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Vibration analysis and reduction in vibrations of steering wheel of an agricultural tractor

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ABSTRACT

Steering wheel vibration is one of the major factors in determining the operator comfort in agricultural tractors. Over the past 20 years automobile quality and consumer perceptions and demands have been an increasing part of the vehicle engineering process. This paper deals with study of vibration related issues. The design and analysis plays a major role for determining the root cause for the problem. Once the problem is well defined, the solution for addressing the problem will be made simple. Main sources of steering wheel vibration are found to be engine imbalance, resonance of steering system, lesser damping, road / field induced vibration. Steering vibration study was conducted on various tractor models and one tractor was identified for improvement. Upon detailed analysis on that particular tractor, it was found that the resonance of steering system with engine excitation is the root cause for excessive vibration. Various methods to reduce vibration due to resonance is considered, such as shifting the natural frequency away from the second order engine frequency and increasing damping coefficient to reduce the vibration amplitude at resonance. Axial damper concept was used for vibration reduction. Various damping materials will be tested for vibration reduction. Analysis will be done in Matlab Simulink with two degree of freedom model with base excitation.

Keywords— **steering wheel, Vibration, dampers, frequency, resonance, amplitude, elastomers.**

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I. INTRODUCTION

Passenger comfort is a vital criterion in the present day vehicle system. In recent times, tractors were considered as performance machines and the operator comfort was not given much importance. Now this has changed and tractor owners also want to have an equal level of comfort, if not more than the passenger vehicles. Tractors generally operate in adverse environmental conditions and an ergonomically inferior tractor could make things worse for the driver. Operator comfort in tractor means many factors like space available for occupant, reach of controls, visible, noise and vibration, temperature, etc. So vibration is one factor which not only makes the operator uncomfortable, but also leads to failure of various parts of the tractor. Tractor operators are exposed to two types of vibration: one is whole body vibration transmitted via seat, floor and another is foot pedal controls and hand transmitted vibration via steering wheel and hand control. There are two strategies for preventing the adverse effects of vibration. They are:

- Vibration control at excitation source itself
- Vibration isolation by taking appropriate action in the transmission path

High exposure to hand transmitted vibration can induce disturbances in circulation of blood in the fingers and neurological functions of the hand and arm. The term “Hand-arm vibration syndrome” (HAVS) is commonly used to refer such disorders like circulatory disorders, bone and joint failure, neurological disorders, muscle disorders and central nervous system disorders. Higher vibration of tractor steering wheel may lead to this problem and hence this subject assumes great importance. ISO 5349-1:2001 standard gives the methodology to correlate the measured vibration from steering wheel to hand-arm vibration syndrome through two parameters namely,

• 8-hour energy equivalent frequency weighted vibration total value and

• Number of years in which 10% of the operators exposed to vibration may develop hand-arm vibration syndrome

This ISO standard has indicated guideline values on vibration. The European Council have directive on the minimum health and safety requirements regarding the exposure of workers who are likely to be exposed to risks from mechanical vibration during their work recommends daily exposure limit value (ELV) of 5 m/s2 and daily exposure action value (EAV) of 2.5 m/s2 for hand-arm vibration. Vibration values specified in this standard are taken as guidelines in this work. In recent developments, tractor manufacturers have been asked to measure and disclose the vibration levels at steering wheel, seat, floor, etc. The objective of this research work is to study the steering wheel vibration in detail and to reduce the same to protect the operator from hand-arm vibration syndrome, develop a mathematical model for steering wheel vibration and to verify the mathematical model with experimental results, so that it will form a base for vibration prediction in future. Literature survey was conducted to understand the work carried out so far in related fields and also the materials for the damper. As explained an experimental method for the reduction of steering wheel vibration and reduction at steering box. Mechanical impedance methods were applied to know the resonant frequency of the steering system. Tewari and Prasad presented a 3degree analytical model for tractor seat suspension system. Even though this is not directly relevant to the present work, the assumptions in the model developed are inherited in the present work as steering wheel excited primarily by the engine vibration. Tewari and Dewangan explained that the discomfort value and pain due to hand transmitted vibration leads to pain. As a effect, operators have to take rest to overcome fatigue which reduces work output and duration of actual work. Researcher have presented the results of vibration transmitted from the handle of a 6.7 kW hand tractor. Gowri Shankar, demonstrated a systematic approach towards reducing the steering wheel vibration of an agricultural tractor. However there was not much working done on the evaluation of vibration parameters as per commonly used ISO 5349:2001 standard and mathematical modeling.

