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A HYDRAULIC POWER UNIT FOR
SOLVENT EXTRACTION COLUMN PULSE GENERATORS

By

V. P. Kelly

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INTRODUCTION

The introduction of the pulsed solvent extraction column in HAPO's separations plants brought new problems in selecting the means for generating the pulse. Mechanical power was chosen on the basis of its proven reliability. However, hydraulic power was a serious candidate because of its inherent simplicity and potentially lower costs, with increased reliability, as compared to the bulkier mechanical drive.

The sole application at HAPO of hydraulic power for pulse generators was made in the Hot Semiworks facility, which was converted for Purex development work beginning in 1954. The development and operation of the hydraulic drives for this installation are described.

SUMMARY

A power unit comprised of a reciprocating hydraulic cylinder controlled by hydraulic, mechanical, and electrical elements was developed to drive pulse generators for solvent extraction columns in the Purex Hot Semiworks. Design bases included remote control of continuously-variable pulse amplitudes between 1/2 and 1-1/2 inches, and pulse frequency up to 120 cycles/min.

Each of nine power units operated 30 to 60 million cycles without serious difficulty, although minor modifications and corrections were made during scheduled shutdowns of the Semiworks. Operational irregularities, such as erratic or drifting amplitudes, occurred with sufficient frequency to indicate deficiencies in the original design.

The triangular pulse wave* which is characteristic of the power unit was suspected on several occasions as having an adverse effect on extraction column performance. However, no correlation was found to show that column performance is adversely affected by the triangular pulse.

DESCRIPTION OF EQUIPMENT

Hydraulic Power Unit

The power unit, Figure 1, has a hydraulic power cylinder and control valves, mechanical components, and electrical control units enclosed in a stainless steel box. The output shaft extends vertically downward in the figure; however, the operation is independent of orientation.

The operation of the power unit may be followed by tracing out the hydraulic connection diagram (Figure 1). Referring to Figure 1, high pressure oil enters the housing and flows through the pilot-operated, four-way, cylinder control valve to the double rod-ended power cylinder. Branch high-pressure oil flows through the stem-operated, four-way, pilot valve to either end of the cylinder control valve spool. This hydraulic control loop is closed mechanically by the rocker arm which pivots around the fulcrum bearing, and, following the motion of the piston shaft, shifts the pilot valve spool.

*Displacement-time motion of the output shaft.

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Thus, it is seen that piston reversal follows this sequence: (1) the rocker arm rotates as the piston moves along one cycle of its stroke, shifting the pilot valve spool; (2) the cylinder control valve spool shuttles in response to the switch in pilot oil pressure; and (3) the power piston is reversed as the control valve changes the direction of oil flow to the cylinder.

The amplitude of the power piston stroke is varied through the assembly of the lead screw, stoplocks, and Selsyn motor. The right- and left-hand threaded lead screw spring-couples to the pilot valve spool stem at the lower end, and sleeve-couples to the Selsyn motor at its upper end. Therefore, the screw can both rotate and reciprocate. When the motor turns, the stopblock spacing changes. This change in block spacing, of course, alters the travel of the rocker arm necessary to shift the pilot valve spool. Consequently, the power piston stroke is increased or decreased.

Power piston stroke and frequency are measured remotely from a voltage signal generated in the linear motion transducer. The transducer, a linear variable differential transformer, has a pencil-like armature directly coupled to the piston shaft. As the armature moves along the transducer bore, the electrical coupling between primary and secondary coils is varied, and an output voltage proportional to armature position results.

The hydraulic, electrical, and mechanical parts are enclosed in the stainless steel housing for protection against decontaminating fluids and for frame connection to the pulse generator. The housing is double-compartmented, with an oil reservoir in the lower section for lubricating working parts and containing oil leakage. An overflow, drain, lifting bail, and mounting brackets are among the housing details.

Miscellaneous mechanical parts include a counterbalance (not shown), upper and lower stub shafts, and the shaft bearings. The counter-balance may be a spring- or mass-type device which is required on vertical power units to prevent premature drop of the lead screw-pilot valve spool assembly. The stub shafts couple to the power piston rod. The lower shaft connects to the pulse generator for transmitting pulse motion.

Remote Control and Power Systems

Hydraulic power supply and electrical control systems are required to operate the hydraulic power unit in a remote zone. The essential components of the system are represented schematically in Figure 2.

As shown in Figure 2, three separate lines connect the power unit with the "cold" zone hydraulic system. A constant-displacement pump discharges high-pressure oil through a pressure relief valve to the supply header for the first connection.

