An Overview of Design and Development of Centrifugal Pendulum Vibration Absorber to Reduce the Engine Vibration by Considering Nonlinear Parameters

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Abstract— Controlling torsional vibrations in rotating systems such as reciprocating engines, turbines, compressors etc. is still subject of research and investigation. A steady rotational speed is desirable in rotating machinery. This helps to extend the fatigue life of components and to reduce vibration and noise which also enhance the ride comfort qualities in vehicles. However, it is generally impossible to maintain a precisely constant rotational speed. The unsteady nature of the external loads, cycle-to-cycle variations (such as those which occur in internal combustion engines), inertial loads from connecting linkages, gas pressure effects, and so forth, all tend to induce torsional vibrations in rotating components during operation. In this paper overviews of various works are done. This paper tries to give an idea about the previous researches and their finding about study of design and development of Centrifugal Pendulum Vibration Absorber (CPVA) to reduce the engine vibration by considering nonlinear parameters.

Keywords— Centrifugal Pendulum Vibration Absorber, Nonlinear Parameters, Rotating Machinery, Torsional Vibrations

I. INTRODUCTION

Centrifugal Pendulum Vibration Absorbers (CPVAs) are used in rotatory machinery for the attenuation of torsional vibrations. In classical applications, including helicopter rotors, radial aircraft engines and combustion engines, the absorbers are designed to have almost order tuned linear dynamical behavior when oscillating about their equilibrium positions. To implement these devices into combustion engines of passenger cars, the design space and weight to effectiveness ratio have to be optimized [1].

New developments of more environmental friendly combustion engines cause high fluctuating torques acting on the crankshaft, drive train and auxiliary units. This results in noise and vibration that are unintentional, especially in automotive engineering. Dual flywheels to damp the vibration are reaching their limits and alternatives have to be found. Centrifugal pendulum vibration absorbers (CPVA) are a long known, energy saving tool to compensate non-uniform torques. Their main advantage is that they are tuned to a specific order instead of one fixed frequency and therefore they are rotational speed adaptive [2].

Most real-world phenomena exhibit nonlinear behavior. There are many situations in which assuming linear behavior for physical system might provide satisfactory results. On the other hand, there are circumstances or phenomena that require a nonlinear solution. A nonlinear structural behavior may arise because of geometric and material nonlinearities, as well as change in the boundary conditions and structural integrity. A nonlinear spring has a nonlinear relationship between displacement and force, and a nonlinear damper has a nonlinear relationship between velocity and force. A graph of force Vs. displacement and force Vs. velocity for a nonlinear spring and damper respectively, will be more complicated than a straight line, with a changing slope. As nonlinear springs have different load-deflection characteristics than the linear spring, there will be difference in the amplitude of main mass obtained by theoretical and experimental methods. The nonlinearity in mass arises when mass moves with certain velocity, which is due to change in mass density of the fluid around it [3].

The objective of this study is to compare the vibration level in engines with and without attaching the Centrifugal Pendulum Vibration Absorbers (CPVA) in order to reduce the engine vibration by considering nonlinear parameters.

By considering all above facts, this paper tries to cover literature which deals with Design and Development of Centrifugal Pendulum Vibration Absorber to Reduce the Engine Vibration by Considering Nonlinear Parameters.

II. TORSIONAL VIBRATION ATTENUATION IN V-TYPE LOCOMOTIVE DIESEL ENGINE CRANKSHAFT USING CENTRIFUGAL PENDULUM ABSORBER

Seyed Mohammad Shojaalsadati [6], studied “Torsional Vibration Attenuation in V-Type Locomotive Diesel Engine Crankshaft using Centrifugal Pendulum Absorber”. Author investigated the capability of centrifugal pendulum vibration absorbers (CPVA) commonly used in rotating machinery to attenuate the torsional vibration in a Locomotive V-type diesel engine crankshaft. First, he carried out an advanced torsional modeling of the locomotive crankshaft then this is followed by the development of an accurate excitation torque of a real locomotive engine to the 8^{th} order and investigated the torsional response of the crankshaft under the derived excitation torque. Finally, he developed the model of the crankshaft incorporating the CPVA (auxiliary system) and then capability of CPVA to attenuate the torsional vibration of the crankshaft (main system) at resonance frequencies had been investigated. Moreover, he studied the effect of pendulum parameters such as length and mass on the torsional vibration response of the crankshaft in both time and frequency domains.

