Acta Technica *62*, No. 3B/2017, 181–188

Speed control system design of hot rolling based on laser Doppler velocimeter[1]

Zhaojun Meng[2], Xuejun He[3], Kegang Zhu[4], Jiayong Sun[5]

Abstract. The problems of laser Doppler velocimeter of the Benxi Iron and Steel hot rolling speed control system are studied. Detailed analysis and description of the solutions are given. Starting from laser Doppler velocimeter working principle, studied is the signal loss phenomenon during speed measurement. According to analysis test results, determined is the relationship between the iron oxide particle size and control system signal loss. For problem analysis, taken are measures for increase of the blast amount to increase the particle size of iron oxide. Good results are achieved.

Key words. Laser Doppler velocimeter, speed control, iron oxide, signal loss.

1. Introduction

Precision speed and length measurements are critical for controlling production costs and improving process control for the steel and non-ferrous metals industry. Traditionally, contact rollers and tachometers have inherent problems with slippage and mechanical wear [1, 2]. Both of these problem causes increased scrap, increase

[1]The authors would like to thank for the support by 2016 Guiding fund project of Liaoning Institute of Science and Technology, under the Grants Yd201610 and Liaoning Province General Project Funded by Liaoning Province Education Administration, CHINA, under the Grants L2015272 and by National Science and Technology Support Program, CHINA, under the Grants 2014BAF08B01. At the same time, thank my collaborators for their experiments.

[2]Corresponding author. School of Electrical and Information Engineering, Liaoning Institute of Science and Technology, Benxi, Liaoning 117004, China; mzj744@163.com

[3]School of Electrical and Information Engineering, Liaoning Institute of Science and Technology, Benxi, Liaoning 117004, China; E-mail: sarah0624@163.com

[4]School of Mechanical Engineering, Liaoning Institute of Science and Technology, Benxi, Liaoning 117004, China; E-mail: chhyrabbit@126.com

[5]Equipment Department, POSCO Cold rolling mill of Benxi Iron & Steel (Group) Co., Ltd, Liaoning 117000

maintenance costs and reduce the quality of the end product. Laser non-contact speed and length gauges solve all of the problems of mechanical contact rollers and tachometers.

Laser speed gauge can measure the speed and length of any product using an optical non-contact technology called dual beam laser Doppler velocimeter. Laser speed gauges were first introduced into the metals industry in 1984 and have been growing in usage ever since. There are thousands of Laser speed gauges installed worldwide with their high-precision, low cost, wide speed range, reproducibility, widely used in rolling, cold rolling, continuous casting and other steel companies [3–5].

Strip online speed measurement is a key parameter to achieve rolling tension control in the hot-rolled sheet production. Also a basis of cutting head and cut tail before steel finish rolling for reducing unnecessary material waste is very important [6–8]. A laser Doppler velocimeter in hot rolling plant of Benxi iron and steel corporation, which has reached the retirement age and needs to be replaced, was installed in front of the finishing rolling area. This paper mainly studies the problems and solutions that appeared in the replacement process of this equipment, and at the same time, it deals with the precautions for laser Doppler velocimeter in hot rolling speed control system design.

2. Principle of laser velocimeter

Laser velocimeter uses dual-beam laser interferometer technology to measure product velocity (speed), which is integrated over time to measure length. Laser Doppler velocimeter is a non-contact optical sensor for measuring the speed of movement of the material. Use the Laser surface velocimeter from the interferogram (produced by intersecting laser beams) emitted by the light scattering to detect the speed of the material. The same principle can be used to accurately measure the length of the material passing through the measurement zone.

Laser Doppler velocimeter works with of two coherent laser beams, producing them at a known distance from the head of the intersection. Intersecting beams produce a three-dimensional interferogram pattern consisting of alternating light and dark stripes, shown in Fig. 1. Interferogram region forms the interferogram measurement area.

