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Factors Analysis of Gear Sound by Using Numerical Simulation

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ABSTRACT

As an approach to identification of a factor that contributes to gear sound, in the quasi - static loading condition of low speed operation, estimation of gear transmission error of spur gear was investigated from combination of vibration measurement and numerical simulation. Furthermore, build a numerical simulation approach to analyze the prediction and contribution of vibration and sound under high speed operation conditions.

Keywords: Dynamic Mesh Force, Transmission Error, Acoustic Power

1. INTRODUCTION

The dynamic characteristics of gear system have great influence for the vibro-acoustic phenomena of gear systems. Therefore, capturing all relevant factors influence, such as for transmission error, gear mesh stiffness, mesh dynamic force, component and system flexibility. It is significant to study the vibro-acoustic phenomena of gear system.

The gear whine noise is one of main vibro-acoustic phenomena of gear system due to gear meshing, it is caused by meshing force transmitted to the housing via the bearing supporting the gear shaft and is generated by the vibration of the housing.

In this paper, modeling the gear system into an excitation Source-Transfer-Receiver. First, a measurement and simulation approach to estimated transmission error and calculate the mesh dynamic force. The combination of vibration measurement and numerical simulation and estimated the gear transmission error in the quasi-static loading condition of low speed operation. In addition, using the simulation model calculate each component contribution for mesh dynamic force and acoustic radiation power.

2. ESTIMATION OF MESH TRANSMISSION ERROR

The transmission error is caused by factors such as micro geometry, assembly error, and bending or twisting of the shaft due to the torque of the operating load. Separately from the resonance due to the vibration mode of the gear system, the frequency response function in the low frequency range is measured to capture the vibration caused by the mesh transmission error. Finally, estimate transmission error from correlation analysis of experimental and analytical vibration results.

2.1 Vibration Measurement

The main shaft of the gear system is put into rotation by an electric motor with a speed controller connected in series through a flexible coupling, the output shaft is braked by a gear head motor with, fix the shaft by mounting the flange type bearing unit on the shaft fixing bracket. For lubrication, apply grease to the tooth surface before each test. As a quasi-static low-speed operating condition, a

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load condition with a rotational speed of 30 rpm and a torque of 30 Nm is placed on the main shaft. Three-axis accelerometer used for vibration measurement; it was positioned at the bracket of the gear system.

The Figure 1 below illustrates the gear system and position of accelerometer.

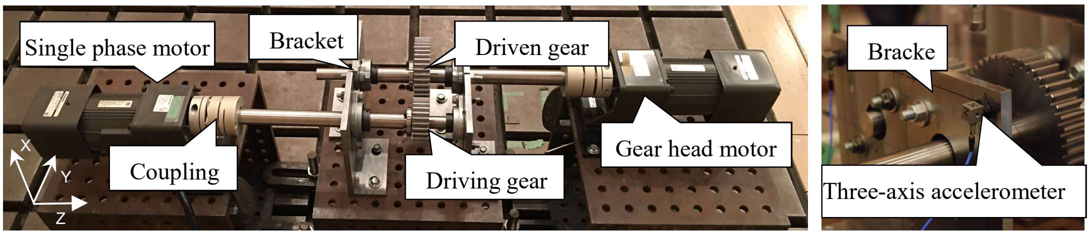

Figure 1 – Measurement Gear System and Position of Accelerometer

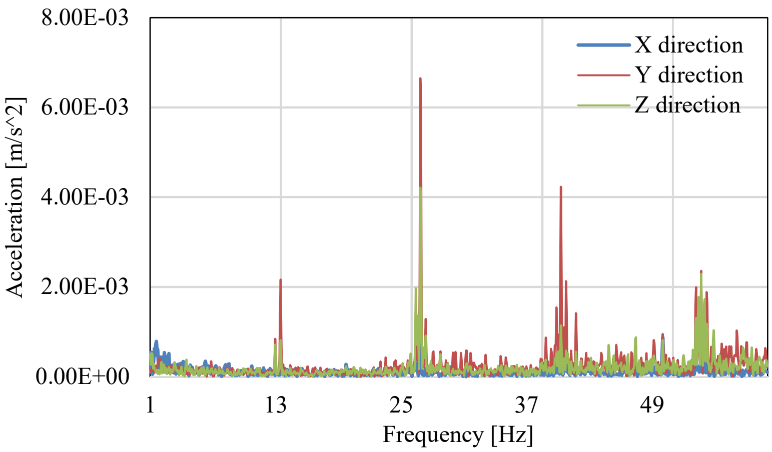

Figure 2 – Translational Acceleration on the Bracket

Figure 2 shows the acceleration data of measurement of a gear system under low-speed operating condition, approx. 30 rpm with a corresponding gear mesh frequency of 13 Hz. From the significant peak value of acceleration with a period of 13 Hz, the gear system was excited periodically at 13 Hz because of transmission errors.

