Research on the Roughness Detection of Hot-Rolled Steel

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Abstract: As an important industrial material, hot-rolled steel has high strength and toughness, and it is easy to process and shape. So it has a wide range of applications in the fields of construction, bridge, shipbuilding and automobile. The surface roughness of hot-rolled steel is a key parameter that need to control and it has a great impact on the performance of the steel. In order to improve the efficiency of hot-rolled steel roughness detection, this paper introduces a method of online roughness detection system based on laser two-dimensional displacement sensor.

1. Introduction

Hot-rolled steel is an important steel, and it’s made of the slab which is rolled by the roughing mill and finishing mill after heating. Due to the high temperature and pressure, the quality of the steel surface may not meet the requirements in the production of hot-rolled steel [1]. The surface roughness of hot-rolled steel is one of the technical indicators that need to be monitored. Surface roughness has a great impact on the performance of the steel, including elongation, tensile strength, wear resistance and so on [2]. Now the contact measurement is the main method in the detection of steel roughness such as the needle type roughness tester. The contact measurement need offline measurement with low efficiency, and may damage the steel surface. There are more researches on the optical non-contact detection, which can achieve online closed-loop control, but it is still difficult for real-time measurement in the part of measurement accuracy and speed.

Based on the surface roughness detection technology, this paper shows a system for online detection of steel’s surface roughness plate to solve the difficulty of online roughness detection.

2. Composition of the System

Surface roughness detection system consists of software, hardware and mechanical parts. The hardware structure diagram is shown in Figure 1. The system hardware includes: probe (laser two-dimensional displacement sensor), servo motor, driver, computer and so on. The detection principle is as follows: The entire device is installed above the industrial pipeline, where the probe is mounted on a two-dimensional displacement table. The computer controls the two-dimensional movement of the probe by controlling the servo motor. When there is no workpiece under the probe, the probe cannot collect the valid data because it is beyond the effective measurement range of the probe. When there is a workpiece under the touch probe, the laser beam emitted by the probe hit the surface of the measured object to obtain effective measurement signal, that is, the outline of the surface of the object data. These profile data are transmitted from the sensor's controller to the computer. Through the data filtering and other processing, the roughness value can be calculated and shown in the computer.
The mechanical structure of the system is shown in Figure 2. The probe is fixed by the connecting plate and two-dimensional displacement. The motor can drive the motion of two-dimensional displacement table, so the probe can achieve Z and Y direction motion. The probe emits a linear laser beam each time and can obtain the surface data of the steel surface in real time. As the hot-rolled steel moves in the X direction and the probe can move along the Y direction, the system can achieve the roughness measurement of multiple areas in the hot-rolled steel.

The software of surface roughness detection is developed in Windows7 environment. Based on Visual Studio 2013, a host computer software is programmed to control the whole system. The entire software contains four parts: the system's switch control; motor control; data storage and processing; the display of results. The sensor collects the surface data of the measured object and transmits the data to the computer through the controller. The computer calculates the surface roughness parameter value through the Gaussian filter algorithm and displays it. The steel can be evaluated through the comparison with the set value to determine the surface roughness.

3. Processing of Surface Profile Data
The system can get the outline data of measured object through the probe, and the outline data. And the signals consist of various frequencies includes surface shape error, waviness and surface roughness. The roughness is the high-frequency signal, while the surface waviness and the shape error are the low-frequency reference signals. And the surface roughness signal can be separated from the surface signal by the filtering process, thereby facilitating the calculation of the roughness parameters.

3.1. Detection Principle of Probe
The system uses laser two-dimensional displacement sensor as a probe, and the sensor can achieve the real-time high-precision measurement. The sampling speed is faster, so it can meet the needs of high-speed measurement. Figure 3 shows the structure of laser two-dimensional displacement sensor. The light emitted from the semiconductor laser emitter passes through the cylindrical objective lens to
form a linear laser beam and hits the object to form an outline. The laser beam is reflected by the measured object and is received by the two-dimensional objective lens and projected onto the three-dimensional CMOS [3]. So the surface data can be collected. The length of the outline and the height of the outline can reflect the topography features of the outline surface.

![Figure 3 The structure of laser two-dimensional displacement sensor](image)

### 3.2. Design of filter

Gaussian filter in the surface roughness extraction has a wide range of applications. According to the ISO11562 standard, a Gaussian filter is designed. The process of Gaussian filtering is the process of continuously moving averages of Gaussian weight function windows on the original outline curve[4]. The definition of the Gaussian filtering weight function is as follows:

\[
h(x) = \frac{1}{\alpha \lambda_c} \exp\left(-\pi \left(\frac{x}{\alpha \lambda_c}\right)^2\right) \tag{1}
\]

Its Fourier Transform:

\[
H(\lambda) = \exp\left(-\pi \left(\frac{\alpha \lambda_c}{\lambda}\right)^2\right) \tag{2}
\]

The \( \lambda \) is the wavelength and the \( \lambda_c \) is the cut-off wavelength of the Gaussian filter. The filter output reaches the 50% pass rate with cut-off wavelength, so \( a = \sqrt{\frac{\log 2}{\pi}} = 0.4697 \) when \( \lambda = \lambda_c \).[5]

