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A Study on the Design of a Gear Transmission Error Test Rig

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기어 전달오차 측정 장비의 설계에 관한 연구

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ABSTRACT

Transmission error (TE) is the most important cause of gear noise and vibration because TEs affect the changes of the force and the speed of gears. TE is usually expressed as an angular deviation, or a linear deviation measured at the pitch point and calculated at successive positions of the pinion as it goes through the meshing cycle. Accurate measurement of TE for gear transmission will provide a reasonable basis for gear design, manufacturing processes and quality control. Therefore, in order to study the accuracy of the gear transmission, stability, TE, vibration and noise after gear micro-geometry modification, a gear transmission test rig is proposed in this paper, which is based on the existing technical conditions, by using reasonable testing methods, hardware and a signal processing method. All of the details and the experience can be taken into consideration in the next upgraded test rig.

Keywords : Spur Gear(스퍼 기어), Transmission Error(전달오차), Test Rig(시험 장비)

1. Introduction

Transmission error (T.E.) is the most important cause of gear noise and vibration because transmission errors affect the changes of the force and the speed of gears. Nowadays, test rigs of gear noise and vibration can be broadly divided into two types. The first one which is widely used is the power recirculation test rig and its energy can be reused in its transmission process, another one is power absorption test rig which means it usually composes of a driving motor, test gears and a power absorbing dynamometer which can generate the resistant torque[1-4]. Fig. 1 is the schematic of two test rigs.

T.E. is usually expressed as an angular deviation, or a linear deviation measured at the pitch point and

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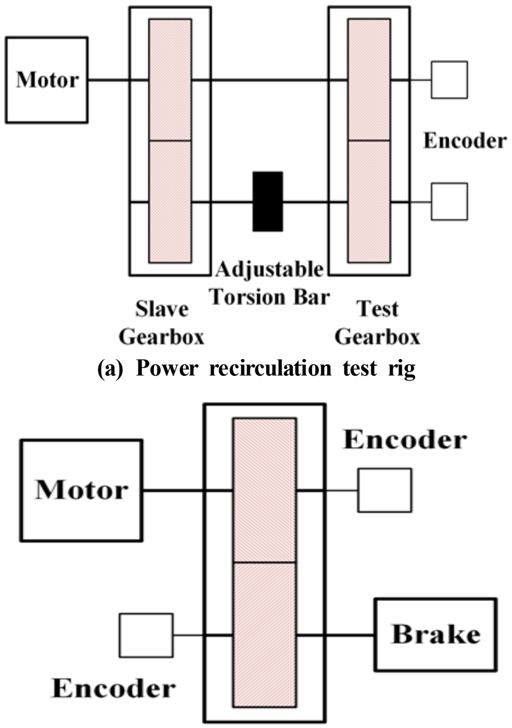


(a) Power recirculation test rig

(b) Power absorption test tig

Fig. 1 The schematic of two test rigs

calculated at successive positions of the pinion as it goes through the meshing cycle[5]. Measurement methods of T.E. can be divided into two categories. The first one is static measurement, which the T.E. is obtained by comparing the rotating angle of the input shaft and the output shaft in the stationary state. Its measurement process is intermittent, not continuous and not subject to the dynamic load, inertia and the stiffness of the gear, which leads to a larger gap from the actual operation. And another one is dynamic measurement which the transmission error is obtained and compared from the state which is close to the actual working condition. So its measurement process is uninterrupted, or is close to continuous. And it can be used to fully reveal the transmission error of gear transmission. The commonest methods used for measuring T.E. are: angular acceleration which accelerometers are tangentially mounted, angle encoders, and laser torsional vibration which is based on the Dopper effect[6-9].

In this paper, in order to study the accuracy of the gear transmission, stability, T.E. and vibration & noise after gear micro-geometry modification, a gear transmission test rig is necessary and obtained which is based on the existing technical conditions, by using reasonable testing method, hardware and signal processing method. Through the accurate measurement and research for the process of gear transmission, it will provide a reasonable basis for gear design, manufacturing and quality control.

