Applying Pneumatic Probe System to Monitor Part's Surface Roughness and Grinding Wheel's Wear in Profile Grinding for Ball Bearing's Inner Ring Groove

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Abstract

The article presents the results of research and apply pneumatic measuring probe to monitor part's surface roughness and grinding wheel's wear in profile grinding for the ball bearing's inner ring groove. On that basis, it makes an online warning for limiting dress grinding wheel according to the given surface roughness threshold or wear threshold. The signals obtained from pressure sensors of pneumatic measuring probe system are processed to calculate grinding wheel's wear and part's surface roughness. The output values of this probe system is very close to experimental data values. The results demonstrate ability to monitor the real status of grinding wheel's wear and part's surface roughness.

Keywords: Profile grinding, online monitoring, grinding wheel's wear.

1. Introduction

In the profile grinding process, besides part's surface roughness indicator, abrasive wear and grinding wheel durability are also important technical and economic output parameters. The surface roughness is one of the most important features to assess the quality of product, while grinding wheel wear directly impacts the cutting ability of grinding wheel, productivity, quality and efficiency of profile grinding's whole process. For profile grinding, area of contact between grinding wheel and workpiece surface is large, thus cutting force and cutting heat are high. Therefore, grinding wheel is worn continuously and unequally over different cross-sections, the cuting ability of grinding wheel is reduced, the original shape accuracy of grinding wheel is changed during grinding process. It leads to increase surface roughness and form tolerances of product. Thus, the precision in general and the surface roughness of part achieved for profile grinding are strongly related to dress grinding wheel in grinding process. Monitoring the amount of wear to determine the appropriate time for dressing grinding wheel will prevent making poor quality product, using too wear grinding wheel, and changing grinding wheel while machining product.

To ensure economic and technical efficiency of profile grinding process, one of the industrial requirements is online monitoring grinding wheel's wear and part's surface roughness. This is the basis of adaptive control and the indispensable components of an innovative and intelligent grinding system.

Both part's surface roughness and grinding wheel's wear are functions of the cutting mode. Thus, they must have a relationship with each other [9, 10]. This relationship has both positive and negative impact on the monitoring process. The negative influence is that the change of cutting mode to improve one parameter would worsen other parameters. The positive side is the ability to caculate hard-to-measure parameters via easy-to-measure parameter. This ability has been utilized to set up online monitoring surface roughness in grinding process.

Part's surface roughness can not be measured directly in the machining process. On the other hand, other parameters such as cutting force (F), grinding wheel's wear (δ_i), etc could be. Therefore, part's surface roughness value (Ra_i) will be caculated through grinding wheel's wear value (δ_i) measured by pneumatic measuring probe system.

From the above analysis, the authors have researched to apply pneumatic measuring probe to perform online monitoring part's surface roughness and grinding wheel's wear for profile grinding ball bearing's inner ring grove.

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2. Content of the study

2.1. Model for monitoring grinding wheel's wear and part's surface roughness in profile grinding process

The basic features of the machining process are complex and nonlinear. It is often influenced by unforeseen factors. In traditional machining, control and monitoring processes often rely on well-training workers. They have ability to recognize situations and handle them in a flexible manner. However, if control is based on worker's senses and handling, it will not be able to guarantee objectivity, reliability and stability in the machining process. Hence, in order to reach a automatic production system, the roles of human in monitoring and controling have to be replaced by machines. Therefore, it is necessary to build a system monitoring automatically technological system's elements in machining processes [9, 10].

In previous studies, some online monitoring and adaptive control systems have introduced [9, 10]. This is a complex mechatronic system involving many different areas. The task of designing these systems is generalized into five main areas and represented in Fig. 1.

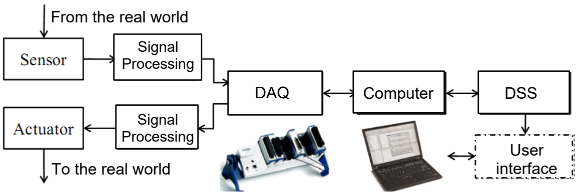

Fig. 1. The structure diagram of an online monitoring system [10]

This diagram shows the general structure of an online monitoring system. This system includes elements as follows: (1) Sensors measuring cutting forces, pressure, temperature, etc; (2) hardware (DAQ) collecting data; (3) software (DSS) processing data, extracting samples and supporting decision-making. However, the system merely performs task of monitoring, supporting decision-making and providing warning signals to users. It has not control functions.

