Dynamic Analysis of the RuTAG Treadle Pump with Rocker-Link Mechanism

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Abstract

Treadle pumps are twin cylinder reciprocating pumps used for irrigation by some of the farmers in developing countries. Invented in Bangladesh in the 1980s, this simple device has been successfully disseminated in countries like India, Philippines, China, Zambia, Kenya, and The Niger [1]. The original treadle pump consisted of two bamboo levers and a frame with rope pulley mechanism attached to it to achieve the reciprocating motion [2]. Since then, there have been many changes in the design of the treadle pump. However, there are few literature that compare the different mechanisms in terms of its dynamic performances.

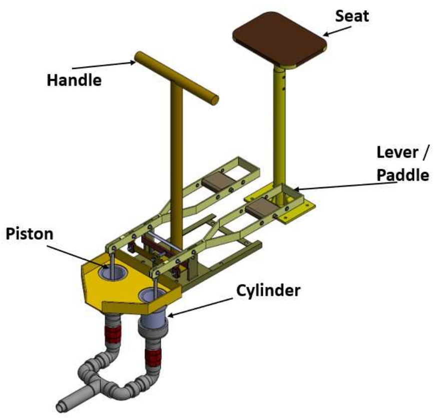

Figure 1: RuTAG Treadle Pump

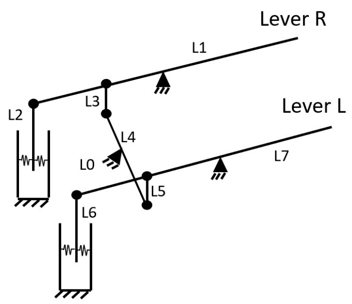

Figure 2: Line Diagram of Lever - Piston Assembly

The treadle pump considered for the analysis is the model improved by Rural Technology Action Group (RuTAG) IIT Delhi (Figure 1), which consists of a Rocker-link mechanism to achieve the reciprocating motion. The treadle pump consists of two levers which are pressed alternatively by the user. Each of the levers are connected to a piston which create suction in the cylinders. The levers are coupled using a four bar rocker-link mechanism making it an eight linked mechanism (Figure 2). The system is symmetric about the pivot of this rocker-link.

If the rocker-link coupler is removed, the resultant system consists of two lever-piston assembly with a reaction force F_r in the place of the coupler (Figure 3). Using Grubler's criterion (Equation 1), the degree of freedom of this assembly comes out to be zero.

$$\boldsymbol{DOF} = 3(\boldsymbol{N}-1) - 2\boldsymbol{J} \tag{1}$$

Here, number of links N = 3 (lever, piston, ground) and number of lower pair joints J = 3 (2R 1P). It can be observed that the motion of this mechanism is due to the flexibility of the leather washer used for the piston. To model this, springs are used in the place of leather washers.

A suction type treadle pump works in two strokes - suction stroke and return stroke. During suction stroke, the user presses the lever, which causes the piston to rise upwards in the cylinder. This generates a suction pressure in the cylinder causing the water to flow in from the inlet pipe. During the return stroke, the piston moves down, causing the valve to open and water gets collected over the piston washer. This water is delivered through the channel during the next suction stroke.

Forces acting on the lever during power and return stroke is shown in Figure 3. Here F_f represents Foot force applied by the user, F_r represents reaction force from the opposite lever, F_s is the suction force, F_d is the drag force, and Kx is the spring force.

(a) Power Stroke (b) Return Stroke

Figure 3: Forces acting on the lever during both the strokes

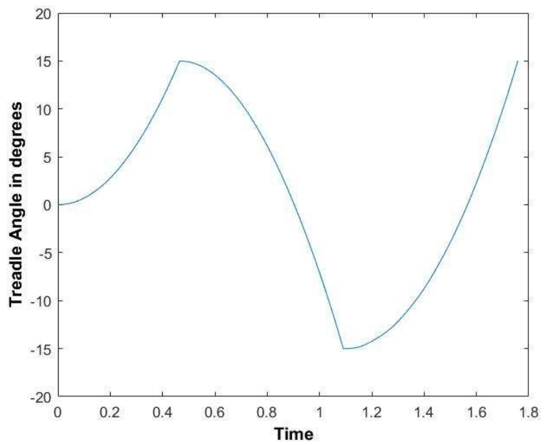

Figure 4: Simulation Results for a suction depth of 7m

The dynamic analysis of both the strokes is done using DeNOC formulation [3] of the Newton-Euler method. For each stroke, the Piston-lever assembly is represented as

$$\begin{bmatrix} \boldsymbol{i}_{11} & \boldsymbol{i}_{12} \\ \boldsymbol{i}_{21} & \boldsymbol{i}_{22} \end{bmatrix} \begin{bmatrix} \ddot{\boldsymbol{\theta}}_1 \\ \ddot{\boldsymbol{\theta}}_2 \end{bmatrix} + \begin{bmatrix} \boldsymbol{h}_1 \\ \boldsymbol{h}_2 \end{bmatrix} = \begin{bmatrix} \boldsymbol{\tau}_1 \\ \boldsymbol{\tau}_2 \end{bmatrix} \tag{2}$$

where $\boldsymbol{i}_{ij}$ is the element of the Generalized Inertia Matrix, $\boldsymbol{\theta}_i$ is the generalized coordinate, $\boldsymbol{h}_i$ is the convective inertia term and $\boldsymbol{\tau}_i$ contains the generalized forces.

The system was simulated for different suction depths and piston stiffness for both the strokes. Figure 4 shows the motion of treadle while pumping water from a depth of 7m. Three strokes, initial, suction, and return, are shown in the graph. Time taken for each stroke is approximately 0.7 seconds, which translates to approximately 1.5 l/s of water output. The results obtained are for an operating force of 220N in the existing configuration of the RuTAG treadle pump. This analysis can be further used to optimize the lever and pump dimensions for better performance such as increased flow rate at a lower input torque.

References

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