The Use of Acoustic Emissions for Process Monitoring in Steel Processing Lines

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Abstract. Steel processing lines are a challenge for measuring devices due to the rough conditions with risks for overheating the electronics, clogging of sensors and damage from moisture. In this work, an investigation was made as to whether AE can be used in this harsh environment. It is known that several problems actually can be heard based on their AE. In this work, the sound from cutting, rolling and levelling was analysed to trace problems like tool wear, galling and scratching. The analysis was done by studying the frequency spectrum, the amplitude levels, the RMS signal behaviour and also by the use of peak counts. The analysis was made using software developed using the National Instruments LabView program.

This study showed that all the production problems investigated could be detected by means of acoustic emissions. There were considerable advantages using AE, since the system was robust and simple to mount. The analysis could be done at a low cost. It is clear that a system needs to be tuned to identify the proper threshold values for various operational ranges.

The strip cutting tests showed that local damage to a shear blade and scratching was traced to high frequency components in the AE. From studying the signal variation in time and using the peak count technique, it was possible to identify problems with a bad cutting geometry. For practical use in on-line operations in industry, a wider selection of the production conditions should be investigated.

This work is based on a limited number of tests. To develop the model for on-line use, a larger part of the production needs to be covered and there is a need to define boundaries for what normal operation is and what is unacceptable.

Introduction

Steel processing lines involve numerous operations where disturbances can occur. Due to the harsh conditions and confined working environment, it is difficult to efficiently monitor the production process. Often equipment gets harmed by material outside of the process path and devices degrade in the harsh environment. AE-monitoring is a technique of general interest due to the compact size of the AE-sensor sensors, their versatile field of application and their robustness for process monitoring. Benefits are that measurements can be made at a single point and the measurements are not disturbed by background noise and low-frequency vibrations.

It is known that Acoustic Emissions (AE) detected from manufacturing processes contains valuable information about the process. The information can be analysed and linked to the efficiency of the process. Still, AE is not commonly used in processing lines,
the reason is that the results might be difficult to interpret since the AE is influenced by both process and material parameters and the limits of what is acceptable AE or not, is dependent on the material and the process. Process analysis using AE has been tested with good results on various forming processes such as grinding, forging, deep drawing, powder pressing, rolling and turning. The application in this study is similar, to characterise the process status between moving surfaces (process material and tool) by studying the AE signals.

There are several publications that characterise the status of- and events occurring at-contact surfaces based on the AE signals. In a study for monitoring of wear [1], it is stated that the measured cutting forces and the measured vibrations are widely applicable parameters. Tests made using laboratory grinding equipment [2] and from analysing machining [3] showed that a wear coefficient can be estimated from the AE RMS signal. In [3] pattern recognition was used for the identification of tool failure. In [4] an on-line model for maintenance and prediction of tool life was developed using neural networks combining information from theoretical models, tools tested, and processed material as well as on-line process measurements (with AE-data). The use of acoustic emissions for the general analysis of contact and friction issues has been demonstrated in [5, 6].

This work focuses on investigating problems during
- plate cutting (chipping and scratching, improper cutting geometry)
- hot rolling (galling and scratching)

Pilot tests and industrial measurements were made to study the above mentioned manufacturing problems. The AE was analysed studying the
- frequency spectra,
- the amplitude levels
- peak counts
- RMS-variation.

The software was designed in the National Instruments program LabView. In this work, a Kistler AE-sensor model 8152B (50 kHz-500 kHz) was used.

1. Analysis of cutting in a plate shear

Hardened steel grades set high demands on cutting tools such as shear blades and rotating blades. To get clean cuts, it is important to have good cutting conditions using appropriate cutting geometries. Hardened steels are a challenge to cut which leads to significant deterioration of the tools, including wear, cracking and chipping of the blades. Shear blades and rotating knives are expensive to regrind and replace. It is difficult to know exactly when chipping occurs or when the blades are to be replaced due to wear.

Even though is known that AE can be used to detect tool wear, it is not often used in steel industry processes. In this work, the technique was used for increasing the knowledge of potential applications and for the design of user friendly interfaces that might assist the decision making of the operators in the steel industry.

1.1 Practical tests and measurements in a standard plate shear

Cutting tests were performed in a plate shear (Fig. 1.). The target was to predict defects in the shear blade as well as bad cutting geometries from the acoustic emission signals. Pre-existing defects in the blade were useful for the evaluation. Knowledge of the proper settings was used for the identification of normal sound spectrums for optimal shearing. Inaccurate settings of clearance and cutting angles were used to generate deviations corresponding to the behaviour for bad cuts such as expected when wear occurs. If the clearance is too loose or too tight, then the cut will be irregular. A higher cutting angle will
concentrate the load on a smaller area. A too high angle can cause distortion in the cut. With a high angle, it is possible to cut through thick material with less power. Signals were recorded and analysed off-line. Based on the results, an on-line program was made where a video film was synchronized with the measurements (Fig. 2.).

