Microwave Interrogation of Woven Straps under Light Loading for Inflatable Applications

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ABSTRACT

NASA uses woven straps for restraint layers in inflatable structures. This work investigates the use of microwaves to measure low level loading in the woven straps. More specifically, microwaves from a linearly polarized antenna are used to investigate four straps composed of Vectran and Kevlar with ratings of 6,000 lbs and 12,000 lbs of force. The straps are all lightly loaded from 2kg to 10kg in 2kg increments. The spectral centroid (SC) technique has been used for the dimensionality reduction method to evaluate the microwave data. The SC method was used to reduce the data from 10001 points to a single point that corresponds to the amount of load on the strap.

1 BACKGROUND

This initial work supports an ongoing project to integrate sensors for real-time nondestructive evaluation (NDE) of woven restraint straps within inflatable structures. NASA's NextSTEP* A: Habitation Systems program is developing light weight inflatable structures [1]. This effort addresses both NASA's 2020 Technology Taxonomy roadmap, section TX12.2.1 Lightweight Concepts, and section TX08.3.5 Electromagnetic Wave-Based Sensors [2] by investigating the use of microwaves to detect load changes in woven straps used for the restraint layer within inflatable structures.

The proposed technique takes advantage of the change in the relative permittivity and thickness of the strap as the loading is changed. As reported in previous work where metallic antennas are placed on different fabrics, "when stretched, the permittivity and the thickness of the fabric change and as a result the resonant frequency changes" [3]. It is hypothesized that permittivity and thickness changes from loaded restraint layer straps will produce similar spectral shifts as a function of the load that is applied. Determination of the spectral centroid (SC) of signals observed in the frequency spectrum data from microwave sensing applications has been demonstrated to aid in measuring relatively small spectral shift [4]. This work explores the results of applying the SC post-processing method to the reflected EM response data of woven straps for use as restraint layer in inflatable structures.

2 EXPERIMENTAL SETUP

The strap monitoring system consists of a frame that holds a hanging strap with a bracket on the end to enable attachment of weights. For each test, weights were added from 2kg to 10kg in 2kg increments. The straps are 25.4mm wide, 250mm long, and have thicknesses of 1.6mm for the 6K straps, and 3.175mm for 12K straps (fig 1). Each strap is interrogated with a linearly polarized, horn antenna positioned 67 mm from the strap, which is connected to a Planar R180 Vector Network Analyzer (VNA) that measures the S_{11} response. The frequency sweep was 12.63 to 12.73 GHz. A metal plate is located behind the strap (in contact) to simulate a conducting layer behind the restraint layer in the inflatable layup. The antenna system is horizontally polarized with respect to the strap because the EM field oscillations are aligned across the width of the strap. It was experimentally determined that horizontal polarization yields a larger response than parallel polarization.

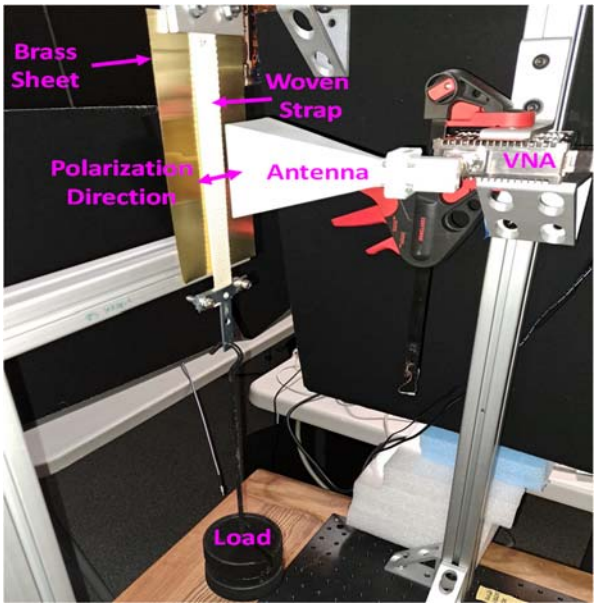


Figure 1. Experimental setup: polarized horn antenna, and network analyzer, woven strap, and metal plate.

3 RESULTS

The electromagnetic response (S_{11}) of four straps, Vectran 6K and 12K, and Kevlar 6K and 12K, all exhibit spectral shifts that decrease in frequency as the load increases. Ten tests were performed for each strap. The SC of the response versus applied load was then fit to a linear equation. The averaged fitted data for the four straps are given in fig. 3~5. The microwave data closely matches the load.

