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The Effect of System Variables on the Ride Quality of a Fulll Tractor and Trailer

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Abstract

This paper presents the use of Taguchi method in studying the effects of the system variables, such as the spring constants and damping coefficients of suspensions and tires, on the ride quality of the full tractor and trailer. The ride quality parameters are defined as the vertical acceleration of the driver seat, road holding, dynamic tire force, suspension travel, and the tractor and trailer body acceleration. The dynamic model of the full tractor and trailer (Hu, 1996) is first briefly reviewed. The Taguchi method is then introduced and applied to study the effect of the system variables on the ride quality parameters. Results show that the soft suspension with low damping is expected for better ride quality, except that the higher damping is desired for suspension travels. The soft tire with low damping is generally preffered; however, the road holding may be worst. Based on the analysis of the Taguchi method, the optimum level of factors (system variables) can also be determined and shown to be effective for the improvement of ride quality. This work provides the guidelines on the selection of system variables based on the different ride quality criteria. A compromise design between the constants and damping coefficients of the suspensions and the tires should be further investgated in the future.

Keywords: full tractor and trailer, ride quality, Taguchi method, suspension, tire.

I. Introduction

Full tractor and trailers are frequently used in modern transportation. The ride quality, including the ride comfort of the driver, performance of suspension and tire elements as well as cargo response, are of great concerns. The vibration level of the vehicle is one of the major factors and widely discussed. Many researches have been devoted to the dynamic analysis of vehicles (Hu, 1996; Rakheja, Afonso and Sankar, 1992; El-Gindy, 1992).

The ride comfort index K-value (Cucuz, 1994) has been developed to quantity the subjective magnitude of vibration forms. The ISO vibration tolerance criteria (ISO 2631, 1978) is one of the frequently used assessing methods, by comparing the PSD over the frequency range. The root mean square (rms) value (Wambold, 1986) or the peak value of acceleration (Dahlberg, 1980) can also be used to evaluate the ride quality of vehicles. The jerk, the derivative of the acceleration, is also specified as the ride quality criteria (Hrovat and Hubbard, 1981; Janeway, 1975). Lee and Pradoko (1968) defined the absorbed power, which is a measurement of the average energy rate dissipated by complex damping elastic properties of the human anatomy, as the ride quality criteria.

Although active suspension systems are gradually adopted for modern vehicles (Thompson and Davice, 1992), passive suspension systems still dominate the market for most of commercial vehicles. The optimum design of suspension is of great concern. Rakheja and Sanker (1985) using parameter optimization technique for suspension design to improve the tractor ride quality. Sharp and Hassan (1986) concluded that if the variable stiffness and damping suspension can be employed, the ride quality performance can be improved. Elmadany (1987) performed covariance analysis to get the optimum damping coefficient of suspension for minimization of the vertical acceleration at the driver position. Fukushima et.al. (1983) determined the optimum characteristics of the shock absorbers for vehicles riding on the different road surfaces, considering the conditions of handling, accelerating and decelerating. Recently, Taguchi methods have been adopted and shown an effective meeans to study the truck ride comfort (Dohi and Maruyama, 1990) and vehicle handling stability (Lee, Dzuiba and Lu, 1996; Liu and Hsiao, 1991).

This paper applies the Taguchi method to the study of the effect of system variables on the ride quality of the full tractor and trailer. The 9 DOF ride model of a full tractor and trailer is first briefly reviewed (Hu, 1996). The objective functions are defined as the standard deviations of ride quality parameters, including the vertical acceleration of driver seat, the road holding of the first axle, the dynamic tire force of the first axle, the suspension travel of the first axle and the verticle acceleration. The analysis of mean (ANOM) and the analysis of variance (ANOVA) are performed. The optimum level of design variables can then be obtained and shown the improvement on the ride quality parameters.

II. Riding Characteristics of Full Tractor and Trailer

A. Full Tractor and Trailer Ride Model

The 9 DOF full tractor and trailer riding model is shown in Fig. 1, z_1, z_2, z_3, z_4 are the response coordinates of unspruhg masses m_1, m_2, m_3, m_4, respectively; z_5 and θ_1 are the vertical and pitch response coordinates of the tractor; θ_2 and θ_3 are the pitch response of drawbar and trailer respectively (Hu, 1996).

