Preliminary Analysis Of Dynamometer Recordings On Bottom Hole Hydraulic Pumps

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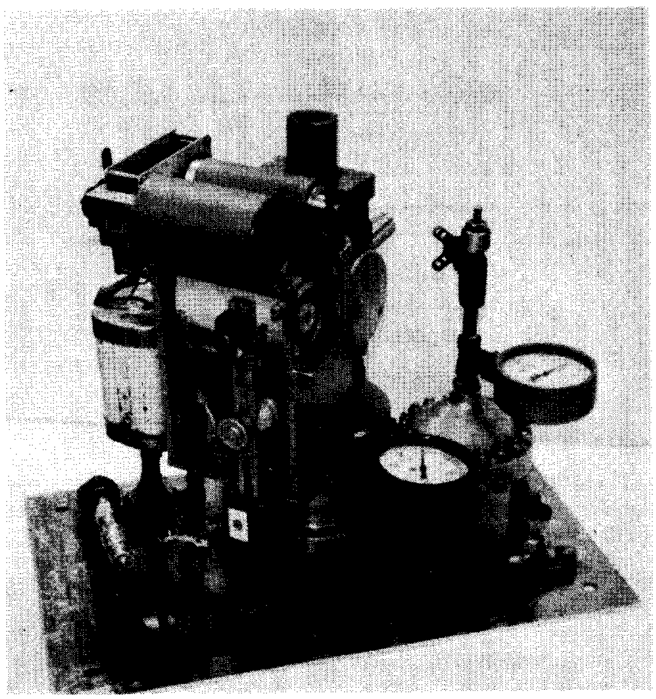


DESCRIPTION

The Hydraulic Dynamometer is essentially a sensitive pressure recording instrument which includes a timing element.

The instrument itself was developed about ten years ago; however, it has only been used extensively in the last four years. The information that has been accumulated points to substantial economies in the hydraulic pumping field.

The instrument 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.

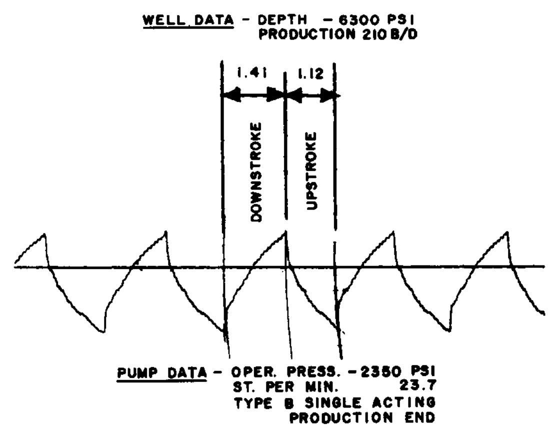
OPERATION

The first step in operation is to bring the triplex pressure into the instrument manifold. Both the top and bottom side of the load cell piston is exposed to this pressure. The total force on each side of the piston is then balanced and the valve is closed leading to the bottom of the piston.

The piston, being in balance, is sensitive to the small pressure changes. This means that the total pressure is not measured, but only the small pressure impulses resulting from pump operation.

The only connection needed at the well is a 1/4 inch pipe outlet in either the power oil side of the system or the production side. Best results can be obtained by taking the card at the well head. If the card is taken at a central manifold, the triplex vibrations may be of such magnitude as to make interpretation of the card difficult. A total of ten dynamometer cards are presented here. Production varies from 2 barrels per day to 210 barrels per day. The operating pressure varies from 1400 psi to 4500 psi. This group includes cards on five different designs of hydraulic pumps.

EXAMPLES



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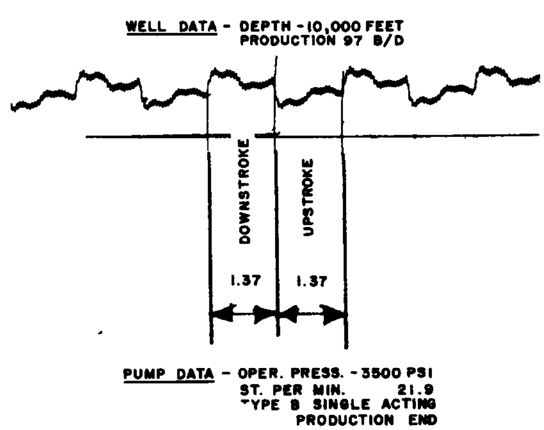

