

Optimal the Process Variables of Internal Grinding for Shrink Fit Tool Holder

Y C Lin^{1,*}, G H Yang², H M Chow¹ and L T Tsai¹

¹Department of Mechanical Engineering, Nan Kai University of Technology, Nantou County 54243, Taiwan

²Department of Industrial Management, Nan Kai University of Technology, Nantou County 54243, Taiwan

*Email: ycline@nkut.edu.tw

Abstract. The goal of this study was to investigate the optimal variables settings in internal grinding for shrink fit tool holder. The effects of the main grinding variables on finishing responses were comprehensively investigated based on Taguchi method. The main process variables such as abrasive grain size (AGS), grinding wheel speed (GWS), feed rate for rough (FRR), depth for rough (DR), feed rate for finishing (FRF), depth for finishing (DF), dressing speed (DS), and workpiece rotational speed (WRS) were chosen to determine their effects on grinding performances related to roundness and surface roughness in the internal grinding of the shrink fit tool holder. The experimental response values were transferred to signal-to-noise (S/N) ratios, and then the significant process variables associated with the grinding performance were examined by analysis of variance (ANOVA). In addition, the optimal combination levels of the grinding variables were also obtained from the response graphs of S/N ratios to improve the surface quality of internal grinding. The experimental results show that the significant grinding variable affecting the roundness was FRF. In addition, the significant variables with regard to surface roughness were AGS, GWS, FRR, DR, DF, and DS. The optimal grinding variable settings were achieved. Consequently, the finishing characteristics of internal grinding could be enhanced to meet the requirements of modern manufacturing applications.

1. Introduction

The shrink fit tool holder utilizes the expansion and contraction properties of metal to provide extremely powerful tool holding. The tool holder will be expanded due to heating operation, and then the cutting tool fixed within the tool holder will be fastened and clamped as the cooling procedure. The cutting tool released from the holder should be reiterated the heating and cooling operations. Thus, the tool holder materials should have the properties such as splendid hardness, strength, wear resistance, and thermal property to withstand the elevated temperature and cutting force during the cutting applications. The depth of grinding and the feed rate in grinding process for tool holder finishing should be tightly adjusted to obtain the desirable finishing effects. Thus, the grinding process is a time-consuming, and the operation cost is inevitably increasing. The small holes grinding would be faced more challenges due to the lack of the rigidity with slender wheel stem. The shape and dimensional accuracy would encounter severe challenges and would receive the failure results occasionally with the small hole grinding process.



The grinding is the most important finishing process for precision components to attain the high surface quality and well dimensional accuracy. The investigation for understanding the machining mechanisms and characteristics in grinding process is an interesting issue for precision engineering manufacture [1-6]. Zhong et al.[7] conducted a study on grinding and pointed out that the grinding process could ensure the components with high dimensional and shape accuracy, so the grinding process was widely used in surface finishing. Qian [8] explored the machining effects on grinding wheel with electrolyte dressing and truing, and then discussed the machining performance by using the grinding wheel for ceramics and metals. The experimental results indicated that the grinding process would obtain the mirror-like surface integrities. Opoz and Chen [9] analyzed the scratch types using cubic boron nitride (CBN) abrasive on workpiece surface. They also discussed the removed mechanism of grinding process and tried to ameliorate the grinding effects and surface quality in grinding process. Gu et al.[10] conducted a scratching test on BK7 optical glass to analysis the chip formation and the material removed mechanisms during the grinding process. Liu et al.[11] examined the grinding effects of process variables on machining characteristics and operation cost by using CBN and Al_2O_3 grinding wheel for nickel-based super alloy. Fathalla et al.[12] studied the finishing effects of various abrasives and cooling methods with different grinding speed for AISI D2 tool steel. The residual stress, surface quality, and machining efficiency were comprehensively discussed in their experimental works. Several researchers also used optimization approach for grinding process to investigate the effects of process variables on grinding characteristics [13-16]. The optimal grinding variables could be obtained from their optimization approach. In general, the grinding process was a complicated machining process and the amount of controlled variables was enormous. The actions were very complex during the grinding process. In this study, the significant variables and optimal combination levels of grinding variables would be attained economically and timely to improve the machining efficiency and surface quality. The Taguchi method was a powerful approach used in the design of experiment and in determining the effect of each machining variable. Moreover, Taguchi method used a specially designed regime called orthogonal array, which nowadays is a predominant approach in the design of experiment. It has been proved that the experiment conducted using Taguchi method is more efficient and less costly to investigate the effects of the entire machining variables. The variable design via Taguchi method can also optimize the machining characteristics through setting process variables and reducing the sensitivity of the system performance to sources of variation. Therefore, high quality of machining characteristics can be achieved without increasing the operating cost [17,18]. In this investigation, an L18 orthogonal array based on the Taguchi experimental design method was employed in determining the effects of essential input variables of the internal grinding for shrink fit tool holder on the roundness and the surface roughness. Moreover, the optimal machining input variables for grinding SKD 61 tool steels could be achieved. A sophisticated grinding process with high efficiency and high quality of surface integrity was attained to fit the modern industrial requirements.