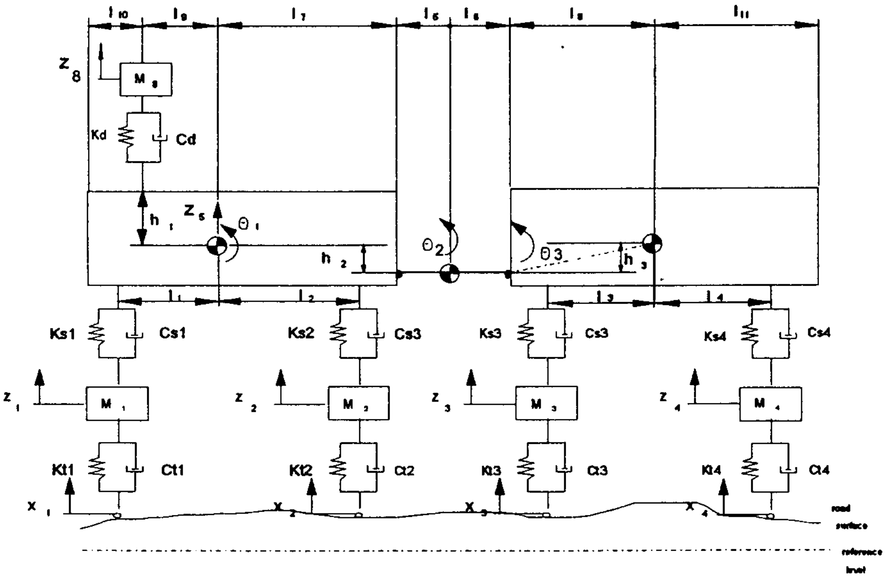

Fig.1 The 9 DOFs model of full tractor/trailer

The equation of motion of the tractor/trailer can be derived as :

$$[M]\{\ddot{y}\} + [C]\{\dot{y}\} + [K]\{y\} = [C']\{\dot{x}\} + [K']\{x\} \tag{1}$$

where

$$\{y\}^T = \{z_1, z_2, z_3, z_4, z_5, z_8, \theta_1, \theta_2, \theta_3\} \tag{2}$$

$$=\{y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8, y_9\} \tag{3}$$

$$\{x\}^T = \{x_1, x_2, x_3, x_4\} \tag{4}$$

$\{y\}$, $\{\dot{y}\}$ and $\{\ddot{y}\}$ are the response matrices of displacement, velocity and acceleration of tractor and trailer respectively. $\{x\}$ and $\{\dot{x}\}$ are the input matrices of displacement and velocity of road profile respectively. The expressions of $[M]$, $[C]$, $[K]$, $[K']$ and $[C']$ can be refered to Hu (1996).

B. Road Model

In order to investigate the vehicle riding characteristics, the ISO road roughness model is adopted (ISO, 1982). The power spectrum density (PSD) function of the ground surface can be defined and applied as the inputs.

C. Ride Quality Parameters

The ride quality parameters for the full tractor and trailer in this paper are defined as the standard deviations of driver seat vertical acceleration, suspension travel, road holding, dynamic tire force and tractor body acceleration.

a. Driver Seat Acceleration. The driver seat acceleration $\ddot{y}_6$ is frequently used to evaluate the ride quality of a vehicle.

b. Suspension Travel. The suspension travels of the front and the rear suspensions of the tractor and trailer can be defined as follows :

$$d_1(t) = y_5(t) + l_1 y_7(t) - y_1(t) \tag{5}$$

$$d_2(t) = y_5(t) + l_2 y_7(t) - y_2(t) \tag{6}$$

$$d_3(t) = y_5(t) + l_2 y_7(t) + (l_5 + l_6) y_8(t) + (l_8 - l_3) y_9(t) - y_3(t) \tag{7}$$

$$d_4(t) = y_5(t) + l_2 y_7(t) + (l_5 + l_6) y_8(t) + (l_8 + l_3) y_9(t) - y_4(t) \tag{8}$$

c. Road Holding. The road holdings of the front and rear tires of the tractor/trailer can be defined as follows :

$$h_i(t) = y_i(t) - x_i(t) \tag{9}$$

where i denotes the *i-th* wheel axle. If $h_i(t)$ is positive, the wheels and the road remain contact.

d. Dynamic Tire Force. The dynamic tire forces between tires and the road surface can also be shown as follows :

$$f_i(t) = K_{t_i} h_i(t) + C_{t_i} \dot{h}_i(t) \tag{10}$$

e. Tractor and Trailer Body Acceleration. The $z_1 \sim z_6$ are the locations on the tractor which is divided into six equal parts; the $z_7 \sim z_{12}$ are the locations on the trailer which is divided into six equal parts. The standard deviations of acceleration of $z_1 \sim z_{12}$ are calculated and used to evaluate the ride quality of cargos, and represented as $\ddot{z}_1 \sim \ddot{z}_{12}$ respectively.

