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# Spectrally formulated modeling of a cable-harnessed structure

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ABSTRACT

To obtain predictive modeling of the spacecraft, we investigate the effects of adding cables to a simple structure with the goal of developing an understanding of the effects of cables interacting with a structure. In this paper, we present modeling of a cable-harnessed structure by means of the Spectral Element Method (SEM). A double beam model is used to emulate a cable-harnessed structure. SEM modeling can define the location and the number of connections between the two beams in a convenient fashion. The presented modeling is applied and compared with the conventional FEM. The modeling approach was compared and validated with experimental measurements. The validated modeling was implemented to investigate the effect of the number of connections and of the spring stiffness of interconnections. The results show that the proposed modeling can be used as an accurate and efficient solution methodology for a cable-harnessed structure.


## 1. Introduction

In satellite applications, modeling is extremely important in order to predict behavior during launch and in orbit. While detailed finite element models are available for satellites, models that include the effects of cables are not available. Previous researchers have not been able to model the effects on the dynamics of adding cables to a satellite [1]. Cables can add up to 30 percent more mass to a satellite and initial attempts to simply add mass to the model have not produced acceptable results. Adding cables not only changes the mass distribution but also adds damping and in general changes the entire dynamic response. With this as motivation, we examine modeling a satellite quality cable attached to a simple beam structure in order provide insight into the effects of adding cables to a structure and to produce a predictive model of a structure with a cable attached. From earlier studies [1,2], it is clear that the best way to model cables of satellite quality is to use a beam model that contains shear deformation. Thus we approach modeling a structure with a cable attached as a double beam system.

The response of single beam has an exact solution, which can be obtained in various ways [3]. However, when a secondary beam is attached to the main beam by means of several spring connections, obtaining the solution of system becomes more complicated. Several authors have investigated double-beam systems elastically combined by a distributed spring in parallel. Seeling and Hoppman II [4] worked out the solution of the differential equation of elastically connected parallel beams. Gürgöze [5,6] dealt with the derivation of the frequency equation of a clamped-free Euler–Bernoulli beam with several spring-mass systems attached in the mid span by means of the Lagrange multipliers method. Vu et al. [7] presented an exact method for the vibration of a double-beam system subject to harmonic excitation. The system consists of

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a main beam with an applied force, and an auxiliary beam, with a distributed spring $k$ and damper $c$ in parallel between the two beams. Wu and Chou [8] considered a beam connected to several two Degree-of-Freedom (dof) systems at specific locations. Rao [9] considered the free response of several Timoshenko beam systems connected elastically.

Our approach here is to use a modified Spectral Element Method (SEM). Doyle [10] and Lee [11] present excellent texts on the spectral element method. Doyle introduced the basic formulation of spectral element matrix by using an Euler–Bernoulli beam. Lee summarized the various ways to derive the spectral element matrix for structural elements such as an Euler beam, a Timoshenko beam and a plate. Lee also presented several practical applications of SEM. Many authors have used the dynamic stiffness approach to modeling, which is very closely related to the SEM approach. Banerjee [12] and Chen [13] used the dynamic stiffness matrix for a beam with attached two dof systems. Li and Hua [14,15] considered elastically connected two and three parallel beams by using dynamic stiffness analysis. Jiao et al. [16] investigated the Euler beam with an arbitrary cross section. Choi and Inman [17,18] considered applying the SEM to a double beams system as a simplified model of a cable-harnessed structure.

The SEM approach delivers excellent accuracy using a small number of elements especially at higher frequencies. In addition, this approach may be considered as a numerical "exact" solution because the SEM is based on the exact solutions of the governing differential equation of the element. Such claims have not been experimentally validated previously. To underscore the value of the proposed approach, the SEM for a single beam is reviewed and validated against a Finite Element Model (FEM) and experimental data. Once validated, the SEM approach was extended to a double beam system. Here the cable attachment is considered as a spring and the cable bundles are modeled as beams. The Frequency Response Function (FRF) obtained from the SEM is compared with the measured FRF data to validate our analysis. The double beam system investigated here consists of two beams connected by springs at several places. One beam represents the host structure and one the cable, while the springs model the ties used to attach the cable to the structure. With the validated model in hand, we then use the model to investigate the effects of the tie arrangement and properties on the dynamic response of the combined system.

## 2. Description of the problem

The double beam system is presented as a simplified model of a cable harnessed structure as shown in Fig. 1. The main structure is modeled as a beam with rectangular cross section. The cable attachment is treated as a circular beam. The interconnections between beams can be defined by means of their locations and spring constants. By utilizing this model, the spectrally formulated modeling for a combined system will be compared with the FEM results and validated experimentally.

## 3. Spectral formulation

### 3.1. Timoshenko beam

The equation of motion of the Timoshenko beam can be expresses as

$$\begin{aligned} \kappa GA(w'' - \theta') - \rho A\ddot{w} &= 0 \\ EI\theta'' + \kappa GA(w' - \theta) - \rho I\ddot{\theta} &= 0 \end{aligned} \tag{1}$$

where $w$ and $\theta$ are the transverse deflection and the slope respectively. The solutions to Eq. (1) in spectral form are

$$w(x,t) = \frac{1}{N}\sum_{n=0}^{N-1} W_n(x)e^{j\omega_n t}, \quad \theta(x,t) = \frac{1}{N}\sum_{n=0}^{N-1} \Theta_n(x)e^{j\omega_n t} \tag{2}$$

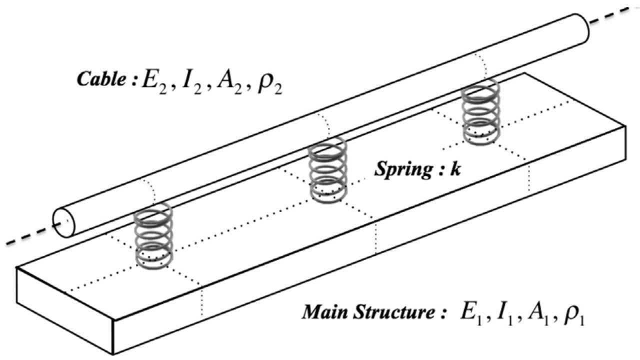


**Fig. 1.** The model of a cable harnessed structure.