CASE 28

Development of Friction Material for Automatic Transmissions

Abstract: In the conventional development process, friction material development has been made in conjunction with the development of automatic transmissions so that the performance of friction material may meet the requirements for ease of use. In this research, besides developing an automatic transmission, we attempted to develop a friction material that has high functionality.

1. Introduction

Figure 1 illustrates the structure of an automatic transmission. At the portions that are circled, friction materials are required for smooth clutching and releasing actions to meet targeted performance goals such as reduction of shift shock or vibration and improvement in fuel efficiency.

2. Generic Function

Traditionally, we have evaluated friction materials by using primarily the μ–V characteristic (representing the coefficient of dynamic friction corresponding to a relative rotating speed between a friction material and its contact surface; Figure 2). The μ–V characteristic need not have a negative slope to prevent shift shock or vibration. However, it tends to become negative. Thus, through many repeated experiments, engineers have made final decisions by looking at μ–V characteristics.

Fundamentally, the friction force follows Coulomb's law, expressed by $F = \mu W$, where F is the friction force, W the vertical load, and μ the friction coefficient. Taking into consideration the fact that a friction material inside an automatic transmission is used in a rotational direction, a commonly used experimental device (Figure 3) was utilized for our study. As a generic function, we defined the proportionality of $y = \beta M$ by setting surface pressure to an input signal, M (equal to load during experiments), and torque to an output, y.

For signal factor levels, we determined them by considering loads applied to friction materials used at various parts of an automatic transmission. The rotating speed is required to evaluate the slopes of μ–V characteristics, which we desire to be flat. However, because of external factors such as complicated part structure in an automatic transmission, the slopes are expected to be slightly positive. So we assigned the rotating speed, M^*, to the outer array to assess the slope of the μ–V characteristic. As noise factors, we picked up some factors from what most affect the μ–V characteristic (Table 1). Knowing from our experience that the characteristic does not change uniformly until it arrives at the deteriorating phase, we took up fit-in conditions to stabilize the characteristic from the initial phase up to the actual use. As for setting of deteriorating conditions, we selected load, which needs a short time for evaluation from the preliminary experimental phase.

3. SN Ratio

Based on the format shown in Table 2, we obtained measurement data. To add the slope of μ–V char-

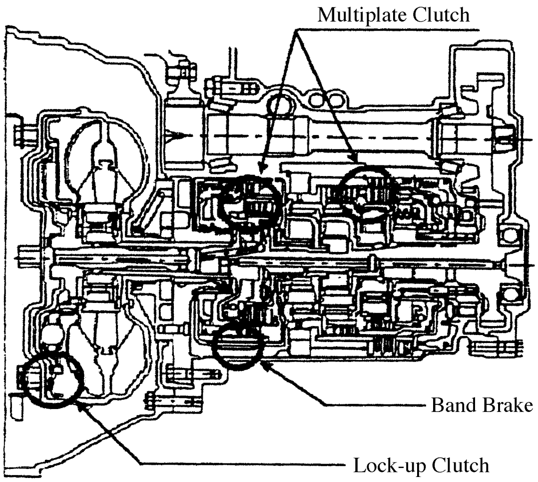

Figure 1
Structure of automatic transmission (sectional view)

acteristics to our evaluation, we prepared the summary table of linear equations illustrated in Table 3 and proceeded with our analysis based on the next procedure. Figure 4 indicates measured data under a certain noise condition. With respect to β, we can replot these data in Figure 5 by setting the rotating speed velocity, M^*, to the horizontal axis. Next we defined the slope in Figure 5 as β^*. That β^* becomes positive is equivalent to a positive slope of a μ–V characteristic. S_{β^*} corresponds to the variation in the first-order element among the variations $S_{M^*\beta}$ due to the relative rotating speed M^*. Orthogonal polynomial equations are used to decompose these data.

