

A Study on Hourglass Worm Gear of Plastics Involute Helical gear Wheel Teeth

*Akiyo HORIUCHI¹, Minoru MAKI², Ichiro KOBAYASHI³, Zih LU⁴

¹*Shin ei Tech Co., LTD*

*6-2240 Shimomino Fukuoka Takaoka-City
Toyama-Pref. 939-0116 Japan*

^{2,3}*Faculty of Engineering, Kanto-gakuin University, 1-50-1 Mutuura Higashi, Kanazawa-ku,
Yokohama-shi, Kanagawa, 236-8501 Japan*

⁴*HiFont System Corp, NO.628 Hong Qiao, China*

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ABSTRACT

The authors developed the new type hourglass worm gear of plastics involute helical gear wheel. The theory, the calculation of the tooth contacts analysis for the prediction of the performance of the gear and the production method of the steel worm and the plastics wheel are reported. A set of the hourglass worm gears was manufactured. And the accuracy of the transmission was measured by the measuring machine for the angular transmission error (abbreviated to ATE) of the reducer invented by A. Horiuchi and others.

The efficiency was tested by the power absorption type worm gear testing machine, designed and made by the authors. The efficiency of the hourglass worm gear was compared with the cylindrical worm gear of steel worm and plastics wormwheel whose dimensions was the same of the hourglass worm gear proposed in this report.

Introduction

The authors developed a new type of Hourglass worm gear whose wheel is an plastics involute helical gear. Plastics involute wheel of cylindrical worm gear are used for cars for power windows, wipers and electrical steering. Miyachika and others report the results of experiment. ⁽¹⁾ HEDCON hourglass worm gear has been developed by A.HORIUCHI, M.Maki and others, ⁽²⁾ by using Secondary action theory of skew gears by T.SAKAI and M.Maki. ⁽³⁾ This Hourglass worm gear has been used in all over the world because of the high efficiency and high strength. ⁽⁴⁾

In this report, the basic theory of this worm gear, the results of TCA, the manufacturing, measuring and the results of experiment of the worm are reported.

Basic Theory

The modifying worm cutting method is applied as used in Hindley hourglass worm gearing.

In the case of classical Hindley worm gear, the wheel surface with high performance transmission ability, which is so called, enveloped surface contact with the half part of the worm width. The theory of the phenomena was made clear by the theory of "Secondary action of skew gear", by T.SAKAI and M.MAKI ⁽³⁾.

S. Ishikawa made the theory of "Modifying Hindley worm cutting method" ⁽⁴⁾. This method is based on the concept that the worm teeth should have the shape after running of long life, namely the shape of wear off after long time running. Fig.1 shows the method of modifying cutting method of Hindley worm.

The straight lined cutter is set as the tangent line of larger circle than the basic circle of classical Hindley worm cutting. The 2~3 larger number of reduction ratio and the cutting distance larger than the mating classical Hindley worm gear and wheel distance are used, as shown in Fig.1

This modifying cutting method of Hindley worm gear of S.ISHIKAWA ⁽⁵⁾ is used in the hourglass worm gear of this report. Plastics involute helical gear is used as the wheel and the grinder of the involute helical gear on which the diamond abrasive grains attached generate the mating worm teeth.

The 2~3 larger number teeth of involute helical gear grinder is used to finish the grinding of the worm teeth.

Table 1 shows the specification of the hourglass worm gear of this report. Number of teeth of worm is 2 and the number of teeth of wheel is 37, while number of the involute helical gear shaped grinder is 39. And the center distance between worm and wheel

is 46mm, while the center distance between worm and grinder is 48.122mm.

