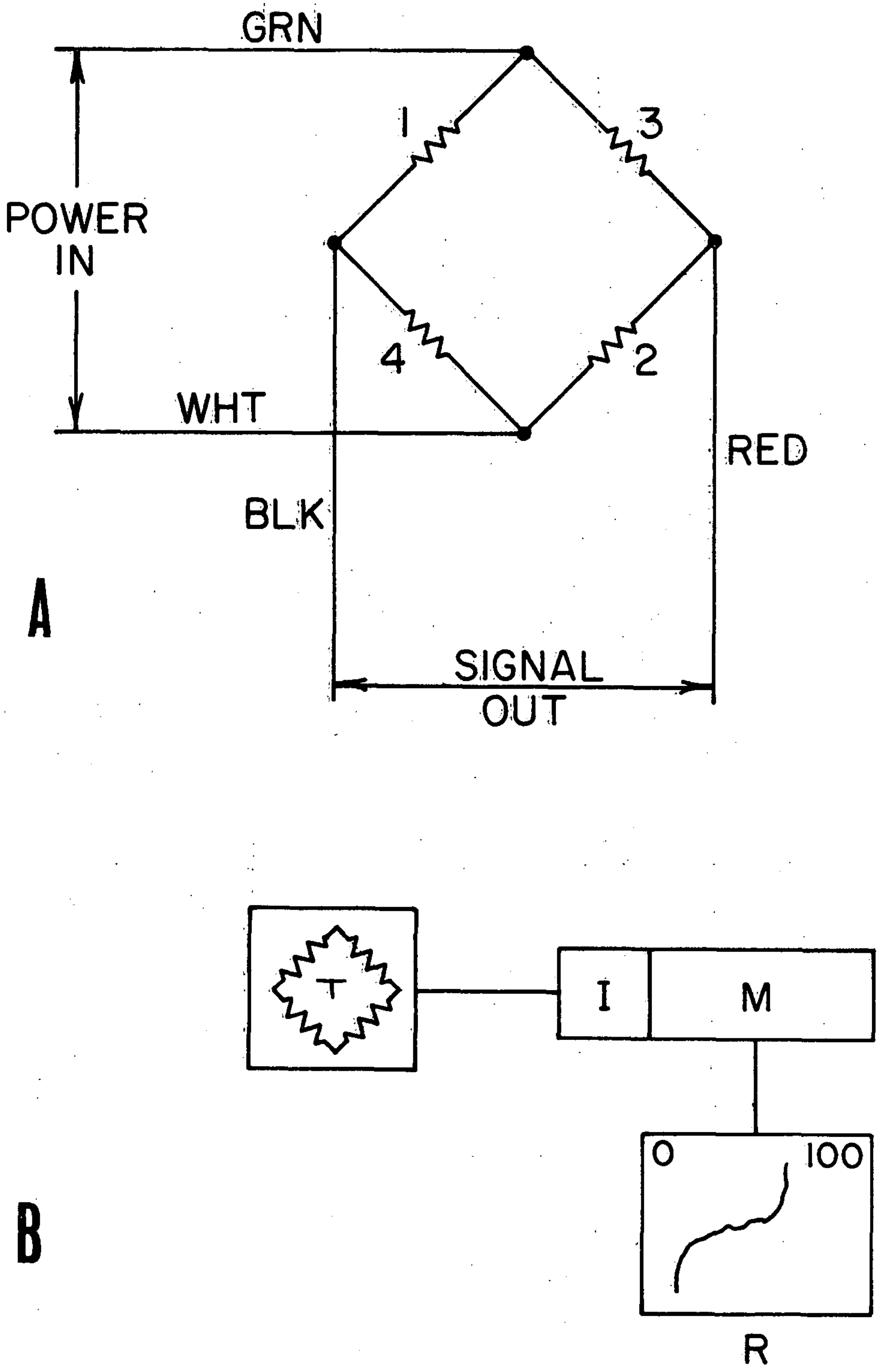
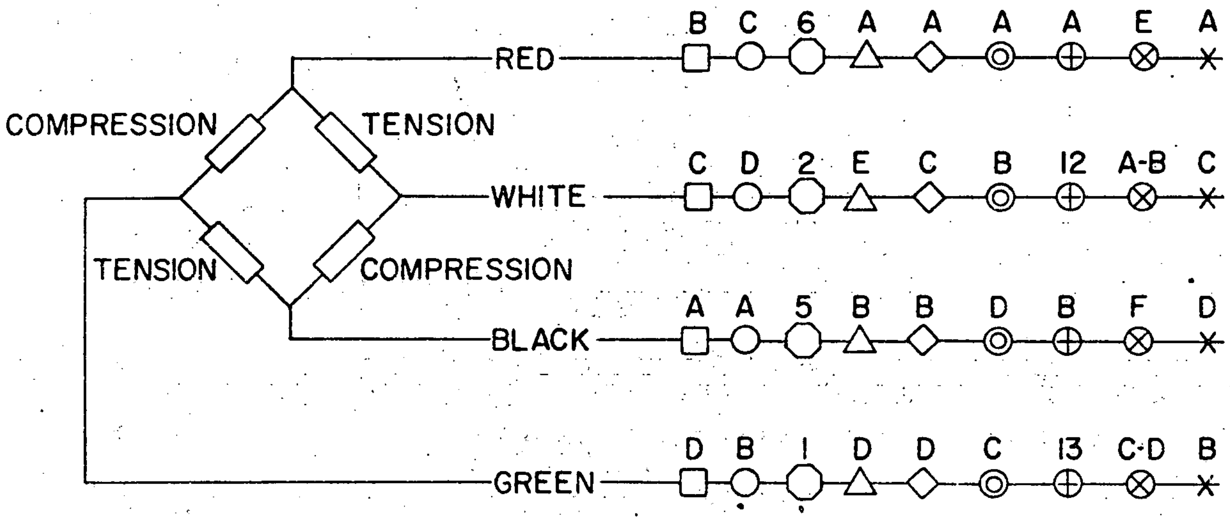