2.2 Build Simulation Model

The full integrated gear system model is generated, search as gear macro geometry, bearing, gear blanks and bracket in full FE in this simulation model. Table1 and Table2 lists the different parameters used to generate the gear pair. Then, the gear geometry computation allows to create in accordance with the ISO 21771 standard. Figure 3 displays the 3D simulation model modeled measurement gear system.

Table 1 – Gear Specification

Parameter	Pinion	Wheel
Number of Tooth	28	48
Module(mm)	2.5	
Pressure Angle (°)	20	

Table 2 – Gear Specification

Parameter	Pinion	Wheel
Face Width(mm)	25	
Center Distance(mm)	97.5	
Tip Diameter(mm)	75	125
Root Diameter(mm)	63.75	113.75

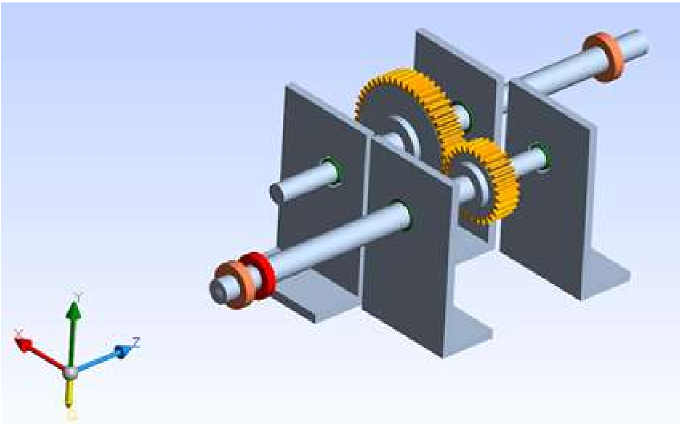

Figure 3 – Simulation Gear System

2.3 Correlation between Simulation and Experiment

Figure 4 shows the comparison acceleration data of bracket with measurement and simulation of a gear system under low-speed operating condition. As a result, the vibration values from the 1 to 4 order of meshing due to the transmission error of the simulation is in almost agreement with the measurement value. Therefore, it is assumed that the simulation model can represent the dynamic characteristics of gear system.

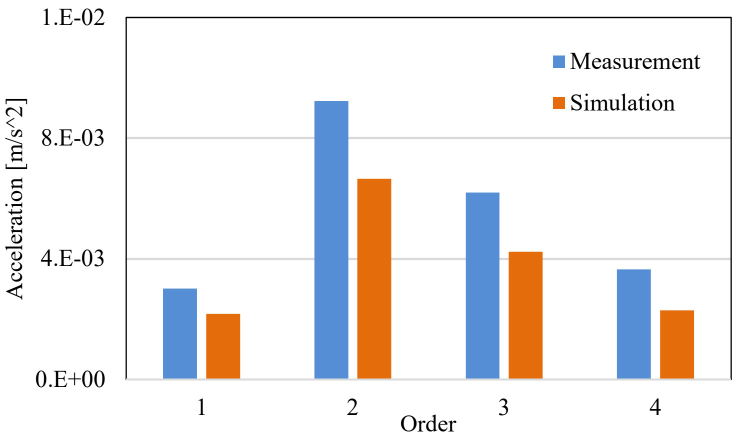

Figure 4 – Translational Acceleration of Measurement and Simulation

3. CONTRIBUTION ANALYSIS BY SIMULATION

The gear whine noise is affected by mesh dynamic force and structure of gear system etc. To reduce noise level is to lower level of mesh force and system vibration. Therefore, require contribution analysis of mesh dynamic force and acoustic power that capturing which structure modes efficient to it. Two methods are used to calculate contribution. The one is modal superposition structural repose analysis calculate component compliance and find which structure mode contribute mesh dynamic force. The other is use the ISO/TS 7849 calculate acoustic power and acoustic power contribution.

