CASE 50

Optimization of Disk Blade Mobile Cutters

Abstract: In this study we attempted initially to consider the function as input/output of energy, as we studied in machining. However, we could not grasp the difference in a motor's power consumption when a cutter is moved without and with cutting. Then we conducted an experiment using cutting resistance as output. As a consequence, we succeeded in optimizing each parameter in the cutter.

1. Introduction

Figure 1 shows the structure of a disk blade mobile cutter. We move a carriage with a disk blade along a fixed blade with an edge on one side by using a motor and cut a label placed on the fixed blade. The carriage has a shaft for rotating the disk blade and compressed spring to press the disk blade onto the fixed blade.

A good label cutter is considered a cutter that can cut a label with less energy regardless of width or material the label is made from. Therefore, the generic function of label cutting is defined as proportionality between cutting resistance of a cutter and width of a cutout label with a cutting range in accordance with the edge's movement. In other words, if cutting length and resistance are set to an input signal, M, and output, y, respectively, the equation of $y = \beta M$ holds true. In addition, sensitivity, β, should be smaller.

For measurement of cutting resistance, load imposed on the carriage from start to end of cutting is measured in the cutting direction (X-direction in Figure 1) and the direction perpendicular to it (Y-direction in Figure 1). As shown in Figure 2, the cutting resistance when the carriage cuts a label is calculated by subtracting the load with no label from the total load and integrating it within the range of a label width. Then, by measuring both cutting resistances X and Y in the cutting and perpendicular directions, respectively, and calculating the following value,

$$y = \sqrt{X^2 + Y^2} \qquad (1)$$

we define y.

As noise factors, we chose edge deterioration, N, and carriage moving direction, N'. For the former, we deteriorated the edge at an increasing speed by cutting a polish tape with it. Additionally, as an indicative factor, we selected P_1 for difficult-to-cut paper due to its thickness and P_2 for difficult-to-cut cloth due to its softness.

2. SN Ratio

Table 1 shows the data of cutting resistance for row 1 in the L_{18} orthogonal array. The following is a calculation method for the SN ratio and sensitivity.

Total variation:

$$S_T = 7.71^2 + 9.47^2 + \cdots + 24.44^2$$
$$= 3274.8 \qquad (f = 12) \qquad (2)$$

Effective divider:

$$r = 30^2 + 67^2 + 100^2 = 15{,}389 \qquad (3)$$

Linear equation:

Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

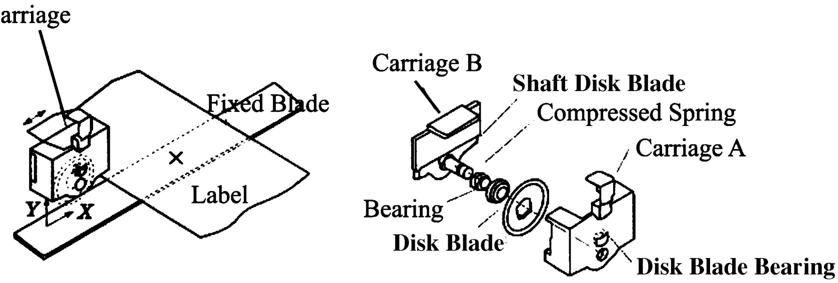

Figure 1
Structure of a disk blade mobile cutter

$$
\begin{aligned}
L_1 &= (7.71)(30) + (15.21) + (67)(21.69)(100) \\
&= 3419.95 \\
L_2 &= 3422.28 \\
L_3 &= 3583.16 \\
L_4 &= 3732.99
\end{aligned} \tag{4}
$$

Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_2 + L_3 + L_4)^2}{4r} = 3256.55 \qquad (f = 1) \tag{5}$$

Variation of differences of proportional terms $S_{N\beta}$ for edge deterioration:

$$
\begin{aligned}
S_{N\beta} &= \frac{(L_1 + L_2)^2 + (L_3 + L_4)^2}{2r} - S_\beta \\
&= 3.65 \qquad (f = 1)
\end{aligned} \tag{6}
$$

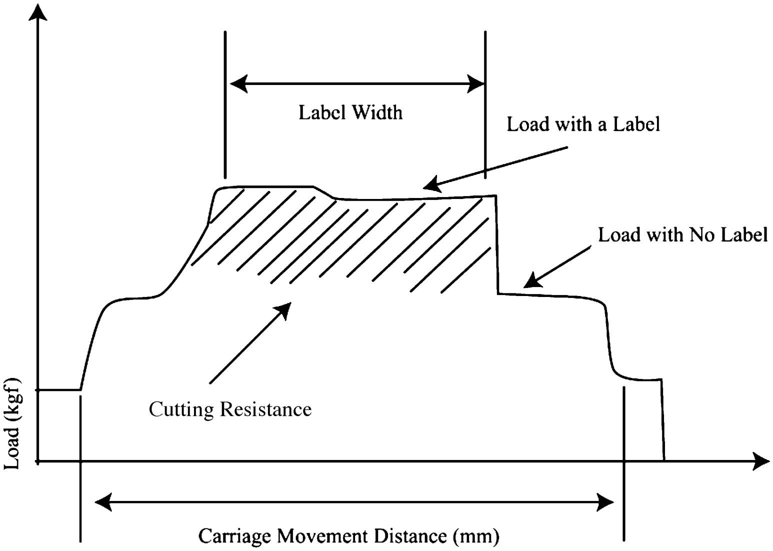

Figure 2
Cutting resistance generated during carriage movement

Table 1
Cutting resistance data for row 1 in L_{18} orthogonal array[a]

