Journal of Materials Processing Tech. 249 (2017) 512–521

Contents lists available at ScienceDirect

Journal of Materials Processing Tech.

journal homepage: www.elsevier.com/locate/jmatprotec

Research Paper

Process monitoring of the wire drawing process using a web camera based vision system

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ARTICLE INFO

Keywords:
Wire drawing
Webcam
CCD-camera
Process monitoring

ABSTRACT

Wire drawing is a cold metal forming process where a wire is drawn through a series of dies, reducing the wire dimension, and enhancing the material properties. The wire drawing process requires lubrication to function, as discrepancies in the lubrication can cause failure of the entire process. Such incidents can be costly and there is a need to monitor the process so that changes in the lubrication can be detected, and addressed, before failures occur. The aim of this work was to determine whether a CCD-camera could be used to monitor the wire drawing process. The purpose of the monitoring was to detect if the process was about to fail. In this work the failure of the process was initiated by removal of the lubricant, causing galling between the wire and the die. The signal from the CCD-camera was compared to the signal from a drawing force measurement that clearly indicates when the friction in the die increases, which in turn indicates imminent failure of the process. It was found that the CCD-camera signal clearly indicated the removal of lubricant, and thus failure. In this work, the CCD-camera was tested on two different wire materials and two different lubricant, both with positive results. All tests were performed in an industrial wire drawing setup.

1. Introduction

Wire drawing is a metal cold forming process where the dimension of a wire is reduced as it is drawn through a series of conical dies. Since the dimension of the wire is reduced through a deformation process the wire material properties are also affected. Wire drawing causes large deformations in the wire and high friction forces in the drawing die, the process is therefore dependant on lubrication to function. The process window for wire drawing is quite wide but if the lubrication of the process fails, there is damage to both the tools and the wire.

Many manufacturing processes use process monitoring systems to monitor the product quality in-line. However, process monitoring is rarely used in the wire drawing industry. If the quality of the wire is investigated, then the investigation is performed on the finished wire. Enghag (2009) describes the use of the eddy-current (EC) testing method for finding defects in steel wire products. He claims that stationary probes can be used to detect short defects, these probes are inexpensive and can be installed after each die in a wire drawing machine. To be able to detect a long defect, such as a scratch, a rotating probe has to be used, this type of probe is substantially more expensive than a stationary EC-equipment. With this type of equipment defects with a depth as small as 0.05 mm can be detected, according to Enghag.

In the 1980s and 1990s experiments were done aiming at monitoring the wire drawing process using a device measuring the electrical resistance between the wire and the die. This method was developed by Nilsson and Stenlund (1984), and evaluated by Holm et al. (1985). Nilsson and Stenlund (1984) presented the principles of the monitoring technique, which follows. The wire is inductively electrically charged before going into the drawing die, which must be electrically separated from the rest of the drawing machine. A transducer is connected to the drawing die on the side where the wire exits, measuring the resistance between the die and the wire. The resistance between die and wire was found to be in the range 0.2–200 mΩ. The researchers also performed an experiment where they applied the monitoring system to drawing of stainless steel wire, indicating promising results. Holm et al. (1985) continued the evaluation of the method by performing multiple long term drawing experiments in drawing plants while using different types of lubrication. Holm et al. concluded that the method works well and that it can detect small defects even at high drawing speeds. However, the data analysing method used can only detect events that lasts longer than 20 milliseconds, due to the use of analog signals. For future work they suggest to add external signal processing to be able to capture shorter events and to be able to monitor the wear of drawing dies.

Several attempts to monitor the lubrication process in wire drawing has also been done using acoustic emission (AE). Pease (1984) filed a

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http://dx.doi.org/10.1016/j.jmatprotec.2017.06.020
Received 6 April 2017; Received in revised form 14 June 2017; Accepted 15 June 2017
Available online 27 June 2017

patent for flaw detection in wire drawing using AE. This was inspired by a paper published by Sato et al. (1980) about assessment of the frictional condition in wire drawing of aluminium using AE. The group mounted an AE-sensor on the drawing die and could estimate the frictional conditions in the process with good results. Masaki et al. (1985) used piezo-electric sensors to capture the stress wave signals caused by the contacts between wire and the die. They compared the AE-signal with the drawing force, and the AE-signal showed good potential in being used to evaluate the lubrication conditions in the wire drawing process. Masaki et al. (1988) continued their work and published a paper where they investigated the frequency spectrum captured by the AE-sensor. They found good correspondence between the AE-signal, the roughness of the wire and the coefficient of friction in the process.

More recently Seuthe (2014) studied AE as a process monitoring tool for wire drawing process, which lead to a patent and a product which was presented at the wire expo in Düsseldorf 2016. The monitoring system analyses both the amplitude and the frequency spectrum of the AE-signal in real-time. The company claims that the system can measure die wear and that it is possible to increase the production rate using the system. The system consists of only one sensor, meaning only one die can be monitored. The system is also highly expensive, using multiple systems in one drawing machine is thus not convenient. Pejryd et al. (2016) also used vibration measurements for monitoring of wire drawing but used accelerometers instead of AE, showing promising results. The accelerometers used in their system was of the same type that today is commonly found in mobile phones, and were thus inexpensive. Their system only analysed the signal using filters, not going into the frequency spectrum, which means less processing power is required for each sensor. The system developed by Pejryd et al. is not yet commercialised.