2. Experimental method

The grinding characteristics of internal face regarding shrink fit tool holder were investigated in this experimental study. The experimental works were implemented according to an L18 orthogonal array based on Taguchi method. The main process variables such as AGS, GWS, FRR, DR, FRF, DF, DS, and WRS were chosen to determine their effects on grinding characteristics relating to the roundness and the surface roughness in the internal surface grinding of the shrink fit tool holder. Moreover, the experimental response values were transferred to signal-to-noise (S/N) ratios, and then the significant input variables were determined by ANOVA. In addition, the optimal combination levels of the grinding input variables were also achieved from the response graph of S/N ratios.

2.1. Experimental materials

The shrink fit tool holder used the expansion and contraction properties of metal to provide extremely powerful tool holding. The SKD 61 tool steel had excellent toughness, wear resistance, and thermal

property for frequently heating and cooling. Therefore, the SKD 61 steel was widely employed in the tool manufacture industry. In this experimental study, the workpiece adopted SKD 61 tool steel with hardness HRC 58-62 after a specific heat treatment. The initial hole diameter was $\phi 5.7$ mm with depth 31 mm, and the desired hole diameter after grinding process was $\phi 6$ mm. Moreover, the internal grinding wheels were made of CBN abrasives with diameter $\phi 5.7$ mm and thickness 6 mm.

2.2. Experimental equipment and procedures

The machining characteristics such as the roundness and the surface roughness were chosen to evaluate the effects of input variables associated with the internal grinding for shrink fit tool holder. The experimental works was conducted by a high speed internal grinding machine (Tsugami UCG). The response values of roundness were measured by a roundness tester (Tokyo Semitsu Co., RONDCOM 44 DX/SD) at specific hole depths (2 mm, 10 mm, and 18 mm), and each depth implemented five roundness values. In addition, the surface roughness was measured by a precision profile meter (DIAVITE DH-5) to evaluate the surface quality of the machined surface. The measuring length was 4.8 mm and the cut-off was set at 0.25 mm. The value of surface roughness (R_z) was obtained by taking the average of five measurements that were stochastically acquired from the different positions of the internal grinding surface for SKD 61 at each machining condition.

2.3. Taguchi method

A systematic and statistical approach was effective and efficient for optimizing the machining variables of a complicated process. Therefore, a design of experiment method was adopted to optimize the variable settings in this work. The experimental design was developed according to an L18 orthogonal array based on the Taguchi method while using the Taguchi orthogonal array would markedly reduce the experimental numbers. The L18 orthogonal array has eight columns and 18 rows, so it has 17 degrees of freedom to manipulate one variable with two levels and seven variables with three levels. Thus, eight machining variables can be appointed to the columns and the rows designated by 18 experiments with various combination levels of the machining variables. The main process variables such as AGS, GWS, FRR, DR, FRF, DF, DS, and WRS were chosen to determine their effects on grinding performance relating to the roundness and the surface roughness in the internal surface grinding of the shrink fit tool holder. In this investigation, only six machining variables were considered, so two columns were empty. The orthogonality was preserved even if two columns of the array remained empty.

