Journal of Engineering and Science Research 1 (2): 222-227, 2017
e-ISSN: 2289-7127

DOI: 10.26666/rmp.jesr.2017.2.33

Application of pneumatic measuring probe to determine appropriate time for dressing grinding wheel in profile grinding for the inner ring groove of ball bearing

Vu Toan Thang[1], *Nguyen Anh Tuan*[2] *and Nguyen Viet Tiep*[1]
[1] Department of Precision Mechanical and Optical Engineering, School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam
[2] Faculty of Mechanical Engineering, University of Economic and Technical Industries, Hanoi, Vietnam

Abstract: Enhancing the dressing efficiency of profile grinding wheels has been increasingly demanded. The importance has been addressed in the practical application of mechanical engineering. In this study, a new online dressing time monitoring system in a wet profile grinding for the inner ring groove of ball bearing is introduced. A special feature of the system is the application of the non-contact measuring method by using pneumatic measuring probe system to calculate the radial wear value of the grinding wheel to determine the resonable dressing time. A series of grinding tests were carried out to investigate grinding wheel's wear, part's surface roughness and the dressing accuracy with the proposed system. Through repeated experimental investigations, it shows that wear value of grinding wheel is a importance parameter in determining appropriate time for dressing grinding wheel to achieve high efficiency in profile grinding process. This is to assure that the waste level of the dresser and grinding wheel can be minimized, the durability of the grindstone is greatest.

Key words: *Dressing; Pneumatic measuring probe; Profile grinding.*

INTRODUCTION

In the grinding process one of the most important factors for obtaining high machining accuracy is the technical specifications of the grinding wheel. However, it is not always easy to get good results due to wear and sharpness loss of the grinding stone according to time progress [1]. Especially, in the profile grinding because of big contact area between grinding wheel and workpiece, the cutting force and the cutting heat arised from this process are much bigger than those generated by other normal grinding processes. Thus, profile grinding wheel is worn continuously and unevenly at various points on its working surface, making its initial shape and accuracy change quickly, causing form errors of processing surface. Furthermore, grinding wheel's wear also decreases its cutting capability and longevity. Therefore, grinding wheel's wear, under the profile grinding, influences directly on the precision elements of grinding parts. That's why the grinding wheel, during the profile grinding, should be dressed regularly. The achieved accuracy of the processed surface here is closely related to the grinding wheel dressing during the grinding process [2]. After a certain processing time, when the wear of the grinding wheel exceeds an acceptable limitation, it's necessary to dress grinding wheel. This grinding wheel repair is aimed to restore the cutting capacity and the initial shape of the grinding wheel. However, it's important to determine the appropriate time for dressing grinding wheel. This decides the accuracy of processing part and the durability of the grinding wheel. To achieve those things, it's necessary to measure the wear value of the grinding wheel under the profile grinding.

A number of methods for the in-situ measurement of the wear of a grinding wheel have been studied. A constant voltage type hot-wire anemometer was used for measuring both the air velocity and its percentage turbulence in oder to assess the wheel wear from air flow characteristics [3]. An acoustic emission (AE) has been used in determinating grinding wheel sharpness [4]. Another method is based on ultrasonic principle [5]. Recently, a non-contact optical measuring method with image digital techniques have also

Corresponding Author: Vu Toan Thang. Tel.: +84912051155. Email address: thang.vutoan@hust.edu.vn

been proposed to evaluate the grinding wheel wear [1, 6, 7]. Although these methods are good enough for measurements in laboratory, the in-situ measurement of the wheel wear in precision profile grinding operations is not adequate due to the adverse influences of the grinding fluid, machining debris, cutting force, eccentricity or thermal deformations, etc.

