

Virtual Prototyping in Redesign and Durability Test Assessment

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ABSTRACT

The durability of a new cost saving frame for the E-Z-GO ST 4X4 utility vehicle is investigated based on known road test data and durability information for the current frame. To validate the concept of the frame redesign, reduce the number of prototypes, shorten test duration and save lab costs, virtual prototyping is applied.

Road test data is acquired and processed by nCode software including rainflow cycle counting with different turning points for fatigue estimation. FEA structure analysis is processed in ANSYS. Optimization analysis is used for correlating real road load with simplified FEA model for the entire vehicle. Based on the correlated FEA model, the estimation of the durability for the current frame and redesigned frame is conducted. Results of both, the stress analysis under peak load and the fatigue prediction for vehicle riding history, are used for relative comparison between the new frame and current design.

Fatigue life distribution has been investigated, and possible failure areas have been diagnosed. Fatigue estimation with constant load tests is conducted and is correlated with the predicted life based on compressed cycling loading data. An acceleration test assessment, applying a constant step load, is suggested. An accelerated durability test is conducted to validate the redesign based on the durability assessment instead of a formal four-poster test.

Static structure analysis, DOE and fatigue estimation are applied to the reliability investigation and to acquire a satisfactory result on both of frame durability and acceleration test settings. Virtual prototyping not only improves redesign, but also saves time and reduces the cost of redesign verification.

INTRODUCTION

Working to reduce R&D and manufacturing cost, while maintaining vehicle reliability, is one of the primary goals

and is also a big challenge. To meet both of cost and reliability targets, virtual prototyping is a powerful tool.

The E-Z-GO ST 4X4 utility vehicle is designed to handle heavy payloads and rough terrain. The current heavy duty tube frame has an 8° bend angle near the shock tower and numerous components in upper A-Frame area. Although the current frame works very well, the bending procedure and number of components increase the cost. The new design concept eliminates the bending process and reduces the number of frame components. Because this change results in different load distribution, the frame structure must be redesigned. To validate the new design, virtual prototyping is applied. Relative comparison methodology is applied since the current frame performs well under heavy loads.

The virtual prototyping in this study includes three steps: First is to correlate the test data with a simplified FEA model for the current frame by optimization analysis using to acquired strain data; Second, is to apply correlated loads and processed load time history to the new design and to confirm that the redesign is better than current frame; Third, is to set an acceleration test assessment for durability. The assessment tests the frame with an equivalent constant load instead of using four-poster test instrumentation for the entire vehicle, which is a time consuming and expensive procedure.

Structure static analysis with optimization is completed in ANSYS, test data processing and fatigue prediction is completed with nCode software.

MAIN SECTION

As described in the introduction, the 8° bend in current heavy duty tube frame will be eliminated, as well as some components. Based on the new concept and the changes of local load distribution, virtual prototyping is required for the structure redesign and the acceleration test assessment.

To validate the new cost saving frame, testing will proceed in three stages: Correlating the FEA model with test data; Verifying the new design with correlated loads; and Setting the acceleration test assessment.

Figure 1 and 2 below show the E-Z-GO ST4X4 in use.

Figure 1. ST4X4 in Use, A



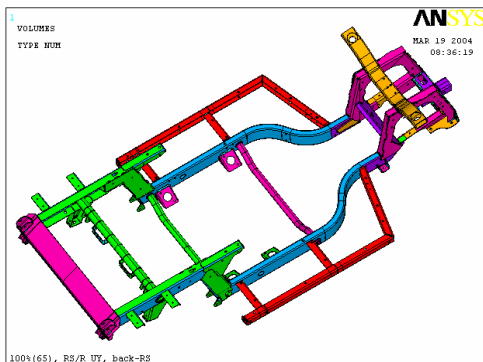
Figure 2. ST4X4 in Use, B



CORRELATING FEA MODEL WITH TEST DATA

Figure 3 shows the ST 4X4 heavy duty tube frame.

