Validation of High Speed Capacitive Pressure Sensor Arrays for Low and High Severity Impact

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I. INTRODUCTION

Pressure imaging has been widely used in the medical and automotive fields to analyze the interaction between individuals and surfaces like seats and beds. In the automotive sector, pressure imaging has primarily focused on evaluating seating comfort and design in static and quasi-static conditions. In 2017, XSENSOR introduced the High Speed Impact (HSI) pressure imaging system, designed to capture 2D pressure data during dynamic test events such as rear-seat impacts, head restraint interactions, and airbag deployments. As the application of pressure imaging expands into dynamic safety testing, recent studies have begun to explore its utility in high-impact environments. In the paper by Bolte et al. (2022) presents the use of the XSENSOR High-Speed Impact System in post-mortem human surrogate (PMHS) thoracic impact testing, demonstrating how high-resolution pressure sensing can capture detailed force distribution and timing during blunt chest impacts to improve biomechanical analysis. In a 2023 submission to the National Highway Traffic Safety Administration (NHTSA), Matthew Brumbelow of the Insurance Institute for Highway Safety (IIHS) highlighted the use of pressure mats in crash testing to assess rib loading on Hybrid III dummies, illustrating the growing role of distributed pressure sensing in injury biomechanics. This paper will assess the performance of HSI sensors, demonstrating their accuracy and repeatability in controlled environments that simulate real-world automotive crash scenarios.

II. METHODS

Experimental

A ballistic pendulum (mass 20.61 kg) was used to create low (target 10-15g) and high (target 45-50g) severity impacts on an XSENSOR HSI vest sensor. An Endevco 7264B-2000T accelerometer was mounted to the pendulum and a Keysight DAQ790A Datalogger equipped with a DAQ909a digitizer unit with a sampling rate of 50kHz was used to record the accelerometer data. Three XSENSOR HSI HX210:36.48.05M sensors were used. The target was a 76mm thick slab of high density foam (2080BK, 1.95-2.05 lbs/cuft, 80+ ILD) and was replaced after each impact. Pendulum tests generating 15–50 g impacts approximate the forces seen at the restraint interface in 1/2 overlap crashes; high-density foam is used to mimic chest or sternum compression of an ATD. An XSENSOR HSI datalogger was used to record data from the vest sensors at 3291 frames per second. Each sensor was calibrated 1-300 psi (0.7-207 N/cm^2). We performed 30 impacts on each sensor at low severity and one series of 30 impacts on a single HSI sensor at high severity. The Keysight and XSENSOR dataloggers were synchronized with a hand held push button trigger to ensure a common t=0 point.

Analysis

Data from the Keysight and XSENSOR dataloggers were exported as csv files and imported into excel. Accelerometer voltages were converted to accelerations (in g's) and force (in Newtons). XSENSOR data was exported as pressure (in psi) and force (sum of pressure * cell area over the entire 2-dimensional pressure map per frame). Adjacent averaging was applied to the accelerometer signal to smooth noise introduced by the SMPS power supply. Due to the sampling rate mismatch between the Keysight and XSENSOR dataloggers, manual time alignment was performed. On average this was about a 1.4msec adjustment. We used statistical tools within excel to perform t-tests as well as ANOVA.

III. INITIAL FINDINGS

The average force curves of all 90 tests at low severity are shown in Figure 1 and the statistics in Table 1. t-Test results comparing the peak force values for XSENSOR and the accelerometer show P to be 0.61 and the ANOVA analysis shows F_{crit} = 3.89 and F = 0.28.

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TABLE 1: STATISTICS FOR ALL LOW SEVERITY TESTS SHOWN IN FIGURE 1.

