Robotics and Computer-Integrated Manufacturing 27 (2011) 785–793

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

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

Feed-axis gearbox condition monitoring using built-in position sensors and EEMD method

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ARTICLE INFO

Article history:
Received 3 March 2008
Received in revised form
21 December 2010
Accepted 23 December 2010

Keywords:
Gearbox
Built-in position sensors
Machine tools
Condition monitoring
EEMD

ABSTRACT

This paper describes a kind of feed-axis gearbox condition monitoring system using the built-in position sensors such as motor encoders and linear scales with high resolution and high precision, which is more directly related to machine dynamics and is sensitive to the early and weak fault. To obtain the position information, several data acquisition approaches for open numerical control systems (NCs) and commercial NCs are suggested. Then, the mathematical models between the faults and the position signals are thoroughly investigated. Finally, the ensemble empirical mode decomposition (EEMD) method is introduced to localize the fault of the feed-axis gearbox. The experimental results show that it is effective to use built-in position sensors and EEMD method for on-line monitoring the gearbox state and fault diagnosis.

1. Introduction

The gearbox is one of the most important components of a high-performance numeric control machine tool feed axis. In the machining process, the vibration, collision and deformation have much effect on the feed-axis driving system, especially the gearbox. And the gearbox parts such as bearings, worms and gears will suffer from backlash, misalignment, friction, wear, corrosion, crack, breakage, etc. Any defect in the gearbox leads to machine tool downtime and results in a loss of production. Therefore, it is essential to investigate on new technology for feed-axis gearbox condition monitoring and fault diagnoses.

Information about the gearbox fault should be acquired in advance to solve the above mentioned problems. Now, the sensors like vibration, temperature, AE, image, displacement and acceleration have been used to obtain the state information [1]. However, such inherent limitations as high cost, inconvenient mount and high bandwidth have blocked their practical application as the on-line state observation method of feed-axis gearbox. A kind of feed-axis gearbox condition monitoring system is proposed in this study, in which signals acquired from the built-in position sensors including the linear scale and motor encoder are applied to monitor its state based on the effective and robust signal processing and feature extraction technologies. Compared with the conventional extra sensors, the built-in position sensors have less noise contamination and are more directly related to machine dynamics. Therefore, it is rather easy to interpret the built-in position information and produce more accurate diagnoses. In addition, the measurement is cheap and the signal is sensitive to the early and weak faults using the built-in position sensors with high resolution and high precision.

Currently, some work has been done on the research and application of the built-in position sensors. Plapper [2] measured the reversal backlash of the ball screw using the motor encoder and linear scale based on open NCs. Jeong and Chow [3] estimated the cutting force from the currents of the rotating, stationary feed motors and motor encoder on a milling machine. Tischler and Goldenberg [5] used the feedback angular position by the rotary scale and motor encoder to analyze the kinematic error in the precision positioning applications of a harmonic drive. Kim and Chu [4] established the relationship between the servo control characteristics and the position information. But these studies are different from this paper in essence that concerns with fault diagnoses of the feed-axis gearbox. Sweeney and Randall [6] showed that a combination of effects will lead to speed fluctuations in a gear-based power transmission system. Sasi et al. [7] used the built-in encoder for monitoring electric motors. Gu et al. [8] developed the theoretical basis and practical implementation of instantaneous angular speed data acquisition and instantaneous angular speed estimation when noise influence is included. Feldman and Siebold [9] estimated the damage location and its size in a rotor system using the encoder information. Although these investigations show that the built-in position information is useful for the condition monitoring of a wide

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doi:10.1016/j.rcim.2010.12.001

variety of machines, they pay little attention to the non-linear and non-stationary gearbox fault diagnoses.

Additionally, some typical faults, such as friction, pitting, wear, corrosion, crack, backlash etc., may cause the feed axis vibration in machining process. Due to the non-linear and non-stationary characteristics of the fault signals, it is hard to troubleshoot these complex faults only with the conventional signal processing methods either in the time domain or in frequency domain. To handle the problem, the time-frequency analysis techniques such as the short time Fourier transform (STFT), wavelet transform (WT) and Wigner–Ville distribution (WVD) are often used [10–12]. Although they have shown the great merits in many fields such as noise processing, filter and incipient fault detection, one of their major limitations is non-adaptiveness.

A novel method named Hilbert–Huang transform for analyzing the non-linear and non-stationary data has been developed by Huang et al. [13], a key part of which is the "empirical mode decomposition"(EMD) method. With EMD method, a given signal can be decomposed into a finite number of oscillatory components through a process called the sifting algorithm. These components, that is, the intrinsic mode functions (IMFs), represent the oscillation modes embedded in the data. Since the decomposition is on the basis of the local characteristic time scale of the data, it is applicable to the non-linear and non-stationary processes. Many simulations and experiments have shown that it is highly efficient to use EMD method for the mechanical part fault diagnoses [14–16].