III. Taguchi-Method

Taguchi method is developed to apply in quality engineering (Peace, 1993). The aims of the Taguchi method are to provide an efficient and new engineering approach in promoting products quality and reducing cost during the production processes. The following gives a brief description of the application of Taguchi method.

A. Definition of the Objective Function

To define the objective function is a very important step in the Taguchi method. Before proceeding experiments, the objective function must be defined and related to the analysis objectives. In this work, the objective functions are defined as the standard deviations of ride quality parameters.

In Taguchi method, the objetive function must be transformed to the signal-to-noise (S/N) ratio for further analysis.The objective function should be as small as possible to have better ride quality for the full tractor and trailer. The S/N ratio can then be defined as follows:

$$\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\sigma_i^2\right) \qquad (11)$$

where σ_i is the i-th standard deviation value of the ride quality parameters, and n is the total number of the selected ride quality.

B. Identification of Design Variables of Objective function

Design variables (or called factors for Taguchi-Method) can affect the objective function. The system design variables (factors) are known to be the stiffness and damping coefficients of suspensions and tires respectively. In this work, each factor is assumed to have three setting values (levels) respectively, in order to proceed the numerical analysis of the ride quality. This work is, therefore, to determine the effect of system variables on the objective functions.

C. Selection of Orthogonal Array

The orthogonal array in Taguchi method takes an important role in analyzing the effects and interactions among complex factors on the objective functions. Before proceeding orthogonal array experiments, it is necessary to determine the total number of degrees of freedom, which are the minimum experiments needed to analyze the characteristics of the objective functions. Total number of degrees of freedom (*DOF*) of factors can be presented as:

$$\text{Total number of } DOF\text{s of factors} = \sum_{i=1}^{n}(D_i - 1) + 1 \qquad (12)$$

where D_i is the number of levels for the i-th factor. When the total number of *DOF*s of factors is calaulated, the proper orthogonal array can be chosen in accordance with the factor number and the levels of each factor. In this work, four factors and each factor having three levels are chosen to study their effects on the ride quality parameters. The total number of *DOF*s for each objective function is, therefore, 9. In accordance with the total degrees of freedom, the orthogonal array is chosen to be $L_9(3^4)$ and shown in Table 1. The orthogonal array of $L_9(3^4)$ requires to perform nine experiments. Factors *A, B, C* and *D* are dummy factors that can be substituted by system variables, i.e., the spring constants and damping coefficients of the tires and suspensions for four wheel axles.

D. Analysis of Mean (ANOM)

The objectives of ANOM is to know the effects of factors on the objective function and to select the optimum level for each factor. The processes of the ANOM can be summarized as follows:

(1)To determine the *S/N* ratio for each experiments in which the different levels of all factors are chosen as specified in Table 1.

(2)To calculate the mean values of the S/N ratio for each factor in differenrt levels. For examples, the calculation of the mean S/N ratio for factor A at the *l-th* level , m_{A_l}, is shown as follows:

$$m_{A_l} = \frac{1}{n_A}\sum_{l=1}^{L_A}\eta_{A_l} \tag{13}$$

where η_{A_l} is the S/N ratio corresponding to the factor A at the *l-th* level; and n_A is the number of factor A shown at the *l-th* level in all of the orthogonal array experiment.

(3)To calculate the mean S/N ratio, m, for all experiments can be shown as follows:

$$m=\frac{1}{N}\sum_{j=1}^{N}\eta_j \tag{14}$$

where N denotes the number of experiments, and η_j is the S/N ratio of the j-th experiment.