Thus, some previous researches have applied the pneumatic measuring probe to measure the roughness of a moving surface [8], measure the wear of grinding wheel at one point on the cylindrical width of the grinding wheel under surface grinding or cylindrical grinding [2, 9], etc. An advantage of this method is the reduction of electromagnetic influence of workpiece as well as the impact of grinding debris and cutting lubricant [2]. Another important feature of the method is that the measuring jet hole is not blocked by small particles in the water, by particles of chip or by broken grains present in the air surrounding the wheel [9, 10]. In addition, the instrumental set-up is simple. However, none of the previous researches has studied to determine appropriate time for dressing grinding wheel in profile grinding for the inner ring groove of ball bearing. Therefore, in the study from the actual requirements for the improvement of the economic and technical efficiency of the fine grinding operation for the inner ring groove of the ball bearing, based on the existing technical and technological conditions in Vietnam, a pneumatic probe system has been designed and made by ourselves in order to measure grinding wheel's wear with the accuracy of 1 µm to determine appropriate time for dressing grinding wheel in wet profile grinding for the inner ring groove of the ball bearing on the grinder 3MK136B.

THE CHARACTERISTICS OF PNEUMATIC METHOD FOR MEASUREMENTS OF GRINDING WHEEL WEAR

Principle of measurement

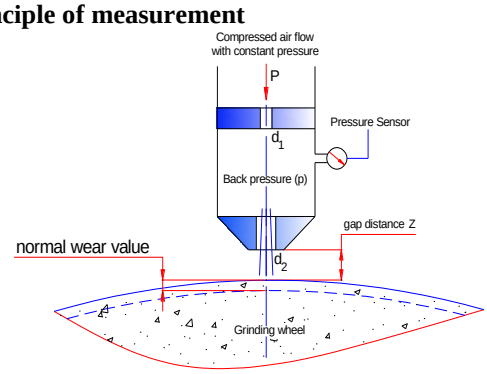


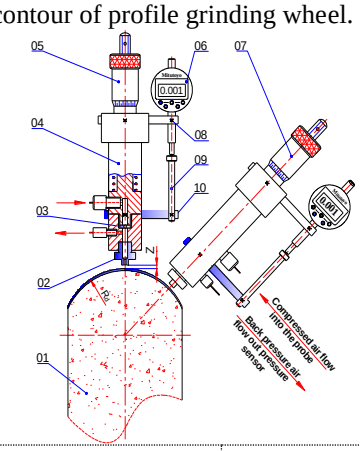
Fig. 1. Measured principle diagram

Fig. 1 shows the wear measurement principle by pneumatic probe. The principle of this measuring method is to use a pressure sensor to capture the change of back pressure when the compressed air issuing from the measuring nozzle (d_2) impinges on the grinding wheel surface. Enlarging the air gap distance (z) between the measured surface and the measuring nozzle (d_2) causes a decrease of the pressure (p) in the measuring chamber. Through proper scaling, this decrease can be used as a measure of the change of gap Δz, which leads to identify the normal wear value of grinding wheel. Specifically, based on the application of the principle of conservation of mass in the variable pressure chamber with assuming incompressible steady flow, the back pressure p can be calculated as:

$$p(z) = \frac{P}{\left(\frac{4d_2}{d_1^2}\right)^2 z^2 + 1} = \frac{P}{\frac{16d_2^2}{d_1^4} z^2 + 1}$$

where d_1 and d_2 are the diameters of the control orifice and the measuring nozzle, respectively [8]. Thus, by determining the change of pressure Δp, the change of gap Δz or the normal wear value can be measured.

However, each pneumatic probe can only measure the wear on a very small area, which can be considered as a point on the working surface of grinding wheel. On the other hand, because profile grinding wheel is worn continuously and unevenly at various points on its working surface, in the study two pneumatic probes have been simultaneously used to capture wear value at two different points on the curving edge surface of the profile grindstone under profile grinding for the inner ring groove of the ball bearing, as shown in Fig. 2. That can be used for determining the wear of contour of profile grinding wheel.