If the material appears in the measurement area, then it generates an interference pattern of alternating bright and dark fringes on the material surface. When the material moves through the measurement area, the light of fringes will be scattering from the rough surface of the material. The optical head of the photodetector collects the scattered light and the output signal is proportional to the received light intensity. Object moving speed is equal to the distance d between two interference fringes divided the time t of the scattering light moving from one interference fringe to the next field pattern, and each period τ of the output signal corresponding to the movement distance of the material is equal to a fringe spacing. So velocity is the distance over time

$$v = d/\tau \tag{1}$$

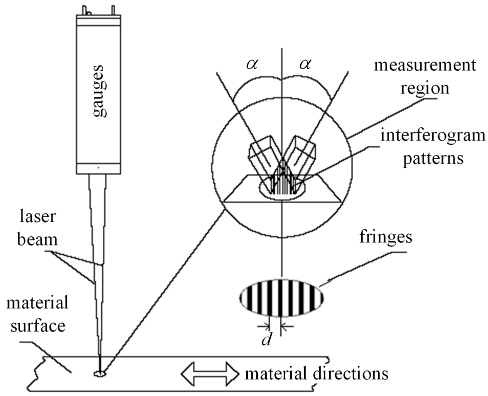

Fig. 1. Laser Doppler velocimeter principle

Signal modulated by photodetector is proportional to material speed and fringes space directly. Fringe pattern spacing only related with laser wavelength and angle. The distance d between the interference fringes, laser wavelength λ and the angle between the two laser beams have the following relationship:

$$d = \frac{\lambda}{2\sin\alpha}\,. \tag{2}$$

This means that the fringe distance is a function of laser wavelength and beam angle. After substituting (2) into (1), the material moving speed equation can be rewritten as:

$$v = \frac{\lambda}{2\tau\sin\alpha}\,. \tag{3}$$

By integrating the velocity v of the object, the length L of the measured object is

$$L = \int_0^T v\,\mathrm{d}t\,. \tag{4}$$

Because of the laser has good direction character and the measurement method is contactless, using laser velocimeter system can provide an accurate value of velocity of the moving object.

Length of the material is determined by counting the number of interval fringes passing through the measurement zone, equal to the cycle count value of the photodetector signal. Figure 2 shows the output signal of velocity measuring photodetector.

3. Laser velocimeter structure

Laser velocimeter system consists of optical head components, electronic unit, optical head cable, optical head extension cable, junction boxes and other components. The most important part is the optical head components and the electronic unit. The system structure is shown in Fig. 3.

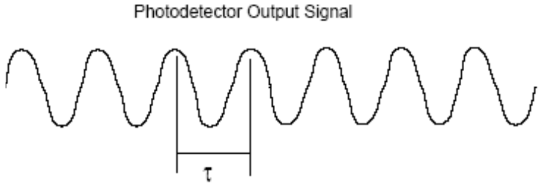

Fig. 2. Schematic view of photodetector output signal

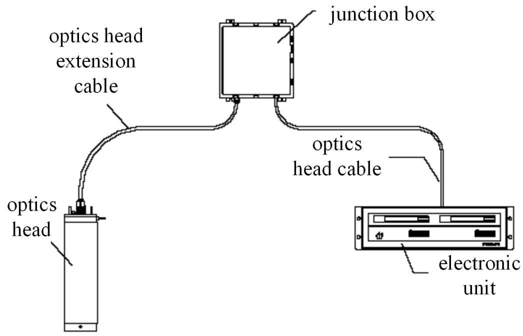

Fig. 3. Basic structure of the system

3.1. Optical head components

Optical head component is constituted of optical components and water jacket. Optical head has two main functions. First: produce, split and control the laser beam to produce a clear fringe pattern in the surface of the moving material. Second: optical head includes a photodetector for collecting scattered light on material surface, and converts it into an optical signal can be resolved the velocity and length data.

3.2. Electronic units

Electronic unit implements processing functions, its work can be divided into three parts: the optical head and the laser power control, signal processing, the external interface. Electronic unit functional block diagram is shown in Fig. 4.

