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Modelling Cumulative Effects of Dry Contact and Laminate Structure on Dynamical behavior of the Assembled Structures

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Abstract

The joints are associated to the local non-linear behaviour, while the material properties are associated to the global behaviour. This paper presents an approach to model - the dry contact interfaces using localized non-homogenous discrete elements and the material behaviour of composite structures using equivalent classical laminate technique. A prototype structure of an Electronic Control Unit (ECU) is used to validate the proposed model's capability in predicting the dynamic behaviour, wherein the global damping is assimilation of contact and material damping.

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Keywords: Contact stiffness; Contact damping; Laminate design; Friction.

1. Introduction

The ECU's are complex-large systems comprising of Printed Circuit Board (PCB) plates (multi-layered structure) and various joints (local non-linearity through bolts), which cannot be solved easily for vibration problems using conventional transient or family of harmonic balance methods. The new approach presented in this paper defines the non-linear contact forces with equivalent contact stiffness and damping based on the constitutive laws of Greenwood-Williamson [1,2] and Mindlin models [3,4]. Local discrete elements based on Kelvin-Voigt representation are used for discretising the contact interface, referred as Damped - Pressure Dependent Joint (D-PDJ) element. The material modelling of PCB plate is done based on principles of equivalent laminate design, similar to

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work of Sottos (1999) [5], with also defining an equivalent proportional material damping required for dynamical calculations. The complete dynamical behaviour is then constituted as the cumulative effects from the material and joint interface properties. The validation for model is done first in sub assembly levels and then for the complete assembled structure with influences from both contact and material properties.

Nomenclature

$_{\mathrm{r}}$	standard deviation of exponential distribution
n	number of peaks in the distribution of peaks
E^*	composite elastic modulus of bodies in contact
G^*	composite shear modulus of bodies in contact
R_{A}	radius of the sphere representing the surfaces roughness peaks
F_{N}	normal force
F_{T}	tangential force
r_{c}	contact radius
$_{\mathrm{N}}$	normal relative displacement
$_{\mathrm{T}}$	tangential relative displacement
P_{N}	contact pressure
P_{N1}	saturation pressure in pressure-penetration law
K_{N}	normal contact stiffness density
K_{T0}	initial tangential contact stiffness density
$_{0}$	coupling factor
$d(x,y)$	localized contact damping
P_{m}	contact pressure at which maximum damping is obtained
$P_{\mathrm{m}}^{\mathrm{loc}}$	locating parameter used in definition of contact damping
	scaling factor used in definition of contact damping

2. Contact Modelling

Greenwood and Williamson (1966) [1] presented the constitutive equations for the contact modelling, with approximation of surfaces roughness with use of Gaussian normal distribution. Later Greenwood and Williamson (1977) [2] proposed a modified exponential distribution [2,6] to have a closed form analytical solution and better correlation to the Gaussian formulation for the predominance at the peaks. The total normal force with use of modified exponential distribution is calculated as the summation of local normal contact forces and is obtained as,

$$F_{\mathrm{N}} = \frac{c\pi^{0.5} n E^* R_{\mathrm{A}} \sigma_{\mathrm{r}}^{1.5}}{\lambda_{\mathrm{c}}^{2.5}} \exp\left(-\lambda_{\mathrm{c}} \frac{\delta_{\mathrm{N}}}{\sigma_{\mathrm{r}}} \right). \tag{1}$$

For all practical purposes, the values of dimensionless constant c = 17 and $_{\mathrm{c}}$ = 3 are feasible [6]. For tangential contact definition, there exist two states - stick and sliding region. Mindlin (1949) [3] defined the tangential force (F_{T}) in the stick state of contact as the integration of the uniform stress distribution *(r)* over the interface area as,

$$F_{\mathrm{T}} = \int_0^{r_{\mathrm{c}}} \tau(r)\, 2\pi r\, dr = 2\pi\tau_0 r_{\mathrm{c}}^2 = 8G^* r_{\mathrm{c}} \delta_{\mathrm{T}}. \tag{2}$$

Apart from existence of the complete stick or the complete sliding state, there exist partial slip state too, such that certain region of bodies in contact are in stick condition and the rest of the region experience the sliding state. Mindlin (1949) [3] presented the expressions for the non-linear tangential force describing partial slip state in terms