1: Grinding wheel	2: Measuring nozzle
3: Control orifice	4: The first probe (The top probe)
5: Micrometer head	6: Mitutoyo Digit Indicator
7: The second probe (The margin probe)	8: Mitutoyo Digit Indicator holder
9: Measuring rod	10: Measuring rod holder

Fig. 2. The schematic diagram of the experimental system

The measuring nozzle (d_2) was located at a certain distance from the working surface of the grinding wheel [2]. This distance is predetermined to ensure an effective response from the pneumatic measuring probe [2]. The optimum distance of the measuring nozzle (d_2) from the grinding wheel surface is determined by calibration [2]. This calibration is done by constructing the dynamic characteristic curve of the transducer after mounting the probes on the grinding machine, as shown in Fig. 3. The location of the nozzle is varied until there is no change in the back pressure value of the measuring chamber. From these curves, the sensitivity and measurement range of the pneumatic probe system can be determined. Specifically, based on the experimental results of the study it is demonstrated that:

The top probe with the parameters $d_1 = 0.85$, $d_2 = 1.5$ and P = 4 Bar has a measurement range of 200 µm (between 50 µm ÷ 250 µm), a speed ratio of 0.01 Bar/µm and a transfer function of:

$$p = \frac{3.5}{1 + 5.4613e - 0.4 * z^2}$$

The margin probe with the parameters $d_1 = 0.65$, $d_2 = 1.6$ and P = 4 Bar has a measurement range of 140 µm (between 20 µm ÷ 160 µm), a speed ratio of 0.03 Bar/µm and a transfer function of:

$$p = \frac{3.5}{1 + 1.8655e - 0.4 * z^2}$$

This work range will ensure optimum response from the transducer. When the grinding wheel diameter reduces, the location of the sensor can be readjusted accordingly by rotating micrometer head to maintain sensitivity.

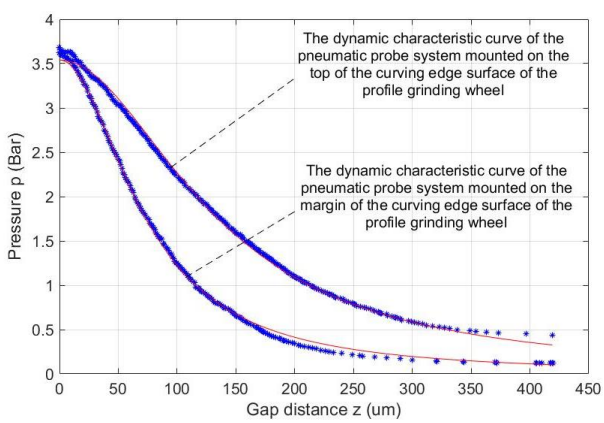


Fig. 3. The dynamic characteristic curves of the pneumatic probe systems mounted on two different points of the curving edge surface of profile grinding wheel

The characteristics of air flow around the periphery of a rotating grinding wheel under profile grinding for the inner ring groove of the ball bearing on grinder 3MK136B

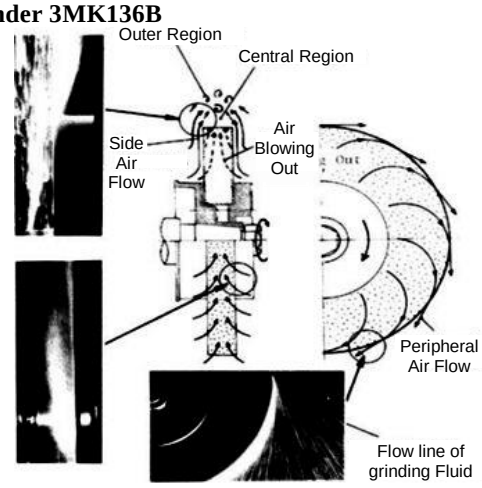


Fig. 4. The state of the air flow around the periphery of a rotating grinding wheel [3]

Fig. 4 shows the state of the air flow around the periphery of a rotating grinding wheel. A grinding wheel rotating at a high speed carries a layer of air on its surface due to the friction of the wheel surface on the air [3, 9]. It is simultaneously driven outwards by the centrifugal force. The pressure change of the air flow caused by the rotating grinding wheel leads to change in the flow area of the air flow blowing from the measuring nozzle d_2 into the working surface of grinding wheel to the surrounding environment. Thus, this causes the change pressure of the chamber. Based on that, the change of the pressure in the chamber throughout the grinding process for a part for each stage of the radial feed motion of the workbench is clearly analyzed as shown in Fig. 5.

