

Robotic Ultra-Sensitive Chemical Monitoring System for Human Safety

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Abstract—The Integrated Output Spectroscopy (ICOS) instrument is designed to detect miniscule chemical leaks in natural gas plants. The ICOS instrument can be deployed on unmanned robotic systems allowing it to accurately record chemical leaks without risking human exposure. The vibrational stresses experienced by the instrument must be minimized to protect its sensitive components. To solve this problem a vibrational testing framework was created to determine the ideal housing solution. By collecting the necessary vibrational data the parameters in which the deployed ICOS instrument can operate reliably will be determined. From the results, a specification for dampeners will be created to minimize vibration effect. The document will also serve as a guideline for further vibrational analysis.

I. INTRODUCTION

Natural gas production in the U.S. remains strong and in increasing demand as it is used in industries and homes across the country. This increase in demand has resulted in the expansion of natural gas production centers. As these facilities expand so too does the need for worker safety and environmental protection.

This leads to the development of a safe method to seek chemical leaks in a natural gas plant. A more optimal solution proposes placing an ultra-sensitive Integrated Cavity Output Spectroscopy (ICOS) system onto a remotely-operated ground rover that is able to roam the plant area. The ICOS system is able to detect dangerous gas leaks with a high degree of accuracy using a combination of highly sensitive components. The sensitive nature and placement of these components leaves the system vulnerable to mechanical vibrations from the rover's motor and its operation over the plant's terrain, resulting in skewed results.

The ICOS system is able to identify trace gases using narrow band lasers from a tunable laser source directed into a gas-containing cavity. This laser would then hit concave cavity mirrors, shown in Figure 1, causing it to bounce back and forth which increases its sensitivity and the distance the laser travels to ~3km. The laser passes through the collimating optics and into the detector which is able to measure changes in its intensity after the gas absorbs the laser's wavelength [2][4]. The highly sensitive nature of these measurements requires testing its accuracy when mounted to a movable platform. It was noted that in prior tests the system did experience visible shaking, resulting in

skewed results and not addressing this issue could lead to equipment failure.



Figure 1. ICOS laser reflects off concave mirrors.

This document details the steps taken to address this issue by identifying sources causing scanning inaccuracies using computer models of the laser cavity and the test rover using ANSYS software. ANSYS will be used to place the digital models under real world stresses and show vulnerable points in the physical models. These results will be used to strengthen those weak points in the form of dampening solutions. A data logger will be used to record vibrational data while attached to the test rover with the ICOS instrument mounted. When driving through the rough terrain the parameters at plays that cause the laser source to move and no longer hit the detector when analyzing our data will be determined.

II. ANSYS MODELING

In order to provide accurate simulations the ANSYS modeling software will be utilized. Solid works models are used to accurately recreate the ICOS instrument along with its proposed housing design for simulations. Through ANSYS modal mesh analysis in conjunction with random vibrational analysis the results as shown in Figure 2 and 3, to obtain power spectral density curves at resonant frequencies are produced. These harmonics allow us to gain a greater understanding of displacement forces acting upon the instrument.

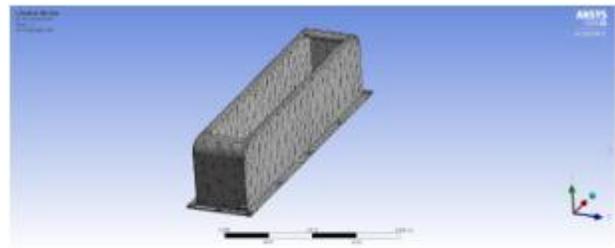


Figure 2: Meshed housing model in modal analysis.

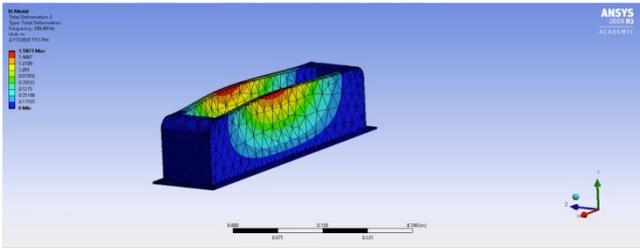


Figure 3: Simulated displacement deformation of Housing cover.