Total variation:

$$S_T = y_{111}^2 + y_{112}^2 + \cdots + y_{135}^2 + \cdots + y_{611}^2 + \cdots + y_{635}^2$$

$$= 1032.4750 \qquad (f = 90) \tag{1}$$

Effective divider:

$$r = M_1^2 + M_2^2 + M_3^2 = 3.50 \tag{2}$$

Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_2 + L_3 + L_4 + L_5 + L_6)^2}{(6)5r}$$

$$= 1029.1453 \ (f = 1) \tag{3}$$

Variation of differences of proportional terms due to rotating speed:

$$S_{M^*\beta} = \frac{K_1^2 + K_2^2 + \cdots + K_5^2}{6r} - S_\beta$$

$$= 0.0319 \qquad (f = 4) \tag{4}$$

Variation of proportional term due to rotating speed:

$$S_{\beta^*} = \frac{(W_1K_1 + W_2K_2 + \cdots + W_5K_5)^2}{J(6r)}$$

$$= 0.0030 \qquad (f = 1) \tag{5}$$

where W_i is the coefficient for an orthogonal polynomial equation. $W_i = X_i - \overline{X}$ and $J = \Sigma\, w_i^2$.

Variation of differences of residual terms:

$$S_{\text{res}\times\beta} = S_{M^*\beta} - S_{\beta^*} = 0.0290 \qquad (f = 3) \tag{6}$$

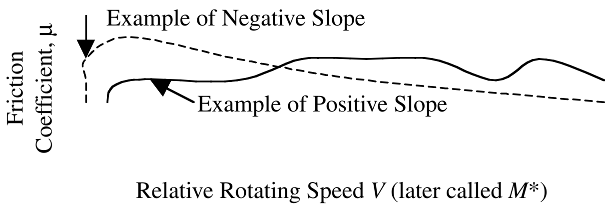

Figure 2
Typical μ–V characteristic

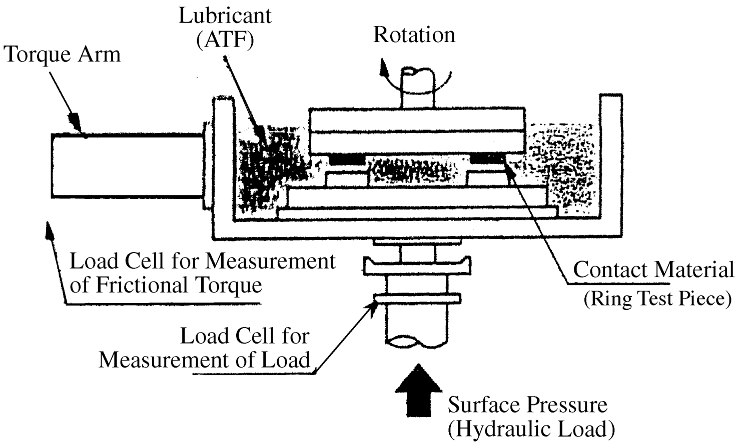

Figure 3
Experimental device

Error variation:

$$S_e = S_T - S_\beta - S_{M^*\beta} = 3.2977 \qquad (f = 85) \tag{7}$$

Error variance:

$$V_e = \frac{S_e}{85} = 0.0388 \tag{8}$$

Total error variance:

$$V_N = \frac{0.0290 + 3.2977}{88} = 0.0378 \tag{9}$$

SN ratio:

$$\eta = 10 \log \frac{(1/30r)(S_\beta - V_e)}{V_N} = 24.14 \text{ dB} \tag{10}$$

Sensitivity:

$$S = 10 \log \frac{1}{30r}(S_\beta - V_e) = 9.91 \text{ dB} \tag{11}$$

Slope:

$$\beta^* = \frac{W_1K_1 + W_2K_2 + \cdots + W_5K_5}{J \times 6 \times r} = 0.00004 \tag{12}$$