FIG. 3

Figure 3A. Strain gages connected in a Wheatstone bridge circuit. B. schematic diagram of recording system; T. transducer; I. input module (Model 93 Daytronic Inc.); M. strain gage amplifier (Model 300D Daytronic Inc.); R. recorder 10 mV.



STANDARD BRIDGE CIRCUIT CONNECTIONS

POWER TO BRIDGE-GREEN AND WHITE
BRIDGE OUTPUT-BLACK AND RED (SHIELDED)

○ CONNECTIONS TO DAYTRONIC 300C TYPE 80, 81 AND 82 PLUG IN MODULES ⏚E
□ " " ELLIS BAMI AND BI
⬡ " " ENDEVCO SRB 200 ⏚16
△ " " 5 PIN WINCHESTER (H SHIELD)
◇ " " MASSA CARRIER AMP. PR401 AND OFNER TYPE 9803 AND 9825 COUPLERS ⏚E
◎ " " PHOTOTRON CARRIER S2
⊕ " " SANBORN CARRIER AMP. 8805A-1 ⏚18 AND SHELL OF J5
⊗ " " DAYTRONIC 300D TYPE 90 TO 93 PLUG MODULES (SHIELDED TO PLUG BODY)
✱ " " STRAINSERT LOAD CELL

Figure 4. E.R.S. Standard strain gage wiring codes.

