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가공최적화를 통한 볼 스크류의 소음성능 향상에 관한 연구

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A Study on the Improvement of Noise Performance by Optimizing Machining Process Parameters on Ball Screw

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ABSTRACT

Ball screw systems are largely used in industry for motion control and motor applications. But the problem of noise, which really perplexes us, is highly correlated with the quality in ball screw systems all the way. In this paper, machining process parameters were evaluated in respects of technique, business, produce and quality to verify which impact influences the noise most. In order to adjust and compare, two comparison groups were set with the present parameters bench mark. Different ball screws were produced as specimens for the noise tests. Through comparing the noise performance of different parameters in the machining process respectively, a group of optimized machining process parameters were obtained. Another noise test was proceeded to know how noise performance was improved by optimizing the machining process parameters. At last, surface roughness tests have been done to know how surface roughness improved by optimization. The improvement of surface roughness is the main factor influences the noise performances.

Key Words : Ball screw, Machining process parameters, Noise, Grinding, Dressing

1. Introduction

Ball screw system is a machine that uses steel balls between a screw and a nut to transfer the force and motion accurately which convert rotate into linear movement. Therefore, ball screw systems are largely used in industry for motion control and motor applications. But the problem of noise, which really perplexes us, is highly correlated with quality in ball screw systems all the way. Generally, the noise of ball screws mainly causes the accuracy of contact surface, thermal deformation, impact between ball and return system and lack of axial stiffness. In order to improve the noise performance, many people concentrated on new grinding methods, adhesives, abrasives and grains. Diamond, cubic boron nitride(CNB), aluminium oxide (Al_2O_3) and silicon carbide(SiC) are employed as some new kinds of grains in grinding wheel. Meanwhile, in order to get a high surface precision, new grinding method is required. It is well known that diamond is the

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hardest natural material. But dressing of grinding wheels with diamond not only causes excessive wheel loss but also interrupts production during the process[1-2]. However, aluminium oxide (Al_2O_3)as the substitute of diamond, has amounts of advantages like low price, good wear resistance and so on[3]. In order to achieve nanometer surface roughness and submicron form accuracy, high-quality grinding protocols for polycrystalline silicon carbide is used[4]. Cubic boron nitride (CBN) grinding wheels have been applied in industry for a few decades, often with very good results. CBN grains are much harder than aluminium oxide (Al_2O_3) and silicon carbide(SiC) grains and also can achieve nanometer surface roughness[5-8].

Many researchers focus on the characteristics of how a ball-screw changes its temperature corresponding to the periodic change of the end-most heat source, based on the theory of heat transfer[9-10]. And according to the characteristics, many methods of cooling in ball screws are engendered. Shaft oil cooling system and nut oil cooling system are the representatives. The above methods can make noise performance better. But the cost is high, not only money, but also manpower and research time. Therefore, improving the existing production processes, methods and controls are needful.

In this paper, first, the machining process parameters were evaluated in respects of technical, business, produce and quality to estimate which impact the noise most. And then, in order to adjust and compare, two comparison groups have been set with the present parameters bench mark. On the basis of the three groups of data, different ball screws were produced as specimens to do the noise tests. Through the analysis of noise performance corresponding to the machining process parameters respectively, a group of optimized machining process parameters were obtained. Another noise test was proceed to know how noise performance can be improved by optimizing the machining process parameters. Finally, surface roughness tests have been done to know how surface roughness improved by optimization, as the main reason that the noise performance was improved.

2. Experimental

Actually, a mass-produced product is best in some respects. Even if most machining process parameters were confirmed by experiments and tests, nearly all parameters were adjusted by experience. In this study, machining process parameters were evaluated in respects of technique, business, produce and quality to verify which impact the noise most. Table 1 shows the evaluation of the machining process parameters. Taper level, grinding wheel speed (rpm), dressing speed (rpm), principal axis rotate speed (rpm) in shaft and spindle rotate speed (rpm), dressing speed in nut have been selected as test elements with which scores the most points.

