

MONITORING OF METAL FORMING BY ACOUSTIC EMISSION

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Abstract: A new method to supervise metal forming processes with acoustic emission signal analysis is discussed. In forming processes the signals are measured under the presence of typical noise and machine induced impulses which complicate an interpretation. A system is defined to filter the signal with an adaptive algorithm and to eliminate disturbing signal components. The method was verified using measurements of a deep drawing process manufacturing cylindrical parts. The results are presented.

Keywords: acoustic emission, metal forming, quality control, adaptive filter

1 INTRODUCTION

In the industrial production metal forming processes with a great number of pieces are highly automated. Production facilities of such processes must be equipped with a failure control system which is able to sort out automatically workpieces with poor quality. A large share of reject arises due to formation of ductile surface cracks or rupture. A reliable recognition of crack formation during deep drawing is presently not known. The evaluation of force signals is not successful and optical surface inspection techniques are large scaled and not employed. In this paper an approach for supervising deep drawing processes with acoustic emission signal analysis is discussed.

Acoustic emission analysis is a well known method in non-destructive testing. Among others it is used for monitoring of fatigue cracking and stress corrosion cracking, for weld monitoring and for supervising of metal working processes like coining, drilling, grinding or cutting [1]. Several authors suggest acoustic emission techniques to monitor deep drawing processes [2,3]. They describe the detection of rupture in the formed parts by a burst detection with threshold analysis of the envelope of solid-borne sound noise or by a short time frequency analysis. Disturbing signal components like machine induced vibrations and impulses or friction noise are not considered. In forming processes however various disturbing sound sources produce burst shaped sound noise. The sources can not be distinguished with a simple analysis of signal envelope or a frequency analysis of the impact sound signal. In this paper a method is proposed to detect metal cracking in a deep drawing process. The metal crack as a sound source is described in chapter 2 and simulated in bending tests in chapter 3. To reduce the influence of disturbing sound sources we propose a processing of the sound impact noise signal with adaptive filters. Chapter 4 contains the system description and results achieved in a deep drawing process of cylindrical parts.

2 ACOUSTIC EMISSION AND METAL CRACKING

Acoustic emission is a class of phenomena generating transient elastic waves by rapid release of energy at local sources in the material (ASTM standard definition). It results from structural changes in the material due to the excess of local stress limits. In principle the signals are divided in pulse-type emission and continuous emission. But it must be noticed that continuous acoustic emission is created by a series of overlapped pulse-type signal components. Anisotropies, phase conversions, martensite formation, dislocation motions and cracking where found as sources of acoustic emission [4,5].

Microscopic cracks are initiated by dislocation pile-ups which are forced together by the applied shear stress. If sufficient energy is released the cracks propagate and transmit kinetic energy in form of a sound wave to surrounding materials. A macroscopic crack is present, if microscopic cracks connect and separation expands vertically to the axle of largest tensile stress. Macroscopic cracks occur, if the stress and the incipient crack depth are sufficient large and the toughness is sufficient small. A macroscopic crack propagation can lead to final fracture of the stressed part [6]. A well-founded physical model which describes the connection between material processes during cracking and acoustic emission has not been proposed so far.

The macroscopic crack propagation occurs rapidly with repeated microscopic crack initiation across the entire crack front producing large bursts of acoustic emissions. In the solid-borne sound

noise signal development and growth of cracks are essentially characterised by burst shaped components. Due to the short time duration of the individual events the emissions have a wide-band spectrum. Because of the typical workpiece dimensions in metal forming processes under consideration the released energy is usually transmitted in the form of Lamb waves (plate waves).

3 SIMULATION OF DEEP DRAWING PROCESSES IN BENDING TESTS

For feature extraction of the acoustic emission signals bending tests with impact free load exposure are performed which simulate crack formation in a deep drawing process. The solid-borne sound was measured using wideband piezoelectric transducers [7]. Figure 1 shows a typical macroscopic surface crack and the acoustic emission signal.