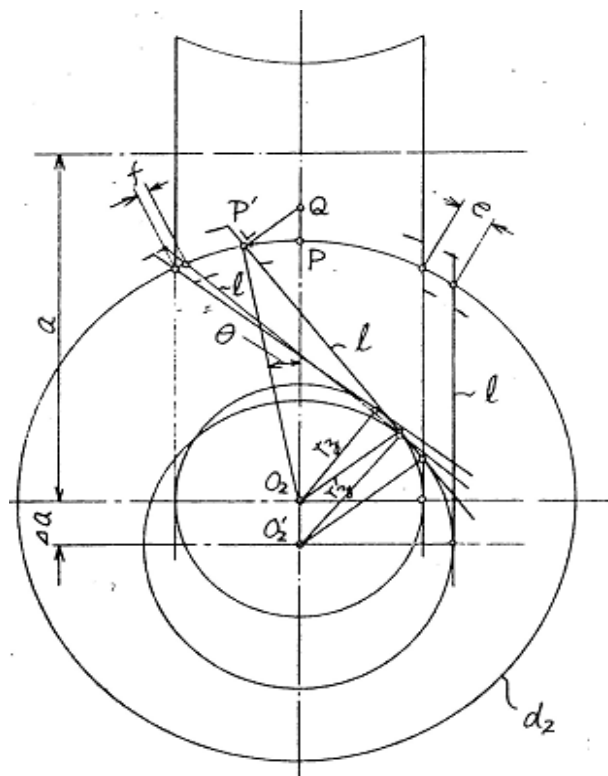


Fig.1 Modifying Hindley Worm cutting method by Ishikawa

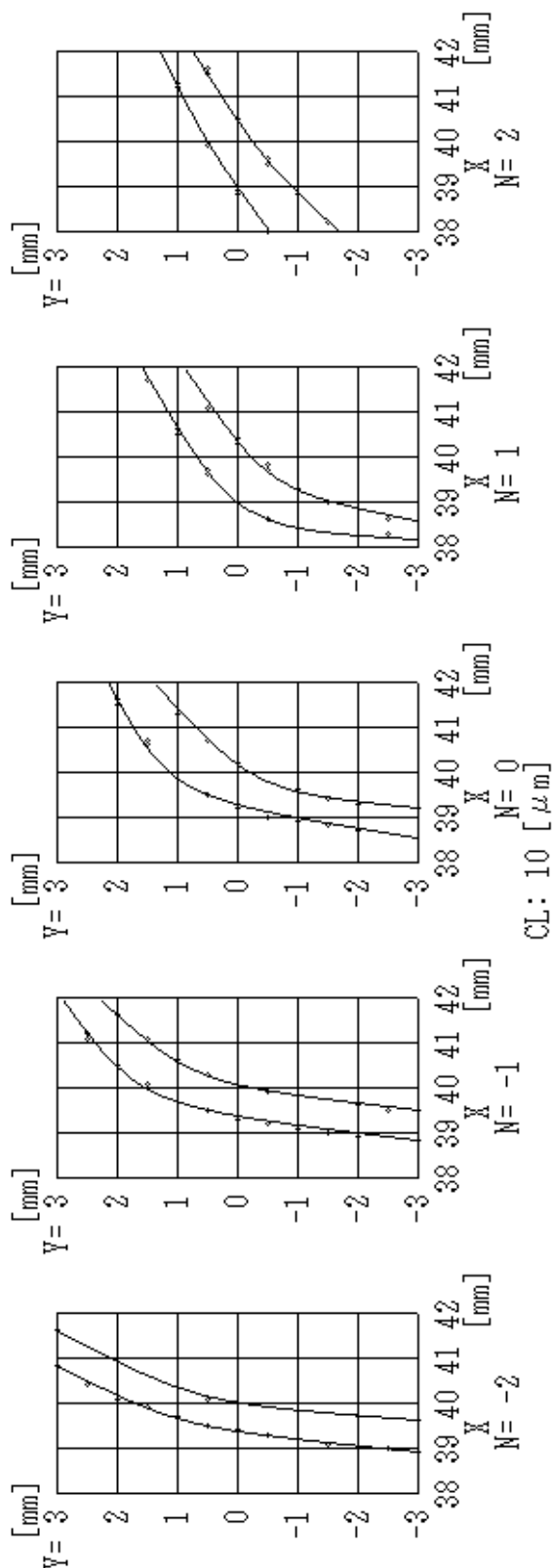
Table 1 Specification of worm, wheel and cutter

