Abstract

Modelling viscoelastic materials is always difficult since under dynamic deformation such materials store energy as well as dissipate it to the thermal domain. Whereas modelling the elastic behaviour is easy, modelling the energy dissipation mechanism poses difficulty. By and large every material may be classed as viscoelastic as damping is inherent in every material; a material may be termed as strongly viscoelastic (e.g., polymers) in which the dissipation is significant in comparison with the energy stored and weakly viscoelastic (e.g. metals) otherwise.

This work presents a theoretical study of the dynamics of a generally viscoelastic (strong or weak) axi-symmetric rotor-shaft system, in terms of stability limit of the spin speed and unbalance response amplitude at a disc location as two indicators where instability is assumed to be caused by the rotary force generated by internal material damping in the rotor system as a result of rotor spin.

The study of dynamics thus needs a reliable time domain rather than a frequency domain model for the material constitutive relationship to get the equations of motion. Though frequency domain models (in terms frequency dependent storage modulus and loss factors or complex modulus) of several materials including polymers are already available in literature yet these are insufficient for an analysis of stability as it needs the eigenvalue analysis. Time domain models are more complete in this respect than the frequency domain models as the former is useful for both transient and frequency response analyses whereas the latter models are only useful for frequency response analysis. Getting, rather extracting, time domain models is challenging unlike the frequency domain model, which are easily available. For linear viscoelastic solids (1) Multi-element spring-dashpot models and (2) The internal variable approach are found in the literature. However, under the second category the Augmenting Thermodynamic Field (ATF) and Anelastic Displacement Field (ADF) approaches were found especially suitable in comparison with others because energy dissipation is modelled by including additional coordinates considered as internal variables (which are the ATF and ADF), which are continuous from element to element for a continuum and also the model extraction is easy.

In this work the ATF, ADF and suitable multi-element models are first either obtained from literature if possible or extracted using Genetic Algorithm and then the equations of motion are obtained after discretizing the rotor continuum using Raleigh-Beam finite elements. An important contribution in this work, not found in literature surveyed so far, is the deduction of the circulatory matrix when any of the approaches: (1) Multi-element spring-dashpot model, (2) ATF or (3) ADF models is used to form the constitutive relationship. The same approach has been extended to study the dynamics of reinforced viscoelastic rotors, for which two theoretical case studies have been reported viz. (1) The dynamics of Aluminium and carbon-fiber-reinforced-Aluminium rotors where the ATF parameters were obtained from the literature and (2) The Dynamics of Poly(Vinyl-Chloride (PVC) and PVC(MWCNT), (where the PVC matrix is reinforced with Multi-walled Carbon Nanotube) rotors, where the ATF, ADF and 4-element liner viscoelastic model was extracted using GA from the frequency dependent storage modulus and loss factor obtained from literature. The objective and important conclusions proposed in this work are as follows.

(1) This work applies a time domain model, useful for complete dynamic analysis (analysis of transient as well as forced response) for a generally viscoelastic rotor continuum using Multi-element, ATF and ADF approaches to form the constitutive relationship. In this process obtaining the circulatory matrix serves as the most important contribution, not found in literature surveyed so far. The procedure is also useful for rotors with multiple layers of viscoelastic materials as well as rotors made of reinforced polymers.

(2) Time domain model extraction is done by applying a Genetic Algorithm to the frequency domain description of the material properties viz. storage modulus and loss factor which are easily obtained from handbooks or from experiments. Extraction of the ADF parameters is the easiest and the least time consuming as the number and range of parametric values are the least.

(3) As usual reinforced viscoelastic rotors either with fiber or using nano-particles show improved performance over simply viscoelastic rotors as reinforcement increases the first bending natural frequency, increases the stability limit of the spin speed, reduces the unbalanced response amplitude and thus are dynamically suitable.