Modeling and Simulation of Vibrations of a Tractor Gearbox

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ABSTRACT

The vibration characteristics of a four-stage reduction tractor gearbox were studied.

These characteristics are: displacement amplitudes, natural frequencies and mode shapes. The main aim of the study was to obtain accurate dynamic response of the system to time varying gear mesh stiffness and periodic frictional torque on the gear teeth and to analyze the effect of gear design parameters on the dynamic response in order to obtain the optimum configuration for the multistage gear train.

A mathematical model for torsional vibrations incorporating the periodic frictional torque on the gear teeth, the time varying mesh stiffness and time varying damping coefficients as the main sources of excitation was developed. Mesh coupling between the four reduction stages of the gear train and shaft flexibility were taken into consideration.

A computer program in FORTRAN that employs fourth order Runge-Kutta integration scheme was developed to simulate the model in the time domain. One of the challenges with models of multiple gear pairs encountered was predicting the initial conditions for the numerical integration. In this research, an iteration scheme was employed where the response after one period of each gear mesh was taken as the initial value for the next iteration until the difference between the initial values and the values after one mesh period was relatively small. This state corresponds to the steady state rotation of the gears. The model was verified by comparing the numerical results obtained with experimental data from NASA Lewis Research Center. The results were found to correlate very well both in the shape of the curves and in magnitude thus indicating that the model represents the physical behavior of gears in mesh. The numerical results obtained showed that gears exhibit large vibration amplitudes which influence the forces and stresses on the gear teeth under dynamic load conditions. It was observed that the dynamic

load on the gear teeth is much larger than the corresponding static load and as a result, the stresses, and hence, bending and contact fatigue lives of the gear set are influenced by its vibratory behavior.

The effect of varying gear design parameters (module, pressure angle and contact ratio) was also studied. The results obtained showed that increasing the contact ratio of a pair of gears in mesh reduces the vibration levels significantly. The results showed that by using gears with a contact ratio of 2.0, the vibration levels can be reduced by upto 75% while the peak dynamic stress on the gear teeth can be reduced by upto 45%. Gear pairs with a module of 2.5 and contact ratio close to 2.0 were found to yield the best combination of low vibrations and low bending stresses for the gearbox studied.

The eigenvalues and eigenvectors of the system were obtained using the Householder and QL algorithm. Prediction of the natural frequencies and mode shapes provided important information for keeping the natural frequencies above the operating speed range. For the gearbox system analyzed in this study, the natural frequencies predicted by the model were found to be way above the operating speed range and thus pose no danger of resonance occurring within the operating speed range. Results from this study showed that, by reducing the mass moment of inertia by about 20%, the natural frequency increases by about 11%.

The model developed in the study can thus be used as an efficient design tool to arrive at an optimal configuration for the gearing system that will result in minimum vibration levels and low dynamic gear root stresses in a cost effective manner.