Table 1 Evaluation of machining process parameters

Port. reasons	Parts	Multi-voting				Sum
		Tech.	Bus.	Pro.	Qua.	
Grinding speed	Shaft	8	5	7	9	29
Prin. axis rotate speed		8	5	7	7	27
Taper level		7	7	5	7	26
Dressing speed		7	5	7	9	28
Dressing time		5	3	3	5	16
B.C.D ovality		5	7	7	5	24
Dressing time	Nut	5	3	3	5	16
Dressing speed		7	7	7	9	30
Verticality		5	5	3	5	18
Spindle rotate speed		9	5	6	7	27
Prin. axis rotate speed		7	5	7	5	24

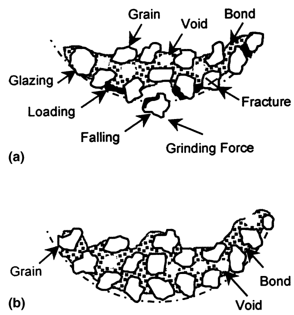

Fig. 1 Schematic structures of wheel surface (a) Worn wheel, (b) dressed wheel[11]

Table 2 Comparable groups

	Factors	Unit	Para. group1	Para. group2	Para. group3
Shaft	Taper level	㎛	2	4	4
	Grinding	rpm	1400	1650	1900
	Prin. axis	rpm	15	20	25
	Dressing	rpm	1000	1200	1400
Nut	Spindle	rpm	13600	14000	14400
	Dressing	rpm	13400	13800	14200

The selected parameters show that grinding quality is a crucial role to reduce the noise on ball screws. The performance of grinding process is defined significantly by preparation of the grinding wheels. Besides the required grinding wheel profile the dressing process must produce an appropriate wheel topography. Fig. 1 shows schematic diagrams of the surface of a worn wheel and that of a well-dressed wheel. A proper dressing strategy (when and how much) should be decided, since otherwise the result will be either a bad work surface due to too much wheel wear, or too much wheel loss for excessive dressing. The wheel topography influences the groove surface roughness and surface layer by the number and shape of the kinematical edges, the pore volume and the wear behavior of the abrasive layer. The dressing process should enable a grinding process as consistent as possible taking into account of the grinding wheel wear.

Fig. 2 Test specimens

Table 3 Grinding wheel information

Shaft grinding wheel	Nut grinding wheel
Type N5A 100I8VBE	Type 32A80J8VBE 1A
Size 510×18×254	Size 42×10×8
MOS 45m/s	MOS 40m/s

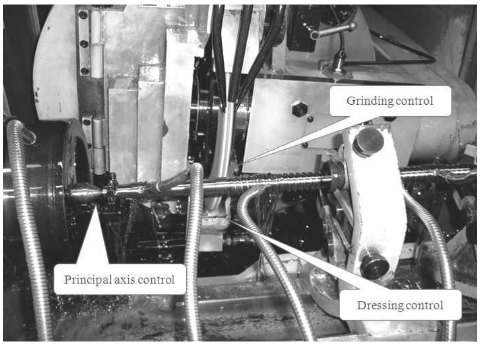

Fig. 3 Shaft grinding process

Three comparison groups have been set as Table 2. With the present parameters benchmark, respectively, two groups of parameters were set. Based on the above data, eighteen different ball screws have been produced as test specimens shown in Fig. 2.

Shaft grinding wheel and nut grinding wheel information is shown in Table 3. Shaft grinding wheel is a special type and nut grinding wheel is standard type.

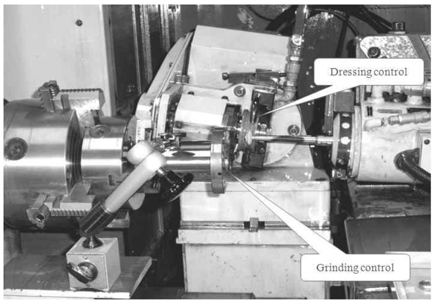

Fig. 4 Nut grinding process

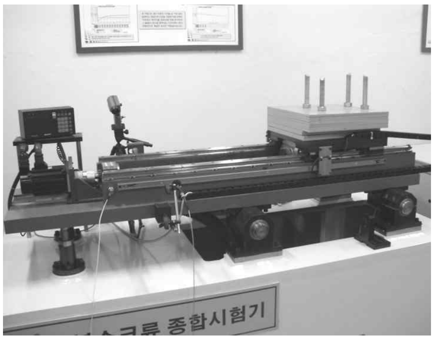

Fig. 5 Experiment facility

The grinding process of ball screw shaft shown in Fig. 3. Principal axis rotate speed, grinding wheel speed and dressing speed as screw shaft machining parameters have been controlled as the figure.

