Dynamometer For Hydraulic Pumping Systems

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Webster's definition of the word "dynamometer" is—"an apparatus for measuring power". One definition of power is "force or energy applied or applicable to work". Work is defined thus—"Work is done when there is movement against a resisting force or when a body is given acceleration; it is measured by the product of the force and the displacement of its point of application in the line of action".

In this light, any type instrument created to measure power could be called a "dynamometer". The reason the term "hydraulic dynamometer" was chosen was because (1) that part of the assembly was a sucker rod dynamometer and (2) whatever the apparatus looks like, it is still for measuring power in a hydraulic system.

At this time, there is no way to accurately measure this power directly. It is highly desirable to be able to do so.

In the late 1950's Johnson-Fagg, Inc. became involved in hydraulic pumping. In the development of the hydraulic pump, it became necessary to know more about the pump's mechanical reaction to pressure. They had developed the sucker rod dynamometer, so it was natural to think in terms of the mechanical linkage device to solve their problem.

In the January 1961 issue of WORLD OIL, the Johnson-Fagg Chief Engineer, Mr. John B. Woods authored an article titled "How to Improve Your Hydraulic Pumping Operations". This article has a diagrammatic sketch of this arrangement of equipment as shown in Fig. 1.

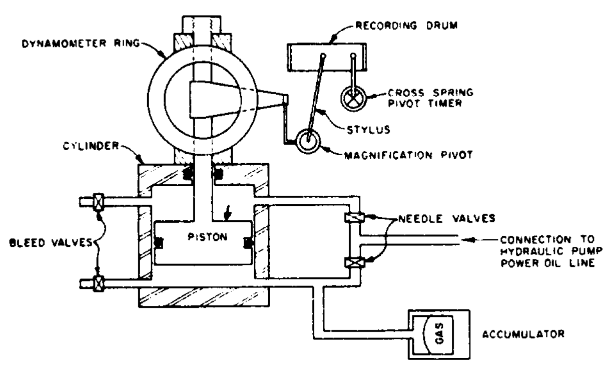

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FIGURE 1

The hydraulic dynamometer consists of a ring type dynamometer in series with a piston in a hydraulic cylinder. When hydraulic pressure is applied to the cylinder, the resulting force on the piston is transmitted to the dynamometer ring and thereafter recorded on a chart. A cross spring pivot timer measures the chart speed. The piston in the load cell is balanced in such a manner as to reflect the pressure change due to operation of the bottom-hole hydraulic pump.