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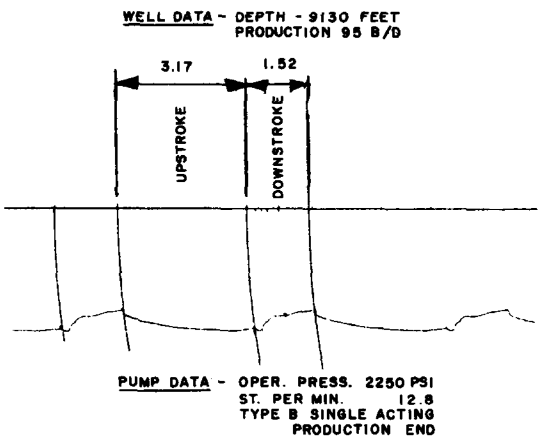

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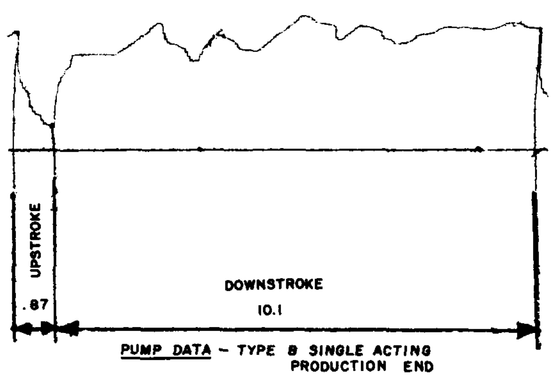

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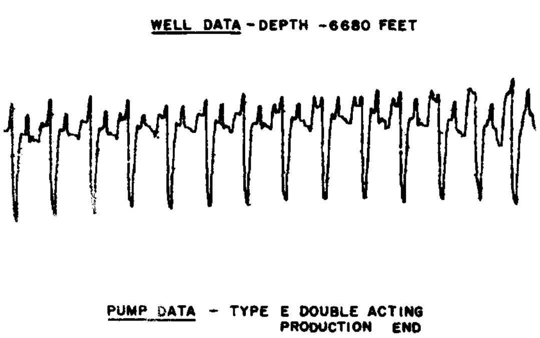

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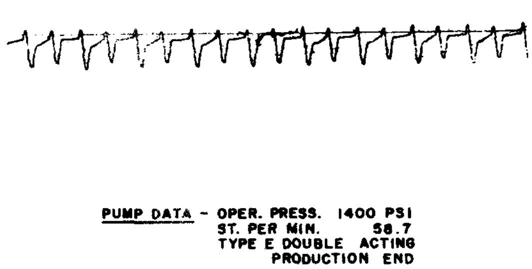

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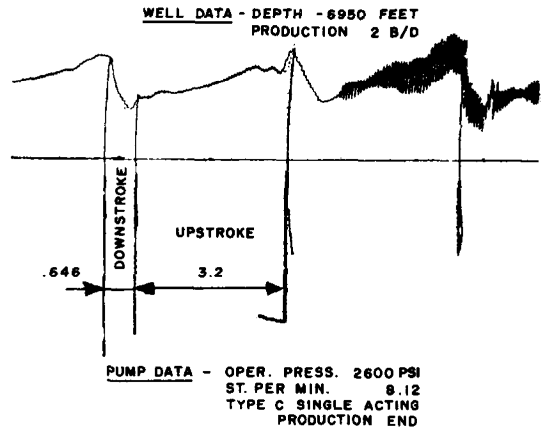

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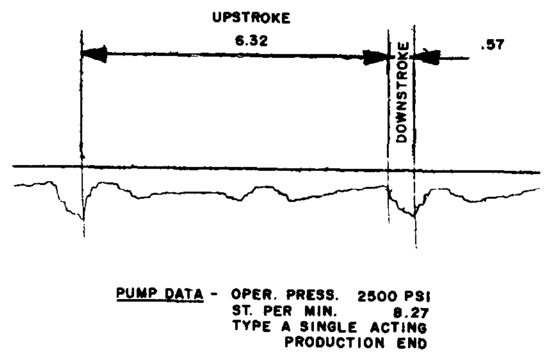


VIII

Card No. 1 was taken on a single acting pump with a controlled downstroke with full loading on the production end of the pump.

Cards No. 2 and 3 were taken on a single acting pump with a controlled downstroke operating under gassy well conditions.

Card No. 4 shows the degree to which control is possible but not practical.

Cards No. 5 and 6 show a double acting pump operation.

