POWER OSCILLATION OF THE

MOD-O WIND TURBINE

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ABSTRACT

The Mod-O power has noise components with varying frequency patterns. Magnitudes reach more than forty percent power at the frequency of twice per rotor revolution. Analysis of a simple torsional model of the power train predicts less than half the observed magnitude and does not explain the shifting frequencies of the noise patterns.

INTRODUCTION

The 60 cycle electrical power generated by the Mod-O wind turbine generator has been relatively noisy. For perfect power the large blades must rotate uniformly despite local wind patterns and power train resonances. An error of only 0.1 degree in rotor position can vary the power by about 20 percent. In the following, a model of the power train is analyzed in the frequency and time domains to understand its behavior, and results are compared with Mod-O data.

MODEL DESCRIPTION

A block diagram of the power train as represented by torsional springs, dampers, and inertial masses is shown in figure 1. Each blade is a single inertia with one dimension of freedom, (cordwise) lag. There are no multi-dimensional degrees of freedom which have importance in helicopter rotor studies. To admit such interactions here would greatly complicate the simple analysis performed.

A typical torque pattern expected from the blades was known from a separate aerodynamic computer code. This torque pattern served as an input to the power train model for a time response analysis. The aerodynamic program assumed a rigid but rotating hub and no blade lag dynamics. To a first approximation the power train model supplies the missing dynamics to the aerodynamics code.

RESULTS

Analytical

The rotor torque from the aerodynamic code is plotted in figure 2. As each blade swings behind the tower, more than 60 percent of the rotor torque is momentarily lost. Also plotted in figure 2 are the generator electrical torque responses to the rotor torque input. Data are shown for three high speed shaft configurations - a steel shaft, an elastomeric shaft, and a 2.3 percent slip coupling. The three responses have a similar oscillation pattern. The basic two per revolution oscillation (2P) is about 14 percent and there is a noticeable 4P component.

The system frequency responses are plotted in figure 3 for the three high speed shaft configurations. The responses at the even harmonics of rotor frequency, 2P, 4P, etc., are of special interest because at these frequencies the rotor torque input (of figure 2) has content. At these harmonics, the responses are similar, which is why the time responses of figure 2 are similar. The harmonic with the most spread is the 2P harmonic for which the slip coupling response is about half the steel shaft response.

Experimental

A sample trace of Mod-0 power and wind speed data is shown in figure 4. Two power variation examples are circled - a (general low frequency) control problem and a 2P oscillation. The control system contains a wind speed input which can directly command pitch changes. The peak to near 150 percent in power occurred when the measured wind speed dropped (but apparently not the true rotor average wind) and the blade pitched for more power. The 2P oscillation, the other variation circled, has a maximum amplitude of about 40 percent. It differs from the model analysis in two basic respects. First, the response can hold a 4P or a 2P pattern for periods of time of about 10 seconds. Second, the 40 percent maximum 2P oscillation is more than twice that predicted by the analysis. Evidently a significant 2P input is missing from the model analysis. To further our understanding, we plan to frequency response test the Mod-0 using the rotor pitch angle as the input and are also following results from a more complicated aerodynamics computer code from a contract effort.

DISCUSSION

Q. Please explain the idea you have for testing the dynamics by commanding harmonic collective pitch, in the field.

A. We plan to oscillate the pitch about a degree with a sinusoidal sweep frequency signal. The input would be on top of the control signal required to keep the synchronous power about constant and on line. Data reduction is to be off line from signals recorded on tape. The analyzer is expected to lock on to the signal and not the tower shadow.

Q. What frequency response capabilities can you get with Mod-0 actuator to induce torque variations for running experimental frequency response of the drive train? This data can also be used to optimize control transfer function.

A. Experimental frequency response data is most desired to better validate the model dynamics. The pitch servo has about a 1.5 cps bandwidth. Care will be taken to avoid extended running at large amplitude to not deplete the hydraulic pressure in the pitch servo accumulator.

