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ANALYSIS OF GROUND VEHICLE GUN MOUNT LOADS AND STRESS DURING GUN FIRE IMPULSE USING A SYSTEM MODEL WITH FLEXIBLE BODIES

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ABSTRACT

A detailed methodology employing a system model of a tracked vehicle with a gun turret is used to analyze the stresses and loads applied to the gun mount as a result of gun firing events. The vehicle system model combines a Virtual Lab.Motion model of the tracked vehicle and gun mount which includes track super element, flexible gun mount body, and a beam element representation of the gun and gun tube sleeve coupled with a MATLAB/Simulink model of the hydraulic/pneumatic recoil system and gun pointing control system. This coupled system model with flexible components is needed for this analysis to determine the portion of the impulse that results in gun mount deformation. A brief overview of the vehicle system model, a detailed description of the gun mount model, and analysis of the gun mount loads and stress is included.

INTRODUCTION

A weapon firing stability model coupled with the gun pointing control system model is heavily utilized during the design and development of a self-propelled howitzer [1-2]. This model simulates system dynamics that result from an applied gun firing impulse. The control system (elevation and traverse drives), vehicle suspension, hydraulic/pneumatic recoil system, and the mechanical component interaction are included in this model. Specific analyses performed with this model include; fatigue analysis, robust design, prediction of worst case component loads and stress, gun pointing control development, and design optimization.

Many of the previously mentioned analyses require multiple simulations. Thus, faster simulation times are beneficial to completing the analysis in a reasonable amount of time. However, achieving a fast simulation time with a model that includes a large number of sub-systems is challenging. Utilizing simplified sub-system models can achieve this, but may result in a loss in model accuracy. The focus of this paper is a methodology for stress analysis of the gun mount component that utilizes simplified components in the system model and can be solved quickly without a significant loss in accuracy.

Ideally, the gun mount stress analysis would be included in the firing stability model because the stress is the result of reaction forces that interact with the system and body accelerations. Finite element analysis will significantly decrease the simulation speed of the firing stability analysis when coupled to the system, however. For this reason, the firing stability model typically includes a rigid body representation of the gun mount and a decoupled finite element model of the gun mount used for stress analysis. This modeling approach is less accurate but will solve significantly faster.

The pseudo-coupled approach, outlined in this paper, will lead to more accurate stress analysis results and a reasonably fast solution time. This method utilizes the firing stability model with simplified representations of flexible components to compute gun mount reaction loads. These reaction loads are the input to a separate stress analysis model of the gun mount. An assessment of the accuracy of this method includes an analysis of system modes, component modes, and the frequency content of the component reaction forces and body accelerations.

The pseudo-coupled gun mount stress analysis methodology is outlined in this paper. An overview of how to predict gun mount loads from a firing impulse is described first. A description of the gun pointing control and firing stability model that is used for this analysis is presented next. Then, the pseudo-coupled method for analyzing the gun mount stress is described. Finally, an assessment of the accuracy of using this method is discussed, as well as a brief overview of other methods that could be utilized for this type of analysis.

MODEL EXAMPLE GEOMETRY

A generic model of a self-propelled howitzer, which is shown in Figure 1, was used to demonstrate the methodology outlined in this paper.