Pulse frequency is controlled via the second connection, which is the power cylinder exhaust oil line. The exhaust oil is returned to the pump reservoir via the pressure-compensated flow control valve. This valve meters the oil discharging from the power cylinder (see Figure 1) at a constant flowrate, and, hence, controls its speed. Pilot valve exhaust oil is returned independently to the reservoir so that spool shuttle time of the cylinder control valve is not affected by pulse frequency.

The pulse amplitude is controlled with the Selsyn system, with its "cold" zone motor-transmitter, and "hot" zone motor-receiver (Figure 1). The two are electrically connected so that rotor movement of the transmitter causes a corresponding rotation in the receiver. As explained above, receiver rotation in turn changes the pulse amplitude. A turns-counter on the transmitter shaft references its position for secondary amplitude measurement.

The pulse frequency and amplitude are measured by counter and oscilloscope readings of the output voltage signal from the linear motion transducer (Figure 1). The counter is a HAPCO-designed⁽¹⁾ electronic device which uses the transducer's ac signal voltage to fire a Thyatron tube and operates an electrical register for pulse count. The oscilloscope has a gridded screen on which the signal is displayed, read by the operator, and then translated into inches of stroke by comparison with calibration charts.

Test Stands

The power units were tested before and during Hot Semworks operation in pulse column systems. The major elements of the system are represented in Figure 2.

Shown in Figure 2 is the vertical solvent extraction column with its pulse nozzle at the lower end. The pulse generator, which may be a bellows or piston as enclosed in the pulse nozzle, and is reciprocated by the power unit. The column is filled with liquid, and, as the pulse generator is reciprocated, the liquid is driven up and down in the column.

For test purposes, 3- to 6-inch diameter columns, 10- to 20-feet high and filled with organic or aqueous solutions were used. Remote control systems were usually omitted, although a recording device (Sanborn 2-channel recorder) was substituted for the oscilloscope of Figure 2 during one test phase.

EXPERIMENTAL

Two brief tests for operability and performance of the power units were carried out. The bulk of the available data is, however, derived from actual operating experience.

Test 1 covered about 100 hours of operation of a prototype power unit, with the flow control valve (Figure 2) in the power cylinder supply line instead of the exhaust line. The unit was replaced by a mechanical drive when adverse column performance, attributed to the triangular wave shape, occurred.⁽²⁾

Test 2 covered studies of:

- (a) Triangular pulse waves (generated by the hydraulic power unit) vs sinusoidal pulse waves (mechanical drive) as they affect solvent extraction column performance;
- (b) Methods of modifying the power unit to produce a near-sinusoidal pulse wave; and

(1) DWG. H-4-2463, "Circuit-Pulse Frequency Counter."

(2) HW-40550, "Purex Pulse Column Studies with Hydrocarbon Diluent," G. A. Nicholson.

- (c) The affect of hydraulic system variables such as oil temperature and pressure on pulse frequency and amplitude.

Service of the power units in the Hot Semiworks from pre-startup to shutdown extended from the latter part of 1954 to February 1956.

DISCUSSION

Mechanical Performance

No mechanical failures of the power units occurred, nor were the major parts replaced, during a service life estimated as high as 60 million piston cycles for individual units. One case of erratic operation, noted below, was corrected during a scheduled shutdown of the Semiworks. However, these shutdowns came at regular intervals so that the performance record of the power units does not represent uninterrupted operation in remote service.

The five major problems associated with power unit operation are listed as follows:

- (a) Erratic power cylinder stroke due to failure of the pilot valve counterbalance to hold the lead screw-pilot valve assembly in its upper position. This "instability," usually short-lived and infrequent, seriously impaired the usefulness of the IA Column pulser during one test run.
- (b) Piston strokes, and pulse amplitudes "drifted" because of lead screw rotation under the impact of the rocker arm on the stopblocks. Stroke drift is eliminated with the Selsyn motor system energized, but extra operator attention is required for this detail.
- (c) Differences between the nulls, or midstroke point, of the power piston and the linear motion transducer increase the difficulty in measuring pulse amplitudes. An inordinate amount of time was spent realigning the transducers for null point balance during periods of maintenance activity.
- (d) Pulse amplitude and frequency measuring with the system of Figure 2 is inherently time-consuming and subject to error. For instance, the operator must read both the transducer and calibration signal amplitudes on the scope screen to calculate pulse amplitudes.
- (e) Hydraulic system leaks in the remote cell increased decontamination problems and working hazards due to slippery floors and equipment. Koncentrick tubing fittings were the worst offenders, and were replaced by standard pipe flanges in some cases. Oil spills during removal of the power units were also troublesome.

