COMPARISON OF PRESENT-DAY LONG-STROKE SUCKER-ROD PUMPING SYSTEMS

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Abstract. Long-stroke sucker-rod pumping units have definite advantages as compared to their traditional counterparts. They produce greater liquid rates with less downhole pump problems and can also increase the life of the rod string due to the reduced number of stress reversals.

This paper presents a complete coverage of present-day long-stroke rod pumping methods and discusses the two main types of technologies available: Rotaflex and DynaPump. After a short historical overview of long-stroke pumping technology these two units are introduced and their technical and operational features are described in detail. The relative advantages and limitations of Rotaflex and DynaPump installations are discussed to facilitate their selection for artificial lift applications.

Keywords: long-stroke SRP system, sucker-rod pumping, Rotaflex unit, Dynapump unit

1. INTRODUCTION

Sucker-rod pumping installations running at low pumping speeds are more energy-efficient than those working at higher speeds. Of the reasons supporting this statement the most important ones are: (a) lower dynamic loads and lower energy losses along the rod string, and (b) better fluid fillage of the pump barrel at lower speeds. Low pumping speeds, however, require the increase of stroke lengths to increase pumping rates and this is only feasible if pumping units completely different from the traditional beam pump mechanism are used; this is why long-stroke pumping units were introduced.

Long-stroke pumping units usually have polished rod stroke lengths greater than 24 ft and require significantly less torques than beam pumping units. To produce high liquid volumes they can be run at much lower speeds and can thus achieve greater overall system efficiencies than traditional installations. The general advantages of long-stroke pumping over traditional pumping can be summed as: (a) greater liquid producing capacities are achieved, (b) downhole pump problems are decreased, and (c) rod string life is substantially increased due to the reduced number of stress reversals.

2. FEATURES OF PRESENT-DAY LONG-STROKE PUMPING UNITS

Although there were several different types of long-stroke pumping units developed in the past with more or less success [1–3], today only two models are available. They work on different principles as presented in the following where the main technical features of such units are detailed.
The Rotaflex Unit
After several attempts in the late 1980s to develop a completely mechanical long-stroke pumping unit, it was Lively’s [4] patented version that became accepted in the oil field. Its trade name is Rotaflex and by offering many advantages over traditional pumping units it is a strong competitor to beam type pumping units and ESP equipment at the same time. As will be shown all benefits of Rotaflex units are a direct consequence of its revolutionary mechanical design. These units are getting more and more popular; the total number of Rotaflex installations was about 800 in 2002 [5] but became more than 7,000 a decade later.

Construction and Operation
The construction and the basic operation of Rotaflex units are explained in Figure 1 that shows a schematic drawing of the main parts and their functions. The unit is driven by a traditional pumping unit gearbox via the drive sprocket of a vertically arranged chain assembly with an idler sprocket situated vertically above the drive sprocket. The heavy duty roller chain, as it is turned by the drive sprocket drives a weight box (containing the counterweights of the unit) which is connected to one of the links of the chain. These components constitute the drive train of the unit.

On the well side, the polished rod is directly connected to an elastic load belt that runs on a drum situated higher up in such a way that polished rod loads generate only vertical forces in the belt. The other end of the belt hanging vertically from the belt drum is fixed to the weight box. The weight box, therefore, carries all operating loads: the pumping load on the polished rod as well as the counterbalance load. Since its movement is strictly vertical, it can always fully utilize the total weight of the counterweights in order to balance the load on the gearbox.

The structural components of a Rotaflex unit are shown in Figure 2. The derrick or tower supports and contains
most of the machinery and stands above the wellhead. The polished rod is connected to the unit in the traditional way: using a carrier bar, a polished rod clamp, and wireline hangers. The wireline hanger is fixed to a strong, flexible load belt hanging from the belt drum situated at the top of the derrick structure. The other end of the load belt is fixed to the counterweight assembly (weight box) that travels in a vertical direction up and down inside of the derrick.

**Kinematic Behavior**

The Rotaflex pumping unit converts the prime mover’s rotation into the reciprocating movement required for pumping with the help of the chain and sprocket and the carriage assemblies. Therefore, the unit’s kinematic behavior can best be described through a thorough analysis of the movement of those components during the pumping cycle. The motion of the carriage assembly during a full pumping cycle is very symmetrical. At the start of the polished rod’s upstroke the carriage is at the top of the idler sprocket, then follows the perimeter of the sprocket, then moves on a vertical line, then turns on the drive sprocket, etc.