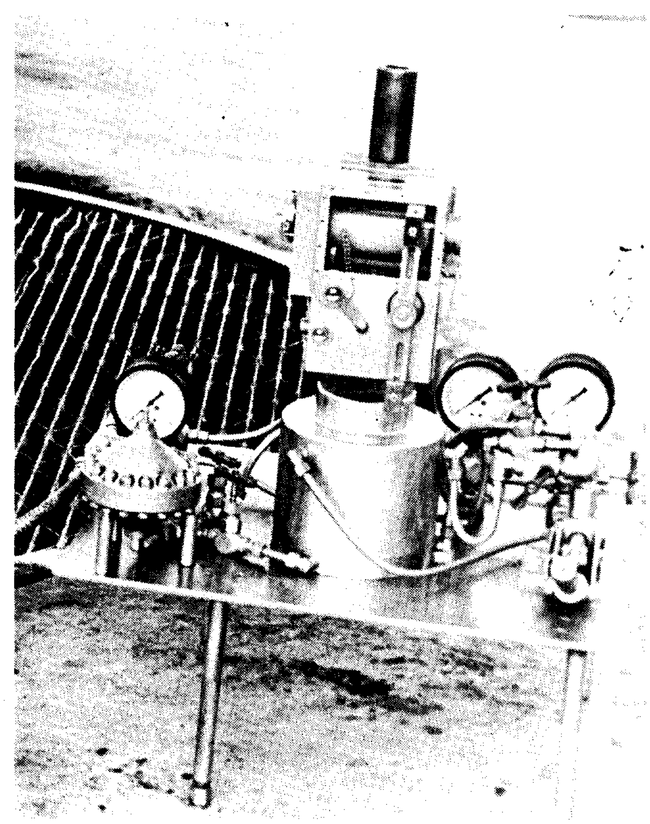


FIGURE 2

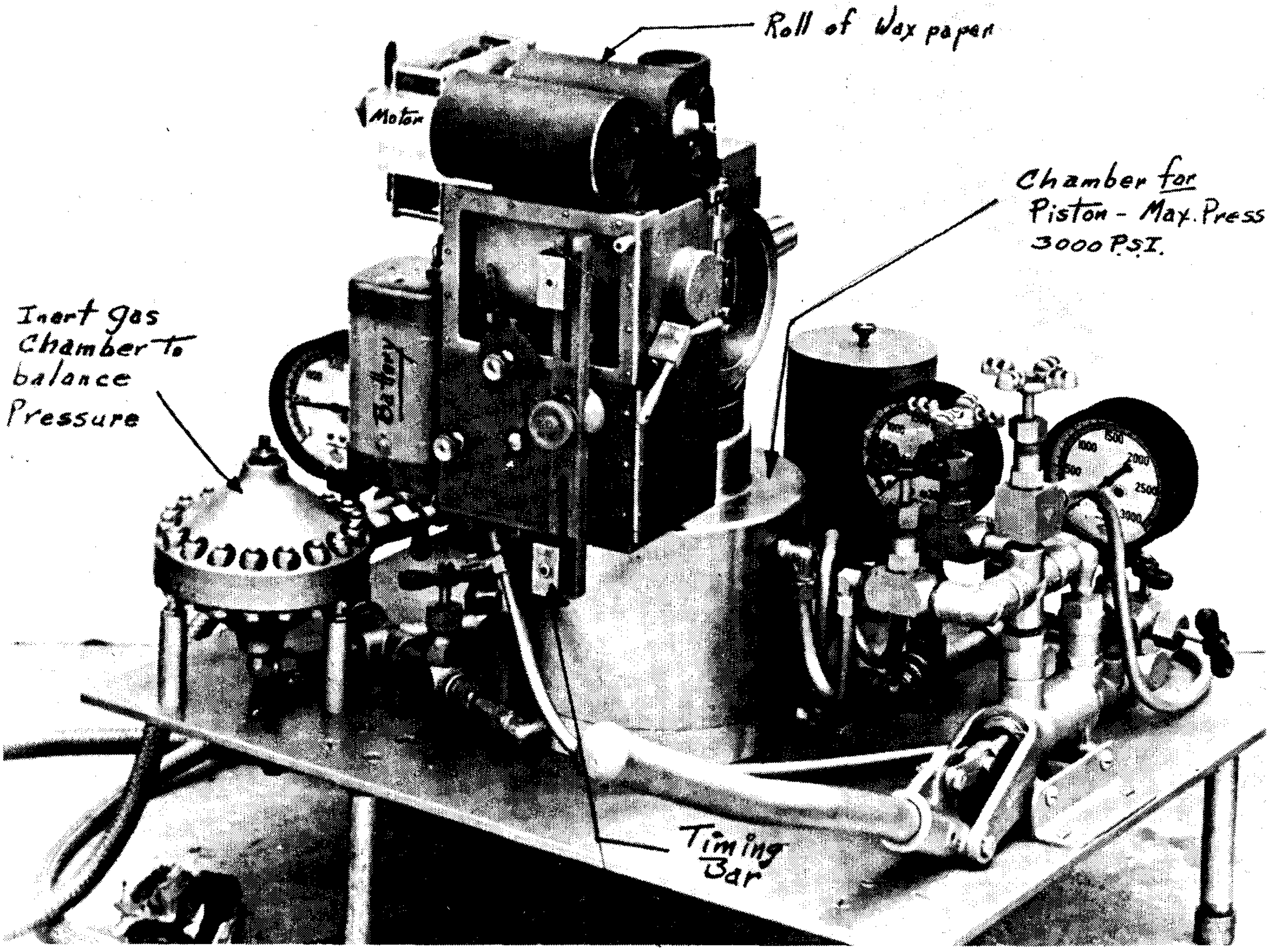


FIGURE 3

Figure 2 shows the original instrument arrangement as it is hooked to the discharge side of a wellhead on a hydraulic installation; it will operate on the power end also. It can be seen that this is a standard dynamometer with the standard strip-size chart operated with a timer instead of a string to rotate the chart drum.