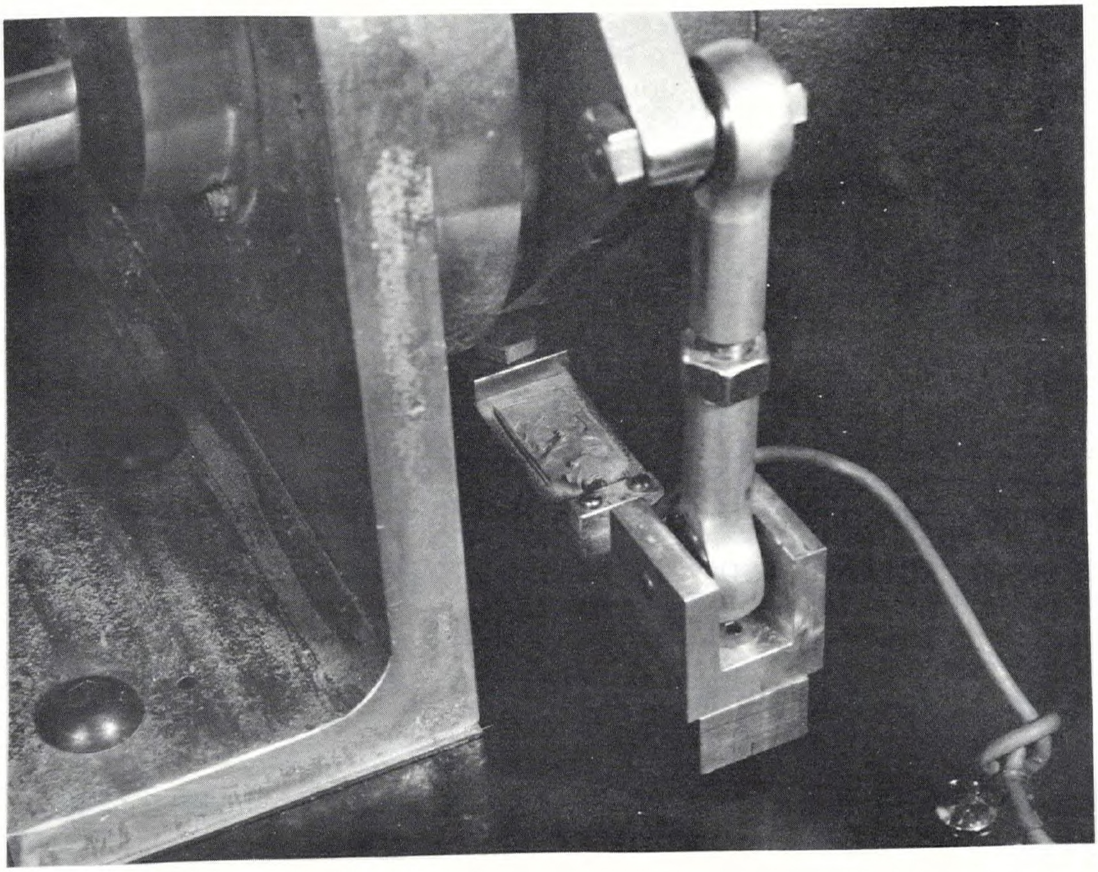


Figure 5. Typical transducer installation.

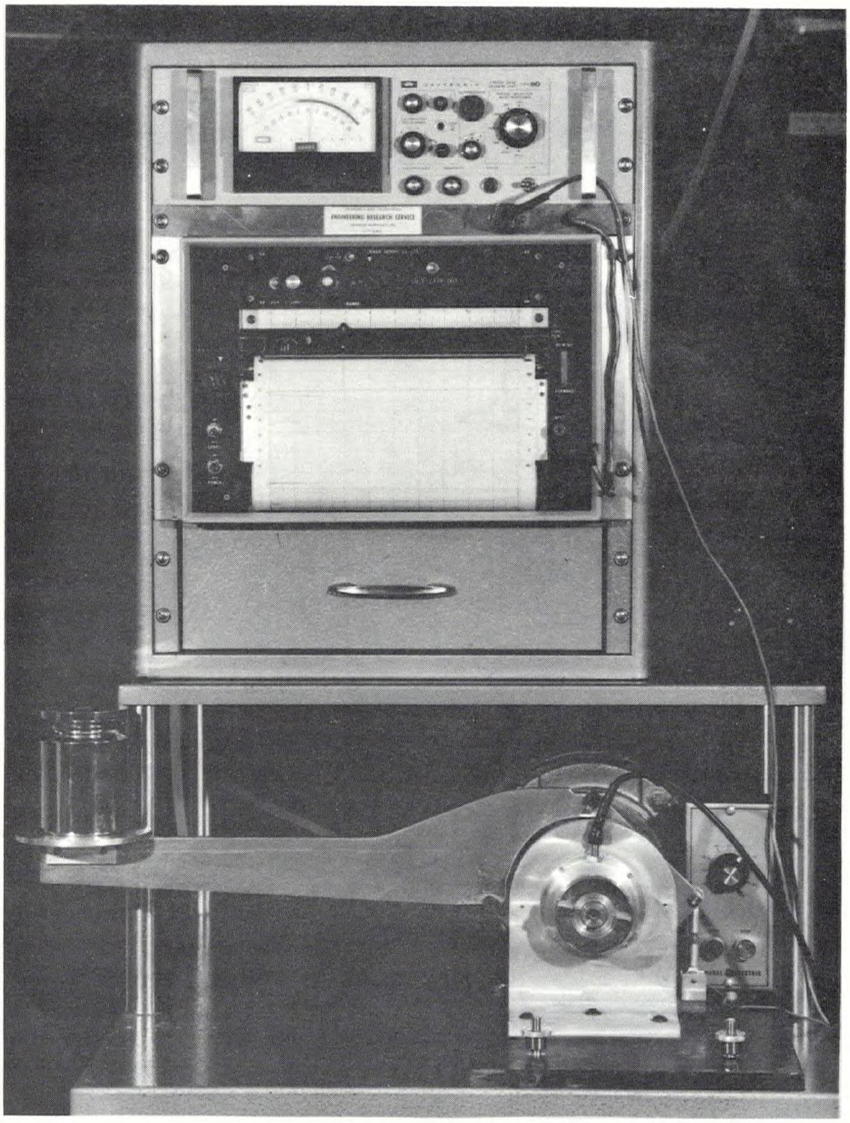


Figure 6. Over-all view of a converted machine showing the calibration lever in place and the electronic recording system.

