Race Car Vibrational Problem & a Suspension System Solution

A race car experiences the following types of undesirable vibrations: Forced Vibration (Base Excitation) at tremendous speeds, Random Vibration due to track abnormalities, and Deterministic Vibration due to discrepancies in internal components.[4] These undesirable vibrations, experienced by the driver in the seat and at the steering wheel, lead to disturbances in driving strategy and hinder the overall performance of the car. In race cars, vibrations of contact surfaces lead to degradation and reduction of device lifetime. Vibration reduces overall system reliability by harming the resistances of electrical contact interfaces, the failure of which could have potentially catastrophic consequences. The avoidable internal vibrations of a race car at speed should be identified and addressed immediately as they could be an indication of a larger problem. The following could be the causes of this vibrational problem: Imbalance of moving parts or rotating assemblies (crankshafts, axles, tires) that vibrate once they hit resonance, warped brake discs or worn out tires due to misalignment. Now, a suspension system is used to solve/minimize this vibrational problem by increasing stability, control and driver comfort. The suspension system of a race car effectively combines elements like the power from the power unit, the down force from the wings and the grip from the tires to produce its performance. The system attenuates the wheel-road vibration to the car body through a spring that absorbs energy from impacts and a shock absorber/vibration isolator that prevents oscillatory force build up by releasing the energy.

Modelling:

Simple Model:

A Single Degree of Freedom (SDOF) base-excited isolation system model is used to examine the effect of the suspension system on the response of the isolated race car mass. It provides a quick insight into the behaviour of the system. A quarter car model system consists of one fourth of the car's mass (sprung mass) and suspensions system components (spring & shock absorber/vibration isolator).[1]

Complex Model:

An intermediate and advanced system with multiple DOFs have been modelled to ensure the reality of the situation and all basic features are fairly represented. As the model complexity and parameters analysed increase, a more accurate response of the system components with respect to subjected vibrations can be achieved. It should be noted that the simple model with a SDOF and the intermediate model with 2 DOF could only be used to optimise the car's bounce mode of vibrations. To account for body pitch and other modes of vibration, an advanced model with 5 DOF is shown.

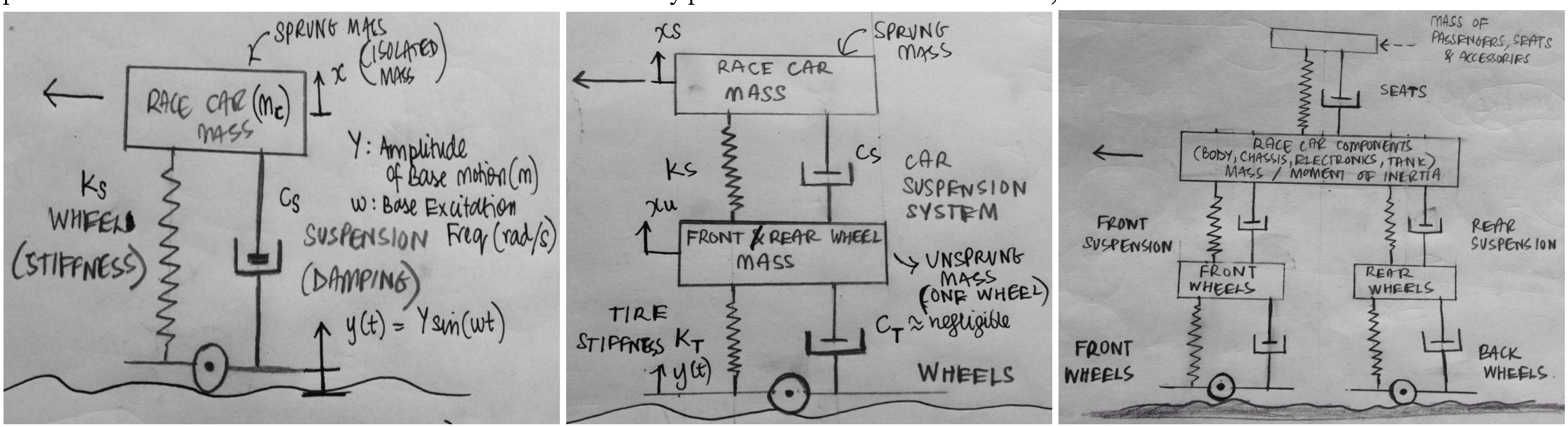

Figure 1, 2 & 3: A SDOF quarter car model (left).
A Two DOF (intermediate) quarter car model (centre) & A Five DOF (advanced) model (right).

Assumptions:

- There is no rotational motion in the wheel or body & movement occurs only in the x-direction.
- The damper, assumed the only way of removing energy from the system, behaves linearly along with the spring. The weight of both are ignored.
- The tire is always in contact with the road surface and its spring is assumed to have infinite stiffness as compared to the suspension spring for the simple model in figure 1.
- The effect of friction is neglected and the masses are considered as point masses.

Measurement:

Vibrational monitoring could help spot mechanical imbalances and in turn define a race car's set up. A Linear Variable Differential Transformer (LVDT) or an accelerometer can be used to measure displacements of clutch plates, gear drums, brake callipers etc.[2]

Method of Analysis and Solution

The discrete vibrational system experiences excitation, expressed in terms of displacement, at the base and the analysis is restricted to harmonic excitation. The displacement input function (excitation/problem) is y(t), the output function (response) is x(t) and the model parameters have been described in the figures respectively. All the key features of the system are represented in the mathematical model to aid in the derivation of the analytical equations that govern the system's behaviour.[4] The model is incrementally refined (from figure 1 to 3) by adding specific components and greater detail to achieve a more concise observation of its response.[4] The governing equations are then determined using the principles of dynamics with the help of a Free Body Diagram and methods like Newton's Laws of Motion and D'Alembert's principle (for complex models).[5] These equations of motion were solved using the initial conditions, standard Ordinary Differential Equation (ODE) methods (for simple model) & MATLAB for the matrix form of the complex models, to find the system response.[5] The goal of the suspension system is to minimise the vibration of the mass while the base vibrated with some characteristic frequency. A graph drawn helped in understanding how this could be achieved by observing how the amplitude of vibration experienced varied with system parameters. In terms of analysis of the system's response, the relationship between the frequency ratio (damped:natural), displacement transmissibility (H) were evaluated to account for how motion transferred from the base to the mass at varying frequencies. It should be noted that $H \to \infty$ for an undamped system at resonance (r = 1) and H = 1 at r = $\sqrt{2}$.[3] It was noted that the vibration the mass was subjected to could be reduced by making $r \gg 1$, damping small, the mass large and spring soft. Damping should not be made too small as it make cause transient vibrations too long to die out.[3] It could also be observed that the steady state response is independent of the initial conditions and the transient response could be neglected if time considered was large enough.

References

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