The eight-inch chart was insufficient to time and adjust the equipment to the best operating arrangement, so it was necessary to install a roll of wax paper which would make a continuous chart and was operated by a battery and motor. This is illustrated in Fig. 3. The "timing bar" vibrated at a speed of 7-1/2 cycles per second to indicate time.

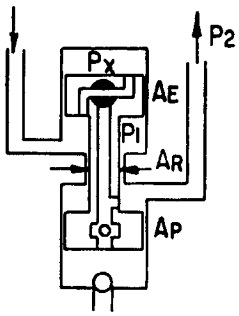
This instrument was used for several years in the study of hydraulic pumping equipment. Mr. Woods, in his article, gave the complete sample calculation for a single-acting pump filled and fully cavitated, Fig. 4. With these calculations, Mr. Woods was able to calculate the "time" involved in pump movement and valve action. From this came calculation of fillup, etc. (It will be noted that an orifice diameter size is necessary for these calculations.) The dynamometer was then used to check the calculations. It was found that from these bits of information, many things about design and operation could be predicted. Figure 5 is representative of three different types of pumps as recorded with this

PUMP DATA

Strokes per min. = 21.9
Triplex Pressure = 3500 psi
Size 2 × 1⅝ × 1¼ × ⅝ × 49
Orifice = 3/16" = .0276 Sq. In.

WELL DATA

Depth = 10,000 ft.
Production = 50 bbl water — 47 oil
Pump end Efficiency = 55.7%
Wt. Production Fluid .362 psi/ft = 3620 psi
Wt. Power Fluid = .35 psi ft.
= 3500 psi



A_E = Area Engine Piston = 2.074 sq. in.
A_R = Area Middle Rod = .358 sq. in.
A_P = Area Pump Piston = 1.227 sq. in.
P_T = Triplex Pressure = 3500 psi
P_1 = Pressure under engine piston = P_T + weight power fluid
P_2 = Weight production fluid
P_X = Pressure above engine piston to establish equilibrium of forces on piston assemblies while pump is on downstroke

DOWNSTROKE ALL FLUID UNDER PUMP PISTON

$$\uparrow P_1 (A_E - A_R) + A_R(P_2) = P_X (A_E) \downarrow$$
$$7000 (2.074 - .358) + .358 (3620) = P_X (2.074)$$
$$P_X = 6380 \text{ psi}$$
$$\Delta P \text{ Below and Above engine piston} = P_1 - P_X = 7000 - 6380 = 620 \text{ psi}$$
$$V = 7.944 \sqrt{\Delta P} = 7.944 \sqrt{620} = 196 \text{ft/sec}$$
$$= 2350 \text{ in./sec.}$$
$$Q = VA = 2350 (.0276) = 64.8 \text{ cu. in./sec.}$$

Amount of fluid to flow through orifice = 2.074 × 49 = 101.63 cu. in.

$$\frac{101.63}{64.8} = 1.566 \text{ sec. for Downstroke}$$

DOWNSTROKE NO FLUID UNDER PUMP PISTON

$$\uparrow P_1 (A_E - A_R) = P_X (A_E) + P_2 (A_P - A_R) \downarrow$$
$$7000 (2.074 - .358) = P_X (2.074) + 3620 (1.227 - .358)$$
$$P_X = 4280 \text{ psi}$$
$$\Delta P \text{ Below \& Above engine Piston} = P_1 - P_X = 7000 - 4280 = 2720 \text{ psi}$$
$$\text{Velocity} = 7.944 \sqrt{\Delta P} = 7.944 \sqrt{2720} = 414.0 \text{ ft/sec.}$$
$$= 4960 \text{ in./sec.}$$
$$Q = VA = 4960 (.0276) = 137.0 \text{ cu. in./sec.}$$

Amount of fluid to flow through orifice = 101.63 cu.in.