In order to have a smart machining system, an adaptive controllers (AC) or adaptive controller optimization (ACO) should be added to the model as Fig. 2 [9, 10]. In essence, this adaptive controller is a decision-making system having function of calculating, identifying, classifying events and giving control signals. Therefore, AC and ACO already contain module DM (Dicision Making).

Two control models show that online monitoring is an indispensable system of adaptive control process. In order to make adaptive control system, the first requirement should be to perform online process monitoring. Although the highest goal is grinding process's adaptive control, in the area of research the authors only focus on the direction to build an system monitoring online grinding wheel's wear and part's surfaces roughness for profile grinding the ball bearing's inner ring grove. The system gives warning signal for users. It indicates the right time needed to dress grinding wheel.

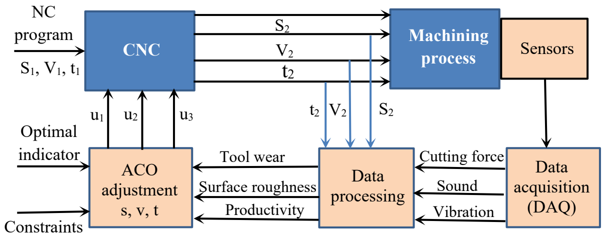

Fig. 2. The general structure of an adaptive control system [9, 10]

Derived from the general structure diagram of an online monitoring system, on the basis of reference to the previous online monitoring and adaptive control systems, the author proposes a functional scheme for system to monitor online grinding wheel's wear and part's surfaces roughness as shown in Fig. 3 and Fig. 4.

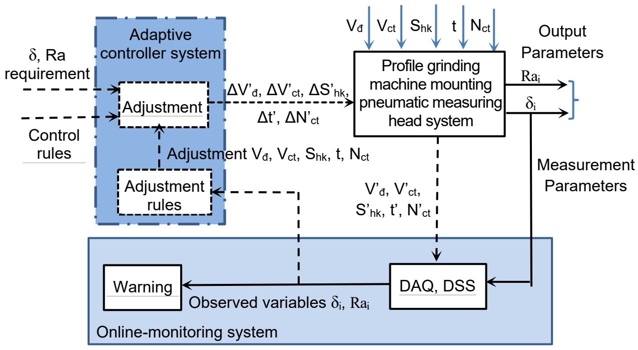

Fig. 3. The functional diagram of system to monitor online grinding wheel's wear and part's surface roughness for profile grinding ball bearing's inner ring grove [9, 10]

In the system, 3MK136B profile grinding machine is fitted with pneumatic measuring probe to measure grinding wheel's wear. The computer connected to DAQ hardware and DSS software is responsible for receiving, processing of measured signals to caculate grinding wheel's wear (δ_i) and part's surface roughness (Ra_i). These values are displayed on the computer screen to inform users. In addition, an adaptive controller could be inserted into the processor to adjust the cutting mode. However in the research of this paper, the system does not have adaptive controller, it consists only of continuous line's elements.

The dash-line elements belong to adaptive control system. It can be developed in the future.

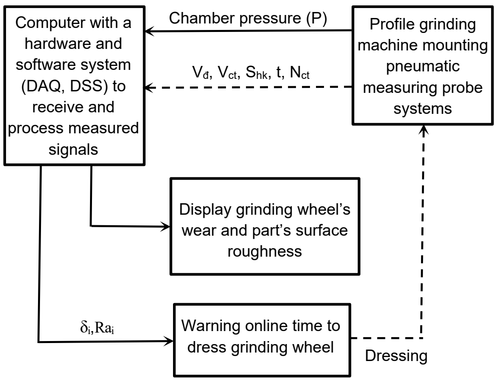

Fig. 4. Online-monitoring model of grinding wheel's wear and part's surface roughness for profile grinding ball bearing's inner ring grove [9, 10]

In this model, the system can perform two tasks: (1) Caculating grinding wheel's wear value and part's surface roughness value; (2) Warning on-line limitation of grinding wheel dressing under the given surface roughness threshold or wear threshold.