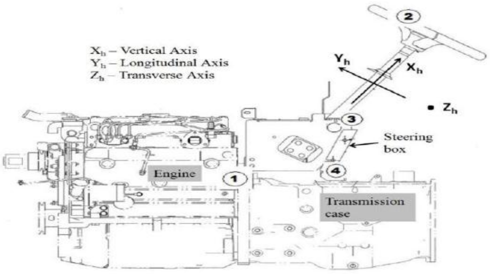

Fig 1.1 Study model of tractor[1]

II. METHODOLOGY

Steering wheel vibration on various tractors in the specific power range to be compared and one tractor have to choose for further study and improvement. Following methodology must be adopted in this work.

- Comparison of steering vibration of various tractors in specific power range.
- Selection of one tractor for further study and improvement
- Detailed experimentation on the tractor and analysis of results
- Identification of primary cause of vibration
- Concept generation, detailed design and proto type making of improved design
- Mathematical modeling of steering wheel vibration and simulation in FEA software
- Comparison of present and improved design as per ISO 5349 standard.
- Comparison of computed and measured vibration

2.1 Experimental setup

The experimental setup consists of data acquisition system of FFT analyzer, transducer and personal computer with FFT analyzer software installed. The data acquisition was made possible using tri axial transducer (B&K Endevco model ISOTRAN.) was made by piezoelectronics, 9.929 mV/g, 10.07mV/g and 10.10mV/g sensitive’s in x, y, z direction respectively, that was connected to laptop using 4 channel cable. The accelerometer converts acceleration into voltage which is fed to the signal conditioner. The setup was supportive to the sampling rate of 26,400 per second. Accelerometers were positioned in one or more locations such steering wheel, steering box. However the mean values were recorded. The recorded data was auto stored in text/excel files in the laptop. The items used in the experimental setup are shown in figure

2.2 Experimentation procedure

Procedure to measure the vibration on tractor steering is very much standardized. Vibration measurement on tractor steering have been performed, vibration are measured along x- as axis vertical axis. The measurements were taken in all three directions. The tractor initially was parked near farm and engine was started. The reading were taken at steering box and steering wheel as shown in figure Then the tractor was driven on rough road surface with varying speed and reading were taken at both locations. Tests are carried out on MAHINDRA 575 model on farm field and rough road which is shown in figure Mahindra 575 from Mahindra and Mahindra Ltd. is a 4 strokes, direct injection diesel run tractor with a capacity of 2.5L. The power of tractor is 45hp. The test is carried out on tractor without any trailer attached.

Experimentation was carried out in two stages

Stage I: Measure the actual vibration produced in tractor steering wheel and steering box

Stage II: Measure the vibration level when damper is provided by producing given level on electrodynamic shaker machine.

2.3 Various materials for damping purpose

As most automotive vibration isolators are made of elastomeric compounds. So the study of the various damping materials becomes essential for our purpose. There are various rubber materials with different properties and different applications are available. Hence study of proper materials and their application becomes mandatory. Rubber is the general name for the existing variety of elastomeric materials, and the term "rubber" can refer to both natural and synthetic compounds. Elastomers have the following three distinguishing characteristics:

1. Resilience and energy storage – Elastomers exhibit a high degree of recovery from large or small deformations through repeated cycling, returning approximately to the original dimension without suffering permanent damage, i.e. resilience. Remarkable energy storage capacity plus the ability
to withstand repeated flexing attribute to rubber's utility as a spring material for mountings or suspensions for vehicles, machines, engines and instruments.

