CASE 51

D-VHS Tape Travel Stability

Abstract: In the case where a capstan and head cylinder rotate and a tape travels in an ideal manner under a proper condition, the output waveform of a D-VHS tape is determined theoretically. Thus, we supposed that we could evaluate the travel stability of a tape by assessing this difference between ideal and actual waveforms. First focusing on time assigned to the horizontal axis of the output waveform plot, we considered the relationship between the time the output reaches the peak point and the ideal time to reach as the generic function.

1. Introduction

What controls travel of a VTR tape is a pinch roller and capstan (Figure 1). Therefore, the generic function is regarded as travel distance of a tape for the number of revolutions of a capstan (Figure 2). However, since the travel stability of the tape used for this study is a few dozens of micrometers and too small compared to the travel distance, we cannot evaluate it. By focusing on a shorter time interval, we considered some generic functions that can be used to evaluate stability at a minute level of a few dozen micrometers. Finally, we selected output waveform during tape playing.

Figure 3 shows the relationship between a signal track and head when a tape travels, and Figure 4 represents the output waveform. If a head traces a record track, output proportional to an area traced is produced.

When a capstan and head cylinder rotate and a tape travels in an ideal manner under proper conditions, the output waveform is determined theoretically. Thus, we supposed that we could evaluate the travel stability of a tape by assessing this difference between ideal and actual waveforms.

First focusing on time assigned to the horizontal axis of the output waveform plot, we considered the relationship between the time the output reaches the peak point and the ideal time to reach as the generic function. While the VTR head traverses the tape one time, the output waveform has six peaks. By selecting 10 out of 12 peak points (maximum, minimum), we set them to signal factors. As control factors, eight items enumerated in Table 1 were chosen. As noise factors, we selected the following three:

1. *Start and end of tape winding*. Any type of tape should travel in a stable manner. In this study the force applied to a tape at the start and at the end of tape winding was considered as a noise factor.
2. *Head*. Since a VTR has two heads, P_1 and P_2, their phases are shifted. Because travel of a tape should be stabilized for both heads, we chose head as a noise.
3. *Positions of head cylinder and tape*. Since a head traces a tape in a moment (1/30 s), we cannot evaluate VTR's travel stability for this short time interval. Therefore, we assessed it while a tape travels more than half circumference of a head cylinder (while it traces 100 times).

2. SN Ratio

We show the data for experiment 4 as an example in Table 2.

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

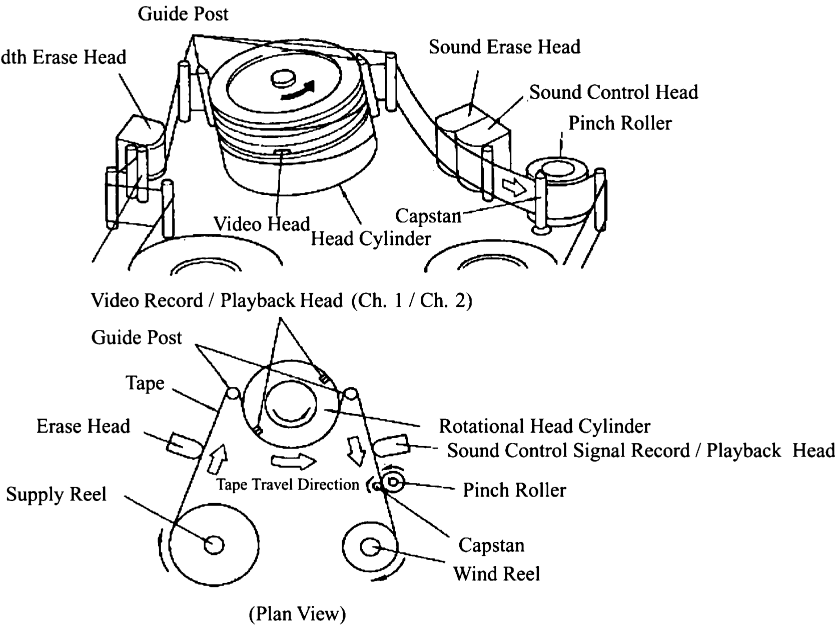

Figure 1
VTR mechanism

Total variation:

$$S_T = 25^2 + \cdots + 308^2 + \cdots + 320^2$$

$$= 153{,}751{,}460 \qquad (f = 4000) \qquad (1)$$

Linear equation:

