USING ADVANCED DIAGNOSTICS AND ROD STRESS DATA TO IMPROVE OPERATING CONDITIONS

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INTRODUCTION

Design and diagnostic tools are an integral part of the modern rod pumping industry. Various quantities such as axial load and buckling tendency are of significant interest to ensure optimum operating conditions. As an example, Figure 1 shows a sample output from a design program predicting rod pumping system performance. The axial load vs measured depth curves are used to determine whether the rods are overloaded on the upstroke or buckled on the downstroke.

Such plots provide definite value at the design stage, yet the reports in the printed documents are rather limited. Only one specific pumping mode is typically reported and the detailed behavior of the rod stress during the pumping cycle is not included for obvious reasons. During actual operation in the field the pumping mode can change, sometimes many times a day. Close monitoring of the rod stress then becomes an essential tool that may be utilized to “zoom into” the system and to detect problems early.

DYNAMIC VERSUS STATIC

Static considerations play an important role in the selection of the pumping mode. For example, [1] provides a formula for the critical compressive load to buckle a slender rod. The approach is based on Euler’s work on stability in the 18th century. Yet every rod pumping system is naturally dynamic and buckling occurs when the rod string is in motion. Reference [2] presents an interesting example demonstrating limitations of Euler’s method. Figure 2a shows a classical setup of a slender column of length l that can buckle under the influence of force P acting vertically. An example of such a force would be gravity. In this case Euler’s method is applicable and yields the critical buckling force as $Pcrit = \pi^2 EJ/(4l^2)$, where EJ is the bending stiffness of the column.

Figure 2b shows a similar situation but now compressive force P “follows” the angle of rotation φ. Axial load would be an example of such a force. It turns out that Euler’s method fails in this case. That is, no other form of equilibrium other than the vertical shape of the column can be found. One could then argue that the rod can’t lose stability no matter what the value of P is. This would be wrong, however, and the correct interpretation of the result is that Euler’s method is inapplicable for this setup. The right approach is to consider small oscillation of the column around the equilibrium, i.e., consider the dynamics of the system. Reference [2] then shows that $Pcrit = 20.19EJ/l^2$, which is significantly higher than in case 2a.

FULL CYCLE ROD STRESS

Every pumping cycle produces literally a mountain of information that can be utilized by the controller. Given a stream of surface cards, i.e., two synchronized sequences of load and position data, a wave equation solver calculates a set of intermediate cards starting at the polished rod and then going all the way to the downhole pump. Using the rod string parameters, load values can be converted to rod stress S. Essentially, S(x, t) is a matrix that shows how stress varies with measured depth x and time t. An appropriate Goodman diagram may then be applied to every x to decide whether the rod is overloaded at this depth.

While all such computations can be done at the controller for every pumping cycle, transmission of all the data to the user would be impractical. Instead, we have developed a cloud-based interface that receives just the surface cards from a device in the field. Stress computations are then performed only for the pumping cycles selected by the user via web interface. Animation of the results has also been implemented. Such level of detail provides a comprehensive and instructive look at the stress and buckling of the entire rod string. It is a new tool offering simple and intuitive diagnostics of the rod pumping system.

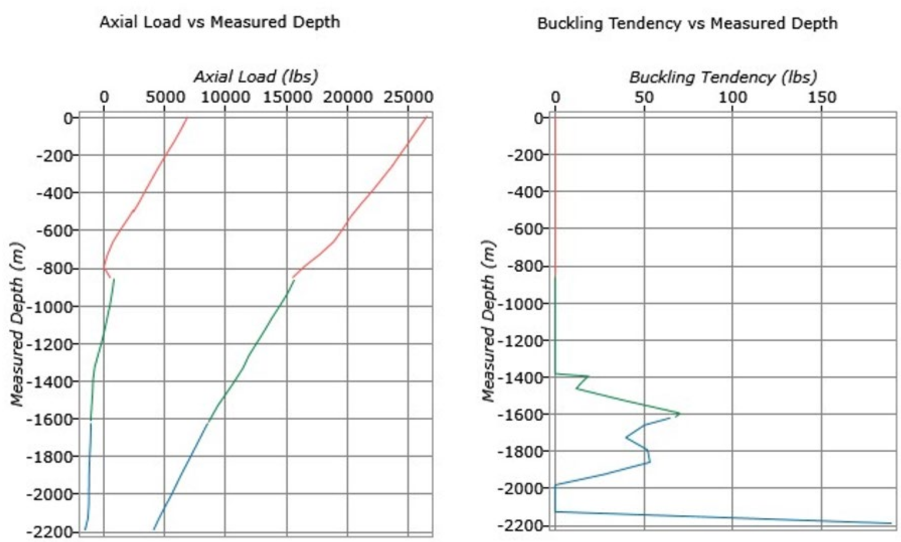

Figure 1 – Axial Load and Buckling Tendency plot by predictive software for a sample well.

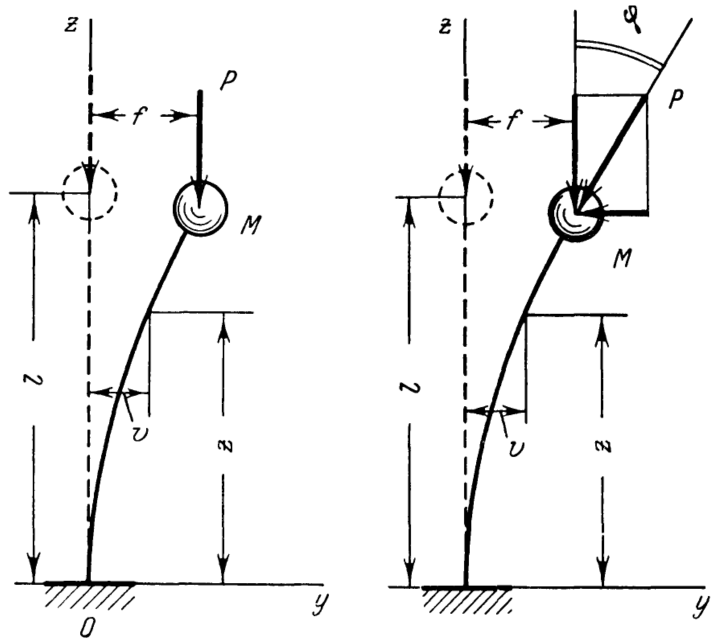

Figure 2a (left) – buckling of a slender rod of length l under the influence of vertical load *P*.
Figure 2b (right) – buckling of the same rod under force *P* "following" the angle of rotation φ.

<u>REFERENCES</u>

[1] J.F. Lea and P.D. Pattillo, "Interpretation of Calculated Forces on Sucker Rods," SPE Production & Facilities, pp. 41–45, Feb. 1995.

[2] V.V. Bolotin, "Nonconservative Problems of Elastic Stability Theory," Moscow 1961.