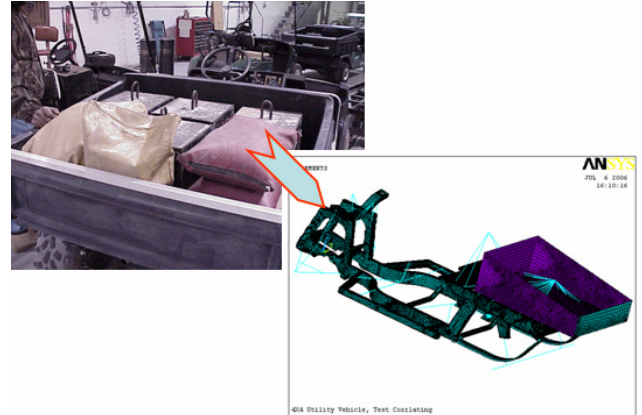
Figure 3. ST4X4 Tube Frame



Modeling an entire vehicle including suspensions is complex and time consuming. Therefore, a simplified FEA model for the vehicle is created first.

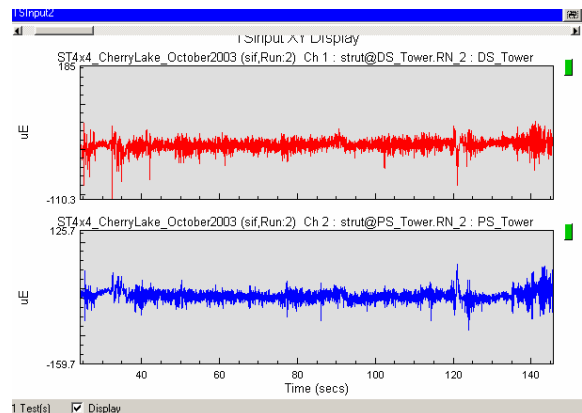
Figure 4 shows the simplified FEA model used for validating the new design and identifying design improvements required for structure strength. The suspensions have been replaced by beam elements and all of the bushing joints have been modeled as revolute joints only. IP load, drive train load, occupant load and cargo load are represented by point mass elements with the exception of the frame mass. Cargo and occupants masses are indicated and will be multiplied by measured G during dynamic test and analysis. Other individual masses are assumed unknown, but their total mass is given.

Figure 4. Simplified FEA Model for Frame Analysis



When the frame is installed, the entire vehicle is simplified. Duplicating the behaviors of the ST 4X4 in 'real-world' applications in the FEA model is a challenge. Determining how to apply proper boundary condition is extremely important in this simplified modeling. When the ST 4X4 is driven at actual work environments, the ground loads transferred to the frame are often different than theoretical prediction. The major issue becomes how to correlate field test data with the FEA model to acquire accurate results for specific frame components and to predict possible failure area. Optimization analysis (OPT) is chosen for this purpose instead of investing the time required to run numerous estimations to get an inexact number.

Figure 5. Strain History – Test Data



The R&D lab installed accelerometer and strain gauges including rosette on specific areas. The test data is used for current frame duration test with four-poster test instrumentation. Figure 5 shows strain history in one area. Figure 6 shows the load history on one axle end. Figure 7 shows the gauge location and final failure spots during testing.

Figure 6. Loading History – Test Data 2

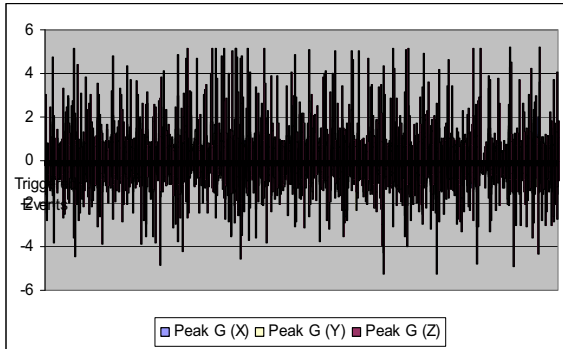
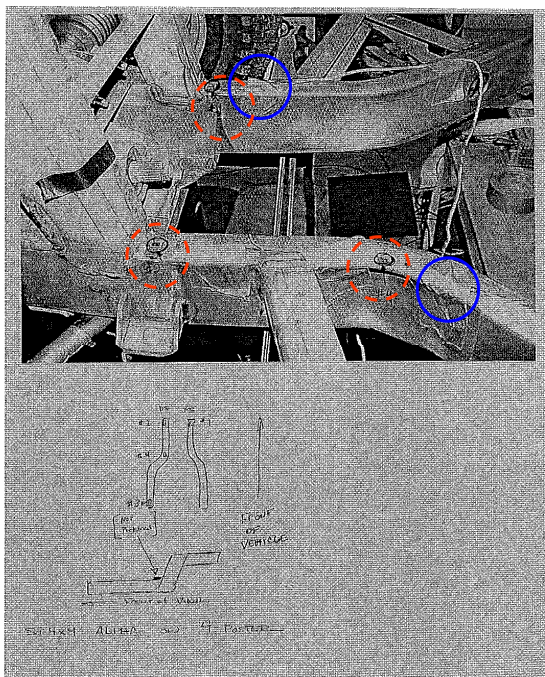