$$\frac{101.63}{137.0} = .742 \text{ sec. for Downstroke}$$

Downstroke time no fluid	=	.742 sec.
Downstroke Time all fluid	=	1.566 sec.
Pump End Efficiency	=	55.7%

.557 (1.566) = .872
.443 (.742) = .328
1.200 Theoretical downstroke time
1.370 — Actual downstroke time

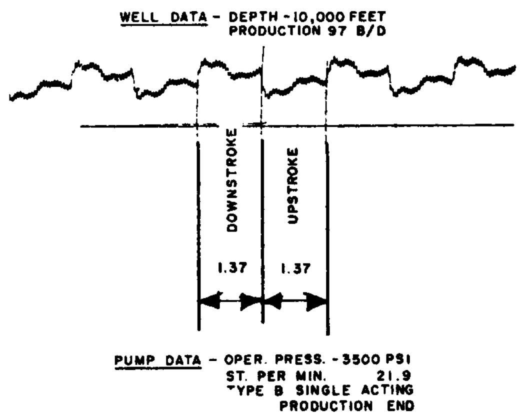


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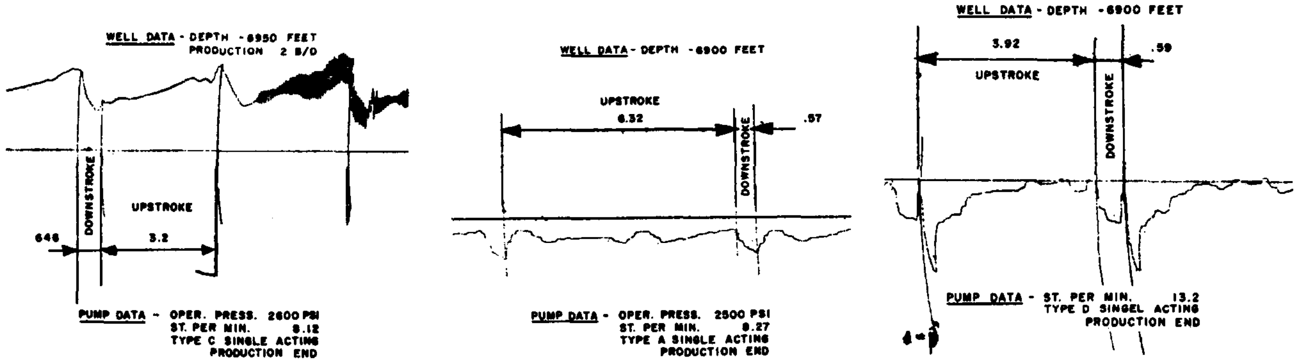
FIGURE 4

Here is a complete sample calculation for a dynamometer card taken on a single acting pump completely filled and fully cavitated.



A B C

CARD 5A

PUMP DATA		WELL DATA	
Strokes Per Minute	= 8.12	Depth	= 6950 Ft.
Operating Pressure	= 2600 PSI	Production	= 2 B/D
Size 2½ × 1¼ × 1½ × ⅝ × 58¾		Wt. Production Fluid	= 40° Gravity
Orifice Two 3/16 Holes — No Control			= 2480 PSI
		Wt. Power Fluid	= 2480 PSI

$\frac{141.5}{247} = .573$ Sec. Downstroke Time

.646 Sec. Actual Downstroke Time

FIGURE 5

These cards were taken on three single acting pumps in the same field made by three different manufacturers. Pressure drop on downstroke is caused by high piston velocity. Figure 5A shows how triplex impulses can affect card.

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instrument. These pumps were all single-acting. There was only limited study of double-acting pumps with this instrument, so very little information was garnered in that direction.

The Fluid Packed Pump Company built an instrument to study their pumps and used it in the field. Figure 6 shows the instrument and Fig. 7 is a chart from the instrument.

The notation on the chart (Fig. 7) says that the well has a leak. This pump has a stroke rating of 75 SPM. It can be seen that this pump is operating at 58 SPM with a pressure of only 1500 psi.

One can measure the time of the upstroke and downstroke very easily on this chart. Also, valve movement is indicated by the small change of pressure. It would also appear that the upstroke is about six-tenths of a second and the downstroke a little bit more than four-tenths of a second.

