Mathematical Modelling of Active Vibration Control on 2-Wheeler Handle Bar by using Smart Material

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***Abstract*—While driving or riding vehicle, vibrations are felt by driver or rider which are unwanted. The main sources of vibrations are because of uneveness in road profile, radial run out of tyre, unbalancing of wheels, misalignment of gears in gearbox, unbalancing of crankshaft inducing engine vibration and failure of bearings. These vibrations are transmitted to the rider through handle bar, tank and seat. Handle Bar becomes most prominent and thus this project will discuss about active vibration control of handle bar. The active control system is to be designed to remove the engine idle vibrations which are being transmitted to handle bar. The system consists of piezo-electric semi rings as sensors and actuators and some electronics as a part of control system. The first bending mode and highest strain energy or deformation section of handle bar was observed using COMSOL software. The finite element model of the structure was made and the locations of placing actuators are identified. Virtual simulations are carried using Matlab Simulink and programming. Different control algorithms, feedback methods like compensator feedback shunt damping are used to develop and design control system. It reduced vibrations upto 11.42 dB**

I. Introduction

Nowadays ride comfort quality is of prime importance mostly in two wheeled vehicles but unwanted vibration affecting it. In two wheelers as compared with four wheelers riders experiences more vibration because of direct and short paths from vibration source to touch sensitive points like handlebar, seat and foot rest. Users first touch point is handle bar and thus vibrations transmitted from it are of more importance. As basic handlebar assembly consists of main handlebar, handlebar clamps and bolts and nuts used for clamping. There are different types of vibration damping system are as follows:

A. Passive control System

This system resists or absorbs the energy. It is the system where stiffness and damping coefficient are fixed and no external force is applied. No sensors and actuators are used. So, it is open loop system. No feedback is used. Ex- Spring, dampers, vibration isolators, tuned mass dampers, etc

B. Semi-Active control System

It is the system where stiffness and damping coefficient of material or spring-dampers are varied depending on the force acting on it. Here, external force is applied through actuator only for some specific range of frequencies. Ex- Magneto-rheological dampers, Electro-rheological dampers, etc.

C. Active control system

It is the active application of force in an equal and opposite fashion to the forces imposed by external vibration on real time basis. This device is integrated with real time processing unit to improve safety. Here, sensors and actuators are used. So, it is closed loop system. Ex- Piezo-electric Materials, Inertial mass actuators, etc.

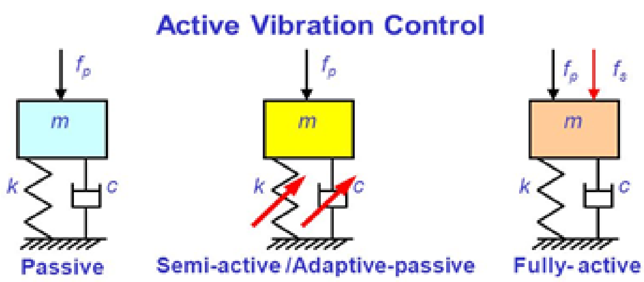

Fig. 1. Types of Vibration damping system

II. TRANSDUCTION PRINCIPLE

Piezo-electric Materials converts mechanical strain energy into electrical energy by application of periodic force and also converts electrical energy into Mechanical strain energy by the application of potential difference. [1] ‘

A. Direct Effect

In Direct effect, Potential difference is generated between the terminals when strain is applied because of the vibrations in piezo-electric material. [2]

$$D = d \times T \dot{+} E \times \epsilon \tag{1}$$

B. In-Direct Effect

In In-Direct effect, strain is generated between the terminals when potential difference (voltage) is applied results into vibrations in piezo-electric material. [2]

$$s = S \times T \dot{+} d \times E \tag{2}$$

where,
D $\rightarrow ElectricalPolarization(C/m^2)$
$d \rightarrow Piezo - electriccoefficientMatrix$