	Worm	Wheel	Cutter
t/z	2	37	39
α_n	20		20
α	21.11244		21.11244
d_{1p}/d_{2p}	12.097	79.903	84.146
γ	19.5000		19.5000
C.D	46		48.122
Tooth height	4.500	4.500	1.800
d_{1k}/d_{2k}	16.097	83.903	4.500
Tooth width	34	16	79.146

Tooth Contact Analysis

The soft wear how the tooth contact marks change against the displacement of mating gear alignment is developed t by Gleason works and named TCA.

As for Japan, TCA software was developed by Maki, one of member of this report and others at first for hourglass worm gearing in 1980⁽⁶⁾



(Two curved lines means that the clearance between worm and wheel teeth on these curves are 10 μ m.)

Fig.2 Results of TCA by numerical work

The specification of this worm gear and cutter are shown in Table 1.



Fig. 3 Tooth contact mark on the wheel after cutting



Fig. 4 Tooth contact mark on the wheel after experiment.



Fig.5 Tooth contact mark on the worm tooth after experiment.

In Fig.2, Numbers N attached to the wheel teeth shows that the wheel tooth contacts with what part of the worm teeth. Number (N=-2) implies that the

wheel tooth contacts with the starting part of mesh of worm tooth. Number (N=0) implies that the wheel tooth contacts with the center part (pitch point) of worm tooth. Number (N=+2) implies that the wheel tooth contacts with the ending part of mesh of worm tooth.

The contact marks run over the wheel tooth as rotation of the worm and the wheel. The gatherings of the contact lines of every instant of rotation of the gearing coincide well with the contact mark of Fig.3.

Fig. 4 shows the contact mark on the wheel after experiment. The contact mark spread largely than the contact mark of Fig.3. Fig. 5 shows the tooth contact mark on the worm after experiment. The contact marks spread all over the worm teeth. This result coincides well with the result of TCA as shown in Fig.2.

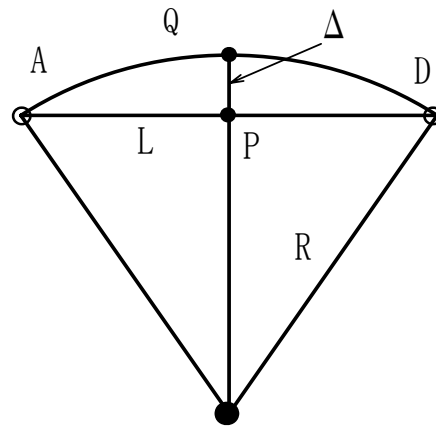


Fig. 6 Explanation of method to calculate relative radius of curvature between worm and wheel teeth

Fig. 6 shows the method to calculate relative radius of curvature between worm and wheel teeth.

In Fig.6, Δ is clearance between worm and wheel tooth. And L is the length perpendicular to the two curved lines of $10 \mu m$ clearance between worm and wheel teeth of Fig.2. From Fig.6, the relative radius of curvature R can be written as follows:

$$R = \Delta/2 + L^2/(8\Delta) \dots \dots (1)$$

From the result of TCA of Fig.2 and eq. (1), the average value of R become about 8mm on the contact lines from starting mesh contact lines of near pitch point.

Manufacturing worm and wheel

By the basic theory of this report, the worm teeth surfaces were generated by involutes helical gear shaped grinding having little bit larger numbers

teeth than mating involutes helical gear wheel as shown in Table1. The authors cut the hourglass worm teeth by pinion cutter having the straight lined tool, at first. Namely, the authors made surface of the modified Hindley worm and then ground the worm teeth by the grinder of the involutes helical gear on which the diamond abrasive grains are attached.



Fig.7 The involutes helical gear shaped grinder on which the diamond abrasive grains are attached and the finished worm.

Fig.7 shows the involutes helical gear shaped grinder on which the diamond abrasive grains are attached and the finished worm. The involutes gear wheel cut by involutes hob.



