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Review

Condition based maintenance of machine tools—A review

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ABSTRACT

During the operation, machines generate vibrations which result in deterioration of machine tools eventually causing failure of some subsystems or the machine itself. The vibration signatures analysis can be used to detect the nature and extent of any damage in machines and components or any maintenance decisions related to the machine. The condition based monitoring has become an important technique to ensure the machine availability by timely maintenance actions and reducing breakdown maintenance. This paper presents the review of work presented by various researchers on instruments used for vibration measurement and signal processing techniques for condition monitoring of machine tools in manufacturing operations.

Contents

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Introduction

Mechanical systems with reciprocating or rotating components such as bearings, engines, gearboxes, shafts, turbines and motors produce low levels of vibrations when designed properly. Vibration is one of the feature of mechanical machinery that if uncontrolled, can cause minor or serious performance, operational or safety problems. Machine vibration is considered as a central component for machine status monitoring, thus it has attracted greater attention towards the researchers to acquire, analyze and quantify this parameter for improving operational efficiency, reduce maintenance cost, enhance structural reliability and safety against catastrophic failure in a real-time. Despite all the technological developments, an automated manufacturing is not achievable in the absence of reliable tool condition monitoring (TCM) systems [1]. Tool condition is a significant parameter that directly influences the machining quality. Vibration can be characterized in terms of three parameters: amplitude, velocity and acceleration, which are observed for the purpose of determining machinery integrity. The sensitivity of instruments used for measuring these parameters alters with the frequency of the vibration. In general, an amplitude sensor is applied to pick up low frequency signals, velocity sensors in the middle ranges, and accelerometers at higher frequencies [2]. Any malfunctioning or deterioration in the operation of a machine tool structural component gives rise to increase in vibration level, which further affects the performance level with respect to time. On a steady footing, the monitoring and diagnosis of a machine are needed to surmount these problems by continuously monitoring the machine health and predicting or detecting faults and malfunctions. The International Standards Organization establishes internationally acceptable criteria for comparing the root mean square (RMS) of the vibratory velocity of a machine with the vibration severity charts to determine the condition of a machine [ISO 2372]. Human controlled machining maintenance has become the stumbling block for the advance of the new manufacturing trend, e-manufacturing [3]. Vibration monitoring has become an essential technique in mechanical structural product's research, design, produce, apply and maintenance [4].

Vibrations as a diagnostics tool

Diagnosis is the art of determining machine health from its signs or symptoms to fix what the fault is and which element of the system is affected. The vibration signatures of the machine can forewarn the operator for time based maintenance or to arrive at a crucial decision before any severe problem or unscheduled downtime. The amplitude of the vibration signature gives an indication of the severity of the problem, whilst the frequency can indicate the origin of the defect [5]. The extraction of these signals can be regarded as a valuable tool to detect and diagnose the run-up failures of the machines and equipments. It is a hard job to extract the feature from the acquired signal as interferences are occurred due to the presence of noise. It arises a need to develop a processing and analysis system of high level data to provide veracious extraction of data about the status of the machine. Several signal processing techniques like statistical domain, frequency domain, time domain and time–frequency domain are applied for obtaining diagnostic information.

Vibration analysis is the most prevalent method used for monitoring, detecting and analyzing the structure's condition in real time or at specified time intervals, due to fast data collection and interpretation. It is becoming more famous and familiar in industry due to non-destructive in nature and allows sustainable monitoring without any interfering in the operation.

Machine tool components can be diagnosed with technical and mathematical approaches for e.g. shafts misalignment by orbit analysis, bearings by power spectrum analysis, gears by cepstrum analysis etc.

Machine condition monitoring (MCM)

The environment of machining operations changes unpredictably and implementing a well consulted damage identification strategy is needed to heighten structural safety, reduce maintenance cost and avoiding human and economic losses. MCM is a continuous and an autonomous tool for measuring the various parameters (i.e. vibration, performance, bearing temperature, etc.). It provides regular or constant monitoring of distinct components of the structural and mechanical systems in order to identify the need for remedial action, and to avoid incipient failures. It can be classified as online and offline. The structural health monitoring (SHM) consists of three steps, i.e. signal monitoring, signal processing, and data interpretation used in damage identification system. Signal processing techniques includes statistical time series models, Fourier transform, short time Fourier transform, Cohen's class, wavelet transform, Hilbert–Huang transform, whereas data interpretation includes artificial neural networks, fuzzy logic, support vector machine, Bayesian classifiers, hybrid classifiers [6].

Methods of machine condition monitoring

The machine condition monitoring methods can be divided into two types: model based and feature based methods [7].

Model-based methods also called failure detection methods used to find a precise computational model to correlate the observational signatures of abnormal structures with analytical or quantitative models to detect the damage parameters. Various models such as autoregressive and moving average (ARMA) model, hidden Markov model (HMM), artificial neural network (ANN) etc. are falling into this category.

Feature-based methods are performed in two steps, one is feature extraction from the signal and another is the decision-making based on these features. Various features can be used, including

(a) Time-domain features (such as mean, standard deviation, range, root mean squares, skewness, kurtosis, crest factor, etc.);
(b) Frequency-domain features (such as frequencies, damping ratios, energy in different frequency bands, etc.);
(c) Spatial domain features;
(d) Time–frequency domain features (i.e. time–frequency distribution);

The various vibration monitoring methods and signal processing techniques for structural health monitoring has been described in [8].