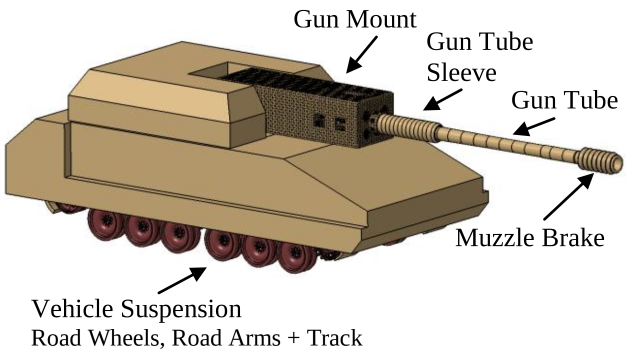


Figure 1: Generic Model of a Self Propelled Howitzer

FIRING STABILITY ANALYSIS FOR COMUPUTING GUN MOUNT REACTION FORCES

When the gun is fired on a self-propelled howitzer, an impulse is applied to the system as a pressure or force in the breech (located at the back end of the gun tube). The system will absorb all of this impulse. Thus, the summation of the system response impulses will equal the applied firing impulse. The system response impulse includes impulses from the hydraulic/pneumatic recoil system, muzzle brake, vehicle motion, suspension/track deformation, component deformation, and friction. The hydraulic/pneumatic recoil system and muzzle brake are designed to absorb large portions of this impulse. Vehicle motion after a firing impulse is limited by design in order to limit vehicle crew acceleration and because vehicle motion may affect gun pointing accuracy. Component deformation is also limited by design to improve gun pointing accuracy and to prevent component fatigue or failures due to excessive stress. Figure 2 illustrates typical proportions of the impulses for the applied and system response during gun fire.

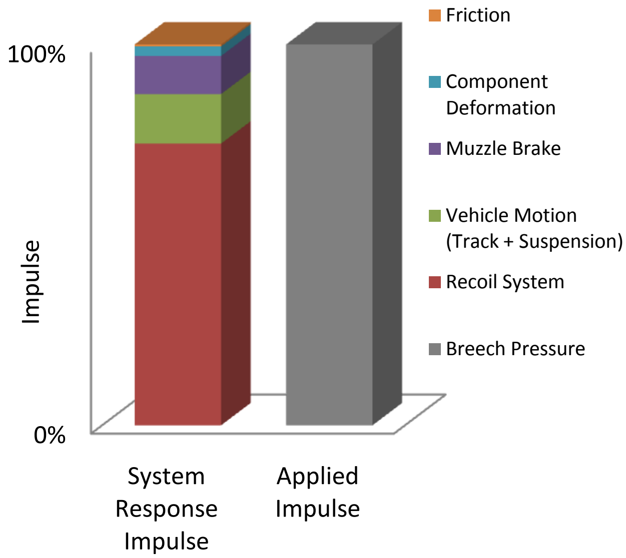


Figure 2: Typical System Response and Applied Impulse Proportions

These proportions are typical, but may vary based on the system design and firing conditions.

The subsystems and components, which contribute significantly to the system response impulse should be coupled in the analysis model because there is significant interaction. If one of these subsystem models is not coupled to the system model, the proportion of the system response impulse from the other subsystems could be artificially increased or decreased. This could lead to inaccurate analysis results. Thus, coupling the muzzle brake, hydraulic pneumatic recoil system, vehicle suspension, and flexible mechanical component models in the firing stability model will improve model accuracy. Additionally, coupling the gun pointing control system will also improve firing stability model accuracy because the components in this system may apply significant transient loads to the system during gun fire.

The firing stability model detailed in the next section of this report provides a high enough level of fidelity to accurately predict the portion of the impulse due to gun mount deformation for an accurate prediction gun mount reaction forces during gun fire.

MODEL DESCRIPTION

The firing stability and gun pointing control model developed by BAE Systems includes coupled subsystem and component models that can accurately predict the dynamic system response from a firing impulse. The model includes an LMS Virtual Lab.Motion (VL Motion) multi-body tracked vehicle model, coupled with a Mathworks MATLAB/Simulink /Stateflow gun pointing control model and a Mathworks MATLAB/Simulink hydraulic/pneumatic recoil model. The topology of this model is shown in Figure 3.

