Dynamic Stiffness Simulation Driven Design Changes for Tractor Cab to Mitigate Structure Borne Noise Levels

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Abstract

The dynamic stiffness of mount systems is a critical factor influencing the overall dynamic behavior and vibration isolation capabilities of mechanical assemblies. Effective cab isolation in product design can reduce structure borne noise and tactile vibrations experienced by operators. Detailed dynamic stiffness analysis of mounting brackets coupled with modal analysis using finite element method provide insights into the vibration response and resonant frequencies of components. By systematically varying parameters such as material properties, shape and geometry, the study elucidates the sensitivity of dynamic stiffness to design alternations. This study investigates on dynamic stiffness and their consequential impact on system dynamics on various design alternations by considering the space constraints at mount locations due to components, wiring harness and structural analysis driven solutions. In overall, this paper emphasizes the pivotal role of dynamic stiffness analysis in shaping the design changes aimed at mount locations.

Introduction

In recent years, the agricultural sector has witnessed a significant evolution in the design and functionality of tractors, with a particular emphasis on enhancing the operator comfort and safety. The cab for tractor works as critical interface between operator and vehicle. One of the major purposes of operator station for agricultural machines like tractors is to provide comfortable and safe environment by protecting them from external noise and vibrations.

Major sources of vibrations in a tractor are excitations due to engine and power train, un-even terrain, shock loads and dynamic forces from tractor implements or attachments. Forces generated in tractor are transmitted to the operator as noise and vibrations through various paths. Mitigating tractor vibrations entirely poses a considerable challenge. The key to protect the operators from external vibrations lies in isolating the operator station effectively from NVH environment as described in Figure 1. Isolators are designed to obstruct vibrations, protecting the cabin from the impact of severe vibrations originating from the ground and operational circumstances.

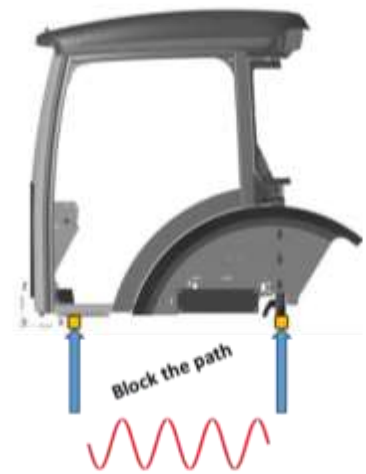

Figure 1: Structural excitation energy passing into the cab through mounts.

Isolators are connected to cab side bracket and chassis, or frame bracket as shown in Figure 2. This can be considered a system of springs in series. The load applied on frame bracket gets carried over to the isolator and subsequently to the cab bracket. In this path, vibration energy is absorbed based on deflection and it is expected that most of the deflection is in the isolators. Ideal isolators take most of the energy if mounting brackets are stiffer as compared to isolators [1].

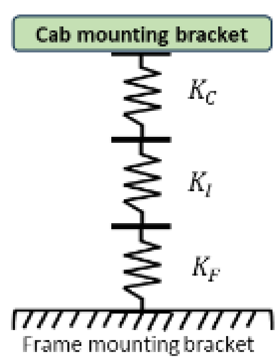

Figure 2: Series of mounting brackets and isolators

Dynamic Stiffness Analysis

Dynamic stiffness analysis is an important analysis to study the dynamic behavior of cab mounting systems. Dynamic stiffness analysis allows and gives direction to understand how the structure responds to vibration. Basically, it is drive-point frequency response analysis which is dynamic force per displacements measured at mount locations as shown in figure (1).

$$\frac{F}{X} = K - M\omega^2 + J\omega C \qquad (1)$$

The dynamic stiffness plot can be divided into three regions as shown in Figure 3. Stiffness of the structure governs the response before natural frequency and mass of structure governs the response away from natural frequency. Damping plays an important role to determine the response at the natural frequency.

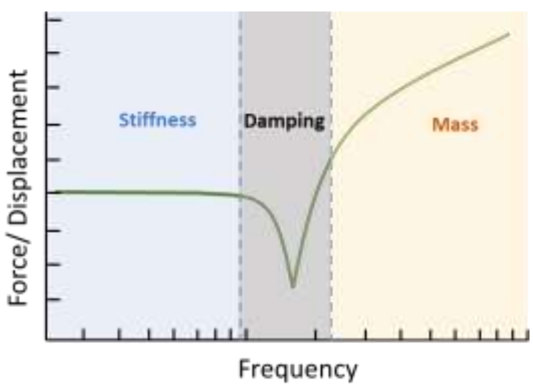

Figure 3: Behavior of dynamic stiffness

This paper describes how stiffness of cab mounting structure affects the dynamic behavior of the cab. It also includes investigation on the combination of design modifications, vibration isolation techniques and material enhancements to optimize the dynamic behavior of the tractor, ensuring the comfortable operating environment.