Receiving lens sensor in optical components received irregular scattered light from stripes, and focused the scattered light onto the light detector. Photodiode in photodetector detected the changes information between the scattered light and emission light, then converted it into the Doppler signal and sent to signal processor. The signal consists of two parts, one is the DC component, and the other is the AC component. DC optical signal is generated by reflected light in Fig. 4 for marking whether the material is present on measurement region. AC optical signal generated by the scattering light in Fig. 4 is used to calculate the material speed by signal processor.

4. Problems and solutions in application

In construction field, we found that most of the time laser velocimeter system worked properly, but sometimes, the data loss phenomenon occurred individually, causing the control system automatically open, and affecting product quality. The main characteristic of this data loss phenomenon is the quality factor that suddenly drops sharply. When the quality factor drops to a certain value, acquisition data will hold the previous data and keep them unchanged. Finally it causes the laser velocimeter system failure. To solve this problem, a lot of field data must be collected, and these data is shown in Fig. 5.

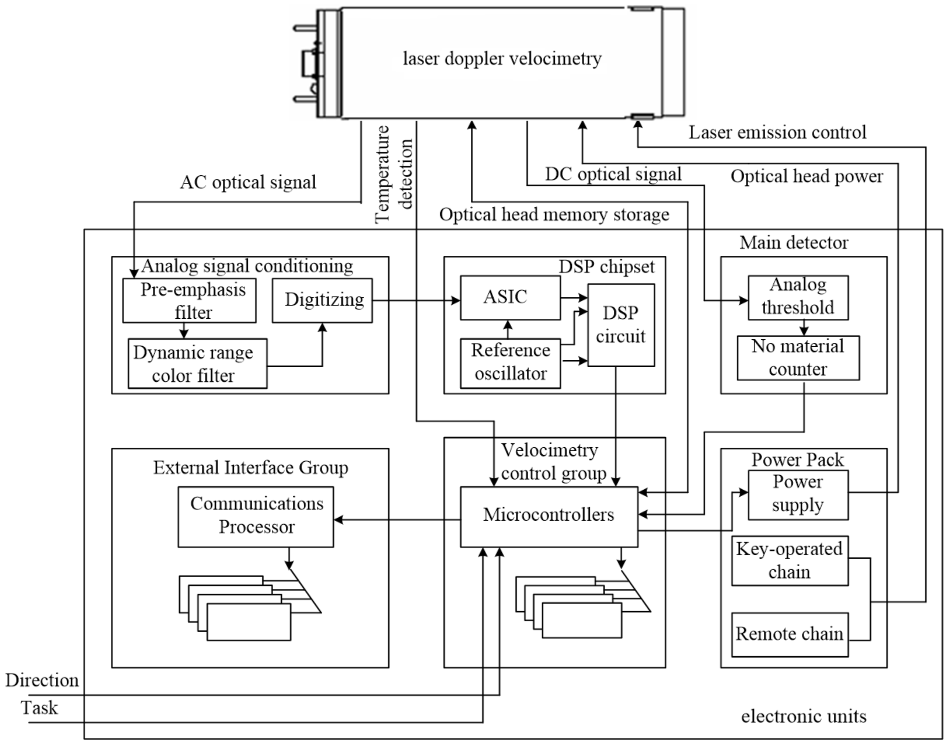

Fig. 4. Functional block diagram of the electronic unit

Through data and environment analysis, the paper considers that the reasons causing this phenomenon can be summarized as follows:

1) Some high-pressure descaling water leaking through measurement area of the laser velocimeter on material surface, may cause decrease of quality factor.

2) Signal data loss occurs when the steel moves at fluctuating speed.

3) In case of signal data loss, the naked eye can observe small but dense iron oxide particles causing steel surface roughness.