The observed values of the roundness and the surface roughness in the internal surface grinding of the shrink fit tool holder were explored. The levels of each input variable were set in accordance with the L18 orthogonal array. The S/N ratios are calculated from the observed values to determine the significant input variables, and the optimal combination levels of input variables are obtained. The response values and the levels of input variables assigned in L18 orthogonal array were listed in the Table 1.

Table 1 Experimental response values and the levels of input variables

Response Values	Input variables	Levels		
	A. abrasive grain size, AGS (#)	60#	120#	
● Roundness (μm) ● Surface roughness ($R_z/\mu\text{m}$)	B. grinding wheel speed, GWS (m/min)	900	1350	1500
	C. feed rate for rough, FRR (mm/min)	500	1000	1500
	D. depth for rough, DR (mm)	0.0015	0.0025	0.0035
	E. feed rate for finishing, FRF (mm/min)	300	600	900
	F. depth for finishing, DF (mm)	0.0015	0.0025	0.0035
	G. dressing speed, DS (mm/min)	200	500	800
	H. workpiece rotational speed, WRS (rpm)	377	739	1001

Based on the Taguchi method, the S/N ratio calculation was decided as “the higher the better, HB” and “the lower the better, LB” as given in the following equations:

$$\text{HB: } \eta = -10 \log \left[\frac{1}{n} \sum_{i=1}^n y_i^{-2} \right] \quad (1)$$

$$\text{LB: } \eta = -10 \log \left[\frac{1}{n} \sum_{i=1}^n y_i^2 \right] \quad (2)$$

where η denotes the S/N ratio calculated from the observed values (unit: dB), y_i represents the experimentally observed value of the i th experiment, and n is the repeated number of each experiment. In this work, the experimentally observed values of the roundness and the surface roughness are “the lower the better” (LB). Therefore, the optimal observed roundness and surface roughness values were the minimum value. Notably, each experiment in the L18 array is conducted three times in this investigation.

3. Result and discussion

3.1. Orthogonal array and S/N ratios

Table 2 presents the S/N ratios calculated from the experimentally response values and the levels of the input variables according to an L18 orthogonal array based on Taguchi method. The optimal combination levels of the input variables with regard to the internal grinding for shrink fit tool holder with a small value roundness and surface roughness were determined. Moreover, the significant input variables associated with roundness and surface roughness were also analyzed by the S/N ratios.

Table 2 L18 orthogonal array, control parameters and S/N ratios.

No.	Input variables									Experimental results	
	AGS	GWS	FRR	DR	FRF	DF	DS	WRS		S/N ratios(dB)	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)		Roundness	Surface roughness
1	1	1	1	1	1	1	1	1		4.8673	-5.4832
2	1	1	2	2	2	2	2	2		-2.7787	-7.3843
3	1	1	3	3	3	3	3	3		6.4296	-1.8684
4	1	2	1	1	2	2	3	3		0.0000	-6.4444
5	1	2	2	2	3	3	1	1		-1.0153	-6.5267
6	1	2	3	3	1	1	2	2		4.9775	-2.2789
7	1	3	1	2	1	3	2	3		7.2302	-12.1491
8	1	3	2	3	2	1	3	1		2.6861	-4.4022
9	1	3	3	1	3	2	1	2		2.7813	-2.2789
10	2	1	1	3	3	2	2	1		-1.0462	-2.7976
11	2	1	2	1	1	3	3	2		7.0523	-0.8279
12	2	1	3	2	2	1	1	3		3.8493	0.6772
13	2	2	1	2	3	1	3	2		3.3882	-1.5836
14	2	2	2	3	1	2	1	3		5.8827	0.7242
15	2	2	3	1	2	3	2	1		0.6490	-4.5062
16	2	3	1	3	2	3	1	2		-1.1488	-4.4022
17	2	3	2	1	3	1	2	3		4.4631	-3.1672
18	2	3	3	2	1	2	3	1		5.6416	-1.4376

Table 3 ANOVA and F test of roundness.

