Self-Excited Acoustic System: enhancing quality control

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***Abstract:** This article discusses the use of self-excited acoustical systems (SAS) for the non-invasive and quick study of aluminium castings used in the automotive industry. The SAS system is incorporated into the industry 4.0 standard production line and provides valuable insights into the quality and reliability of the aluminium castings. This approach is innovative and aims to enhance the efficiency of the production process.*

***Keywords**: ALUMINIUM CASTING,SELF-EXCITATION, QUALITY CONTROL, NON-DESTRUCITIVE, MICROSTRUCTURE*

1. Introduction

In the era of global trade and intercontinental shipping, ensuring the quality and reliability of industrial products has become paramount. This holds true for aluminum castings used as subassemblies in the automotive industry. These castings are subjected to various mechanical stresses, and any defects or inclusions can significantly compromise their structural integrity. Traditional examination methods, while effective, often require destructive or time-consuming procedures. To overcome these limitations, the integration of self-excited acoustical systems (SAS) into the industry 4.0 standard production line has emerged as a promising solution. This article explores the utilization of a SAS measurement stand for the quick and non-invasive study of aluminum castings, enabling manufacturers to enhance product quality and optimize performance.

The utilization of self-excited acoustical systems presents numerous advantages compared to conventional inclusion detection methods. One notable benefit is the ability to swiftly and accurately detect inclusions in real-time, without the need for additional equipment or external stimulation. This empowers manufacturers to promptly identify and address defects during the production process, minimizing the potential for costly delays and rework. Furthermore, self-excited acoustical systems excel in detecting inclusions that may go unnoticed by alternative techniques, such as X-ray imaging.

2. Principle of operation

The principle of operation behind self-excited acoustical systems (SAS) revolves around the autodyne effect.

The autodyne effect occurs when a speaker is brought close to a microphone, resulting in an undesired hum or feedback. In certain systems, such as radio technology, this effect has been utilized intentionally.[1] The autodyne effect refers to the phenomenon where a system becomes self-excited and sustains vibrations or oscillations due to the positive feedback loop created by the coupling of the emitter and receiver. This loop sustains and reinforces the vibrations within the casting, leading to self-excitation. By leveraging the autodyne effect, the SAS system achieves a continuous and self-sustained oscillation within the test element[1]–[5]. Similar effect can be achieved when the microphone is replaced by a accelerometer.

The SAS measurement stand consists of essential components such as a loudspeaker acting as the inductor, a piezoelectric accelerometer, a signal generator, a signal amplifier, a data acquisition card, and a signal conditioner as shown on Fig.1. The system begins by applying the loudspeaker, or vibration emitter, to the aluminum casting under investigation. By appropriately adjusting the amplifier gain, the autodyne effect leads to the excitation of vibrations within the test element, such as the aluminum casting.

Next, the piezoelectric accelerometer is strategically positioned in proximity to the studied measurement point on the casting, enabling the measurement of the resulting vibrations. The accelerometer operates on the principle of the piezoelectric effect, which involves the conversion of mechanical stress or strain into an electrical charge. This effect allows for the precise and sensitive measurement of vibrations in the casting.

The signal received by the accelerometer undergoes conditioning to ensure compatibility with the voltage levels required for further processing. Conditioning may involve amplification, filtering, or adjustment of the signal's amplitude and frequency range.[1]–[3], [6] Research has indicated that application of low-pass or bandpass filter allows the elimination of unnecessary frequencies that are not the test object's own frequency. The conditioned signal is then amplified and passed as positive coupling to the signal generator, completing the feedback loop necessary for self-excitation.

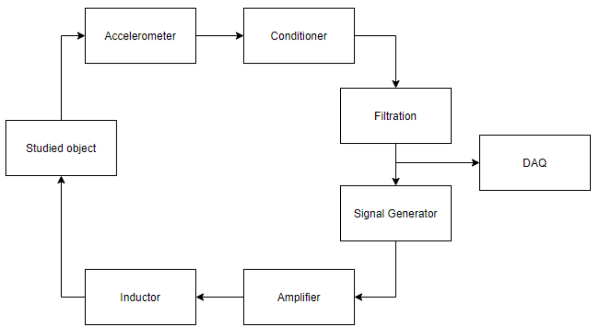

Fig. 1 Schematic diagram of the measurement system**.**

To facilitate analysis and interpretation, the conditioned and amplified signal is read by the data acquisition card (DAQ). The data acquired by the data acquisition card during the self-excited acoustical system (SAS) measurement process is processed using LabVIEW software. LabVIEW provides a powerful platform for data analysis and visualization, enabling efficient and effective evaluation of the acquired data.

One of the primary processing steps involves conducting a Fast Fourier Transform (FFT) on the acquired signal. The FFT algorithm converts the time-domain signal into the frequency domain, allowing for the identification of specific frequency components within the signal. In the context of the SAS system, the FFT analysis helps identify the highest peak in the power spectrum, which corresponds to the natural frequency of the studied object.