Pulse Wave Shapes

The pulse wave, or output shaft displacement-time motion, of the power unit is basically triangular since the power piston travels at constant speed between stroke limits. At the stroke limit, rapid piston reversal creates

undesirably high pressures in the pulse column system. "Smoothing" the triangular pulse wave reduces the pressure amplitudes and resultant shock on the pulse systems. Figure 3 shows a comparison of various types of pulse waves, including a "smoothed" triangular wave obtained during Test 2.

Referring to Figure 3, Curve A and B are ideal sinusoidal and triangular waves, while Curve C is an ideal sawtooth, or "ramp" wave. A form of Curve C results when the flow control valve meters oil to the power cylinder supply instead of from the exhaust oil line. For the former case, the force due to the column liquid head "runs away" with the piston during one-half of the stroke cycle. Severe pressure shock and adverse column performance result.⁽²⁾

Curve D is a smoothed triangular wave resulting from (a) changing cylinder control valve spool geometry, and (b) using a low-capacity hydraulic pump discharging at low pressures to relatively short system lines. The proximity of Curve A and D suggest the reduced pressure amplitudes and smooth operation associated with Curve D's pulse wave.

Curve E represents a composite pulse wave, variations of which will occur when system parameters cannot be juggled as for Curve D. The short, steep lines at stroke limits go hand-in-hand with rapid piston acceleration (and high pulse pressures). Long supply lines, with induced control lags, large pump capacities, high oil pressures and unmodified cylinder control valve spools contribute to this motion. The superimposed oscillation is symptomatic of instability due to long elastic oil lines, and unbalanced pulse generator loading.

Figure 3 shows that various forms of pulse waves can be produced by changing hydraulic system conditions. However, chemical engineering studies⁽³⁾ on 3- and 4-inch diameter HC-type-solvent extraction columns show that none of the modifications of the triangular (not sawtooth) pulse wave seriously affect column performance as compared to the sinusoidal pulse wave.

Operating Characteristics

The pulse amplitudes and frequencies produced by hydraulic power units will vary even though their respective control parameters are unchanged. Figure 4, for instance, shows that piston stroke increases almost 30 per cent with a four-fold pressure increase although stopblock spacing remains constant. Figure 5 shows that 3-fold frequency changes occur with a 4-fold pressure increase at constant flow valve setting. From this, it follows that an increase in oil temperature, with an attendant drop in viscosity and increase in available pressure at the power unit, will also increase pulse frequency.

Also shown in Figure 4 is the variation of piston stroke with frequency. Opening the flow valve increases pulse frequency, and, for 400 lb/sq in. supply oil pressure, piston stroke increases from 0.5 to about 0.7 inches, or 40 per cent with no change in stopblock spacing.

These data show, of course, the extra problems created for the operator in setting pulse frequencies and amplitudes. For instance, changing the frequency requires resetting the amplitude to its former value, since the interaction also affects the amplitude.

(3) HW-36490 "Progress Report - Chemical Development Subsection," F. W. Woodfield, April 1955.

CONCLUSIONS

The hydraulic power unit represented in Figure 1 is a flexible unit, suitable for driving solvent extraction column pulse generators in remote zones at variable strokes and frequencies.

The unit is mechanically reliable, although re-design⁽⁴⁾ of the pilot valve spool counterbalance is needed to eliminate tendencies for erratic operation.

From the operator's viewpoint, measurement of both pulse frequency and amplitude is cumbersome. Further development in electronic equipment is needed to simplify the measuring procedure and reduce inherent errors in the existing system. From a maintenance viewpoint improvement in hydraulic oil containment is a must to reduce fire and safety hazards.

Further from the operator's viewpoint, the power unit has two basic characteristics which may represent serious disadvantages:

- (a) Pulse wave shape is variable, being either basically triangular or sawtooth depending on flow control method. Also, variations on the basic forms arise from changing hydraulic system parameters. Therefore, until sufficient data are available to indicate the independence of the two, the inter-relation of pulse wave and solvent extraction column performance must be studied for each system.
- (b) Pulse amplitude and frequency are subject to variation with each other, oil pressure, and temperature. Thus, setting these primary quantities in a solvent extraction battery may be a troublesome and time-consuming task for the operator.

V. P. Kelly:lg

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(4) DWG. SK-2-50155 (Issue 2) "Modifications to Hydraulic Pulser Drives."

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FIGURE 1

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