Variables (A)	Degree (f_A)	Square sum (S_A)	Variance (V_A)	F_{A0}	$F_{0.05,n1,n2}$
AGS	1	7.9190	7.9190	8.3761	18.51
GWS	2	2.4687	1.2344	1.3056	19.00
FRR	2	31.4320	15.7160	16.6232	19.00
DR	2	13.3498	6.6749	7.0602	19.00
FRF	2	48.4443	24.2222	25.6204*	19.00
DF	2	20.6209	10.3104	10.9056	19.00
DS	2	33.0161	16.5081	17.4610	19.00
WRS	2	5.4009	2.7005	2.8563	19.00
Error	2	1.8909	0.9454		
Total	17	164.5427			

*, Significant variable

3.2. Roundness

Table 3 indicates the ANOVA and F test of roundness obtained from the internal surface grinding of the shrink fit tool holder. The analysis results indicate that the significant input variable affecting the roundness for SKD 61 steel was FRF. Figure 1 shows the S/N ratios response graph of the roundness. The response graph indicates that the optimal combination levels of the input variables for roundness were: AGS 120#, GWS 900 m/min, FRR 1500 mm/min, DR 0.0015 mm, FRF 300 mm/min, DF 0.0015 mm, DS 800 rpm, and WRS 1001 rpm.

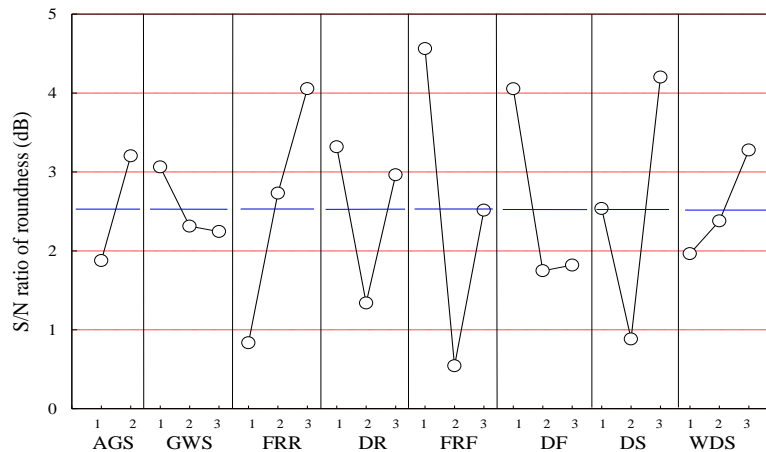


Figure 1 S/N ratios response graph of roundness.

Table 4 ANOVA and F test of surface roughness.

Variables (A)	Degree (f_A)	Square sum (S_A)	Variance (V_A)	F_{A0}	$F_{0.05,n1,n2}$
AGS	1	55.1079	55.1079	265.0283*	18.51
GWS	2	9.1016	4.5508	21.8859*	19.00
FRR	2	37.3907	18.6954	89.9109*	19.00
DR	2	15.0267	7.5133	36.1336*	19.00
FRF	2	5.7455	2.8728	13.8159	19.00
DF	2	17.9055	8.9527	43.0560*	19.00
DS	2	26.2463	13.1232	63.1127*	19.00
WRS	2	3.4192	1.7096	8.2220	19.00
Error	2	0.4159	0.2079		
Total	17	170.3593			