2.2. Theoretical basis of monitoring grinding wheel's wear in grinding profile process

The authors apply pneumatic measuring probe to monitor online grinding wheel's wear for grinding profile ball bearing's inner ring grove. The diagram of online monitoring system is shown on Fig. 5. In profile grinding process, the amount of wear at various points on the curving edge shape of grinding wheel will not be the same. Therefore, in order to monitor grinding wheel's wear, the author uses two pneumatic measuring probe systems to evaluate wear at the top of the curving edge shape and at the edge of the curving edge shape of grinding wheel. These are two points having the largest difference in the amount of wear compared to all the other points on the whole curving edge shape of grinding wheel's working surface. Also, to measure pressure in the measuring chamber of each pneumatic measuring probe, two pressure sensors (SEU-31 of the Pisco) with measurement range 1-10 Bar, resolution 0.001 Bar have been used and taken signal continously during measuring process. Especialy, in order to perform online monitoring grinding wheel's wear, a hardware and software system connected to computer is designed and manufactured to continuously receive pressure signals from pressure sensors. On that basis, the system will calculate radial wear value at the peak point and at the edge point of the curving edge shape of grinding wheel after each time a part grinded completely.

In this monitoring model, the authors have chosen a STM32F4 microcontroller (No.11 part) for processing and transmission signals of two pressure sensors measuring pressure of measuring chamber in each measuring probe system. The interface software is built to transmit control signal between computer, connection circuit and pressure sensors. Matlab software is used as a tool to connect, handle data, store results because programme language on Matlab is quite simple [8, 9].

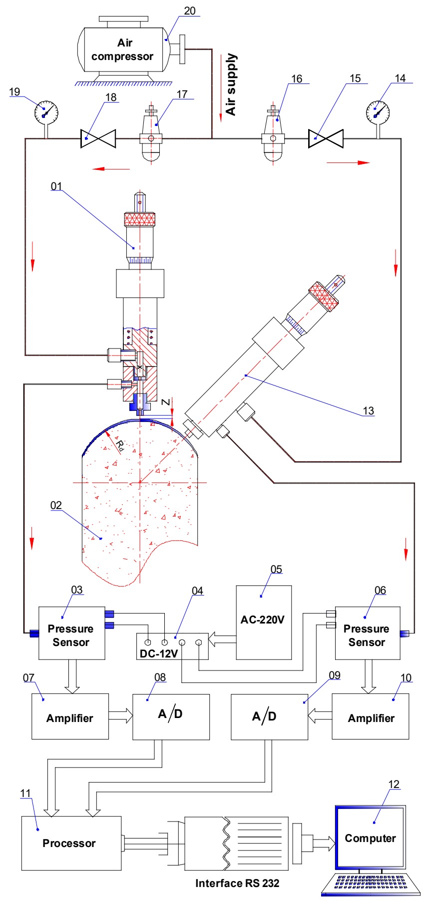

Fig. 5. The system diagram for online monitoring grinding wheel's wear in profile grinding process [1-5]

In the above system diagram:

1: Pneumatic probe measuring wear at the top of the curving edge shape of grinding wheel (The top probe).
2: Grinding wheel.
3: Pressure sensor for measuring pressure in measure chamber of the top probe.
4: Adapter DC -12V; 5: Power supply - 220V
6: Pressure sensor for measuring pressure in measure chamber of the margin probe.
7, 10: Amplifier; 8, 9: Analogue to digital converter
11: STM32F4 processor; 12: Computer (PC)
13: Pneumatic probe measuring wear at the edge of the curving edge shape of grinding wheel (The margin probe); 14, 19: Source pressure gauges.
15, 18: Constant-pressure valve.
16, 17: Air filter; 20: Air compressor.

