New Electronic Peening Intensity Sensor: Comparison with Almen Arc Height Verification

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Introduction

Almen strips are often used for peening intensity determination and verification. For intensity verification, one must measure the pre-bow of the Almen strip, install the strip on the holder, peen the strip for a period of time, remove the strip from the holder and measure the arc height of the strip with a dedicated gage. For intensity determination, these steps must be repeated at least four different times to generate a saturation curve. Intensity determination and verification can account for 10% to 30% of machine usage.

A new electronic peening intensity sensor was recently developed to help provide an easier, faster and better method for tracking the peening process. This wireless sensor offers the possibility for near real-time peening intensity measurement and verification. It also provides new insight into the process by counting the number of impacts on the sensor and showing the force of impacts with an intensity histogram. All data generated is digital which facilitates feedback for machine control as well as data analysis and transfer for process tracking and storage.

Objectives

The objective of the paper is to show the use of an electronic peening intensity sensor for daily machine parameter verification in comparison with the Almen strip arc height measurements. The measurements from both methods are illustrated and the variability over a 31 day period is discussed.

Sensor Description

The electronic peening intensity sensor was custom designed for peening applications [1]. The sensor is illustrated in Figure 1. It features a load cell pin, a protective cover and a metal base with five screw locations for installation. It has the size and screw pattern of a SAE J442 [2] Almen strip holder to easily be installed on most jigs and fixtures.

Figure 1 Sensor Exterior and Back

The pin of the load cell is made of tungsten carbide for durability. It is very small and is the only part of the sensor that needs to be subjected to the peening media stream. It is thus possible to design fixtures for the sensor that ensures realistic impact scenarios and representative peening intensity measurements even in difficult to reach locations such as gear roots or turbine disc fir tree slots (Figure 2). The rest of the sensor has a protective cover that absorbs the impact energy of the media and protects the internal components of the device. This protective cover can be replaced if necessary.

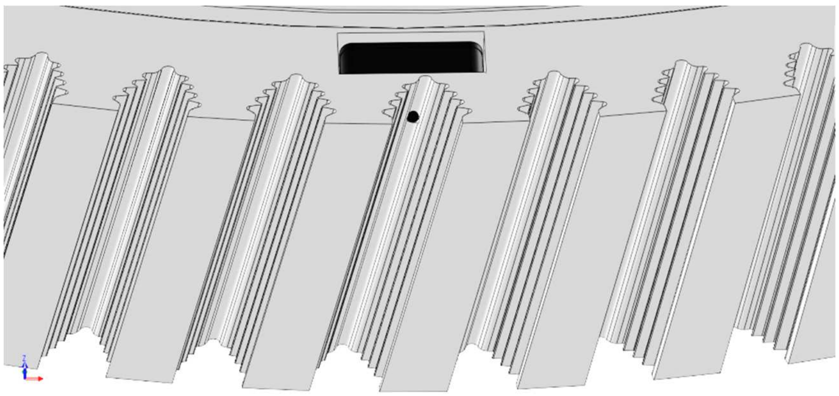

Figure 2 Example of a sensor usage in a difficult to reach location

The sensor records individual impacts during the peening process when media particles hit the load cell. Only a few hundred impacts are necessary to determine the intensity. Each impact has a different level of energy because of the size, hardness and velocity of the media particle. The impacts are recorded and sorted by a processor and a proprietary algorithm is used to calculate an equivalent Almen intensity. The sensor output is transferred via wireless communication to custom software on a computer. The software can accept data from an unlimited number of sensors. The software shows data from each sensor such as the calculated equivalent intensity, the battery level and the strength of the wireless communication (Figure 3).