$T \rightarrow StressMatrix(N/m^2)$
$\epsilon \rightarrow Electricalpermittivity(F/m)$
$s \rightarrow StrainVector$
$S \rightarrow ComplianceMatrix$
$E \rightarrow Electricfield(V/m)$

III. RECENT STUDIES

Kalsule et al, reduced engine vibration problems in frame of motorcycle bike with the help of finite element modal analysis, harmonic analysis and experimental techniques. They reduced overall vibrations upto 80% to 90%. [3]

Shivraj Harale et al, analyzed the strength of structural mountings with various frequency ranges. They used Altair solver code Radioss Bulk data to carry frequency response analysis. They developed handle-bar model in HYPERMESH. They used HYPERVIEW and HYPERWORKS for post Processing. [4]

S. Agostoni et al, worked on ride comfort of motorcycles and focused on the handle bar as it is in contact with riders hand. They used Tuned mass damper (TMD) to damp vibrations of the handlebar. They reduced structural vibrations of handle bar. [5]

Juntao fei et al, used Lead Zirconate Titanate (PZT) Patches which acts as actuator and sensor, on surface of cantilever beam bonded to it and performed active vibration control by using Strain Rate Feedback (SRF) and Positive Postion Feedback (PPF) control methods. [6]

Emanuele Bianchini, introduced new approach of reducing engine idle vibrations transmitted to steering column by using smart material (piezo-electric material). He developed Active Vibration Control System comprises of sensors ,actuators, etc. He achieved 25dB reduction in intensity of vibrations. [7]

IV. METHODOLOGY

Methodology used in this project is as follows-
1. Constrained Modal Analysis using COMSOL Finite Element Model (FEM) package to find out the System Level Natural Frequencies.
2. Conducting vibrational analysis test by applying same constraints as used in FEM using Fast Fourier Transform (FFT) Analyzer to find out Natural Frequencies.
3. Mathematical Modelling of total Vibration system with active control system is done in Matlab Simulink.
4. FFT of the Undamped and damped data is analysed.
5. Two types of feedbacks i.e, a) Compensator (Acceleration feedback) b) Shunt Damping is used in control system design of the system.

V. CALCULATION OF NATURAL FREQUENCIES

To damp vibration of any system, its fundamental frequency is to be known. Intensity of vibration is reduced by using various Techniques. To calculate frequencies of a system, various methods like Mathematical Modelling by using Matlab Simulink Model, Finite Element Method and by Experimental Analysis are used.

A. Mathematical Modelling by using Matlab Simulink Model

Mathematical modelling is done by using Matlab Simulink model and natural frequency is calculated by conducting FFT on output data obtained from the model. The following is the schematic of the mechanical system

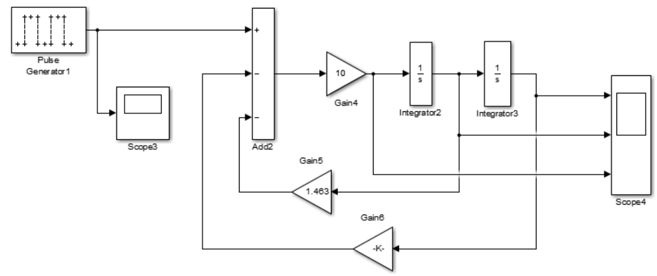

Fig. 2. Matlab simulink model of a mechanical system

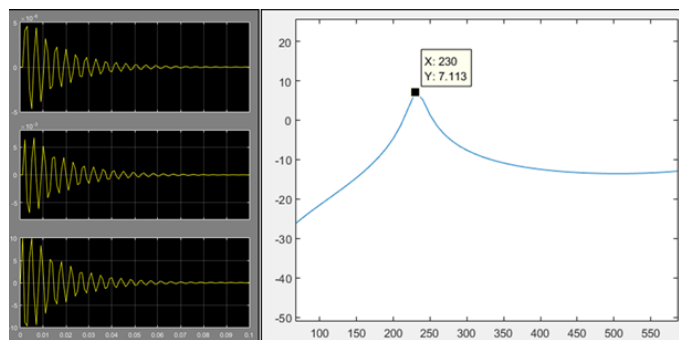

Fig. 3. Plots of displacement, velocity, acceleration and their FFT. (Matlab)

So, Above figure indicates natural frequency of the system is 230 Hz. It is first mode of its fundamental natural frequency. Its intensity of vibration is 7.113 dB.

