Study on Condition Monitoring of Lathe Cutting State Under Various Cutting Conditions Based on Motor Current Signature Analysis

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Abstract. Lathe machining occupies a large proportion in modern production and processing, which affects the machining accuracy of the workpiece and results in vibration and noise of the machine tool. To improve the efficiency of lathe cutting state monitoring, this paper presents a new method on studying the monitoring of lathe tool, with Motor Current Signal Analysis (MCSA) as the main research method, the characteristics of stator’s working current are selected as the analysis object. Three cutting depths, 1mm, 2mm, and 3mm are respectively performed on the same workpiece material, and the cutting conditions are blunt tool and sharp tool. The frequency characteristic of the current is analyzed under various cutting conditions mentioned above and the internal relation of the current variation and the cutting condition is presented as the conclusion of this paper, by which provides a new idea for the research of conditions monitoring and fault diagnosis in field operation on lathe tool.

1. Introduction
In traditional mechanical state monitoring, the cutting tool state recognition usually adopts the sensor and the dynamic test technology to analyze the vibration signal. The most widely used method is to install vibration sensor on the tool, collecting the vibration signal of the tool, and then identify the cutting state of the tool through analysis. This method is relatively simple and is mainly used in case of good operating conditions, but for the case of large vibration interference, the method has great limitations, and the results are often unsatisfactory. Current signal contains a lot of tool state information, using current analysis method has the advantages of low cost, non-intrusive installation, strong anti-interference and so on, so it is a practical industrial application method.

Motor Current Signature Analysis (MCSA) is a noninvasive technology with the idea that the variation of motor current can reflect the change of the external load condition of the motor, which drives the peripheral equipment thus the dynamic characteristics of the motor drive is reflected. MCSA has already been applied to fault diagnosis in Refs [1-4]. The basis MCSA idea is shown in Fig.1 The stator current signal of the motor is collected, and then on which Fast Fourier Transform (FFT) is performed for spectrum analysis. The cutting frequency characteristics of the turning tool are analyzed from the amplitude spectrum diagram, and the changing pattern of the cutting state on the turning tool is analyzed for state recognition. The MCSA method uses the stator current signal of the motor as the
entry point for conditions monitoring to study the corresponding relationship between the current characteristics and the lathe cutting conditions.

Whenever there is a load fluctuation, a change in speed occurs thus changing the per unit slip, which subsequently causes changes in sidebands across the line frequency ($f_l$). The current will have two components, magnetising current component ($I_M$) that is in phase with flux vector; and torque producing component ($I_T$) that is 90° ahead of the flux vector. The air-gap torque in the induction motor consists of a constant (or average) torque and some oscillatory torques due to torsional vibrations at frequency ($f_v$) with respective phases. Due to torsional vibration, these components will also have an average value as $I_{M0}$ and $I_{T0}$, respectively, the current in any phase of the motor, which would have been a pure sinusoidal function, had there been no defects. The C-phase current can be given by the following equation [9]:

$$I_C = I_{CM} \sin(2\pi f_{l} t) + I_{CT} \cos(2\pi f_{l} t)$$

$$= I_{C0} \sin(2\pi f_{l} t + \theta_{b}) + \sum_i \left(\frac{A_{CT_i} + A_{CM_i}}{2}\right)\cos(2\pi (f_{l} - f_{i}) t - \theta_{M_i}) + \left(\frac{A_{CT_i} - A_{CM_i}}{2}\right)\cos(2\pi (f_{l} + f_{i}) t + \theta_{M_i})$$

(1)

2. Performance analysis

2.1. Methodology

In this section, the architecture of the monitoring for lathe cutting will be described. The overall procedure is presented as Fig. 2, the entire experimental strategy could be seen as two cutting types, Sharp lathe tool and blunt lathe tool. With each type, 3 different cut depths feeds are machined on the same kind of material individually, during the machining, the stator current signal is sampled. With the sampled data, on which the Fast Fourier Transform will be operated, the frequency spectrum is obtained with which a sideband analysis and envelop analysis will be carry out. At last, the characteristic of both the sharp and blunt will be compared.
2.2. Experimental Setup

To study the Condition of lathe cutting under various conditions with MSCA, several experiments have been carried out with the industrial graded equipment. In this experiment, as Fig.3 and Fig.4 shows, a general lathe (CZ6132A) with an operating motor (YD160s-4/6) who’s current 9.5/7.7 A is used. For current of the motor stator sampling, an AC current clamp, attached to a data logger connected to a laptop, is clamped on the green B inlet wiring of three-phase to the motor. The entire algorithm has been executed in an intel core i7, 8-GB processor in MATLAB 2015a software environment. For various lathe cutting, several amount of feeds for both of sharp and blunt tool have been carried out as Fig.3 shows.