*, Significant variable

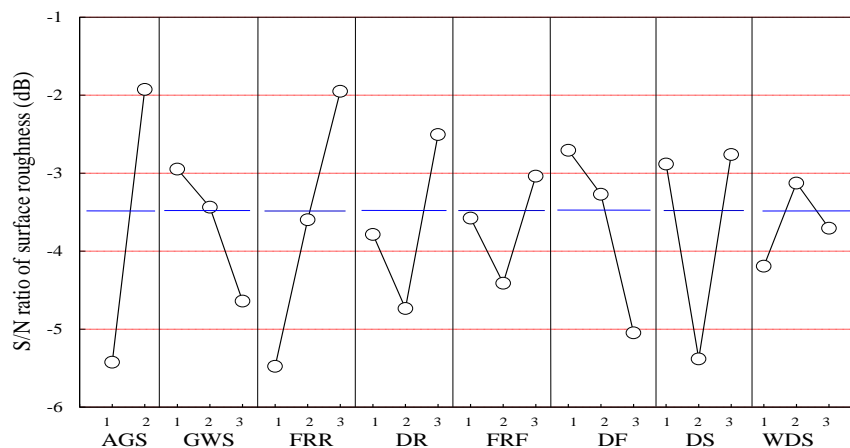


Figure 2 S/N ratios response graph of surface roughness.

3.3. Surface roughness

Table 4 lists the ANOVA and F test of surface roughness obtained from the internal surface grinding of the shrink fit tool holder. The analysis results reveal that the significant input variables affecting the surface roughness for SKD 61 steel were AGS, GWS, FRR, DR, DF, DS. Figure 2 illustrates the S/N ratios response plot of surface roughness. The response graph indicates that the optimal combination levels of the input variables for surface roughness were: AGS 120#, GWS 900 m/min, FRR 1500 mm/min, DR 0.0035 mm, FRF 900 mm/min, DF 0.0015 mm, DS 800 rpm, and WRS 739 rpm. As the grinding conditions set at the optimal combination levels, the internal surface grinding of the shrink fit tool holder could obtain the best response value such as surface roughness.

3.4. Confirmation Experiments

The optimal combination levels of the input variables were determined and confirmed as follows. The estimated S/N ratios are calculated as,

$$\hat{\eta} = \bar{\eta}_m + \sum_{i=1}^{n_o} (\bar{\eta}_i - \bar{\eta}_m) \quad (3)$$

$\hat{\eta}$: Estimated S/N ratio for optimal combination levels of input variables.

$\bar{\eta}_m$: Total mean S/N ratio.

n_o : The number of significant variables.

$\bar{\eta}_i$: Mean S/N ratio at the optimal level.

Table 5 illustrates the results of confirmation experiments. As the analysis results indicate below, the roundness increased from 2.75 dB to 7.51 dB, and the surface roughness advanced from -3.64 dB to 1.51 dB. In addition, the S/N ratios correlated with roundness and surface roughness for the optimal combination levels of machining variables are 4.76 dB and 5.15 dB larger than those obtained at the initial experimental conditions; the initial conditions were set at AGS (120#), GWS (1350 m/min), FRR (1000 m/min), DR (0.0025 mm), FRF (600 mm/min), DF (0.0025 mm), DS (500 mm/min) and WRS (739 rpm), ($A_2B_2C_2D_2E_2F_2G_2$). The experimental results confirm that the input variables of the internal grinding for shrink fit tool holder would be optimized for roundness and surface roughness, so the observed values would thus be significantly improved.

Table 5 Results of the confirmation experiments

		Initial levels of input variables	Optimal combination levels of input variables	
			Prediction	Experiment
Roundness	Level	$A_2B_2C_2D_2E_2$ $F_2G_2H_2$	$A_2B_1C_3D_1E_1$ $F_1G_3H_3$	$A_2B_1C_3D_1E_1$ $F_1G_3H_3$
	Response values (μm)	0.728	-	0.421
	S/N ratio (dB)	2.75	4.03	7.51
Surface roughness	Level	$A_2B_2C_2D_2E_2$ $F_2G_2H_2$	$A_2B_1C_3D_3E_3$ $F_1G_3H_2$	$A_2B_1C_3D_3E_3$ $F_1G_3H_2$
	Response values ($R_z/\mu\text{m}$)	1.52	-	1.32
	S/N ratio (dB)	-3.64	0.98	1.51

4. Conclusions

The effects of essential variables associated with the internal grinding for shrink fit tool holder on roundness and surface roughness were explored, and the optimal input variables were determined

based on Taguchi method for SKD 61 steel. According to the experimental results and imperative analysis, the following conclusions have been drawn.