B. Finite Element Method

Here, Handle Bar model with Semi-Piezo rings of PZT 5-H material attched is drawn in Catia. Handle bar Model is meshed fine and solved for modal analysis for calculation of natural frequencies.

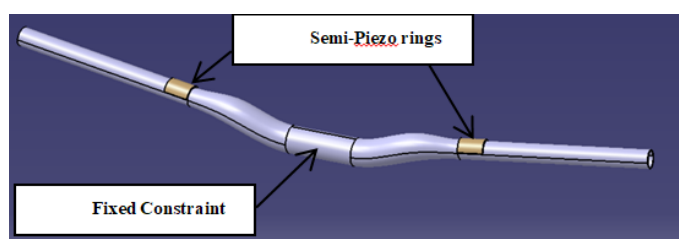

Fig. 4. Catia Model of Handlle Bar

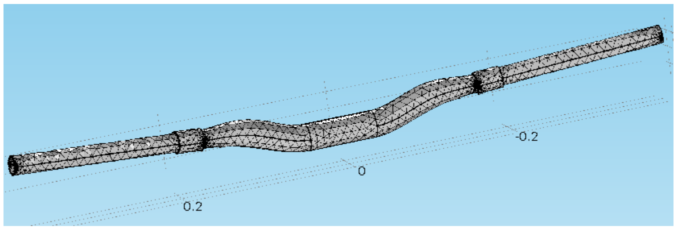

Fig. 5. Fine Meshing of Model in COMSOL software

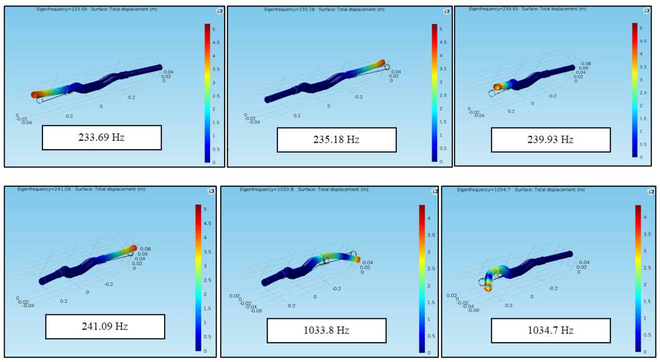

Fig. 6. Natural Frequencies of 2-wheeler Handle Bar (COMSOL Software)

After computing for the solutions, we get required frequencies COMSOL simulations plots from are as follows:

The first 6 modes of natural frequencies are obtained. Two frequencies are approximately equal which indicates right and left side of handle bar frequencies.

TABLE I
NATURAL FREQUENCIES OF 2-WHEELER HANDLE BAR

Sr. No.	*Frequency*	*Deflection*	*Handle side*
1	233.69 Hz	Along Y direction	Left
2	235.18 Hz	Along Y direction	Right
3	239.93 Hz	Along Z direction	Left
4	241.09 Hz	Along Z direction	Right
5	1033.8 Hz	Along Y direction	Right
6	1034.7 Hz	Along Y direction	Left

Here, first natural frequency of the handle bar is 233.69 Hz.

VI. CONTROL SYSTEM DESIGN

Various Control System Feedbacks can be used such as strain rate feedback, Positive position feedback, Shunt damping feedback, Acceleration feedback, PID controller, etc. Here, Vibrations sensed by piezo as sensor is circulated through control logic system and sent back to Piezo as actuator with 180 phase shift. Thus vibrations reduces actively.

