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high-lead ball screw nuts
new grinding process
surface roughness

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A STUDY ON THE DEVELOPMENT OF A NEW GRINDING PROCESSES FOR HIGH-LEAD BALL SCREW NUTS

This paper proposes a method that machines the race of high-lead ball screw nuts, which is difficult to machine using the existing geometrical machining method, without any interferences and changes in its load rating in order to perform the high-speed in ball screws. This study calculates the inclination angle of the axis of the grinding stone for avoiding the contact of the axis to the inner diameter of the nut and determines the shape of the grinding stone through changing the inclination angle and dressing curvature determined in a dressing device. Then, the grinding condition will be determined by measuring the shape meter of the screw race for solving the problem. Also, the surface roughness of the grinded surface was measured using a surface roughness tester, and check with applying a grinding process of product not being high-lead ball screw.

1. INTRODUCTION

Owing to the recent development of industries, the production of high-speed and high-precision equipments has been increased. In particular, studies and developments on ball screws have been actively investigated for achieving the positioning of machine tools and precision measurement equipments. The ball screw becomes an essential part in positioning equipments and has been largely used in the transportation system in various fields due to its superior characteristics in rolling resistance, back lash, and wear compared to other elements[1]. Also, studies on the precision[2,3] and high-speed[4,5] of transportation systems have been largely investigated. In addition, studies on the contact angle in races and the improvement of surface roughness for reducing noise and heat caused by a high-speed in ball screws[6,7]. have also been investigated. A method that increases the pitch of ball

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screws has been used as a way to achieve the high-speed of ball screws. However, an increase of the pitch causes interference between the grinding stone and the inner diameter of nuts and that shows some difficulties in machining and decreases its load rating due to the change in the curvature of the race. Thus, this study proposes a method that machines the race of high-lead ball screw nuts, which is difficult to machine using the existing geometrical machining method, without any interferences and changes in its load rating in order to perform the high-speed in ball screws.

2. GRINDING PROBLEMS AND SPECIAL DRESSING

2.1. PROBLEMS IN THE GRINDING OF THE INNER SCREW OF THE NUT

Fig. 1 shows a grinding process of the screw race of a nut where β, β, and β_3 represent the lead angle of the grindstone, rake angle of the grinding stone axis, and rake angle of the dressing device, respectively. In a general grinding process, the machining can be performed by a certain inclination as much as the lead angle in which a high-lead angle causes interference between the axis of the grinding stone and the inner diameter of the nut. For avoiding the interference, the grinding is to be implemented with a small angle of the grinding stone as the same as the lead angle as illustrated in Fig. 2. However, it may cause interference between a side of the grinding stone and a raceway of the ball screw nut. To avoid the problem, the contact angle of balls should decrease, as a result, load rating decreases. Thus, it is necessary to determine a smaller inclination angle of the grinding stone than the lead angle and apply a special dressing method of avoiding interference between the grinding stone and the ball screw race. In addition, it is necessary to significantly modify the screw grinder and dressing device that are maintained in order to prevent the increase in production costs and develop a machining method that avoids a new exclusive device and satisfies grinding conditions. However, it is a very difficult issue that calculates the amount of interference between the grinding stone and the screw race as a three dimensional way. Thus, this study calculates the inclination angle of the axis of the grinding stone for avoiding the contact of the axis to the inner diameter of the nut and Fig. 1. Interference between grinder shaft and inner diameter part determines the shape of the grinding stone through changing the inclination angle and dressing curvature determined in a dressing device. Then, the grinding condition will be determined by measuring the shape of the screw race for solving the problem.