![Fig. 1. Plate shear where the measurements were made.](image1)

![Fig. 2. Interface with on-line visualization and on-line analysis. The AE from the cut is recorded simultaneously with a video recording. For off-line use the user can sync the video image and the acoustic signal. The chipped and scratched areas on the blade show as peaks in the frequency range of 50-100 kHz.](image2)

The tests showed that a bad cutting geometry could be detected from the signal history during the cut. The signal from a bad cutting geometry is more irregular than from a proper cutting geometry and it also results in higher signal amplitudes. To be able to distinguish between good cuts in a wide production range, knowledge is needed about what a normal cut/cut signal looks like for the production range and also what variations that are acceptable.

The analysis of wear (cutting geometry) can be done simultaneously on-line when listening for scratches and chipping. The irregular AE can be traced using peak counting methods (counting the number of peaks exceeding a threshold) or by studying the variations in the amplitudes. Wear will develop over a period of time as the shear blades degrade. An on-line system would act as a support for operators to immediately detect serious defects or for regular planning for the replacement of blades during maintenance stops.
1.2 Statistic analysis of amplitude levels from the cutting tests

A drawback with AE is that it is not a physical parameter in the strict sense. Physical parameters are often required when setting boundaries that tell what is acceptable and what is not. These kinds of limits and assessments would be useful when making general models. For an evaluation, the AE signals measured were treated as a physical factor in a statistical model. It was seen that it was possible to make a fairly good model based on the results of a test series where the cut geometry was varied by changing the clearance and the blade angle (Table 1). The evaluation shows that it is possible to use the acoustic emission signals measured as an assessment parameter of process issues that can be difficult to formulate in physical dimensions. Other data such as the material dimensions and yield stress can easily be added to this kind of model. (In this study, a 2 mm thick carbon steel plate was cut.)

Table 1. Results from cutting tests.

<table>
<thead>
<tr>
<th>ID</th>
<th>Deviations</th>
<th>Clearance [mm]</th>
<th>Angle [deg]</th>
<th>Counts</th>
<th>Amplitude</th>
<th>RMS</th>
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<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>2</td>
<td>0.8°</td>
<td>446</td>
<td>2</td>
<td>4.2</td>
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<tr>
<td>2</td>
<td>c+1</td>
<td>3</td>
<td>0.8°</td>
<td>645</td>
<td>3</td>
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<td>3</td>
<td>c+1</td>
<td>3</td>
<td>0.8°</td>
<td>711</td>
<td>3</td>
<td>5.4</td>
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<tr>
<td>4</td>
<td>c+1</td>
<td>3</td>
<td>0.8°</td>
<td>723</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>c+1</td>
<td>3</td>
<td>0.8°</td>
<td>732</td>
<td>2.5</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>c+1, a+0.35</td>
<td>3</td>
<td>1.25°</td>
<td>1540</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>c+1, a+0.35</td>
<td>3</td>
<td>1.25°</td>
<td>2135</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>c+1, a+0.5</td>
<td>3</td>
<td>1.5°</td>
<td>244</td>
<td>2</td>
<td>4.4</td>
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<tr>
<td>9</td>
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<td>3</td>
<td>1.5°</td>
<td>266</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>a+0.5</td>
<td>2</td>
<td>1.5°</td>
<td>65</td>
<td>1.3</td>
<td>2.3</td>
</tr>
<tr>
<td>11</td>
<td>a+0.5</td>
<td>2</td>
<td>1.5°</td>
<td>127</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>c+2, a+0.5</td>
<td>4</td>
<td>1.5°</td>
<td>1205</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>c+2, a+0.5</td>
<td>4</td>
<td>1.5°</td>
<td>1214</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

The statistical evaluation (Fig.4) showed that the AE signals could be linked to the cutting parameters “clearance” and “angle”. The results showed a significant impact of the clearance and the angle on the parameters peak count based on a time period of 0.1 s. The cut giving the least vibration is the cut having the 2 mm clearance and the steepest cutting angle. The strongest correlation in this model was found using the peak RMS value in the evaluation which is in correlation with observations in the literature [2, 3].
With additional information about the production range (dimensions, grade, yield stress, etc.) and the acceptable limits for the equipment, this kind of model might be used on-line to indicate problems, alert operators and as a support for planning tool maintenance.