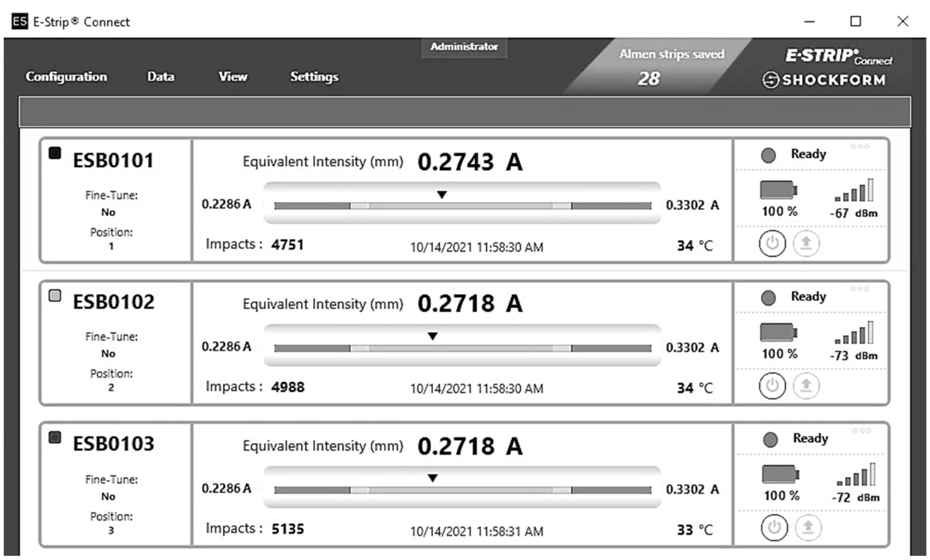

Figure 3 Software output for each sensor

Because the intensity is easy to measure and requires no human manipulation, it becomes feasible to perform measurements each time the machine operates. This data can be recorded in a database for quality tracking and could eventually be used in a feedback loop to adjust peening parameters in real-time.

The sensor also provides new insight into the peening process by counting the number of impacts on the sensor and showing the distribution of impacts with an intensity histogram. The number of impacts can be associated to the media flow rate, while the distribution of impacts illustrates the quality of the peening stream. A change in number of impacts or a change in the shape of distribution and equivalent intensity are signs the process is no longer stable. More insight into these functions will be discussed in future papers.

Experimental Method

To show the use of an electronic peening intensity sensor for daily machine parameter verification, five sensors and five Almen strips were placed alternatively on the turn table of a SmartPeen® peening machine. Peening was performed at five pressures 0.55, .83, 1.10, 1.38, 1.65 bar at a media flow rate of 9.1 kg/min using AWCR28 cut wire media meeting specification SAE AMS 2431/3D [3]. This machine features full control and recording of the pressure and media flow rate for accurate process control. The setup is illustrated in Figure 4.

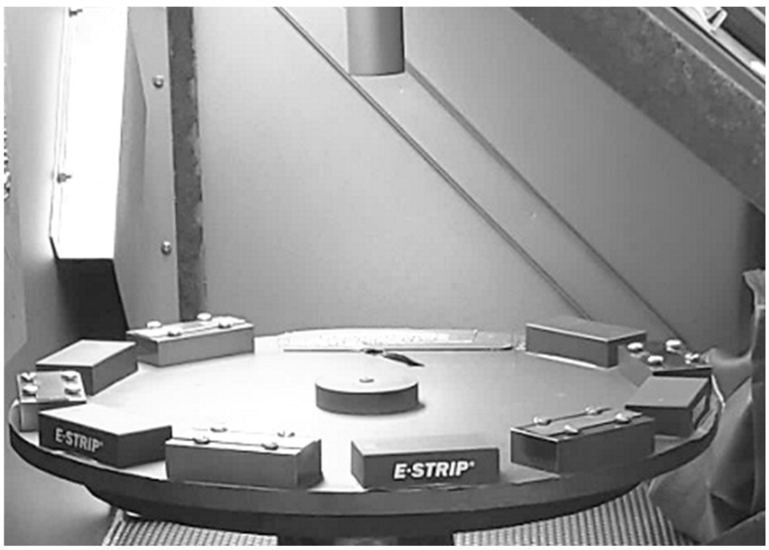

Figure 4 Sensors and Almen Strips in Peening Machine

A 9.52mm internal diameter nozzle was used for peening. It was fixed perpendicular to the turn table at a distance of 152 mm. The turn table was rotated at 4 rpm which translates to a tangential velocity of 4775 mm/min.

Almen strips were type A-1 sourced from Reference [4]. Pre-bow compensation was performed on all strips before measurements. Almen intensities were determined using the Shockform Saturation Curve Solver (SSCS) [5] with five data points, the three parameter curve fit equation and the 10% rule as per SAE J443 [6].

On day one, the Almen intensity at five different pressures was determined along with the output for the five sensors. The sensor output was fine tuned to match the recorded Almen intensities. These values served as the baseline reference for the measurements taken the following days. Arc height values were then recorded every day for 30 additional days along with the sensors equivalent intensity. The variability of the arc height readings is compared with the variability of sensors equivalent intensity.