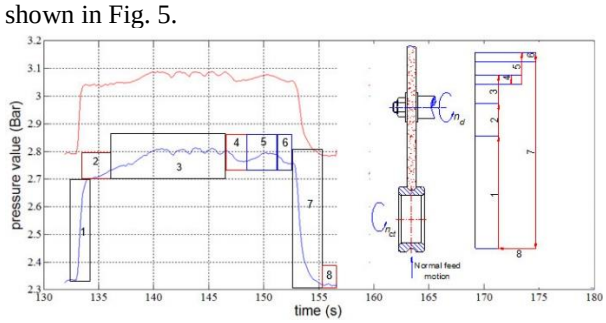


Fig. 5. The changes of back pressure during the grinding process of one part

In the Fig. 5, the drawing on the right shows the operation principle of profile grinder 3MK136B that machines the inner ring groove of the ball bearing. The radial feed motion of the workbench are divided into the 8 stages. The drawing on the left of Fig. 5 shows the pressure change in the chamber over time in a grinding process. Thus, the back pressure of the chamber in the process of grinding a one part is not stable but changes

constantly according to the radial motion of the workbench mouting the parts. Therefore, it is necessary to determine the amount of back pressure difference Δp between the grinding times at the same grinding condition to calculate the the wear value of the grinding wheel after each finished grinding of one part. In the study, the timing when the workbench at its original position corresponding to the pressure (p) at the minimum value during the grinding process of a part is selected. Because this is the time when the process of grinding a part has just finished and is preparing for the next grinding process, the pressure of air flow surrounding the periphery of a rotating grinding wheel is most stable and unaffected by the process of normal feed motion of worktable. Moreover, at this time under the impact of very high pressure of air flow impinging on the wheel surface it is sufficient to avoid any interference from coolant or debris carried by the wheel [9]. Therefore, based on the analysis of the pressure changes in the meaning chamber throughout the grinding process for one part, the appropriate time is selected to determine the wear of the grinding wheel accurately under the profile grinding for the inner ring groove of the ball bearing on the profile grinder 3MK136B.

DIGITIZATION TECHNIQUE

The solution for signals processing and receiving in online measurement of grinding wheel wear

The output signal from the pressure sensor of each probe is linked to a data-acquisition system. Fig. 6 shows a diagram of the control circuit principle to receive and process measurement signals. In the measurement system, two Pisco's SEU-31 pressure sensors are used to measure the pressure in the chamber of each pneumatic probe. By using the ADS1256 converter along with STM32F407 microcontroller, the analog voltage signals from pressure sensor are converted to pressure values. A software program on Matlab Guider was written to handle data and store results on the computer. The software program will always compare the program run-time with the initial installation dressing time and grinding time between two consecutive parts to find out minimum pressure value (P_{min}) during dressing time or grinding time. This is also pressure value of measuring chamber at the time one part grinded completely. Based on that, it counts gap (Z) to calculate the amount of change of gap (Z). This is radial wear value of grinding wheel after each dressing or after each finished grinding of one part. Next, the program will compare this wear value with the given limitation wear value of the grinding wheel to make signal "warning" to users, as the algorithm diagram in Figure 8. If wear value at the top or at the edge of grinding wheel is greater than the limitation wear value, the program will give a "warning signal" to users. Thanks to that, users will know that this is the time to dress grinding wheel in order to ensure the accuracy of parts in the grinding process.