2. T.E. Test Rig Setup

2.1 Design of system layout

By the analysis of T.E. measurement system, the final selection of the test rig structure is shown in Fig. 2. Here, the input power is a brushless DC motor. Combined with the company's own hardware resources, RV reducer is used to decrease the input speed and increase the input torque. And the steady rotational torque and rotational speed can be read by the torque meter. The absorbing torque is from a magnetic power brake. Finally, all parts are connected by metal flexible diaphragm couplings. And the T.E. test rig is shown in Fig. 3.

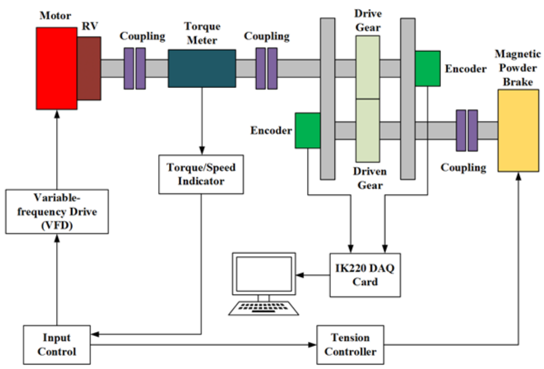


Fig. 2 The schematic of T.E. test rig

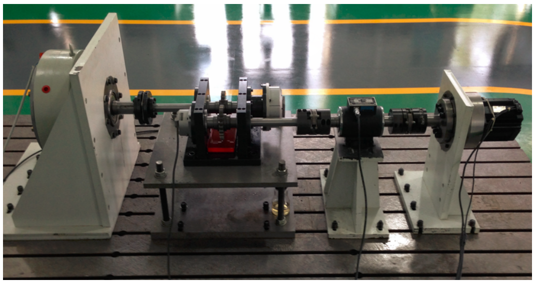


Fig. 3 T.E. test rig

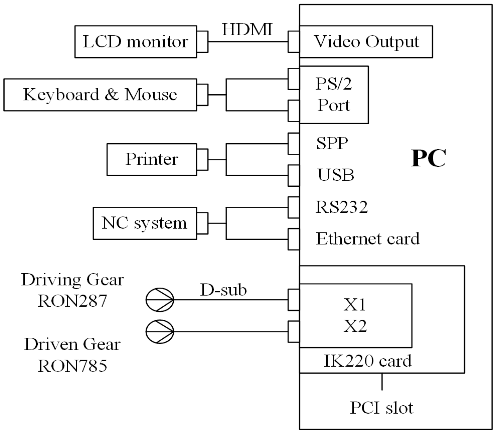


Fig. 4 The block diagram of measurement system

Besides, its measurement is based on the use of HEIDENHAIN incremental angle encoders (RON 287 & RON 785)[10]. And HEIDENHAIN PC counter card is applied to acquire encoder signals. Its principle role is to convert the electrical signals of encoders to precise angle measurements, and transmit the measured values to a PC or computer test software. The block diagram of T.E. measurement system is shown in Fig. 4.

2.2 Data acquisition software

For data acquisition of the test rig, virtual instrument (VI) is used, which means that the data acquisition card is inserted into a computer slot (PCI slot). And by using software (LabVIEW 8.2) to generate virtual panel on the screen[11], different DLL functions are called by IK220 count cards to achieve the synchronization acquisition of the two-way position signals. Thus, signal acquisition, computation, analysis and processing can be achieved by the VI testing software. Fig. 5 is the partial view of testing software's block diagram.

