Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 144 (2016) 68 – 76

Procedia Engineering

www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

The Stability of a Precessing and Nutating Viscoelastic Beam with a Tip Mass

S. Bose[a,*], A. Sinha[b], A. Nandi[c], S. Neogy[d]

[a,b,c,d]*Department Of Mechanical Engineering,Jadavpur University, Kolkata-700032,India*

Abstract

The present work aims at stability analysis of a uniformly precessing and nutating viscoelastic beam with a tip mass as a simple model of a polymeric mechanical arm. The motion of the beam is described as small deformations superposed on rigid body rotation about a point. The damping in the viscoelastic material is considered to be of non-viscous type. The material is modeled in the time-domain using a Voigt model and Maxwell model in parallel. The resulting parametric equations are derived in a rotating frame and analyzed using a variant of Hill's method. The stability borderlines are generated with precession and nutation speeds as parameters for materials with different frequency versus storage modulus and loss coefficient graphs. It is observed that the beam, which only precesses is also unstable for a certain range of non-zero nutation angles.

Peer-review under responsibility of the organizing committee of ICOVP 2015

*Keywords:*viscoelastic; nutation; stability

1. Introduction

The present work proposes to develop a simple model for a mechanical arm meant for handling of materials. Its path or at least a portion of it is specified as a combination of uniform precession and nutation. In an effort to reduce weight and increase damping of the robotic arm, the conventional material is replaced by a polymeric one. The reduction of vibration is always a major requirement in engineering applications. Passive damping technology using viscoelastic materials is traditionally used to control vibrations of structures.

Anderson[1], Gur''go''ze, Dogrueg and Zerena[2] analyzed viscoelastic beams with tip mass. Mei[3] considered mast antennas and robot arms as beams with tip mass. Teng and Cai[4] analyzed frequency characteristics of a hub-

* Corresponding author.
E-mail address: subhadip10@yahoo.com

Peer-review under responsibility of the organizing committee of ICOVP 2015
doi:10.1016/j.proeng.2016.05.008

beam system. They settled the attached mass at different arbitrary positions. Gur’’go’’ze and Zeren[5] considered a rotating (precessing) viscoelastic (Kelvin-Voigt model) beam. Stability analysis of a spinning and precessing rotor with non-symmetric shaft was done by Ghosh et al[6].

Bland and Lee[7] attempted to fit a linear four element model to the experimentally obtained properties of polyisobutylene. Nakra and Chawla[8] used the four-element model mentioned above for vibration control of plates with viscoelastic core. Dutt and Roy[9] used the same viscoelastic model in operator form for a spinning viscoelastic shaft disk system.

In the present work, the viscoelastic material property is modeled in the time domain using a parallel combination of a Voigt model and a Maxwell model. The governing equations for such a viscoelastic beam are expressed in the simultaneously precessing and nutating frame. The resulting equations are parametric in nature with coupling between two transverse directions. The stability borderlines are computed considering precession and nutation speeds as parameters. The effect of material damping (quantified as loss coefficient), storage modulus and the effect of centrifugal stiffening is studied in details. A precessing beam with constant nutation angle is also considered.

2. Analysis

2.1. Coordinate System

Fig.1 shows the precessing and nutating beam along with the coordinate systems considered. The inertial reference is represented by the coordinate system $\mathbf{XYZ}$. The configuration of the beam can be specified by a precession followed by a nutation. The beam precesses about the inertial axis $\mathbf{Z}$ with a uniform speed $\mathbf{\Omega_p}$. The $\mathbf{x'y'z'}$coordinate system precesses with the beam. The coordinate axes $\mathbf{z'}$ and $\mathbf{Z}$ are coincident. Had the beam been rigid, the $\mathbf{xyz}$ coordinates would have been the body-fixed coordinate system, which simultaneously precesses and nutates. The angles of precession and nutations are expressed using symbols $\boldsymbol{\phi}$ and $\boldsymbol{\theta}$ respectively. The $\mathbf{y}$ axis is aligned with the centerline of the beam. The motion of the beam can be conceived as small bending vibrations superposed on rigid body rotation about a point.

The mass of the beam is not considered in the present analysis. The two transverse displacements at the tip are the two degrees of freedom of the beam. The displacement at any point along the axis of the beam can be interpolated from displacement degrees of freedom $\mathbf{u_{cx}}$and $\mathbf{u_{cz}}$using an assumed interpolation function. In addition to the actual degrees of freedom, another two fictitious displacements $\mathbf{u_{bx}}$and $\mathbf{u_{bz}}$are also considered in order to model the viscoelastic material.

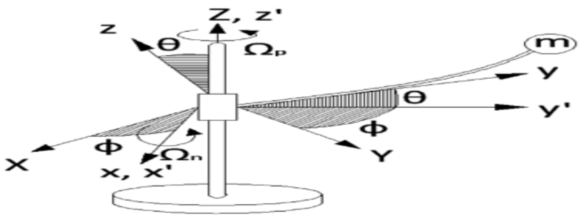

Fig 1. Small deformations superposed on a simultaneously precessing and nutating beam

2.2. Variational Principle

The tip-mass has kinetic energy due to the rigid body motion of the beam and the associated small elastic vibrations. The viscoelastic forces act as restoring force. The Hamilton’s principle for this system can be expressed as

$$\int_{t1}^{t2}(\delta T + \delta W_{ve} + \delta W_{cf})dt = 0 \tag{1}$$

δT is the first variation of the kinetic energy. The symbols δW_{ve} and δW_{cf} stand for virtual work done by the internal viscoelastic force and the centrifugal force respectively.