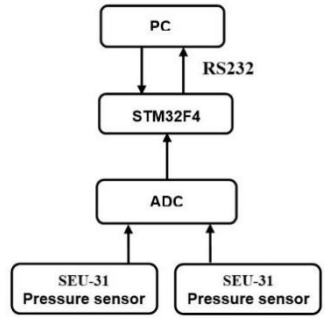


Fig. 6. Diagram of control circuit principle

On the other hand, if optimum grinding parameters are determined and fixed throughout the grinding process, the relation between part's surface roughness (Ra_i) and grinding wheel's wear (δ_i) is determined. Therefore, it can caculate part's surface roughness values (Ra_i) through grinding wheel's wear values (δ_i). Based on a set of empirical value pairs (δ_i, Ra_i), this relation is constructed by partial linear interpolation method as shown in Fig. 7. Therefore, after each finished grinding of one part, from wear values (δ_i) measured online in the grinding process, the software system will interpolate to caculate surface roughness values (Ra_i) respectively. Then, the program will always compare this surface roughness value (Ra_i) with the given surface roughness threshold ($Ra_{requirement}$) to give warning signals for users as shown in the diagram of the algorithm Figure 8. In machining process, if surface roughness value at the top or at the edge of the part's shape (Ra_i) is larger than the given surface roughness threshold ($Ra_{requirement}$), the program will give a "warning signal" to users. Thanks to that, users know the right time to dress grinding wheel to ensure part's surface roughness.

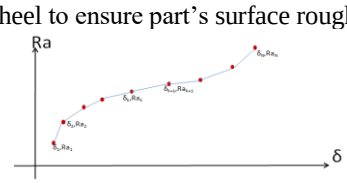


Fig. 7. Construction characteristic line Ra(δ) between grinding wheel's wear and part's surface roughness based on experiment

Algorithm of the data processing program

Fig. 8 shows an algorithm of the data processing program to measure the radial wear value of the grinding wheel. Inputs include the following signals: Analog signals from two pressure sensors in two pneumatic probes are stored in two data arrays A1[N] and A2[N]; Pressure values in the measuring chamber at two probes are stored in two data arrays P1[N] and P2[N]; Grinding time is stored in the data array T1[N]. Outputs include the following parameters: Wear values measured at two probes after each dressing grinding wheel are stored in two data arrays C1[N'] and C2[N']; Wear values

measured at two probes after each grinding done one part are stored in two data arrays M1[N'] and M2[N']. Total wear values caculated at two probes after each grinding done one part are stored in two data arrays SUM1[N'], SUM2[N']. Surface roughness values at the bottom and at the edge are stored in two data arrays Q1[N'] and Q2[N'].

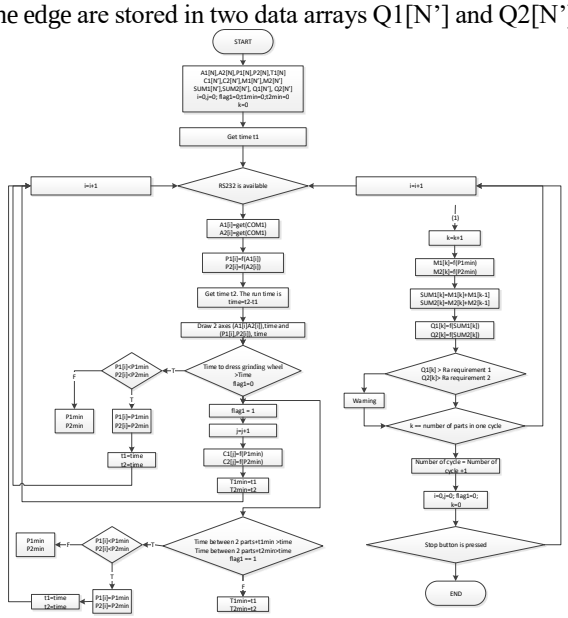


Fig. 8. Algorithm diagram of the data processing program

EXPERIMENTS AND RESULTS

The experimental process is performed on grinder 3MK136B to grind profile inner ring grove of 6208 ball bearing. The experiment system is set up as shown in Figures 2 and 9. Two pneumatic measuring probe are used to measure grinding wheel's wear at two different points on its working surface. The first probe measures wear at the top of the curving edge surface of the grinding wheel. The second probe captures wear at the margin of the curving edge surface of the grinding stone.