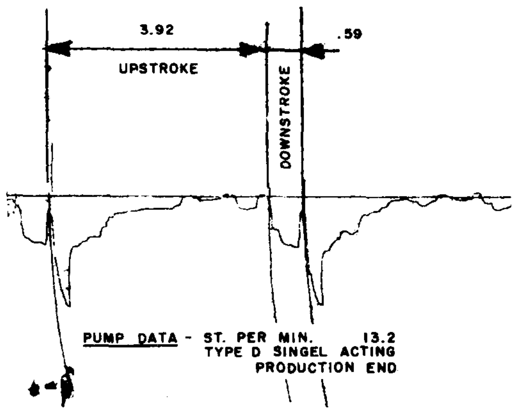
Cards No. 7, 8, and 9 are of three pumps made by three manufacturers. All wells are in the same field. In this case, the operator desires to produce all available fluid. The stroke lengths vary from 60 to 65 inches. All three pumps are single acting type with no downstroke velocity control. In each case the downstroke velocity is very fast — approximately .60 seconds. The downstroke times are within .08 seconds of each other.

Card No. 10 was taken on a single acting controlled pump operating in a pumped-off well.

In order to attach the proper significance to the above dynamometer cards, a brief review of what happens inside the production end of the well seems appropriate.

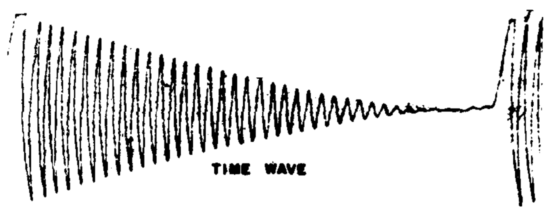
The most common hinderance to efficient pumping is pump cavitation. This is evident when it is realized that only a small percentage of pumping wells operate with a high pump efficiency. In the majority of cases, pump displacement is greater than the well's ability to produce. This means cavitation or a partial filling of the pump barrel with gas.

When cavitation occurs in a single acting hydraulic pump, the downstroke velocity is governed by the weight of the column of fluid on the pump plunger. This force is so much greater than the force exerted by the triplex pressure that it takes charge and dominates the downstroke. In double acting pumps, both the upstroke and downstroke become very rapid when cavitation in the production end of the pump occurs.



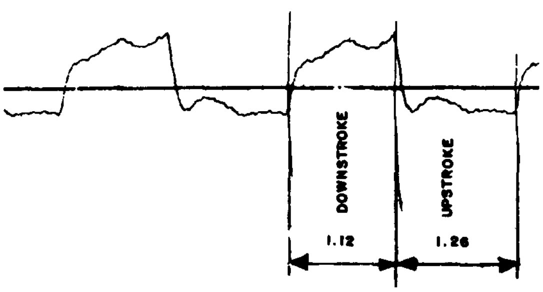
PUMP DATA - ST. PER MIN. 13.2
TYPE D SINGEL ACTING
PRODUCTION END

IX



WELL DATA - DEPTH - 8800 FEET

PUMP DATA - OPER. PRESS. 2700 PSI
ST. PER MIN. 25.2
TYPE B SINGLE ACTING
PRODUCTION END



X

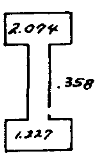
CARD NO. 1

PUMP DATA

Strokes per minute = 23.7
Operating Pressure = 2350
Size 2 x 1-5/8 x 1½ x 3/8 x 49
Orifice = 7/32 = .0376 sq. in.

WELL DATA

Depth = 6300 ft.
Production = 210 B/D
Wt. Production Fluid = 2595 psi
Wt. Power Fluid = 2320 psi



DOWNSTROKE ALL FLUID UNDER PUMP PISTON

$P_1\ (1.716) + (.358)\ P_2 = P_x\ (2.074)$

$4670\ (1.716) + (.358)\ 2595 = P_x\ (2.074)$

$P_x = 4310$ psi

$\Delta P = 4670 - 4310 = 360$ psi

$V = 7.944\ \sqrt{\Delta P} = 7.944\ \sqrt{360} = 150.8$ ft./sec. $= 1810$ in./sec.

$Q = VA = (1810)\ (.0376) = 68.0$ cu. in./sec.

