AE Monitoring System for Belt Grinding and Polishing Processes by Industrial Robot

Chun-Wei Liu[1,a *], Po-Chun Chi[1,b], Chih-Hsuan Shih[1,c], Kao-Der Chang[1,d], Ta-Hsin Chou[1,e] and Chih-Ming Tsai[2,f]

[1] Mechanical and Mechatronics Systems Research Laboratories, Industrial Technology Research Institute, 195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu 310, Taiwan

[2]BASO PRECISION OPTICS LTD., 14, Chien-Kuo Road, Taichung Export Processing Zone, Tantzu, Taichung 427, Taiwan,

[a] weilu@itri.org.tw, [b] itri454634@itri.org.tw, [c] itriA20303@itri.org.tw, [d]changkaoder@itri.org.tw, [e]TaHsinChou@itri.org.tw, [f] joser.tsai@baso.com.tw

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Abstract.

The robotic process optimization system is utilized to compensate the variance of the workpieces by Acoustic emission (AE) signal, which having different bandwidth is complementary for grinding/polishing process monitoring. In order to analysis the quality of workpieces, a fractional factorial design of 2^{5-1} was used for experimental planning. In this study, belt speed, belt quality, manipulator feeding rate, workpiece contact area and workpiece material were tested, and the experiments were then conducted to examine the effects of workpieces accuracy and fabrication process. In the experimental tests, the optimized parameters combination for AE signals which were derived from the statistical analysis could be found for higher removal rate through the above design of experiment (DOE) results.

Introduction

With the rapid development of smart manufacturing in recent years, industrial robots have been widely applied to grinding and polishing processes. During the contact manufacturing process, the workpiece and robot are influenced by different factors of production, including accuracy of workpieces and wear of equipment. It is difficult to grind and polish for workpiece's cutting edges and irregular geometry, so monitoring processes is necessary for this system to conduct optimization and control.

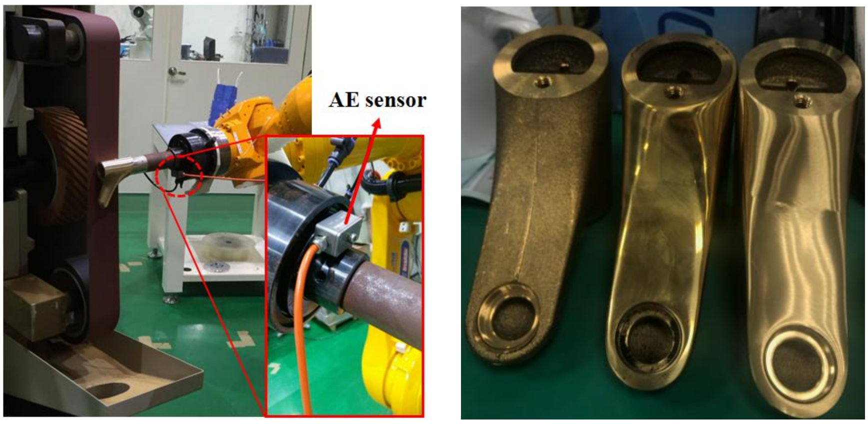
Acoustic emission (AE) has become an increasingly popular monitoring technique. This sensor is inexpensive, easy to mount, sensitive, and easy to filter the noise. In recent years, researchers have shown the AE signals to provide experimental results for monitoring the grinding and polishing process [1-4]. AE signals can also be used as a feature for forecast model. Chang et al. use AE sensor to monitor the material removal rate (MRR) during the polishing process [5]. Tang et al. try to classify the polishing process by analyzing AE signals for the purpose of preventing microscratching [6]. Wang et al. use artificial neural network approach based on AE signals to detect undesirable changes under inappropriate grinding process. [7]. Paulo et al. use neural networks trying to predict the surface roughness of ground workpieces based on the analysis of output variables, such as AE signals and cutting power [8].

In this study, AE sensor is used to analyze the grinding/polishing quality. A 2^{5-1} factorial design of experiments is discuss for the interaction among the process variables. The aim is to establish the process optimization system of grinding and polishing for robot, which can monitor the quality of process and improve the rate of product failure.

Experiment Methods and Results

The robotic process optimization system with AE signal used for this study is set up and shown in Fig. 1 (a). This robot CAD/CAM system is adopted in the grinding and polishing processes for water hardware industry such as toolpath generation, kinematics simulation and collision detection. The robot program is automatically generated by the path data. Finally, simulation and force control dominate the quality of workpieces. Fig.1 (b) shows different periods of grinding/polishing process and the roughness (Ra) is about 867nm and 29nm.

The fractional factorial design of 2^{5-1} is used for experimental planning. The DOE method of factor 5 level 2 is selected for the process variables including belt speed(A), belt quality(B), manipulator feeding rate(C), workpiece contact area(D) and workpiece material(E) and this was shown as the Table 1.