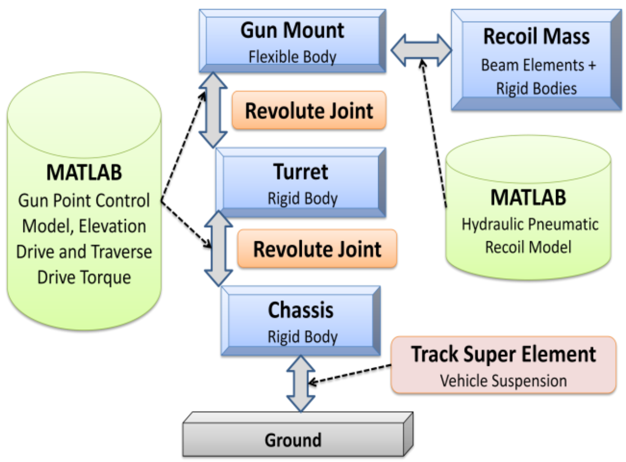


Figure 3: Topology of Coupled Gun Pointing Control and Firing Stability Model

The four main bodies in the plant model are the chassis, turret, gun mount, and recoiling mass. The VL Motion track super-element is used to model the road arms, road wheels, and track interaction with a soil model [3]. A hydraulic/pneumatic recoil simulation model computes the recoil force which is applied between the recoiling mass and the gun mount to resist the gun tube ballistic force and to return the recoiling mass back to battery position. Elevation drive forces and traverse drive torque, which point the weapon and actively stabilize the gun during gun firing, are computed in a gun pointing control model and applied to the gun mount, turret, and chassis. The elevation drive, and turret top plate compliance are incorporated through equivalent drive stiffness. The equilibrator is included in the multi-body tracked vehicle model and applies force between the gun mount and turret. The chassis and turret bodies in the multi-body vehicle model are assumed rigid. The gun tube, gun tube sleeve, and gun mount can be represented as flexible or rigid bodies. A design table included in the VL Motion model is used to select the model configuration which utilizes rigid or flexible bodies for these components, is dependent on the type of analysis being performed.

When analyzing gun mount reaction forces, flexible bodies are use to represent the gun mount, gun tube sleeve, and gun tube in the firing stability model. Beam elements connecting several rigid bodies are used to model the gun tube and gun tube sleeve components. The gun mount is modeled as a Craig-Bampton mode set computed from a meshed finite element model of the solid body with the LMS Virtual Lab Component Structural Analysis tool [4-5]. These flexible components are shown in Figure 4.

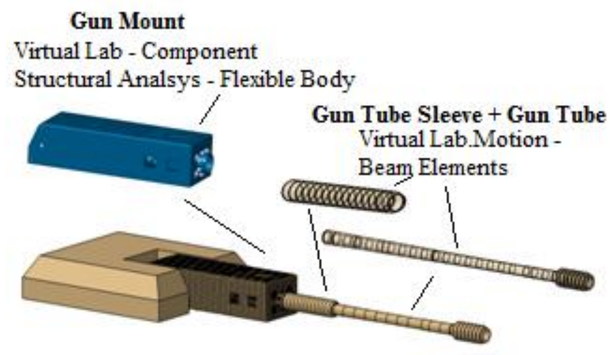


Figure 4: Firing Stability Model Flexible Components

FLEXIBLE COMPONENT MODEL DETAILS

The beam element parameters and the number of rigid bodies used to model the gun tube and gun tube sleeve are chosen carefully in order to ensure that they are capable of accurately predicting transient dynamics. The section and material properties of each beam element match the geometry and material properties used in the design. Each section has a torsional, axial, and bending stiffness. The number of beam elements used is selected such that the mode shapes and frequencies are accurately predicted. A comparison of component frequency results computed with the linearization tool in VL Motion with results from frequency analysis performed with separate finite element models of the components can be performed to verify this.

The accuracy of the gun mount flexible body is investigated with a study of the modal participation factors of the frequency modes used in the Craig-Bampton mode set which represent this body in the firing stability model. The sum of the modal participation factors must be high enough to ensure accuracy of the transient dynamic analysis performed with this body [6]. All selected frequency modes in a modal reduction set are artificially stiffened to compensate for the unselected modes. If too few modes are selected, then the dynamic response predicted with the model will not be meaningful due to the large amount of inaccuracy. However, if too many modes are selected, the model will be inefficient and may have an unnecessarily long solution time. Thus, the number of frequency modes included in the Craig-Bampton set should be no larger than the amount required for reasonably accurate results.