Fig. 4 shows the grinding process of ball screw nut. And spindle rotate speed, dressing speed as nut grinding process parameters have been controlled as this figure.

An experiment facility is shown in Fig. 5 which consists of test table, ball screw, motor, noise receiver and analysis system. There are two rounds of noise tests had been done in this facility. First, eighteen ball screws which machined by different parameters as Table 2 had been done noise tests in 2000rpm. On the basis of the analysis for noise performance in the machining process parameters respectively, a group of optimized machining process parameters is obtained. And then, two ball screws were produced again with present machining process parameters and optimized machining process parameters respectively to do noise tests to show how noise performance improved. At last, surface roughness tests have been done to know how surface roughness improved by optimization. The improvement of surface roughness is the main factor influences the noise performances.

3. Results and discussion

There are six parameters selected as test elements. Logically speaking, there must be 486 ball screws made to do the tests. But to some degree, it's impossible to make so many ball screws as specimens. Hence, modest number of ball screws as specimens were confirmed to eighteen. Homogeneous distribution has been implemented in the eighteen ball screws to make sure the parameter variables have equality. It means, for instance, all the six ball screws which shaft grinding wheel speed is 1400 and 1650 have the same number of other parameter variables respectively. By doing so, we can insure that the noise test data is accuracy and the cost is the lowest.