III. FIELD TESTING

The rover that was used for field testing was a Traxxas TRX-4 Scale and Trail Crawler. It's body kit was removed, leaving the vehicle's frame exposed, and replaced with a flat 2'x4' platform. A replica of the system was set on the platform and made to account for the weight and dimensions of the actual system. This includes the ICOS system, a diaphragm pump, and all relevant electronics. The ICOS replica was constructed by drilling a laser diode into a sheet metal box pointed at a detector that was secured on the opposite end. The detector consists of a photo resistor connected to a set of diodes indicating a range of intensity the photo resistor is being hit with. The ICOS replica and the dummy weight were secured onto the platform using screws without dampening material as a baseline was needed to be established. An accelerometer, used to measure and record vibrations, was secured onto the vehicle's frame.

The rover would traverse a wide variety of terrain while patrolling a gas plant and avoid obstacles in front of it. The system may experience gravel, rocky, smooth and paved surfaces and possible crashes into obstacles due to user operation. The readings should be accurate while operating under these conditions; the laser should still be able to hit the necessary targets to produce accurate and reliable data. For the purposes of this test, a successful run would result in minimal to no loss of intensity shown by the light indicator.

IV. RESULTS AND DISCUSSION

A. ANSYS Results

Through our ANSYS simulations we were able to develop an understanding of the harmonics of the majority of components within the ICOS instrument. Our analysis was able to identify several key weaknesses such as the pump component, laser cavity and housing. As seen in Figure 3 the housing suffers from intense displacement deformation at the 700 Hz resonant frequency. We were able to determine through shock simulation the failure of pump integrity. After 7100 Hz the pump component experienced large deformation leading to collisions with the aluminum base plate.

B. Field Testing

The rover including the mounted dummy load was put through multiple runs, which include three different terrains; uniform pavement, gravel, and stairs. A camera was mounted behind the instrument allowing the LED activity to be recorded. After these runs, the footage showed that the LED stayed on and constant, indicating that the laser contact to the photo resistor was also constant. The data logger in conjunction with more accurate sensors would more accurately showcase results in further testing.

Though our test did not show possible failure, it did present important take-away. Vibration data was collected on the three different terrains, uniform pavement, gravel, and stairs, as shown in Figures 4, 5, and 6 using the

accelerometer. The various vibrational stresses for each terrain type can be determined.

This data can be used in further tests to improve analysis of vibration and shock effects on the instrument. Using a shaker table and laser vibrometer, Figure 7, would help create a more controlled test environment in future tests for the original ICOS sensor to undergo.



Figure 4. Accelerometer Data on Uniform Pavement.



Figure 5. Accelerometer Data on Gravel Terrain.

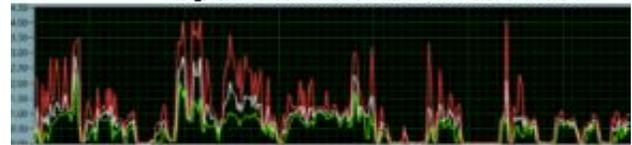


Figure 6. Accelerometer Data on Stairs

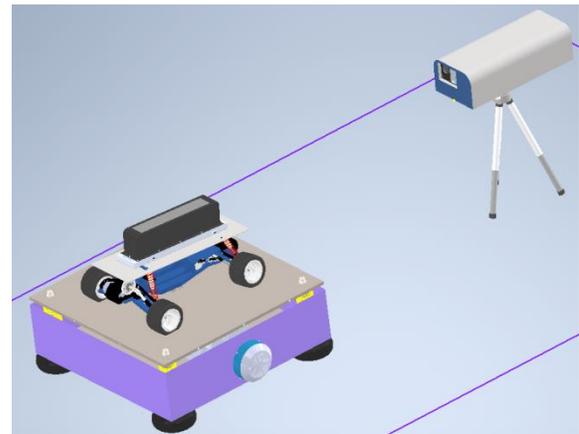


Figure 7: ICOS instrument, rover, shaker table, and laser vibrometer virtual build

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