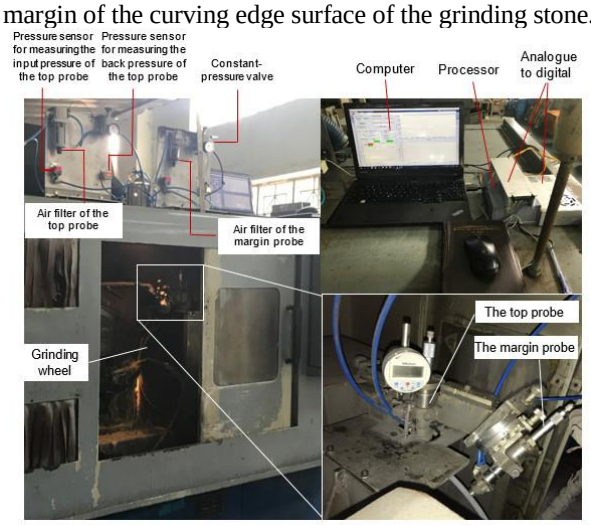


Fig. 9. Image of the real probe system for measuring wear value in profile grinding process after mounting the probes on the 3MK136B grinding machine

Thirty parts are grinded in the experimental process with the specifications of the grinding conditions and grinding wheels as shown in table 1 and table 2.

Table 1. Specifications of grinding conditions

Grinding speed	60 m/s
Fine depth of cut	10 µm
Rough depth of cut	120 µm
Fine feed rate	5 µm/s
Rough feed rate	30 µm/s
Part speed rate	6 m/min

Table 2. Specifications of grinding wheel

JIS code	A100L5V
Grade	Soft
Grain	White fused alumina
Bond	Vitrifide
Wheel size	500 in outer diameter and 8 in width

Experiment results are exported to 1 txt file and 1 image file. Grinding wheel's wear values (δ_i) and part's surface roughness values (Ra_i) are calculated after each finished grinding of one part as shown in software interface in Figure 10. In the software interface has 3 graphs as follows:

- The first graph shows pressure change in the measuring chamber of each probes over grinding time. This graph is located at the third quadrant on the right hand side. While the above graph corresponds to pressure change of the top probe, the below graph corresponds to pressure change of the margin probe.

- The second graph shows the total amount of grinding wheel's wear (δ_i) over the number of grinding parts. This graph is located at the first quadrant on the left hand side. While the above blue graph corresponds to wear value of the margin probe, the below red graph corresponds to wear value of the top probe.

- The last graph shows surface roughness value change (Ra_i) over the number of grinding parts. This graph is located at the fourth quadrant on the right hand side. While the above blue graph corresponds to surface roughness value of the margin probe, the below red graph corresponds to surface roughness value of the top probe.

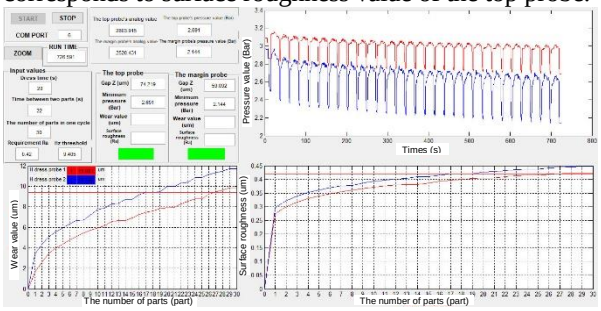


Fig. 10. Software interface after finished grinding 30 parts in one cycle for both the top probe and the margin probe

From these graphs, it can be seen that grinding wheel's wear values and part's surface roughness values at the edge of the curving edge surface of grinding wheel is higher than those of at the top of the curving edge surface of grinding wheel. The unequal distribution of grinding stock is the main reason for this. Mechanical surplus at the edge is greater than that at the top. In addition, the grinding wheel at the initial parts (the first part and the second part), after just dressing grinding

wheel, will be worn more than at the later parts. The wear value of grinding wheel at the initial parts corresponds to the initial wear phase of grinding wheel. The wear value in the following parts tends to decrease. It corresponds to the steady wear rate stage of grinding wheels.