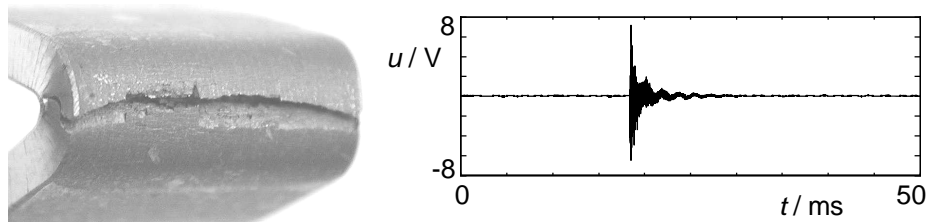


Figure 1. Macroscopic crack in a bent metal strip and emitted burst signal measured in the frequency range below 30 kHz (Transducer: Piezotronics PCB 353B68)

The bending test have shown that macroscopic surface cracks arise abrupt without previous indications and produce significant bursts in the solid-borne sound signal. Initiation and propagation of individual microscopic cracks before the final fracture where not measured. Due to the quick crack growth one cannot differentiate between the emissions of individual microscopic cracks after initiating the cracking. The form of the signal and the frequency content are mainly determined by the propagation path of the dilatational waves from the source to the transducers mounting location and by the transducers transmission properties. To describe theoretically these influences is only practicable with a high degree of simplifications for simple geometric structures. Characterising a deep drawing processes with acceptable expenditure in these ways does not appear useful. Therefore crack detection in deep drawing processes using acoustic emissions must be confined to a time domain burst detection in the solid-borne sound noise.

4 INVESTIGATIONS IN AN INDUSTRIAL PROCESS

4.1 Typical signals

Measuring emissions from rupture events is comparative unproblematically. They have a high energy content and are clearly identifiable in the solid-borne sound signal [7]. These events are not considered here. Interesting are low energy level acoustic emissions by small macroscopic surface cracks. In metal forming processes these emissions are superimposed by machine induced vibrations, shocks, stream and friction noise. Figure 2 shows signal sequences with examples of typical signal shapes in a forming process. A differentiation of the sources of the individual events in the signal envelope is not possible.

4.2 Adaptive noise suppression

For a reliable crack detection in a forming process noise reduction and suppression of disturbing events is necessary. In this field several techniques in the frequency and time domain were published. We apply the adaptive noise cancelling algorithm proposed by Widrow et.al. [8]. The algorithm does not require a priori information about the statistical characteristics of the disturbing noise and it is suitable to suppress non stationary signals. Applications are especially known in processing of speech signals but also in medical diagnostics for heart sound analysis and in process measuring technique for flow velocity measurement [9,10,11].

The adaptive noise cancelling technique based on the usage of two different transducers. The signal from transducer 1 (Fig. 3) contents the relevant information of the acoustic emissions $a(t)$ superimposed by disturbing noise $y(t)$. The signal of a second transducer only contains the noise $n(t)$.

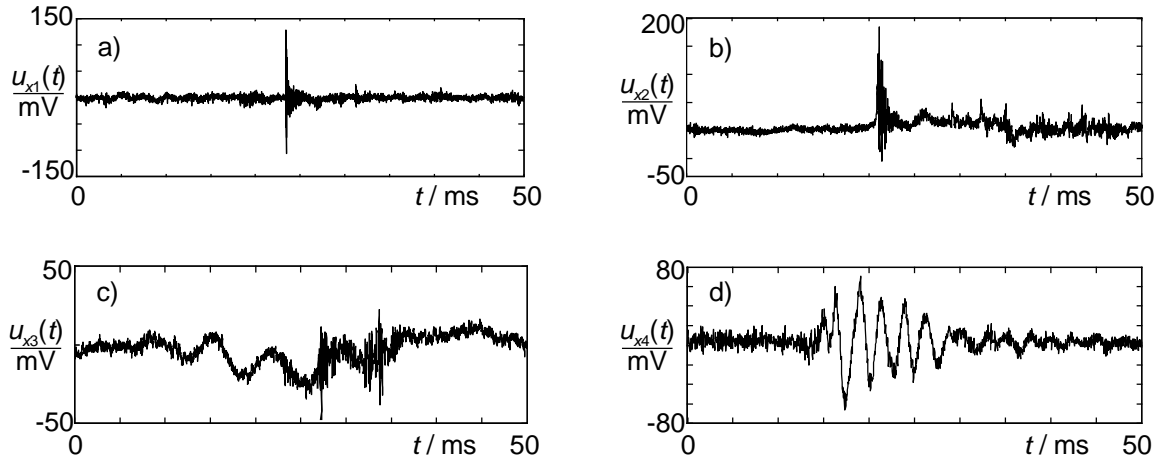


Figure 2. Typical examples of bursts in the solid-borne sound noise of a forming process
 a) An acoustic emission burst caused by a surface crack at the workpiece
 b) Impulse from a tool impact
 c) Acoustic emission with low energy superimposed by an impulse from a neighbouring machine
 d) Damped vibration from an unknown source

