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Vibration Analysis of Functionally Graded Rotating Shaft System

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Abstract

This paper mainly deals with the dynamic analysis of functionally graded (FG) rotor shaft system. Power law gradation is adopted for mathematical material modelling of FG rotor shaft. Timoshenko beam theory (TMBT) is also been used for the finite element (FE) modelling of the FG shaft. The FG shaft model has been verified by comparing critical speeds with the available literature. Different analyses have been carried out (such as Campbell diagram, Stability speed limit (SSL) and damping ratio) by considering shear deformation, rotary inertia, gyroscopic effects, strain, the kinetic energy of shaft, and internal damping.

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Keywords: Functionally graded material (FGM); Power-law gradation; TMBT; FE modelling; SSL; Damping ratio

1. Introduction

Vibration reduction is a major concern in the industries for the safe and efficient functioning of all rotating machines. Rotating machinery is commonly used in mechanical systems, including machine tools, industrial turbomachinery. Various studies revealed that the vibration change brings a change in the physical properties like stiffness, mass and damping capacity that forces a change in modal parameters like natural frequencies and mode shapes. [1] Introduced a new type of materials are functionally graded materials (FGMs) used as shaft materials. Material properties distribution in FG shaft is considered varied along the radial direction. [2] Explained about a simple spinning laminated composite shaft model contains discrete isotropic rigid disks and is supported by bearings. [3] Developed a computational model for the analysis of elastic, partially plastic and residual stress states in long FG rotating solid shafts. In the present study vibration and stability analysis of FG rotor shaft has been analyzed by incorporating internal damping of shaft materials. Vibration analyses (such as Campbell diagram, stability limit speed

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(SLS) and damping ratio) of FG shaft over steel shaft are presented and the study of various responses of FG shaft considering different values of power law index values are also carried out.

2. Modelling of FG shaft system

2.1. Mathematical modelling of material properties for FG shaft using power law

As FGMs are heterogeneous, so to achieve the best performance of rotating machinery, accurate material property estimation and optimal volume fraction selection are essential. An FG shaft (as shown in Fig.1) has been considered with finite length L, inner radius (r_m) and outer radius (r_c). And it has taken ceramic and metal as top and bottom surfaces respectively.

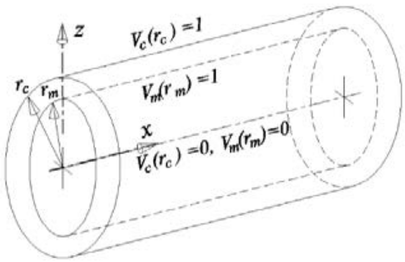

Fig. 1. Volume fraction of ceramic and metal throughout the FG layer

The effective material properties P can be written as,

$$P = P_c V_c + P_m V_m \tag{1}$$

The volume fractions of ceramic and metal are related by

$$V_c + V_m = 1 \tag{2}$$

In Fig.1 V_c and V_m are the volume fractions of ceramic and metal respectively at any point z throughout the radius r. According to power law, V_m can be expressed as

$$V_c(z) = \left(\frac{r - r_m}{r_c - r_m} \right)^k \tag{3}$$

From the Eqs. (1) and (3)

$$P(\mathrm{z}) = \left\{ P_c(\mathrm{z}) - P_m(\mathrm{z}) \right\} V_c(\mathrm{z}) + P_m(\mathrm{z}); \quad z = r \tag{4}$$

2.2. FE modelling of FG shaft using Timoshenko beam theory

According to the FSDT, the FG shaft is modelled as a Timoshenko beam considering the rotary inertia and gyroscopic effects. The shaft is of circular cross-section, it rotates at a constant speed about its longitudinal axis. The displacement field of a rotating shaft is assumed by taking the coordinate axis ‘x’ to coincide with the shaft axis and the displacement fields are supposed as follow,