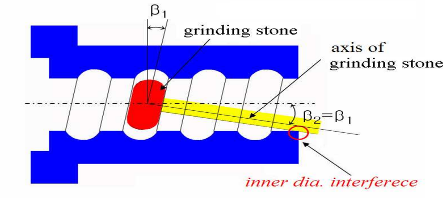

Fig. 1. Interference between grinder shaft and inner diameter part

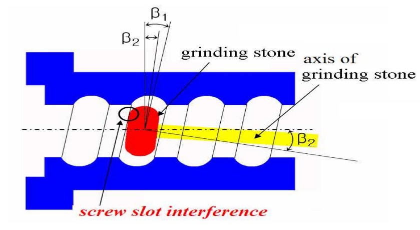

Fig. 2. Interference between grinder and inner race

2.2. SPECIAL DRESSING METHOD

As shown in Fig. 3, the shape of the screw race is a type of Gothic Arc where *R* and *d* represent the curvature of the screw race and diameter of the grinding stone, respectively, in which the ball contact angle is determined by 45°. Also, the rotary diameter dresser was fabricated by the same shape of the screw race. If the rotary diameter angle is determined as the same as the lead angle, the desired shape can be machined even though the axis of the grinding stone is changed. The screw race of the rotary diameter is machined formed on the outside of a 90*mm* cylinder, and the screw race of a single direction nut is machined on the inside of the inner diameter side. However, as it is usually smaller than the rotary diameter, it is difficult to obtain a desired shape due to the interference of the left and right sides of the grinding stone to the screw race as the axis of the rotary diameter is grinded as the same as the lead angle. Fig. 4 illustrates the machined orbit of the grinding stone and rotary diameter. As shown in Fig. 4, it is possible to determine the curvature of the screw race and calculate the range of the diameter of the grinding stone through the determination of the angle of the rotary diameter.

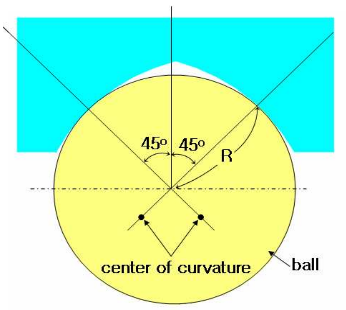

Fig. 3. Contact shape of a ball and nut race

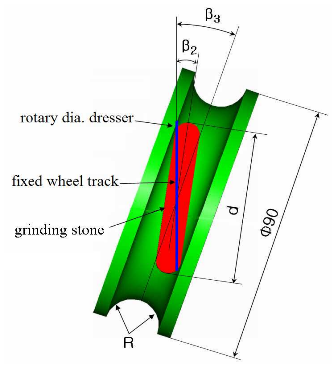

Fig. 4. Orbits of grinder and rotary diameter

3. EXPERIMENTS

3.1. METHODS

The experiment was performed under the conditions presented in Tab. 1 and Fig. 5. For verifying the machined workpiece, the ball contact angle and the amount of wear in the grinding stone were calculated for comparing their characteristics based on the screw race of the nut measured by using a shape meter, roundness and cylinder geometry can be measured on products, manufactured by Taylor Hobson. Also, the experiment was implemented using two rotary diameter dresser angles, such as 15^{o} and 16.5^{o}. As noted in Tab. 2, the surface roughness of the grinded surface was measured using a surface roughness tester, which is the VC-10 manufactured by Optacom(GERMANY). The measurement of the surface roughness was carried out using an angle gauge through varying the angle toward the vertical direction for the lead angle.

Table 1. Conditions of the test

condition	value
workpiece size	axis diameter 20 mm lead 20 mm
material	SCM420H, carburizing
grinding stone	WA8018V (ø18 x w4)
lead angle(β_1)	16.86°
rake angle of grinding stone spindle(β_2)	8.5°
rake angle of dresser(β_3)	15°/16.5°
grinding wheel speed	20,000 rpm
nut speed	10 rpm
ball diameter	3.969 mm
rotary dresser slot diameter	3.175 mm
grinding relief	0.5 mm
depth of cut	0.02 mm

