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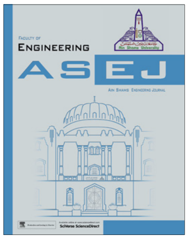

MECHANICAL ENGINEERING

Optimal mass ratio of vibratory flap for vibration control of clamped rectangular plate

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Abstract Dynamic vibration absorbers generally have been used to suppress harmonic excitation of plate like structures at a point of attachment and at a given frequency. The vibratory flap is a plate type dynamic vibration absorber and has been developed to suppress plate vibrations over entire plate in more than one frequency. This paper presents an experimental study of transverse vibration of harmonically excited, clamped rectangular plate with vibratory flap. The investigation aims to discover the effect of the mass ratio of the flap on dynamic response of the plate. Consequently, the mass ratio has been optimized to get best attenuation in the first and second target frequencies. The study reveals that, the attenuation in vibration of the plate has increased to a large extent due to the use of optimized vibratory flap. Finally, the experimental results of the plate with optimized flap have been compared with finite element analysis results.

1. Introduction

The plates are most common structural elements employed in many structural engineering applications such as automotive, civil, marine and other machinery structures. In many instances, plates are subjected to a wide variety of excitations and can be controlled by different methods. Use of dynamic vibration absorber (DVA) [1] is one such method for vibration control of plate like structures. The basic principle of a DVA is about neutralizing the resonant vibrations of primary structures by attaching absorber mass vibrating at the same resonant frequency. Vibration absorbers reduce vibrations of the original system by channelizing the energy to the absorber itself. The DVA is usually used to suppress a harmonic excitation at a given frequency by shifting its natural frequency from an excitation frequency with minor modifications of structure. The vibratory flap is a plate type dynamic vibration absorber that can vibrate on the plate, when attached as a cantilever plate. When flap is designed suitably, it can be used to suppress harmonic excitation effectively in more than one frequency. The significant design parameter considered in this paper is the mass ratio (MR), which is the ratio of mass of the vibratory flap (secondary structure) to mass of the bare plate (primary structure).

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Numerous reports are available on the use of dynamic vibration absorber method for vibration control of plate like structures. Vibration of plates with attached masses is a subject of extensive research over past few decades. Related to this research, Leissa [2] reported the most of the early work in the field of free vibration of isotropic rectangular plates with point supports. The analysis of modal parameters and location of concentrated mass attached to a rectangular plate was reported by Cha [3]. Bambill et al. [4] presented the free transverse vibration analysis of clamped and simply supported plates carrying a concentrated mass. Free vibration analysis was performed on isotropic plates with an orthotropic patch and orthotropic plates with a hole. Lin and Lim [5] developed a method to predict exact natural frequencies and mode shapes of plates with arbitrary mass, stiffness and damping modifications.

Several authors have studied the vibration analysis of structure with distributed mass loading. Among them, the free vibrations of plate carrying distributed mass are found in Refs. [6,7]. A forced vibration of rectangular plates under harmonic loadings with distributed mass was presented by the authors [8]. Ranjan and Ghosh [9] worked on forced vibration response of a rectangular thin plate with single discrete mass patch using finite element method and analyzed the effect of varying thickness and area of the patch on the dynamic response of the plate. The authors applied this concept to control vibration in spinning disk [10].

Plate type dynamic vibration absorbers have been used for vibration control of plates. Oniszczuk [11] has presented vibrations of an elastically connected rectangular double-plate system. Farag and Pan [12] developed a mathematical model for the coupling of two finite plates at an arbitrary angle for the prediction of the dynamic response. Aida et al. [13] proposed the optimum design of a plate-type dynamic vibration absorber for controlling the several predominant modes of vibration of the main plate under harmonic excitation. In the investigation, the main plate and dynamic absorbing plate with the same boundary condition were connected through uniformly distributed springs and dampers.

The study has been initiated on auxiliary flap for vibration control of plates by Ulz and Semercigil [14] and proposed the use of cutouts to improve the performance of the plate by creating the flaps as incision. The authors have reported the use of an auxiliary flap for vibration control of plate subjected to random vibrations. In a related work, recently, the effect of the tilt angle of the flap on vibration control of rectangular plate using auxiliary flap was investigated and reported optimum tilt angle as 45° through finite element analysis [15] and experimental method [16]. The authors also reported the influence of the aspect ratio of flap [17] on dynamic response of the plate at a constant mass ratio and at a constant frequency ratio.

A brief review of the literature revealed that, most of the work on vibration of different structures with concentrated mass, distributed mass and spring mass type dynamic vibration absorbers. Little attention was paid to the vibration control of plate by plate type vibration absorber. Most of the design methods previously proposed are based on analytical or numerical technique. To the best of authors' knowledge, optimal mass ratio of vibratory flap for vibration control rectangular plate through experimental approach has been considered for the first time and is still a subject of great interest to researchers.

In this paper, the transverse vibration control of harmonically excited, clamped rectangular plate by vibratory flap has been addressed through extensive experimental investigation. The specific objective of the investigation was to find the effect of the mass ratio of the flap on dynamic response of the plate and to optimize the mass ratio to achieve best possible attenuation in first and second target frequencies. This has been achieved by studying independently the effect of the width and height of the flap on dynamic response of the plate. The effect of thickness has not been considered in the experimentation due to manufacturing issues. In the investigation, the mass of the plate is taken as constant and mass of the flap is varied to get different mass ratios. Therefore, the mass ratio mainly depends upon mass of the flap and hence the study leads to the effect of mass ratio alone. Finally, experimental results of the plate with optimized flap are compared with the finite element analysis results for validation. The vibratory flaps can be used in the applications such as automotive panels, railway engines, casings of machinery, marine structures, electrical generators, and civil structures without affecting the design functions and aesthetics.

2. Experimentation

A rectangular plate of size 400 mm × 200 mm × 3 mm with aspect ratio 2 (length to width) and the flap of different mass ratios were considered. In the investigation, experiments were carried out for two different cases. The first case is of variable width of the flap, which has been obtained by varying the width of the flap with constant height and thickness. The second case is of variable height of the flap, which has been obtained by varying height of the flap with constant width and thickness. To know the effect of the mass ratio of flap on dynamic response of the plate, different mass ratios considered are listed in Table 1 for two cases of variable width and variable height of the flap.

Table 1 Dimensions and mass ratios of the flap.

Variable width		Variable height	
Width × height × thickness (mm)	Mass ratio (%)	Width × height × thickness (mm)	Mass ratio (%)
40 × 80 × 3	3.5	80 × 40 × 3	3.5
60 × 80 × 3	5.2	80 × 60 × 3	5.2
80 × 80 × 3	7.0	80 × 80 × 3	7.0
100 × 80 × 3	8.6	80 × 100 × 3	8.6
120 × 80 × 3	10.4	80 × 120 × 3	10.4
140 × 80 × 3	12.1	80 × 140 × 3	12.1