These two instruments are still being used in well studies.

Woods has provided the following equa-

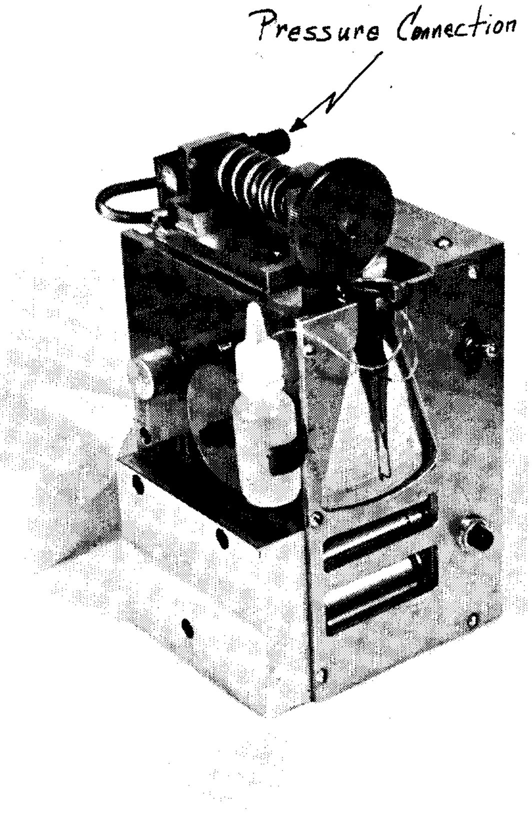

FIGURE 6

tions for calculating theoretical downstroke time:

Formula for Dempsey-type pump (also fits Johnson-Fagg):

Downstroke (time) 100 per cent loaded with fluid (pump end of pump):

$$T_1 = \frac{(\ell)\,(A_E)}{(97.64)\,(a)\sqrt{P_1\left(\frac{A_R}{A_E}\right) - P_2\left(\frac{A_R}{A_E}\right)}}$$

Downstroke 10 per cent cavitation pump end:

$$T_2 = \frac{(\ell)\,(A_E)}{(97.64)\,(a)\sqrt{P_1\left(\frac{A_R}{A_E}\right) + P_2\left(\frac{A_P}{A_E} - \frac{A_R}{A_E}\right)}}$$

Where:

$$\text{Production, } \frac{\text{Bbl}}{\text{Day}} = \left[\frac{D_y - T_2}{T_1 - T_2}\right] \times \text{SPM} \times \text{Displacement constant}$$

T_1 = Theoretical downstroke time in sec, all fluid

T_2 = Theoretical downstroke time in sec, cavitated, (no fluid)

D_y = Downstroke time measured on chart (sec)