Although much has been done in the field, none of above mentioned process monitoring techniques are used in the wire drawing industry today. AE is sensitive for external interference, causing the systems to risk giving many false error indications, which leads to unwanted production stops. The same issue occurs when monitoring the resistance between the die and wire. The systems are generally too sensitive and difficult to adjust. Another problem is that if a wire drawing monitoring system is to be efficient, one sensor should be placed at each die in the drawing line. This means that the sensors should be inexpensive to be viable for wire drawing.

Byrne et al. (1995) have studied tool condition monitoring in machining. From the groups work it can be seen that the type of sensors that have been more or less successful used for monitoring the wire drawing process such as force, temperature and vibration, have been successfully implemented for monitoring of tool wear in metal cutting processes. The group also discussed CCD-camera sensors and how they are used for tool wear monitoring in metal cutting processes.

Larsson et al. (2013) presented an investigation of possible monitoring processes for the detection of defects in the wire during the wire drawing process. One of the methods that were investigated was the use of a CCD-camera to monitor the wire brightness as it was winding up on the block in a drawing machine. Experiments displayed poor performance in detectability of wire surface brightness, due to ambient light and problems with uneven winding on the block.

The use of CCD-cameras for monitoring is today widespread in many, vastly different, areas. Atienza-Vanacloig et al. (2015) used a CCD-camera, and shape finding algorithms, to identify and monitor growth of individual tuna fish in underwater conditions. Liu et al. (2014) used a CCD-camera to verify weld quality dependence on temperature measurements in an additive manufacturing process.

More relevant to the wire drawing process, research has shown that CCD-cameras can detect tool wear in grinding and cutting processes. Kurada and Bradley (1997a) presented a vision system for tool wear monitoring. The system consists of a CCD-camera with high resolution and microscope objective, using a texture image segmentation algorithm to measure the tool wear. Kurada and Bradley (1997b) also published a review paper where different vision sensors for monitoring of tool condition was compared. Lanzetta (2001) presented a paper where the possibility of using a CCD-camera, and image processing, to monitor the condition on cutting tools was investigated. The paper described a process to identify worn areas on the cutting tool by analysing the light intensity profile in an image showing the tool edge. Lanzetta found good agreement between his measurements and the actual tool wear. Jurkovic et al. (2005) presented a paper using the same approach of analysing an image of a tool, with the aim to automate the wear monitoring process in a cutting process. They could automate the procedure by adding a detour in the toolpath, the tool pass by the CCD-camera in a predetermined path, the system captures images and analyse the wear as the tool pass by. Their measurements were comparable with results from microscopy of the tool edges.

The purpose of this paper was to investigate if a CCD-camera based monitoring system could detect changes in the wire drawing process in-line. The reasoning for this, is the possibility to develop simple to use, reliable and low cost solutions for monitoring of the wire drawing process in industrial settings. Equipment for CCD-camera monitoring of wire drawing was developed and tested in a single block wire drawing machine. The viability of the method was evaluated by a comparison of drawing force data and surface investigations of the wire. The capability of detecting changes in the wire drawing process in-line, such as changes in lubrication, could possibly help the industry reduce the number of tools in need of replacing, and excessive scrapping of damaged wire.

2. Materials and methods

The hypothesis in this paper is that if the surface of the wire is affected, for example by scratching/tearing or lack of lubricant, its reflectivity will change. An intensity measurement using an inexpensive CCD-camera should be able to capture this change.

To test the hypotheses a housing was designed that allowed a CCD-camera to record the wire as it was being drawn. From the recording an average intensity was calculated and plotted so that the process could be monitored. The average intensity signal was compared to the signal from a drawing force sensor that indicated when the friction in the die changed. Two tests were performed with different wire materials and lubricants to ensure that the monitoring could work for wires with various reflectivity's. All the tests were performed using a single block wire drawing machine, seen in Fig. 1.

The proposed monitoring method was evaluated by correlation between the drawing force signal and the CCD-camera signal. Further, the wire surface was investigated using optical microscopy, SEM, optical profilometry, and tactile surface roughness measurement.

2.1. Materials

The material used for this test were chosen based on their reflectivity. It was desirable to test materials with large differences in reflectivity to evaluate the stability of the monitoring system in different conditions. The process parameters, lubricants, and wire types used in this work are presented in Table 1.

Chemical composition and mechanical properties for the wire materials used for the different setups is presented in Tables 2–4.

2.2. CCD-camera monitoring

The CCD-camera housing was designed as can be seen in Fig. 2. The housing was designed as a dividable tube with hinges, this allows for an easy changeover procedure when the wire needs to be removed and replaced. The tube was also designed with small overlapping flanges to help shield the CCD-camera from ambient light. This was important since changes in the ambient lightning would be interpreted by the