The above reasons might result in velocimeter automatic withdrawal. We believe that the descaling water is not the signal loss core elements for considering that the

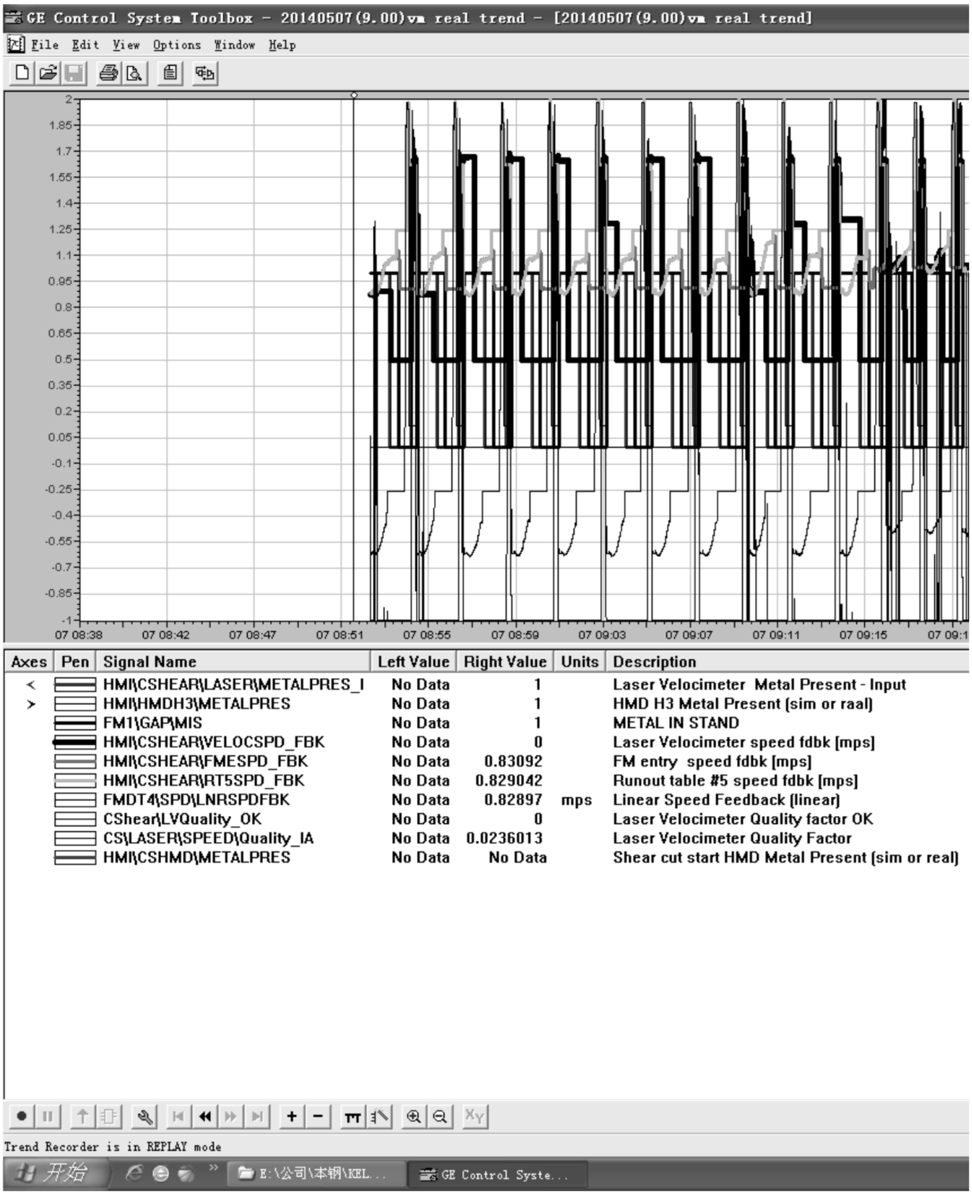

Fig. 5. Variety of data acquisition curve (left part of monitor)

original velocimeter works properly in the same conditions. So, it needs considering other aspects, such as the laser head and electronics unit, improve the velocimeter resolution, control particle concentration and so on.

After a review of relevant literature and documents[9, 10], we known that the laser Doppler signal quality depends not only on the particle size, but also on the number of particles in measurement area as well as their relative position in that region of interference fringes.

For solid surface, the number of particles has inverse relationship with particle size in the same detection volume. That is, the laser velocimeter can well detect the large sized particles, and when the particles are about 1 micron, the measurement error increase up to about 80 %, the quality factor is substantially zero, resulting in signal loss.