Similarly, the size of the meshed elements in the gun mount body should not be larger than needed to accurately represent the highest mode in the Craig-Bampton mode set. Although a large number of elements will not directly affect the analysis solution time, the post and pre-processing time required to update the flexible database and the amount of memory allocated the model is affected by the size of the mesh. The gun mount mesh used in firing stability model is only used to determine the mode sets. Therefore, it does not need to be optimized for stress analysis.

The meshed gun mount body is integrated to the firing stability model with interface nodes. A meshed gun mount with interface nodes is shown in Figure 5.

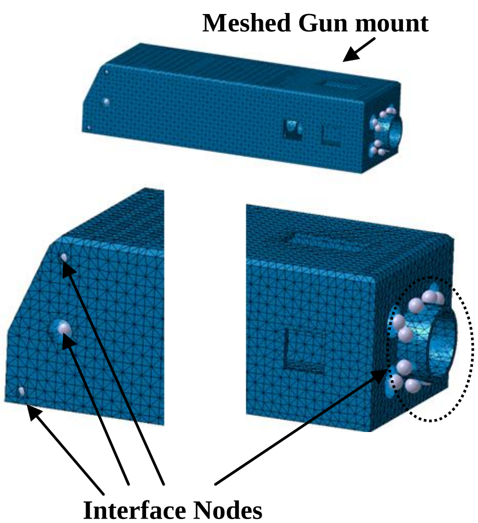


Figure 5: Meshed Gun Mount with Interface Nodes

Each interface node is connected to a surface on the gun mount with several rigid beam elements. If these rigid connector elements affect the modal analysis results of the component significantly, then the surfaces which they connect to can be partitioned in order to minimize the amount of analysis error. A comparison of modal analysis results with a different number of interface nodes and partitioned surfaces can be performed in order to determine the number of interface nodes needed for the required accuracy of the analysis.

PSEUDO-COUPLED GUN MOUNT STRESS ANALYSIS

An outline of the procedure for performing the pseudo-coupled stress analysis of the gun mount during gun fire is shown in Figure 6.

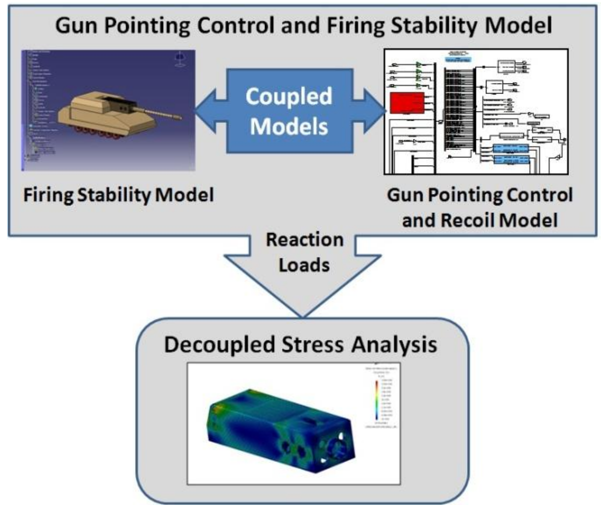


Figure 6: Procedure for Pseudo-Coupled Gun Mount Stress Analysis

The reaction loads or relative displacements located at the interface nodes, computed with the coupled gun pointing control and firing stability model, are applied to a separate model for stress analysis. The location of the interface nodes must be identical for the stress analysis mesh and the flexible gun mount mesh used in the firing stability model. The solid body mesh, however, may be different for each model.

The independent mesh sizes and the separate stress analysis model lead to several advantages in the analysis process. The biggest advantage is that the firing stability model does not solve a coupled finite element stress analysis. Thus, the solution time is much faster. In addition, the time period analyzed for gun mount stress may be different than the system model. This allows the gun mount stress analysis to focus on time periods or instants which are known to produce the highest stress, rather than the time period required for other analysis done with the system model. Another advantage is that analysis iterations performed to determine the optimal mesh size for stress can be done independent from the system model.