Q. Where would you add more inertia in the drive train to avoid the 2P bloom?

A. The power train is supposedly not near a 2P resonance. The bloom, however, does look like the response of a low damped resonance. The planned experimental frequency response test should help separate effects here. The most effective place for adding inertia, if deemed advisable for moving the <u>first</u> mode, is probably on any shaft rotating at (or above) the generator speed.

Q. Where does the second resonance come from?

A. A normal modes analysis (with no blade degree of freedom) has shown the second mode to be primarily across the effective generator spring. The model frequency is quite sensitive to the blade degree of freedom, however. For example, the second mode natural frequency is nominally 3.50 cps for a blade natural frequency of 2.47 cps. If the blade spring constant is halved, the second mode frequency drops about 30 percent to 2.51 cps.

Q. What was the generator model?

A. It was a third order "voltage behind subtransient reactance" dynamic synchronous machine model connected to an infinite bus.

Q. What kind of excitation control was used for the alternator?

A. The Mod-0 has a slow VARS control which was simply modelled as a constant set to obtain the desired .8 power factor.

Q. How were numerical values for stiffness and damping properties obtained for the shafts, pulleys, and speed changers between the rotor and the generator?

A. The generator model is effectively the weakest stiffness element and the maximum damping element. Mechanical shaft stiffness values were calculated from geometry and material properties. The manufacturer's values for the Falk coupling were used. The external damping parameters were estimates based on a 75 percent efficiency and internal damping parameters were estimates to achieve at least about .05 damping ratios for the higher order modes.

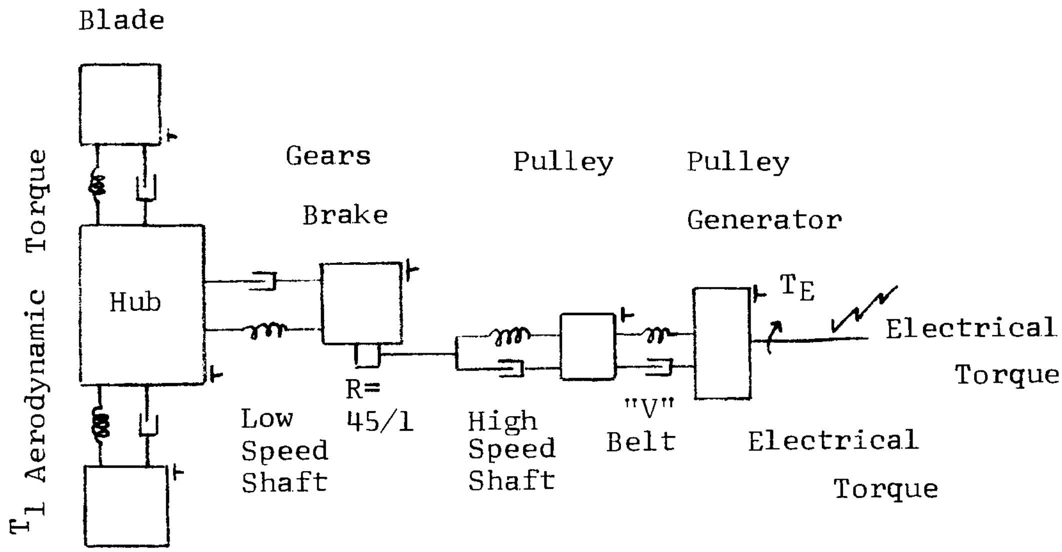

Figure 1. - Block diagram of mechanical elements in power train.