Table 1
Signal and noise factors

Factor	Level				
Signal factors					
Main signal	Low	Mid	High		
M: surface pressure					
Subsignal					
*M**: relative rotating speed	M_1^*	M_2^*	M_3^*	M_4^*	M_5^*
Noise factors					
O: ATF oil temperature	Low	High	—	—	—
P: fit-in, deterioration			After Degradation	—	—
	Initial	Fit-in			

Table 2
Examples of torque data

Noise Condition (Oil Temperature)			**Signal Factor (Surface Pressure)**									
			$\boldsymbol{M_1}$					$\boldsymbol{M_2}$ Relative Rotating Speed (rpm)		⋯		$\boldsymbol{M_3}$
			$\boldsymbol{M_1^*}$	$\boldsymbol{M_2^*}$	$\boldsymbol{M_3^*}$	$\boldsymbol{M_4^*}$	$\boldsymbol{M_5^*}$	$\boldsymbol{M_1^*}$	$\boldsymbol{M_2^*}$	⋯	$\boldsymbol{M_4}$	$\boldsymbol{M_5^*}$
Low	Initial	N_1	y_{111}	y_{112}	y_{113}	y_{114}	y_{115}	y_{121}	y_{122}	⋯	y_{134}	y_{135}
	Fit-in	N_2										
	Deterioration	N_3										
High	Initial	N_4										
	Fit-in	N_5							y_{622}			
	Deterioration	N_6	y_{611}	y_{612}	y_{613}	y_{614}	y_{615}	y_{621}	y_{634}	⋯	y_{635}	

Table 3
Summary of linear equations

	Linear Equation for Each Rotating Speed					Linear Equation for Each Error Condition	
	M_1^*	M_2^*	M_3^*	M_4^*	M_5^*		
N_1	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}	55.0480	L_1
N_2	L_{21}	L_{22}	L_{23}	L_{24}	L_{25}	56.8663	L_2
N_3	L_{31}	L_{32}	L_{33}	L_{34}	L_{35}	57.6040	L_3
N_4	L_{41}	L_{42}	L_{43}	L_{44}	L_{45}	51.7542	L_4
N_5	L_{51}	L_{52}	L_{53}	L_{54}	L_{55}	52.3932	L_5
N_6	L_{61}	L_{62}	L_{63}	L_{64}	L_{65}	55.0596	L_6
	K_1	K_2	K_3	K_4	K_5		
Subtotal	65.6614	66.4108	65.6962	65.6730	65.2838		

4. Results of Analysis

Figure 6 summarizes the response graphs of the analysis of results obtained by the aforementioned analysis procedure.

5. Optimal Configuration and Results of Confirmatory Experiment

To determine the optimal configuration, we performed the parameter design after selecting the control factors enumerated in Table 4. In selecting each level for the optimal configuration, we took into account the slope β* and cost issue as well as SN ratios. Table 5 shows the estimations and confirmatory experimental results. We can see that both the SN ratio and sensitivity have a high reproducibility, and the SN ratio, particularly, is improved by 3.65 dB. Now the sensitivity level was regarded as sufficient for the automatic transmission system. Although we believed that the slope β* was good enough because it was approximately equivalent to that under the initial configuration, a better result was obtained. In addition, a confirmatory experiment was conducted using the oil of the initial development stage. We can see that an approximate 4.5 dB improvement in the SN ratio and a flat characteristic of β* were realized. We confirmed that by selecting the optimal specifications, we could obtain a better tendency even if the property of the oil is