2.3 Signal processing

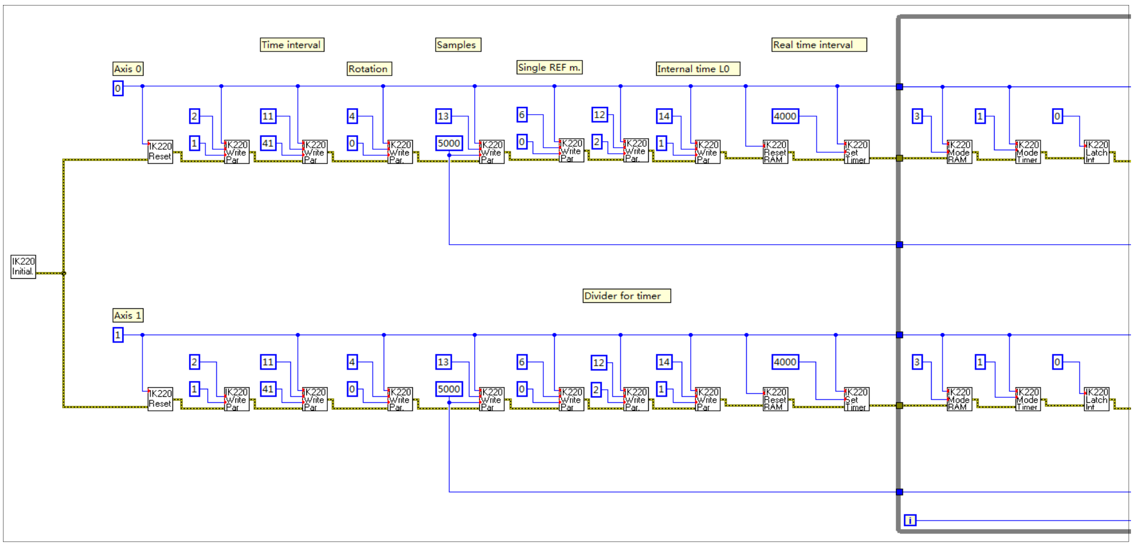


Fig. 5 Partial view of testing software's block diagram

Analogue to digital conversion is a delicate issue, because information cannot be lost during the sampling process. Shannon's sampling theorem states that the passage from the continuous to the discrete domain occurs with no loss of information if and only if:

$$f_s \geq 2f_{\max} \tag{1}$$

where, f_s is the sampling frequency, and $f_{\max}$ is the maximum frequency of the sampled signal. Therefore, the sampling frequency is usually slightly larger than the ideal minimum, which $f_s = (2.5 \sim 3)f_{\max}$, different windows functions are used to reduce the energy leakage of spectrum, e.g. Hanning, Hamming, FlatTop and Uniform etc. Each window function has its own advantages and disadvantages, which the effect of spectral leakage is not the same.

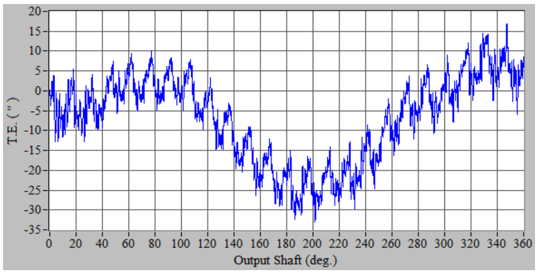
3. Experiment and Discussion

3.1 Experiment setup

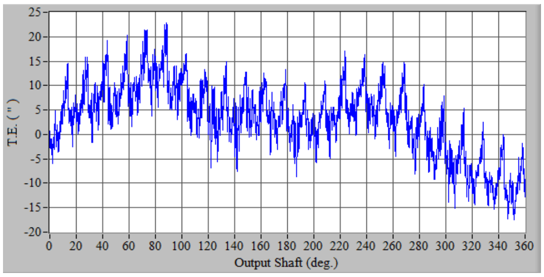
In this paper, in order to verify the reasonability of the designed test rig, a spur gear pair without micro-geometry modification will be used to investigate the T.E. of the spur gear under the design torques. And the loaded torques are separately 20, 40, 60, 80 and 100 Nm. Table 1 is the summary of the specification of the spur gear pair.

