Simulated Dynamic Model of Tractor-Implement System using Power Spectral Densities

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Abstract

When tractors work in fields with implements high amplitude vibrations are transmitted to the seat of driver. As mostly tractors are without any suspension systems so these vibrations are harm full to the health of operator. These vibrations also reduce the working efficiency of the operator. The work is focused on to analyse the vibrations transmitted to the seat base using the power spectral densities. The real time data was collected from the tractor and a dynamic model was created in Matlab/Simulink software. The model was simulated using parameters of tractor and was validated by modifying the parameters. Power spectral densities of data was analysed. It was concluded that the frequency for maximum value of PSD in the measurement is higher than 4 Hz, which means that the energy is centered around 4 Hz. For vertical vibrations, this value falls at the frequency that is most sensitive to person and is not adequate for driving comfort. As vibrational amplitude at 4 Hz is most dangerous for driver, the main focus of study was to analyse the vibration of operators seat by a dynamic simulated model with power spectral densities concept so that analysis can be used to design a controller to reduce the vibrations in future.

Keywords -Tractor, Implements, Vibration, Modelling and Simulation, Power Spectral Densities.

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1. INTRODUCTION

The study of human responses to vibration is extremely diverse multi- disciplinary nature of the subject. Vibration is a magnitude (force, displacement or acceleration) that oscillates about a mean reference position. The time interval in which the sequence of motion is repeated is called the cycle or period. The number of cycles performed in a unit of time (eg. second or minute) is called frequency. Any kind of vibration is commonly characterized by frequency in Hertz (Hz) and acceleration in m-s^2. Griffin (1985), Martin and Smith (2004) suggested that the vibration characteristics which mostly influence human response are the direction, the point of contact with the body, frequency, magnitude, duration etc. Resonance occurs when the excitation frequency matches one of the natural frequency of the system. This results in large oscillations, which are harmful/undesirable. When a system is disturbed and can vibrate by itself, the frequency at which it vibrates without damping and without external force is known as its natural frequency. If the damping is present, then it is; known as damped natural frequency of the system. Most seats exhibit resonance at low frequencies, which results in higher magnitude of vertical vibrations occurring on the seat.

2. DYNAMIC MODEL OF TRACTOR IMPLEMENT SYSTEM

In present work simulation of Full tractor vibration model with hitched implement (John deere) was created.Moment of inertia and mass of tractor with implements was the key factor in representing the tractor-implement structure. The dynamic model of tractor and implement is shown in figure 2.1. Due to surface roughness front tires and rear tires of tractor are subjected to displacement excitations $q_{fz}(t)q_{rz}(t)$ respectively. Because of the difference in amplitudes of qfz(t)and $q_{rz}(t)$ an angular displacement with respect to centre of mass comes into picture. Due to this angular displacement with respect to mass centre roll,

yaw and pitch movements of tractor came into the picture.

The ground excitation relation between front axle and rear axle of the tractor-implement system at any instant i by considering the time lag between $q_{fz}(t)$and $q_{rz}(t)$ can be expressed as

$$q_{fzi}(t) = q_{rzi}(t + \tau) \qquad (2.1)$$

Where$q_{fzi}(t)$ and $q_{rzi}(t)$ are displacement excitations at front and rear axles respectively, Ƭ is time lag and can be calculated as

$$\tau = \frac{l_{bf} + l_{br}}{v}$$

Where $l_{bf}$is distance of mass centre between chassis and front axle, l_{br} is the distance of mass centre between chassis and rear axle. Velocity of tractor-implement system is represented by v.

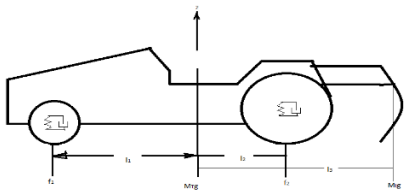

Figure 2.1 Dynamic Model of Tractor Implement System

The motion equations can be expressed as

$$(M_T + M_I)\ddot{z} = f_1 + f_2 - (M_T + M_I)g \qquad (2.2)$$

The displacement of wheels can be calculated as

$$z_1 = z + \left(l_1 + l_3 \frac{M_I}{M_T + M_I}\right) \qquad (2.3)$$

$$z_2 = z + \left(l_2 - l_3 \frac{M_I}{M_T + M_I}\right) \qquad (2.4)$$

The effect of implement on displacement of wheels can be calculated from equations (2.3) and (2.4). So the effective mass of tractor and implement will be expressed by m_t and its effect on wheel displacements, roll, yaw and pitch of tractor implement system will be included by using equations (2.1) to (2.4). Off -road vehicles like tractors operate without primary suspension. The tires play a role of spring cushion due to the bending of the tire and the properties of the air in the reduction of energy. The conventional suspension system of the tractor is modelled as damping of the tires of the tractor and the driver's /operator seat, which is a type of suspension for the operator of the tractor. Since the front axle of the tractor rotates towards the centre of the tractor chassis, this must be considered when modelling the vibration model of the tractor. Figure (2.2) presents the physical model of the complete tractor with implement. This complete model consists of three sub-models: four wheels, a body and a driver's seat.

3. SIMULINK FULL TRACTOR MODEL WITH IMPLEMENT

Figure 3.1 shows a developed MATLAB- Simulink computer model of the full tractor model, employing the derived equations of motion.