	XSENSOR		Accelerometer	
	Peak Pressure [psi]	Peak Force [N]	Peak Acceleration [g]	Peak Force [N]
Average	12.7	2144	10.5	2121
Standard Deviation	1.7	297	1.6	322

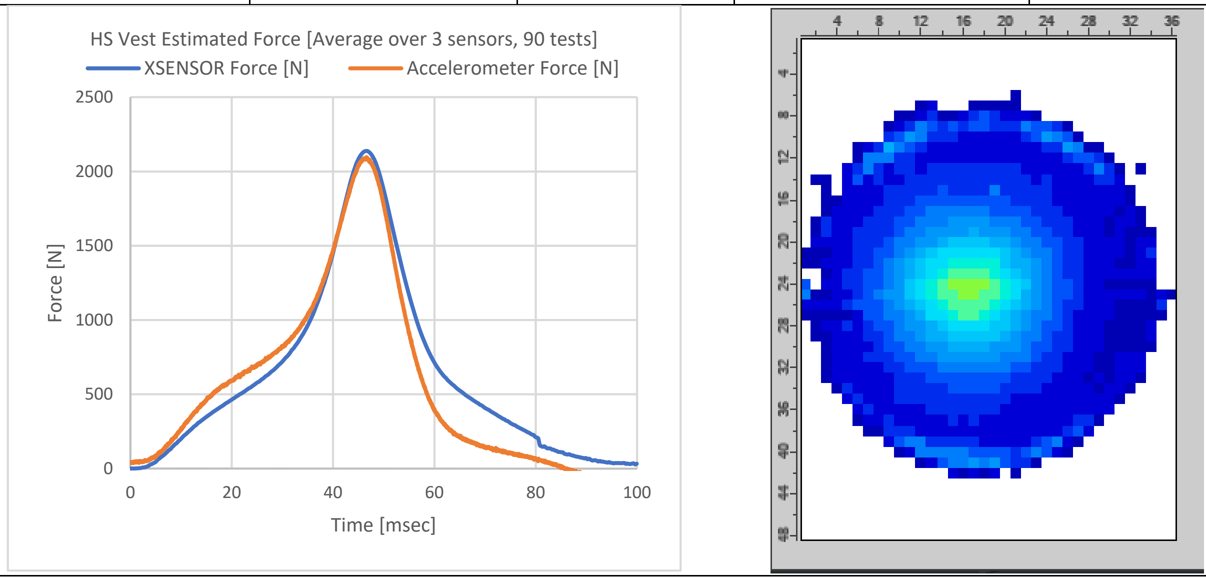

Figure 1: Average Force vs Time curves for 90 low severity impacts (left) and typical pressure image at the peak force point (right).

Similarly, we performed a series of high severity tests (one sensor, N=30) and performed the same analysis on them with P = 0.445 and F_{crit}=4.00 and F=0.59.

TABLE 2: STATISTICS FOR ALL LOW SEVERITY TESTS SHOWN IN FIGURE 2.

	XSENSOR		Accelerometer	
	Peak Pressure [psi]	Peak Force [N]	Peak Acceleration [g]	Peak Force [N]
Average	50.9	8640	43.0	8682
Standard Deviation	1.3	224	1.2	246

IV. DISCUSSION

Our analysis demonstrates that forces calculated from pressure sensor array measurements are accurate, repeatable, and align with those measured by accelerometers. This provides end-users with confidence that data collected at the same location will be consistent across multiple tests and that different sensors deployed in various locations will yield comparable results.

The use of a pressure sensor array offers several key advantages over traditional point load cells or accelerometers. It provides a comprehensive two-dimensional map of force distribution across the entire surface, enabling precise analysis of how pressure is applied during impact events. Additionally, it allows for accurate identification of object location and positioning on the surface. This capability is particularly valuable in capturing the complex interactions between the crash test dummy, seatbelts, airbags, and the seating structure or frame, offering deeper insights into injury mechanisms and system performance. The use of high-resolution pressure sensing arrays quantitatively improves upon previous methods that relied on discrete sensors with low spatial resolution by capturing continuous, detailed pressure distributions that reveal localized force concentrations and subtle variations that would otherwise be missed. This enhanced spatial fidelity enables more accurate assessment of impact dynamics, leading to better-informed design decisions and improved occupant protection strategies.

V. REFERENCES

[1] Bolte, J. IV, et al (2022). *XSENSOR High-Speed Impact System in PMHS Thoracic Impact Testing.* Proceedings of the IRCOBI Conference 2022, IRC-22-43.

[2] Brumbelow, M. L. (2023). *Comment submitted to Docket No. NHTSA-2023-0031: Response to RFC on Test Devices and Instrumentation in Crashworthiness Testing*. National Highway Traffic Safety Administration. Retrieved from https://downloads.regulations.gov/NHTSA-2023-0031-0015/attachment_1.pdf