A drawback of EMD is the appearance of disparate scales across different IMF components, that is, mode mixing, which is often the result of signal intermittency and can leave the IMF components devoid of physical meaning. To overcome the scale separation problem without introducing a subjective intermittence test, a new noise-assisted data analysis (NADA) method called ensemble EMD (EEMD) was proposed [17]. The EEMD defines the true IMF components as the mean of an ensemble of trials, each consisting of the signal corrupted by additive white noise of finite variance.

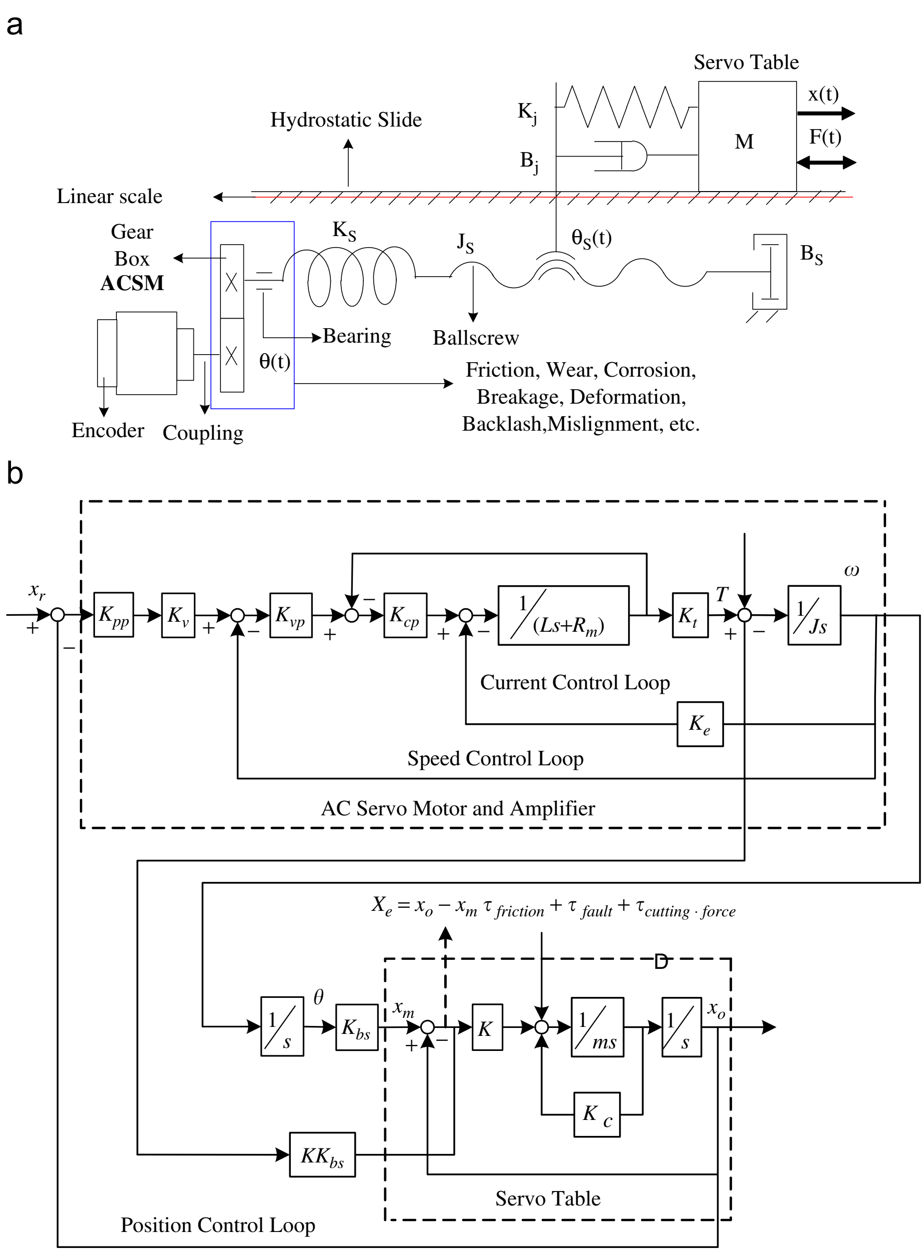

Fig. 1. Mechanical and control system design of machine tool: (a) mechanical configuration of feed drives; (b) block diagram of the servo system.