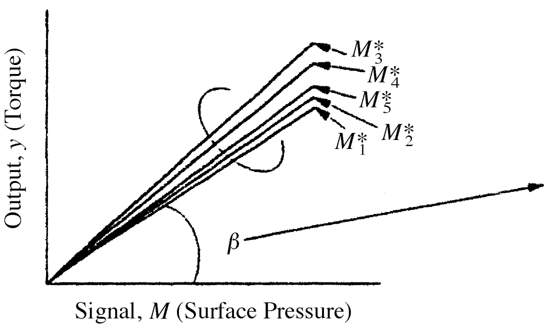

Figure 4
Typical measured data

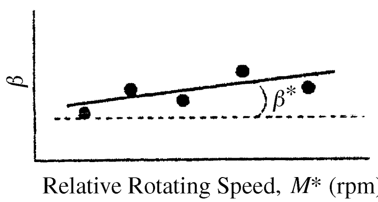

Figure 5
Relationship between relative rotating speed and β*

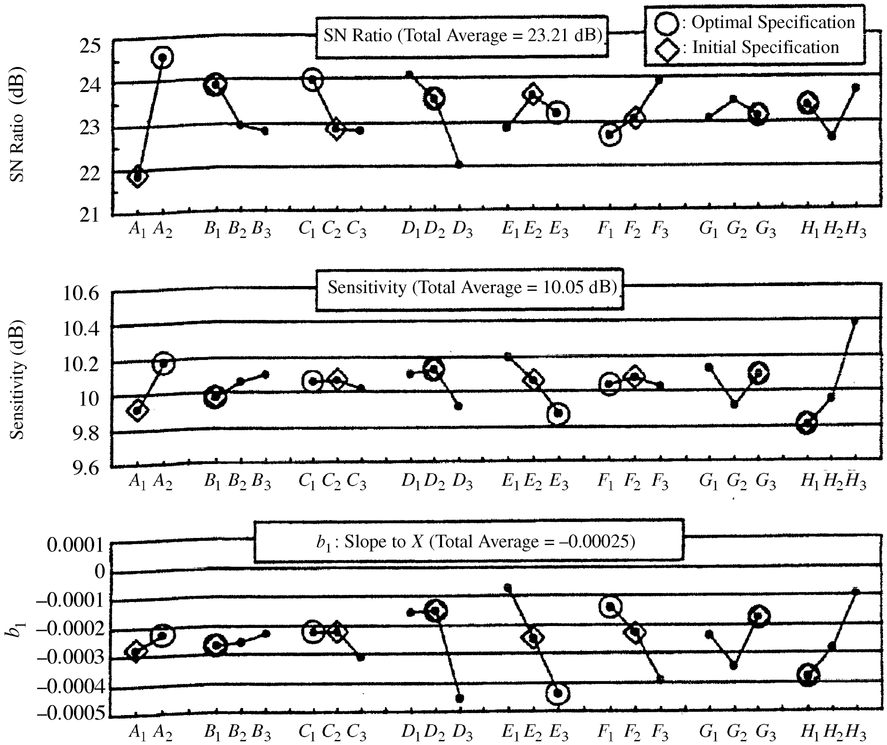

Figure 6
Response graphs

Table 4
Control factors and levels

Control Factor		Level 1	2	3
A:	fiber diameter	Small	Large	—
B:	ratio of abrasion material to adjustment material	Small	Mid	Large
C:	amount of fiber	Small	Mid	Large
D:	fiber ratio	Small	Mid	Large
E:	amount of resin	Small	Mid	Large
F:	compression rate	Small	Mid	Large
G:	plate thickness	Small	Mid	Large
H:	surface treatment	None	1	2

Table 5
Results of confirmatory experiment

Configuration	SN Ratio, η (dB)		Sensitivitiy, S (dB)		Slope, β^*	
	Estimation	Confirmation	Estimation	Confirmation	Estimation	Confirmation
Optimal	25.80	27.29	9.82	9.74	−0.00024	−0.00017
Initial	22.72	23.64	9.79	9.65	−0.00018	−0.00026
Gain	3.08	3.65	0.03	0.09	−0.00006	0.00009

different. More important results from oil development are expected.

Reference

Makoto Maeda, Nobutaka Chiba, Tomoyuki Daikuhara, and Tetsuya Ishitani, 2000. Development of wet friction: material for automatic transmission. *Quality Engineering*, Vol. 8, No. 4, pp. 39–46.

This case study is contributed by Makoto Maeda, Nobutaka Chiba, Tomoyuki Daikuhara, and Tetsuya Ishitani.