			M_1 30 mm	M_2 67 mm	M_3 100 mm	Linear Equation
P_1	N_1	N'_1	7.71	15.21	21.69	L_1
		N'_2	9.47	14.52	21.65	L_2
	N_2	N'_1	8.10	15.28	23.16	L_3
		N'_2	8.67	15.35	24.44	L_4
P_2	N_1	N'_1	1.01	1.31	1.88	L_5
		N'_2	2.11	1.44	1.31	L_6
	N_2	N'_1	11.69	18.10	25.83	L_7
		N'_2	12.96	19.52	29.64	L_8

[a] M, signal factor; N, edge deterioration; N', carriage movement direction; P_1, thick paper; P_2, cloth.

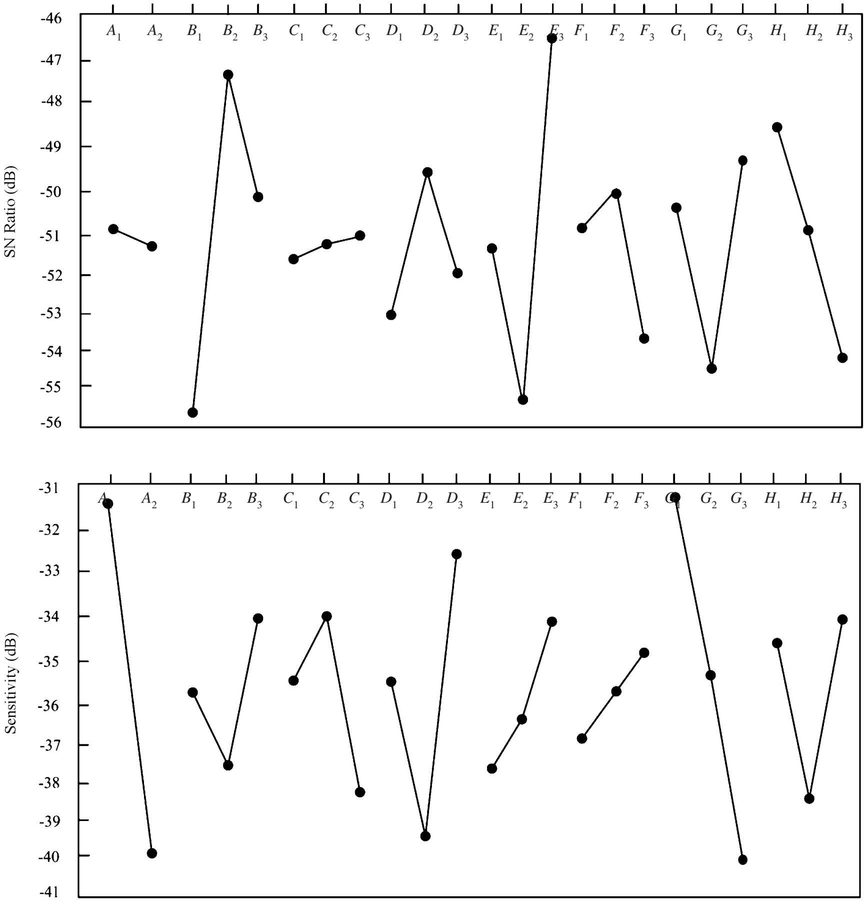

Figure 3
Response graphs

Table 2
Control factors and levels (dB)

Control Factor	Level 1	2	3
A: pressing position on carriage	A_1[a]	A_2	—
B: rake angle of disk blade	Small[a]	Mid	Large
C: edge width of disk blade	Large[a]	Mid	Small
D: material of disk blalde	D_1[a]	D_2	D_3
E: rake angle of fixed blade	E_1[a]	E_2	E_3
F: material of fixed blade	Low	Same as current[a]	High
G: pressing force	Small[a]	Mid	Large
H: bearing position on carriage	H_1[a]	H_2	H_3

[a] Current condition.

