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Tuned Vibration Absorber to Minimize Hand-Arm Vibration: -An Overview

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Abstract: The presence of vibration often leads to excessive wear of bearings, formation of cracks, loosening of fasteners, structural and mechanical failures, frequent and costly maintenance of machines. Vibration can be used for useful purposes as in vibration testing equipment's, vibratory conveyors, hoppers, sieves, musical instruments, and propagation of sound. But vibration in some cases has disadvantageous too. Self-tuning combined vibration absorbers are devices, which use energy from the primary system to change the tuned frequency of the absorber to match the primary system's excitation frequency. In this paper an overview of the tuned in vibration absorber is presented.
Keywords: Self-tuned absorber, vibration isolation, FEA, Dynamic Analysis, FFT Analyser.

I. INTRODUCTION

Some researchers proposed the dynamic vibration absorber combining a translational-type absorber and a rotational-type absorber is proposed for isolation of beam vibration under point or distributed harmonic excitation. The different tuned vibration neutralizers and absorbers which provide an effective method of attenuating tonal vibration within a structure [1-3]. Dynamic vibration absorber is found useful in machining processes to avoid the tool chatters on components [4-5]. The tuned vibration absorber has been effective than other absorbers which reduced the accelerations in the system up to 95% [6-7]. Tuned Vibration absorbers also showed better performance in machining processes [10]. Some researchers also studied the piezoelectric based dynamic absorbers [11].

II. OVERVIEW

The Review of the literature shows that different researchers and experts work in the fields of design and analysis of adaptive tunable vibration absorber.

W.O. Wang et.al [1] studied a new dynamic vibration absorber combining a translational-type absorber and a rotational-type absorber is proposed for isolation of beam vibration under point or distributed harmonic excitation. Finite element analysis and Euler–Bernoulli beam theory are used for evaluation of the performance of vibration isolation of the proposed absorber mounted on a beam. It is proved theoretically that the absorber can isolate the vibration in one part of a beam when it is subjected to a point or distributed harmonic excitation. A prototype of the combined translational and rotational dynamic absorber had been designed and made for evaluation. Both numerical and experimental tests have been done for verification of the theoretical prediction of vibration isolation in beam vibration. The numerical tests show that beam vibration under harmonic excitations can be isolated in a region of the beam by the proposed absorber but not the traditional translational absorber alone. In the experimental test, forced vibration of a beam were measured and compared for the cases of the beam carrying the proposed absorber, the beam carrying only the traditional translational absorber, and the beam carrying no absorber. The case of the beam with the proposed absorber has the best performance of vibration suppression and isolation in comparison of the case of using only the translational absorber.

Carl Howard [2] studied different tuned vibration neutralizers and absorbers which provide an effective method of attenuating tonal vibration within a structure. If the frequency of the tonal vibration alters, then an adaptive tuned vibration neutralizer or absorber can be utilized to track and adapt to changes in the frequency of the source vibration. This work provides an overview of some of the issues associated with the development of adaptive tuned vibration neutralizers. One of the inherent difficulties associated with tuning the device is the sharp change in the phase-response for small changes in the resonance frequency of the device. Several designs of adaptive tunable vibration neutralizers were presented that utilize a change in the stiffness of the device to provide the capability of varying its resonance frequency. Several adaptive control algorithms were described that can be used to tune the device to the driving frequency.

Simon G. Hill et.al. [3], presented design of a vibration absorber to reduce structural vibration at multiple frequencies, with an enlarged bandwidth control at these target frequencies. While the basic absorber is a passive device a control system has been added to facilitate tuning, effectively giving the combination of a passive and active device, which leads to far greater stability and robustness. A design procedure for a vibration absorber capable of providing attenuation at multiple frequencies has been described. Multiple absorber resonances were used successfully to widen the bandwidth of the device, leading to vibration attenuation at multiple frequencies on a highly flexible structure.

H. L. Sun et.al [4] analysed the response properties of a single-degree-of-freedom system under dual harmonic excitation and analysed to provide some principles for the choice of time span and step in the simulations. The performances of a single DVA, state-switched absorber (SSA) and dual DVAs are compared. The results indicate that dual DVAs almost have the same performance as the SSA and they both have better performances than single DVA. In addition, two DVAs compared with the SSA have some advantages such as lower ratio of tuning frequencies, more rapid optimization process and lower requirement for the anti-fatigue property of the material. Furthermore, the performances of different frequency tuning methods for excitation with multiple frequency components are investigated. The results show that the one–one method almost has identical performance with the optimization method and it does not need time-consuming optimization process. In addition, the method can be easily expanded to the case of the excitation including more frequency components.