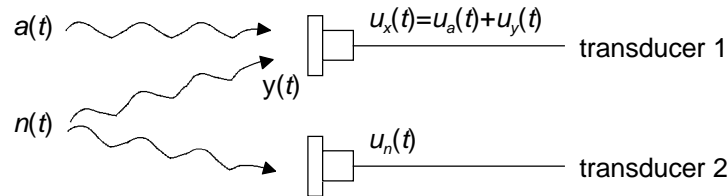


Figure 3. Superposition of sound solid-borne noise in a metal forming process

It is assumed that the noise signals $y(t)$ and $n(t)$ are correlated, that means the expected value

$$E\{n(t) \cdot y(t)\} \neq 0 \tag{1}$$

and the useful signal $a(t)$ and the noise signals are not correlated

$$E\{a(t) \cdot y(t)\} = 0 \text{ and } E\{a(t) \cdot n(t)\} = 0 \tag{2}$$

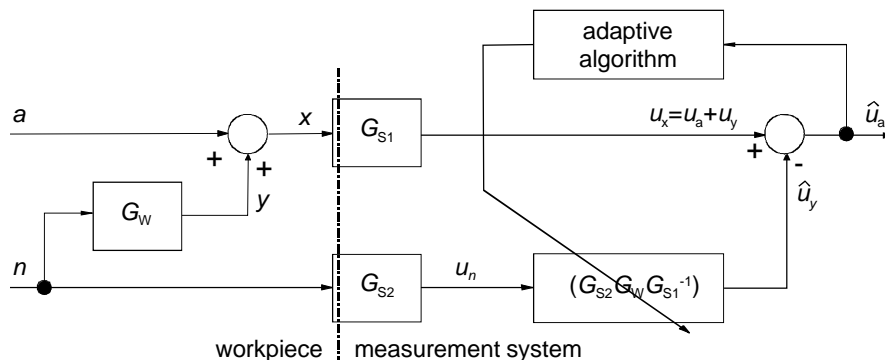


Figure 4. Adaptive filter for noise suppression

Under the assumption of partial statistical stationarity an adaptive filter can be used to estimate the transfer function between the two transducers (Fig. 4). G_W contains the transmission parameters between the transducer locations and G_{S1} and G_{S2} are the transfer functions of the transducer. Because

of its stability, low expense and good convergence characteristics a digital transversal filter of the direct form (FIR-Filter) is used [9]:

$$u_y[n] = \sum_{i=0}^M c_i x[n-i] \quad (3)$$

where M is the filter order and c_i are the filter coefficients to be adapted with an LMS-algorithm. With the assumptions (1) and (2) the adaptation criterion can be defined as:

$$E\{\hat{u}_a^2[n]\} = E\{u_a^2[n]\} + E\{e^2[n]\} \rightarrow \min \quad (4)$$

4.3 Measurement system

The application of the adaptive algorithm in a deep drawing process of cylindrical parts is discussed in the following. Because of the limited contact area between workpiece and forming tool acoustic emission waves with comparatively low energy are damped on their way to the transducers mounting place. In worst case they can not be identified in the signal from a transducer which is mounted on the outside of the forming tool.

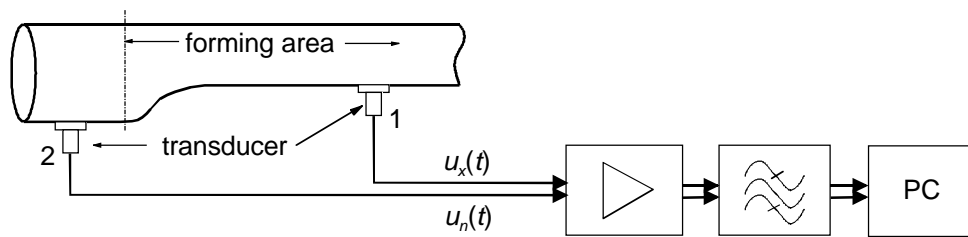


Figure 5. Measurement system

In Figure 5 a system for measurement of the solid-borne sound signal directly on the workpiece surface is outlined. We measure with two identical piezoelectric transducers (accelerometers) which are coupled unclosed on the formed part. Transducer 1 measures the vibrations $x(t)$ in the forming zone. Transducer 2 is placed outside the forming zone to measure the disturbing noise $n(t)$. The transducers operate in a frequency range until 30 kHz. It is assumed that an acoustic emission signal only will be contained in $x(t)$. The signals are filtered, amplified, sampled and conditioned in an PC-based data acquisition system.

