Condition Monitoring Technology for Bearing Ring Groove Grinding

Hou Zhi*, Zeng Jie

Department of Industrial Engineering, Chongqing University of Technology, Chongqing, 400054, China

*Corresponding author’s e-mail: houzhi@cqut.edu.cn

Abstract. Bearing is the most important basic components of mechanical equipment, and its machining quality directly affects the quality. The ring groove is the working surface of rolling bearing, and its accuracy will directly affect performance and lifecycle of rolling bearing. Grinding method is often used to ensure the machining quality of ring groove, and grinding processing is crucial to final quality of bearing products. Therefore, in order to research and understand the quality assurance technology of grinding process for ring groove, three technologies such as grinding technology, condition monitoring technology and ring groove grinding state monitoring technology are discussed and analysed.

1. Introduction
Bearing, as a base member which is sophisticated and difficult to machine, its performance level and quality directly affects the quality of the machine. According to statistics, in rotating machinery using rolling bearings, about 30% of mechanical failures are caused by bearing failures. It can be seen that the quality of the bearings has a great impact on the working conditions of the machine. In precision machinery, the requirements for bearings are even higher, even if there are micron-level defects on the bearing raceway, it will affect the performance of the entire machine system[1]. Therefore, ensuring bearing quality will have far-reaching implications for improving the overall level of manufacturing.

Grinding is the preferred method of processing for most of high quality parts. The quality of the grinding process is very important to ensure the final quality of the product. According to statistics, in the manufacture of bearings, grinding processing accounts for more than 60% of the total production labor of the bearings, grinding machine usage also accounts for about 60% of all processing machine tools, and grinding processing costs account for more than 15% of the total bearing production cost[2]. In the processing of bearing rings, although there are dozens of processing steps, the end is finished by grinding. After the grinding of the bearing rings, the roundness error can reach 0.001mm or less, and the surface roughness can reach below 0.01um. Such high machining accuracy is difficult to achieve with other machining methods[3]. Therefore, the quality of the bearing depends to a large extent on the quality of the grinding, including the groove, the inner and outer circle, the end face, etc., and among them, the working surface of the bearing - the grinding quality of the groove is the most important.

As the most common and oldest deep groove ball bearings, which constitute mainly including three parts: ring (inner, outer), rolling bodies (balls), and holder. The ring is an important part of the rolling bearing. It forms the frame of the whole bearing. The ring groove is the working surface of the bearing.
It is in contact with the steel ball and is the rolling track of the steel ball. It will withstand huge axial and radial directions during operation. The load, its shape and groove position accuracy are very high, and the surface roughness and roundness error are very strict, so as to reduce the rolling resistance, vibration and noise of the steel ball in the inner and outer ring grooves, and ensure the rotation precision. Therefore, the accuracy of the ring groove directly affects the working performance and service life of the bearing.

The rings undergo several important processes, such as forming, heat treatment and grinding, from the raw materials to the delivery assembly. The grinding process has the greatest influence on the final processing quality of the ring. The general grinding process of the bearing ring, as shown in Fig.1, is: inner ring: grinding both ends - grinding inner and outer diameter - grinding inner groove - grinding inner diameter - super fine inner groove. Outer ring: grinding both ends - grinding outer diameter - grinding outer groove - super fine outer groove.

Figure 1. Ring grinding process

Generally, for ring raceway grinding, there are three ways: Swing method, Vane method and Cut-in method. The current widely used method is the cutting method. The principle is to use a shaped grinding wheel that has been trimmed by a circular wheel dresser, to make a Cut-in feed perpendicular to the surface of the ring groove. The relative motion of the grinding wheel and the work piece ultimately creates the required circular arc groove.

The vibration and noise level of rolling bearings is a comprehensive reflection of the dynamic performance of the bearing, the groove of the bearing ring is to guide the rolling elements to move along the correct track and to withstand large radial and axial loads, the processing accuracy of the groove directly affects the vibration and noise of the bearing, the most influential ones are groove roundness, groove surface roughness and trench shape error. Therefore, these three indicators are important control indicators for the ring groove grinding process and are also difficult to control.

The groove bearing ring grinding process including large amounts of data, such as grinding wheel, work piece, machine tool, grinding fluid, heat, grinding force, displacement, power, vibration, noise, work piece dimensional accuracy and surface quality after grinding, etc. These data contain a wealth of useful information related to product quality, and to collect, analyse and utilize important information reflecting the processing; it will play an active role in optimizing the parameters of the
machining process, and will also contribute to the improvement and improvement of the groove grinding quality of the bearing ring.

In order to deeply study the monitoring technology of the bearing ring groove grinding state, understand the research status and development trends in this field, this paper will review and analyse the research results of grinding technology, grinding condition monitoring technology and ring groove grinding condition monitoring technology.