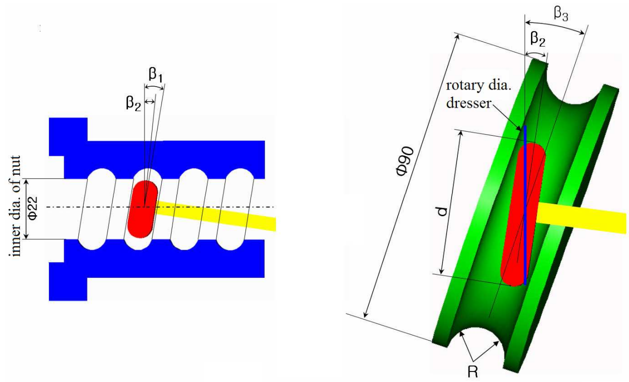

Fig. 5. Test condition

Table 2. Surface roughness measurement condition

mode	value
assessment mode	roughness
cutoff length	0.25mm
data length	1mm
number of cutoffs	3
filter type	gaussian

3.2. RESULTS

Fig. 6 illustrates the change in the diameter of the grinding stone and the contact angle obtained by using the shape meter. In case of grinding with the dress angle of 15°, the amount of interference shows a large value, and the ball contact angle is significantly decreased as the diameter of the grinding stone is more than 17 *mm*. Also, it causes a deviation between the left and the right contact angles and that is due to the fact that it turns off the center point between the nut and the grinding stone. Thus, it can be seen that modification of the dressing device is required. In case of grinding with the dress angle of

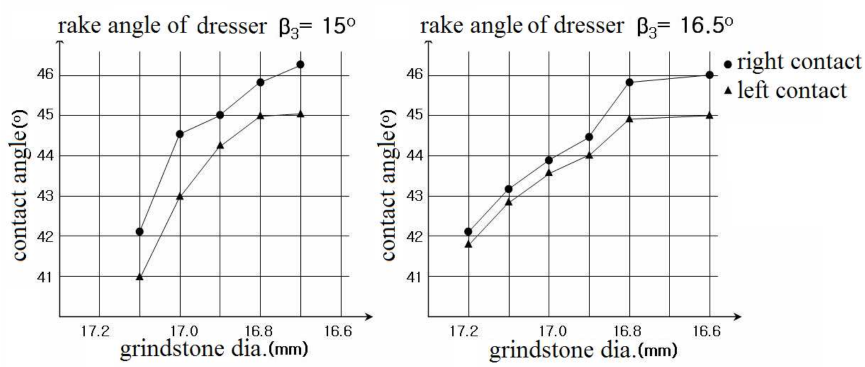

Fig. 6. Contact angle according to rake angle of dresser

the 16.5°, the contact angles can be determined by 42°~ 45° for the diameters of the grinding stone ranged by 17.2 *mm* ~ 16.8 *mm* in which the change in the angle is increased linearly. As a result of the verification of the basic dynamic load rating (C_a) based on these contact angles. The grinding method can assure more than 94% compared with a regular grinding method.

Table 3. Comparisons of calculated and measured data

	calculated data	measured data
contact angle [°]	45	42
ball diameter [mm]	3.969	3.969
radius of curvature [mm]	2.183	2.50
distance in center [mm]	0.281	0.300
basic dynamic load rating[kN]	9.3	8.8

Table 3 represents the comparison of ideal calculation values using a theoretical method and the experiment. The results calculated by using the theoretical method are shown in Fig. 7, where α, R, a, D and C show the ball contact angle, radius of curvature, distance of the center point, ball diameter and distance between the center of the curvature and the center of the ball, respectively. Because the allowance of the ball contact angle of general ball screws is determined by 55%, the distance between the radius of curvature and the center point can be expressed as equation[1] by trigonometric function. Fig. 8 represents the shape of the screw race with the contact angle of 42°. The maximum grinding interference of 0.01*mm* was generated at the inner side of the nut. The radius of curvature and the distance of the center point are presented in Table 1. The measured value of the basic dynamic load rating (C_a) was 8.8*kN*, and that did not affect the service life significantly compared with the theoretical value of 9.3*kN* as the contact angle was configured by 45°. In addition, it can be considered that there were no problems in its practical application because the deviation of the left and right contact angles was within 0.25. Furthermore, the deviation can be corrected through modifying the vibration of the center of the grinding stone that is contacted by the grinding point. The difference between the theoretical and the measured values in the radius of curvature was 0.019. It is the data within the allowance error of the radius of curvature, ±0.020, in general. It was also verified that the grinding method can be used as an aspect of its shape.

