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ROBUST OPTIMIZATION DESIGN METHOD FOR POWERTRAIN MOUNTING SYSTEMS BASED ON SIX SIGMA QUALITY CONTROL CRITERIA

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ABSTRACT−This paper presents a robust optimization design method based on Six Sigma quality control criteria to improve the design of a powertrain mounting system (PMS). The powertrain is modeled as a rigid body having six degrees of freedom (DOF) connected to a rigid base by four rubber mounts, and each mount is simplified as a three-dimensional spring-damper element in its local coordinate system (LCS). The calculation method based on energy decoupling is used to estimate the decoupling ratios of a PMS. The location and static stiffness of each mount and the orientations of the two anti-torsion mounts are selected as uncertain design variables, and the nominal values of these design variables are optimized to obtain a robust Six Sigma design for a PMS. The uncertain design variables are characterized by a perturbation or percent variation around their nominal values. The generalized reduced gradient (LSGRG2) optimization method is employed to solve the robust optimization problem, and a second-order Taylor series expansion is used to estimate the statistical properties of the performance constraints and objectives. The optimization results show that the robust design ensures good robustness or high reliability for the natural frequencies, decoupling ratios, and frequency separation constraints of a PMS.

KEY WORDS : Powertrain mounting system, Optimization design, Robustness, Six sigma

1. INTRODUCTION

A powertrain mounting system (PMS) generally consists of a powertrain (engine and gearbox) and several mounts connected to a base structure (Yu *et al*., 2001). Rubber mounts (rubber boned to metal) or hydraulic engine mounts (HEM) are usually used in the PMS. The four-cylinder engine and transversely mounted powertrain have found recent popularity for use in cars, which tends to exacerbate powertrain vibrations on the car body.

There is a substantial body of literature on the study of dynamic analysis and optimization design methods for a PMS (Bernard and Starkey, 1983; Cho, 2000; Demic, 1990; Geck and Patton, 1984; Ishihama *et al*., 1995; Johson and Subhedar, 1979; Shangguan and Lu, 2004; Snyman *et al*., 1995; Suh *et al*., 2003; Swanson *et al*., 1993; Tao *et al*., 2000; Zhang and Shangguan, 2006). In PMS modeling, the powertrain is usually assumed to be a six degrees of freedom (DOF) rigid body that is supported by three or four mounts fixed to a rigid base (Bernard and Starkey, 1983; Brach, 1997; Geck and Patton, 1984; Johson and Subhedar, 1979; Swanson *et al*., 1993; Tao *et al*., 2000; Zavala *et al*., 2000). The PMS natural frequencies, frequency separations, and decoupling ratios (also defined as the mode kinetic energy distribution) are closely related to the stiffness, location, and orientation of each mount (Sirafi and Chang, 2006). Thus most past efforts have focused on the stiffness, location, and orientation of each mount by decoupling the bounce and pitch modes of a powertrain and locating the six PMS frequencies in the prescribed ranges (Bernard and Starkey, 1983; Brach, 1997; Geck and Patton, 1984; Johson and Subhedar, 1979; Zavala *et al*., 2000), or by minimizing the forces transmitted to the base structure (Suh *et al*., 2003). However, all the above analysis and optimization design methods are deterministic ones.

In practical situations, the stiffness, location, and orientation of the mount are uncertain due to numerous reasons. For example, the rubber materials used by mount suppliers generally have stiffness properties that vary by 15% due to manufacturing errors. Additionally, the locations and orientations of the actual mounts as compared with the designed nominal values will be different due to assembly errors. These uncertainties and variations have a significant impact on the PMS natural frequencies, frequency separations, and decoupling ratios. In other words, the PMS vibration characteristics will be strongly affected. To reduce the influence of uncertainties on the PMS vibration characteristics, appropriate nominal values for the design variables must be found. This will reduce the sensitivity of the frequencies, decoupling ratios, and frequency separations to

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