The process of retrieving data takes place as Fig. 6: Signals from two sensors will be transmitted to the IN0 and IN1 pins of ADS1256 module. After microcontroller configurates for ADS1256 module, it will send a 16-bit data frame. Each bit is transmitted on the DIN pin of microcontroller, 1 bit will be received from module on the DOUT pin. Therefore with 16 bit is transmitted, DATA register of ADS1256 will be received 16 bit [6, 7]. After pressing START in software interface, the data receiving flag is equal to 1. The program will set time t_1 at this time as the starting point. At the same time, analog values in both pressure sensors will be transmitted consecutively from the microcontroller onto PC via RS232 connection. They are stored alternately in $A_1[i]$ and $A_2[i]$ array. At this moment, the data receiving flag will be equal to 0 for pausing transmittation data from microcontroller to PC. Then, the program calculates the conversion from analog values to pressure values. Next, these pressure values will be saved into $P_1[i]$ and $P_2[i]$ array. At this time, the program will update the current time t_2 to identify program run-time (Runtime=t_2-t_1). Based on that, it draws analog value graph and pressure value graph from time to time. These graphs are displayed on the screen of PC. Simultaneously, the data receiving flag at the moment will be transferred to 1. Thus, microcontroller continues sending next analog values from both pressure sensors onto the PC. Therefore, after each such sampling, the program will determine program run-time. It will always compare the above 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 a part grinded completely. Based on dynamic characteristic lines of each pneuamatic measuring probe, it will find the corresponding transfer functions (with the top measuring probe: $p = \frac{3.5}{1+5.4613e-0.4*z^2}$; with the margin probe: $p = \frac{3.5}{1+1.8655e-0.4*z^2}$) [3]. Therefore, from minimum pressure value (P_{min}) it counts gap (Z) to calculate the amount of change of gap (Z). This is radial wear value of grinding wheel after every dressing or after every a part grinded completely. Next, the program will compare this wear value with the given wear threshold to make signal “warning” to users, as the algorithm diagram in Fig. 8. If wear value at the top or at the edge of grinding wheel is greater than the wear threshold, the program will give a signal "warning" 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.

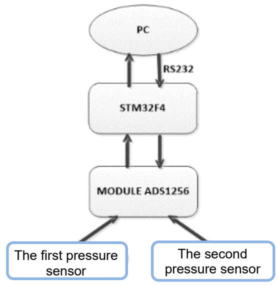

Fig. 6. The diagram of control circuit principle

2.3. Theoretical basis for monitoring part’s surface roughness in profile grinding process

Although parameters in grinding process have relations with each other, the relations between them are very intricate and complex. It is difficult to identify explicitly relations between them by mathematics. So far it has not seen any announcement about mathematical relations between them, such as between durability and cutting force, durability and cutting temperature, etc. It can only build the experimental parameters. On the other hand, the relationship between parameters is nonlinear. It affected by many unforeseen disturbances factors. In addition, it is also not easy to analyze multi-variables functions in mathematics. This explains why traditional approximation methods, such as the smallest square method, are not suitable for online monitoring issue.

However, when the optimal input parameters of the technology system are already known, their values will be permanently installed on the machine during the grinding process. With this case, relation between part’s surface roughness (Ra_i) and grinding wheel’s wear (δ_i) is determined. Therefore, by caculating part’s surface roughness values (Ra_i) through grinding wheel’s wear values (δ_i), part’s surface roughness (Ra_i) can be monitored in the grinding process. However, establishment of the relation between grinding wheel’s wear (δ_i) and part’s surface roughness (Ra_i) by mathematical formula is very difficult and infeasible. Thus, the determination of this relation based on approximation interpolation methods by experiment shows more effectiveness than other methods. Concretely, from experimental results a set of empirical value pairs (δ_i, Ra_i) is identified. A set of discrete experimental points is defined as shown in Fig. 7.