2. Research status of grinding technology

The essence of the grinding process is the metal surface on which the work piece is ground, Deformation and shedding under the action of extrusion and friction of numerous abrasive grains and the process of forming a smooth surface, it involves many fields such as grinding mechanism, abrasive tools, grinding technology, and intelligent grinding. The lateral grinding of the outer circle such as DanaiK is the object. From the grinding mechanism of the microscopic angle, the mathematical model of the grinding force is obtained[4]. Based on this research, Malkin S et al. derived a mathematical model of the longitudinal grinding force of the outer circle[5]. New CBN abrasives ABN60O and ABN800 developed by DeBeers have high thermal stability and compressive strength, American companies have launched Norton SG, TG abrasive, compared with ordinary fused alumina abrasive, with a higher hardness, better self-sharpening, abrasion resistance, In addition, it has less grinding heat during grinding, and has a longer service life and better grinding quality[6]. Koeing and Ferlemann of the laboratory of the Aachen University of Technology in Germany claim that the laboratory has adopted ultra-high speed grinding wheels with a peripheral speed of 500m/s, This speed has broken the working limit of current machine tools and grinding wheels. Japan's Shinizu et al. used a modified grinding machine to obtain a result that the relative grinding line speed of the grinding wheel and the work piece was close to 1000 m/s. Hunan University in 2011 China CNC Machine Tool Fair, introduced a maximum line speed of 120m/s CNC camshaft grinder and began to study high-speed ultra-high speed for a 250m/s Ultra High Speed Grinder Spindle System in 2013, And for the first time in the country were maglev bearing design[7]. Xiao.G et al. And Anne, who for cylindrical plunge grinding process, respectively, in the shortest grinding times and maximum grinding efficiency as the objective function to establish a nonlinear optimization model[8] cut into the cylindrical grinding. On the basis of this, Rowe et al. summarized the intelligent control and optimization methods applied to the grinding process[9].

It can be seen from the above literature that the development trend of grinding technology is to develop super-hard abrasives, research precision and ultra-precision grinding, high-speed and high-efficiency grinding mechanism and develop new grinding technology, and develop high-precision, high-rigidity automation grinder. Second of all, further build a knowledge base and database based on prior knowledge, and the resulting process model, providing a reliable key technical basis for grinding intelligent control. Last but not least, the application of artificial intelligence technologies such as expert systems, fuzzy logic, and artificial neural networks has great potential for optimizing and controlling the grinding process.

3. Research status of grinding condition monitoring technology

Grinding is a complex process with multi-parameter cross-effects. Its machining accuracy is affected by many factors such as tools, materials, machine tools, environment, personnel, etc., These influencing factors constitute the input conditions for grinding, resulting in complex grinding phenomena and the formation of new working surfaces[10]. In order to further improve the automation and intelligence of the grinding process, it is essential to effectively monitor the state of the grinding process, which is the basis for optimizing the machining process and intelligent decision making. In foreign countries, Domfeld and Rangwala have used the wheel and wheel wear monitoring system developed by force and acoustic emission sensors to obtain better results [11-12]. Chryssolouris et al. used force, temperature and acoustic emission sensors to monitor the grinding process[13]. Inasaki has developed a grinding process monitoring system that monitors the power signal and acoustic emission
signal of the grinding process. The system not only detects flutter but also evaluates the surface roughness of the grinding and determines the service life of the grinding wheel[14]. Ahrens and Matsumoto et al. used AE and various sensors to study the measurement of grinding force and grinding temperature[15-16]. Eda studied the feasibility of using acoustic emission technology to monitor the grinding of burns[17]. G. Byme studied the monitoring techniques required for tool condition monitoring[18]. P. Lezanski used the force, vibration and AE sensors to establish an intelligent monitoring system for the grinding wheel state. The fuzzy logic-based neural network was used to identify the state of the grinding wheel and verify its effectiveness [19]. In China, Huang Wei proposed a prediction model for the change of grinding force with the amount of metal removal in the grinding process of grinding wheel based on BP neural network [20]. Xie ping used wavelet neural network to establish the mapping relationship between acoustic emission, main motor current, feed current and grinding wheel wear[21]. Liu Guijie used neural network to establish the mapping model between grinding wheel motor current signal, grinding force signal and grinding acoustic emission signal and grinding state, and used this model to grind burn, grind flutter and passivation degree of grinding wheel. Wait for online monitoring[22]. Gao Hong li used the B-spline fuzzy neural network to establish the recognition model between the characteristics of cutting force, vibration, acoustic emission and the wear of the grinding wheel, which provides a useful solution for the monitoring of the wear state of the grinding wheel under any processing conditions[23]. Luo Zhen duo and others used the fuzzy discriminant method to intelligently monitor the damage of the grinding wheel with the acoustic emission signal, which significantly improved the damage recognition rate[24]. Wang Jia Zhong and others based on heuristic expert knowledge, combined with grinding optimization model, developed a hybrid external longitudinal grinding expert system using evolutionary algorithm[25].