3.1 Contribution Analysis for Mesh Dynamic Force

The aim is to solve the equations of motion of the gear system

$$M\ddot{u}+Ku=f \tag{1}$$

f is the dynamic mesh force, in the line of action; u is an n-dimensional, time dependent vector, representing the displacements of the system; M is the n×n mass matrix for the full system is the n×n; K stiffness matrix for the full system.

Dynamic mesh force

$$f= D\times \delta \tag{2}$$

D is the dynamic mesh stiffness, in the line of action; δ is the static transmission error.

Dynamic mesh stiffness

$$D=1/(Cp+Cw) \tag{3}$$

Cp, Cw is the compliance of pinion and wheel sides respectively.

When torque and rotation excite input shaft through bearing, bracket and gear, the mesh dynamic force at the line of action was same as Figure 5. There were 2 peaks in Fig 5. Those peaks had higher probability occurring pinion and wheel side compliance.

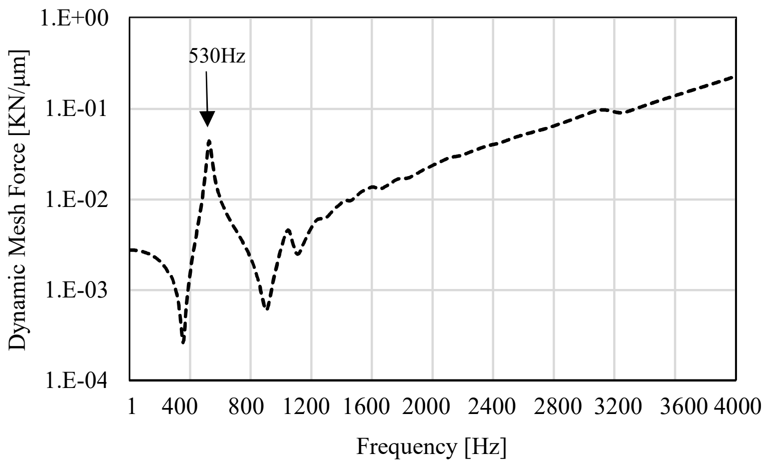

Figure 5 – Dynamic Mesh force of Gear system

Figure 6 shows the compliance amplitude and phase, acceleration data of measurement of a gear system, the value of pinion side compliance is close to value of pinion side compliance at 530 Hz and 1100 Hz, furthermore, it could be confirmed that dynamic mesh force became a peak at 530 Hz and 1100 Hz due to the phase difference.

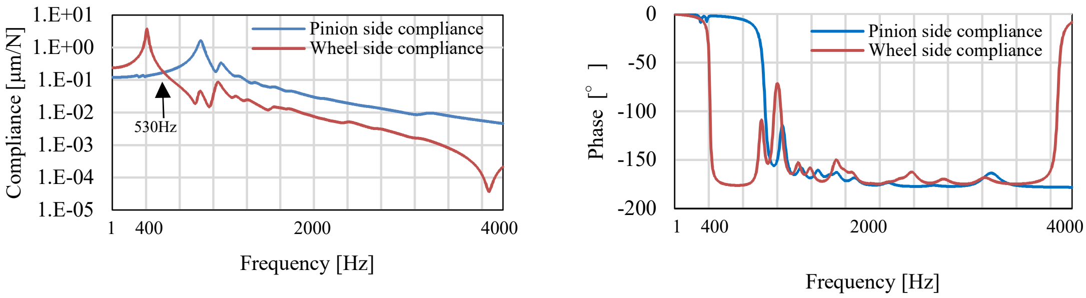

Figure 6 – Gear Mesh Compliance

Figure 7 showed Modal Compliance Factor for dynamic mesh force, modes were separated pinion side modes and wheel side modes. The results showed that 6th wheel side mode and 9th pinion side mode was more effective to mesh dynamic force at 530 Hz.