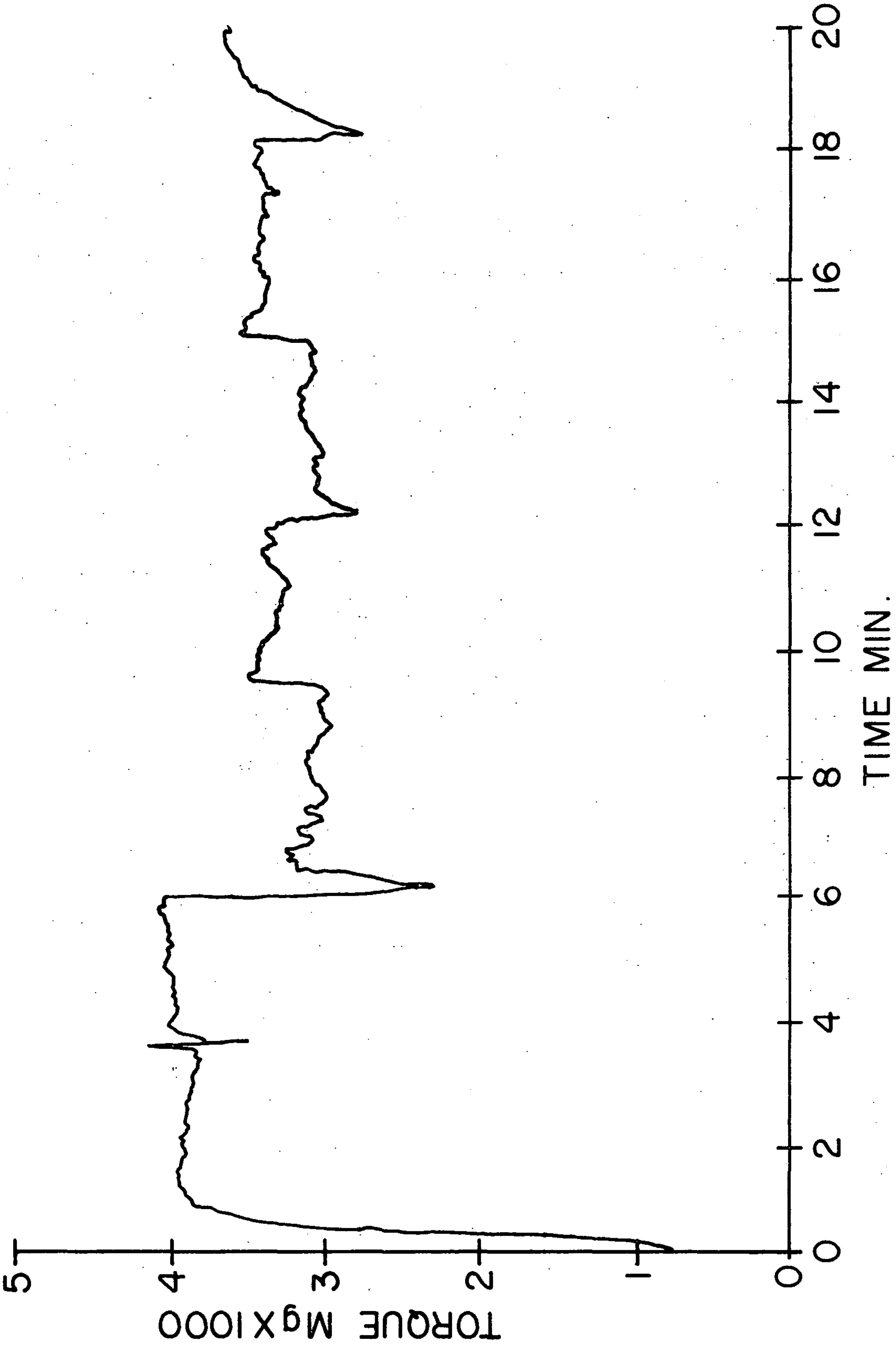


Figure 7. Typical torque-time record obtained in extruding rice flour. Each step in torque record corresponds to a change in RPM or extrusion temperature.