* NextSTEP (Next Space Technologies for Exploration Partnerships)

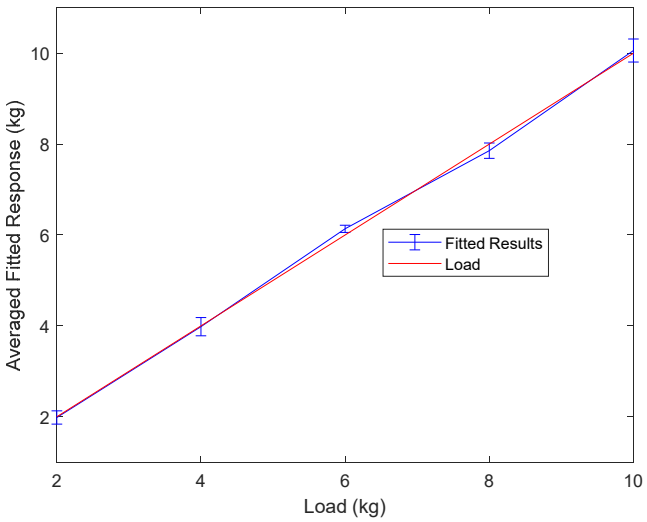


Figure 2. The average fitted spectral centroid of the Vectran 6K strap response, vs. Load. The error bars represent one standard deviation.

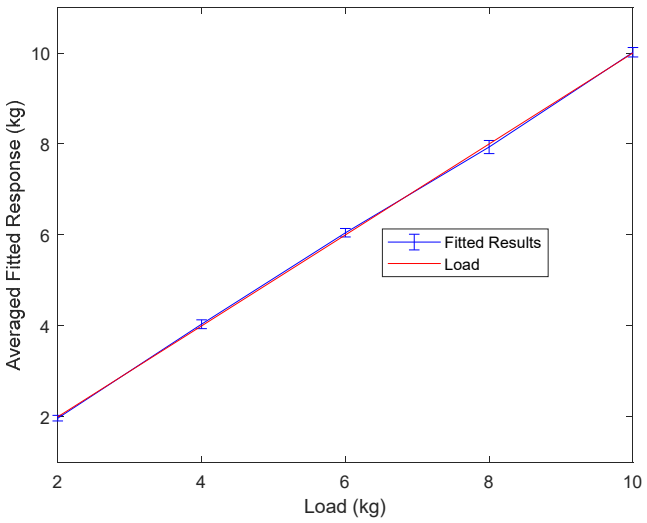


Figure 3. The average fitted spectral centroid of the Vectran 12K strap response, vs. Load. The error bars represent one standard deviation.

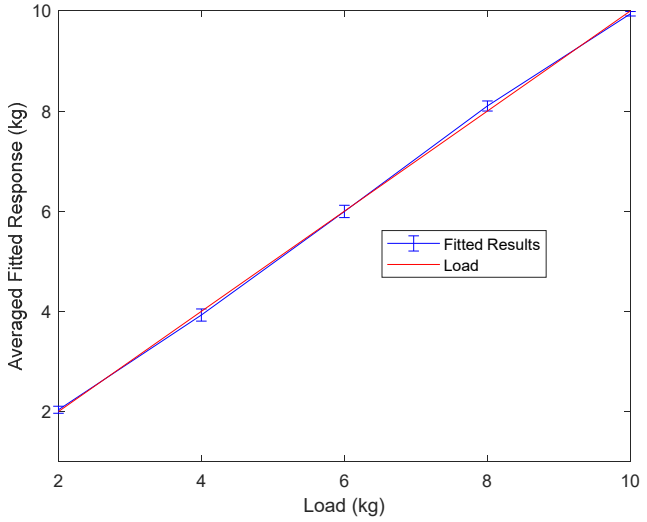


Figure 4. The average fitted spectral centroid of the Kevlar 6K strap response, vs. Load. The error bars represent one standard deviation.

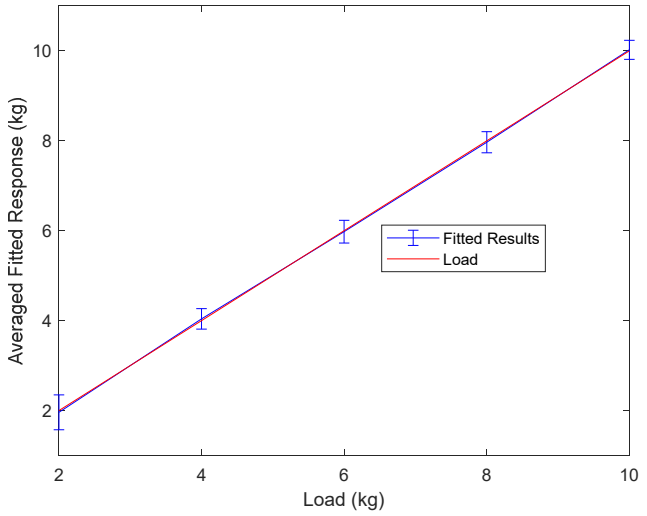


Figure 5. The average fitted spectral centroid of the Kevlar 12K strap response, vs. Load. The error bars represent one standard deviation.

4 CONCLUSIONS

A microwave system has been demonstrated to sense loading in woven restraint straps for inflatable structures under light loads from weights of 2kg to 10kg. This initial work supports an ongoing project to integrate sensors for real-time NDE of woven restraint straps within inflatable structures. While this effort demonstrates the feasibility of making load measurements using microwaves at light loads, future work will investigate the measurement of the restraint material layups subjected to realistic loads in a load frame.

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