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Sensorless fault detection in linear axes with dynamic load profiles

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Abstract

Press lines are commonplace in the automotive industry. They typically use transfer systems to transport parts from one manufacturing stage to the next. Since these transfers are forced to endure great loads, both the gears and the shaft break fairly frequently and need to be replaced. Since every minute of downtime these maintenance tasks require costs manufacturers a lot of money, a condition monitoring system able to detect or predict damaged parts in linear drives would allow them to schedule maintenance so that downtime can be minimized and costs reduced. This paper presents a new method of fault detection for dynamic load profiles which is non-intrusive and requires no additional sensors. After a brief overview of the state of the art in fault detection and condition monitoring, the new method will be explained and demonstrated using measurement data from a press transfer.

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Keywords: Condition monitoring; Servo system; Motor current signature analysis

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1. Motivation and state of the art in linear axis fault detection

Damages on press lines, especially those occurring to critical components such as the press transfer, will usually result in a forced shutdown of the entire press line. If the worsening physical condition of the components in

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question is known before the damage gets too bad, it is however possible to schedule repairs in a way that minimizes downtime. To identify wear and damage to drive components in advance, the press can be equipped with a condition monitoring system, the installation of which usually requires a great deal of cost and effort, depending on how accessible the drive system is.

Condition monitoring systems comprise sensors for recording signals, processors (PC, microcontroller, etc.) for data processing and displays for the visualization of the plant status. The retroactive installation of condition monitoring systems on presses is costly and requires a lot of effort, particularly the sensor installation. Critical components such as roller bearings or gears, the condition of which is typically monitored by acceleration sensors, are usually difficult to reach. Therefore, this paper investigates the possibility of monitoring the condition of critical press components without the use of additional sensors. Modern presses feature a series of electrical main drives and auxiliary drives. These drives, for the most part, are regulated servomotors whose operation relies on data such as rotational speed and phase current in the internal control system. These data form the basis for the proposed sensorless condition monitoring.

Established condition monitoring methods based on motor current analysis enable the detection of electrical faults such as short-circuited coils or broken rotor bars in asynchronous motors [1, 2]. Le Roux investigates experimentally how rotor faults on permanent magnet synchronous machines affect the motor current [3]. Nandi provides an overview on condition monitoring for electrical motors [4]. An extensive review of the relevant research up to 1999 can be found in [5]. Mechanical faults on motor driven components such as gear damage in drives can also be detected via motor current analysis [6, 7, 8, 9, 10]. Common to all of the mentioned publications is that they investigate rotating components. Indications for faults such as gear damage are derived from increases in the amplitude of characteristic frequencies like the gear mesh frequency or the gear rotation frequency on a gear rack at constant speed or the characteristic order for variable speeds.

In contrast to these works, the focus of this paper lies on the detection of gear rack damage on linear axes with dynamic load profiles. The selected linear axis has no constant operating point. Therefore, methods based on the detection of specific characteristic frequencies cannot be applied. The anomaly caused by the fault is non-periodic and occurs only when the damaged section of the gear rack is traversed. In order to detect gear rack damage in spite of this difficulty, a new signal based detection method for dynamic motion profiles is proposed and experimentally verified.

The signals needed for the fault detection are read directly from the drive‘s control so that no external sensors are necessary. In contrast to the diagnostic tools described in [11] and [12] which use motor torque or the axis position, the new method is based on the evaluation of the motor current. This has the advantage of creating a more universal diagnostic tool, since the motor current can easily be measured drive-independent or alternatively read from the drive control. The inclusion of the axis position allows the determination of the exact location on the gear rack where the damage has occurred. A comparison of several consecutive measurements covering the same section of the gear rack also provides additional reliability to the new detection method.

2. Time-frequency distributions

Signals are classically represented in either the time domain $s(t)$ or frequency domain $S(f)$. Both representations are averaged with respect to the omitted variable and therefore unable to express local changes in that variable. Time-frequency analysis concerns the study of discrete signals with time-varying frequency content $p(t,f)$. Time-frequency distributions (TFD) reveal the energy content of a signal in the 2D time-frequency space [13]. Therefore a TFD is usually designed so that the integral over the time-frequency plane is equal to the energy of the signal.

A fundamental principle limiting the TFDs is the uncertainty principle which limits the achievable time resolution for a given frequency resolution and vice versa [13]. Methods of time-frequency analysis such as Fourier, Hilbert or wavelet transforms vary mainly in their trade-off between time and frequency resolution and their windowing technique [14]. While this makes most TFDs formally equivalent, their usage and correct parametrization for any given application will usually make some methods preferable to others.

One important aspect in the selection of a TFD method is the number of the basic components in the signal. While the Short-Term Fourier Transform (STFT) [17], the Wavelet Transform (WT) [16] or the Wigner-Ville distribution (WVD) [15] work well with monocomponent signals, they produce a large interference for overlapping