Fig.8 Grinding of the worm teeth by the involutes helical gear shaped grinder

Fig.8 shows grinding of the worm teeth by the involutes helical gear shaped grinder.

Measuring of the ATE of the Reducer



Fig. 9 Photo of M-MATE (abbreviated from Measuring-Machine for the Angular Transmission Error of the Reducer)

The accuracy of the transmission of the reducer was measured on the measuring machine for the ATE invented by A. Horiuchi and others (Fig.9). The center distance of the reducer box can be changed to become the backlash on the output shaft under 3 arc-min. In Fig.10 upper graph shows the result of measuring of the ATE with backlash. Vertical axis shows the ATE and the unit is 30 arc-sec. Horizontal axis shows the wheel shaft rotational angle and the unit is 30arc-degree. ATE can be calculated by the subtraction actual wheel shaft rotational angle from theoretical wheel shaft rotational angle. Later can be gotten from dividing worm shaft rotational angle by reduction ratio i ($i=z/t>1$). Red line shows the ATE of CW rotation of the wheel shaft and blue line shows the ATE of CCW rotation of it. As the both lines are gotten on same origin point, the subtraction the ATE of CW from the ATE of CCW shows the backlash between worm and wheel tooth on output shaft. Pink line shows this calculated backlash. Lower graph shows the frequency analysis result of ATE. Vertical axis shows the ATE and the unit is 2 arc-second. Horizontal axis shows the times of the periodical ATE component in 1 wheel shaft rotation and the unit is 20 times. From these 2 graphs, next conclusion for characteristic of a worm reducer with reduction ratio $37/2$ can be drawn.

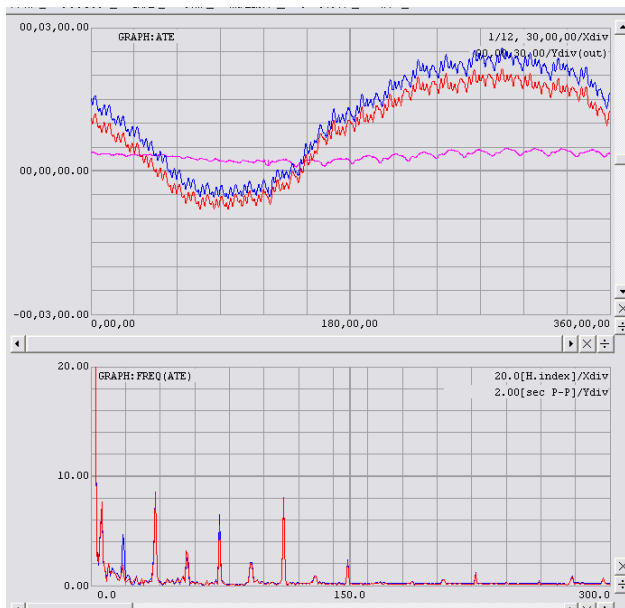


Fig. 10 M-MATE measurement graph (ATE, backlash and frequency analysis)

- 1) The ATE in 1 rotation of the wheel shaft is about ± 87 to ± 95 arc-sec. And this fluctuation was supposed to be the eccentricity of the wheel shaft mainly.
- 2) In 1 rotation of the wheel shaft, worm shaft rotate $37/2$ times. The ATE in 1 rotation of the worm shaft is about ± 18 to ± 19 arc-sec for each CW and CCW rotations.
- 3) This is also reflected on the results of frequency analysis and the peak appearing on the 19,38,57,76,95 of the horizontal axis indicates the fluctuation amplitude at each time.
- 4) Backlash is under 30arc-second and this is very small and convenient for the motion control.

Experiment of Efficiency of the worm gear



Fig.11 Worm gear testing machine of power absorption type.
The authors designed and made the worm gear

testing machine of power absorption type. (Fig.11) Torque instruments for input and out put are connected to the worm gear box and the powder brake is connected to the out put torque instrument. The input and out put torque were measured and taken into the computer. 1000 points of the input and out put torque are taken in 30 minutes.