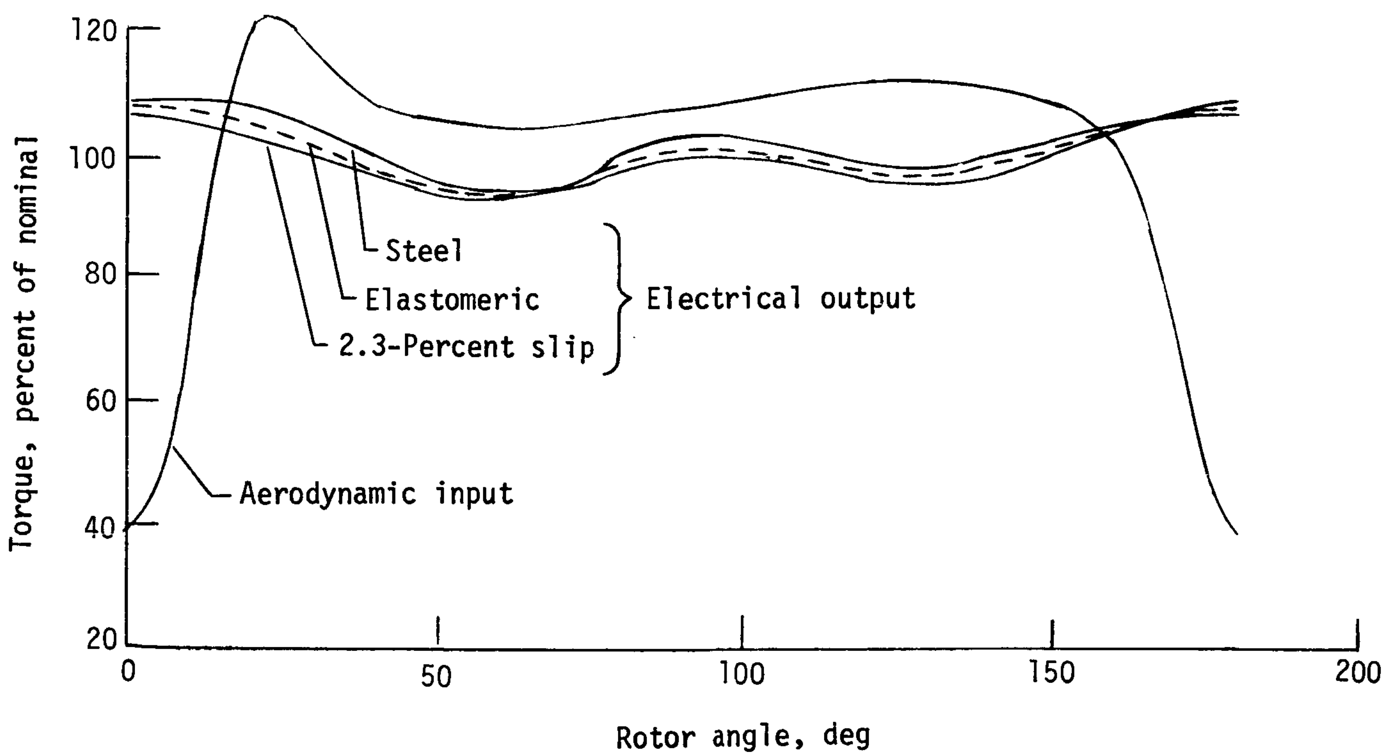

Figure 2. - Output response comparisons of three high-speed shaft configurations to the same input.

