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姓名職稱：鄭永長 副教授

派赴國家：日本

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摘　要

本次會議是在日本東京舉辦。會議從 3 月 15 日到 3 月 17 日，共是 3 天的議程。發表的論文共約百餘篇左右,是一大型的研討會。領域包含了 Biomedical Engineering、Electrical Engineering、Mechanical Engineering 等方面的問題。本次與會學者專家來自世界各國，包含美國、德國、法國、英國以及台灣、日本、新加坡等國家。本次出國目的主要參加國際研討會，並且發表學術論文，希望藉由學術論文的發表多認識其他國家的專家學者，增廣見聞。

目　次

一、目的

本次出國目的主要參加在日本舉辦的 2013 年工程與應用科技國際研討會，並且發表學術論文，論文名稱為: Using Uniform Design and Quantum Particle Swarm Optimization to Robust Optimization of a Railway Vehicle System。希望藉由學術論文的發表多認識其他國家的專家學者，增廣見聞。

由於這個國際研討會包含了許多的領域與主題，有 Biomedical Engineering、Electrical Engineering、Mechanical Engineering、Civil Engineering 等，選擇參與此國際研討會的理由是研討會中網羅上述眾多研究領域，可以與這些領域的專家學者進行學術交流，並且可以拓展自己的視野。尤其是機械工程、土木工程、醫學工程方面，與本人目前的研究方向有關，可以在一個研討會同時吸收到這三個方面的相關知識，是個相當難得的機會。

二、過程-參加會議經過

本次會議是在日本東京舉辦。會議從3月15日到3月17日，共是3天的議程。發表的論文共約百餘篇左右,是一大型的研討會。領域包含了Biomedical Engineering、Electrical Engineering、Mechanical Engineering 等方面的問題。本次與會學者專家來自世界各國，包含美國、德國、法國、英國以及台灣、日本、新加坡等國家。本人前往該會議並且與會聆聽的相關主題有:

(1) A New Approach for Calculation of Transient Temperature Distribution on Submerged Arc Welded Plates

(2) Impact Pressure Measurement of High-Speed Liquid Jets

(3) Some Guidelines for the Development of An Object-Oriented Finite Element Analysis Code for Non-Linear Structural Mechanics Analysis

(4) Innovative Cooling Lubrication Technology in the Grinding Process

會中與學者專家共討論了數個問題，彼此受益不少。會後順便走訪了東京市區的幾個景點與參觀一些建設。附件中有會議現場的照片。

本次研討會發表的論文題目是: Using Uniform Design and Quantum Particle Swarm Optimization to Robust Optimization of a Railway Vehicle System。研討會第一天(3/15)是報到的程序，以及開放現場註冊。第二天與第三天是整個研討會論文的發表。本人發表的論文是在第二天的下午進行報告。該場次進行的口頭報告論文主題為 Mechanical Engineering II，進行的時間為 2013/3/16 Saturday 16:45-18:15，會議主持人: Prof. Parkpoom Sriromreun，發表的論文有:

(1)Innovative Cooling Lubrication Technology in the Grinding Process

(2)A New Collision Avoidance Strategy for Five-Axis NC Machining

(3) Using Uniform Design and Quantum-Behaved Particle Swarm Optimization to Increase the Robustness of a Railway Vehicle System

(4) Heat Transfer Characteristics Impinging Jet on Dimple Surface

(5) The Computational Aeromechanics of the Rotorcraft Blades for VTOL UAV Platform

(6) A Brief Survey of Scaling Applied to Structures Subjected To Impact Loads

(7) The Vibrational Analysis and Study of the Rotorcraft Blade Designed for VTOL UAV Platform

本篇論文的主題是以鐵路車輛系統的懸吊參數進行最佳化設計，首先建立新式輪軌接觸力的理論模式，完成整車系統的運動方程式推導，使用穩定性理論進行因子特性分析，探討不同的懸吊參數對車輛系統臨界速度的影響。在最佳化設計的方面，先使用均勻實驗設計法規劃一系列的模擬實驗，並且求出兩種車輪圓錐度下的臨界速度。接著利用克利金插值法建立輸入與輸出的代理模型，最後根據代理模型，使用粒子群演算法，以兩種車輪圓錐度下的臨界速度的差為最小當作目標函數，對代理模型進行最佳化參數的求解。最後將球出的最佳解與最佳值帶回原程式，進行確認實驗的比對，如此可以確認代理模型的準確性。結論發現，經過均勻實驗設計與粒子群演算法的最佳化流程，不僅可以提高系統的臨界速度，更可以縮小車輪圓錐度下的臨界速度的差異。附件中有本論文的全文檔案。

本人論文發表完畢後有幾位國外學者提出很多問題與建議，也成為該論文日後繼續深入研究的方向，受益良多。會議第三天則有其他主題的論文發表，包含: Civil Engineering、Environmental Sciences、Mechanical Engineering、Communication and Multimedia等方向的議題。