SPM = Actual strokes/min taken from chart

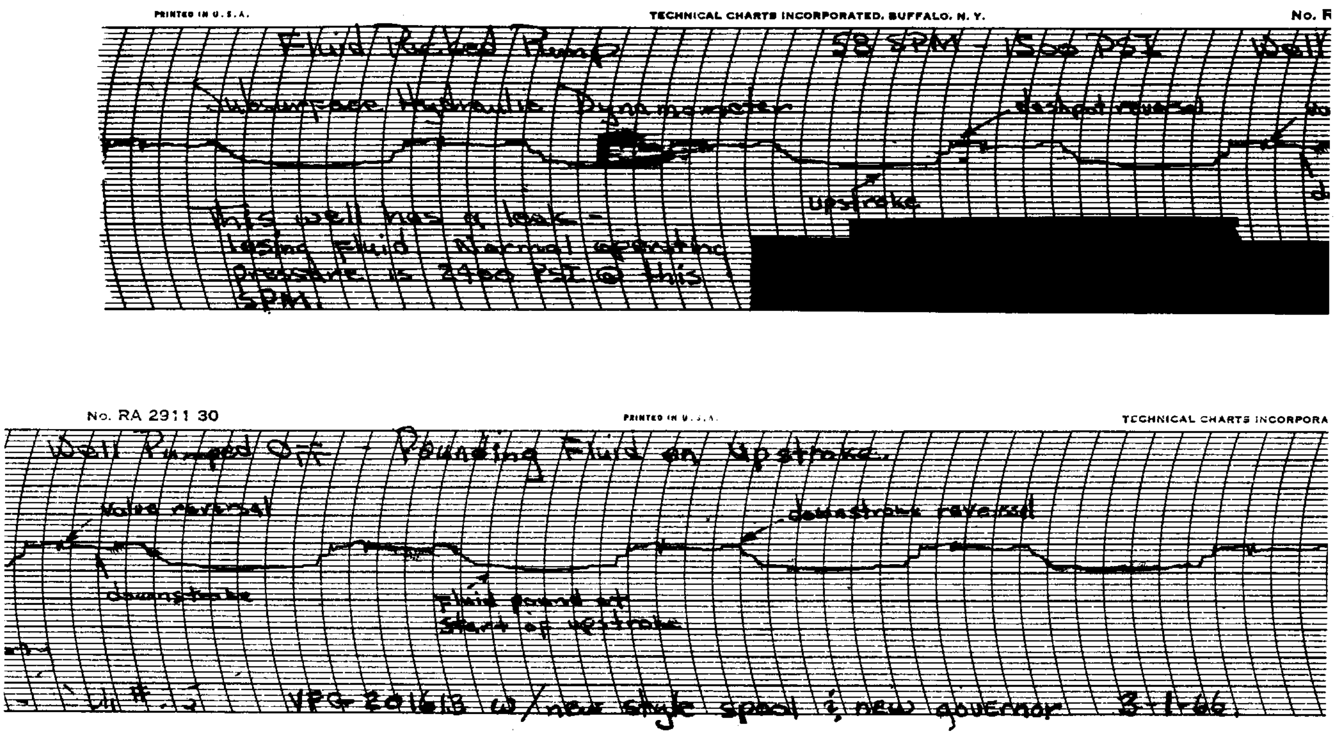

FIGURE 7

Displacement = Displacement constant for pump end

ℓ = length of pump stroke in inches

a = area in sq. in. of downstroke orifice

P_1 = Operations pressure plus static weight, power side

P_2 = Static weight, production side

A_E = Area engine piston, sq. in.

A_P = Area pump piston, sq. in.

A_R = Area middle rod, sq. in.

Formula for Sargent pump (2-1/2 X 2-1/16 X 1-1/4 X 7/8 X 52):

A_E = 3.341 in^2

A_P = 1.227 in^2

A_R = 0.601 in^2

P_2 = static weight = 0.355 X 12,500 = 4430 psi

P_1 = 4430 + 2500 = 6930 psi, assume operating pressure = 2500 psi

ℓ = 52 in

a = orifice diameter = 9/32 in = 0.62 in^2 (assumed) for downstroke

$$T_1 = \frac{52 \times 3.341}{97.64 \times 0.062 \sqrt{6930\left(\frac{0.601}{3.341}\right) - 4430\left(\frac{0.601}{3.341}\right)}}$$

= 1.355 sec.

$$T_2 = \frac{52 \times 3.341}{97.64 \times 0.062 \sqrt{6930\left(\frac{0.601}{3.341}\right) + 4430\left(\frac{0.601}{3.341}\right)}}$$

= 0.63 sec.

$$\text{Production} = \left[\frac{D_y - 0.63}{1.355 - 0.63}\right] \times \text{SPM} \times 9.5$$

The above has been added to show that some are using this type of data. It is recognized that something better must be furnished. There are several people working on the problem.

One recent instrument is shown in Fig. 8. It is a basic Sonolog (well sounder). To the basic instrument is connected part #1, a small electronic device, which in turn is connected to part #2, which is the microphone of a standard wellhead attachment. The microphone is attached to part #3 which is an adapter to make the 1/4-in. connection at the wellhead or other desired place.