It can be seen from the above literature that the development trend of the grinding state monitoring technology is to continue to develop and develop a special monitoring sensor with high performance, high life, high reliability and strong anti-interference ability. Second of all, Multi-sensor information integration and fusion technology will be developed, from single-parameter monitoring to multi-parameter monitoring, increasing the amount of information and improving decision-making accuracy. The third, in the information processing, advanced processing methods and algorithms such as neural networks, genetic algorithms, time series, and fuzzy recognition are increasingly used. Last but not least, further study the basic theories and techniques of monitoring and further understand the intrinsic link between monitoring signals and monitoring objectives.

4. Research status of ring groove grinding state monitoring technology

The groove of the rolling bearing ring is the rolling track of the rolling element, and it is also the load surface when the bearing works. The quality of the groove processing directly affects the performance and life of the bearing. Compared with foreign countries, domestic ring groove grinding generally has problems such as unstable quality level and low efficiency. In order to improve the quality of groove grinding, domestic scholars have done a lot of research work. Xu Hao et al. based on the bearing outer ring groove grinding test, Regression analysis method is used to find the repetitive law of outer diameter roundness error during groove grinding, and a linear regression equation between groove sparse and outer diameter sparse waves is established, which provides powerful theoretical support for reducing groove waviness[26]. Zhao Yong et al. analysed the mechanism of waviness generation on the groove surface, the method of improving the balance of the grinding wheel, rationally selecting the feed displacement and finishing time, and adjusting the eccentricity calculation of the electromagnetic centre less fixture are proposed to reduce the groove waviness[27]. Lin Shuwen used the orthogonal test method to establish a mathematical model between the circularity of the inner ring groove and the surface roughness and the process parameters by stepwise regression modelling of the experimental data[28]. Li Chunju et al. tested the theoretical analysis of the grinding temperature field and the change of the micro hardness of the groove surface before and after grinding. The calculation model of the grinding zone temperature and groove grinding process parameters is established, which achieves the purpose of effectively predicting the surface quality of the work piece after grinding[29]. Xiang
Wenjun developed a monitoring system for the grinding state of the ring by monitoring the displacement signal and the spindle power signal of the lap grinding process, and verified the availability of the system by using the time series analysis method[30].

It can be seen from the above documents that the monitoring technology of the ring groove grinding still has the following problems. The first, there are many factors influencing the ring groove grinding, and there is no special means and tools for effective online monitoring and forecasting of grinding state and grinding quality. Second of all, Limited to the monitoring of single or a small number of signals, there are insufficient monitoring strategies, and the identification methods are not accurate enough and efficient. Last but not least, the quality of the work piece is indirectly controlled by judging the state of the grinding wheel, and the mapping relationship between the state of the grinding wheel and the final mass of the work piece is neglected, which leads to certain limitations of the research results.

5. Conclusions
This paper makes a useful exploration of the theory, method and technology of grinding process monitoring. However, in general, the existing research is still insufficient in systemicity and integrity, which is reflected in the following research aspects. The first, the monitoring objects are mostly concentrated on the state quantity of temperature, force and power during the processing, which limits the scope of the process state monitoring. Despite the continuous improvement of information processing methods, it is still difficult to extract enough useful information from limited monitoring objects. Second of all, the synergy between the grinding process state parameters and the output parameters (grinding quality) is weak. The selection of monitoring objects, the extraction of signal features and the use of decision-making methods are mostly based on the experience of the researcher or by trial and error methods, making the monitoring one-sided, so the monitoring accuracy is not high, and the versatility is not strong. The third, existing research is specific to specific objects and is effective in a particular application. However, its versatility cannot be guaranteed because of the lack of systematic and generalized monitoring theories and methods. Last but not least, it lacks of monitoring systems that can be applied to the bearing manufacturing process. Although the bearing processing monitoring system has been extensively studied, it has not yet been scaled up

Acknowledgments
This Research is funded by Chongqing Research Program of Basic Research and Frontier Technology (cstc2015jcyjA70015, cstc2016jcyjA0081).

