Development of Gear noise Reduction Method used Quality Technology Tequnique

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ABSTRACT

Gear train modification is effective measures for reduction of transmission gear noise. This requires selecting a effective parameter out of great number design parameters. Compared with a transmission in the development stage, it is difficult that the examination of gear noise reduction of a ready-made by estimating vibration because modifiable parameters are restricted. As a consequence, it is expected that selecting parameters have difficulty .This study examined for reduction of 3rd driving gear noise of Fujiunivance's lightweight type transmission .As a result, by having analyzed vibration using a finite element model is adopted parameter design that is quality technique , we could design method of reducing gear noise effectively.

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Development of Gear Noise Reduction Method using Quality Engineering Technique

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INTRODUCTION

There have been a number of studies conducted for reducing automotive transmission gear noise utilizing Finite Element Method. However with the use of FEM alone, it is difficult to efficiently select effective design parameter from many design parameters available.

In order to accomplish this task efficiently, gear noise reduction method combining FEM and Quality Engineering Technique was developed. This method was applied to study manual automotive transmission gear noise for the case where third gears are being engaged.

Objective

■*Manual Transmission Gear Noise Reduction*

→ ***Reduction of Rear Engine Mounting Bracket Vertical Dynamic Acceleraion for the case where third gears are being engaged.***

Vibration Analysis using FEM
and
Parameter Design(Quality Engineering)

■*Effectively Selecting Design Paramer*

OBJECTIVE

Objective of the project was to efficiently select effective design parameters to reduce structure born vehicle interior noise caused by transmission case vibration. By employing quality engineering technique with conventional FEM analysis, optimum set of design parameters was selected with substantial efficiency. For evaluating level of gear noise, acceleration level at the rear engine mounting bracket was monitored.

Procedure

Correlation of FE model to Test measurement

⬇

Vibration Frequency Response Analysis. ➡
- *Dynamic Mesh Force, Acceleration and Compliance*
- *Natural Modal Shape*

⬇

Parameter Desigin ➡
- *Determine Control Factors, Noise Factors and Layout to Orthogonal Arrays*
- *FEM Simulation*
- *Calcurate Sygnal-To-Noise Ratio,*
- *Investigate Factorial Effect*
- *Decide Optimum Level and* most effective ontrol factor

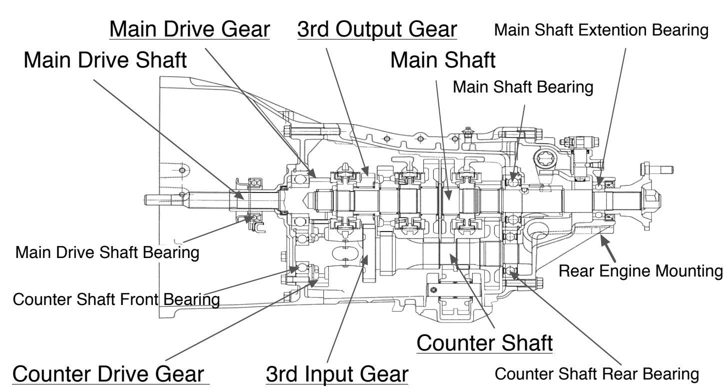
⬇

Validate by Simulation

PROCEDURE

This project was divided into four steps: (1) creation of FE model and its correlation to test measurement, (2) vibration frequency response analysis, (3) parameter design, and (4) simulation to validate effectiveness of selected design parameters.

Manual Transmission



MANUAL TRANSMISSION

In this project, transmission being studied was a manual transmission for a front wheel drive vehicle of light weight desigion. The project aimed at reducing transmission gear noise in the third gear posistion by changing design parameters such as shaft and bearing stiffnesses.

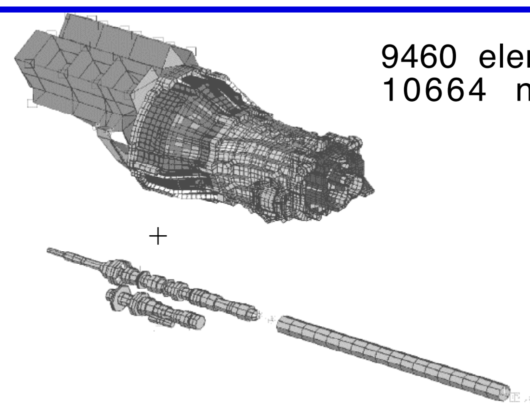
FEM Modeling and Analisys Software

- *Pre Processing*
  I-DEAS MS6A/Simulation
- *Normal Modes Analysis*
  MSC.NASTRAN Ver.70 (SOL103)
- *Frequency Response Analysis*
  MSC.NASTRAN Ver.70 (SOL110)
- *Post Processing*
  I-DEAS MS6A/Simulation, Test

FEM MODELING AND ANALISIS SOFTWARE

FE model of the transmission was created using I-DEAS MS6A Simulation. Normal modes and frequency response analyses (dynamic acceleration, mesh force, and compliance) were performed using MSC.NASTRAN. I-DEAS was used also for post processing of FE analysis results such as mode shapes, strain energy densities, and synthesis of analytical transfer functions.