E. Anaysis of Variance (ANOVA)

The objectives of ANOVA and F-Test are to determine the effect of the contribution of each factor to the objective function. The processes of ANOVA and F-Test are summarized as follows:

(1)To calculate the sum of square values due to each factor (S_A for factor A is illustrated), the sum of total square S/N ratios S_T, and the error S_e as follows:

$$S_A = \sum_{l=1}^{L_A} n(m_{A_l} - m)^2 \tag{15}$$

$$S_T = \sum_{j=1}^{N}\eta_j^2 - Nm^2 \tag{16}$$

$$S_e = \frac{\text{the sum of minor effect of } (S_A, S_B, S_C, S_D)}{\text{the sum of DOF for the minor factor}} \tag{17}$$

(2)To calculate the F-Test value for each factor. For examples, the F-Test value of factor A, F_A, can be shown as follows:

$$F_A = \frac{S_A}{S_e D_A} \tag{18}$$

where D_A denotes the DOFs of the factor A.

(3)To analyze the effect of each factor through ANOVA and the F-Test method can provide the sensitivity of each factor to assess the objective function. The larger value of S_A idicates the more effect of factor A on the objective function.

IV. Results and Discussions

It is interesting to know that the effect of system variables on the ride quality parameters, including (1)the driver seat acceleration, (2) suspension travel, (3)road holding, (4) dynamic tire force, and (5) tractor body acceleration at location $\ddot{z}_1$. The followings present the analysis of means (ANOM) and the analysis of variance (ANOVA) considering the effect of spring constant and damping coefficient of tires and suspensions on all of the ride quality parameters. The vehicle is assumed to be half-laden in the tractor and trailer running at a constant speed 90Km/h on the ISO road class B (good). Four factors, including K_{s_i}, C_{s_i}, K_{t_i} and C_{t_i}, are assumed to be the same for all wheel axles and all tires. The starting level and reference values of each factor is set as level 2 and shown in Table 2.

The raw data for the nine experimental results are shown in Table 3 for those five ride quality parameters. The S/N ratio is defined for the minimization process as shown in Eq.(11) and calculated as listed in Table 4. The average of a factor level can then be computed by Eq.(17) and shown in Table 5. The factor effects are plotted in Figs. 2～6. The overall mean value of S/N ratio is also shown and denoted by the dotted line. From Figs. 2～6, one can determine the optimum level for a factor that will minimize the S/N ratio. The optimum level is the level that gives the highest S/N ratio. The slope of curve for each factor indicates the effect of the level variation on the S/N ratio. The higher slope indicates a significant effect on the ride quality parameters.

From Fig. 2, the driver seat acceleration is mostly affected by K_{s_i} and C_{s_i}. The smaller the K_{s_i} and C_{s_i}, the higher the S/N ratio, i.e., the smaller the driver seat acceleration. The tire spring constant K_{t_i} and damping coefficient C_{ti} result in less effect on the driver seat acceleration. The level two for K_{s_i} and level one for C_{s_i} are the optimum ones. From Fig. 3, the suspension damping coefficient can be seen to significantly influence the suspension travel σ_{d_1}. The higher the C_{s_i}, the higher the S/N ratio, i.e., the lower the suspension travel σ_{d_1}, the other system variables have little effect on the suspension travel σ_{d_1}. From Fig. 4, the road holding σ_{h_1} is dominated by C_{s_i} and K_{t_i}. The smaller the C_{s_i} and the higher K_{t_i}, the higher the S/N ratio, i.e., the smaller of the road holding σ_{h_1}. From Fig. 5, the dynamic tire force is dominated by K_{t_i}, and the lower of all system variables the smaller dynamic tire force. From Fig. 6, the tractor body acceleration at z_1 are dominated by the K_{t_i} and C_{s_i}. The K_{s_i} and C_{t_i} have little effects.The smaller values of K_{t_i} and C_{s_i} $\sigma_{\ddot{z}_1}$ will resukt in smaller tractor body acceleration at the ride quality parameter $\sigma_{\ddot{z}_1}$. The trend of the effect of the system variables on the ride quality parameters is summarized in Table 6.

Table 1. Orthogonal array of $L_9(3^4)$

Exp.No.\Factor	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2. Levels of four factors K_{s_i}, C_{s_i}, K_{t_i} and C_{t_i}.

