The Surface Dynamometer Card

- In use for 80+ years
- Plots surface load versus position
- Shows -
  Structure load
  Rod load
  Hints of downhole conditions
The Downhole Card

- W.E. Gilbert and S. B. Sargent built a dynagraph in 1936 to measure a downhole card.

- The rods and pump had to be pulled to retrieve the downhole card.

<table>
<thead>
<tr>
<th>Run</th>
<th>N</th>
<th>S</th>
<th>B/D</th>
<th>Mef/D</th>
<th>H_p</th>
<th>H_p*</th>
<th>E_r</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18.2</td>
<td>48</td>
<td>243</td>
<td>3.24</td>
<td>6.6</td>
<td>7.1'</td>
<td>98</td>
</tr>
<tr>
<td>B</td>
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<td>48</td>
<td>176</td>
<td>7.9</td>
<td>6.3</td>
<td>7.1</td>
<td>88.5</td>
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</tbody>
</table>
The Downhole Card

- Gilbert and Sargent taught us how to determine what was happening at the pump by interpreting the shape of the downhole card.
- Their work also helped improve the primitive methods for predicting pump stroke.
The Digital Computer Era Dawns

- A manager at Shell Development in Houston, Bob McEntee, was a student of rod pumping and an advocate of rod pumping research.
- He introduced me to Gilbert’s work. Soon I begin trying to compute a Gilbert type pump card using surface dynamometer data (December 1960).
Wave Equation Describes the Elastic Behavior of a Sucker Rod

- Look for solutions \( u(x,t) \) which fit measured surface load and position

\[
\frac{\partial^2 u^2(x,t)}{\partial t^2} = v^2 \frac{\partial^2 u^2(x,t)}{\partial x^2} - c \frac{\partial u(x,t)}{\partial t} + g
\]
Wave Equation Solution Gets Downhole Cards Without Pulling the Rods

- Evaluate load and position at pump depth and plot a pump card.
- The pump card is easier to interpret than the surface card.
Pump Cards Show Downhole Conditions Unambiguously
New Type of Dynamometer Needed

- Ordinary dynamometers have no sense of time
- Solution of wave equation involves time
- New dynamometer includes
  - Strip chart recorder
  - Horseshoe load cell
  - Position transducer
Pump Cards First Obtained With Mainframe Computers (1961-)

Process used:

- Weigh well with strip chart dynamometer
- Digitize strip chart manually
- Enter data on punched cards
- Run program on mainframe computer
- Manually draw pump card

This procedure was inefficient and slow!
Finally, the Downhole Card Could Be Obtained At the Well Site

- HP minicomputer
- Photoreader
- A-D converter
- D-A converter
- X-Y plotter
- ASR 33 teleprinter

Process described in SPE 4068 (1973)
Process Available Nationwide With Time Shared Computers (1980s)

- Software licensed to oil/service companies
- Dyno data digitized with microcomputer graphics tablets
- Input data sent to time shared computers via telephone modem
- Pump cards and finished analyses transmitted back to user via telephone modem
Microcomputers Become Powerful and Cheap

- Microcomputer based dynamometers become available
- Dynamometer cards and finished analyses displayed on computer monitor and printers
- Process is truck borne and finished at the wellsite.

Process now very efficient!
Computing Producing Pressure From the Pump Card

- Use Agnew’s equation to conclude -

  Low fluid load on pump card means pumping unit is getting significant help from the reservoir in lifting the well.

  High fluid load means pumping unit is doing most of the work with little help from the reservoir.

\[ P_i = P_a - \frac{L_f}{A_p} \]

Agnew's Formula 1950s

- \( A_p \): area of pump
- \( P_a \): discharge pressure
- \( P_i \): intake pressure
- \( L_f \): fluid load from pump card
Pump Card Used in POC Algorithm

- Teach POC microcomputer to recognize complete and partial liquid fillage.
- Instruct POC to shut down when liquid fillage drops below preset value.
Inferring Production Rate Using Downhole Pump as a Meter

- Using pump card, compute volume on each stroke
  \[ \delta V_l = \frac{\pi}{4} d^2 S_n \]

- Accumulate volumes to obtain daily production rate
  \[ R_{IP} = 8.905 \frac{\sum \delta V_l}{T_d + T_p} \]
Pump Card POC Controls VSD to Maintain Desired Pump Fillage

- Overpumped—Slow down
- Desired Fillage
- Underpumped – Speed up
Downhole card continues to be of research interest

- In the new century, pump cards computed with the wave equation have been compared with measured cards in a Sandia National Lab/Industry study
- The Gibbs Conjecture was proved by the mathematician J. J. DaCunha, Ph.D. SPE 108762 (2007)
Wave equation shown to be accurate

- Measured by Sandia National Laboratories
- Computed with wave equation
Statement of the Gibbs Conjecture

- Solutions of the wave equation which match measured time histories of surface load and position will produce the exact downhole pump card if the friction law in the wave equation is perfect. In computing the pump card, no knowledge of pump conditions is required. Any error in the friction law will cause error in the computed pump card.
Use of Gibbs Conjecture in improving friction law
Personal hopes of an old man for his younger friends

- I hope you have a job that you love
- I hope you will stay in touch with those who have helped mold your life. Thank them while you can.
- I appreciate the opportunity to speak at the 2008 Sucker Rod Pumping Workshop. I commend the organizers and workers for their valuable service.