2. Large deformability- Elastomers exhibit the capability to withstand relatively high amounts of extension within the working range of the material, which, in extreme cases can reach 300%, and the ultimate elongation may reach 1000% of the original length. Comparatively, steel may not be extended more than .5% of the original length without exceeding the elastic limit, and the ultimate elongation seldom exceeds 25%. 3. Low modulus- When exposed to large deformation elastomers exhibit low stress levels. Rubber is seldom subjected to stresses greater than 6895 kPa (1000psi). elastomeric dampers works well at the resonance hence it will be beneficial to use the dampers to reduce the vibration level. Additional ingredients are also used in the formulations of both natural and synthetic rubber elastomers to provide specific performance characteristics, and the function of these ingredients is outlined in the following table:

TABLE 2.1 Properties of material and applications [8]

	Elastomer	**Major properties**	**Application**
1	Natural Rubber	Broader properties Excellent tensile strength and tear resistance	Powertrain mounts, shock and strut mounts, front axle bushings, mounts
2	Butyl	inert, excellent weathering resistance, high damping	bumpers, vibration dampers
3	Poly-Urethane	excellent weathering resistance, high gum strength, high damping	Body mounts, jounce bumpers, suspension bushings
4	Poly-butadiene	Resilience and low temperature flexibility better than NR and IR	Same as Natural Rubber

III. MATHEMATICAL MODEL

With the introduction of dampers in the system, a simple mathematical model was developed to predict the vibration at the steering wheel. When a dynamic system is excited by the motion of the support point, the same is considered as a support motion or base motion problem.

Let *y* and *x1* be the harmonic motion of support base and displacement of steering box respectively. Let *x2* be the displacement of steering column and wheel assembly. *m1* and *m2* are the masses of steering box and steering column-wheel assembly respectively. The free body diagrams of masses *m1*and *m2* are shown in Figure . The derived equation gives the transmissibility from the engine to the steering wheel.

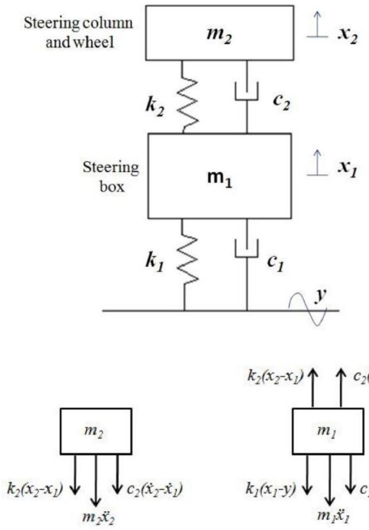

Figure. 3.1 Two DOF support motion

Equation of motion for *m2* is given by Eq.

$$m_2\ddot{x}_2+c_2(\dot{x}_2-\dot{x}_1)+k_2(x_2-x_1)=0$$

Similarly, equation of motion for *m1* is given by following Eq.

$$m_1\ddot{x}_1+k_1(x_1-y)+c_1(\dot{x}_1-\dot{y})=k_2(x_2-x_1)+c_2(\dot{x}_2-\dot{x}_1)$$

$$m_1\ddot{x}_1-k_2(x_2-x_1)-c_2(\dot{x}_2-\dot{x}_1)+k_1x_1+c_1\dot{x}_1=k_1y+c_1\dot{y}$$

By solving these equations we can get the magnitude of the transmissibility from engine to steering wheel

$$\left|\frac{X_2}{Y}\right|=\sqrt{\frac{(k_1k_2-c_1c_2\omega^2)^2+((k_1c_2+k_2c_1)\omega)^2}{(k_1k_2-(m_1k_2+m_2k_1+m_2k_2+c_1c_2)\omega^2+m_1m_2\omega^4)^2+((k_2c_1+k_1c_2)\omega-(m_1c_2+m_2c_1+m_2c_2)\omega^3)^2}}$$

IV. METHODOLOGY FOR VIBRATION REDUCTION

Due to the complex fabricated structure it is difficult to provide more stiffness since it will increase the weight. This will corresponds to increase in the natural frequency. Hence it will be beneficial. The present steering is one of the lightest in its range. To avoid the resonance we have to reduce the weight since to get desirable natural frequency. This is practically impossible to execute. Since damper works good at resonance hence it will be beneficial to provide elastomeric damping to reduce much vibrations. From the study of different elastomeric materials discussed in section it is found that Polyurethane as an axial damper.