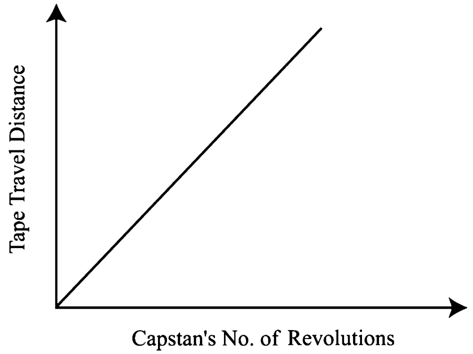

Figure 2
Generic function

$$L_1 = (32.1)(25) + \cdots + (320.5)(308)$$

$$= 377{,}307.7 \qquad (2)$$

Similar calculations are continued up to L_{400}.

Effective divider:

$$r = 32.1^2 + \cdots + 320.5^2 = 395504.6 \qquad (3)$$

Variation of proportional terms:

$$S_\beta = \frac{1}{400r}(L_1 + \cdots + L_{400})^2$$

$$= 153{,}671{,}134.7 \qquad (f = 1) \qquad (4)$$

$$S_{O\beta} = \frac{(L + \cdots + L_{200})^2 + (L_{201} + L_{400})^2}{200r} - S_\beta$$

$$= 19{,}468 \qquad (5)$$

$$S_{P\beta} = \frac{(L_1 + \cdots + L_{100} + L_{201} + \cdots + L_{300})^2 + (L_{101} + \cdots + L_{200} + L_{301} + \cdots + L_{400})^2}{200r}$$

$$= 1964 \qquad (f = 1) \qquad (6)$$

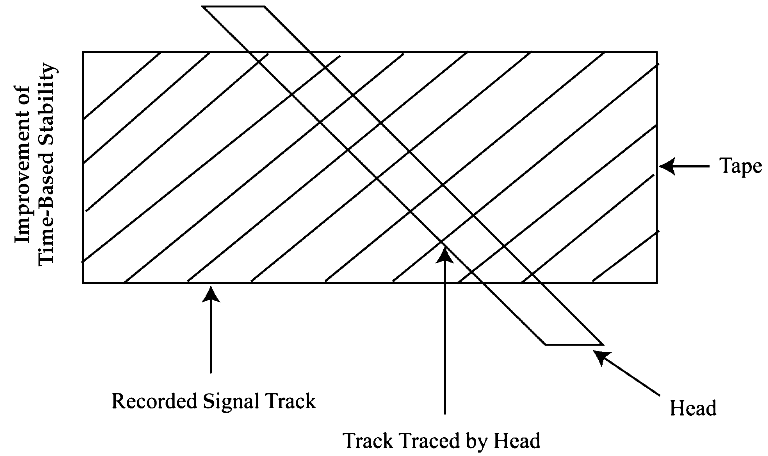

Figure 3
Relationship between signal track and head

$$S_{Q\beta} = \frac{(L_1 + \cdots + L_{301})^2 + (L_2 + L_{302})^2 + \cdots}{4r} - S_\beta$$

$$= 5584 \qquad (f = 99) \tag{7}$$

$$S_e = S_T - S_\beta - S_{O\beta} - S_{P\beta} - S_{Q\beta}$$

$$= 53{,}309 \qquad (f = 3898) \tag{8}$$

Error variance:

$$V_e = \frac{S_e}{3898} = 13.676 \tag{9}$$

Magnitude of noise:

$$V_N = \frac{S_{O\beta} + S_{P\beta} + S_{Q\beta} + S_e}{3999} = 20.086 \tag{10}$$