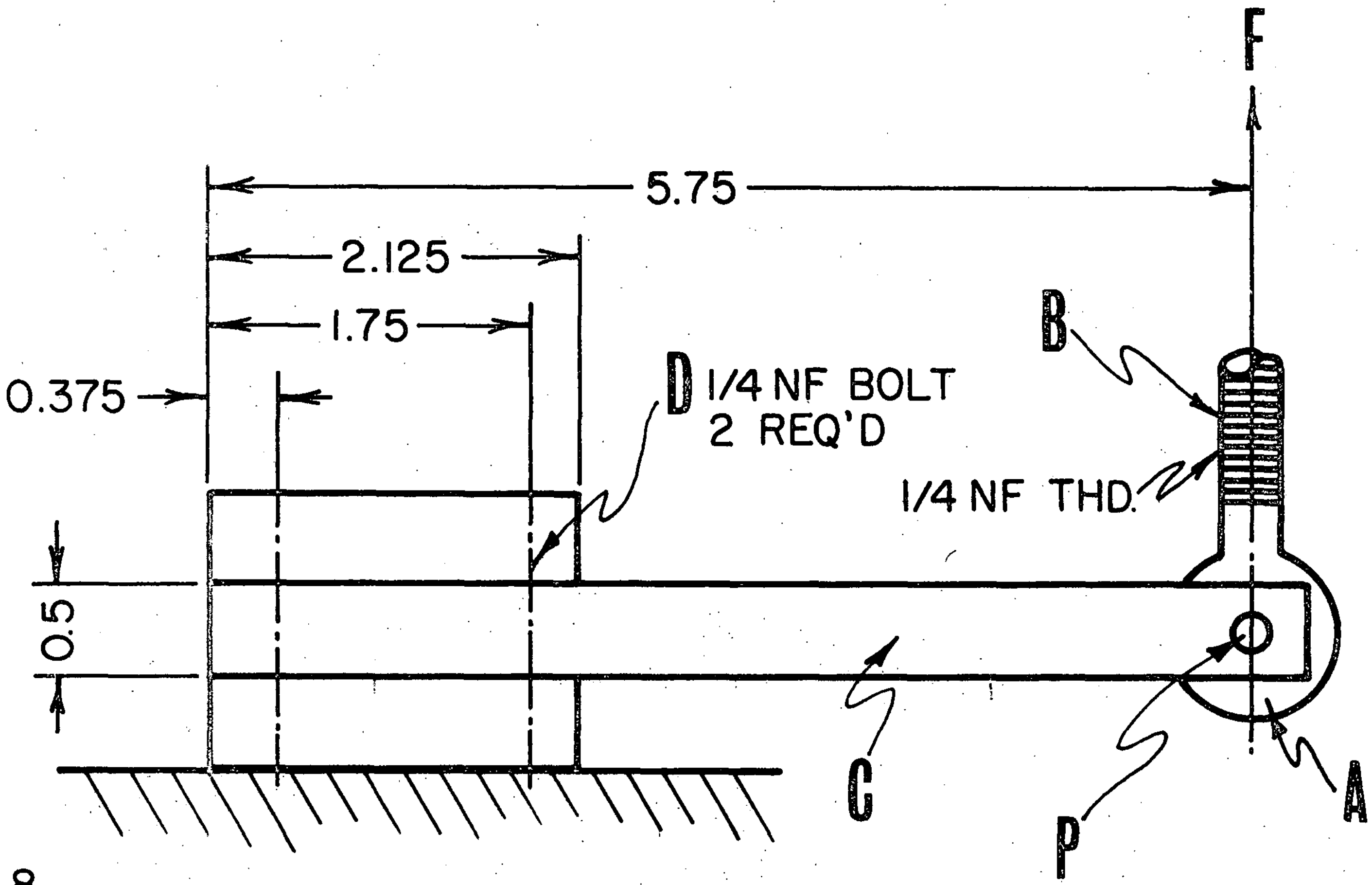


FIG. 8

Figure 8. Dimensions of transuducers installed on 3 HP Plasticorders. A. ball bearing rod ends; B. adjustable link; C. transducer made of 1 x 0.5 in tool steel; D. clamping bolts; F. force due to reaction torque of motor; P. 0.19 in pin.