Abstract

Rotor dynamic systems are often analyzed with ideal drive assumption. However, all drives are essentially non-ideal, i.e., they can only provide a limited amount of power. One basic fact often ignored in rotor dynamics studies is that the drive dynamics has complex coupling with the dynamics of the driven system. Increase in drive power input near resonance may contribute to increasing the transverse vibrations rather than increasing the rotor spin, which is referred to as the Sommerfeld effect. The unique feature of Sommerfeld effect is a missing speed range during rotor coast up and coast down. The severity of Sommerfeld effect is mostly observed in unbalance systems. When the system becomes complex (e.g. multi-disk systems), the chance of residual unbalance is high and also some different unbalance conditions arise. The presence of unbalance in rotor systems is very common and they are generally due to manufacturing defects and their rigorous use in dynamic environment. A small unbalance can cause large vibration and sometimes it is enough to destroy the whole system. In rotating systems, more power consumption occurs at resonance zone due to Sommerfeld effect and also this leads the vibration amplitudes to a very high value. The vibration amplitudes and power consumption drop down to a lower value after the rotation speed makes a sudden increase beyond the resonance speed. The full balancing of rotor system is a tedious task, therefore smoother resonance passage needed to be performed by predicting the jump voltage and Sommerfeld effect.

An analytical steady state energy balance method is performed to predict the Sommerfeld effect in single degree freedom foundation system driven by DC motor. The effect of foundation damping on jump voltage is also analyzed by root loci. The transient simulation of the full non-ideal system is done by bond graph method. The jump voltage for single degree freedom foundation system driven by a three phase induction motor is obtained by bond graph approach. The speed control method is performed for the system to ensure smoother passage through resonance region. A pure mathematical model is developed to calculate the critical speeds and predict the Sommerfeld effect in discrete overhung disk shaft rotor system, offset disk shaft rotor system and in a multi-disk rotor system (Discrete means the shaft mass of the system is not considered but the shaft stiffness, Internal or material damping presented in the shaft, and bearing damping values are considered). The various systems are considered for significant reasons and with substantial conditions. The overhung disk shaft rotor systems is highly gyroscopic in nature, the offset disk shaft rotor system with lower and higher pare external damping effects are analyzed from frequency excitation and stability threshold point of view and the Sommerfeld effect in multi disk rotor system is studied with various unbalance conditions. Then the continuous systems of the same models are analyzed by FE Approach. The modal analyses of continuous systems are done by FE software Ansys. As Ansys software is incapable of modeling non-ideal drive, the modeling and transient simulations of full non-ideal systems are done by bond graph approach. The predicted steady state results are validated with transient simulation results.

The insufficiency in supply power to overcome the resonance may catch the rotor speed at resonance and the persistent high vibrations at that zone can damage the machine. Various proposed solutions to this problem deal with modifications to the mechanical structure and active/semi-active control of structural parameters. This thesis proposes modification to the prime mover so that peak available power is delivered exactly at the structural resonance frequency. Various control strategies to modify the torque-speed characteristics of permanent magnet, shunt and series wound DC motors to promote escape through resonance are considered. Transient simulations are performed using bond graph models for this multi-energy domain (here, electro-mechanical) system.

The prediction of the presence of the Sommerfeld effect is very important from the point of view of actuator sizing in a rotor dynamic system designed to operate in super-critical region. One can decide on the required motor power and its other ratings needed to drive the rotor through the critical speeds for a given maximum allowable eccentricity. On the other hand, if the motor specifications are known then one can determine the maximum allowable eccentricity based on which balancing requirements of the rotor may be worked out for easy passage through the critical speeds.

Key words: Sommerfeld effect, Non-ideal drive, Rotor dynamics, Finite element model, Multi-energy domain modeling, Bond graph, DC motor control.