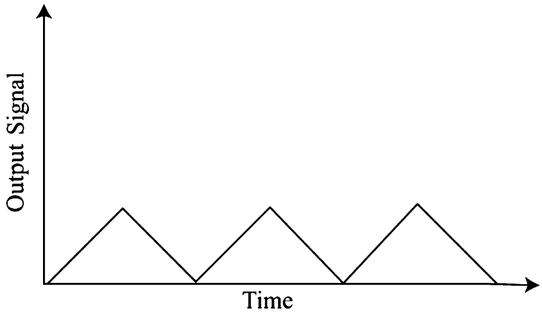

Figure 4
Output waveform during tape traveling

SN ratio:

$$\eta = 10 \log \frac{(1/400r)(S_\beta - V_e)}{V_N} = -13.16 \text{ dB} \tag{11}$$

Sensitivity:

$$S = 10 \log \frac{S_\beta - V_e}{400r} = -0.126 \text{ dB} \tag{12}$$

3. Optimal Condition and Confirmatory Experiment

In the experiment, tapes had been damaged under 10 conditions. Since we could not analyze the conditions where a tape becomes damaged, from the SN ratio and sensitivity of the remaining eight conditions, we estimated optimal levels using the sequential approximation method. Table 3 shows the experimental results. From the results shown in the table we selected $A_2B_3C_1D_1E_3F_2G_2H_2$ as the optimal condition by taking into account the number of NGs.

Using the result calculated through sequential approximation of the data that were obtained even when a tape was damaged, we also estimated the

Table 1
Control factors and levels

Control Factor	Level 1	Level 2	Level 3
A: stick-out length of head	Low	Current	—
B: height A of tape guide	Low	Current	High
C: height B of tape guide	Low	Current	High
D: height C of tape guide	Low	Current	High
E: reel clutch torque	Small	Current	Large
F: angle D of tape guide	Small	Current	Large
G: angle E of tape guide	Small	Current	Large
H: angle F of tape guide	Small	Current	Large

optimal condition (for experiments 1 and 8, we obtained no data because of the serious damage of a tape). This estimation showed the same results as the case using no-damage data only.

To confirm the effect under the optimal condition, we conducted a confirmatory experiment. The result is shown in Table 4 (for sensitivity, we do not use the data as judging criteria because there is no significant difference around 0 dB). From this we noticed that poor reproducibility was obtained with a small gain.

4. Reproducibility

Control factor D, which is likely to have an interaction, has to be determined by the level of control

Table 2
Raw data for experiment 4 of the L_{18} orthogonal array (bits[a])

Error Factor			Measurement			
Tape O	Head P	Position Q	M_1 32.1	···	M_{10} 320.5	Linear Equation
Start	P_1	1	25		308	L_1
		···	···	···	···	···
		100	28		313	L_{100}
	P_2	1	29		316	L_{101}
		···	···	···	···	···
		100	26		313	L_{200}
End	P_1	1	32		317	L_{201}
		···	···	···	···	···
		100	32		323	L_{300}
	P_2	1	28		315	L_{301}
		···	···	···	···	···
		100	32		320	L_{400}

[a] 1 bit = 4×10^{-5} s.

Table 3
SN ratio of control factor levels for tape traveling and "damage" data[a]

	Level					
Control Factor	**1**	**NG**	**2**	**NG**	**3**	**NG**
A	−13.04	6	**−13.60**	4	—	—
B	−13.87	4	−14.05	4	**−12.96**	2
C	**−13.46**	1	−13.70	4	−12.98	5
D	**−13.38**	2	−13.94	4	−13.15	4
E	−13.75	4	−13.15	4	**−13.47**	2
F	−13.88	4	**−13.09**	3	−13.55	3
G	−13.06	4	**−12.96**	3	−14.23	3
H	−13.15	5	**−13.95**	2	−12.96	3

[a] NG, not good. Boldface represents optimum conditions selected.

factor *C*. Next, selecting factors *B* and *E*, considered to contribute much to gain among the remaining control factors, we reset the levels. We did not select other control factors because their optimal levels were identical to the ones under the current condition. In contrast, control factor *I*, which was not chosen in the previous experiment, was added.