Factor\Lervel	1	2	3
A(K_{s_i})	40000	***80000***	120000
B(C_{s_i})	15000	***30000***	450000
C(K_{t_i})	400000	***800000***	1200000
D(C_{ti})	1000	***2000***	3000

Table 3. Experimental raw data of ride quality parameters for K_{s_1}, C_{s_1}, K_{t_1} and C_{t_1}

Exp. No.	$\sigma_{\ddot{y}_6}$	σ_{d_1}	σ_{h_1}	σ_{f_1}	$\sigma_{\ddot{z}_1}$
1	0.2194	0.0065	0.0036	1491.00	0.3613
2	0.2861	0.0046	0.0035	2901.00	0.7702
3	0.3176	0.0037	0.0034	4232.00	1.1710
4	0.2875	0.0063	0.0030	2688.00	0.5284
5	0.3096	0.0046	0.0031	3795.00	0.9707
6	0.4170	0.0038	0.0051	2196.00	0.5934
7	0.3820	0.0065	0.0030	3675.00	0.6656
8	0.4028	0.0045	0.0044	2063.00	0.4979
9	0.3933	0.0039	0.0042	3350.00	0.9996

Table 4. S/N ratios of ride quality parameters for K_{s_1}, C_{s_1}, K_{t_1} and C_{t_1}

Exp.No.	$\eta_{\sigma\ddot{y}_6}$	$\eta_{\sigma d_1}$	$\eta_{\sigma h_1}$	$\eta_{\sigma f_1}$	$\eta_{\sigma\ddot{z}_1}$
1	13.175	43.758	48.847	-63.470	8.843
2	10.870	46.732	49.111	-69.251	2.268
3	9.962	48.615	49.376	-72.531	-1.371
4	10.827	43.979	50.314	-68.589	5.541
5	10.184	46.681	50.045	-71.584	0.258
6	7.597	48.526	45.734	-66.833	4.533
7	8.359	43.738	50.469	-71.305	3.536
8	7.898	46.878	47.230	-66.29	6.057
9	8.106	48.185	47.616	-70.501	0.003

Table 5. ANOM of factors K_{s_1}, C_{s_1}, K_{t_1} and C_{t_1} for ride quality parameters.

ANOM	$\sigma_{\ddot{y}_6}$	σ_{d_1}	σ_{h_1}	σ_{f_1}	$\sigma_{\ddot{z}_1}$
m_{A_2}	9.536	46.396	48.697	-69.002	3.444
m_{A_1}	11.336	46.368	49.111	-68.417	3.246
m_{A_3}	8.121	46.267	48.438	-69.365	3.199
m_{B_1}	10.787	43.825	49.877	-67.788	5.973
m_{B_2}	9.651	46.764	48.795	-69.042	2.861
m_{B_3}	8.555	48.442	47.575	-69.955	1.055
m_{C_1}	9.557	46.387	47.270	-65.531	6.478
m_{C_2}	9.934	46.299	49.014	-69.447	2.604
m_{C_3}	9.502	46.344	49.963	-71.807	0.808
m_{D_1}	10.488	46.208	48.836	-68.518	3.035
m_{D_2}	8.942	46.332	48.438	-69.130	3.446
m_{D_3}	9.563	46.491	48.973	-69.137	3.409
m	9.664	46.343	48.749	-68.928	3.296

Table 6. Effect of the system variables on the system parameters

	K_{s_1}, C_{s_1}, K_{t_1}, C_{t_1}
$\sigma_{\ddot{y}_6}$	↓ ↓ ∧ ∨
σ_{d_1}	– ↑ – –
σ_{h_1}	↓ ↓ ↑ ∨
σ_{f_1}	↓ ↓ ↓ ↓
$\sigma_{\ddot{z}_1}$	∧ ↓ ↓ –

Notes:

↓: the lower the value, the higher S/N
↑: the higher the value, the higher S/N
∨: the middle the value, the lower S/N
∧: the middle the value, the higher S/N
–: no significant effect

Table 7. ANOVA of K_{s_1}, C_{s_1}, K_{t_1}, C_{t_1}

ANOVA	$\sigma_{\ddot{y}_6}$	σ_{d_1}	σ_{h_1}	σ_{f_1}	$\sigma_{\ddot{z}_1}$
S_A	15.578	0.027	0.691	1.373	0.101
S_B	7.474	32.775	7.957	7.102	37.131
S_C	0.332	0.012	11.192	60.294	50.380
S_D	3.633	0.120	0.464	0.756	0.310
ERROR	0	0	0	0	0
S_T	27.017	32.934	20.304	69.525	87.923
S_e	0.166	0.010	0.289	0.378	0.103