The kinematic parameters: position, torque factor, and acceleration of the carriage are expressed as functions of the sprocket angle, \( \theta \). For simplicity, this is defined as the angle of rotation of the idler sprocket and is measured in the direction of the sprocket’s rotation starting at \( \theta = 0 \) valid at the start of the upstroke. In order to cover the pumping cycle, the two sprockets make several full turns; their total angular movement reaches the angle \( \theta_{\text{max}} \) at the end of the downstroke. This angle is found from the length of the chain and the radius of the sprocket as follows:

\[
\theta_{\text{max}} = \frac{L_{\text{chain}}}{R}
\]

where: 
- \( \theta_{\text{max}} \) = sprocket angle at the end of the downstroke, radians, 
- \( L_{\text{chain}} \) = length of the roller chain, in, and 
- \( R \) = sprocket radius, in.

Carriage position, \( CP \), is defined as zero at the start of the polished rod’s upstroke (\( CP = 0 \)) and reaches \( CP = S \) at the top of the stroke; where \( S \) is the total stroke length of the carriage’s travel. \( CP \) is calculated as the vertical component of the carriage assembly’s motion at any sprocket angle, \( \theta \). The carriage assembly’s movement exhibits two different behaviors during the pumping cycle: (a) it follows a harmonic motion while it rides on one of the sprockets, and (b) otherwise it moves vertically only.

The additional kinematic parameters of the Rotaflex pumping unit are carriage velocity and carriage acceleration that are, for the reasons already discussed, identical to the velocity and acceleration of the polished rod. Carriage velocity, in principle, is found by differentiating carriage position, \( CP \), with respect to time. The
acceleration of the sprocket assembly which is identical to polished rod acceleration is found by differentiating carriage velocity with respect to time.

**Torque Factor, \( TF \)**, values represent the torque arm to be used at any carriage position to find the gearbox torque valid at the given loading conditions. In analogy to traditional sucker-rod pumping units torque factors are found by differentiating the carriage position with respect to sprocket angle.

The variation of the major kinematic parameters with time during a complete pumping cycle for an example Model 1151 Rotaflex unit is plotted in Figure 3. As seen, carriage position i.e. polished rod position changes linearly with time, i.e. with sprocket angle for most of the up-, and downstroke. Acceleration values for a pumping speed of \( N = 2 \) SPM are given also in the figure; the long, quiet movement of the carriage results in zero acceleration for most of the pumping cycle. Torque factors are, except for two short periods around the two extremes of the stroke, constant, only their sign is different for the up-, and the downstroke.

In conclusion, the Rotaflex unit has an extremely quiet operation with very low accelerations and negligible dynamic effects and offers a kinematic behavior that very profoundly differs from that of any beam pumping unit. The polished rod of traditional beam pumping units continuously accelerates-decelerates during the up-, and downstroke causing varying velocities; those units, in contrast to Rotaflex units, experience high dynamic loads.
The DynaPump Unit
The DynaPump unit, a computer-controlled hydraulically driven long-stroke sucker-rod pumping unit was invented by A. Rosman at the end of the 1980s [6, 7]. Since its commercial introduction to the oil field in 2001 the technology underwent several improvements that have lead to the present-day models. Just like the Rotaflex units, DynaPump units can also compete with traditional rod pumping and ESP installations by offering greater system efficiencies and lower production costs.

Due to their advantageous features DynaPump units are getting popular; the worldwide number of installations reached 500 in the year 2008 [8].

Construction and Operation
The two main components of a DynaPump installation are (a) the pumping unit and (b) the hydraulic power unit; the first converts the hydraulic power to lift the well load, the second provides the power fluid of a controlled volumetric rate to drive the pumping unit. A schematic drawing is given in Figure 4 that depicts the main parts of the system. The power and the pumping units are connected by high-pressure hoses not shown in the figure.

The pumping unit of the DynaPump system drives a traditional downhole pump attached to the sucker-rod string. The polished rod is lifted by the usual carrier bar attached to two wireline cables. The other ends of the cables are fixed to the unit base and the cables run on two sheaves to form a 2:1 pulley system. The sheaves are situated at the top of a plunger that protrudes from a special hydraulic three-chamber cylinder; vertical position of the sheaves being the function of the hydraulic fluid rate received from the power unit. To counterbalance the variation of the well load during the pumping cycle gas pressure is utilized that also acts in the three-chamber cylinder; gas pressure being provided by a high-volume gas (usually nitrogen) storage cylinder. Because of the pulley system the displacement of the polished rod is exactly twice as much as the vertical movement of the sheaves caused by the three-chamber cylinder. For the same reason the load on the cylinder at any time equals twice the polished rod load.
Kinematic Behavior

In contrast to beam pumping units, DynaPump units allow the operator to select the variation of most of the kinematic parameters during the pumping cycle; these can be input at the unit’s controller.