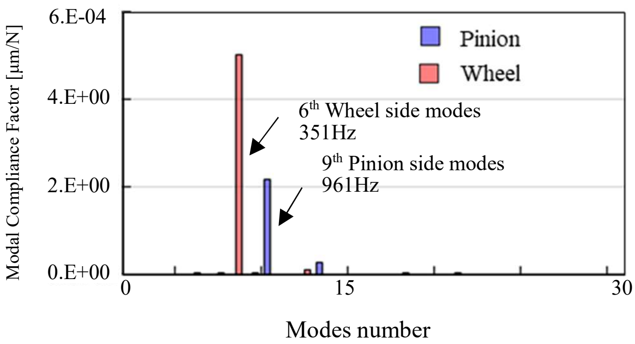

Figure 7 – Modal Compliance Factor

Figure 8 showed the torsional mode of 6th wheel side modes and 9th pinion side mode effect to dynamic mesh force.

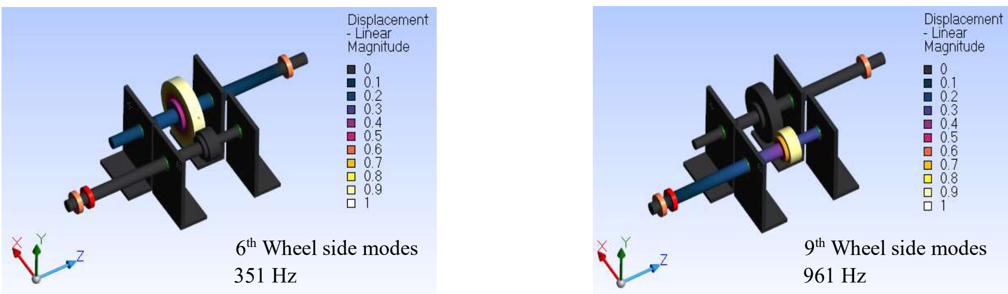

Figure 8 – Component Mode Shape

3.2 Contribution Analysis for Acoustic Power

The acoustic power contribution analysis is focused on the effect frequency finding. This method is to find which structure modes is correlated with acoustic power level. Therefore, it is useful to find specific structure modes.

Figure 9 showed the total acoustic power and each component acoustic power; the results showed the acoustic power at 530 Hz is due to the vibration by dynamic mesh force. The acoustic power of input shaft affected the total acoustic power at 270 Hz, and the acoustic power of output bracket affected the total acoustic power at 1620 Hz.

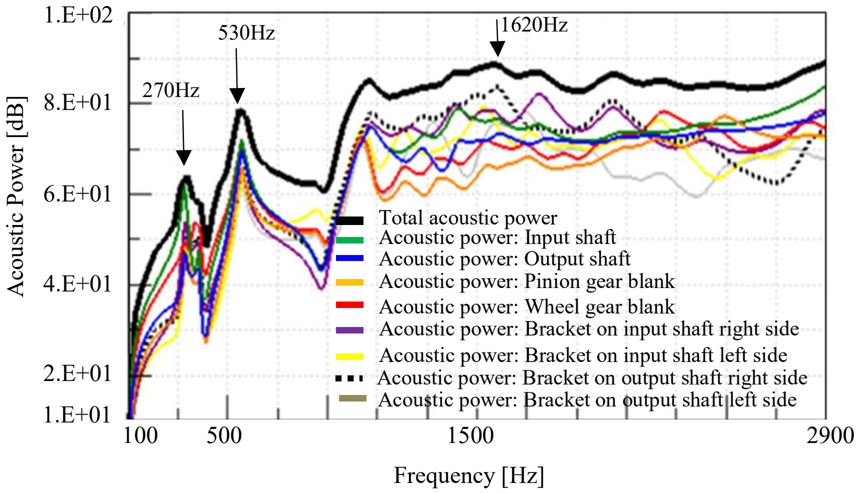

Figure 9 – Acoustic Power

Figure 10 showed the system coupled modal participation factor analysis results, 3rd modes and 19th modes are influence the peak of acoustic power at 270 Hz and 1620 Hz.

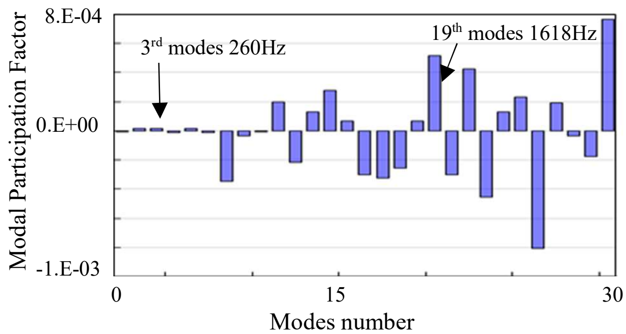

Figure 10 – Modal Pacification Factor

Figure 11 showed the 3rd modes is bending mode of input shaft and 19th modes is bending modes of wheel side.

