# Optimum Tuning of a Gyroscopic Vibration Absorber for Vibration Control of a Vertical Cantilever Beam with Tip Mass

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In this paper, a symmetric gyro with coupling to the tip mass of a beam mounted on a vibrating base is considered. Taking advantage of the angular momentum of the rotating gyroscope, gyrostabilizer systems are expected to become more widely actualized as they provide an effective means of motion control with several significant advantages for various structures. This paper mainly focused on finding optimized stiffness and damping values that minimize the vibration responses with the derivation of the frequency equations of a special combined gyro-beam system. Correctness of the analytical results is verified by numerical simulations. The comparison with the results from the derivation of the corresponding frequency equations shows that the optimized stiffness and damping values are very accurate.

## 1. INTRODUCTION

Beams carrying a tip mass with (or without) rotary inertia can find application in the modeling of many engineering fields such as tall buildings, towers, piles, antennas, robotic manipulators, appendages of aircrafts, spacecrafts or vehicles, etc. Hence, there has been a lot of research work on the nonlinear dynamics of such beams subject to various boundary and load conditions over the past few decades due to both theoretic and practical demands. In some previous studies, a Euler-Bernoulli beam model has been used to investigate the problem of a vertical cantilever beam having a concentrated mass and various springs along the beam.[1–3]

Currently, a number of researchers studied and tried to solve the vibration problem due to low stiffness of the lightweight and flexible structures by applying one or more passive dynamic vibration absorbers. The most widely used passive vibration absorbers in engineering are tuned mass absorbers, beam absorbers, pendulum-type absorbers, and liquid absorbers. Cuvalci investigated the dynamic behavior of a beam-tip mass-pendulum system subjected to a periodic excitation in the presence of autoparametric interaction between the beam and pendulum.[4] Ertas et al. investigated experimentally an orientable flexible beam with a tip mass and pendulum.[5] The passive vibration absorbers can be quite effective and desirable due to their simplicity and low cost; but, since passive vibration absorbers have their limitations, one needs to develop the active vibration absorbers. The passive control method is activated by the structural motion without requiring external force or energy to reduce structural responses and utilizes the motion of the structure at the location of the device.[6] The active control method requires a considerable amount of external power to operate actuators that supply a control force to the structure. Due to requiring sensors and controller equipments, active control devices are more complex, and they do not have the reliability and robustness compared to passive control techniques.[7]

In recent years, several researchers have conducted studies investigating the complicated motions which appear in a gyrostabilizer, of which there are various types and arrangements. One engineering application of the gyroscopic effect is as an effective means of motion control in many situations, for example stabilization of bicycles, cars, monorails, building wind induced vibrations, and ships.[8–12] Compared to conventional active mass dampers for wind vibration suppression, gyrostabilizers represent a weight and volume saving. The mechanism does not require any other external source of energy, in which the rotor speed is produced by an electric motor in a rotating gimbal. Therefore, this can be classified as a passive control device in a variation of passive vibration control systems. The gyrostabilizer is effective for bending moments rather than shear forces because the gyrostabilizer utilizes the gyroscopic moment to reduce or eliminate the undesirable motions. This paper considers the motion of a symmetric gyro with coupling to the free end of a beam subjected to a harmonic base excitation, which is supported with a torsional spring and damper. The optimal values of the rotor speed, torsional spring, and damper are theoretically analyzed and derived for a cantilever beam. The relations for the optimal values of the gyrostabilizer are so tuned that this system is more adaptable and has a smaller mass than other conventional control devices with the same ability to be employed for vibration control.

## 2. EQUATIONS OF MOTION OF THE GYRO-BEAM SYSTEM FOR SMALL VIBRATION

Figure 1 shows the beam as a vertical cantilever of length $L$ with an end mass $M_t$ to which an additional gyro system was attached at the free end and subjected to a harmonic base excitation at the other end of the beam. The horizontal displacement of base was $z$. The beam was assumed to be initially straight, of length $L$. The horizontal and vertical elastic displacements at the free end were $v$ and $u$, respectively. Due to elastic deformation of the beam, $s$ represented the distance along the arc-length of the beam.

The gyro system consisted of a disk mass $m$, which can