**Up, and downstroke velocities.** The unit provides constant polished rod velocities for long portions of both the up-, and downstroke periods; this feature greatly decreases dynamic forces and reduces energy requirements for most of the stroke. Upstroke and downstroke speeds are selected independently of each other.

**Acceleration and deceleration periods.** Both the up-, and the downstroke of the polished rod’s movement includes periods of (a) acceleration, (b) constant speed, and (c) deceleration. The lengths of the acceleration and deceleration periods (four in total) can be independently selected on the DynaPump allowing an excellent control of the unit’s dynamics at the stroke reversals.

**Starts of decelerations.** The starting point of deceleration is selectable for both the up-, and the downstroke. The so called “switches” are set based on the position of the three-chamber cylinder’s plunger which is continuously monitored and easily translated to polished rod position.

After the parameters just described are set the polished rod stroke length and the pumping speed are automatically established. Polished rod stroke length is determined by the “switch” settings, i.e. the positions in the up-, and the downstroke where deceleration starts, and the selected up-, and downstroke velocities. Acceleration and deceleration periods have a minor effect only. Polished rod stroke length and pumping speed are interrelated; pumping speed in SPM units is found from the calculated length of the pumping cycle.

A typical DynaPump unit’s velocity and acceleration pattern during the pumping cycle is depicted in **Figure 5**. As shown, big portions of both the up-, and downstroke are performed at constant polished rod velocities and the accelerations at the top and bottom stroke reversals are fully controlled by the operator for an optimum dynamic performance.

![Figure 5](image-url)
Polished rod position is found by integration of the velocity with respect to time. For the given case calculated positions during the pumping cycle are given in Figure 6; the figure reveals the different phases of the movement of the unit. From point 1 to 2 during the upstroke acceleration period the polished rod reaches the set upstroke speed then movement with a constant velocity follows from point 2 until the top switch position is reached at point 3. Now the deceleration period comes until point 4 where the polished rod’s travel reaches its maximum. Downstroke is starting next with the downstroke acceleration period from point 4 to 5. From here downward travel continues with a constant velocity; note that this velocity is less than that during the upstroke. Finally, from point 6 belonging to the bottom switch position the unit slows down to reach the bottom of the downstroke at point 7.

3. COMPARISON OF PUMPING UNITS

Available Models

Rotaflex units are presently manufactured in four sizes with a minimum stroke length of 288 in. Maximum stroke length is 366 in while maximum polished rod capacity is 50,000 lbs. Other operational data are contained in Table 1.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>900</th>
<th>1100</th>
<th>1150</th>
<th>1151</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque Rating, 1,000 in lbs</td>
<td>320</td>
<td>320</td>
<td>320</td>
<td>420</td>
</tr>
<tr>
<td>Max. Polished Rod Load, lbs</td>
<td>36,000</td>
<td>50,000</td>
<td>50,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Stroke Length, in</td>
<td>288</td>
<td>306</td>
<td>366</td>
<td>366</td>
</tr>
<tr>
<td>Max. Speed, SPM</td>
<td>4.50</td>
<td>4.30</td>
<td>3.64</td>
<td>3.75</td>
</tr>
<tr>
<td>Structural Height, ft</td>
<td>40.5</td>
<td>44.5</td>
<td>49.5</td>
<td>49.5</td>
</tr>
</tbody>
</table>
DynaPump units are classified according to the size (in inches) of the three-
chamber cylinder’s plunger, the models are named accordingly. Main technical
data of available models are contained in Table 2.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>5</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Plunger Size, in</td>
<td>5.0</td>
<td>7.0</td>
<td>9.0</td>
<td>11.0</td>
<td>13.0</td>
</tr>
<tr>
<td>Max. Hydraulic Pressure, psi</td>
<td>1,800</td>
<td>1,800</td>
<td>1,800</td>
<td>1,800</td>
<td>1,800</td>
</tr>
<tr>
<td>Max. CB Gas Pressure, psi</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Max. Polished Rod Load, lbs</td>
<td>15,000</td>
<td>25,000</td>
<td>40,000</td>
<td>60,000</td>
<td>80,000</td>
</tr>
<tr>
<td>Max. Stroke Length, in</td>
<td>168</td>
<td>240</td>
<td>288</td>
<td>336</td>
<td>360</td>
</tr>
<tr>
<td>Max. Speed, SPM</td>
<td>6.8</td>
<td>4.8</td>
<td>4.0</td>
<td>3.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Structural Height, ft</td>
<td>23</td>
<td>28</td>
<td>34</td>
<td>39</td>
<td>41</td>
</tr>
</tbody>
</table>

Power units come in seven different power capacities in the range of 15 to
150 HP. Each power unit can work with different pumping units but bigger models
usually require more power; proper selection of the combination of power-, and
pumping units is important.