III. EXPERIMENTAL INVESTIGATION OF CENTRIFUGAL PENDULUM VIBRATION ABSORBERS

J. Mayet et al. [5], published paper on “Experimental Investigation of Centrifugal Pendulum Vibration Absorbers”. They developed an experimental setup for testing centrifugal pendulum absorbers. They evaluated the performance for a broad operating range by generating typical torque excitations, arising in applications, by using an electric motor. They proposed a hybrid controller design, which solves the conflict of simultaneous speed maintenance and torque generation. They studied steady-state responses of the absorber and the performance of the controller was investigated. Furthermore, they presented transient responses, where fast changes in the averaged rotation speed under torsional torque excitation occur. Finally they conclude with experimental results of a novel centrifugal absorber and it shows that steady-state responses of the absorber confirm theoretical predictions and the angular velocity of the rotor is accurately maintained.

IV. DESIGN AND DEVELOPMENT OF A PENDULUM TYPE DYNAMIC VIBRATION ABSORBER FOR A SDOF VIBRATING SYSTEM SUBJECTED TO BASE EXCITATION

Irshad M. Momin, et al.[8], published the paper on “Design and Development of a Pendulum Type Dynamic Vibration Absorber for a SDoF Vibrating System Subjected to Base Excitation”. They presented a detailed analysis and experimental investigations of the effect of parameters affecting the motion transmissibility of the sprung mass such as size of the pendulum mass, eccentricity of the pendulum pivot with respect to axis of rotation of the pendulum assembly, mass ratio (ratio of the pendulum mass to the sprung mass), gear ratio (the ratio of the pendulum rotational frequency to the excitation frequency) and the frequency ratio (the ratio of the excitation frequency to the natural frequency of the SDOF system). Finally they proved that the CPVA is effective in reduction of motion transmissibility of the sprung mass of the SDOF system with the proper selection of the affecting parameters.

V. ANALYSIS AND COMPARISON OF VEHICLE DYNAMIC SYSTEM WITH NONLINEAR PARAMETERS SUBJECTED TO ACTUAL RANDOM ROAD EXCITATIONS

Prof. S. H. Sawant, et al. [3] published a paper on “Analysis and Comparison of Vehicle Dynamic System with Nonlinear Parameters Subjected to Actual Random Road Excitations”. They investigated that the importance of effects depend upon the degree of nonlinearity and so the effect on the response. In this paper, nonlinearity in mass, spring and damper are considered and compared for their individual and relative significance. Also, it is studied how nonlinearity affects the response compared to linear system. The theories of non-linear dynamics are applied to study non-linear model and to reveal its non-linear vibration characteristics. Thus this paper deals with comparison between simulation results obtained for passive and semi active linear systems with nonlinear mass, spring and damper. The excitation is taken as actual random road excitation to achieve improved performance. Thus, the emphasis is to study the nonlinearities in mass, spring and damper for passive suspension system performance and compare the reactive significance.

VI. REDUCTION OF VIBRATIONS IN ENGINES USING CENTRIFUGAL PENDULUM VIBRATION ABSORBERS

Anders Wedin [7], studied “Reduction of Vibrations in Engines using Centrifugal Pendulum Vibration Absorbers”. When he worked at Volvo Cars engine development department his main goal for this study was to model and simulate different types of CPVAs in the software Simdrive 3D by Contecs Eng, where simple vibration models can be made for first investigations. He modelled Different CPVAs through a fully customizable element, programmed in C/C++ for Simdrive and Special attention had been given to model CPVAs with cycloidal and epicycloidal paths, since they are important for practical use. The CPVA unit performance was analyzed in one model with an n^{th} order sine-signal torque, and also in a more realistic powertrain model with cylinders. He found that in simulations with sine-signal torque, all CPVA types considered are capabilities of absorbing vibrations and concluded that Some of the types with cycloidal or epicycloidal paths shows some potential of reducing vibrations of the designated order to a level very close to zero.