Results and Discussion

The output of the sensors is called "Equivalent Intensity" to differentiate from "Almen Intensity". The relationship between the Almen intensity and the sensor equivalent intensity after calibration is illustrated in Figure 5. The sensors provide a good representation of Almen intensities. If the sensor output perfectly matched the Almen intensity, all the point would lie directly on the line. In this case, the goodness-of-fit measure R-squared has a value of 0.9952.

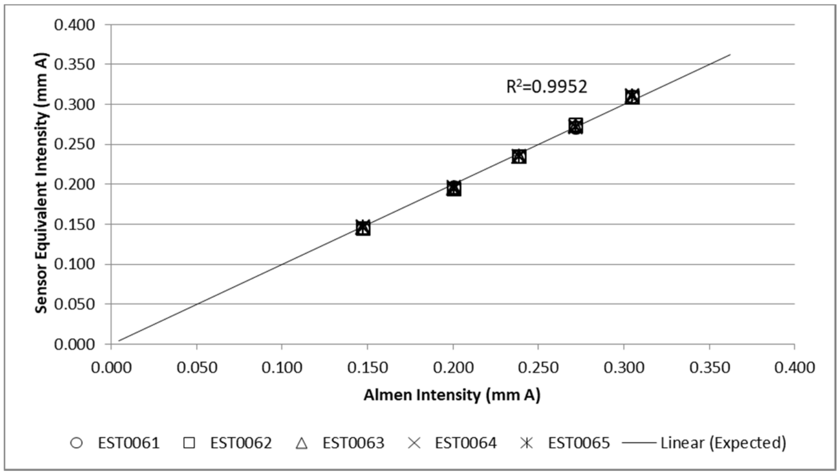

Figure 5 Day 1 Sensors Equivalent Intensity vs. Almen Intensity

The saturation curves obtained at the different pressures were used to find the target arc heights. These target arc height are the reference for the process verification performed the following 30 days. The target arc heights were determined at 4 passes of the turn table which is at or slightly after the number of passes where intensity was calculated.

This illustrates a major complication with Almen strips. Almen intensity cannot be measured with a single strip. Peening at different times on at least four Almen strips is required to generate a saturation curve. Since generating saturation curves is very time consuming, process verification is usually performed by measuring the arc height of a single strip at a pre-determined time. Many people are confused by the relationship between Almen intensity and target arc height for process verification.

For the sensors, the output equivalent intensity from day 1 was used as the reference for the verification performed the following days. The sensors measure intensity directly each time they are used. Target arc height values for the Almen intensity and target equivalent intensities for the sensors are shown in Table 1.

Table 1 Target Almen Arc Heights and Target Equivalent Intensities on Day 1

Pressure (bar)	Almen Intensity (mm A)	Target Arc Height (mm)	Target Equivalent Intensity (mm A)				
			EST0061	EST0062	EST0063	EST0064	EST0065
0.55	0.147	0.145	0.145	0.145	0.145	0.146	0.147
0.83	0.201	0.201	0.196	0.193	0.195	0.196	0.194
1.10	0.239	0.251	0.235	0.234	0.234	0.234	0.234
1.38	0.272	0.295	0.271	0.274	0.273	0.272	0.271
1.65	0.305	0.333	0.310	0.309	0.309	0.309	0.311

The variation of Almen arc height and sensor equivalent intensity was studied over a period of 31 days. Almen arc heights and sensor equivalent intensity were measured each day at the five different pressures and compared with the baseline values shown in Table 1. A total of 155 Almen strips were required for the study. The same five sensors were reused every day. Figure 6 illustrates a histogram of the 31 measurements at 0.55 bar pressure for the Almen strips and sensor EST0062. The histogram shows that the Almen strips have more variability than the sensor with several very low measurements compared with the target value. The sensor shows a tighter distribution closer to the target equivalent intensity.