三、心得及建議

本次國際會議頗具規模，各主題的相關性還不錯，參加本次會議有所受益。會後順便走訪東京市區時，發覺有許多值得國人學習之處，包含市區規劃、綠色建築設計等，相當具有特色。而且在政府有效率的規劃並拼經濟，以至於國民所得大幅提昇，人人充滿了希望。

(1) 多拼經濟，少拼政治！

(2) 我國應多主動的補助、舉辦國際會議，此將促進學術交流與國際合作的機會，對於提昇國際競爭力與國際學術地位亦有助益。

四、攜回資料名稱及內容

研討會論文集光碟, Proceedings of International Conference on Engineering and Applied Science，ISBN:978-986-87417-1-3

附件

(1)發表論文內容

Using Uniform Design and Quantum-Behaved Particle Swarm Optimization to Increase the Robustness of a Railway Vehicle System

Cheng-Kang Lee[1]
Associate Professor, Department of Industrial Engineering and Management, Cheng Shiu University, Kaohsiung, Taiwan
leeck588@csu.edu.tw

Yung-Chang Cheng[2]
Associate Professor, Department of Mechanical and Automation Engineering, National Kaohsiung First University of Science and Technology, Kaohsiung, Taiwan
yccheng@nkfust.edu.tw

Cho-Pei Jiang[3]
Associate Professor, Department of Power Mechanical Engineering, National Formosa University, Yunlin, Taiwan
cpjiang@nfu.edu.tw

The corresponding author: Yung-Chang Cheng[2]

Abstract

Based on uniform design and quantum-behaved particle swarm optimization (QPSO), this paper has increased the robustness of critical hunting speed for a railway vehicle modeled by a fourteen degrees of freedom system with nonlinear coupled differential equations of motion. In this system, a new heuristic nonlinear creep model is applied and is determined by adding the linear creep moment and the semi-axis lengths in the nonlinearity of the saturation constant. The vehicle's critical hunting speed, which is determined by Lyapunov's indirect method, is very sensitive to the noise factor, wheel conicity, if suspension parameters of the vehicle are not designed properly. This paper has shown that integration of uniform design and QPSO can effectively find out optimal solutions for suspension parameters. After optimization, the vehicle's critical hunting speed can become no longer sensitive to wheel conicity.

Keyword: Hertz contact theory, new nonlinear creep model, quantum-behaved particle swarm optimization, uniform design.

1. Introduction

The high-speed railway (HSR) has already become one of the most important transportation systems in modern society. For studies on the dynamic stability of a vehicle running on curved tracks, a car is generally modeled by systems of various degrees of freedom with traditional linear and nonlinear creep model. Molatefi et al. [1] and Polach [2] investigated the dynamic responses and critical speeds of railway vehicle with both linear and nonlinear creep models. Little attention has so far been given to the robustness of critical hunting speed. However, the sensitivity problem of critical hunting speed is noticeable.

This paper aims at applying uniform design and quantum particle swarm optimization to increase the robustness of a railway vehicle which has fourteen nonlinear equations of motion and fourteen degrees of freedom. The novel nonlinear creep model presented by [3] is adopted as the nonlinear creep model for the vehicle. The noise factor for the vehicle is wheel conicity whereas the control factors are suspension parameters. To advance the robustness for the vehicle, quantum particle swarm optimization is used. To let initial particles spread uniformly in the design space, uniform design is used. After iterations of quantum particle swarm algorism, the optimization solution for the 14-DOF vehicle system will be obtained.

2. New Nonlinear Creep Forces and Moments

Considering the effect of the vehicle speed on the creep coefficients, the new nonlinear creep model is constructed and presented by modifying the traditional heuristic nonlinear creep model. The detailed descriptions are presented as follows.

(1). Calculate the creep coefficients

According to the Kalker's linear theory (Garg and Dukkipati [4]), the creep coefficients are given as

$$f_{11}=\left(\bar{a}\bar{b}\right)GC_{22},\quad f_{12}=\left(\bar{a}\bar{b}\right)^{3/2}GC_{23},\quad f_{22}=\left(\bar{a}\bar{b}\right)^{2}GC_{33},\quad f_{33}=\left(\bar{a}\bar{b}\right)GC_{11} \tag{1}$$

where G is the combined shear modulus of rigidity of wheel and rail materials and given by Garg and Dukkipati [4]. C_{11}, C_{22}, C_{23} and C_{33} are creepage and spin coefficients given by Cheng [3]. $\bar{a}$ and $\bar{b}$, are the semi axes lengths at the contact area between rails and wheels presented in Appendix. Therefore, the Equation (1), the creep coefficients, f_{ij}, of the new nonlinear creep model are functions of vehicle speed V.

(3).Calculate the nonlinear creep forces and moments.