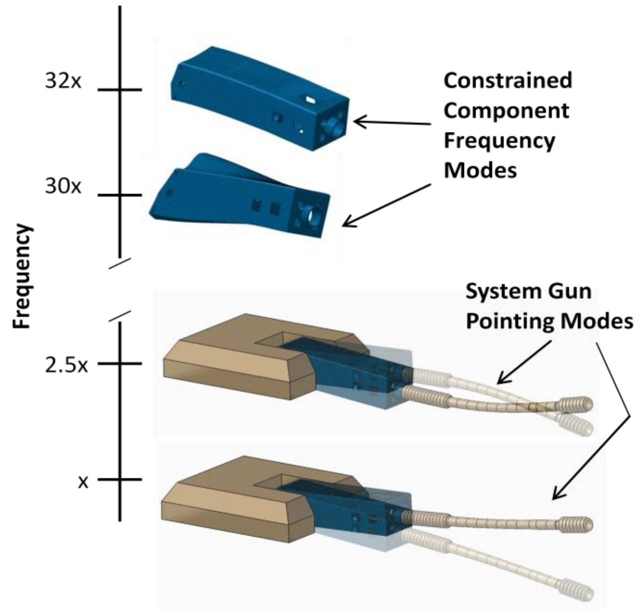
ASSESMENT OF PSEUDO-COUPLED GUN MOUNT STRESS ANALYSIS ACCURACY

The pseudo-coupled stress analysis method is reasonably accurate when analyzing the gun mount component because this component has a relatively high stiffness when compared to the frequency content of the body accelerations and reaction forces analyzed. The lowest constrained component mode of the gun mount is significantly higher than the frequency content of the reaction loads and body accelerations typically analyzed during a firing impulse. Because of this, the reaction loads from body accelerations are represented in the separate finite element model proposed in the pseudo-coupled analysis method.

A study of the frequency content of the constrained gun mount modes, system modes, reaction force, and body accelerations will determine if this assumption is valid. Two assessments are proposed for this study. The first is to compare the frequencies of the constrained gun mount modes with the system gun pointing modes. The results from this analysis will indicate if the pseudo-coupled stress analyses will likely be accurate and will provide insight as to whether this may be valid for a wide range of conditions. A more rigorous second assessment is an analysis of the frequency content of the gun mount body accelerations and reaction loads derived from firing stability analysis cases. The accuracy of the pseudo-coupled analysis method for specific analysis cases can be evaluated with these results.

The first assessment is a comparison of the constrained gun mount frequency modes with the gun pointing system modes. All of the system modes of the self propelled howitzer are excited by the breech pressure impulse. Typically, the largest gun mount reaction force amplitudes occur at the frequencies of the lowest few gun pointing system modes. If the lowest constrained frequency mode of the gun mount component is significantly larger than the lowest system gun pointing modes, then it is reasonable to expect the frequency content of the reaction loads on the gun mount component to be significantly less than the lowest constrained gun mount mode.

The system linearization tool in VL Motion can be used to compute the system modes in the firing stability model. Some of the system gun pointing modes and constrained gun mount component frequency modes for the example model are shown in Figure 6.



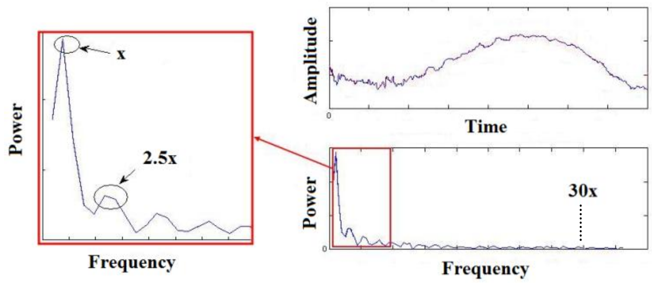
(x is the frequency of the first gun pointing mode)

Figure 6: System Gun Pointing Modes and Constrained Frequency Modes of Gun Mount

For this case, the pseudo-coupled method would probably be accurate because the frequency content of the applied reaction loads will likely be significantly lower than the lowest constrained frequency mode of the gun mount.