In particular, at the time 17th part grinded completely, the program gives a "warning" signal. At that time, surface roughness value at the edge of of the curving shape of part has surpassed the value of requirement surface roughness ($Ra_{requirement}$ = 0.42). It is time to must dress grinding wheel to ensure requirement quality of part's surface roughness. Therefore, the wear value of grinding wheel at this time have to pass the limitation wear value of the grinding wheel. Thus, wear value threshold of the grinding wheel can be determined through the requirement surface roughness value of the operation. From the requirement surface roughness value of the profile grinding operation for 6208 ball bearing's inner ring grove, using the method of partial linear interpolation, the corresponding wear value will be determined (Hz_{17} = 9.405 µm). This value is the limitation wear value of the grinding wheel for the profile grinding operation with the cutting mode being investigated.

CONCLUSION

In-process detection of profile grinding wheel dressing conditions by using two pneuamatic measuring probes is newly developed. The above experiment results show that the solution for determining reasonable dressing time by applying pneuamatic measuring probes is reliable and accurate. Grinding wheel's wear value is measured directly in the grinding process based on the application of pneumatic measuring probe. By combining two pneumatic measuring probes, the system determines online wear value at the top and at the edge of the curving surface of grinding wheel. Then, on the basis of application of the partial linear interpolation method, the software system calculates surface roughness's value at each point corresponding on part's surface. Based on that, if surface roughness's value passes requirement surface roughness value, the software system give online warning signal for users. Thanks to that, users determine the resonable time to dress grinding wheel to ensure the accuracy of part and enhance the durability of grinding wheel. Specifically, in profile grinding for inner ring groove of 6208 ball bearing on grinder 3MK136B at cutting mode having fine depth of cut of 10 µm, fine feed rate of 5 µm/s, the part speed rate of 6 m/min and grinding speed of 60 m/s, the user should dress the grinding wheel at the 17th grinding part.

ACKNOWLEDGMENTS

The authors acknowledge the support from 911 Budget for PhD Student, Ministry of Education and Training, Viet Nam.

REFERENCES

[1] Hong-Tsu Young Der-Jen Chen. 2006, Online dressing of profile grinding wheels, Int J Adv Manuf Technol, 27, 883-888.

[2] T M A Maksoud, A A Mokbel, J E Morgan. 1997, In-process detection of grinding wheel truing and dressing conditions using a flapper nozzle arrangement, Proceeding of the Institution of Mechanical Engineerings, 211, 335-343.

[3] J. Shibata, T. Goto and M. Yamarnoto. 1982, Characteristics of Air Flow Around a Grinding Wheel and Their Availability for Assessing the Wheel Wear, Annals of the ClRP, 31, 233-238.

[4] Dong WP, Annecchino L and Webster JA. 1996, On-line measurement of grinding wheel wear using acoustic emission, Proceedings of the 11th Annual Meeting of American Society for Precision Engineering, USA, 11, 566–571.

[5] Spur G, Leonards F. 1975, Sensoren zur Erfassung von Prozesskenngrössen bei der Drehbearbeitung, Ann CIRP 24 (1), 349–355.

[6] Stephane LaChance, Andrew Warkentin and Robert Bauer. 2003, Development of an Automated System for Measuring Grinding Wheel Wear Flats, Journal of Manufacturing Systems, 22 (2), 130-135.

[7] Haiyue Yu, Yushan Lu and Jun Wang. 2016, Study on wear of the grinding wheel with an abrasive phyllotactic pattern, Wear Journal, 358, 89-96.

[8] P. Koshy, D.Grandy and F.Klocke. 2009, Pneumatic non-contact roughness assessment of moving surfaces, Manufacturing Technology, 58, 515-518.

[9] J. Fazlurrahman and V.Radhakrishnan. 1981, Surface condition monitoring of grinding wheels by pneumatic back-pressure measurement, Wear, 70, 219-226.

[10] Nguyen Viet Tiep. 1984, Obrobtitelnost Kovových materlálú brousením, Dotoral thesis - Vysoká Skola Strojí a textliní Liberec, Czechoslovakia.