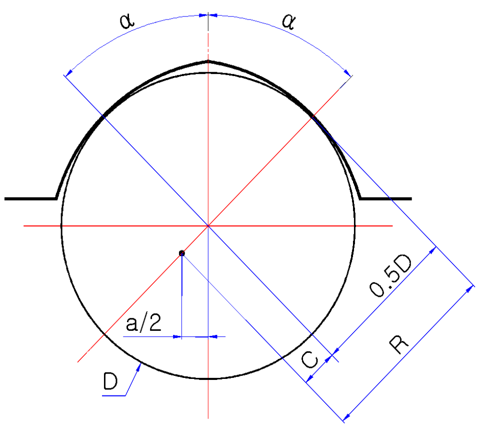

Fig. 7. Principle of curvature and distance in center

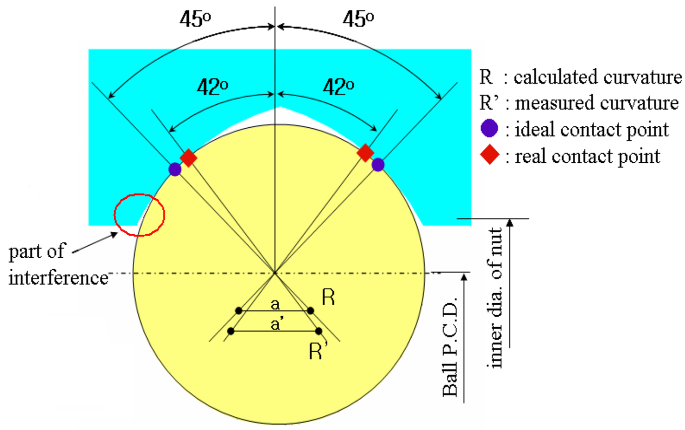

Fig. 8. Ideal contact point and real contact point

$$
\begin{aligned}
R &= 0.55D \\
a &= 2 \times 0.05 D \sin \alpha
\end{aligned}
\qquad (1)
$$

Fig. 9 illustrates the results of the surface roughness measurement based on the method presented in Table 2 by using the processed workpiece according to the experiment, In Fig. 9 a) represents the results of the workpiece measurement used in this study, and b) shows the center line average roughness, 0.153 μm, in which the value of *Ra* was measured by 0.389 μm. By considering the surface roughness, *Ra*, which was determined by 0.3~0.42 μm after applying a grinding process of product not being high-lead ball screw, it can be considered that the results obtained in this study can be generally accepted