M.H. Miguelez et.al [5], focused on the behaviour of boring bars with a passive dynamic vibration absorber (DVA) for chatter suppression. The boring bar was modelled as a cantilever Euler–Bernoulli beam and only its first mode of vibration was considered. The stability of the two-degree-of-freedom model was analysed constructing the stability diagram, dependent on the bar characteristics and on the absorber parameters (mass, stiffness, damping, and position). Two analytical approaches for tuning the absorber parameters were compared. The selection criterion consisted on the maximization of the minimum values of the stability-lobes diagram.

Ko Ying Hao et.al [6], presented a simple approach for the suppression of hand-arm vibration in electric grass trimmer. The proposed system is a tuned vibration absorber (TVA). Modal analysis and operating deflection shape analysis of the electric grass trimmer were carried out and a TVA was designed and fabricated for testing. The results indicated that minimum vibration level was related to the position of the TVA on the shaft of electric grass trimmer. The TVA was found to have best performance with 95% reduction on the acceleration level at position 0.025L. The results from modal analysis and operating deflection shape revealed that the presence of TVA has successfully reduced the large deformations of the handle where the node was shifted nearer to the handle location. The effect of TVA was also evaluated during field test involving grass trimming operation and subjective rating. The results indicated that average reduction of frequency-weighted rms acceleration in the Zh- axis was 84% and 72% in Xh- axis for the cutting operation. For the no cutting operation, the reduction is 82% in Zh- axis and 67% in Xh- axis. The presence of TVA in the electric grass trimmer has amplified the vibration level in Yh- axis by 19% (no cutting) and 21% (cutting). From the field test, subjective rating of vibration perception consistently rates better for controlled electric grass trimmer.

Ko Ying Hao et.al [7], designed and developed a suspended handle for reducing hand-arm vibration in petrol driven grass trimmer. The portable petrol driven grass trimmer was identified as a type of machine whose operator can be subjected to large magnitude of hand-arm vibration. These vibrations can cause complex vascular, neurological and musculoskeletal disorder, collectively named as hand-arm vibration syndrome. The vibration total level on the handle of grass trimmer of 11.30 m/s2 was measured, and it has reached the exposure limit value of 5.0 m/s2 for daily vibration exposure. New suspended handles were designed to reduce the vibration level. Three different prototype handles with rubber mounts were designed. Handles were made of different materials, and the distance of rubber mounts were varied. From the study, it was observed that not all the handles with rubber mounts were effective in reducing hand-arm vibration. The reduction of vibration depended on the handle material and distance installed between rubber mount and vibration transmissibility of handle-isolation system. Subjective ratings of perception of vibration were measured, and the results indicated that operators were not fully aware of the level of vibration. A prototype handle that is made of heavier material results in the lowest hand-arm vibration of 2.690 m/s2. The new handle has significantly reduced the vibration total value by 76% compare with the existing commercial handle. S. Naresh Kumar and S. Gunasekhara [8], introduced dynamic vibration absorber (DVA) which has high property for absorbing vibration compared to the other. The work includes simple clamping technique with the rail along the line. By the use of this technique, one can achieve reduction in vibration in an easier and economical way. The advantage in this work is replacement can be done easily if failure occurs. The dynamic vibration absorber is designed in such a way that it reduces the vibration comparatively high rate than others by the collected details. The details consist of various properties of the parameters of the materials used in this project concluded from the literature survey. The high frequency vibrations are reduced to their maximum extent that they occur below the noise level.

La Duc Viet [9], studied the pendulum swing which was suppressed by two dynamic vibration absorbers (DVAs) moving in tangential or in normal directions. The first one is linear and interacts directly with the pendulum through the spring and damper. Conversely, the second one is nonlinear and interacts indirectly with the pendulum through the Coriolis force. The classical fixed point method and the on-off ground hook controller can be used to design the passive and semi active DVA moving in tangential direction but they fail in the design of the remaining DVA. In this work, a unified scheme to obtain the optimal passive parameters and semi active on off damping controllers for both types of DVA. This paper proposes a unified scheme to design the passive and semi-active DVA moving in the tangential or in the normal direction of a pendulum's orbit. The optimal passive parameters are obtained by equalizing the frequency responses. The semi active on-off damping controllers are constructed from the idea of amplifying the DVA motion. The frequency responses are analytically derived. The numerical calculations show the accuracy of the analytical predictions and the effectiveness of the proposed passive and semi-active DVA.