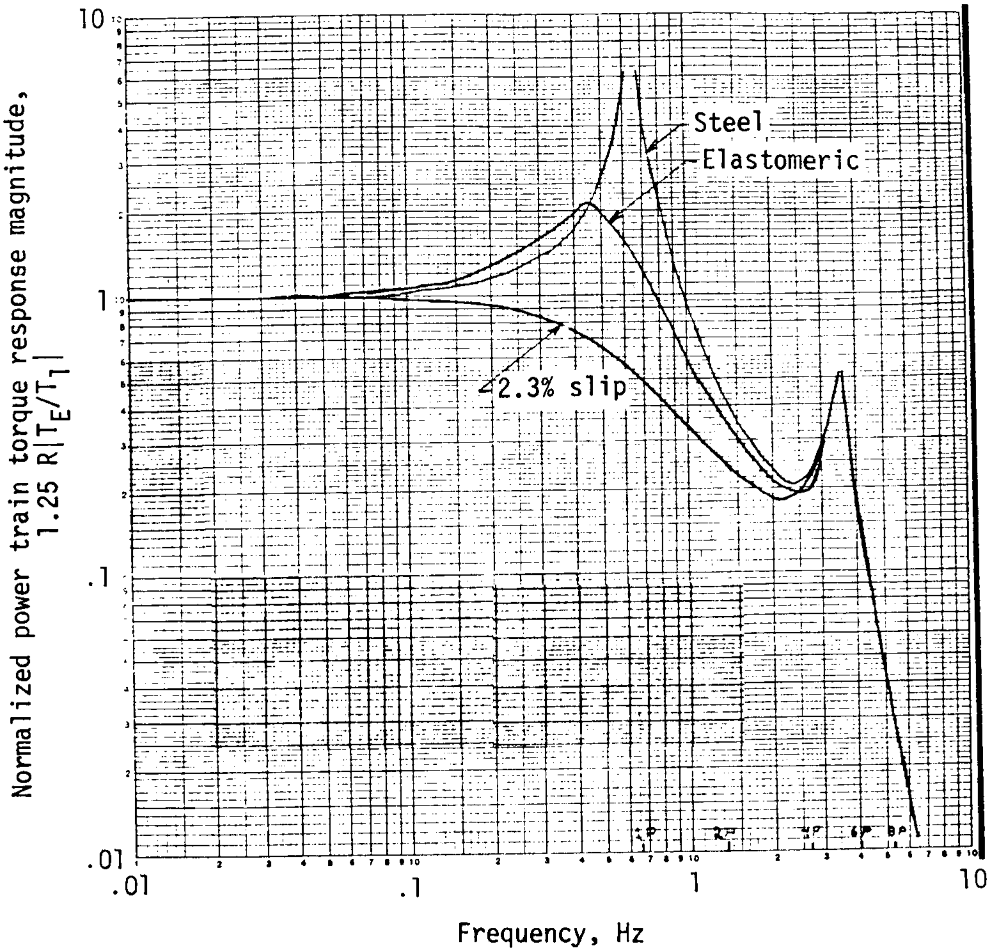

Figure 3. - Power train frequency response magnitude comparisons for three high-speed shaft configurations.

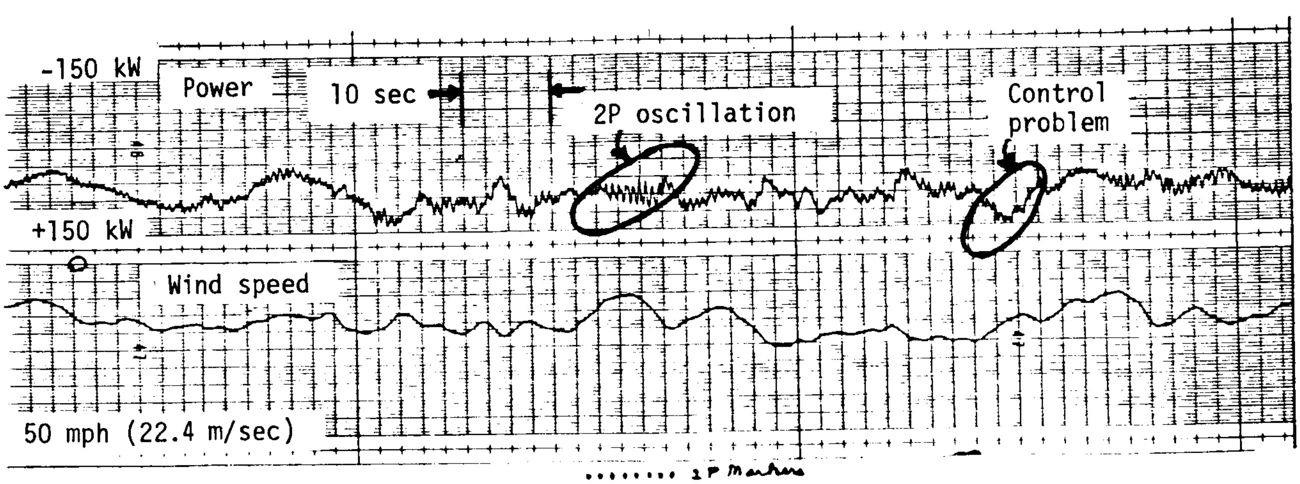

Figure 4. - 2.3-Percent slip coupling with feed forward control, recorded on 10/8/77.