DYNAMICS OF A BEARINGLESS HELICOPTER ROTOR BLADE WITH A NON-LINEAR ELASTOMERIC CONSTRAINT

The dynamic characteristics of the rotor blades play a significant role in the overall performance and stability of a helicopter. There has been a continued effort to develop a mechanically simple yet efficient rotor blade and hub configuration. Early rotor blades were provided with flap (out-of-plane) and lag (in-plane) hinges at the root of the blade. These rotor systems having complicated construction are usually referred to as articulated rotors. With the advancement in fiber-reinforced composite material technology, increasing emphasis has been placed on the development of hinge less and bearing less rotor systems. Both articulated and hinge less rotors are provided with external hydraulic dampers to increase damping in the lag mode and thereby to avoid aero elastic and/or aeromechanical instabilities. In a bearing less rotor, external damper is eliminated by incorporating a specialized elastomer with high loss factor.

For the last two decades, considerable effort has been put in by industry and R & D establishments to develop a bearing less main rotor. Though a bearing less rotor is mechanically simple, its dynamic analysis becomes very complicated because of multiple load paths, presence of non-linear electrometric damper and existence of kinematic constraint at the pitch link. With the consolidation of rotor blade structural dynamic and aero elastic formulation applicable for articulated and hinge less rotor blades, academic research has now focused on the fundamental understanding of the effects of non-linearities of elastomer on the dynamics of bearing less rotor blades.

In general, the elastomer used in a bearing less rotor exhibits highly non-linear characteristics both in stiffness and damping with respect to the amplitude of deformation. It is expected that due to the presence of the elastomer, the lag and flap frequencies should dependent on the amplitude of motion which is a typical feature of a non-linear system. But so far no attempt has been made to study the effect of amplitude on the frequencies of a bearing less blade. Although several researchers have proposed different non-linear models for the elastomer, while performing the stability analysis, only linearised equations of the blade and elastomer are solved. In addition, all the aero elastic response studies of the rotor blade have focused on the steady state response. No information is available on the transient response characteristics of a bearing less rotor with the inclusion of kinematic constraint and multiple load paths.

The major objectives of the present study are as follows.

(i) Formulate a simple non-linear model to capture the non-linear stiffness and damping characteristics of an elastomer.

(ii) Study the influence of non-linear stiffness of the elastomer on the free vibration characteristics of uncoupled flap and lag dynamics of the blade.

(iii) Examine the amplitude dependent stability of an idealized bearing less rotor system under ground resonance. And

(iv) Analyse the transient response of an isolated bearing less rotor blade undergoing coupled flap-lag-torsional deformations in hovering condition. The transient response results are compared with those of a hinge less blade with identical blade properties. A brief outline of the chapter wise contents of the thesis is summarized below.

The experimental data on the non-linear stiffness and damping properties of an elastomer show very weak dependence on frequency in the range of interest for rotor blade analysis. In the light of this observation, the non-linear characteristics of the elastomer is modeled in chapter 2 by a parallel combinations of a non-linear spring, a coulomb damper and a hysteretic damper. The model is kept in a simple form so that it can be easily integrated with the blade model. The parameters of the analytical model are obtained by correlating with the experimental data available in the open literature.

In chapter 3, both linear and non-linear free vibrations of a idealized bearing less rotating blade undergoing uncoupled flap and lag bending have been studied. First a linear problem has been solved using two different solution techniques, one based on power series expansion and the other based on the Rayleigh-Ritz method. The natural frequencies are obtained for different values of spring stiff nesses and elastomer locations. In the non-linear analysis, a numerical-perturbation technique based on multiple-time-scale is formulated to determine the frequency-amplitude relationship for the rotating blade.

In chapter 4, an amplitude dependent stability analysis has been carried out for a coupled rotor/fuselage system under ground resonance condition. The stability analysis is carried out for different locations and amplitudes of motion of the elastomer.

In chapter 5, a suitable numerical technique has been formulated to study the transient response of an isolated bearing less rotor blade to a step control pitch input. The blade is assumed to undergo coupled flap-lag-torsional deformation in hovering condition. A time varying inflow model (based on the dynamic inflow model) has been used for the analysis. The expressions for aerodynamic loads are treated by an implicit formulation. The study is carried out for different locations of the elastomer and pitch link. The transient response characteristics of the bearing less rotor blade is compared with that of the hinge less blade. The comparison is made to highlight the difference in their response behaviours. A quantitative measure of the aero elastic couplings (pitch-flap, pitch-lag), based on the steady state response has been proposed and an attempt is made to relate the couplings and the response characteristics of the blade.

An analysis has been carried out, in chapter 6, to investigate the phenomenon of limit cycle oscillation and elastomer model. Finally, in chapter 7, the overall conclusions are included. The major conclusions of the present thesis are summarized below.

(i) Using an idealized model for a bearing less rotor, both linear and non-linear free vibrations of the rotating blade have been studied. Two different solution techniques are used for the linear analysis. The natural frequencies obtained by both techniques are in excellent agreement. The results of the non-linear free vibration analysis of the rotor blade indicate that upto a fairly high-value of amplitude, a seventh order approximation of the non-linear spring is sufficient to correctly the frequency amplitude relationship.

(ii) It is revealed from the ground resonance stability analysis that the elastomer amplitude does not significantly alter the stability of the system in the region of maximum instabilities. However, it exhibits appreciable influence in other regions. The elastomer locations seem to have considerable influence on the stability of the system. The results indicate that for a given location of the elastomer, there is an optimum location for the torque tube attachment.

(iii) The transient response analysis to a step control pitch input is performed for both hinge less and bearing less rotor blade configurations having identical blade properties. It is observed that there is a qualitative difference in the nature of the response as well as in the dynamic overshoot of the rotor thrust for the two types of blades.

(iv) It is noticed that the locations. In particular, it is observed that the blade depends on the pitch link locations. In particular, it is observed that the blade response with trailing edge pitch link configuration is significantly different from that of a leading edge configuration. For certain trailing edge configurations, the blade exhibits a divergence transient response indicating instability. The reason for these significant differences in the response behaviour can be attributed to the changes in the aero elastic couplings and the constraint loads due to the pitch link. The aero elastic coupling measures are observed to be dependent on the magnitude of the control input, exhibiting a non-linear relationship.

(v) The results of the transient response characteristics with two different elastomer models (for the same experimental data) indicate that the phenomenon of limit cycle oscillation is highly dependent on the elastomer model. Therefore, sufficient care must be excercised in modeling the elastomer.