Table 1 The specification of the spur gear pair

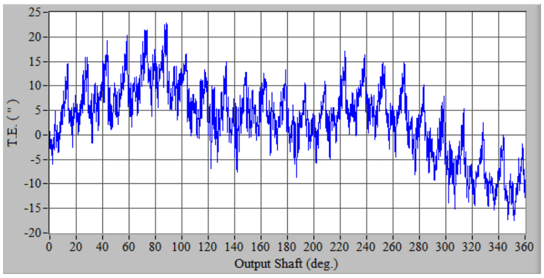
	Driving / Driven
Number of teeth	24
Module (mm)	4.5
Pressure angle (deg.)	20
Helix angle (deg.)	0
Addendum mod. coeff.	0.171
Center distance (mm)	109.5
Face width (mm)	14
Outside diameter (mm)	118.35
Root diameter (mm)	97.85
Standard pitch diameter (mm)	108
Transverse tooth thickness at SPD (mm)	7.564
Profile / face contact ratio	1.34/0
Total contact ratio	1.34



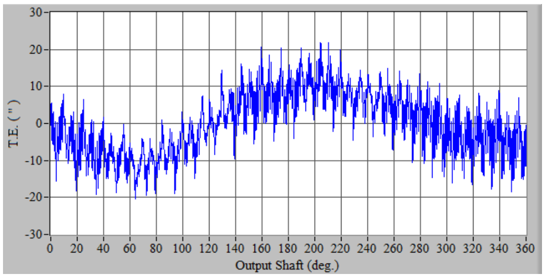
(a) 20Nm 49.8arcsec



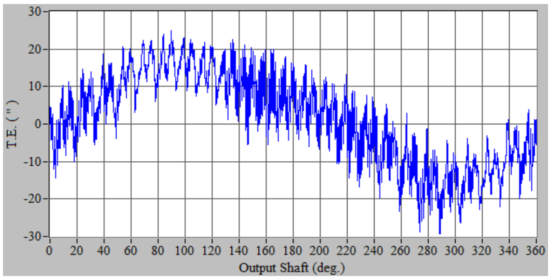
(b) 40Nm 40.2arcsec



(c) 60Nm 41.7arcsec



(d) 80Nm 42.2arcsec



(e) 100Nm 54.4arcsec

Fig. 6 Testing results of loaded torques

3.2 Results and discussion

A pair of gears should transmit rotary motion uniformly from the drive shaft to the driven shaft. This test rig is aimed to investigate the rotational movement of the axes of a spur gear pair and numerically describe the irregularities in the transmission. And finally, all testing results are shown in Fig. 6. The unit of the ordinate is arcsec, by taking the angular units (u-rad) and multiplying them by the base radius of the pinion, T.E. can then be expressed in linear units (u-m).

The T.E. curves result from the deviation in rotating angle between the two encoders. In Fig. 6, they are observed in the form of a regular once-per-tooth pattern superimposed on large waves which are related to once-per-revolution type errors. The short wave components are from tooth meshing which are caused by gear surface effects, and the long waves are due to run-out errors. The long wave of the resulting total error curve could be isolated by using a low pass digital filter to reject tooth mesh and high frequencies, and the short wave portion is obtained by subtracting the long wave components from the total error. From 20Nm to 60 Nm, the tooth-tooth meshing frequency of the gear is clear, but from 80Nm to 100Nm, the meshing frequency is not so clear, which could be due to the vibration of magnetic powder brake or the effect of another working test rig for efficiency testing. All the resulting details should be taken into consideration in the next upgraded test rig.

4. Conclusion

In this paper, a gear transmission test rig is designed to investigate the T.E. of a spur gear pair. The T.E. curves of the first three loaded torques are consistent to verify the reasonability of the designed test rig, but for the other loaded torques, the tooth-tooth meshing frequency of the gear is not so clear because of external interferences. All of the details should be taken into consideration in the next upgraded test rig which are listed as follows[12-14]:

1. In order to accurately control the hardware (e.g. input motor and absorbing dynamometer), DASYLab software package with some extra hardware can be chosen as an optimal control tool for the next test rig.
2. Additional business measurement software, like Rotec-RAS from Germany, can be used to verify the accuracy of the VI testing software.
3. Commercial software can be applied to simulate the T.E. of the test gears, and the results of simulation and testing can be compared to find the general law for gear design later.
4. It's necessary to avoid the testing time of other test rigs, or the test results will be affected by other external factors.

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