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Process monitoring of wire drawing using vibration sensoring

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ABSTRACT

Automating the detection of processing conditions that may lead to defects in the wire during the wire drawing process is of high interest to the industry. Current practise is based primarily on operator experience. Increasing demands on product quality and process robustness emphasises the need for development of robust in-process detection methods. This work is focusing on investigating the potential of using vibration monitoring to detect process deficiencies or variations that may lead to defects in the product. Wire drawing of a carbon steel in different lubricating situations was used to investigate vibration signal response together with force measurements and surface investigation of the wire product. The results show that vibration measurement is capable of detecting loss of lubrication that leads to poor surface quality of the wire.

Introduction

The drawing of wire is an important manufacturing process used for several applications in many different materials such as e.g. steel, copper, aluminium, tungsten and molybdenum. In Sweden, the production of steel wire alone is around 225 000 tonnes per year. The requirements on surface quality and thereby the process robustness is extremely high for advanced wire products. One group of such products is spring steel wires that are e.g. used in automotive industry applications where the requirements on surface fatigue resistance are of utmost importance. Development of new specialised wire products places even higher demands on the processes.

Within the wire drawing process, surface defects are one of the potential quality problems that are of great concern to the industry. Surface defects may be caused by welding of small particles of wire material to the die surface which may cause scratching of the wire surface. Another cause may be that foreign hard particles will scratch the wire. The quality of the wire may also vary through the process due to a variation in lubrication conditions, e.g. reduced amount of lubricant picked up by the wire before entering the die, etc.

To control the wire quality, some different approaches are used. A normal praxis in industry is to use manual monitoring of the wire surface. This is however highly dependent on the operator's experience. In this, the operator makes an assessment of the lubrication conditions from the wire brightness on the block and is judging the risk of galling and scratches by experience. Touching the wire with a finger, studying the wire surface by a magnifying glass (requires stopping the process), rotating a micrometer around the wire are other methods used. Detecting the presence or risk for any type of defects can be addressed by adjusting the processing conditions such as the drawing speed, die cooling, etc., in order to improve the wire surface quality. Monitoring systems for detection of defects or variations in the processing conditions, and thereby assessing risk for quality problems on the product could be an advantage providing more objective judgement and secure decision support. This can also reduce the need for manual work.

The problem of automating the detection of defects or processing conditions that may lead to defects has been addressed over a long period of time. The approaches may be divided into direct and indirect methods. Direct methods are attacking the detection of defects on the wire itself through e.g. Eddy current (EC) testing and optical methods using camera arrays and triangulation of laser line deflections. The indirect methods aiming at measurement of process conditions or process signals that may show a risk for producing surface defects that have been studied include e.g. electrical resistance, acoustic emission, drawing force, wire surface brightness and die temperature. Pease [1], Masaki et al. [2,3] and Suzuki et al. [4] have studied acoustic emission. Equipment for measurement of the electrical resistance between wire and die has been developed by Nilsson [5–8]. Nilsson also made studies of temperatures using wire and die as

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thermocouples. Larsson et al. [9] evaluated the potential of using force measurements in plant experiments and found that this could be a promising method of detecting starved lubrication conditions. These efforts however, have not resulted in any significant implementation in wire drawing plants. One of the present authors have used vibration signals and advanced signal analysis techniques for studying the possibility to detect process changes in metal cutting operations [10–13].

Accelerometers are quite cheap and easy to apply in an industrial situation. Measuring vibrations with accelerometers can therefore be seen as an interesting technology for implementing in industrial environment provided that the signals picked up can be analysed and interpreted and show strong enough differences between wanted and unwanted conditions. The use of vibration sensing was therefore identified as a potentially interesting method to evaluate for possible use in the wire drawing process to identify changes in process conditions that can lead to quality issues on the drawn wire. This work was therefore directed towards investigation of the capability of using vibration signal as a basis for a process monitoring system for wire drawing.

Experimental

Materials

The wire rod that was used in all the experiments was made from a silicon chromium alloyed steel grade Oteva 70, Table 1, which was mechanically descaled by shaving and had a diameter of 5.9 mm. The hardness (HV_5) of the wire rod and the drawn wire was 360. The wire rod had a yield strength of 635 MPa and an ultimate tensile strength of 1025 MPa while the drawn wire showed a yield strength of 102 MPa and an ultimate tensile strength of 1200 MPa. Prior to the drawing experiments the wire rod was dipped in a salt-based lubricant carrier.