The second generation of this equipment is

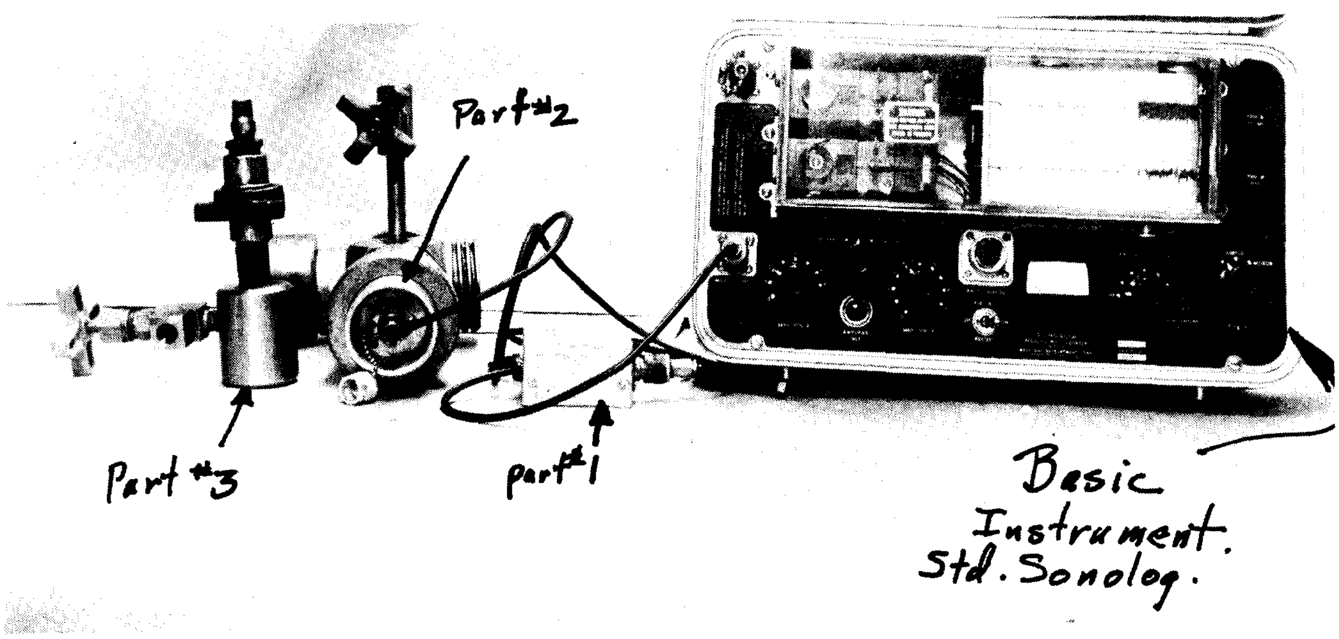

FIGURE 8

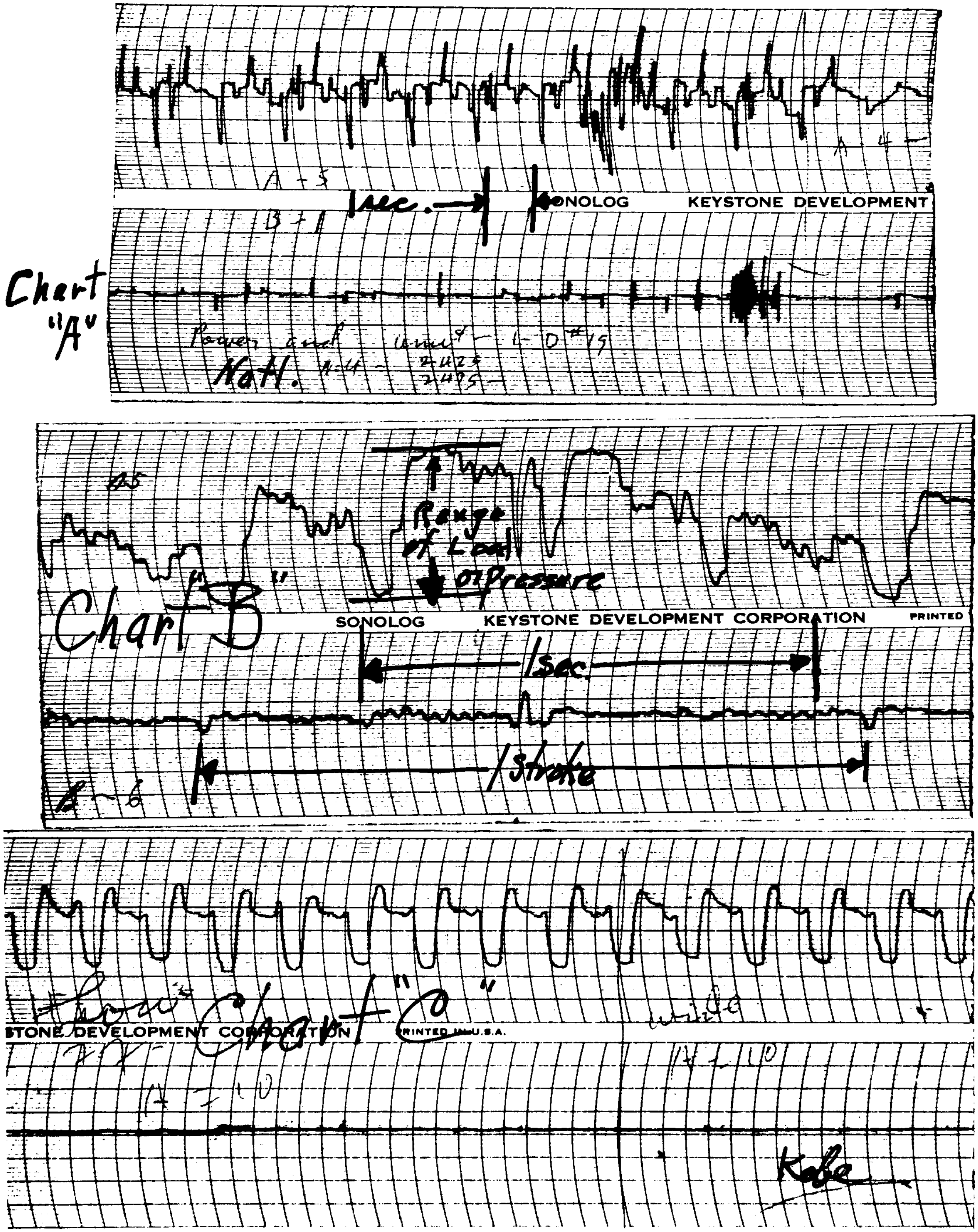
SONOLOG KEYSTONE DEVELOPMENT
1 sec.
Chart "A"
Range of Load or Pressure
Chart "B"
SONOLOG KEYSTONE DEVELOPMENT CORPORATION PRINTED
1 sec
1 stroke
Chart "C"
STONE DEVELOPMENT CORPORATION PRINTED IN U.S.A.

FIGURE 9

now being used by a major oil company for testing. The results are much better and have led to better thinking on the subject.

It has become clear that it is much better to have both pens of the Sonolog recording, and at high speed.

The second generation instrument will be able to record calibrated pressures and at a chart speed which is accurate to 1/500 second.

The chart moves at one cm/sec or 10 cm/sec. Figure 9-A is a chart running at one cm/sec. (One cm is two divisions.) Chart Fig. 9-B is running at 10 cm/sec. These are not the same well but are shown to illustrate how time stretches out the chart. In fact, there is just a little over one stroke on the chart and its real length is 5-3/4 in. (One stroke length in Fig. 9-A is 5/8 in. at slow speed.)

The markings shown as A-10 or A-5 and B-1 or B-6 are sensitive adjustments. These charts do not have another marking but it is the adjustment for the range of pressure, such as 1-1/4#/mm to 1.8#/mm, 2.8#/mm to 4.2#/mm and up to 11 settings and the 11th would be 28#/mm deflection. A mm on this chart is the vertical distance from one horizontal line to another. In this manner the full width of the chart could represent 50# to 1120# from 0 setting. This is very desirable to keep from damaging the equipment. One can set the equipment up for the 1120# setting to start and then reduce the pressure setting to get a maximum deflection desirable for the study.

It is much better to adjust to minimum sensitivity on the B scale to count the strokes and to use the A scale for a larger sensitivity range for the pressure impulses.

The study is far from complete. A grand scale of research is scheduled for late spring to be conducted with a major oil company and two of the pump manufacturers. It is felt that this will lead to a better understanding of how the tool can be used to aid the production of oil and increase profits.