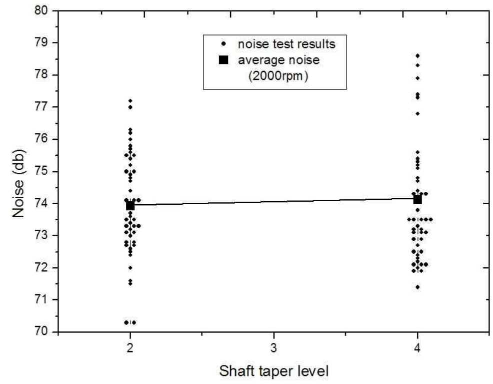

Fig. 6 Influence degree of shaft taper level on noise performance

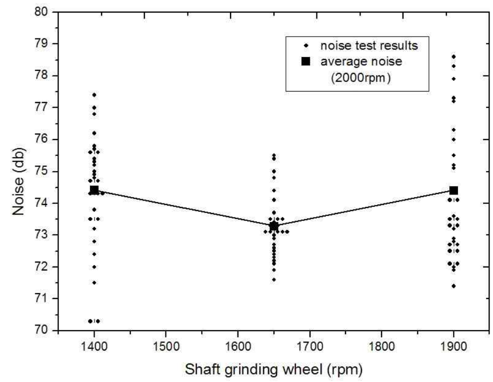

Fig. 7 Influence degree of shaft grinding wheel speed on noise performance

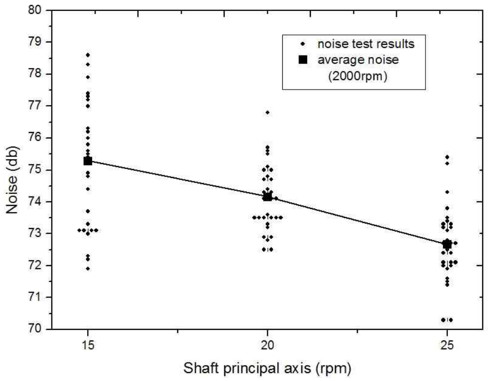

Fig. 8 Influence degree of shaft principal axis speed on noise performance

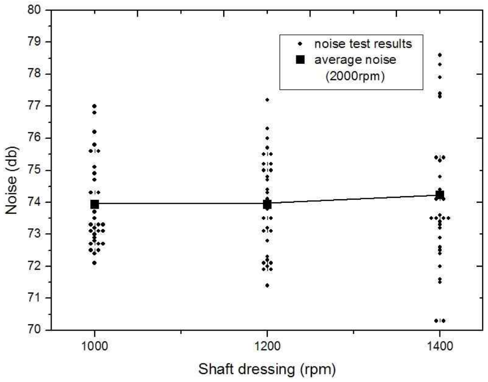

Fig. 9 Influence degree of shaft dressing speed on noise performance

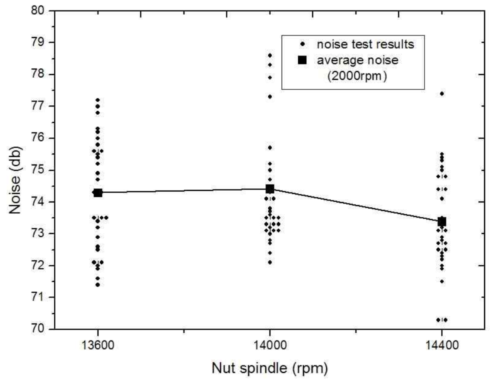

Fig. 10 Influence degree of nut spindle speed on noise performance

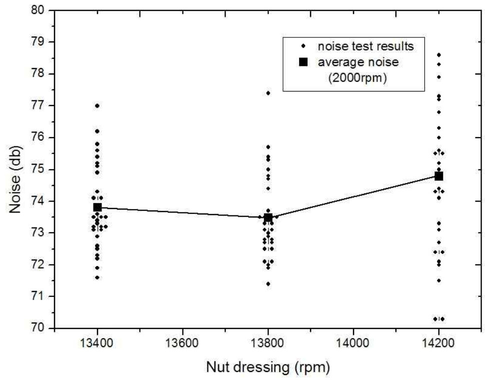

Fig. 11 Influence degree of nut dressing speed on noise performance

From Fig. 6 to 11 shows how the six parameters impact on noise in 2000rpm. Temperature is room temp. grease lubrication, reload is 320kgf, reload torque is 10~15kgf.cm, shaft material is SCM 445H, nut material is SCM 420H. Fig. 6 shows the influence degree of shaft taper level to noise performance. The noise test results distributed essentially the same. So, an exact average test data testified that shaft taper level is 2 better than 4 as 73.93db to 74.12db in average. It can be ascertain that shaft taper level is not so important to the noise performance as machining process parameter.

Fig. 7 shows how the shaft grinding wheel speed impacts on the noise performance. This figure is so apparent to understand which parameter variable makes the noise lowest. 1650rpm is the best as 74.41db, 73.27db and 74.39db in average respectively. In theory, the grinding speed is the faster the better. But all things have a degree, dizzy speed of grinding wheel should cause exaggerate vibration on the grinding machine. High grinding speed can bring high surface precision and large amplitude vibration at one time. So a balance point exists and should be searched by tests and experience. The vibration from machining process is one of the factor impacts the machining accuracy. Although, just an difference exists between 1400rpm, 1900rpm and 1650rpm, but it can be the reason that the balance point is very near in 1650rpm. Another reason is the residual deformation. High grinding speed causes high residual stress residue which can bring some wispy deformation.

Fig. 8 is the same situation as last one. A judgment that shaft principal axis rotate speed of 25 is the best of all, can be made simply. The noise performances are 75.27db, 74.15db and 72.66db in average and own a 2.61db difference from best to worst. The reason why the shaft principal axis rotate speed the higher the better is that the relative line velocity enhanced without vibration increase.

Fig. 9 shows how shaft dressing speed impacts on the noise performance. In this figure, most test results in 1000rpm are congregated under 73.5db. A precise average noise data proved that shaft dressing speed of 1000 is better than 1200 and 1400 with 73.93db in average. In dressing situation, Rough contact grinding causes more intense vibration than grinding process. Therefore, the dressing speed is lower than grinding speed. The balance point is near the 1000rpm around.

Fig. 10 and 11 are nut machining process parameters, shows the influence degree of nut spindle rotate speed and nut dressing speed to noise performances. In Fig. 10, it shows clearly that 14400rpm is the optimum with 73.38db in average. It can be understood from this figure, the nut grinding speed can be some higher than 14400rpm. In Fig. 11, the situation is a little ambiguous in 13400rpm and 13800rpm. An exact average test data testified that nut dressing speed of 13800 is better than 13400 as 73.48db to 73.80db in average. In the case of nut grinding, it is roughly the some in the shaft grinding situation. Machining process residual stress and vibration are the reason why optimum parameters can make noise performance better.

Synthesize the above data, a group of optimized machining process parameters were confirmed as Table 4. The optimized and present ball screws were employed as test specimens to noise experiment. Fig. 12 and 13 shows the noise test result of 1000rpm and 2000rpm. Fig. 12 shows the noise performance improved from 74.12db (5 times in average) to 67.47db (5 times in average). And Fig. 13 shows the noise performance improved from 78.52db (5 times in average) to 72.28db (5 times in average). The optimization of machining process parameters bring about 6.65db improvement in 1000rpm and 6.26db improvement in 2000rpm.

