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Model Development for a Bellcrank Mechanism Used in a β-Type Stirling Machine

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ABSTRACT

A numerical model has been developed for a bellcrank mechanism intended for use in a β-type Stirling machine. The proposed Stirling machine has two co-axial reciprocating components, the piston and the displacer, whose motion is controlled by the bellcrank mechanism. The mechanism reduces side loads on the reciprocating components while remaining relatively compact, and allows partial dynamic balancing using counterweights. The mechanism also allows adjustment of the piston stroke while maintaining the top dead center position, small side load angles, and the relative position of the counterweights. To describe the mechanism mathematically, first, a kinematic equation set is derived by combining two existing equation sets from the literature and mapping them onto a common set of variables. This is possible because the proposed bellcrank mechanism is comprised of a four-bar mechanism connected to a slider-crank mechanism. Using these kinematic equations, the model then calculates the speed fluctuations of the machine by considering the mechanical energy of the machine as a whole. This requires incremental calculation of the work done by the engine working fluid, the kinetic and potential energies of each mechanism component, and work consumed by the driven load. The speed fluctuation results can be used for sizing the flywheel, and providing input to both the gas path model and the inertia force calculations. Finally, a kinetic equation set is solved to give the forces on each component of the mechanism as a function of crank angle. The kinetic equation set relies on the kinematic, speed fluctuation, and gas path model results for its inputs. Specifically, the estimated component masses are used to calculate the gravitational forces, the speed fluctuation results are used to calculate the inertia forces, and the gas path model results are used to calculate the pressure forces. Joint loads, shaking forces, and shaking moments follow from application of these forces to the mechanism at each crank angle increment. The detailed force results are useful for bearing selection, estimation of bearing friction, and calculation of stresses in the mechanism components. The details of the gas path model are beyond the scope of this presentation.

Early results show that the pressure forces far outweigh the inertia and gravitational forces on the mechanism. This is due to the large area of the piston faces, and the relatively low running speed. Further, perfect dynamic balance will be difficult to achieve because there is no way to counteract the shaking moments in the current configuration.

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