Hamed Moradi et.al [10], designed a tunable vibration absorber (TVA) to suppress regenerative chatter in milling of cantilever plates. In machining industry, the majority of work-piece materials or the interaction of work-piece/cutting tool causes the cutting forces to demonstrate nonlinear behaviour. The application of TVA (as a semi-active controller) is investigated for the process with an extensive nonlinear model of cutting forces. Under regenerative chatter conditions, optimum values of the absorber position and its spring stiffness are found such that the plate vibration is minimized. For this purpose, an optimal algorithm is developed based on mode summation approach. Results are presented and compared for two cases: regenerative chatter under resonance and non-resonance conditions. It is shown that the absorber acts efficiently in chatter suppression of both machining conditions, in a wide range of chatter frequencies. Moreover, using TVA leads to the great improvement in stability limits of the process. Therefore, larger values of depth of cut and consequently more material removal rate can be obtained without moving to the unstable machining conditions.

S Mohanty and S K Dwivedy [11], designed and analysed a single degree of freedom; spring-mass-damper primary system with a piezoelectric based dynamic vibration absorber (DVA). The proposed DVA model consisting of a lead zirconatetitanate (PZT) actuator which is connected in series with a spring. The analysis is done in two sections by considering a static force and harmonic force acting on the primary system respectively. In the first section linear stiffness is considered in the primary mass and in the second section cubic nonlinear stiffness along with the linear stiffness is considered. The voltage applied to the stack PZT actuator is considered to be proportional to the acceleration of the primary mass. Method of multiple scales (MMS) is used to obtain the system response in the nonlinear analysis and compared with linear analysis. For linear system optimum system parameters of the absorber are obtained using fixed point theory of optimization and Routh's stability criterion is used for stability analysis. Primary resonance condition is studied in the nonlinear analysis. In the proposed model as a spring is connected in series with PZT actuator for which force developed by the absorber to suppress the vibration of the primary system is not solely depending upon the voltage, so one can use small voltage to reduce the vibration of primary system. From the linear analysis, it is found that the amplitude of the primary system without active force is 6.45 to the static deflection but its amplitude reduces to 1.15 times the static deflection when controlling force is applied within the stability region of operation. Nonlinear analysis also investigated by considering a cubic nonlinear stiffness along with the linear stiffness in the primary system.

Ko Ying Hao and Zaidi Mohd Ripin [12], in this paper imposed node technique to the grass trimmer shaft in order to achieve very low vibration (node) at the handle location. The optimum tuning frequencies of the two-tuned vibration absorbers (TVAs) attached at 0.74L and 0.85L along the shaft of the grass trimmer are determined using the imposing node technique. Transverse deflection, experimental modal analysis and operating deflection shape analysis of the grass trimmer were carried out, and the results indicated that nearly zero deflection(node) was induced at the position very close the loop handle location. Moreover, the vibration along the segment of the shaft (0.70Le0.94L) was also found to have relatively small amplitude. The TVAs were found to have best performance with 71% reduction on the frequency weighted rms acceleration at the loop handle and 72% for the rear handle. The results from the experimental modal analysis and operating deflection shape revealed that the presence of the two TVAs has successfully reduced the large deformations of the loop and rear handle where the node was shifted nearer to the handle location. The effects of TVAs were also evaluated during the field test involving grass trimming operation and subjective rating. The results indicated that average reduction of frequency-weighted rms acceleration was by 25%, 69%, 17%, and 58% in Xh-, Yh-, Zh- axes and vibration total value respectively during the cutting operation.

G. Habib and G. Kerschen [13], developed a principle of similarity for the design of a nonlinear absorber, the nonlinear tuned vibration absorber (NLTVA), attached to a nonlinear primary system. Specifically, for effective vibration mitigation, we show that the NLTVA should feature a nonlinearity possessing the same mathematical form as that of the primary system. A compact analytical formula for the nonlinear coefficient of the absorber is then derived. The formula, valid for any polynomial nonlinearity in

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the primary system, is found to depend only on the mass ratio and on the nonlinear coefficient of the primary system. When the primary system comprises several polynomial nonlinearities, we demonstrate that the NLTVA obeys a principle of additively.