(a) (b)

Fig.1 (a) Integrated robot with AE sensor and (b) Workpiece quality through grinding/polishing process

Table 1 Parameter ranges of robotic grinding/polishing process for DOE method

Process parameters	Low level(-)	High level(+)
(A)Belt speed	1000rpm	1250rpm
(B)Belt quality	old	new
(C)Manipulator feeding rate	~1mm	~4mm
(D)Workpiece contact area	14mm	33mm
(E)Workpiece material	Carbon steel	Copper

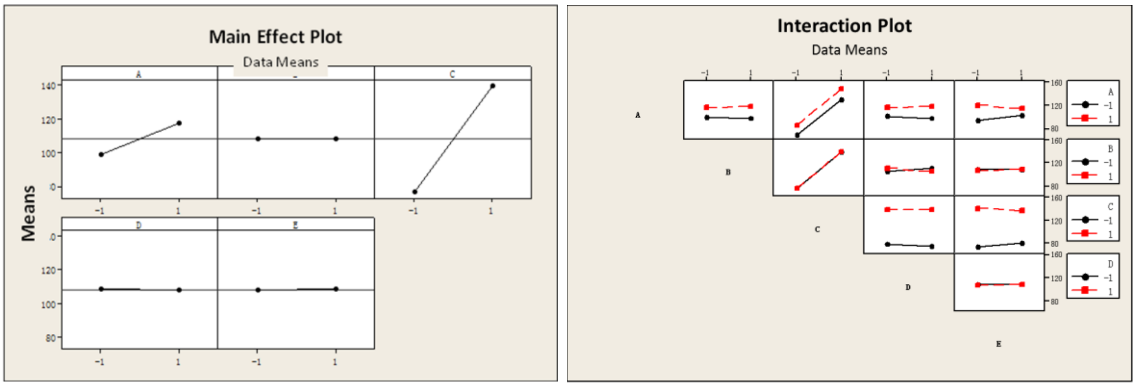
AE signal values were determined by the reactions of variables. The design of experiment software, MINITABTM (Minitab Inc.) is analyzed for the corresponding results. The type L16 orthogonal array of process variables is used by DOE method regarding MRR. While $\boldsymbol{\alpha}$ is set as 0.05, P values of the main effect and interaction effect smaller than 0.05 are significant. From Table 2, the sixteen combination of experiments is set up. Each one is repeated and verified for three times, and the effect of A,C,AD,AE,BD and CE is significant with AE signal values. The main effect has reactions to the fourth-order, and the second-order has reactions to the third-order. Multivariate linear regression equation is derived from DOE methods where the model capacity is stable from the results of R^2 (Prediction) =96.80%:

$$\text{Signal value} = 108 + 9.39\,A + 31.4\,C - 3.64\,AE - 2.55\,BD + 1.64\,AD - 2.43\,CE \qquad (1)$$

When the main effect plot is performed at a higher slope, the values of factors highly effect to the experimental results. From Fig. 2 (a), the significant level is determined with AE signal values as C > A > D ≥ E ≥ B substantially. The parameters of robotic grinding/polishing process are optimized while the high level is belt speed, manipulator feeding rate and workpiece material and low level is belt quality and workpiece contact area. In order to discuss the trend of interaction effect relative to these variables, the effects of variables were examined using the interaction plot, as shown in Fig. 2(b). The interactions between the two variables show that the AD, AE, BD and CE tend to be affected by AE signal values due to the appearance of an intersection on the graph.

Table 2 The effect of AE signal and the coefficient analysis

Process parameters	Effect	Coefficient	Standard error	T	P
Constant	--	108.095	0.7064	153.03	0.000
A	18.784	9.392	0.7064	13.30	0.000
B	-0.175	-0.088	0.7064	-0.12	0.902
C	62.881	31.441	0.7064	44.51	0.000
D	-0.909	-0.454	0.7064	-0.64	0.525
E	0.858	0.429	0.7064	0.61	0.548
A*B	1.750	0.875	0.7064	1.24	0.225
A*C	0.558	0.279	0.7064	0.39	0.696
A*D	3.276	1.638	0.7064	2.32	0.027
A*E	-7.289	-3.644	0.7064	-5.16	0.000
B*C	0.600	0.300	0.7064	0.42	0.674
B*D	-5.096	-2.548	0.7064	-3.61	0.001
B*E	1.399	0.699	0.7064	0.99	0.330
C*D	1.457	0.729	0.7064	1.03	0.310
C*E	-4.866	-2.433	0.7064	-3.44	0.002
D*E	1.089	0.544	0.7064	0.77	0.447
S = 4.89394					
R^2= 98.58% , R^2 (Prediction) = 96.80% , R^2 (Modification) = 97.91%					



(a) (b)

Fig.2 (a) Main effect and (b) Interaction effects of process parameters for MRR

Summary

In order to analysis the quality of workpieces, the acoustic waves are recorded by AE sensor. The Run-to-Run control optimizes the process of grinding and polishing and compensates the variance of the workpieces.

In this study, we investigate a variety of factors such as belt speed, belt quality, manipulator feeding rate, workpiece contact area and workpiece material. A fractional factorial design of 2^{5-1} was used for experimental planning. The experimental results monitored by AE signals show that AE signal characteristics are compatible to distinguish between materials and fabrication process. Then, it revealed that belt speed and manipulator feeding rate were the critical factor influencing the material accuracy, and the interaction effects of factors were also discussed how to increase product quality and efficiency of process.

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