Fig. 1 - Razor Scooter being tested

Fig. 2 - DTS Slice Micro DAQ

Strains and Load reconstruction of two-wheeled Scooters

Cost-effective, efficient method of calculating complex loading on structures

The following article provides a complete evaluation of a 2-wheeled Razor™ Scooter with analysis models and experimental strain measurement. It shows the application of the commercial software True-Load to calculate operating loads from a variety of dynamic loading events. This software leverages the concept of influence coefficients for the purpose of load reconstruction. It includes correlation plots of simulated strain versus measured strain; the simulated strains are derived from the loads calculated from the load reconstruction of the measured strains. The Razor Scooter is an inexpensive children's scooter. The evaluation simulated the X, Y, Z loads at the foot, and X, Y, Z loads and RY moments at the rear wheel. The loading events ranged from static to extreme riding over sidewalk and roadway surfaces.

Problem description

This simulation exercise recovered the loading on the Razor Scooter, purchased from Amazon. The 3D model of the scooter was reverse engineered. A large portion of the instrumentation work was performed by Wolf Star Technologies' intern, DeAngelo Stewart. The data acquisition (DAQ) system used was a 12-channel DTS Slice Micro DAQ. The unit is powered by a small battery. Data is downloaded via USB cable. The strain gauges used were Micro Measurements CEA-XX-250UW-350-P2 strain gauges, which are 0.250-inch gauge length gauges with pre-soldered lead wires. The lead wires were trimmed short and attached to the shielded cabling of the DAQ system to minimize external electronic noise.

Unit Loads

The unit loads for the Razor Scooter were created in a Finite Element Analysis (FEA) model. The unit loads were applied at the foot contact point (FX, FY, FZ), the rear tire patch (FY, FZ, MY), and the center of the rear axle (FX). The bottom of the steering stem was fixed in three-degrees-of-freedom (3DOF). The top of the steering stem was fixed in two-degrees-of-freedom (2DOF). The 2DOF at the top are the radial DOF.

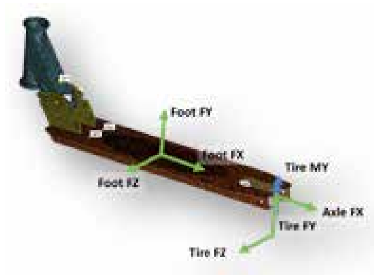

Fig. 4 - FEA Unit Loads

A coordinate system was created along the axis of the steering stem for the restraints. This coordinate system was also used for the inertial relief. The inertia relief used only the rotation DOF going through the center of the steering stem. The FEA solution Inertia Relief (IRL) was used to eliminate the singularities introduced by insufficient restraints.

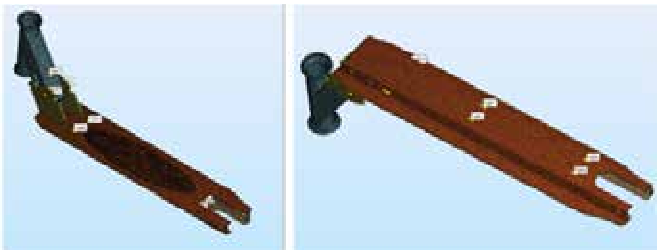

Fig. 5 - Virtual Strain Gauge Placement

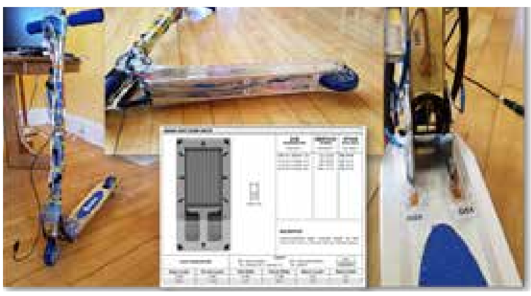

Fig. 3 - Strain Gauge Placement

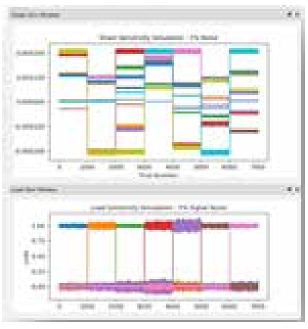

Fig. 6 - Load Sensitivity to Strain Signal Noise

Pre-Test

The True-Load/Pre-Test software was used to leverage the seven, unit load cases and the corresponding strain results from the FEA model. The final strain gauge placement is shown in Figure 5.

An important phenomena to understand is the stability of the correlation matrix. The True-Load software provides a utility that calcuates the ideal strain for each unit load case and then applies a 5% random signal noise to the idealized strain. These strain signals are then multiplied by the correlation matrix to determine

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the corresponding load response. Ideally, each load should be turned on one-by-one and the other loads would be turned off. The plot in Figure 6 shows the load sensitivty to strain noise for this configuration of gauges. This plot shows that the system of gauges chosen produced a very stable system of load reconstruction that could tolerate noise in the strain signals.

Strain Gauge Application

A series of drawings was created to locate the strain gauges on the physical structure. These drawings were then used to place the gauges on the physical part using calipers and other measurement techniques.