(1) The significant variable affecting roundness is FRF associated with the internal grinding for shrink fit tool holder. The optimal combination levels of input variable for roundness are AGS 120#, GWS 900 m/min, FRR 1500 mm/min, DR 0.0015 mm, FRF 300 mm/min, DF 0.0015 mm, DS 800 rpm, and WRS 1001 rpm.

(2) The significant variables affecting surface roughness are AGS, GWS, FRR, DR, DF, and DS associated with the internal grinding for shrink fit tool holder. Moreover, the optimal combination levels of input variable for surface roughness obtained from the S/N ratio response graph are AGS 120#, GWS 900 m/min, FRR 1500 mm/min, DR 0.0035 mm, FRF 900 mm/min, DF 0.0015 mm, DS 800 rpm, and WRS 739 rpm.

(3) The S/N ratios of roundness and surface roughness are improved as 4.76 dB and 5.15 dB based on the optimal approach of Taguchi method. The roughness ameliorated from 0.728 μm to 0.421 μm , and the surface roughness meliorated from 1.52 μm to 1.32 μm . The roundness and surface roughness in internal grinding for shrink fit tool holder were obviously improved at the optimal setting levels of input variables obtained from Taguchi experimental analysis.

Acknowledgments

The authors would like to thank the Action Tools Corp, Taiwan, for technical supporting the experimental works.

References

- [1] Brinksmeler E and Giwerzew A 2003 *CIRP Annuals -Manuf Technol.* **52**(1) 253.
- [2] Durgumahanti U S P, Singh V and Rao PV 2010 *Int. J. Mach. Tool. Manuf.* **50** 231.
- [3] Ghosh S, Chattopadhyay AB and Paul S 2008 *Int. J. Mach. Tool. Manuf.* **48** 1242.
- [4] Jackson MJ, Khangar A, Chen X, Robinson G M, Venkatesh V C and Dahotre N B 2007 *J. Mater. Process. Technol.* **185** 17.
- [5] Krajnik P, Drazumeric R and Badger J 2013 *CIRP Annuals –Manuf. Technol.* **62**(1) 347.
- [6] Wang X Y, Wu Y B, Wang J, Xu W J and Kato M 2005 *J Mater Process Technol*, **164-165** 1128.
- [7] Zhong Z W and Venkatesh V C 2009 *Int. J. Adv. Manuf. Technol.* **41** 468.
- [8] Qian J, Li W and Ohmori H 2000 *J. Material Process. Technol.* **105** 80.
- [9] Opoz T T and Chen X 2012 *Int. J. Mach. Tool. Manuf.* **63** 32.
- [10] Gu W, Yao Z and Liang X 2011 *Wear* **270** 241.
- [11] Liu Q, Chen X and Gindy N 2007 *Int. J. Adv. Manuf. Technol.* **33** 940.
- [12] Fathallah B B, Fredj N B, Sidhom H, Braham C and Ichida Y 2009 *Int. J. Mach. Tool. Manuf.* **49** 261.
- [13] Gopal A V and Rao P V 2003 *Int. J. Adv. Manuf. Technol.* **22** 475.
- [14] Krishna A G and Rao K M 2009 *Int. J. Adv. Manuf. Technol.* **26** 475.
- [15] Lee T S, Ting T O, Lin Y J and Htay T 2007 *Int. J. Adv. Manuf. Technol.* **33** 468.
- [16] Saravanan R, Asokan P and Sachidanandam M 2002 *Int. J. Mach. Tool. Manuf.* **42** 1327.
- [17] Lin Y C, Chow H M, Tsui H P and Chen Y F 2013 *Adv. Mater. Res.* **675** 365.
- [18] Wang D A, Lin Y C, Chow H M, Fan S F and Wang A C 2012 *Adv. Mater. Res.* **459** 170.