As the Table 1. shows below, two types of cutting tool, sharp and blunt, have been used in the experiment with same moving speed to the same processing materials. In order to compare, different amount of feeds corresponds to different number of cuts have been implemented.
Table 1. Parametric value in experiment.

| Tool type | Moving speed | Processing materials | No. of cuts | Feed amount Per cut |
|-----------|--------------|----------------------|-------------|---------------------|
| Sharp     | Mitsubishi nx2525 | A3 steel rod Length:136mm diameter:22mm | 12          | 1mm                 |
|           | 0.05m m/r     |                      |             |                     |
| Blunt     | Kyocera PR930 | A3 steel rod Length:136mm diameter:22mm | 13          | 1mm                 |
|           | 0.05m m/r     |                      | 6           | 2mm                 |

2.3. Experimental Results

Because of the advantage of convenient signal acquisition and high information integration, the current signal is selected as the basis of tool analysis. When the rotor drives the workpiece to rotate in contact with the tool, the rotational stiffness changes and then produces a periodic fluctuation in the load torque. In order to balance the load torque fluctuation, the motor will produce a corresponding electromagnetic torque, resulting in a nonlinear current signal in the stator current of the motor. Therefore, the stator current will in-crease with the increase of the load, which is, with the increase of the feed amount, the stator current will also increase accordingly.

During the process of lathe cutting, the information of tool machining state is included in the frequency range of the current signal, thus Fast Fourier Transform is the very first and important step for the whole process. Fig.7 shows FFT of the 2mm feed process, the power frequency is 50Hz, the sampling frequency for signal is 25000Hz, and the rotation speed of the lathe is 1080rpm, which makes the rotating speed frequency lathe is 18Hz. As the figure shows, the modulated sideband appears on both sides of the centered power frequency spectrum equidistantly with a approximant distance 2.8Hz. With the machining proceeds, the amplitude of the sideband varies, by analysing the components of which, the characteristic parameters of the cutting tool of the lathe can be obtained.

To summaries all the computing results like Fig.7, a figure of root mean square for each cutting depth is shown as Fig.8 and Fig.9. Both of the sharp and blunt lathe tool have a trend that as the remaining materials drops, the stator current value drops.
From other aspect, an envelope analysis is performed for more characteristic for comparison of two types of tools. As the Fig.10 shows, with a Hilbert transform for the FFT signal, envelope spectrum of sideband signal modulated by various machining condition is obvious. The peak of 31.5Hz is f0-fx, while f0 is power frequency and fx is the spindle rotating frequency, the amplitude of sharp tool is way larger than the blunt one, which indicates that tool wear could be recognized as a reference. For most of the modulated sideband frequency, the amplitude value of the blunt tool is higher than the sharp one while only the 3 frequency, 40.1Hz, 43Hz, 45.8Hz near the 50Hz contrariwise.

3. Conclusions
This paper proposed a method of monitoring on lathe cutting condition under various cutting conditions based on motor current signature analysis. In the proposed framework, FFT process was designed to obtain spectrum in a stator current signal. Then, frequency spectrum analysis was performed to obtain the characteristic. Finally, the experimental data of the two types of the tools had been compared in order to find more patterns from envelope spectrum. The results show that the larger the spindle load, the greater the stator current value detected. The FFT of the sampled signal, frequency domain, shows that different cutting state such as amount of feed, cutting depth, sharp or blunt, have different amplitude of sideband, which leads to the envelope analysis demonstrates that the spindle frequency and its doubling frequency contains lots of cutting state characteristic information. The results show that the spectrum analysis has a certain reference value for tool wear and fault detection.
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Author Contributions
SQ.H. improved the algorithm and wrote this paper; ZX.Z. analyzed the data; YB.L. conceived the experiments and designed the experiments; FS.G provided some key ideas and revised the manuscript.

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