References
[1] Wang Zhijian. Study on the support software system of quality analysis for bearing ring grinding Progress Parameters Optimization [D]. Zhejiang University, 2006
[2] Song Xiaobing. Study on Six Sigma quality information system for miniature bearing assembling process [D]. Zhejiang University, 2003
[3] Zheng Qian. Measurement and Technological Test on Grinding State Parameters of Bearing Ring Raceway[J]. Bearing, 2010(4):31-35.
[4] Xiao, Guoxian ; Malkin, Stephen ; Danai, K. Intelligent Control of Cylindrical Plunge Grinding, American Control Conference, 2002 , 391-399.
[5] XiaoG, Malkin S .Online Optimization for internal Plunge Grinding [J]. Annals of the CIRP, 2006(45):287-292.
[6] Cai Guangqi. Latest Advances in Grinding and Abrasive Machining[J]. Aeronautical Manufacturing Technology, 2003(4):31-35.
[7] Li Changhe. The Development and Key Technology of High Speed and Super High Speed Grinding Technology[J]. Precision manufacturing and automation, 2006,4(168):16-21.
[8] Anne Venu Gopal, P Venkatesuara Rao. Selection of optimum condition for maximum material removal rate with surface finish and damage as constraints in Sic grinding [J]. International Journal of Machine Tools & Manufacture, 2003(43): 1327-1336.

[9] W Brian Rowe, Y Li, et al. Application of intelligent CNC in grinding and manufacturing[J]. Computer in Industry, 2006(31): 45-60.

[10] Ren Jinxin. Grinding Principle [M] Xian: Northwestern Polytechnic University Press, 1998.

[11] Dornfeld D A. Neural network sensor fusion for tool condition monitoring [J]. Annals of the CIRP, 2010, 39(1): 101-105.

[12] Rangwala S, Dornfeld D A. Integration of sensors via neural networks for detection of tool wear states [J]. Intelligent and integrated Manufacturing Analysis and Synthesis, ASEM Winter annual meeting, Boston, 2007 Dec.

[13] Chryssolouris G, Domroese M. Some aspects of acoustic emission modeling for machining control [J]. NAMRC-XII SEM, 2009: 228-234.

[14] Inasaki I. Monitoring technologies for an intelligent grinding system [J]. VDI Berichte Nr. 1179, 2005: 31-35.

[15] Ahrens O, et al. Development of temperature and force sensors for in-process monitoring of grinding [J]. Sensors 99, NURNBERG, 2009: 1-4.

[16] Matsumoto T, Inasaki I, Ogawa K. Mentioning of grinding Process With a sensor integrated CBN wheel [J]. Proceedings 5th international grinding conference, Cincinnati, SEM, 2003.

[17] Eda H K, et al. In process detection of grinding burn by means of utilizing acoustic emission [J]. Annals of the CIRP, 2004.

[18] G Byrne, DA Dornfeld, L Iiasald, et al. Tool condition monitoring (TCM) - the status of research and industrial application [J]. CIRP Annals, 2005, 44(2).

[19] P Lezanski. An intelligent system for grinding wheel condition monitoring [J]. Journal of Materials Processing Technology, 2011(109): 258-263.

[20] Huang Wei. BP Neural Network and Its Application in Prediction of Grinding Force Sequence [J]. Diamond & Abrasives Engineering, 2011, 2(122): 42-43.

[21] Xie Ping, Liu Bin. Fault Detection on Cutting Tools Based Wavelet Neural Network [J]. Journal of Mechanical Engineering, 2002, 38(2): 108-111.

[22] Liu Guijie. On-Line Monitoring for Grinding Wheel States Based on Neural Network [J]. Journal of Northwestern University (Natural Science), 2002, 23(10): 984-987.

[23] Gao Hongli. The Investigation of Intelligent Tool Wear Monitoring Technical for Metal Cutting Process [D]. Chengdu: Southwest Jiaotong University, 2005.

[24] Luo Zhengbi. Research on Principle of Tool Wear and Tear Monitoring [J]. Mechanic Technologist, 2006(4): 4-6.

[25] Wang Jiazong. Prediction of Surface Roughness in Cylindrical Traverse Grinding Based on FBFN and ALS Algorithm [J]. China Mechanical Engineering, 2006, 17(12): 1223-1227.

[26] Xu Hao. Influence of machining base precision on groove grinding precision [J]. Technology and Application, 2004(1): 74-75.

[27] Zhao Yong. Method to Reduce Bearing Wawiness [J]. Journal of Harbin Bearing, 2005, 26(4): 39-41.

[28] Lin Shuwen. Influence of grinding parameters on grinding deterioration layer of bearing groove [J]. Bearing, 2006(12): 64-66.

[29] Li Chunju. Analysis of cut groove grinding [J]. Bearing, 2009(9): 20-21.

[30] Xiang Wenjun. Grinder Progress Parameter Measuring System and Application of the System [D]. Zhejiang University, 2005