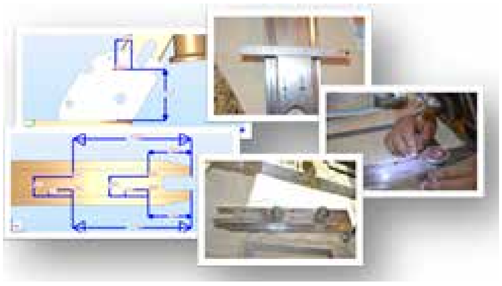

Fig. 7 - Strain Gauge Installation

Test-Data Collection

Once the scooter had been fully instrumented, the strain gauges were connected to the DTS Slice Micro DAQ system. The strain data was sampled at 1000 samples per second. The data collection was performed under normal operation on a variety of surfaces. A typical trace of strain data is shown below.

Fig. 8 - DAQ used for Strain Data Collection

Post-Test

Once the strain data had been collected, it was processed to reconstruct the loading applied to the system. This was done by multiplying the measured strain data by the correlation matrix extracted from the FEA model (Figure 9). The result was a time history of the loading scale factors for each of the loads applied to the scooter (Figure 10).

The True-Load/Post-Test software was used to perform this load reconstruction. In addition to the load reconstruction, several automatic post-processing tasks were performed. This produced an HTML report that contained plots of the reconstructed loads and a set of plots showing the measured strain and the simulated strain from the reconstructed loads at the strain gauge locations in the FEA model. These measured/simulated strain plots were summarized in an overall plot of the simulated strain (blue) and the measured strain (green). A cross plot of the simulated vs the measured strain was produced by the Post-Test software. Ideally this should be (and was) a perfectly straight line along a 45-degree angle (Figure 11).

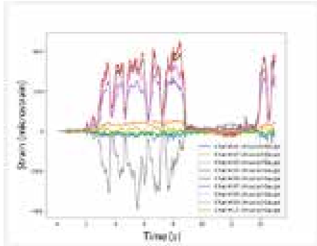

Fig. 9 - Typical Strain Traces from Test

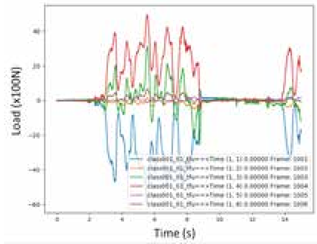

Fig. 10 - Reconstructed Loads

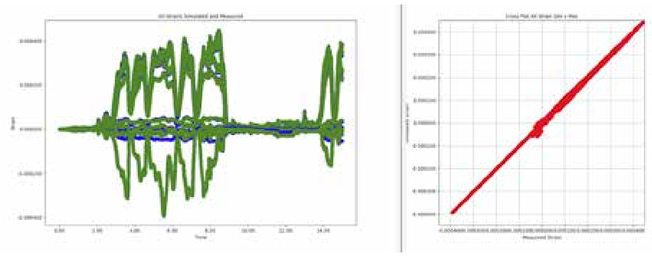

Fig. 11 - Overall Strain Correlation Plot

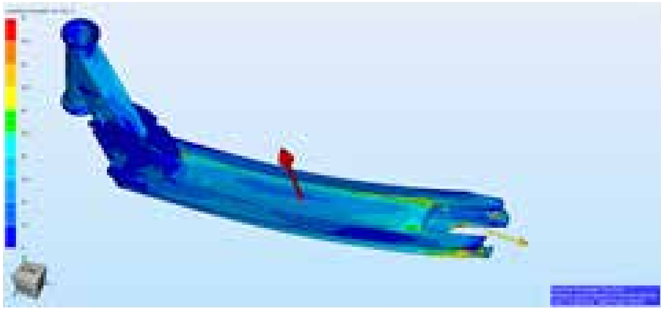

Fig. 12 - Typical Frame from a Reconstructed Operating Deflection Shape

Post-Processing

Once confidence in the reconstructed loads was acquired, the detailed post-processing of the FEA model could be performed. Having a complete time history of the loads, it was possible to construct the operating deflection shapes of the entire scooter utilizing the time history of loading and the FEA model. Figure 12 shows a typical frame plot from an operating deflection shape on the scooter.

Conclusion

This article has shown that complex, nonlinear loading on a structure can be recovered with very high accuracy. The loading DOF were sufficiently complex (FX, FY, FZ at the foot, FX at axle, FY, FZ, MY at the tire patch) to make this a non-trivial problem. If traditional load measurement techniques had been deployed, the scooter would have been rendered inoperable. A 3DOF load transducer could perhaps be reasonably applied at the foot location. However, extracting the 4 loading DOF on the rear wheel would have required removing the wheel and replacing it with other load transducers, thus rendering the device inoperable. With moderate skill and test plan processes, strain gauges can be efficiently placed on the structure to back-calculate virtually any load that can be conceived by the FEA analyst. The cost to calculate these loads consists of two uniaxial strain gauges per loading DOF, which is approximately $20. Consequently, this is a highly cost-effective and efficient process for determining complex loading on structures.

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For more details on the True-Load software:
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