TABLE I. Gear schedule and cup speeds.

Gear set	Position	Gear	At drive position: Axel gear	At drive position: Transmission gear	Calculated at cup	Maximum rpm (Motor—3450 rpm, Tachometer—100 rpm): Measured at tachometer	Maximum rpm: Measured at cup[a]	Maximum shear rate (sec^{-1}): Cylinder set #1 $\dot{s}=(0.965n)$	Maximum shear rate (sec^{-1}): Cylinder set #2 $\dot{s}=(2.245n)$
	1	48	Direct		367	1092±6	362±2	349	809
1	2	16	couple						
	1	48	Direct		733	1092±6	730±3	704	1632
2	2	32	couple						
	1	48	Direct		1100	1092±6	1097±3	1062	2459
3	2	48	couple						
	1	48	Na16B	NA20B	458	1092±6	455±3	439	1017
1	2	16		NA40B	917		911±3	879	2036
	1	48	NA16B	NA20B	917	1092±6	911±3	879	2036
2	2	32		NA40B	1833		1830±6	1766	4090
	1	48	NA16B	NA20B	1375	1092±6	1370±5	1327	3073
3	2	48		NA40B	2750		2750±10	2654	6146

[a] Using maximum rpm *measured* at cup.

build up. It also enables one to switch to a "hold" (constant shearing) at any desired shear rate. The resistor above the speed meter (R_4 in Fig. 9) controls the needle's maximum deflection for different maximum shear rates. The resistor labeled Y controls the Y axis of the recorder and enables one to expand or compress the Y component (shear rate) of the flow curve.

An "auxiliary" tachometer was used to calibrate the viscometer's tachometer and cup rpm. Figure 6(a) gives the tachometer-meter readings, with a direct couple at the drive position, for the helical gear sets 1 and 2 (Table I).

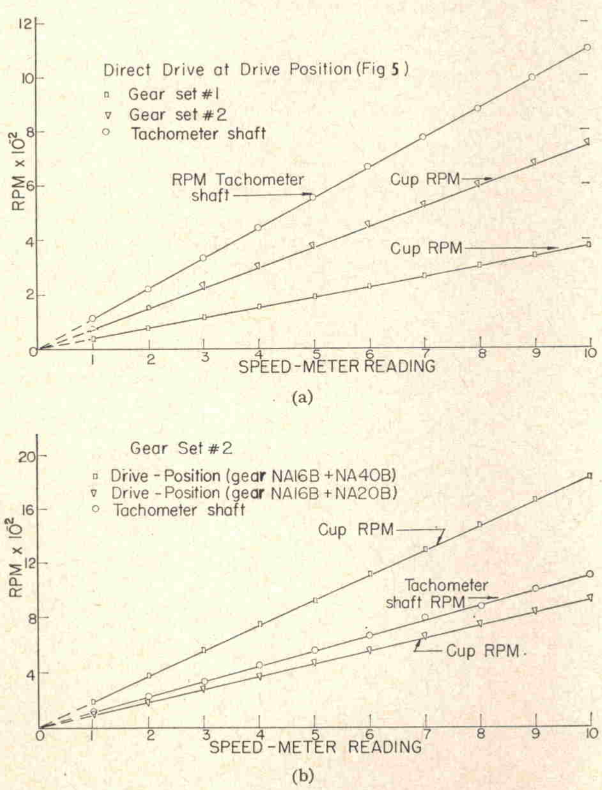

FIG. 6. Calibration of speedmeter readings versus rpm for two sets of gears at drive position.

The difference between the rpm at the tachometer shaft and that at the cup results from the ratio of helical gear G_1 to G_2 (Fig. 5).

Figure 6(b) gives the meter calibration for various rpm when using helical gear set #2 at the G_1-G_2 positions, and the noted gear combinations at the drive position. Table I gives the measured rpm maxima.

2. Cylinder Sets

Two cylinder sets consisting of one cup and two bobs are designed (Fig. 4) with the dimensions given in Table II. This design keeps the end effects negligible. The appreciable enlargement of the cup diameter at both ends of the meaningful length h of the annalus makes "outside" forces negligible when compared with the forces exerted on the bob within length h.

Streamline flow in the cylinder involves the orderly motion of liquid in circular paths concentric with the cylinder, with velocities increasing from zero at the surface of the bob to a maximum at the cup. The clearance between cup and bob (R_c-R_b) is kept as small as possible since (a) the distribuiton of shear stress within the material being sheared varies inversely with the square of the radius and (b) heat dissipation from the sample during shear is more rapid.

The maximum $(\mathrm{Re}_{\max})$ Reynolds numbers for the two cylinder sets are given in Table II. The Reynolds numbers $\mathrm{Re}_{\max}$ are calculated for the rotational speed of 1800 rpm

TABLE II. Dimensions of Reynolds numbers and shearing-stress limits of two cylinder sets.

Cylinder set	R_c (cm)	R_b (cm)	R_c-R_b (cm)	R_b/R_c	h (cm)	$\mathrm{Re}_{\max}=2\pi nR_c^2\times[1-(R_b/R_c)]\rho/\eta^{a}$ ($n=1800$ rpm)
1	1.785	1.580	0.205	0.885	6.89	985
2	1.785	1.700	0.085	0.952	6.89	412

[a] $\eta=0.07$ P, $\rho=1$ g/cm³.

(Gear set #2, Table I). The data indicate that Re_{max} is well within the limits of the critical values for turbulent flow.[18,19] Using Eq. (8) and the ratio of R_b/R_c from Table II, the shear rate $\dot{s}$ is found to be $0.965n$ and $2.235n$ for cylinder sets #1 and #2, respectively, where n is the variable rpm.