Table 4 Obtained optimum parameters

	Factors	Unit	Optimum	Present
Shaft	Taper level	㎛	2	4
	Grinding wheel	rpm	1650	1650
	Principal axis	rpm	25	20
	Dressing	rpm	1000	1200
Nut	Spindle	rpm	14400	14000
	Dressing	rpm	13800	13800

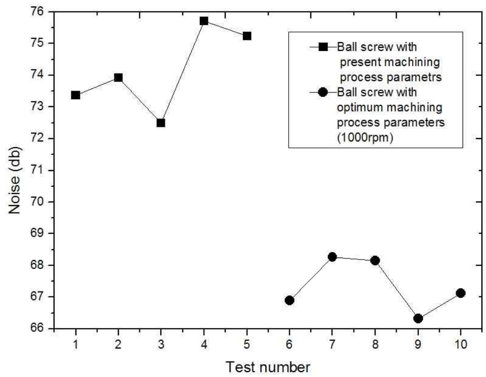

Fig. 12 The noise test comparison of present and optimum ball screws in 1000 rpm

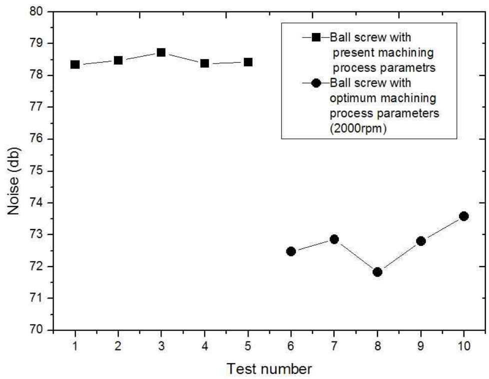

Fig. 13 The noise test comparison of present and optimum ball screws in 2000 rpm

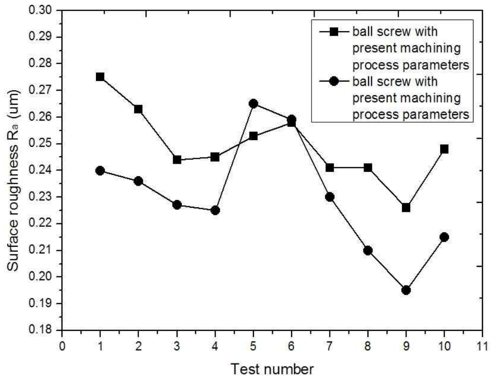

Fig. 14 The surface roughness comparison of present and optimum ball screws

There are many factors that can affect the magnitude of noise. The surface roughness is maybe the essential point. Fig. 14 shows the improvement of surface roughness on optimized and present ball screws. Mpos(measure position) is a line where ball and screw contacted and the gage length is L=2.5mm. Ten different positions were taken as Mpos(measure position). As the result in present ball screw, the average number of Ra was 0.2494㎛. And at the optimum processing situation, the result became 0.2304㎛ in average. A considerable surface roughness improvement, 8.246% happened though optimizing machining process parameters. It should be the number one reason for improvement of noise performance.

4. Conclusion

In this paper, six machining process parameters were selected as test elements. Among the rest, shaft taper level and shaft dressing speed behave a trifling impact on noise, and shaft grinding wheel speed, nut spindle rotate speed and nut dressing speed show a non-ignorable impact on noise. Shaft principal axis rotate speed shows a considerable impact on noise as 2.61 db difference from best to worst. In order to obtain the quietest ball screw, taper level, grinding wheel speed, principal axis rotate speed, dressing speed in shaft respectively, takes 2, 1650, 25, 1000 and spindle rotate speed, dressing speed in nut takes 14400 and 13800 as shown in Table 3. The second round of noise test result is that noise performance improved from 74.12db to 67.47db in 1000rpm and from 78.52db to 72.28db in 2000rpm. The optimization brings about 6.65db improvement in 1000rpm and 6.26db improvement in 2000rpm. As the result of surface roughness test in present ball screw, the average number of Ra is 0.2494㎛. And at the optimum processing situation, the result became 0.2304㎛ in average. A considerable surface roughness improvement, 8.246% happened though optimizing machining process parameters.

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