Figure 7. Strain Gauge Setting and Failure Location



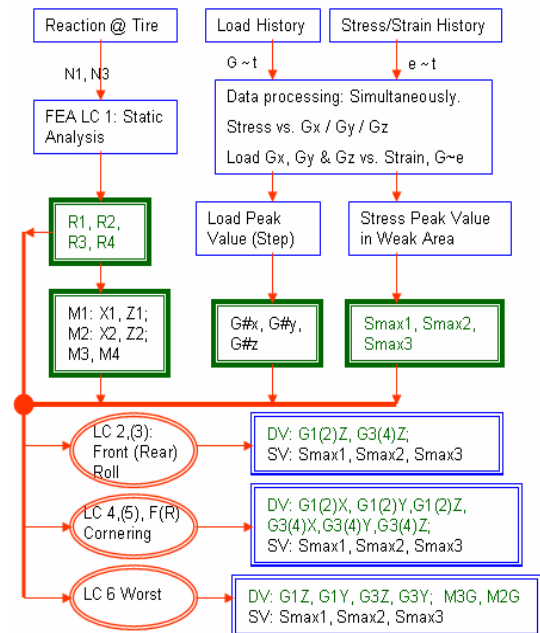
None of the other frame components are changing and the high stress areas in the frame are known. Therefore, the analyzing uses relative comparison between the current and the new design to confirm that the new design is better.

Figure 8 shows the process to correlate the FEA current frame model with field test data. The test data includes both Static and Dynamic Tests.

In the graph, G represents the load along X, Y and Z direction; R represents axle end load at the four axle ends respectively; M represents the mass of the sub-

assembly, which is not modeled in FEA instead being represented by point mass elements; X and Z represent calculated mass point locations; and S represents the peak value of stress in X, Y and Z direction.

Figure 8. FEA Correlating Procedures



Static testing data provides tire reaction forces (identified as R1, R2, R3 and R4) under static status. Lab static testing can also provide a way to figure out mass distributions for the drive train subsystem and IP subsystem including the magnitudes of M1 and M2, and the locations represented by X1, Z1, X2, Z2, where cargo mass, occupant mass and total mass are known. These parameters of M, X, Z can be calculated manually or determined by kinematics model with optimization analysis.

Dynamic testing provides both load time history and strain time history. Load time history is processed and converted to the curves describing the relationship of load Gx, Gy, and Gz with strain; or strain vs. different load respectively. Reviewing acquired converted curves, the peak values of GX, GY and GZ can be found while strain reaches its peak value locally. Combining field driving conditions with such reviews, six load cases, LC 1, 2, 3, 4, 5 & 6 have been determined for correlating test data with FEA simplified model. This procedure can be found in Figure 8 also. Targeted stress or strain and load range are involved in those six load cases for manipulating the vehicle running situation, such as static rolling, braking over bumper, wheeling in pothole, cornering and etc.

To correlate with the test data, strain or stress at frame is set as response variables based on field-test data. Concerned loads, which are set as the product of G and R in X, Y and Z direction and located at the front or rear axle end or the product of M and G located at point mass elements, are set as input factors. OPT is used to