The Gaussian filter weight function and the measured profile data \( z(x) \) are convoluted to filter out the high-frequency roughness signal and we can obtain the low-frequency surface profile baseline \( w(x) \).[6] Therefore, the difference between the surface profile \( z(x) \) and \( w(x) \) yields the roughness signal \( s(x) \):

\[
w(x) = \int_{-\infty}^{\infty} z(x - \delta) h(\delta) d\delta \tag{3}
\]

\[
s(x) = z(x) - w(x) \tag{4}
\]

Because the collected data is discrete and limited, the Gaussian function needs to be discretized and limited to meet the needs of signal processing[7]. Gaussian weight function is discretized as:

\[
h_k = \frac{1}{\alpha \lambda_c} \exp\left(-\pi \left(\frac{k \Delta x}{\alpha \lambda_c}\right)^2\right) \tag{5}
\]

The \( \Delta x \) is the sampling interval of the outline curve. The half-width of the Gaussian weight function is \( m \) and the number of contour sampling points is \( n \). The Gaussian filter centerline can be discretized as:

\[
w_i = \sum_{k=-m}^{m} z_{i+k} h_k \Delta x \quad i = m, \ldots, n = m \tag{6}
\]

At both edges of the outline, the process of weighted average uses only half of the data at the middle position, so there is distortion in the data at the boundaries of the contour. Therefore, the use of Gaussian filtering needs to be discarded at both edges of the half cut-off wavelength data points [8]. Through the design of the filter, the roughness information can be separated from the surface data, and then the roughness of the parameter values can be calculated.
4. Analysis of Experimental Results

In the experiment, we use the white-light interferometer to measure the hot-rolled steel. The local surface morphology and three-dimensional micro-map are shown in Figure 4. It can be seen that the surface of the steel is irregular, and there is a certain shape error. The probe used in this experiment has a measuring range of 8mm and sampling points of 10μm. Due to the large roughness of the steel, Ra is among the range of 2-10μm, and the cut-off wavelength selected is 2.5mm. Figure 5 and 6 shows the Gaussian filter processing results.

Figure 4 The surface of hot-rolled steel using white-light interferometer

Figure 5 The original outline and Gaussian baseline
Two sections A and B are selected at the steel. The roughness information is obtained by using a stylus-type roughness tester and the roughness results can be a reference for the experiment. Then the two areas are scanned using the roughness tester of this experiment for five times. The results are recorded and are shown in Table 1. It can be seen that the error of the system's Ra indication is $\leq \pm 10\%$ and the indication error of the system Rz is $\leq \pm 10\%$. The results of the system can meet the requirements.

| A Section | 1 | 2 | 3 | 4 | 5 | The result using a stylus-type roughness tester |
|-----------|---|---|---|---|---|-----------------------------------------------|
| Ra(μm)    | 3.07 | 2.98 | 2.93 | 2.98 | 3.16 | 2.91                                          |
| Rz(μm)    | 13.76 | 12.77 | 12.36 | 13.92 | 13.50 | 13.69                                         |

| B Section | 1 | 2 | 3 | 4 | 5 | The result using a stylus-type roughness tester |
|-----------|---|---|---|---|---|-----------------------------------------------|
| Ra(μm)    | 3.68 | 3.70 | 3.49 | 3.49 | 3.36 | 3.42                                          |
| Rz(μm)    | 16.57 | 16.65 | 14.84 | 17.81 | 15.85 | 15.61                                         |

5. Conclusion
This paper presents a roughness tester for online detection of steel surface, including its hardware and software. The system uses a laser two-dimensional displacement sensor as a probe, with Gaussian filter for filtering. So it can achieve the online measurement of surface roughness of the hot-rolled steel. As the probe can achieve two-dimension movement, the tester designed can measure the multi-point of steel roughness in real-time. Through the test of the experiment, it is found that the instrument can meet the needs of surface measurement of steel.

References
[1] Wang N, Hou N, Song H. Research on the quality online control technology for hot rolled strip[J]. Steel Rolling, 2017, 34: 59-62.
[2] Yu H. Surface Roughness Measurement Technique Study of Cold-Rolling Process[D]. Changchun: Changchun University of Science and Technology, 2002.
[3] Zhang Y. Research about the Information Acquisition System of 2D Laser Displacement Sensor[D]. Jilin: Jilin University, 2015.
[4] ISO 16610-21: Geometrical Product Specifications (GPS)-Filtration-Part 21: Linear Profile Filters: Gaussian Filter [S]. Geneva: ISO, 2011.

[5] Wang J, Xu X, Huang H. Application of Gauss Filtering in Study of Roughness to Granite Surface Profile [J]. Acta Metrologica Sinica, 2006, 27(2): 104-106.

[6] Seewing J. Linear and robust Gaussian regression filters [J]. Journal of Physics: Conference Series, 2005, 13(3): 254-257.

[7] Luo W. Surface Roughness Testing Method for Automotive Steel Plate [J]. Surface Technology, 2015(10): 125-126.

[8] Su X. Research on Data Acquisition and Gaussian Filtering Method in the Surface Roughness Measurement System [D]. Harbin: Harbin University of Science and Technology, 2015.