Dynamic Stiffness at Cab Mounts

This study of dynamic stiffness analysis and governing parameters is done on the one of small tractor cab mounts as shown in Figure 4. Dynamic stiffness analysis is carried out at cab front and rear mount locations using finite element method. This analysis is performed by applying unit load at mounting locations in the frequency range of 1-800 Hz and dynamic stiffness is evaluated by estimating the response at same locations. Front control support is added in the FEA model to incorporate mass and the effect on dynamic behavior at front mounts.

It is desirable to have the dynamic stiffness at mounting bracket to be significantly higher than that of the isolator. However, practically it is difficult to achieve very high dynamic stiffness ratio equivalent to a rigid structure. Target value for dynamic stiffness ratio is set in the range of 5-10 times the isolator stiffness based on application of the machinery. If the dynamic stiffness at mount locations meets the target value, most of the structural vibration energy gets absorbed by the isolator and vibrations will not pass into the cab.

Figure 4: FE model of tractor cab and global co-ordinates direction

Dynamic stiffness plots

Dynamic stiffness analysis is carried out at all mount locations in all three mutually perpendicular directions of mounts alignment and compared with target value. Dynamic stiffness curves meet the target value in all cases except the cases as shown in Figure 5 and Figure 6.

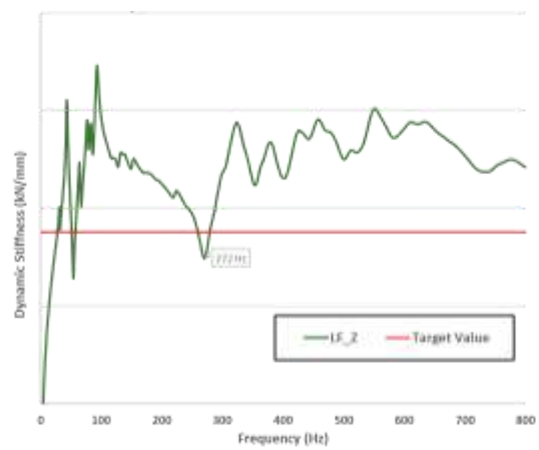

Figure 5: Dynamic stiffness results at LF in Z- Direction

Figure 6: Dynamic stiffness results at LR in Z- Direction

Dynamic stiffness at left and right mount locations shows a remarkable similarity due to a symmetric nature of the model. X-direction represents the fore-aft direction of cab, Y-direction represents the lateral and Z-direction is vertical direction of cab. From the dynamic stiffness plots in Figure 5 and Figure 6, one can conclude that the dynamic stiffness values are low at left front mount in Z-Direction at 272 Hz and it does not meet the target value. Similarly, it does not meet the target value at left rear mount in lateral directions at 206 Hz.

Strategies for Design Considerations at Front Mounts

Let's consider the frequency corresponding to a trough in dynamic stiffness curve as a critical frequency where it has a lower dynamic stiffness below the target value. To improve the dynamic stiffness at critical frequencies, one should look at the mode shape and strain energies. The mode shape and corresponding strain energy for the mode at 272 Hz is shown in Figure 7 and **Error! Reference source not found.**. These plots provide a direction for engineers to modify the structure to enhance the stiffness at critical frequencies.

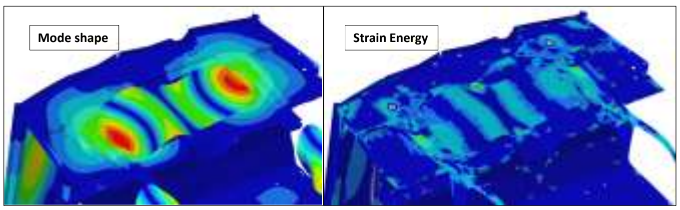

Figure 7: Mode shape and strain energy at 272 Hz at near front mount locations

By looking at mode shapes and strain energies, one can conclude that the tube structures and plate on floor have a mode and more strain energy is accumulated on the same components. Increasing the thickness of the tube structures certainly help to improve the bending stiffness and shift the critical frequency away from it. Similarly, increasing the thickness of same steel plate or using stiffer plate can help to increase the bending stiffness of plate and hence dynamic stiffness at 272 Hz.