Because of four factors to be investigated, we used an L_9 orthogonal array for the reexperiment. Table 5 illustrates control factors for the experiment. Based on the reexperimental result, we plotted the factor effects in Figure 5. This plot implies that the optimal condition was estimated to be $B_2C_3E_3I_2$. Table 6 shows the results of the confirmatory experiment. Although there might exist some problems because the graph has many V-shapes and peaks, we obtained relatively good reproducibility.

As a reference, we calculated the eventual economic effect. The loss is expressed by $L = (A/\Delta^2)\sigma^2$. Now A is the loss when the travel exceeds a tolerance, Δ the tolerance, and σ the variance. As an example, we supposed that when the travel exceeds 30 μm, the VTR cannot display any picture. As a result, the customer has A = 10,000 yen of repair cost.

Taking into account the fact that the difference of the travel between under the current and optimal conditions is approximately 2.4 μm, we obtained the following economic effect per unit:

$$L_{\text{current}} - L_{\text{opt}} = \frac{A}{\Delta^2}(\sigma^2_{\text{current}} - \sigma^2_{\text{opt}})$$

$$= \frac{10{,}000}{30^2}(2.4^2) = 64 \text{ yen} \qquad (13)$$

Table 4
Confirmatory experimental results for the L_{18} orthogonal array

	SN Ratio	
Configuration	**Estimation**	**Confirmation**
Optimal: $A_2B_3C_1D_1E_3F_2G_2H_2$	−6.52	−11.06
Current: $A_2B_2C_2D_2E_2F_2G_2H_2$	−12.50	−12.41
Gain	5.98	1.35

Table 5
Control factors for the L_9 orthogonal array (reexperiment)

	Level		
Control Factor	**1**	**2**	**3**
B: height A of table guide	Current	—	+
C: height B of table guide	—	Current	+
E: reel clutch torque	—	Current	+
I: tension A	—	Current	+

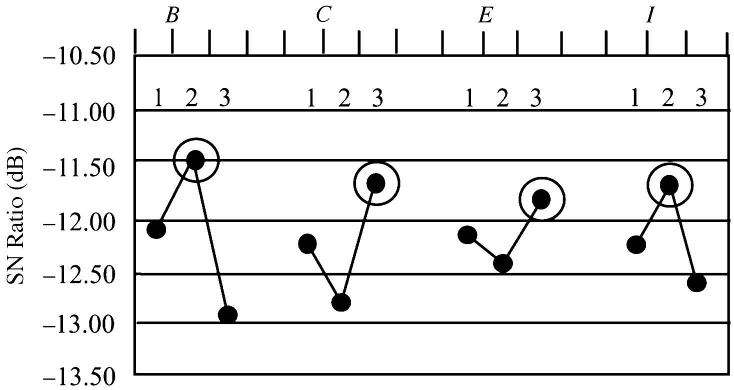

Figure 5
Response graphs of the SN ratio for the L_9 orthogonal array

Table 6
Confirmatory experimental result for the L_9 orthogonal array (economic effect) (dB)

	SN		Sensitivity	
Condition	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	−10.17	−10.38	−0.22	−0.01
Current	−12.17	−12.41	−0.06	−0.06
Gain	2.00	2.03	−0.16	−0.05

Since the annual production volume of D-VHS is about 100,000, the total annual economic effect amounts to 6.4 million yen. Moreover, if this result is applied to all VTRs, we expect a larger-scale economic effect because the total annual production volume is over 4 million.

Reference

Hideaki Sawada and Yoshiyuki Togo, 2001. An investigation on the stability of tape run for D-VHS. *Quality Engineering*, Vol. 9, No. 2, pp. 63–70.

This case study is contributed by Hideaki Sawada and Yoshiyuki Togo.