

THE ULTIMATE ROD STRING DESIGN PROCEDURE

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ABSTRACT

Available sucker-rod string design models calculate rod taper lengths that ensure proper operation without premature fatigue failures. Their common design problems are (a) defining the principle of taper length determination, and (b) calculating the true mechanical stresses along the string. The universally accepted principle of taper length calculations is to provide the same level of safety against fatigue failure in each taper section. Mechanical loads and stresses, on the other hand, are found from highly approximate calculations in most of the design procedures. These loads, therefore, can greatly deviate from the true mechanical loads that would be measured in the rod string run in the well. The paper discusses the development of a novel procedure that estimates rod loads from the predictive solution of the damped wave equation when designing the rod string. Since loads calculated that way imitate very accurately the actual loads, the most important limitation of previous rod string design procedures is eliminated. Strings designed using the proposed model, therefore, have a much enhanced safety against fatigue failures as compared to previous designs.

INTRODUCTION

The sucker-rod string is the most vital part of the rod pumping system because it connects the prime mover situated at the surface to the subsurface pump that provides the useful work of the installation. A properly designed sucker-rod string should provide failure-free pumping operations for an extended period. Improper design of rod tapers can lead to early mechanical failures (rod breaks) with a complete termination of pumping action and an inevitable loss of production.

Due to the usually great length of the string dictated by the typical depths of oil wells, a single rod size cannot be used for the full length. The general solution is the use of tapered rod strings made up of sections (tapers) of increasing diameters toward the surface. This construction very efficiently matches the shape of the ideal rod string which is an inverted cone continuously tapering from top to bottom. The mechanical design of tapered rod strings is highly complicated because of the type of loading the rods are subjected to. Investigation of the possible loads that occur during the pumping cycle shows that the following distributed and concentrated loads act on the rod string:

- Weight of rods in air; it is a distributed load along the string.
- Buoyancy forces oppose the rod weight and are the result of the immersion of the rods into the produced liquid.
- Fluid load on the plunger of the downhole pump is a concentrated force acting during the upstroke only.
- Dynamic loads are the results of changes in acceleration of the moving masses (rods, fluid column).
- Frictional forces are: (1) fluid friction between the rods and the produced liquid, and (2) mechanical friction between the rods and the tubing string.

After considering the variation of these forces during a complete pumping cycle, one can easily conclude that the rod string is exposed to a cyclic mechanical loading. During the downstroke, the string carries the buoyant weight of the rods minus dynamic and friction forces only, while on the upstroke it also carries the load of the fluid lifted. Mechanical stresses follow the variation of rod loads and are cyclic, too; they are typically tension stresses with the tension level considerably increasing during the upstroke as compared to the downstroke. This is the reason why the loading of the rod string can be classified as pulsating tension.

The typical failure mechanism of sucker-rod strings is the consequence of the type of loading: mostly fatigue failure. Fatigue failures occur at much lower levels of mechanical stresses than the tensile strength or even the yield point of the material and are basically caused by the extremely high number of repetitions of the variable loads. This type of failure is absolutely different from tensile (overpull) failures and is the root cause of the great majority of rod string breaks. Therefore, rod string design procedures must inevitably take into account