Isolation was provided at the mounting of the steering box by pads. The pads were constraints with the studs. The axial damper was selected of compressive stress of 143kPa. Polyurethane has very good damping characteristics at resonance. A hardness of 60A was chosen for the damper. It shows better results than other elastomeric materials like natural rubber, NBR, EPDM. The application of polyurethane is shown in fig

V. MEASUREMENTS AND READINGS

Measurements were made in all three directions as shown in Figure. the Xh, Yh and Zh axes are termed as vertical, longitudinal and transverse axes respectively. The tractor was parked on a rough road surface and the engine was started. Measurements were taken with the gear in neutral position. Initially, the engine speed was increased from idling to various speeds slowly and steadily over a period of 2-3 minutes and the measurements were made. The vibration was not significant at low speeds and it became significant only after certain speed. This was done considering the scarce availability of testing resources. At each engine speed, vibration was measured for a period of 30-40 seconds and stored in the computer for further analysis.

Readings further taken were studied for the next stage. The values obtained at the steering wheel and the steering box were taken and given input to the electrodynamics shaker machine and then results were measured with FFT analyzer with the help of piezo electric transducer.

Fig 5.1. Accelerometer mounting at steering wheel

Fig. 5.2 Accelerometer mounting at steering box

5.1 Reading taken with the use of FFT analyzer

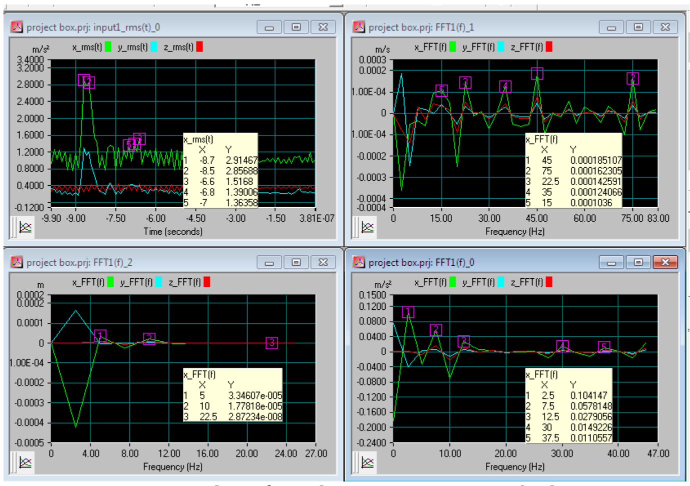

Fig. 5.3 Reading of Accelerometer at steering wheel

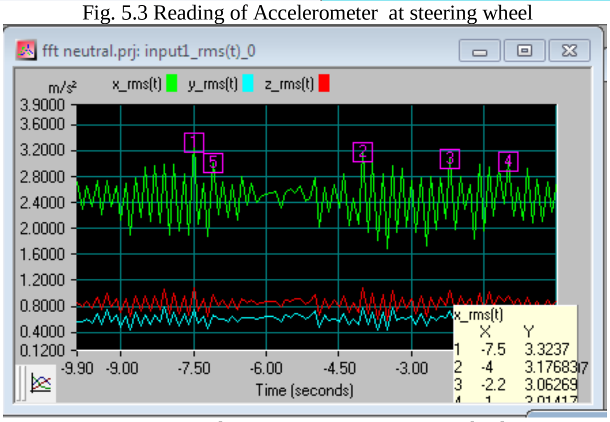

Fig. 5.4 Accelaration vs time at steering wheel

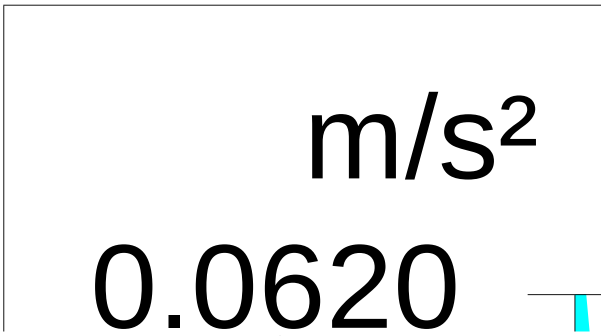

Fig. 5.5 Acceleration vs frequncy graph at steering box

5.2 Reading taken with the use of FFT analyzer with damper

This is second stage of experimentation. In this stage the use of measured values of the acceleration and frequency from the selected tractor were studied. The peak and rms values of acceleration, velocity and displacement were chosen and input is given to the electrodynamic shaker machine. The electrodynamic shaker machine was developed and manufactured by Sarswati Dynamics Pvt Limited, Pune. The shaker is essentially an electro-magnetic assembly comprises of electro-magnetic