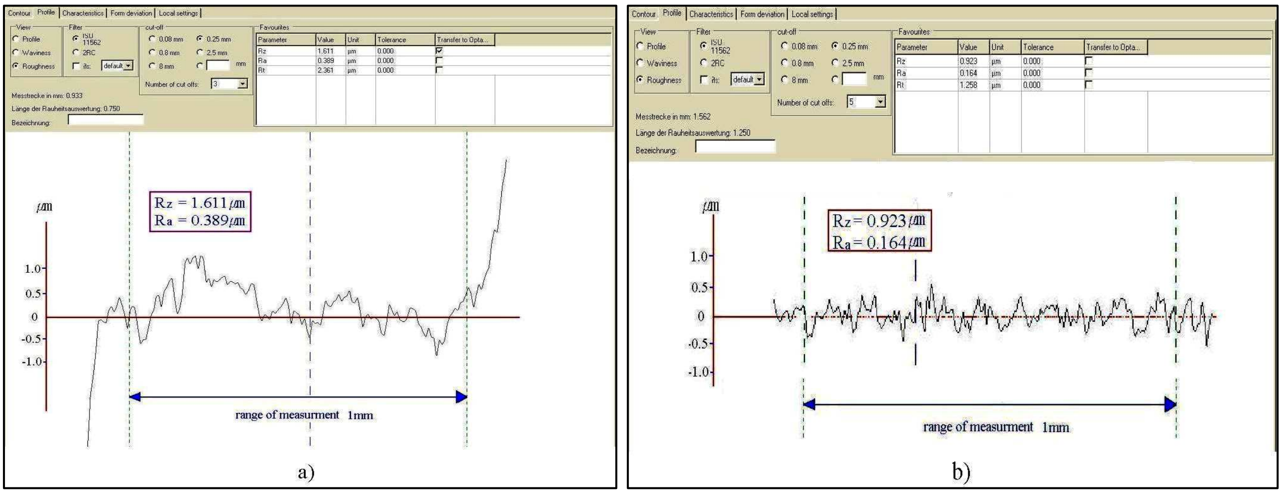

Fig. 9. Surface roughness: a) experimental workpiece ; b) common workpiece

4. CONCLUSIONS

This study showed that the grinding of the screw race can be implemented as a desired shape by machining it as a special shape through modifying the curvature shape of the rotary diameter and rake angle of the grinding stone, which is determined by 1/2 of the lead angle, based on the experiment. In the results of the grinding, the ball contact angles were obtained by 42°~ 45° according to the diameters of the grinding stone determined by 17.2 *mm* ~ 16.8 *mm*. These contact angles represent the smoothest rotation in screw balls and the most stable range in the dynamic characteristics in ball screws due to the small influence on the change in the load capacitance. The surface roughness obtained by the experiment showed the similar results to the surface roughness level after applying a general grinding process. Thus, it was possible to fabricate products easily and efficiently using the method proposed in this study for machining high-lead ball screw nuts. In addition, it is necessary to perform studies on the methods that are able to obtain better surface roughness and its machining methods in the comparison of the study on the noise and heat according to the recent tendency of the high-speed of ball screws.

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REFERENCES

[1] LEE E. S., KIM J. G., JE T. J., WHANG K. H., 1997, *Surface Finishing of Ball screw by Abrasive Wheel Brush*, Proc. of the KSPEC., Spring Annual Meeting, 1049-1052.

[2] CHO G. J., HONG S. O., LEE S. C., 2008, *A Study on the relationship between Pretension and Thermal Strain of the Lathe Ball Screw*, Proc. of the KSMPEC. Spring Annual Meeting, 320-324.

[3] PARK C. H., HWANG J. H., 2004, *Examples of Performance Estimation on the Feed System of Precision Machine Tools*, Journal of the KSPE, 21/8/19-26.

[4] CHOI Y. H., HONG J. H., 2004, *A Study on the Feed Rate Optimization of a Ball Screw Feed Drive System for Minimum Vibrations*, Proc. of the KSNVEC. Autumn Annual Meeting, 962-966.

[5] EUN I. U., LEE C. M., CHUNG W. J., 2002., *Thermal Deformation Characteristics and Compensation of High Speed Feed Mechanism*, Journal of the KSPE, 19/5/13-18.

[6] PARK D. K,, KIM H. K., LEE C. M., 2002, *A Study of Endcap Type on Ball Screw*, Journal of the KSPE, 19/5/13-18.

[7] ISAWA M., 1990, *Ball Screw and Application Technology*, Kogyo Chosakai Publishing Co. Ltd, 88-93.

[8] DOHI T., 1990, *Were Characteristics of Casehardened Materials*, Doshisha University, 30/4/273.

[9] VICKERSTAFF T. J., 1973, *Wheel Wear and Surface Roughness in Crossfeed Surface Grinding*, Int. J. of Machine Tool Design and Research, 13/1/183-198.

[10] YOUDEN D. H., 1992,*Capstans or Lead Screws*, Pro. Of the ASPE 1992 Annual Meeting, 116.