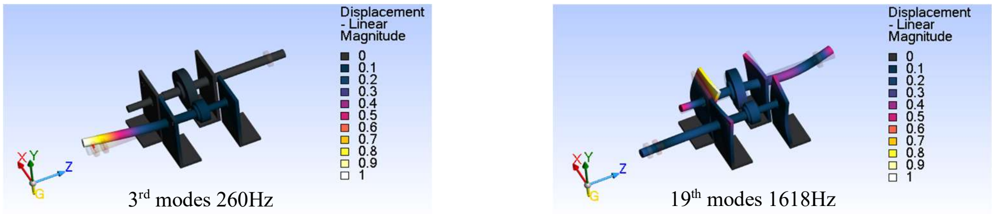

Figure 11 – Coupling Mode Shape

4. Estimation of Noise Reduction Potential

Two methods can use to reduce the gear whine noise. The one is using the micro geometry optimization and reduce the amplitude value of transmission error. Other is optimized the structure based on the results of the contribution analysis in the previous section that is tuning the structure modes and reduce the mesh dynamic force and modes contribution for acoustic power.

In this section, examine the possibility of tuning the structure modes and reduce the mesh dynamic force, finally evaluate the total acoustic power and effectiveness of simulation approach.

Necessary to provide a tuning approach for increase the compliance of meshing point of either pinion or wheel side for mesh dynamic force reduction. Based on compliance value of simulation, build simulation model that increase the wheel side stiffness and reduce the pinion side stiffness.

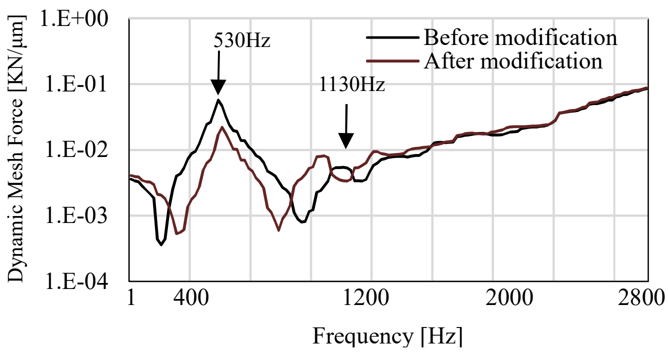

Figure 12 – Comparison of Dynamic Mesh Force Before and After Modification

Figure 12 showed the comparison of values of dynamic mesh force before and after modification, as a result, able to reduce the targeted 530 Hz peak. However, the peak value of mesh dynamic force is shift to lower frequency with increase in low frequency domain and 1130 Hz due to by changing the stiffness of the pinion and wheel side models, the natural frequency of system model is changed.

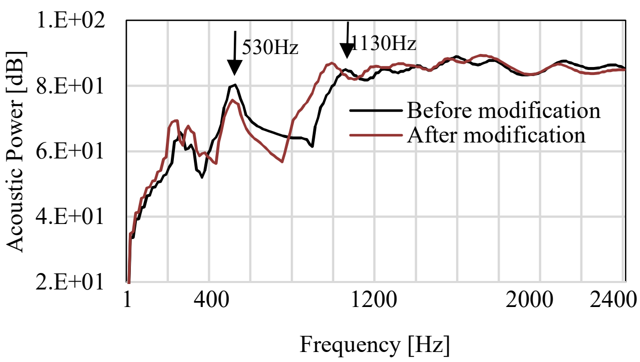

Figure 13 – Comparison of Total Acoustic Power Before and After Modification

Figure 13 showed the comparison of values of total acoustic power before and after modification, as a result, able to reduce the acoustic power at 530 Hz peak.

5. CONCLUTION

The combination measurement and numerical simulation in of external component vibration of gear system seems to be a promising approach to significantly identify transmission error in gear system. Further, to identify affective mode for reduce gear whine noise was used modal participation factor analysis and acoustic power contribution analysis. In numerical simulation approach, able to modify stiffness of the component of gear system and tuning modes to reduces the gear whine noise of the specific frequency domain. accommodate numerical simulation approach to the actual gear system is in progress.

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