The main reason that measured inaccurate to small but dense iron oxide is average effects. So, for the measuring object has small but dense iron oxide on hot rolling sheet, the data output is not stable enough, need further improvement. In order to effectively suppress the average effect, the slit of infrared sensor in optical system can be reduced. However, reducing the slit will cause signal energy decrease, therefore, must be considered to increase the energy of the signal when the slit is reduced.

Based on the results, the workshop agreed that can increase the amount of cooling wind on the front of measurement area side to make the iron oxide particle on strip surface rapid growth to fit size, so that the velocimeter will not reduce the quality factor and the signal loss does not occur. Accordingly, the workshop made improvements to blowers of the production line, to increase the amount of the blast. By repeatedly debugging, the final results achieve the desired purpose, laser velocimeter signals loss phenomenon does not occur, the control system is working normally.

5. Conclusion

Through this laser velocimeter upgrade, successful resolve the problem of signal loss arise from the strip surface iron oxide particles, which accumulated experience for solve similar problem appearing in the production process in the future. Meanwhile, also made a request to filed engineers, that is, the problem solving of production process must be supported by deep knowledge and data analysis, not rely on previous experience blindly. Solve the problem not rely on experience, but more important, dependent on the knowledge and innovative thinking.

References

[1] J. L. Song, D. H. Wang: *Tracking laser Doppler measurement for velocity of moving target.* Proc. International Conference on Computer Science and Information Processing (CSIP), 24–26 Aug 2012, Xian, Shaanxi, China, 426–431.

[2] J. Lee, Y. J. Choi: *Development of camber and steering control system in hot strip mill.* Proc. IEEE Emerging Technology and Factory Automation (ETFA), 16–19 Sept. 2014, Barcelona, Spain, 1–4.

[3] B. Knigge, F. E. Talke: *Nonlinear dynamic effects at the head-disk interface.* IEEE Transactions on Magnetics *37* (2001), No. 2, 900–905.

[4] M. R. Khare: *Automatic system for measuring and controlling the length of a moving product in industries.* IEEE Transactions on Instrumentation and Measurement *57* (2008), No. 4, 781–790.

[5] H. Shiozawa, Y. Abe, M. Niwayama, H. Yoshida, S. Shinohara: *Construction and estimation of new measurement system of range finding speedometer using self-mixing laser diode.* Proc. SICE Annual Conference, 4–6 August 2003, Fukui, Japan *1*, 801–806.

[6] Y. Isei, Y. Yakita, Y. Buei: *Development of interstand velocimeter for hot strip finishing mill.* Proc SICE-ICASE International Joint Conference, 18–21 Oct. 2006, Busan, South Korea, 2508–2511.

[7] A. Abuazza, D. Brabazon, M. A. el-Baradie: *Design and development of a novel noncontact fibre optic laser scanning system.* Proc. Annual Meeting of the IEEE Lasers and Electro-Optics Society, 10–14 November 2002, Glasgow, UK, 175–176.

[8] J. Liu, C. S. Wang: *Study on a new method for detecting flatness defects of hot rolling strip.* Proc. IEEE Conference on Industrial Electronics and Applications, 15–17 June 2010, Taichung, Taiwan, 1891–1896.

[9] M. S. Kim, W. I. I. Lee; J. W. Yoo, P. G. Park: *Image stitching algorithm for camber measurement in hot rolling process: Cross-correlation approach.* Proc. International Conference on Control, Automation and Systems (ICCAS), 13–16 October 2015, Busan, South Korea, 1577–1580.

[10] N. Tsukuda, S. Shinohara, T. Shibata, H. Yoshida, H. Ikeda, M. Sumi: *New range-finding speedometer using a self-mixing laser diode modulated by triangular wave pulse current.* Proc. IEEE Instrumentation and Measurement Technolgy Conference, 10–12 May 1994, Hamamatsu, Japan *1* (1994), 332–335.

Received April 30, 2017