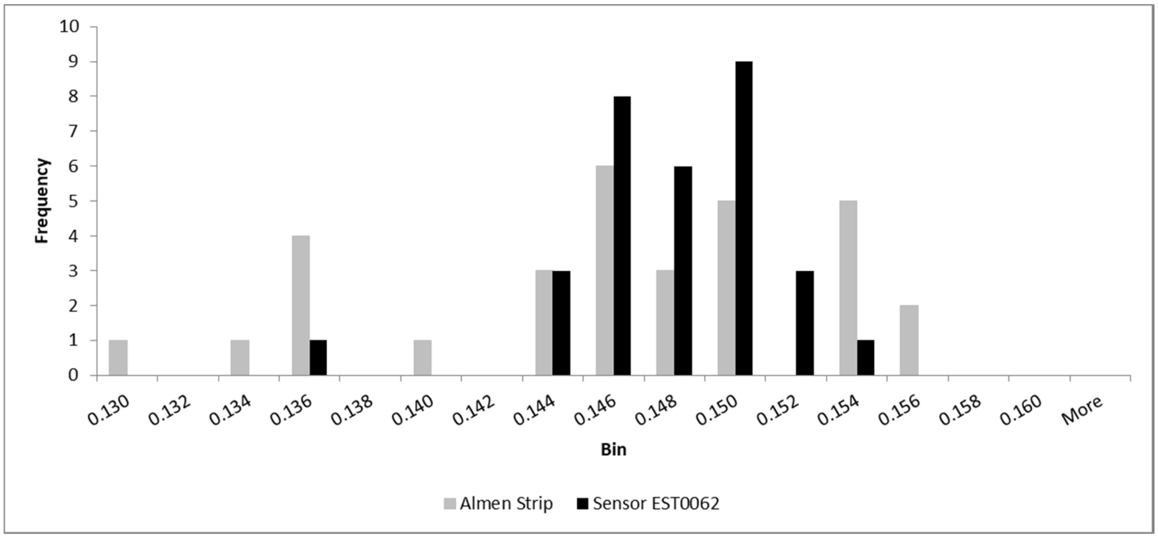

Figure 6 Almen Arc Height and Sensor Equivalent Intensity Variation over 31 days

The average of the measured values along with the standard deviation for the 31 days is presented in Table 2. The data shows that the standard deviation for both the Almen strips and the sensors is not affected by the different pressures. The variability seems constant at the different intensities. Overall, each sensor seems to have slightly less variability than the Almen strips at each of the five pressures. This is reflected in the average standard deviation for the five pressures found at the bottom of the table.

Table 2 Data Average and Standard Deviation over 31 days

Pressure (bar)	Almen Strips (mmA)		EST0061 (eq. mmA)		EST0062 (eq. mmA)		EST0063 (eq. mmA)		EST0064 (eq. mmA)		EST0065 (eq. mmA)	
	Avg.	Std. dev.	Avg.	Std. dev.	Avg.	Std. dev.	Avg.	Std. dev.	Avg.	Std. dev.	Avg.	Std. dev.
0.55	0.145	0.0072	0.146	0.0037	0.147	0.0036	0.147	0.0032	0.147	0.0043	0.149	0.0035
0.83	0.206	0.0070	0.195	0.0035	0.195	0.0042	0.195	0.0025	0.197	0.0048	0.196	0.0034
1.10	0.254	0.0069	0.237	0.0042	0.237	0.0036	0.235	0.0026	0.238	0.0050	0.237	0.0043
1.38	0.297	0.0067	0.278	0.0040	0.274	0.0059	0.275	0.0026	0.278	0.0060	0.277	0.0052
1.65	0.338	0.0073	0.318	0.0049	0.312	0.0057	0.314	0.0032	0.315	0.0068	0.314	0.0053
Avg.		0.0070		0.0041		0.0046		0.0028		0.0054		0.0043

Almen strip variability has been studied by a large OEM in Reference [7]. A sample of 153 Almen strips were tested on different machines, at different peening intensities and using different media type and size. For A type Almen strips, the overall variability for all tests was found to be 0.0056mm. This is similar to the 31 day variability presented here for the five different pressures.

Reference [8] compared three sources of Almen strips in a common machine setup using various shot types and sizes at different peening intensities. The standard deviation for the three different manufacturers for a total of 105 strips is 0.0142. This is twice the variability that was measured on the Almen strips in this study. Data for a single manufacturer was found to be 0.0054mm. Again this is similar to the variability found here.

Overall, the data shows that over the 31 days period, the sensors are as stable as the Almen strips to verify machine consistency. Sensors also offer the advantage of a digital output for easy data analysis and transfer for process tracking and storage. Furthermore, the output is directly in equivalent intensity instead of arc height thus avoiding much confusion in the process.

Conclusion

A new electronic peening intensity measurement sensor was presented. It was designed specifically for peening applications and allows for intensity measurements even on two and three dimensional surface curvatures difficult to represent accurately using Almen strips. The output of the sensor was shown to correlate very well with Almen intensity. Once correlated, the sensor provides a stable measure of peening intensity over 31 days with standard deviation smaller or equivalent to Almen strips. This new sensor offers the possibility to save considerable manipulation time when determining or verifying intensity. It avoids much confusion with intensity verification and is also a much better choice for the environment.

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