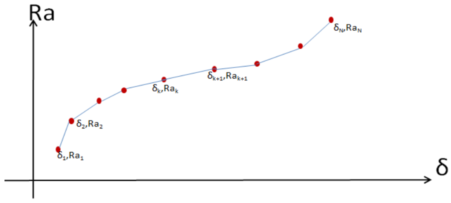

Fig. 7. Construction characteristic line Ra(δ) between grinding wheel’s wear and part’s surface roughness based on experiment

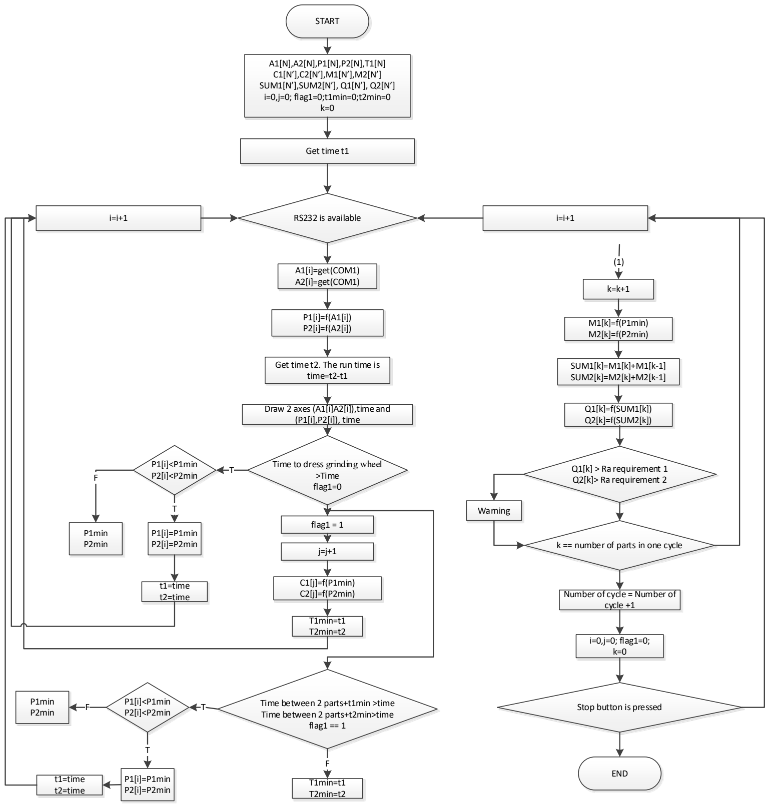

Fig. 8. Algorithm for interface software program to find grinding wheel's wear value

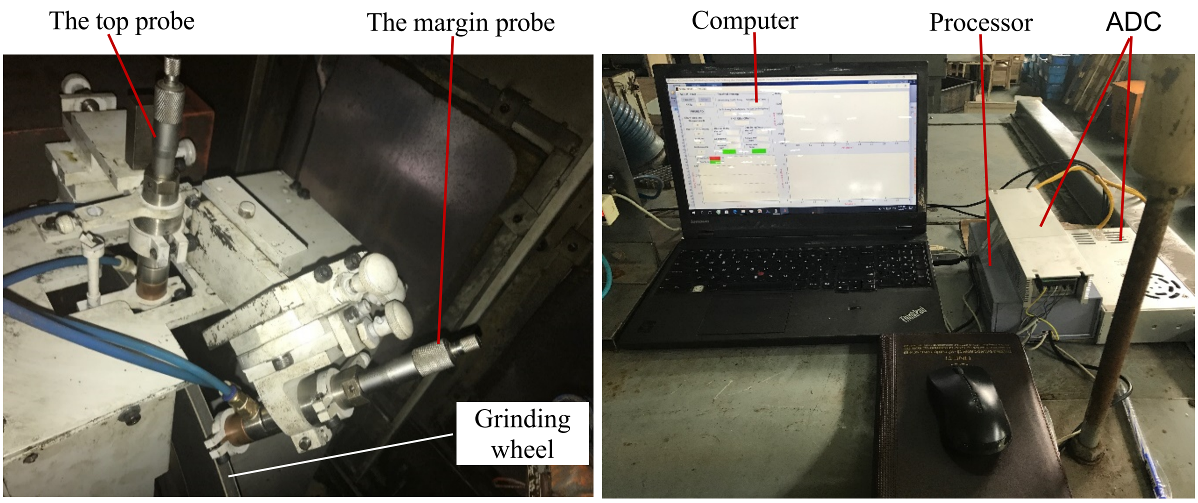

Fig. 9. Experimental system measuring grinding wheel's wear for profile grinding ball bearing's inner ring grove after mounting two probes onto profile grinding machine 3MK136B [2, 3]