Kefu Liu and Gianmarc Coppola [14], focused on the optimum design of the damped dynamic vibration absorber (DVA) for damped primary systems. Different from the conventional way, the DVA damper is connected between the absorber mass and the ground. Two numerical approaches are employed. The first approach solves a set of nonlinear equations established by the Chebyshev's equioscillation theorem. The second approach minimizes a compound objective subject to a set of the constraints. First, the two methods are applied to classical systems and the results are compared with those from the analytical solutions. Then the modified Chebyshev's equioscillation theorem method is applied to find the optimum damped DVAs for the damped primary system. Various results are obtained and analysed.

Hassan Rivaz [15] studied Vibro-elastography, a new medical imaging method that identifies the mechanical properties of tissue by measuring tissue motion in response to a multi-frequency external vibration source. Previous research on vibro-elastography used ultrasound to measure the tissue motion and system identification techniques to identify the tissue properties. This paper describes a hand-held probe with a combined vibration source and ultrasound transducer to implement the new method as a practical device. The device uses a proportional integral active dynamic vibration absorber with an electromagnetic actuator to counterbalance the reaction forces from contact with the tissue. Experiments show an operational frequency range of 5–20 Hz, with at least 15 dB vibration absorption in 0.4s for single frequency excitation. Experiments with variable frequency and amplitude excitation also show a high level of vibration absorption.

S.M. Shaukat Rafi and Asif Sami [16], studied active vibration control of a fixed beam using surface bonded piezoelectric sensors and actuators and was examined in this work. The finite element model developed is based on Reddy's third order laminate theory. The simulation results show that an increase in the number of sensor/actuator pairs improves the vibration control of the beam. However, the location of the sensors/actuators is even more important in controlling active vibrations. The sensors/actuators pairs when placed near the regions of highest strains give the best vibration suppression and show little effect in the lowest strain regions.

Jinhao Qiu and Hongli Ji [17] studied that piezoelectric materials have become the most attractive functional materials for sensors and actuators in smart structures because they can directly convert mechanical energy to electrical energy and vice versa. They have excellent electromechanical coupling characteristics and excellent frequency response. In this article, the research activities and achievements on the applications of piezoelectric materials in smart structures in China, including vibration control, noise control, energy harvesting, structural health monitoring, and hysteresis control, are introduced. Special attention is given to the introduction of semi-active vibration suppression based on a synchronized switching technique and piezoelectric fibres with metal cores for health monitoring. Such mechanisms are relatively new and possess great potential for future applications in aerospace engineering.

Juntao Fei [18], presented results on active control schemes for vibration suppression of flexible steel cantilever beam with bonded piezoelectric actuators. The PZT patches are surface bonded near the fixed end of flexible steel cantilever beam. The dynamic model of the flexible steel cantilever beam is derived. Active vibration control methods: optimal PID control, strain rate feedback control SRF, and positive position feedback control PPF are investigated and implemented using xPC Target real-time system. Experimental results demonstrate that the SRF and PPF controls have better performance in suppressing the vibration of cantilever steel beam than the optimal PID control.

Deepak Chhabra et.al [19] considered the active vibration control of beam like structures with laminated piezoelectric sensor and actuator layers bonded on top and bottom surfaces of the beam. A finite element model based on Euler-Bernoulli beam theory has been developed. The contribution of the piezoelectric sensor and actuator layers on the mass and stiffness of the beam has been considered with modelling of entire structure in a state space form. The designing of state/output feedback control by Pole placement technique and LQR optimal control approach are demonstrated to achieve the desired control. From the analysis, it has been observed that the LQR control scheme is very effective in controlling the vibration. Numerical simulation shows that including and varying the location of the sensor / actuator mass and stiffness from the free end to the fixed end on the beam produces a considerable change in the system's structural vibration characteristics. The study illustrates that sufficient vibration suppression can be attained by means of the proposed methods.

Prathap Narayan appa & Y.V. Daseswara rao [20] studied that vibration suppression has always been an important issue in developing efficient motion control **systems.** Traditionally, in a mechanical system, the vibrations are suppressed by adding more material to the system in order to increase the rigidity. However, recent advancements in mechatronics, has provided with many alternative solutions that avoid excess material addition and increased performance. This paper attempts to summarize various methods that are being developed for vibration detection and suppression. The techniques included in this paper are motion control strategies based on sensors, sensor-actuator and sensor less controllers.

