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Sensitivity Analysis of Barkhausen Noise Measurements for Residual Stress Correlation

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Summary:
As recent tendencies in the efficient design of forming processes show a clear trend towards property-control, suitable measurement techniques for inline monitoring must be identified and investigated regarding their measurement suitability. Since Barkhausen noise analysis offers a to the microstructural evolution susceptible measurement technique that may allow a correlation to residual stresses using symmetry effects seen in the measurement signal, this work introduces a sensitivity analysis of the available measurement parameter settings and their respective suitability for signal processing.

Keywords: Barkhausen noise analysis, sensitivity analysis, correlation, soft sensor, metal forming

Background, Motivation and Objective

Recent developments in the manufacturing engineering industry show a clear trend towards the development of monitoring techniques for forming processes [1,2]. Especially, the implementation of property-controlled monitoring techniques and thereupon based closed-loop control of the processes, are promised to make the process design more efficient regarding resources, time as well as economic aspects [3,4]. During forming processes, the microstructure undergoes permanent changes which then dictates the components application post forming [5]. Meaning, that for the successful implementation of property-based controls, suitable measurement techniques that detect the microstructural evolution need to be identified and investigated how they may be correlated to the properties of interest. Among many sensor systems, Barkhausen noise (BHN) analysis offers a non-destructive testing technique that is susceptible to a microstructural evolution [6]. However, dependent upon the investigated material, for BHN analysis, suitable measurement parameters need to be investigated. Hence, this work will introduce a sensitivity analysis of measurement settings of the QASS µmagnetic measurement equipment for a P235 TR1 tube steel to find the ideal measurement settings for the derivation of a property-based control.

Description of the New Method

Although, BHN analysis is very susceptible to a microstructural evolution, primary studies of the authors showed that both macrostructural evolution trends in hardness and residual stress state have a notable impact upon the signal intensity of the BHN sensor. As during the forming process the material not only hardens but also shows a significant redistribution of residual stresses, a sole investigation of the signal intensity cannot be recommended. Literature [7] however suggests, that a change in the residual stress state has an influence on the geometric characteristics of the hysteresis curve, which is also seen in the geometry of the QASS µmagnetic measurement signal. Hence, to ultimately be able to quantitatively correlate residual stresses and BHN based upon the geometry and intensity of the signal, an investigation regarding the best measurement settings is introduced. The varied parameters include the amplitude of BHN [mV] quantized in steps of 64 mV as is predefined by the equipment, frequency [Hz] in steps of 100 Hz up to 1.5 kHz, Amplification from 500:1 up to 5000:1 in steps of 100, sample rate from 30 kHz up to 4 MHZ also as predefined by the equipment and oversampling from “no oversampling” up to 64:1 during measurement. All testing was done on unbent P235 TR1 tube and results were investigated regarding their suitability for evaluation of signal intensity as well as symmetry characteristics. Symmetry characteristics were determined in defining symmetry factors (SF) for the hill shaped signal, giving information on whether the signal is left- or right-skewed according to eq. (1).

$$S = \frac{t_{max} - t_{center}}{l} \quad (1)$$

Where l is the bottom length of the BHN hill, t_{max} is the x-coordinate of the maximum point and t_{center} the x-coordinate of the middle point. For $S = 0$, the hill is symmetrical, $S < 0$, the hill left-skewed and respectively $S > 0$, right-skewed. Thus, this work lies an important foundation for the quantitative correlation of signal intensity and signal symmetry to the residual stress state.

Results

During the systematic variation of the different measurement settings, it was observed that a variation of the oversampling as well as sample rate in most combinations led to very poor measurement results on the P235 TR1 where data processing was made impossible. Furthermore, setting the BHN amplitude to higher energies than 466 mV led to magnetic saturation, meaning the intensity of the signal plateaued. Hence, amplitudes above 466 mV are also ruled out for further processing. The parameter frequency showed, that with an increase, the signal intensity led to good results, however the detected Barkhausen hill symmetry became very irregular, leaving the authors to exclude high frequencies as that would require the signal to be smoothed strongly, thus distorting the measurement result significantly. The higher the chosen amplification, the higher the signal intensities, however at high amplifications the SF evaluation showed that both SF left and right did not differ much from zero, making it a poor choice for correlation to residual stresses. The most robust and steady results using the prototype sensor from QASS µmagnetic were ultimately identified to:

Tab. 1: Measurement settings for future testing

Amplitude [mV]	Frequency [Hz]	Sample rate [MHz]	Over sampling	Amplification
255	100	4	8	2000

Fig. 1 shows a characterization along the (a) the in- and (b) outside of a formed tube. It can be seen that the results are robust and differ from each other along the measurement points, making a correlation to residual stresses possible.

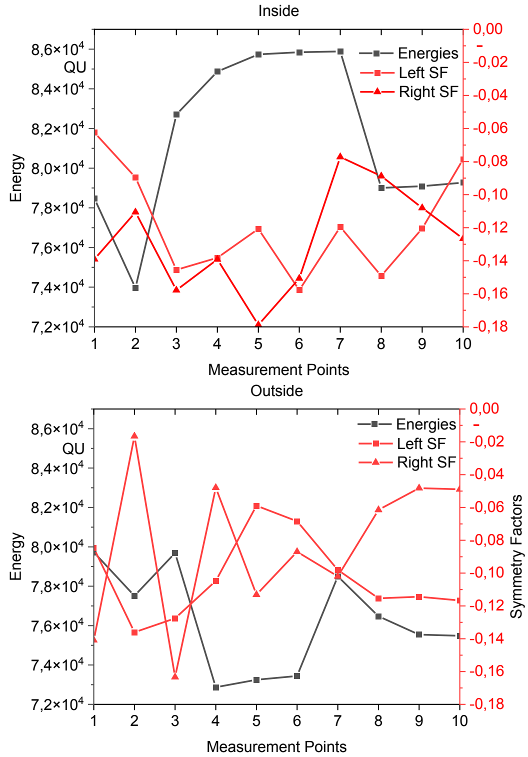

Fig. 1. Development of energies in QASS Units [QU] and symmetry factors of left and right BHN hills along (a) inside and (b) outside of a bent tube.

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