Sensitivity Of Dynamic Stiffness to Design Alterations

The design changes have been driven from modal results as described. Dynamic stiffness analysis is performed on some of the design iterations as shown in following Figure 8.

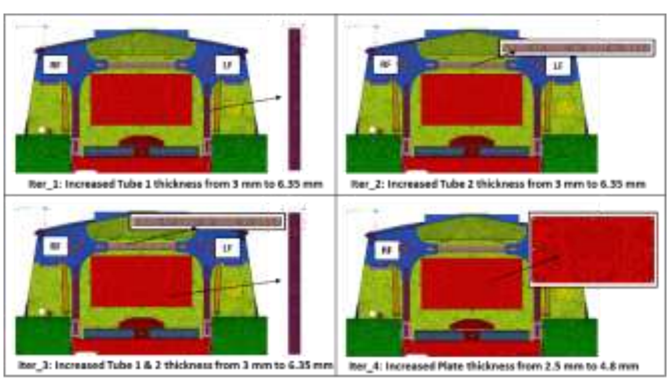

Figure 8: Design Iterations near front mount locations

Dynamic stiffness analysis is performed for all design iterations and compared with baseline model as shown in Figure 9.

Figure 9: Dynamis stiffness results for design iterations near front mounts and comparison with baseline model

All design iterations help to improve the dynamic stiffness results at critical frequency. However, the design iterations 1,2 and 3 do not meeting the target value. Design iteration 4 looks to be much stiffer than other cases and meets the target value.

Strategies for Design Considerations at Rear Mounts

Dynamic stiffness at rear mount location is estimated by taking the displacement response. These values are below the target value at 206 Hz in lateral direction. Modal results and element strain energy is also calculated at 206 Hz as shown in Figure 10.

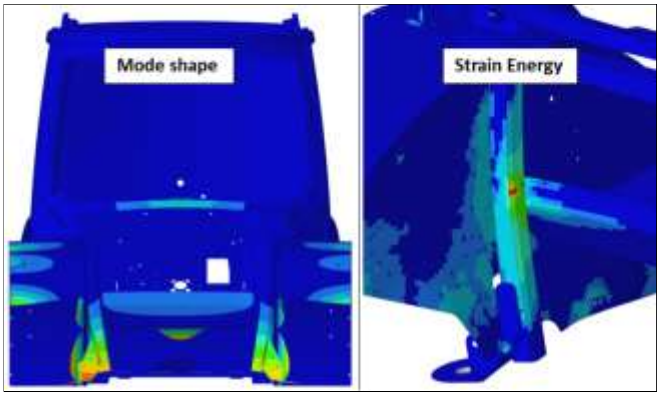

Figure 10: Mode shape & strain energy at 206 Hz at near rear mount locations

Rear vertical tubes have a mode in lateral direction showing out of phase flapping at 206 Hz. Long vertical tube structures are designed to align the large diameter of the tractor wheel and space constraints at the rear side. Flapping modes of vertical tubes are expected due to limited support or constraints on the edge towards mounts. Strain energy is accumulated at the junction of bending point, where it needs more support. Gussets can be added here to provide additional stiffness to the bending tube structure and in overall it helps to improve dynamic stiffness at rear mount locations. Increasing the thickness of tube structure may also help to increase the bending stiffness.

Sensitivity Of Dynamic Stiffness to Design Alterations

The design alterations find their roots in modal results and the insights gained from strain energy calculations as elucidated. Dynamic stiffness analysis is performed on some of the design iterations as shown in following Figure 11.

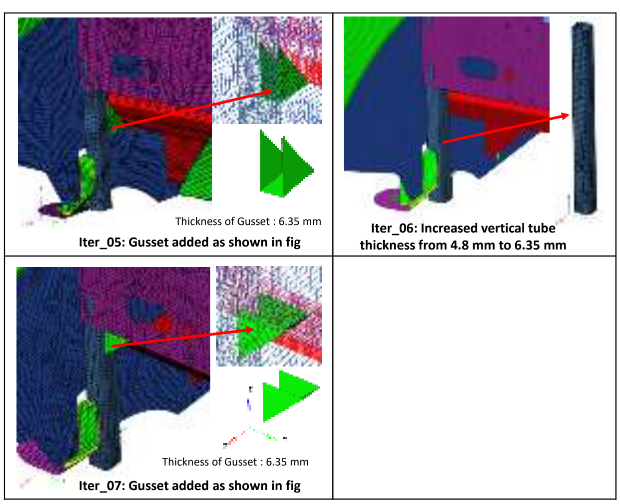

Figure 11: Design Iterations near rear mount locations

Dynamic stiffness analysis is performed for all design iterations and compared with baseline model as shown in