4.4 Results

Fig. 6 shows two examples for noise reduction results. In (a) a sequence of $u_x(t)$ is plotted which contains an acoustic emission burst superimposed by an impulse induced by putting on neighbouring machine parts. This impulse is also measured outside the forming area $u_n(t)$ and plotted in (b). The adaptive filter reduces the noise (c) and the burst can be detected for example with an RMS-based threshold.

In d) a damped vibration in $u_x(t)$ caused by an unknown source is shown. In the signal $u_n(t)$ of transducer 2 a burst is caused from that source (e). With the adaptive filter the vibration can be almost completely eliminated (f)

The examples show that adaptive noise cancelling improve the signal quality of the solid-borne sound noise in a metal forming process. The application of the system in an deep drawing process allows a reliable crack detection using acoustic emission analysis. Non stationary disturbing signal components from other sources are eliminated. Acoustic emission events from macroscopic crack formation and propagation will be identifiable with well known methods for signal peak detection like RMS-based threshold or investigations of the signal envelope.

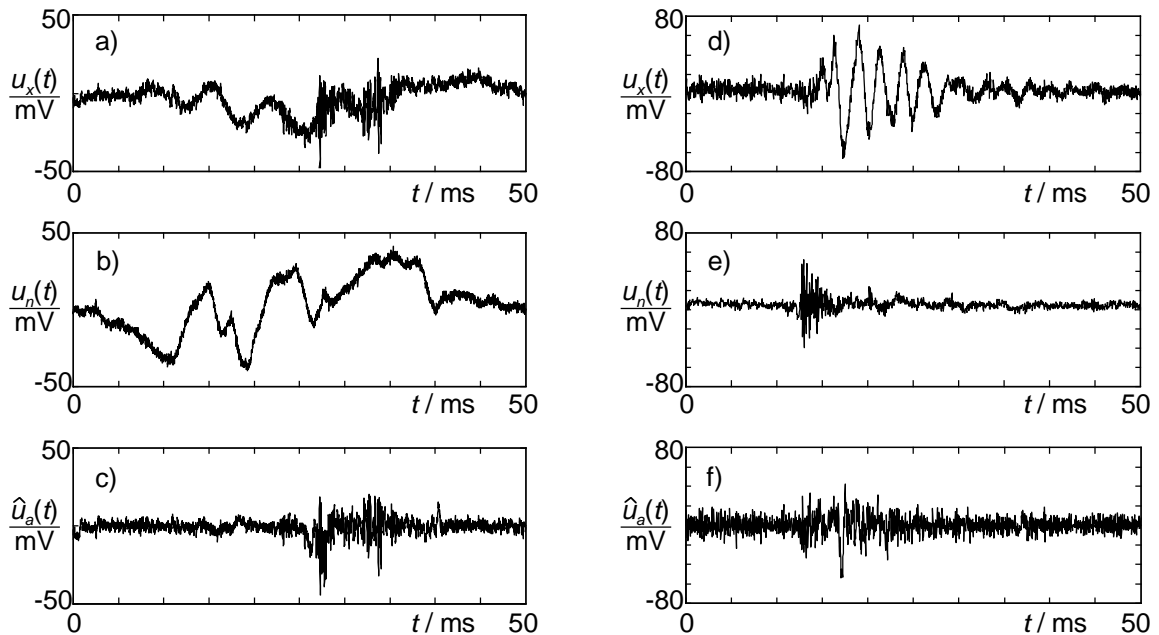


Figure 6. Application of the adaptive filter for noise reduction
 a),d): Examples for useful signal corrupted by noise
 b),e): Noise measured outside the forming area
 c), f): Output of the adaptive filter algorithm

5 SUMMARY

The analysis of acoustic emission signals is a useful method of non-destructive testing also in metal forming processes. But in such processes the solid-borne sound noise is strongly influenced by disturbing events which cause burst shaped signal components like the acoustic emissions themselves. Damping of these influences can be achieved by a system with two transducers inside and outside the forming area. The signals are processed with the adaptive noise cancelling algorithm. It was shown that this method is able to suppress disturbing noise by known or unknown sources. Our investigations show good results in an industrial deep drawing process of cylindrical parts. The system is able to identify not only ruptures of the structure but also surface cracks. Problems occur if signal components caused by micro-cutting of hard dirt particles between workpiece and tool surfaces inside the forming area. Sound noise from such sources has the same transmission behaviour like acoustic emissions and the signal components can not be clearly classified.

By adopting this method in a production process a disadvantage with regard to a short cycle time of the process is the relatively high computing expenditure. This limits the sample frequency and with it the frequency range of the vibration measurement equipment. Special signal processor hardware can solve this problem.

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