The wire drawing experiments were performed under lubricated conditions using a calcium soap dry lubricant, Traxit TR40, with a melting point of approximately 165 °C and a density between 650 and 750 kg/m^3. Cemented carbide nibs, Paramount TR 4, were used in all experiments.

Wire drawing experiments

The wire drawing experiments were conducted in an experimental set up for wire drawing at Örebro University, Figs. 1 and 2. This set up is a single die machine and the parameters used were; wire reduction from 5.9 to 5.15 mm, die angle 12°, bearing 30%. For each of the experiments, several hundred metres of wire were drawn to ensure that the measured signals come from a stable and representative experimental condition.

Table 1
Chemical composition (wt%) of the Si/Cr-alloyed steel wire rod used in the wire drawing experiments.

C	Si	Mn	P_{max}	S_{max}	Cr	Fe
0.50–0.60	1.20–1.60	0.50–0.80	0.025	0.02	0.50–0.80	Balance

Vibration in the direction of the wire was measured using an accelerometer with a sampling rate of 12 500 Hz. The vibration sensor was applied on the drawing box and held in place by magnetic fastening, Fig. 2. The signals obtained were processed in Matlab and evaluated using Fourier transformation. Forces were measured with KIS load cells that was built in to the drawing box that contains both the dry lubricant container and the drawing die holder.

At first, an experiment (Experiment 1) was performed as a pre-study in order to investigate if the hypothesis that vibration signals can be used to detect poor processing conditions in wire drawing was worth pursuing. Here, a wire speed of 0.5 m/s was chosen. This represents a common drawing speed in the early stages of industrial wire drawing. Two different lubrication conditions were evaluated, i.e. wire drawing using a lubrication box filled with the dry lubricant, and wire drawing with an empty lubrication box.

The subsequent experiments were performed in order to in more depth investigate the capability of vibration measurements as a process monitoring technology for wire drawing processes. For the following experiments, great care was taken to place the vibration sensor in the same position and orientation for all experiments.

In order to find stable tribological drawing conditions to be used in the following experiments, and to investigate the sensitivity of vibration measurements to drawing speeds, an experiment (Experiment 2) was performed using a lubrication box filled with the dry lubricant and three different drawing speeds, i.e. 0.1 m/s, 0.25 m/s and 0.5 m/s.

Experiment 3 was a revisit to the conditions used in the pre-study. Based on the results from Experiment 2, the wire speed was of 0.5 m/s was chosen. This resulted in a repetition of the

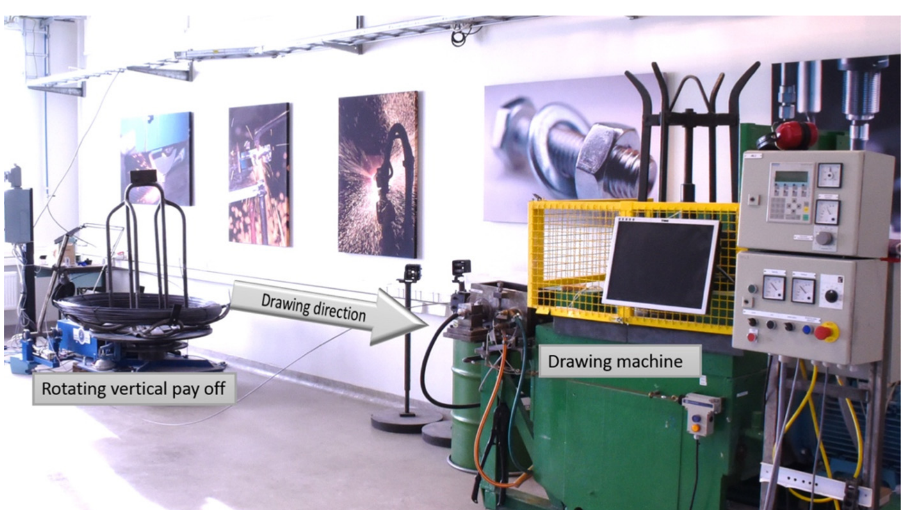

Fig. 1. Drawing line where the experiments were conducted.