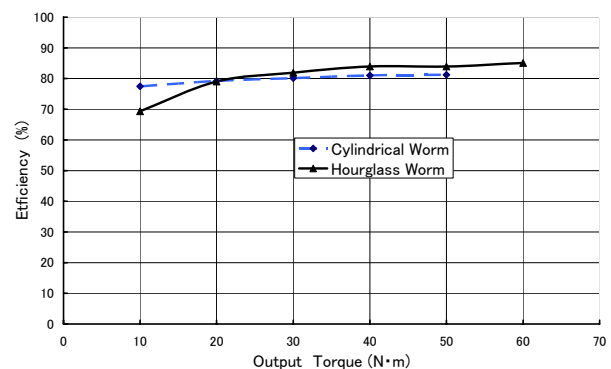


Fig.12 Results of efficiency test.

The authors measured the efficiency of cylindrical worm gear of traditional type cylindrical worm gear with plastics wheel and the hourglass worm gear proposed in this report. The specification of the cylindrical worm gear is same with the hourglass worm gear, namely the module is 2mm and the reduction ratio is $37/2$.

Lubricant is grease in both cylindrical worm gear and the hourglass worm gear.

In Fig.12, the efficiency of the hourglass worm gear of this report is upper curve and the efficiency of the cylindrical worm gear is lower curve.

The hourglass worm gear shows the efficiency of 85% at 60Nm. While the efficiency of the cylindrical worm gear showed the highest efficiency about 81% at 50Nm.

Considerations

- (1) In the case of the hourglass worm gearing of this report, involutes helicoids shaped cutter envelopes the mating worm teeth. So, this gearing can be recognized as the category of involutes worm gearing, which the involutes helicoids shaped hob cutter envelope the mating wheel teeth. Then, the modifying method of worm teeth enveloping by the little bit larger numbers teeth of involutes helical gear shaped grinder than mating involutes helical gear wheel recognized as

the same method of wheel crowning method of involutes worm gearing. Namely, involutes helicoids shaped worm hob envelopes the wheel teeth. In the case of this report, the modified values of both starting part and ending part of worm teeth are about $50 \mu\text{m}$ or more.

In the case of this wormgearing of this report, the involutes helical gear shaped cutter with the infinity number of teeth can modify the worm teeth, theoretically. The involutes helical gear shaped cutter with the infinity number of teeth becomes helical rack plane with infinity center distance. The rack envelops the involutes helicoids. Then, the hourglass worm gearing of this report having involutes helical gear wheel becomes the involutes screw gear does the point contact along the locus of straight line.

- (2) As shown in Fig.4, the contact mark on the wheel after experiment spread largely than the contact mark of Fig.3 just after cutting the wheel. The phenomena can be considered that the secondary tooth surface named by T.Sakai and

M. Maki⁽⁴⁾. This secondary surface appears in classical Hindley worm wheel and HEDCON worm gearing invented by T.SAKAI, M.MAKI, S.UESUGI and A.HORIUCHI. The secondary tooth surface has the points of infinity relative radius of curvature between mating teeth surfaces. And the good performance of the Hindley worm gearing and the HEDCON worm gearing have been used in all over the world and proved the high performance of running.

So, the hourglass worm gearing of this report can be expected of high performance of running.

Conclusion

1) The authors developed a new type of worm gearing which worm wheel is plastics involutes helical gear. In this report, the result of tooth contact analysis, the method of manufacturing and measuring the accuracy of the transmission are reported.

2) A set of new worm gears are manufactured and assembled to the reducer. And the measuring machine measured the accuracy of the transmission for the ATE of the reducer.

3) The efficiency of the hourglass worm gear was compared to the traditional steel worm and plastics wheel cylindrical worm gear. The efficiency of cylindrical worm gear shows the highest efficiency

about 81% at 50Nm output torque. While, the plastics involutes wheel hourglass worm gear shows the higher efficiency than that of the traditional cylindrical worm gear. The hourglass worm gear shows the highest efficiency of 85% at 60Nm.

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