T/M FEM Modeling

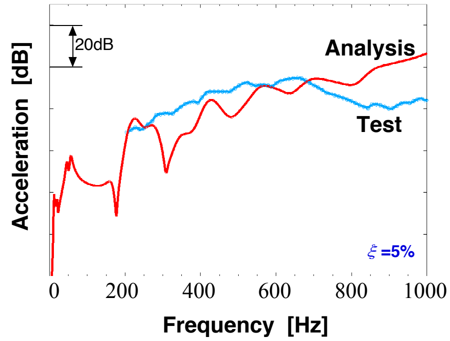


9460 elements
10664 nodes

T/M FEM MODELING

The transmission caseing was modeled using shell and solid elements. The shafts were modeled using beam elements. Gears were modeled using lumped mass and rigid elements. Stiffnesses at gear mesh and of bearings were modeled using spring elements.

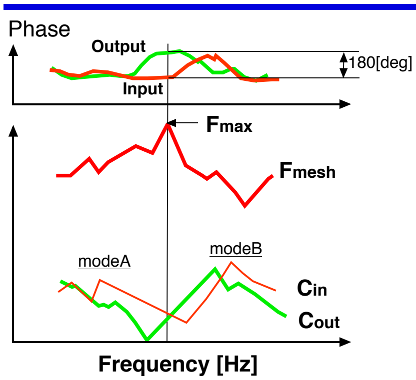
Acceleration at Rear Engine Mounting Bracket (Comparison of Test and Analysis Results)



ACCELERATION AT REAR ENGINE MOUNTING BRAKET (COMPARISON OF TEST AND ANALYSYS RESURT)

After performing correlation task to match FE model results to test results, the model showed good agreement with the test measurement for frequency range of 0 Hz to 1000 Hz. Modal viscous damping, ξ, of 5 % was used for all the modes obtained from the FE analysis.

Conventional Mehod of Gear Noise Reduction using FEM



δ: transmission error

F_{mesh}: Dynamic Mesh Force

D_{mesh}: Dynamic Mesh Stiffness

$$F_{mesh}=D_{mesh}\delta \qquad (1)$$

C_{in}: Input Gear Compliance

C_{out}: Out Gear Compliance

$$D_{mesh}=(C_{in}+C_{out})^{-1} \qquad (2)$$

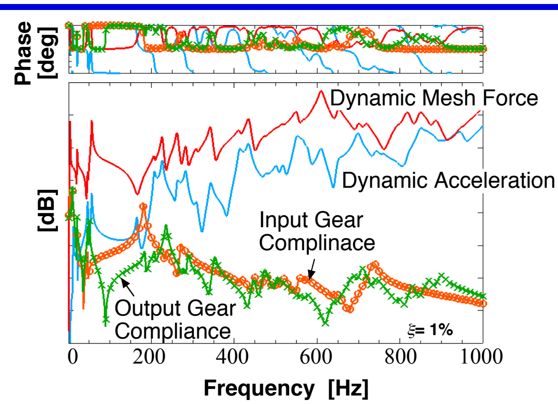
CONVENTIONAL METHOD OF GEAR NOISE REDUCTION USING FEM

It has been well known that one of the most effective approaches in reducing gear noise is by controling of dynamic mesh force [1, 2]. Gear noise is a result of transmission error imposed between the mating gear teeth. This transmission error generates dynamic mesh force through the dynamic mesh stiffness as in equation (1). Dynamic mesh stiffness is determined from the dynamic compliances of the mating gears as in equation (2).

From these two relationships, it can be seen that mesh force has a peak at frequency where the magnitudes of the Input gear dynamic complince is equal to the magnitude of the Output gear dynamic compliance with their phase angle 180 degree apart from each other.

Thus for a mode that make up compliance peak below the mesh force peak frequency, changing its modal mass will change the mesh force. On the other hand, for a mode that make up compliance peak above the mesh force peak frequency, changing its modal stiffness will change the mesh force.