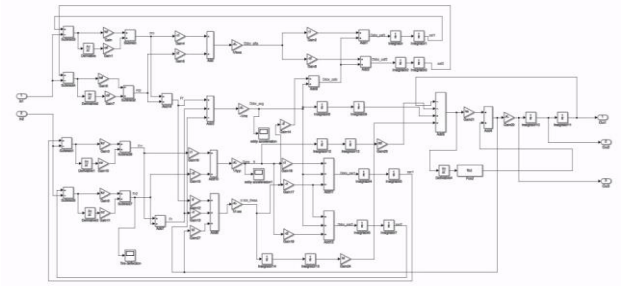

Figure 3.1 Full Tractor-Implement Simulink Model

4. VALIDATION OF SIMULATED DYNAMIC TRACTOR-IMPLEMENT MODEL

The procedure of the model validation is presented in Figure 4.1. All the simulation results were compared with the corresponding experimental result. With a view to acknowledge the weak points the simulation model was reviewed to enhance the equivalence between simulation and experimental outcomes.

With a view to assess the likeness between the

simulation and actual test results, a vibration measuring apparatus was employed on test tractor. The setup was capable to quantify the expeditious vibration at the frequency of 10 Hz in X, Y and Z axes. Moreover, the vibration measuring setup stores the accelerations obtained in the form of three excel files on system memory card. The obtained acceleration can afterwards be transferred to a computer for subsequent analysis.

5. POWER SPECTRAL DENSITY (PSD)

Data processing comprises of low pass filtering and Fourier Transform. All the data obtained from experimentation and simulation was processed by Matlab.The power spectral density explains the energy distribution of a signal across the frequency. Figure 5.1 represents the PSD comparison of the translational accelerations of seat in measurement and simulation.

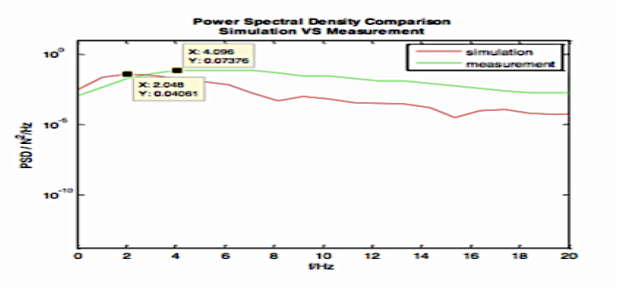

Figure 5.1 PowerSpectral Densities forSeat Acceleration

Since the excitement times and the trend of acceleration changes were precisely simulated, therefore, the results of the acquired result thus provide a clear indication of the diversity between the simulation values and actual values of acceleration of the seat base. Examination of the input parameters of the developed model revealed (pointed out) that the rigidity of tractor tires effectively controls the model outputs in the model parameters. Since the standard inflation pressure was higher than the inflation pressure of the old tires, a new values of the stiffness parameters of tractor tire was considered to improve the equivalence between actual and simulated result.

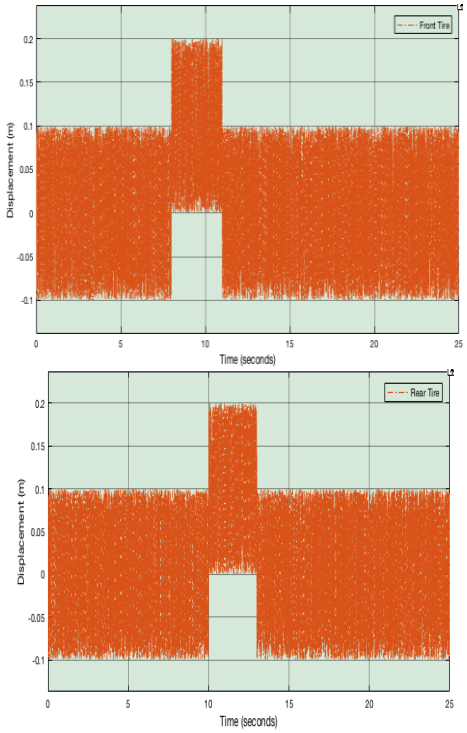

Figure 5.3 New field inputs, Front tire and Rear tire displacement input

Table 5.1 Modified Parameters of full tractor-implement vibration model

Notations	Description	Values	Units
k_{tf}	stiffness of front tire of tractor	30,000	N/m
c_{tf}	damping of front tire of tractor	1,000	N-s/m
k_{tr}	stiffness of rear tire of tractor	30,000	N/m
c_{tr}	damping of rear tire of tractor	2,000	N-s/m
m_t	Mass of tractor	2,800	Kg
t_1	Distance of center of gravity of tractor from left portion of chassis	0.87	M
t_2	Distance of center of gravity of tractor from right portion of chassis	0.87	M
l_r	Distance of center of gravity of tractor	0.91	M

	from rear portion of chassis		
l_f	Distance of center of gravity of tractor from front portion of chassis	1.35	M
I_{xxt}	Mass moment of inertia of tractor about x axis	600	kg-m^2
I_{yyt}	Mass moment of inertia of tractor about y axis	2,000	kg-m^2
I_{xxa}	Mass moment of inertia of tractor front axle about the pivot point	5	kg-m^2
m_s	Mass of seat	35	Kg
l_d	Longitudinal distance of seat from cg of tractor	0.69	M
k_s	stiffness of seat	8000	N/m
c_s	Damping of seat	130	N-s/m

In addition to this, the influence of the engine running at an angular velocity of 2100 rpm was also considered to modify the model. Considering this modification, a new input was applied to the developed model as a sinusoid excitation.

RESULTS AND DISCUSSION

From this study it is concluded that;

1. Power Spectral Densities curve shows that the frequency for maximum value of PSD in the measurement is higher than 4 Hz.
2. The energy is centered around 4 Hz and this value falls at the frequency that is most sensitive to person and is not adequate for driving comfort.
3. So the vibration level should be reduced for comfortable ride of operator and to increase the work efficiency.
4. This validated simulated model can be further used for design of vibration controllers.

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