3. Transducer Calibration

The output of the transducer reflects the instantaneous torque values for the flow curves which are plotted by the X–Y recorder. The accuracy of the plotted torque depends primarily on the precision of transducer operation, which in turn depends to a large extent on the calibration. Various methods[20] of calibration can be used equally well. One is given below.

The current and voltage available from the transducer for the recorder, Fig. 7, are given by the following equations:

$$I_r = SnE/R_{23}+R_r \qquad (17)$$

$$E_r = SnER_r/R_{23}+R_r. \qquad (18)$$

For $R_r \gg R_{23}$, Eq. (18) becomes

$$E_r = SnE_r. \qquad (19)$$

The values of S (sensitivity), R_{23} (output resistance), and E (excitation voltage) are obtained from the transducer data sheet which is supplied by the manufacturer. R_r is the resistance of the recorder and n is the number of units of the variable for which the output is computed.

Equations (17) and (18) are applied for a current or voltage measuring instrument, respectively. Equation (19) is applied when the voltage measuring instrument is of a high impedance.

In the given calibrating circuit Fig. 7, the resistor R_c can be chosen to give the desired fraction of full range output from the relationship

$$R_c = [(10^6/4nS) - 0.5]R_{23}. \qquad (20)$$

The number of scale units n which will be produced by a given value of R_c is given by

$$n = 10^6/4S(R_{23}/R_c + 0.5R_{23}). \qquad (21)$$

Following the above calibration, a "response" check should be made on the transducer. Figure 8 gives the responses of two transducers to loading and unloading. No detectible difference for the "up-down curve" is shown, signifying reproducibility of the transducer to greater or lesser shearing force. This check should be made, especially if transducer had been over-loaded.

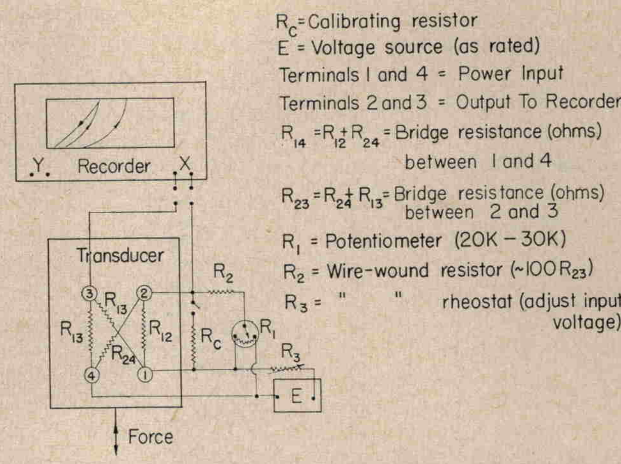

FIG. 7. Schematic of circuit for transducer calibration.

4. Shear Rate Recording

The drive motor is directly coupled through the transmission by the driving rod, Fig. 5, to a dc model D

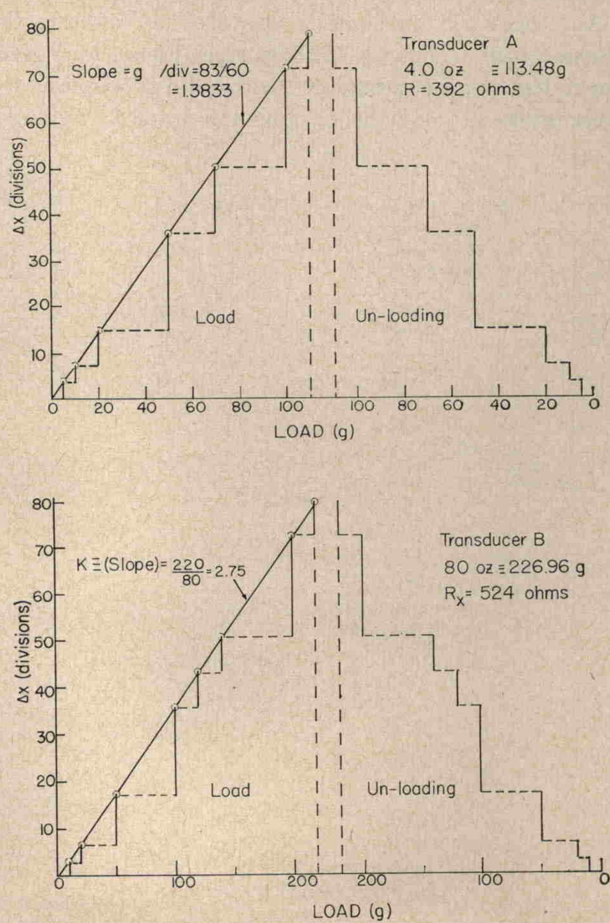

FIG. 8. "Histograms" of transducer response to loading and unloading for constants, k.

[18] G. I. Taylor, Proc. Roy. Soc. (London), A157, 546 (1936).
[19] G. I. Taylor, Proc. Roy. Soc. (London) A157, 565–578 (1936).
[20] Detailed information on controlling the translation of the force, which is applied to the strain sensitive resistance wires in the transducer, into an exact electrical equivalent can be found in the following "Statham" bulletins and notes: 1. Transducer Element, Bulletin No. 1.0; 2. Selection Table (model G1), Bulletin No. 1.1; 3. Selection Table (model G7), Bulletin No. 1.3; 4. Calibrating Resistors, Bulletin No. 600; 5. Indicating and Recording, Instrument Note No. 4.