Frequency Response Analysis of Transmission



FREQUENCY RESPONSE ANALYSIS OF TRANSMISSION

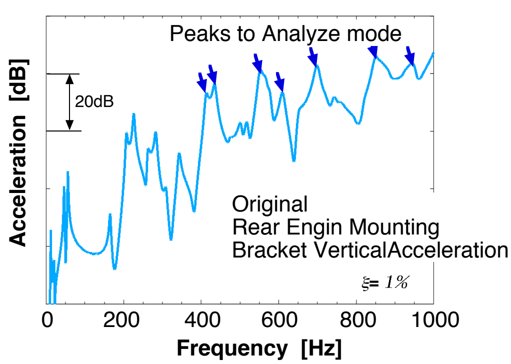
In the FE model, transmission error of 1 micro-meter was applied between the mating gear teeth, and resulting rear engine mounting bracket acceleration and mesh force were calculated. The graph shows that there is quite a number of peaks in the frequency range shown.

Input and output gear compliances were also calculated from the model by detaching the mating gear teeth.Mesh force peaks appear at the frequencies where input and output gear compliances cross each other with their phase angle 180 degrees apart from each other. By changing the respective

compliance curves, mesh force level and peak frequencies can be controlled. In order to reduce the overall mesh force amplitude, it is necessary to understand all modes that make up the compliance peaks.

However, since there are many compliance peaks, such gear noise reduction method involves considerable amount of difficulty. Thus, to accomplish the task in a more systematic and efficient manner, quality engineering method was adapted.

Determining Control Factors



DETERMINING CONTROL FACTORS

As a first step of quality engineering method, control factors that affect the acceleration must be determined. For this purpose, mode shapes of the modes that make up the acceleration peaks were analyzed.

Determining Control Factors with High Contribution (Strain Energy Distribution Table)

Mode Number	19	20	25	28	31	32	36	37	42
Frequency (Hz)	401	428	560	584	686	699	815	843	945
ENGINE									
HAUSING,CASE&EXTEMSION					×				
INPUT SHAFT									
MAIN SHAFT	○	○	○	○	×	○	×	×	×
COUNTER SHAFT	×	○	×	×	×	×	×	×	×
M/S_FR_RAD	○	×	○	×	×	×	×	×	×
M/S_FR_AX	×	×	×	×	×	×	×	×	×
C/S_FR_RAD	○	×	○	○	○	×	×	×	×
C/S_FR_AX	×	×	×	×	×	×	×	×	×
C/S_RR_RAD	×	○	×	○	○	×	○	○	○
C/S_RR_AX	×	○	×	○	×	×	×	×	×
M/S_RR_RAD	×	○	○	○	×	×	×	×	×
M/S_RR_AX	×	×	×	×	×	×	×	×	×
M/S_EXT_RAD	○	○	×	○	○	×	×	×	×

○:High Contribution

DETERMINING CONTROL FACTORS WITH HIGH CONTRIBUTION

Furthermore, strain energy distribution table for the previously determined modes was created in order to determine control factors with high contribution.

Generating Levels of Control Factors

Control Factor	Level1	Level2	Level3
A: Transmission Error	Original×0.5	Original	-
B: Main Shaft Rigidity	Original	Original×3	Original×5
C: Bearing C Radial Rigidity		Original×6	Original×11
D: ". D "			
E: " E "			
F: " F "			
G: " G "			
H: " H Axial Rigidity			

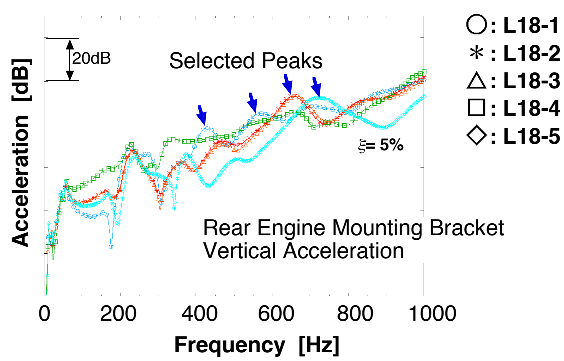
GENERATING LEVELS OF CONTROL FACTORS

As a second step of quality engineering method, levels of control factors were generated using the result from the previously determined control factors. Three levels of the control factors were generated. One of the three levels is with original structural rigidity, and the remaining two levels are both with higher rigidity. Transmission error was also treated as one of the control factors.

Analysis No. \ Factor	A	B	C	D	E	F	G	H
1	Level1	1	1	1	1	1	1	1
2	Level1	1	2	2	2	2	2	2
3	Level1	1	3	3	3	3	3	3
		⋮						
16	Level2	3	1	3	2	3	1	2
17	Level2	3	2	1	3	1	2	3
18	Level2	3	3	2	1	2	3	1

L18 ORTHOGONAL ARRAYS

As a third step, 18 sets of control factors were created as seen in this L18 Orthogonal Arrays. For each case, dynamic acceleration was simulated using the FE model.