By identifying the highest frequency peak, the analysis aims to determine if the studied object exhibits any characteristic resonant behavior or if there are any anomalies associated with its natural frequency.[2], [3], [5]–[8] This information is crucial in assessing the integrity and quality of the object being studied. If the highest frequency peak aligns with the expected natural frequency, it suggests that the object is intact and meets the desired specifications. On the other hand, deviations or abnormal peaks indicate potential faults or defects within the object.

The analyzed data, including the frequency peak information, can be further processed and evaluated to make decisions regarding the object's quality. This analysis can be customized based on specific criteria or thresholds set for determining the acceptability of the object. If the object is deemed faulty or exhibits irregularities, this information can be communicated to the control SCADA system (Supervisory Control and Data Acquisition) in real-time.

Integration with the control SCADA system allows for immediate actions to be taken based on the analysis results. The intact castings can proceed down the production line for further processing, while faulty objects can be promptly identified and discarded from the manufacturing processes. This seamless integration between the SAS system, LabVIEW software, and the control SCADA system ensures efficient quality control in the production line, minimizing the risk of defective components reaching the final stages of production.

3. Manufacturing line integration

To enhance the measurement process and enable full automation, the self-excited acoustical system (SAS) was mounted onto an industrial robot's arm using a specially designed gripper attachment (Fig.2). This innovative setup allows for the precise positioning and manipulation of the vibration emitter and accelerometer during measurements, offering increased flexibility and repeatability.

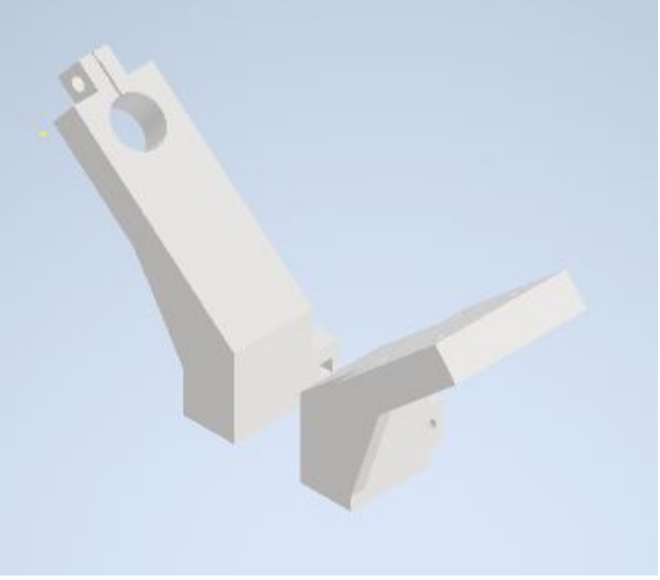

Fig. 2 Gripper attachment visualization

By integrating the SAS system with an industrial robot as shown on Fig. 3, the measurement process becomes more efficient and reliable. The gripper attachment securely holds the vibration emitter and accelerometer, ensuring their stable positioning and alignment with the studied object. This eliminates the potential for manual errors and inconsistencies that may occur when placing the components manually.

The industrial robot's arm provides controlled and precise movement, allowing for accurate and repeatable measurements even when the studied object is replaced. The robot arm can be programmed to follow predefined paths and execute specific motions, ensuring consistent application of the vibration emitter and accelerometer to the object's surface. This automation eliminates operator variability and enhances measurement precision.

Moreover, the incorporation of an industrial robot enables the measurement process to be seamlessly integrated into a larger production line or manufacturing environment. The robot arm can be synchronized with other process steps, such as conveyor systems or assembly stations, ensuring smooth and efficient operation. This integration enhances productivity, reduces manual labor, and allows for continuous and reliable measurements.

With the automated SAS system mounted on an industrial robot's arm, the measurement process becomes highly efficient, accurate, and repeatable. The precise control and movement provided by the robot arm, coupled with the specially designed gripper attachment, ensure consistent positioning and application of the vibration emitter and accelerometer. This eliminates variability, enhances measurement precision, and enables reliable assessments of the studied object's integrity.

Fig. 3 SAS system mounted onto robotic arm

4. Data analysis

To validate the measurement system and ensure its accuracy, four identically shaped aluminum casts were selected as the objects of study. Each casting was equipped with ten measurement points strategically placed on various sides of the cast. The study was conducted five times for each measurement point to ensure reliability and consistency of the results.

After acquiring the time domain signals from the measurements, Fast Fourier Transform (FFT) analysis was performed to identify the natural frequency peaks for each measurement point. By analyzing the frequency spectrum, the system was able to determine the resonant frequencies of the aluminum castings.

To assess the consistency and variability of the measurements, statistical analysis was conducted on the acquired data. For each measurement point, the average value of the natural frequency peak was calculated to represent the central tendency of the data. Additionally, the standard deviation was computed to quantify the dispersion or variability of the measured values around the mean.