Caculating part's surface roughness value (Ra_i) at grinding wheel's wear value (δ_i) is based on an approximation function constructed by interpolation method from a set of empirical value pairs (δ_i, Ra_i). Several methods can be listed such as partial linear interpolation, quadratic part interpolation, spline interpolation … In this paper, the authors apply partial linear interpolation method. Therefore, after each a part grinded completely, from wear values (δ_i) measured online in the grinding process, the software system will be used to interpolate to caculate surface roughness values (Ra_i) respectively. The wear values (δ_i) measured at the top probe will be used to interpolate to caculate surface roughness values (Ra_i) respectively at the bottom on the shape of ball bearing's inner ring grove. The wear values measured at the margin probe are used to interpolate to caculate values of corresponding surface roughness at the edge on the shape of ball bearing's inner ring grove. Then, the program will always compare this surface roughness value (Ra_i) with the given surface roughness threshold ($Ra_{requirement}$) to indicate warning signals for users as shown in the diagram of the algorithm Fig. 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.

2.4. Data processing algorithm

The algorithm of data processing program is represented as Fig. 8. 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'].

2.5. Experimental and Results

The experimental process is performed on 3MK136B profile grinding machine to grind 6208 ball bearing's inner ring grove. The experiment system is set up as shown in Fig.s 5 and 9. Two pneumatic measuring probe are used to measure grinding wheel's wear at two different points on its working surface. The top probe has the following parameters: Source pressure P_0=4 Bar; Control orifice d_1=0,85; Measuring nozzle d_2=1,5. The margin probe has parameters as follows: Source pressure P_0=4 Bar; Control orifice d_1=0,65; Measuring nozzle d_2=1,6.

Thirty parts are grinded in the experimental process with technological parameters as follows:

- Grinding wheels: 500x8x203A/WA100xLV60
- The speed of grinding stone: n_w= 2500 rpm
- The speed of part: V_s = 6 m/min
- The depth of cutting: t_{raw} = 0.2 mm; t_{fine}= 0.01 mm
- The rate of normal feed: S_{raw} = 30 μm/sec; S_{fine} = 5 μm/sec
- Time to dress grinding wheel: t_{dress} = 20 seconds.
- Time to grind a part: t_{grind} = 22 seconds

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 time one part grinded completely as shown in software interface in Fig. 10. In the software interface has 3 graphs as follows:

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

- A 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 the margin probe, the below red graph corresponds to the top probe.

- A 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 the margin probe, the below red graph corresponds to the top probe.

From these graphs, the authors find that: Grinding wheel's wear values and part's surface roughness values at the edge of the curving edge shape of grinding wheel is higher than those of at the top of the curving edge shape of grinding wheel. The unequal distribution of grinding stock is the main reason for this. Mechanical surplus at the edge is greater than those of 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 amount of grinding wheel's wear at the initial parts corresponds to the initial wear phase of grinding wheel. The amount of wear in the following parts tends to decrease. It corresponds to the steady wear rate stage of grinding wheels.

In particular, at the time 19^{th} 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 amount of grinding wheel wear at this time have to pass the given wear threshold. Thus, grinding wheel wear threshold 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 grinding wheel wear threshold for the profile grinding operation with the cutting mode being investigated.