Table 3
Confirmatory experimental results (dB)

	SN Ratio		Sensitivity	
Condition	Estimation	Confirmation	Estimation	Confirmation
Optimal	−45.26	−37.94	−47.89	−48.60
Current	−54.06	−52.86	−26.80	−31.67
Gain	8.80	14.92	−21.09	−16.93

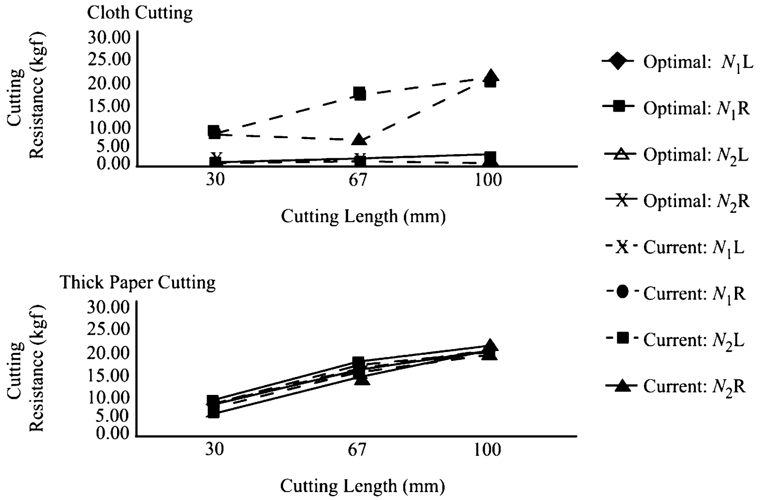

Figure 4
Measured data in confirmatory experiment

Table 4
Confirmatory experimental results

	Number of Cutting Polish Tape until Cutter Becomes Unable to Cut Standard Cloth					
Condition	**0**	**50**	**100**	**150**	**200**	**250**
Current	⟶					
Optimal	—	—	—	—	—	⟶

Variation of differences of proportional terms $S_{N\beta}$ for carriage movement direction:

$$S_{N'\beta} = \frac{(L_1 + L_3)^2 + (L_2 + L_4)^2}{2r} - S_\beta$$

$$= 0.38 \qquad (f = 1) \tag{7}$$

Error variation:

$$S_e = S_T - S_\beta - S_{N\beta} - S_{N'\beta} = 14.30 \qquad (f = 9) \tag{8}$$

Error variance:

$$V_e = \frac{S_e}{9} = 1.59 \tag{9}$$

Total error variance:

$$V_N = \frac{S_{N\beta} + S_{N'\beta} + S_e}{11} = 1.67 \tag{10}$$

Table 5
Evaluation of cutting performance

	Current Condition		Optimal Condition	
Material	N_1	N_2	N_1	N_2
Thick paper	○	○	○	○
Standard cloth	○	×	○	○
Soft cloth	×	—	○	×
Extremely soft film	×	—	○	×

[a] ○, can be cut; ×, cannot be cut.

SN ratio:

$$\eta = 10 \log \frac{(1/4r)(S_\beta - V_e)}{V_N} = -14.98 \text{ dB} \tag{11}$$

Sensitivity:

$$S = 10 \log \frac{1}{4r}(S_\beta - V_e) = -12.77 \text{ dB} \tag{12}$$

3. Optimal Condition and Confirmatory Experimental Results

Figure 3 illustrates the response graphs of the SN ratio and sensitivity. As shown in Table 2, we chose control factors supposed to contribute much to cutting. By calculating the SN ratio and sensitivity for thick paper and cloth as an indicative factor and considering all aspects of SN ratios, sensitivities, cost, and ease of application to real products, we chose $A_2B_2C_3D_2E_1F_1G_3H_2$ as the optimal condition. After implementing a confirmatory experiment under optimal and current conditions, we obtained the results shown in Table 3, which reveals an insufficient reproducibility for gain.

Figure 4 shows the data for cutting resistance when cloth and thick paper are cut under the current and optimal conditions in the confirmatory experiment. As compared to the current condition, both the variability and magnitude of cutting resistance are reduced. In addition, Tables 4 and 5 demonstrate the robustness in basic cutting performances.

Figure 4 shows the comparison of durability for cutting a standard cloth under the current and optimal conditions. To evaluate edge deterioration, we attempted to cut standard cloth after cutting a polish tape a certain number of times. As a result, under current conditions, the cutter became unable to cut the standard cloth after cutting the polish tape approximately 25 times, whereas the number was 250 under the optimal condition. On the other hand, Table 5 highlights that extremely soft cloth and film, both of which cannot be cut under the current condition, can be cut under the optimal condition, N_1 (initial condition).

These results prove that we can improve a cutter's durability, achieve a wider range of objectives to be cut, and increase versatility of a cutter under the optimal condition.

In this study we attempted initially to consider the function as input/output of energy, as we studied in machining. However, we could not grasp the difference in a motor's power consumption when a cutter is moved without and with cutting. Then we gave up an experiment based on input/output of energy and conducted an experiment using cutting resistance as output. As a consequence, we succeeded in optimizing each parameter in the cutter.

Reference

Genji Oshino, Isamu Suzuki, Motohisa Ono, and Hideyuki Morita, 2001. Robustness of circle-blade cutter. *Quality Engineering*, Vol. 9, No. 1, pp. 37–44.

This case study is contributed by Genji Oshino.