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”DYN2#2 - Phase transitions in a resonating free-piston engine generator”

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Free-piston engine generators (FPEGs) offer significant advantages over conventional combustion generators, in particular, higher efficiencies, compactness, and lighter weight. These attributes give higher gravimetric and volumetric energy densities, compared to alternatives. Moreover, an FPEG allows unlimited scalability to high power, and also, electrically controlled variable compression ratio, which offers fuel flexibility, including potential to run on zero carbon fuels. By fitting a very stiff resilient member to an FPEG, a nearly-linear mass-elastic system can be created capable of resonance. Resonating FPEGs offer significant advantages over FPEGs that use a bounce chamber. These advantages include more precise control, a significant reduction in electrical machine currents, and a corresponding reduction in electrical power losses. Resonance using a square wave external excitation source, has also been used to start an FPEG fitted with a bounce chamber. In operation, a resonating FPEG is actually a nonlinear, self-excited system, where the nonlinearity stems from the adiabatic gas compression and expansion processes. Self-excitation stems from the occurrence of combustion which largely depends on the piston displacement. A significant difficulty starting any type of FPEG by exploiting resonance, is first to recognise that the phase of the fundamental harmonic component of any linear system response, is Ï€/2 radians out-of-phase from the external excitation. In operation however, under self-excited resonant conditions, the phase difference between the dynamic response and the excitation, is significantly different from Ï€/2. The first question therefore is: were the system to be entirely linear, in operation, what would the resonant phase difference be between the self-excitation and the response? The second question is: if the phase difference is significantly different from Ï€/2, how is it possible to make the transition from externally excited resonance (used for starting) to self-exited steady-state resonant operation. The third question is how does nonlinearity affect the phase differences in resonant starting and resonant steady-state operation? This paper addresses these three questions by modelling and simulation. The overall objective is to provide clear guidance on how to transition between resonant starting and subsequent self-excited operation of a resonating free-piston engine generator.

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