cicuit cinsisting of stationary (field) and moving coil which is part of head that moves or vibrates. The whole steering system was mounted on shakertop plate ith the help of designed fixture. the inputs were given and by giving all specified inputs, the shaker was operated The vibration level was measured with the help of accelometer described in section . following graphs shows the reading taken from the shaker machine experimentation.

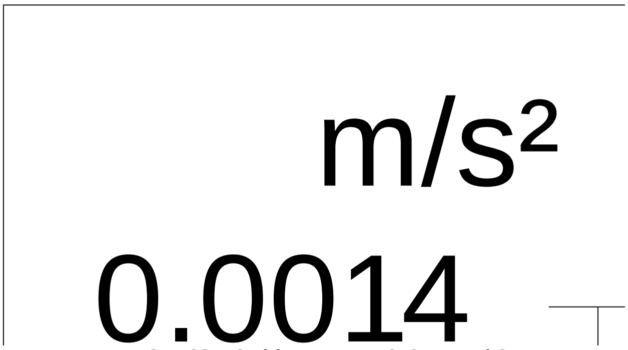

Fig. 5.6 reduced level of frequency with the use of damper

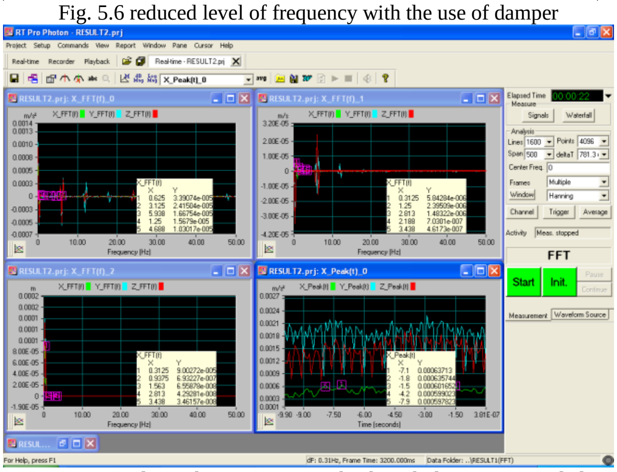

Fig.5.7 Reading taken at steering wheel with damping provided

Fig.5.8 Experimental setup on shaker

Fig. 5.9 location of accelerometer when steering system is mounted on shaker machine

VI. RESULT AND DISCUSSION

Measurements were taken on Steering of tractor was taken by using FFT analyzer with the help of laptop. figure- shows the vibration level on steering wheel and Figure-5.3 shows the vibration level on steering wheel. Likewise, figure-5.7 and figure-5.8 shows the vibration level on steering wheel and steering box after providing damper. The vibration level on the steering wheel and box has measured and analyzed and the acceleration and Frequency spectra for the chosen working conditions were obtained. It is found that acceleration (rms) value of steering wheel is about 3.3m/s and after providing isolation it is decreased to 2.7 m/s. that means decrease in the acceleration by about 0.6 to 0.9m/s. The results indicate that the maximum transmissibility was observed in the first two frequency interval (in Hz) i.e.1-25 and 25-50.the frequency interval was 1-25 (steering box), 1-25, 25-50 (base steering), 25-50 (base steering). It is found that the operators of power tools with frequencies below 25 Hz may experience greater muscles/tissues fatigue and symptoms of musculoskeletal disorder when working with extended arm posture. Hence with the use of damping the frequency value decreased upto 10 to 15 Hz which is comfort zone for hand-arm according to the ISO 5349-1:2001.

VII. CONCLUSION

The base tractor chosen for study had shown high level of vibrations. It is found that resonance as the primary cause of vibrations produced. Elastomeric damper was found to be the most appropriate solution. The axial dampers provide a reduction of about 33% of total vibration level produced.

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