Table 8. The F-Test of factors K_{s_1}, C_{s_1}, K_{t_1} and C_{t_1} for ride quality parameters

F-TEST	$\sigma_{\ddot{y}_6}$	σ_{d_1}	σ_{h_1}	σ_{f_1}	$\sigma_{\ddot{z}_1}$
F_A	46.872	*******	*****	1.816	******
F_B	22.488	1670.745	13.778	9.394	180.478
F_C	*****	*******	19.378	79.748	244.874
F_D	10.933	6.135	*****	*****	******

Table 9 The optimal level of each factor for ride quality parameters

	K_{s_i}	C_{s_i}	K_{t_i}	C_{t_i}	Improvement in percentage
$\sigma_{\ddot{y}_6}$	1	1	2	1	35.58%
σ_{d_1}	2	3	1	3	20.8%
σ_{h_1}	1	1	3	3	14.79%
σ_{f_1}	1	1	1	1	48.38%
$\sigma_{\ddot{z}_1}$	2	1	1	2	52.33%

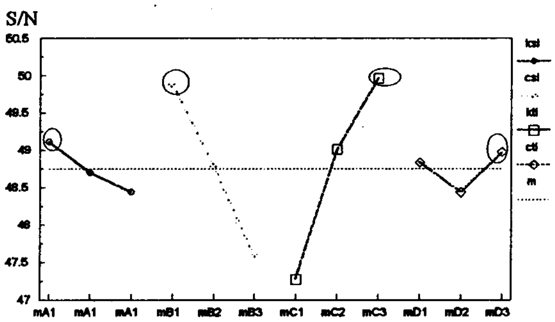

Fig.4 mean S/N ratios plot for σ_{h_1}

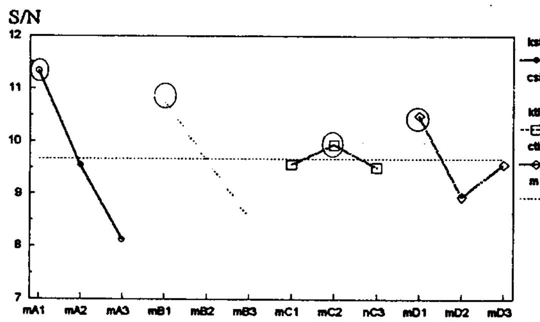

Fig.2 mean S/N ratios plot for $\sigma_{\ddot{y}_6}$

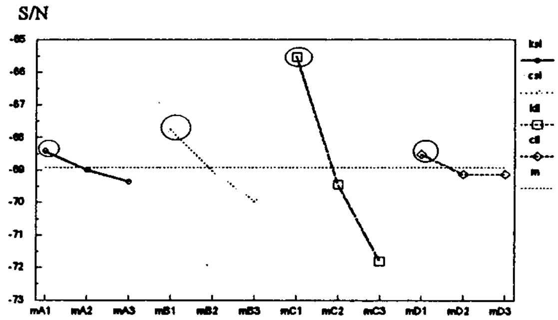

Fig.5 mean S/N ratios plot for σ_{f_1}

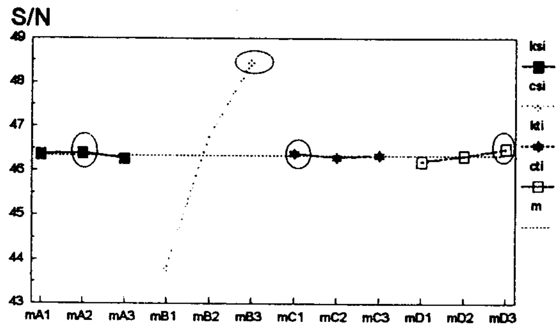

Fig.3 mean S/N ratios plot for σ_{d_1}

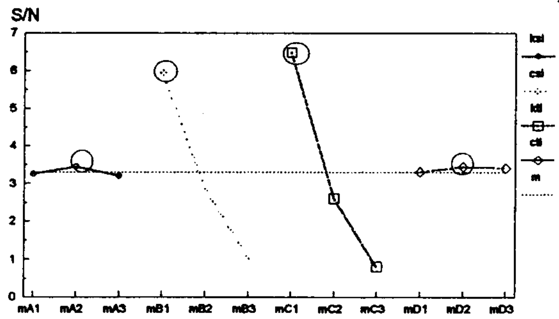

Fig.6 mean S/N ratios plot for $\sigma_{\ddot{z}_1}$

The results of ANOVA is shown in Table 7. The sum of square values due to each factor and the sum of total square S/N ratios are first calculated by Eqs.(15) and (16) respectively. The error S_e can then be calculated based on Eq.(17) by identifying the minor factor. For the example of $\sigma_{\ddot{y}_6}$, the minor factor is S_c =0.332, and its associated DOF is 2. Therefore, the error can be determined as $\frac{S_c}{2}$ =0.166. The F-Test values for each factor can then be determined through Eq.(18). The larger value of the factor's F-Test value indicates a significant effect on the ride quality. One can easily show that the F-Test agrees well with those shown in Figs. 2～6. The F-Test also provides the quantified evaluation of the effect of each factor on the ride quality.

From the above analysis of the effects of system variables, K_{s_i}, C_{s_i}, K_{t_i} and C_{t_i}, on the ride quality parameters, some observations are summarized as follows :

(1) K_{s_t} has major effect on the driver seat acceleration but less influence on the others.

(2) C_{s_t} almost has equal effect on all ride quality parameters.

(3) K_{t_t} has significant effect on the road holding h_1, dynamic tire force f_1 and tractor body acceleration at z_1.

(4) C_{t_t} has less significant influence on the parameters.

(5) In general, smaller K_{s_t} is better, and smaller C_{s_t} is desired so as to minimize the ride quality parameters except the suspension travel.