Fluid Lifting Capacities

![Graph showing fluid lifting capacities for Rotaflex Model 1151 and DynaPump Model 13](image)

_Figure 7_
The production capacities of the biggest Rotaflex and DynaPump units are compared in Figure 7, based on data received from Beck [9] and Rosman [10]. As shown the two different units can produce very similar liquid rates from the same pumping depths.

**Other Factors Affecting Selection**

Since the application ranges of the two units are very similar, other important operational features must also be investigated when selection of the proper unit is desired.

*Adjustment of Pumping Capacity.*
- Rotaflex units permit changing of the pumping speed only and because of the fixed polished rod stroke length the possible range of pumping rates is limited.
- Pumping capacity of DynaPump units can be changed in very broad ranges made possible by an almost unlimited possibility of changing polished rod stroke lengths and pumping speeds at the same time.

*Counterbalance Adjustment.*
- Rotaflex units need to be stopped to change the unit’s counterbalance conditions.
- DynaPump units must not be stopped to adjust their counterbalancing; change of counterbalance effect is simple by changing the gas pressure in the counterbalance cylinders.

*Pumping Speed Adjustment.*
- Speed changes on Rotaflex units require changing of V-belt sheaves; pumping speed is the same for the up-, and the downstroke.
- Pumping speed of DynaPump units is easily changed on their controller, different upstroke and downstroke speeds can be set. Higher up-, and lower downstroke speeds, as normally set, decrease leakage in the downhole pump and reduce buckling tendency of sucker rods.

*Pump-Off Control.*
- Rotaflex units necessitate the use of separate pump-off controllers; most controllers shut down the unit for intermittent operation thus reducing daily liquid rates.
- Pump-off operation is controlled by the DynaPump unit itself; no extra equipment is needed. The built-in variable frequency controller (VFC) slows the unit down reducing the system’s liquid production capacity to match the inflow from the well. Since the unit must not be shut down, daily liquid production from the well increases.

Finally, Table 3 presents an interesting aspect of comparing long-stroke and conventional pumping units. The table contains main operational parameters like maximum polished rod load and stroke length of beam, DynaPump, and Rotaflex units of comparable capacities along with their approximate weights. Since the
weight of machines made of steel is a good indicator of their price, investment costs of the three units are easily compared. According to the data contained in the table, beam and Rotaflex units are in the same weight range; while DynaPump units of comparable capacities have weights of about 50% less.

Table 3

<table>
<thead>
<tr>
<th>Conv. Beam Pumping Units</th>
<th>DynaPump Units</th>
<th>Rotaflex Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td><strong>Maximum PR Unit</strong></td>
<td><strong>Maximum PR Unit</strong></td>
</tr>
<tr>
<td>Load</td>
<td>Stroke</td>
<td>Weight</td>
</tr>
<tr>
<td>lbs</td>
<td>in</td>
<td>lbs</td>
</tr>
<tr>
<td>160</td>
<td>20,000</td>
<td>74</td>
</tr>
<tr>
<td>228</td>
<td>21,300</td>
<td>120</td>
</tr>
<tr>
<td>320</td>
<td>25,600</td>
<td>144</td>
</tr>
<tr>
<td>456</td>
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<td>640</td>
<td>36,500</td>
<td>120</td>
</tr>
<tr>
<td>912</td>
<td>36,500</td>
<td>192</td>
</tr>
<tr>
<td>1280</td>
<td>36,500</td>
<td>192</td>
</tr>
<tr>
<td>1824</td>
<td>36,500</td>
<td>192</td>
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<tr>
<td>11</td>
<td>60,000</td>
<td>336</td>
</tr>
<tr>
<td>13</td>
<td>80,000</td>
<td>360</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

Today there are only two kinds of long-stroke pumping units that are widely used: Rotaflex and DynaPump. This paper demonstrates the different features of these units and compares their features and capabilities. Main findings are the following:

- Although the units have widely different operational principles both provide very similar advantages.
- Lifting capacities of the two units are comparable so they can be used under the same conditions.
- The detailed comparison of operational features of the two units presented in the paper facilitates the proper selection between Rotaflex and DynaPump units.

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