III. CONCLUSION

1) The most of the studies are related to dynamic vibration absorber with numerical analysis to find out resonant frequencies.
2) Research did not focus on effect of absorber position on the vibration amplitude at hand arm.
3) Effect of the absorber material on vibration levels is not studied in the most of the research.

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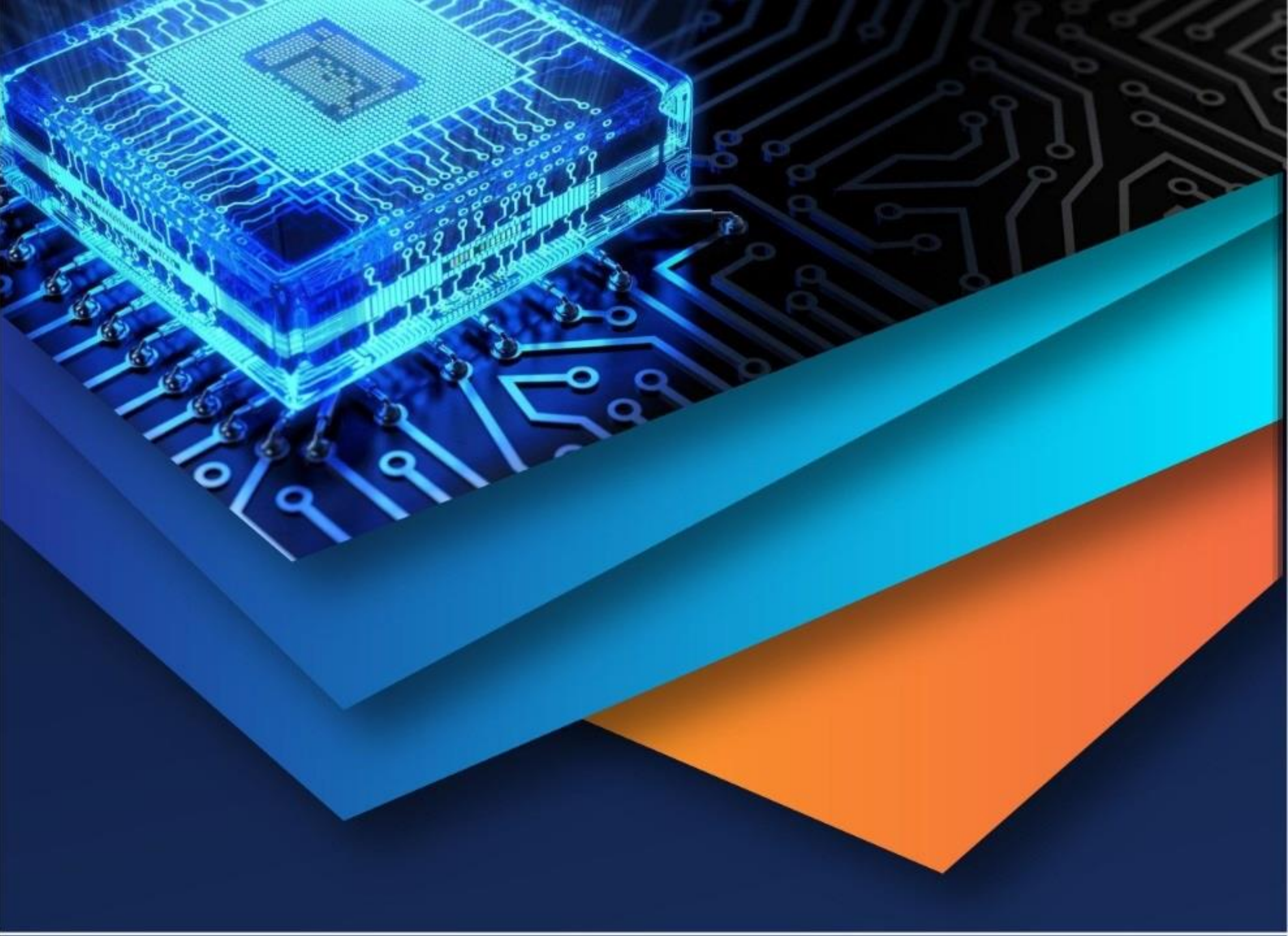

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