The average value provides an estimation of the typical natural frequency for each measurement point, indicating the expected behavior of the aluminum casting. On the other hand, the standard deviation offers insights into the level of variation or uncertainty associated with the measured natural frequency values. This statistical analysis allows for a comprehensive evaluation of the measurement system's performance and the inherent variability within the studied objects. Results are shown in Table 1.

***Table 1**: Measured natural frequencies of studied objects*

	Cast 1	Cast 2	Cast 3	Cast 4
Point 1	5487,15± 0,8Hz	5931,76± 0,03Hz	5818,14± 0,05Hz	2068,37± 0,01Hz
Point 2	2083,56± 0,08Hz	5072,82± 3,63Hz	1878,49± 0,65Hz	5132,13± 10,41Hz
Point 3	2751,24± 0,66Hz	2362,4± 360,19Hz	2498,5± 48,19Hz	2535,17± 19,59Hz
Point 4	2842,49± 4,66Hz	2661± 23,52Hz	2629,33± 0,7Hz	2403,18± 49,28Hz
Point 5	2805,75± 2,57Hz	3147,9± 27,47Hz	5699,9± 0,06Hz	2469,48± 0,53Hz
Point 6	2799,1± 0,61Hz	1891,19± 0,6Hz	2647± 7,02Hz	2445,93± 11,22Hz
Point 7	3104,01± 0,49Hz	2593,59± 5,54Hz	1929,51± 0,43Hz	2389,56± 1,7Hz
Point 8	1928,34± 2,54Hz	1334,14± 7,33Hz	2611,61± 17,65Hz	2630,04± 27,93Hz
Point 9	3078,45± 18,63Hz	3128,8± 2,44Hz	2604,52± 2,47Hz	2524,45± 4,11Hz
Point 10	2978,68± 29,7Hz	2978,42± 29,71Hz	2544,79± 100,25Hz	2500,5± 18,88Hz

By calculating the average values and standard deviations for each measurement point, the data analysis provides valuable information about the consistency and repeatability of the measurements. These statistical metrics serve as indicators of the quality and reliability of the measured natural frequency peaks, contributing to the overall assessment of the integrity and characteristics of the aluminum castings.

5. Results

The results obtained from the analysis of the self-excited acoustical system (SAS) measurements provide valuable insights into the quality and integrity of the studied aluminum casts. It was observed that the natural frequency peaks varied among the corresponding points on different casts, suggesting potential casting imperfections or inconsistencies in the manufacturing process.

Some of the identified casting imperfections include variations in the composition of the casting material, uneven cooling rates, and the presence of inclusions or defects. These variations in natural frequency can be indicative of structural inconsistencies or localized areas of weakness within the castings.

Furthermore, the standard deviation values calculated for each measurement point offer an assessment of the reliability and consistency of the measured data. Higher standard deviation values indicate greater variability among the repeated measurements, which may suggest measurement uncertainty or inconsistent properties within the studied casts.

It is important to note that results with high standard deviation values should be interpreted with caution, as they may indicate measurement issues or inconsistent properties within the studied casts. Such results may require further investigation or additional measurements to ensure reliable and accurate assessment of the casting quality.

6. References

[1] J. Kwaśniewki, I. Dominik, and K. Lalik, “Application of self-oscillating system for stress measurement in metal,” *J. Vibroengineering*, vol. 14, no. 1, 2012.

[2] I. Dominik, J. Kwasniewski, L. Krzysztof, and R. Dwornicka, “Preliminary signal filtering in Self-Excited Acoustical System for stress change measurement,” in *Chinese Control Conference, CCC*, Oct. 2013, pp. 7505–7509.

[3] K. Lalik, I. Dominik, P. Ćwiąkała, and J. Kwaśniewski, “Integrated stress measurement system in tower crane mast,” *Meas. J. Int. Meas. Confed.*, vol. 102, 2017, doi: 10.1016/j.measurement.2017.01.041.

[4] J. Kwaśniewki, I. Dominik, K. Lalik, and K. Holewa, “Influence of acoustoelastic coefficient on wave time of flight in stress measurement in piezoelectric self-excited system,” *Mech. Syst. Signal Process.*, vol. 78, 2016, doi: 10.1016/j.ymssp.2016.02.035.

[5] J. Kwaśniewski, I. Dominik, J. Konieczny, K. Lalik, and A. Sakeb, “Application of self-excited acoustical system for stress changes measurement in sandstone bar,” *J. Theor. Appl. Mech.*, vol. 49, no. 4, 2011.

[6] K. Skrzypkowski, W. Korzeniowski, K. Zagórski, I. Dominik, and K. Lalik, “Fast, non-destructive measurement of roof-bolt loads,” *Stud. Geotech. Mech.*, vol. 41, no. 2, 2019, doi: 10.2478/sgem-2019-0013.

[7] K. Lalik and M. Kozek, “Cubic SVM neural classification algorithm for self-excited acoustical system,” Jul. 2020, doi: 10.1109/MSM49833.2020.9201724.

[8] J. G. Kaufman and E. L. Rooy, “The Influence and Control of Porosity and Inclusions in Aluminum Castings,” in *Aluminum Alloy Castings*, 2021.