A. Compensator Control System Feedback

A compensator containing a complex conjugate pair of poles coinciding with the natural frequency of the target mode is used. [6]

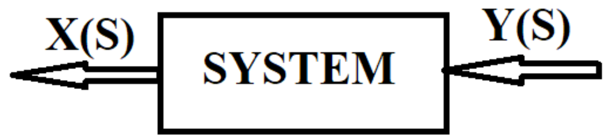

Fig. 7. Block diagram of transfer function of compensator system damping feedback

The general expression for this kind of compensator is as follows:

Transfer function for acceleration feedback:

$$Hc = \frac{X(s)}{Y(s)} = \frac{G \times \omega^2}{(s^4 + 2 \times \zeta \times \omega \times s^3 + \omega^2 \times s^2)} \tag{3}$$

Transfer function for velocity feedback:

$$Hc = \frac{X(s)}{Y(s)} = \frac{G \times \omega^2}{(s^3 + 2 \times \zeta \times \omega \times s^2 + \omega^2 \times s)} \tag{4}$$

Transfer function for position feedback:

$$Hc = \frac{X(s)}{Y(s)} = \frac{G \times \omega^2}{(s^2 + 2 \times \zeta \times \omega \times s + \omega^2)} \tag{5}$$

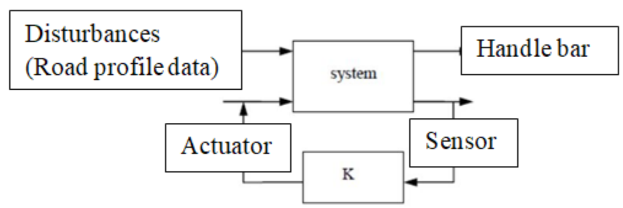

Fig. 8. Block Diagram of control system design for active vibration control

B. Shunt Damping Control System Feedback

The piezoelectric materials convert mechanical energy to electrical energy, which is then dissipated in the RLC circuit through joule heating. An impulse is applied to a handle bar and by varying the inductance and resistance values, the natural oscillation frequency for the RLC circuit is tuned to damp vibrations. [8]

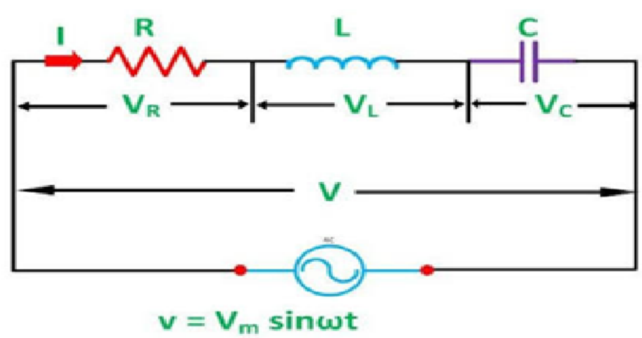

Fig. 9. Series RLC circuit

Shunt Damping Transfer function is as follows:

$$T_{Shunt} = \frac{RC \dotplus sLC}{1 \dotplus (RC \dotplus sLC)\, s} \tag{6}$$

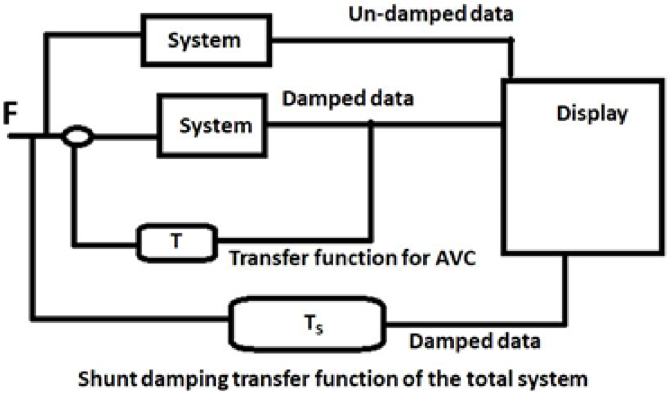

Fig. 10. Block diagram of Matlab Simulink model of control system by using compensator and passive shunt damping feedback

VII. RESULTS

Simulation results are obtained from Matlab Simulink Model. Matlab Simulink output plots are displayed below.