$\frac{101.63}{68.0} = 1.495$ sec. for downstroke time

1.410 sec. actually measured

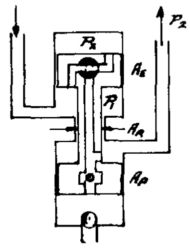
CARD NO. 2

PUMP DATA

Strokes per min. = 21.9
Triplex Pressure = 3500 psi
Size 2 x 1-5/8 x 1-1/4 x 3/8 x 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

$\uparrow P_1\ (A_E - A_R) + A_R(P_2) = P_x\ (A_E) \downarrow$

$7000\ (2.074 - .358) + .358\ (3620) = P_x\ (2.074)$

$P_x = 6380$ psi

ΔP Below and Above engine piston $= P_1 - P_x = 7000 - 6380 = 620$ psi

$V = 7.944\ \sqrt{\Delta P} = 7.944\ \sqrt{620} = 196$ ft/sec $= 2350$ in./sec

$Q = VA = 2350\ (.0276) = 64.8$ cu. in./sec.

Amount of fluid to flow through orifice $= 2.074 \times 49 = 101.63$ cu. in.

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

DOWNSTROKE NO FLUID UNDER PUMP PISTON

$\uparrow P_1\ (A_E - A_R) = P_x\ (A_E) + P_2\ (A_P - A_R) \downarrow$

$7000\ (2.074 - .358) = P_x\ (2.074) + 3620\ (1.227 - .358)$

$P_x = 4280$ psi

ΔP Below & Above engine Piston $= P_1 - P_x = 7000 - 4280 = 2720$ psi

Velocity $= 7.944\ \sqrt{\Delta P} = 7.944\ \sqrt{2720} = 414.0$ ft/sec. $= 4960$ in./sec.

$Q = VA = 4960\ (.0276) = 137.0$ cu. in./sec.

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

$\frac{101.63}{137.0} = .742$ 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

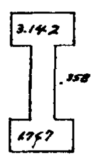
CARD NO. 3

PUMP DATA

Strokes per minute = 12.8
Operating Pressure = 2250 psi
Size = 2-1/2 x 2 x 1-1/2 x 3/8 x 66
Orifice - 1/4" = .0491 sq. in.

WELL DATA

Depth = 9130 ft.
Production = 95 B/D oil
Pump end efficiency = 41.7%
Wt. Production Fluid = 3380 psi
Wt. Power Fluid = 3380 psi



DOWNSTROKE ALL FLUID

$P_1\ (2.784) + P_2\ (.358) = P_x\ (3.142)$

$5630\ (2.784) + .358\ (3380) = P_x\ (3.142)$

$P_x = 5380$ psi

$\Delta P = 5630 - 5380 = 250$ psi

$V = 7.944\sqrt{\Delta P} = 7.944\ \sqrt{250} = 125.7$ FT./SEC. $= 1509$ IN./SEC.

$Q = VA = 1509\ (.0491) = 74.0$ CU. IN./SEC.

$$\frac{207.37}{74.0} = 2.8 \text{ SEC. FOR DOWNSTROKE}$$

DOWNSTROKE NO FLUID

$P_1\ (2.784) = P_x\ (3.142) + P_2\ (1.409)$

$5630\ (2.784) = P_x\ (3.142) + 3360\ (1.409)$

$P_x = 3485$ PSI

$\Delta P = 5630 - 3485 = 2145$ PSI

$V = 7.944\sqrt{\Delta P} = 7.944\ \sqrt{2145} = 367.5$ FT./SEC. $= 4410$ IN./SEC.

$Q = VA = 4410\ (.0491) = 216$ CU. IN./SEC.

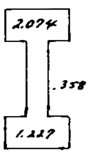
$$\frac{207.37}{216.0} = 0.96 \text{ SEC. FOR DOWNSTROKE}$$

DOWNSTROKE TIME NO FLUID	=	0.96 SEC.
DOWNSTROKE TIME ALL FLUID	=	2.80
PUMP END EFFICIENCY	=	41.7%
2.8 x .417	=	1.165
.96 x .593	=	.569
		1.734 THEORETICAL DOWNSTROKE TIME

1.520 ACTUAL DOWNSTROKE TIME

CARD NO. 10

PUMP DATA		WELL DATA	
STROKES PER MINUTE	= 25.2	DEPTH	= 6900 FT.
OPERATING PRESSURE	= 2700 PSI	PRODUCTION – PUMPED OFF	
SIZE = 2 x 1-5/8 x 1¼ x 3/8 x 60		WT. PRODUCTION FLUID	= .36 PSI/FT = 2480 PSI
ORIFICE 3/16 ORIFICE		WT. POWER FLUID	= 2480 PSI



DOWNSTROKE NO FLUID UNDER ENGINE PISTON

$P_1\ (1.716) = P_x\ (2.074) + P_2\ (.869)$

$5180\ (1.716) = P_x\ (2.074) + 2480\ (.869)$

$P_x = 3250$ PSI

$\Delta P = 5180 - 3250 = 1930$ PSI

$V = 7.944\ \sqrt{\Delta P} = 7.944\ \sqrt{1930} = 348.$ FT./SEC. ≈ 4180 IN./SEC.