Although this assessment does not provide a definitive conclusion as to whether the pseudo-coupled stress analysis will be accurate, it is relatively easy to perform and provides meaningful results which may be used to identify an expectation for the accuracy of this method over a large range of conditions. This assessment may also be used to identify other components which may be considered for stress analysis with the proposed decoupled method.

The second assessment includes an analysis of the frequency content of the gun mount reaction loads and body accelerations derived from specific firing stability analysis cases. The time history data of the reaction forces at each interface node are used for this study. If the frequency content of the reaction forces is significantly less than the lowest constrained frequency mode of the gun mount, then the pseudo-coupled stress analysis results will likely be accurate. Some example results of transient force at an interface node from a firing stability analysis are shown in Figure 7.



(x is the frequency of the first gun pointing mode)

Figure 7: Node Reaction Force from a Firing Stability Analysis in Frequency and Time Domain

A Fast Fourier Transform (FFT) is used to analyze the frequency content for this example. For this case, the pseudo-coupled method would lead to reasonably accurate results. Note that the majority of the frequency content of the reaction force is well below the lowest gun mount constrained frequency mode which is identified at "30x" in the plot. Also, note the large power in the FFT at the gun pointing system modes which are labeled as "x" and "2.5x", which is consistent with the prediction made in the first assessment. Some reaction force frequency content does exist above the "30x" value and will be neglected in the stress analysis. The loss in accuracy for this case would be minimal. Engineering judgment or a comparison with transient results should be used to determine if this loss in accuracy is acceptable. All of the interface nodes as well as the body accelerations should be analyzed in this manner before making a conclusion that the pseudo-coupled method will provide a reasonable level of accuracy for stress analysis.

The pseudo-coupled method will not provide accurate stress analysis results for any analysis case that has body acceleration frequency content above the frequency of the lowest constrained gun mount mode. For other cases, this method method requires either a static or a transient solution for accurate results. The type of analysis required is problem specific. If the reaction force frequency content is above the frequency of the lowest constrained gun mount mode, then the finite element model should be solved with a transient solution for accurate results. Otherwise, reasonable results will be attained with static stress analysis.

For analysis cases with relatively high gun mount component acceleration frequency content, a more advanced method must be used for the stress analysis of the gun mount because the pseudo-coupled stress analysis method does not account for component accelerations that are a higher frequency than the constrained component modes. A brief discussion of some advanced stress analysis techniques that could be used to for stress analysis for the gun mount in such cases is included in the next section of this paper.

OTHER METHODS FOR STRESS ANALYSIS OF GUN MOUNT

If the frequency content of the gun mount component acceleration is higher than the lowest constrained frequency of the gun mount, then the accelerations must be applied to the decoupled stress analysis model. The pseudo-coupled stress analysis proposed in this paper is not capable of doing this. Therefore, a more advanced technique would be required. One technique is to apply the Craig-Bampton mode accelerations measured in the firing stability model to a separate stress recovery model [7]. A second technique is the hybrid superposition method [8], which combines static finite element analysis with modal accelerations using linear superposition.

SUMMARY

A methodology for analyzing gun mount stress using the results from a gun pointing control and firing stability analysis was presented in this paper. Flexible components, which are capable of accurately predicting the dynamic response of a firing impulse load, must be included in the firing stability model in order to perform this analysis. A relatively simple method of applying the interface reaction forces to a separate finite element model of the gun mount can often be utilized for this analysis because the gun mount is stiff relative to the system stiffness. This method is a great benefit to the analysis of gun mount stress resulting from a firing impulse because it does not add significantly to the solution time of the firing stability model. However, a rigorous assessment of the frequency content of component reaction loads, and body acceleration measured with the analysis cases and a modal analysis of the constrained gun mount is required in order to determine if this method will provide reasonably accurate results.

ACKNOWLEDGEMENTS

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