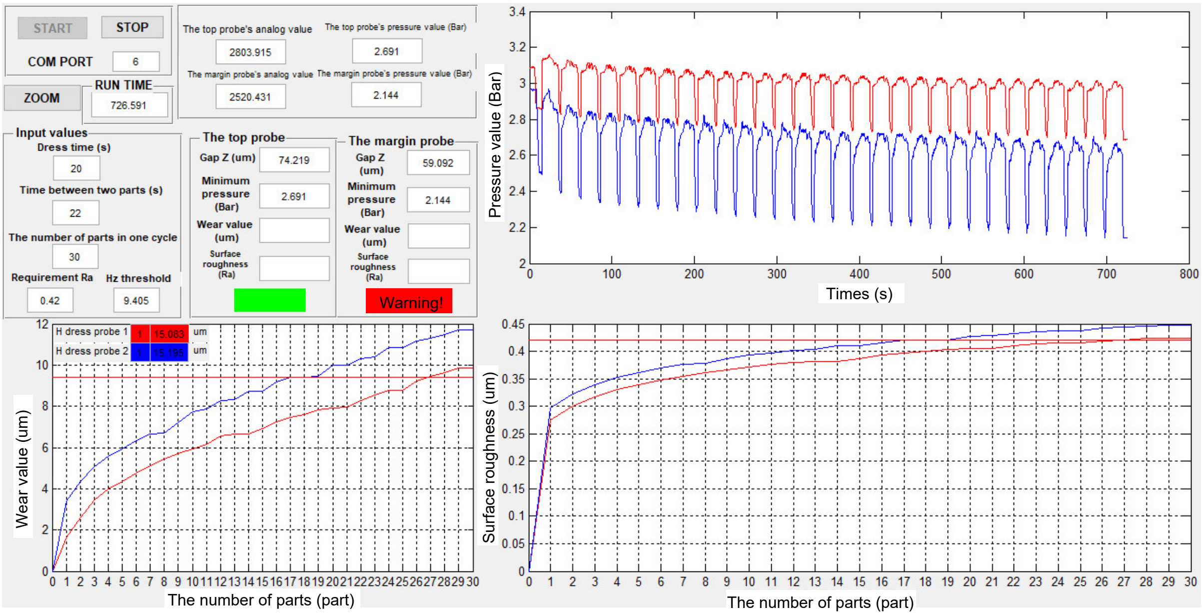

Fig. 10. Software interface after finished grinding 30 parts in one cycle for both the top probe and the margin probe

3. Conclusion

The above experiment results show that the solution for determining part's surface roughness through grinding wheel's wear value has achieved satisfactory results. This solution is based on application of the partial linear interpolation method. Grinding wheel's wear value is measured directly in the grinding process on the basis of 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 shape of grinding wheel. Then, on the basis of application of linear interpolation method, the software system has calculated surface roughness's value at each point corresponding on part's surface to give online warning signals for users. Thanks to that, users determine the resonable time to dress grinding wheel 3. In addition, these results can be applied as the basis of adaptive control for automatic compensation of grinding wheel's wear.

References

[1]. Nguyễn Tiến Thọ, Nguyễn Thị Xuân Bảy, Nguyễn Thị Cẩm Tú, "Kỹ thuật đo lường kiểm tra trong chế tạo cơ khí", Nhà xuất bản Khoa học Kỹ thuật, 2002.

[2]. Nguyễn Anh Tuấn, Nguyễn Viết Tiếp, Vũ Toàn Thắng "Xây dựng hệ đầu đo khí nén để đo lượng mòn đá mài khi mài định hình", Hội nghị khoa học kỹ thuật đo lường toàn quốc lần thứ VI 2015.

[3]. Nguyễn Anh Tuấn, Nguyễn Viết Tiếp, Vũ Toàn Thắng "Nghiên cứu phương pháp đo mòn đá khi mài định hình bằng hệ đầu đo khí nén", Hội nghị KH&CN toàn quốc về cơ khí – động lực 2016.

[4]. T M A Maksoud, A A Mokbel, J E Morgan "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, 1997.

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

[6]. Texas intrusment, "Data sheet – ADS1256", SBAS288J – JUNE 2003 – REVISED AUGUST 2008.

[7]. STMicroelectronics group of companies, "Data sheet –STM32F4", May 2012.

[8]. Đặng Đình Duẩn, Tạ Thị Thúy Hương, Vũ Toàn Thắng "Giải pháp thu nhận và xử lý số liệu cho mô hình đo độ tròn kết hợp nhiều đầu đo", Hội nghị khoa học kỹ thuật đo lường toàn quốc lần thứ VI 2015.

[9]. Đào Văn Hiệp, Phạm Vũ Dũng "Giám sát mòn của đá mài có ứng dụng mạng mờ nơron nhân tạo", Hội nghị toàn quốc về Điều khiển và Tự động hóa, lần thứ II 2013.

[10]. Đào Văn Hiệp "Giám sát và điều khiển thông minh quá trình công nghệ", Tài liệu chuyên khảo sau đại học của Trường Học Viện Kỹ Thuật Quân Sự, Hà nội 02/2014