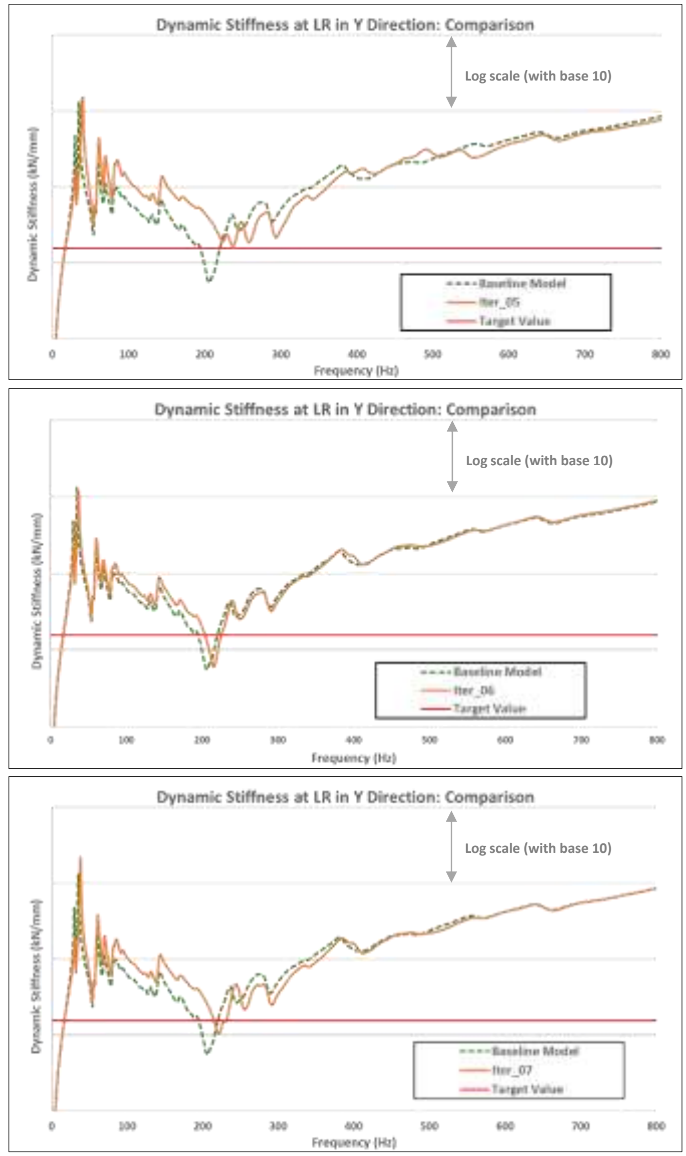

Figure 12: Dynamis stiffness results for design iterations near rear mounts and comparison with baseline model

All design iterations help to improve the dynamic stiffness results at critical frequency. However, the improved values for design iterations 2 and 3 do not meet the target value. Increasing thickness of tube increases the bending stiffness of structure but it also increases the mass which does not help to shift the natural frequency. Design iteration 1 is looks much stiffer than other cases and meets the target value. It creates a constraint for vertical tube structure with floor plate and restricts the flapping mode. Practically, using such large thickness of tube weldment may not be feasible. But the analysis provides a direction to modify the structure in such a way that it increases the overall stiffness at mount brackets and meets the target value.

Conclusions

This paper demonstrated a comprehensive analysis for dynamic stiffness evaluation carried out through modal analysis, employing finite element method. It sheds light on the intricate dynamics of mounting brackets, providing valuable insights into vibration response and resonant frequencies. By considering space constraints at mount locations due to components, wiring harnesses, and structural considerations, this study delves into the practical suggestions to improve dynamic stiffness analysis to meet the target value. The systematic variation of parameters such as material properties like thickness, shape, and addition of gusset in the geometry reveals the nuanced sensitivity of dynamic stiffness to design alterations. It provides a clear path to develop effective isolation system for a cab.

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Definitions/Abbreviations

LF	Left Front mount location
RF	Right Front mount location
LR	Left Rear mount location
RR	Right Rear mount location
ROPS	Roll Over Protective Structure
FEA	Finite Element Analysis
M	Mass Matrix
F	Dynamic Load
K	Stiffness Matrix
C	Damping Matrix
K_C	Cab mounting stiffness
K_i	Isolator stiffness
K_F	Chassis frame stiffness