2. Analysis of Galling Problems During the Rolling of Ferritic Stainless Steels

2.1 Background

Steel under certain conditions and compositions has a tendency to stick onto the rolls, guides, etc. This phenomenon is called galling. Galling is a common problem between sliding surfaces. Galling is caused by adhesion where material gets stuck in asperities on tool surfaces. The surface defects build up over time. The protruding areas (build-ups) tear scratches in the manufactured products and can fall off and stick onto the product and get pressed in giving a poor product quality. Galling can create serious surface defects and contributes to increased wear on the production equipment. Galling does not occur for all conditions, some materials are more prone to sticking than others and some are sensitive to the contact conditions, temperature etc. It is difficult to trace exactly when galling occurs. Scratches and other problems are detected downstream in the process, when the galling has already caused a chain of damage. Ferritic stainless steel and aluminium alloys are more prone to galling than hardened steels, due to the atomic structure of their crystals and their low hardness.

In steel rolling, there are a vast number of sliding contacts that are difficult to monitor. In this work, galling was analyzed in pilot scale trials by listening to roller guides during hot rolling of ferritic stainless steel bars.
2.2 Study of galling in a fine sections rolling mill

There was no tendency for galling in the first tests. This was probably due to the relatively new and clean roller guides. Therefore artificial defects were welded onto the roller guides. It turned out to be difficult to locate the critical position for contact areas, so some trial and error was needed for finding the critical positions.

Table 2. Specifications of the trials.

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Ferritic stainless steel</td>
</tr>
<tr>
<td>Square bars</td>
<td>25 mm x 25 mm</td>
</tr>
<tr>
<td>Length</td>
<td>0.5 and 1 m</td>
</tr>
<tr>
<td>Temperature</td>
<td>950 °C</td>
</tr>
<tr>
<td>Rolling speed</td>
<td>1 m/s</td>
</tr>
</tbody>
</table>

![AE-sensor mounted with a magnet at the entry roller guide in Swerea MEFOS pilot section mill.](image)

Fig. 5. AE-sensor mounted with a magnet at the entry roller guide in Swerea MEFOS pilot section mill.

![Artificial defect (weld) inside the roller guide. Resulting scratch on hot rolled steel bar](image)

Fig. 6. Rolling tests made in Swerea MEFOS pilot section mill.

The artificial defects generated scratches on the bar surface during rolling that could be predicted from the AE signals recorded. Irregular scratches showed as irregularities in the AE signals.
In the tests, it was seen that a proper positioning of the sensors might be important. The origin of scratches can come from different unexpected sources before or after the mill stand. Efficient pinpointing the source of scratches depends on adequate process knowledge and smart positioning of sensors for the AE system.

![Fig. 7. Comparison of acoustic response during a normal bar (top) and a scratched bar (bottom).](image)

3. Industrial Tests

Industrial tests were made in a roll leveller to study if galling behaviour could be traced inside a continuous processing line. An AE-sensor was attached on one of the housings of a bearing in a roller leveller. The evaluation of the AE signals showed that the galling might be seen as slightly higher amplitudes in the normal frequency range. However, no safe general conclusions about the leveller conditions could be made for avoiding galling, since the process conditions and the material properties vary. Still the tests showed that the technique is applicable for harsh conditions.

![Fig. 8. Comparison of AE for non-sticking and sticking material passing a leveller.](image)

a) Frequency spectrum for strips that does not stick on rollers  
b) Frequency spectrum for strips that stick on rollers
4. Summary and discussion

The pilot tests were useful for evaluating the possibilities of using AE techniques in industrial metal working applications. Methods for identification of common problems in steel production using AE were identified. Process disturbances were detected as high frequency sounds and in irregularities in the measured AE signals. The detection of problems could be made from frequency analysis or from the amplitude level or by using peak counting.

In the scratch related cases, the high-frequency sound was strongly linked to the problems and detection was fairly simple, at least in the pilot tests. In industrial measurements, defects could be detected with the same techniques, however, since the study could not cover the influence of the normal variations occurring in full production, no general conclusions could be drawn for avoiding problems. It would be useful to link the acoustic evaluation with the material handling system to be able to set limits and threshold values for the various indicators.

The statistical evaluation of number of counts and peak values for various cutting geometries shows that the technique might be used in a more general form. The quantified AE such as counts and peak values can be used in a wider extent where there is a lack of general parameters that describe the production condition.

The main conclusion is that the AE technique appears to be useful in industrial applications such as steel production lines. The work showed that all the problems investigated could be detected by means of acoustic emissions.

5. Acknowledgement

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6. References