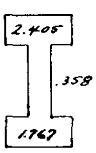
$Q = VA = 4180 \times .02761 = 115.5$ CU. IN./SEC.

$$\frac{124.44}{115.5} = 1.08 \text{ SEC. DOWNSTROKE TIME}$$

1.12 ACTUAL DOWNSTROKE TIME

CARD NO. 7

PUMP DATA		WELL DATA	
STROKES PER MINUTE	= 8.12	DEPTH	= 6950 FT.
OPERATING PRESSURE	= 2600 PSI	PRODUCTION	= 2 B/D
SIZE 2½ x 1¾ x 1½ x 3/8 x 58¾		WT. PRODUCTION FLUID	= 40° GRAVITY = 2460 PSI
ORIFICE Two 3/16 HOLES – NO CONTROL		WT. POWER FLUID	= 2480 PSI



DOWNSTROKE NO FLUID UNDER ENGINE PISTON

$P_1\ (2.047) = P_x\ (2.405) + P_2\ (1.409)$

$5080\ (2.047) = P_x\ (2.405) + 2480\ (1.409)$

$P_x = 2870$

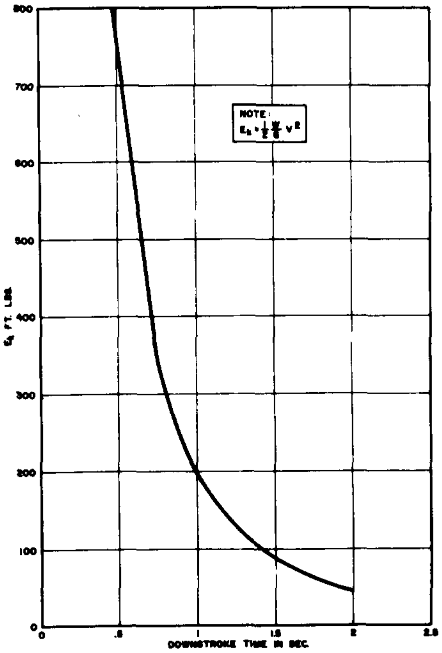
$\Delta P = 5080 - 2870 = 2210$ PSI

$V = 7.944\ \sqrt{\Delta P} = 7.944\ \sqrt{2210} = 373.5$ FT./SEC. $= 4480$ IN./SEC.

$Q = VA = 4480\ (.0552) = 247.$ CU. IN./SEC.

$$\frac{141.5}{247} = .573 \text{ SEC. DOWNSTROKE TIME}$$

.646 SEC. ACTUAL DOWNSTROKE TIME



IMPACT CURVE

Analysis of the above dynamometer cards shows that in a single acting pump the downstroke time has a definite relationship to the fluid in the production end. This relationship can also be shown theoretically. Comparison of the actual cards with the theoretical calculations agree very closely.

The attached calculations are presented to show the method used and the close correlation between theoretical and measured downstroke times.

Dynamometer cards have also been taken on double acting pumps. In one case, dynamometer cards were taken during normal operation. The well was shut in for 24 hours. After startup, dynamometer cards were taken at regular intervals until the well conditions again returned to normal. The last dynamometer card was identical in shape to the original card. Thus, it also seems apparent that dynamometer cards on double action pumps reflect actual well conditions.

Dynamometer cards No. 7 and 10 show two single acting pumps operating on the same lease. Card No. 7 is without downstroke control, and Card No. 10 is with downstroke control. By controlling the downstroke velocity, the detrimental effects of high impact loads may be decreased to a tolerable value. The need for this control is further shown by the impact curve.

CONCLUSIONS

The dynamometer card is not only a record of the pump strokes, but is also an accurate count of the strokes per minute. Pump volumetric efficiency cannot be computed accurately without knowing how fast the pump is running. It is believed that as the interpretation of hydraulic dynamometer cards expands, the hydraulic dynamometer will become as necessary a part of hydraulic pumping as the polished rod dynamometer is to beam pumping.