VII. REDUCTION OF PERIODIC TORSIONAL VIBRATION USING CENTRIFUGAL PENDULUM VIBRATION ABSORBERS

Mathias Pfabe, et al. [2], studied “Reduction of Periodic Torsional Vibration using Centrifugal Pendulum

Vibration Absorbers". They decided to optimize the design space and weight to effectiveness ratio in order to implement CPVA into combustion engines of passenger cars by using the principle design patented by Sarazin because of its compact configuration. At the end they found that to use CPVA over the complete range of input torque the pendulum center of mass has to move on an epicycloidal path. Finally they concluded that by implementing CPVA at the crankshaft, flywheel, or counterbalance shaft we have an advantage to use existing masses as absorber mass and CPVA cannot vanish the torsional vibration but can reduce them significantly.

VIII. VIBRATION SUPPRESSION OF NON-LINEAR SYSTEM VIA NON-LINEAR ABSORBER

Y.A. Amer, et al. [4], studied "Vibration Suppression of Non-linear System via Non-linear Absorber". In this study the coupled non-linear differential equations of the non-linear dynamical two-degree-of-freedom vibrating system including quadratic and cubic non-linearities are reviewed. The method of multiple scales perturbation technique (MSPT) was applied throughout to determine the solution up to third order approximations. The different resonance cases were reported and studied numerically. Stability was studied applying frequency response functions. The effects of different parameters of the system were studied numerically. They conclude that optimum working conditions for the absorber were obtained at internal resonance ratio 1:3.

IX. VIBRATION REDUCTION IN A VARIABLE DISPLACEMENT ENGINE USING PENDULUM ABSORBERS

Tyler M. Nester, et al. [1], published a paper on "Vibration Reduction in a Variable Displacement Engine Using Pendulum Absorbers". The work attempts to analyze that design, implementation and testing of crankshaft-mounted pendulum absorbers used for reducing vibrations in a variable displacement engine. The absorbers were designed to replace the large counterweights at the ends of the crankshaft, and thus serve for both balancing and vibration absorption. In this paper they describe the design and implementation of pendulum absorbers for a variable displacement engine application and report results from systematic vibration testing of a vehicle equipped with that engine. These results are compared with measurements taken from a nominally identical vehicle and engine that did not have absorbers. Both vehicles were tested at idle under various load conditions. The tests demonstrate that these absorbers offer an effective means of vibration attenuation in variable displacement engines.

X. DESIGN AND DEVELOPMENT OF TUNED MASS DAMPER FOR CENTRIFUGAL PUMP

Ramji Koona , et al. [9], published the paper on "Design and Development of Tuned Mass Damper for Centrifugal Pump". Authors mainly focused on the design and development of a tuned mass damper (TMD) for the given machinery to reduce vibration levels at operating speeds. They carried out evaluation of the effectiveness of the device both experimentally and analytically. An attempt was made by authors to validate the methodology using finite element analysis and experimental method for a typical cantilever beam and the results are found to be in good agreement. They also presented a typical case study to demonstrate the application of TMD on a centrifugal pump running at 2900 RPM. They designed and developed A TMD device for the centrifugal pump and evaluated the performance in terms of acceleration.

XI. CONCLUSION

From the literature survey it is seen that the design of Centrifugal pendulum vibration absorbers has been a hot research topic for many researchers, due to its important role in attenuation of torsional vibrations in engines. The researchers started from developing theories related to general behavior of Centrifugal pendulum vibration absorber and further moving to implementing the optimizing various parameters according to their application. In order to carryout Vibrational Analysis of Centrifugal pendulum vibration absorber it is necessary to optimize the design space and weight to effectiveness ratio of CPVA as well as consider nonlinear parameters in order to get better realistic results.

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