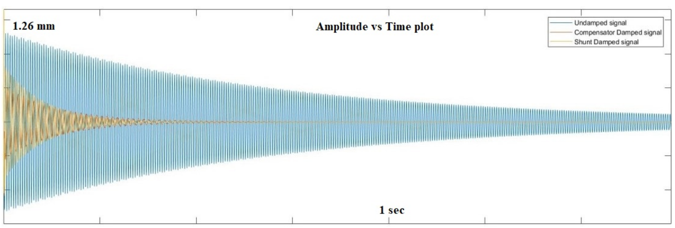

Fig. 11. Matlab Amplitude plot of Undamped and Damped data of compensator and passive shunt damping feedback

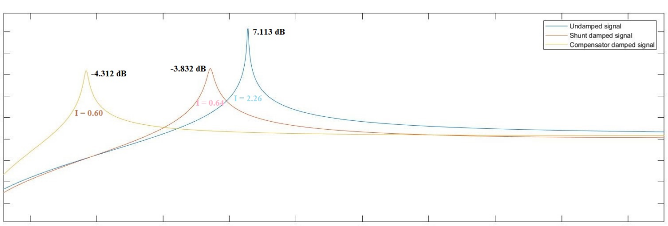

Fig. 12. Matlab FFT plot of Undamped and Damped data of compensator and passive shunt damping feedback

A. Calculations

$$I(W/m^2) = 10^{[I(dB) \div 20]} \tag{7}$$

So Intensity of undamped data can be calculated as follows:

$$I_{Undamped}(W/m^2) = 10^{[7.113 \div 20]} = 2.26 \tag{8}$$

Similarly, for damped data , Intensities are calculated as follows:

For Shunt damping control function

$$I(dB) = -3.832 \tag{9}$$

$$I_{damped}(W/m^2) = 10^{[-3.832 \div 20]} = 0.64 \tag{10}$$

Percentage Reduction in Intensity of Vibrations

$$I_{Reduced} = \frac{I_{Undamped} - I_{Damped}}{I_{Undamped}} = \frac{2.26 - 0.64}{2.26} = 0.7168 \tag{11}$$

For Compensator control function

$$I(dB) = -4.312 \tag{12}$$

$$I_{Undamped}(W/m^2) = 10^{[-4.312 \div 20]} = 0.60 \tag{13}$$

Percentage Reduction in Intensity of Vibrations

$$I_{Reduced} = \frac{I_{Undamped} - I_{Damped}}{I_{Undamped}} = \frac{2.26 - 0.60}{2.26} = 0.7345 \tag{14}$$

B. Result Table

TABLE II
REDUCED VIBRATIONS OF DAMPED SYSTEMS

Sr. No	*Type of control System*	*Reduced I*	*Reduced I(dB)*
1	Undamped	-	-
2	Damped (Shunt damping)	71.68 percent	10.94
3	Damped (Compensator)	73.45 percent	11.42

VIII. CONCLUSIONS AND FUTURE WORK

A. Conclusion

1. By using Shunt damping feedback, 10.94 dB of intensity is reduced which denotes 71.68% in Intensity reduction and by using compensator feedback, 11.42 dB of intensity is reduced which denotes 73.45% in Intensity reduction.
2. Actuators and sensors like strain gauges, Semi-Piezo rings are integrated/Pasted.
3. 7.113 dB of intensity of vibration was noticed at 230 Hz frequency.
4. Frequencies of both obtained from Matlab Simulink Model (230 Hz) and FEM (233.69 Hz) are approximately same.
5. As Software (FEM) method can predict good results within less time so, there is no need of actual or prototype formulation to conduct experimental test. FEM approach can be used to reduce design cycle time.

B. Future Work

1. Piezo-electric material can be used for active vibration control of various automotive components.
2. COMSOL Software can be used for Piezo-electric transient simulation modelling.
3. Narrow/Broad band control of frequencies can be damped on handle bar

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