(6) The smaller K_{t_t} is preferred for the minimization of the dynamic tire force f_1 and the tractor body acceleration at z_1; however, the road holding may be worst.

(7) According to the analysis of means, the optimum level of each factor for the the system parameters can be selected, as circled and shown in Figs. 2 ~ 6.

The optimum level of each factor for the ride quality parameters ($\sigma_{\ddot{z}_1}$, σ_{h_1}, $\sigma_{\ddot{y}_6}$, σ_{d_1} and σ_{h_1}) can be determined from Figs. 2 ~ 6, and summarized in Table 9. The improvement of the ride quality parameters for the optimum levels of the factors in comparison to the initial levels is shown over 15% ~ 50%. For pratical application, a compromize design of system variables may be required to meet the need of all of the ride quality parameters.

V. Conclusion

Taguchi method has been shown to be an efficient and economical means to study the effects of system variables on the ride quality of a full tractor and trailer. Five ride quality parameters, i.e., the verticle acceleration of the driver seat, road holding, dynamic tire force, suspension travel and the tractor and trailer body acceleration, are defined and evaluated that based on the variation of spring constants and damping coefficients of tires and suspensions. The soft and low damping suspension can be desired for better ride quality of the driver seat's acceleration and road holding; however, the suspension travel may be increased. The tire damping has little effect on all of the ride quality parameters. The stiffer tire gives the less road holding. On the contrary the softer tire will minimize the dynamic tire force and the tractor body acceleration. It is also shown that the tire stiffeness has little effect on the driver seat's acceleration and suspension travel. The optimum design of the system variables based on the Taguchi method is demonstrated to efficiently improve the ride quality of the full tractor and trailer.

VI. Acknowlegements

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系統參數對全聯結車行駛品質之影響

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摘要

本文旨在應用田口法探討懸吊系統及輪胎彈簧常數和阻尼係數等系統參數對全聯結車行駛品質之影響，行駛品質之定義包括，駕駛座之加速度，貼地性，輪胎受力，懸吊器行程及全聯結車體之加速度。首先簡略介紹全聯結車行駛動態模型 (Hu, 1996)，並說明田口法於系統參數對行駛品質影響之應用，結果顯示較軟及低阻尼之懸吊器有較佳之行駛品質，而高阻尼之懸吊可減小懸吊行程，一般而言，較軟及低阻尼輪胎對行駛品質較佳，但是貼地性可能不好。經由田口法之分析，亦可得到系統參數之最佳水準，並可對行駛品質獲得改善。本文提供了基於不同行駛品質的考慮對系統參數選擇之通則。對懸吊系統及輪胎彈簧常數和阻尼係數之選用，將來應進一步作折衷式的最佳化設計。

關鍵字: 全聯結車，行駛品質，田口法，懸吊器，輪胎