NOISE FACTORS

In this graph, four of the simulation results from the L18 Orthogonal Arrays are displayed. After examining all 18 results, four frequencies were selected at which the vibration levels need to be reduced. In quality engineering, these four frequencies are refered to as the noise factors.

Determining SN Ratio from the Noise Factors

Rear Engine Mounting Bracket Verticak Accelerations(Error Factors)

Analysis No.	430Hz	570Hz	660Hz	700Hz	SN Ratio η
1	a	b	c	d	-0.685
⋮		⋮			⋮

$\eta = -10 \log \sigma^2 = -0.685$(dB)

where

$\sigma^2 = \{(\log a)^2 + (\log b)^2 + (\log c)^2 + (\log d)^2\}/4$

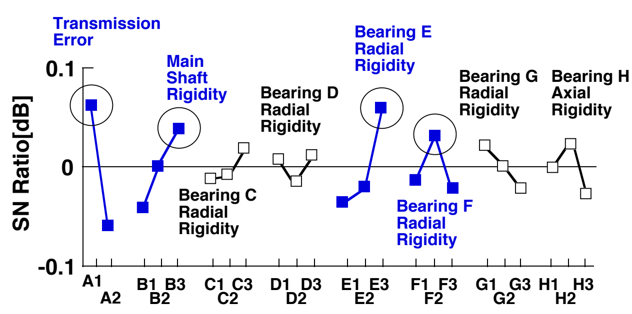
η : Smoller-is-better Performance SN Ratio

Take logarithm of a,b,c,d,to normalize individual contribution

DETERMINING SN RATIO FROM THE NOISE FACTORS

Generally with noise and vibration analysis, engineers aim to reduce vibration levels. Therefore, as a measure of how well each control factor performs, signal-to-noise ratio of greater-is-better performance index was adapted. So, as a fourth step, acceleration levels at four different frequencies were transformed into a single signal-to-noise ratio for each case of the Orthogonal Arrays.

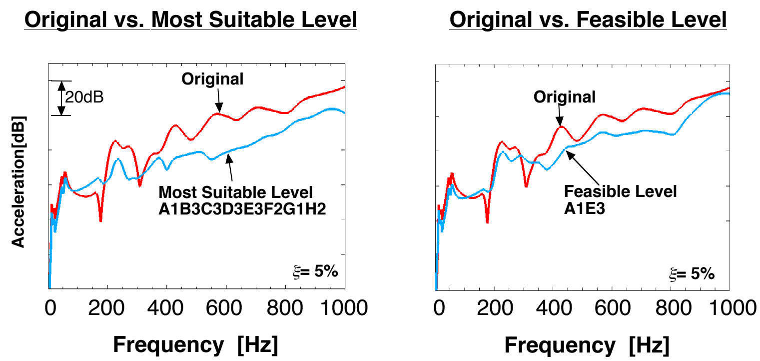
Factorial Effect Result



■ : Most Effective Parameters, ○ : Most Suitable Level = A1B3C3D3E3F2G1H2

FACTORIAL EFFECT RESULT

As a final step in the quality engineering method, SN ratios for each control factor were plotted in order to determine the most suitable level or the most effective set of design parameters. High SN ratio indicates that the control factor or the design parameter has a favorable effect in reducing the vibration level. Also, for each control factor to be effective, the curve should be a straight line with a steep slope. From the plot, the combination of A1-B3-C3-D3-E3-F2-G1-H2 was determined to be the case with the most suitable level or the most effective set of design parameters. Of these parameters, the most effective parameters (curve with straight line with a steep slope) are transmission error (A), main shaft rigidity (B), and bearing radial rigidity (E).



VERIFYING THE MOST SUITABLE LEVEL WITH AN SIMULATION

For the previously determined most suitable level (A1-B3-C3-D3-E3-F2-G1-H2), frequency response simulation was performed to verify how much acceleration level reduction can be expected. The simulation result shows that the most suitable level is capable of reducing acceleration level for a wide frequency range (shown in the left hand side graph). Specifically, the reduction in acceleration level of approximately 20-30 dB may be expected for frequency range of 450-550 Hz. Of the most optimum design parameters, A1 and E3 can be implemented without much difficulty. A1-E3 frequency response simulation result also shows that the acceleration level can be reduced for a wide frequency range, and the reduction of approximately 10-20 dB can be expected for frequency range of 400-850 Hz.

CONCLUSION

■ It was confirmed that the reduction of transmission vibration can be expected using the most suitable level of design parameters determined from the quality engineering method.

■ Gear noise reduction study with only FEM requires trial-and-error study with unknown number of repetitions. By employing quality engineering method.(parameter design method), the effective design parameters for gear noise reduction were determined with only 18 simulations.

■ Currently, testing is being conducted to verify the results obtained through the quality engineering method.

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