According to Garg and Dukkipati [4], the normalized longitudinal and lateral creep forces and the spin creep moment are calculated as

$$F^{**}_{kxijN}=\frac{F^{*}_{kxij}}{fN},\quad F^{**}_{kyijN}=\frac{F^{*}_{kyij}}{fN},\quad M^{**}_{kzijN}=\frac{M^{*}_{kzij}}{CfN} \tag{2}$$

where subscripts $k=L,\ R$ indicate that the corresponding properties related to the left and right wheels, respectively. C is given by (Garg and Dukkipati [4])

$$C=\sqrt{\bar{a}\bar{b}} \tag{3}$$

Considering the spin creep moment, by following the approach of heuristic nonlinear creep model, the nonlinearity β^{*}_{kij} of the saturation constant for the new nonlinear creep model is given by

$$\beta^{*}_{kij} = \frac{\sqrt{\left(F^{*}_{kxij}\right)^2 + \left(F^{*}_{kyij}\right)^2 + \left(M^{*}_{kzij}/C\right)^2}}{fN} \tag{4}$$

where F^{*}_{kxij}, F^{*}_{kyij} and M^{*}_{kzij} indicate the linear creep forces and creep moments given by Cheng [3]. By following Horak and Wormley's approach [5], the saturation to the constant α_{ij} in the new nonlinear creep formalisms given as

$$\alpha_{ij} = \begin{cases} \dfrac{1}{\beta_{ij}}\left[\beta_{ij} - \dfrac{1}{3}\beta_{ij}^{2} + \dfrac{1}{27}\beta_{ij}^{3}\right] & \text{for } \beta_{ij} \le 3 \\ \dfrac{1}{\beta_{ij}} & \text{for } \beta_{ij} \ge 3 \end{cases}, \quad \beta_{ij} = \frac{\beta_{Rij} + \beta_{Lij}}{2} \tag{5}$$

3 Equations of Motion of Railway Vehicle Model

Consider a railway vehicle traveling on a curved track with radius R (Figure 1). The governing equations of motion for lateral displacement y_{ti}, and yaw angle ψ_{ti} of the truck frame are given as

$$m_t \ddot{y}_{ti} = F_{syti} + (\frac{V^2}{gR} - \phi_{se}) m_t g, \quad I_{tz} \ddot{\psi}_{ti} = M_{szti} \tag{6}$$

Meanwhile, the governing equations of motion for lateral displacement y_c, and yaw angle ψ_c of the car body are

$$m_c \ddot{y}_c = F_{syc} + (\frac{V^2}{gR} - \phi_{se}) m_c g, \quad I_{cz} \ddot{\psi}_c = M_{szc}, \tag{7}$$

where V is the speed of the railway vehicle in the forward direction and ϕ_{se} is the superelevation angle of curved tracks.

The governing coupled differential equations of motion for lateral displacement y_{wij}, and yaw angle ψ_{wij} of the wheelsets are

$$\begin{aligned} m_w\left(\ddot{y}_{wij} - \frac{V^2}{R}\right) = & -\frac{2\alpha_{ij} f_{11}}{V}\left(\dot{y}_{wij} - V\psi_{wij}\right) - \frac{2\alpha_{ij} f_{12}}{V}\left(\dot{\psi}_{wij} - \frac{V}{R}\right) - \frac{2r_0 \alpha_{ij} f_{11}}{V}\left(\frac{\lambda}{a}\right)\dot{y}_{wij} \\ & -\left[\left(W_{ext} + m_w g\right) + \frac{V^2 W_{ext}}{gR}\phi_{se}\right]\left(\frac{\lambda}{a}\right) y_{wij} - \left(W_{ext} + m_w g\right)\phi_{se} + \frac{V^2 W_{ext}}{gR} + F_{syij} \end{aligned} \tag{8}$$

$$\begin{aligned} I_{wz}\ddot{\psi}_{wij} = & -\frac{2a\lambda\alpha_{ij} f_{33}}{r_o} y_{wij} + \frac{2\alpha_{ij} f_{12}}{V}\dot{y}_{wij} - \left(I_{wy}\frac{V}{r_o} - \frac{2r_o\alpha_{ij} f_{12}}{V}\right)\left(\frac{\lambda}{a}\right)\dot{y}_{wij} - 2\alpha_{ij} f_{12}\psi_{wij} \\ & + \left(W_{ext} + m_w g + \frac{V^2 W_{ext}}{gR}\phi_{se}\right) a\lambda\psi_{wij} - \alpha_{ij}\left(\frac{2a^2 f_{33}}{V} + \frac{2f_{22}}{V}\right)\dot{\psi}_{wij} + \frac{2\alpha_{ij}}{R}\left(a^2 f_{33} + f_{22}\right) \\ & + M_{szij} \end{aligned} \tag{9}$$

where $\alpha_{ij} = \alpha_{ij}\left(y_{wij}, \dot{y}_{wij}, \psi_{wij}, \dot{\psi}_{wij}\right)$..Note also that the physical quantities F_{syc}, F_{syti},

M_{szc}, M_{szti}, F_{syij}, and M_{szij} are suspension forces and moments and given by Cheng [3]. The 14-DOF model of the railway vehicle is therefore given by Equations (6)–(9).

4. Optimization

4.1 Uniform design

Uniform design, proposed by professor Fang and Wang [6], is a kind of space filling design. Uniform design can be used to construct a set of experimental points which are scattered uniformly in a continuous design space. For a particle swarm optimization, the initial population of particles is determined randomly. Therefore, the initial population of particles might not be distributed uniformly in the design space. For this reason, this paper adopts uniform design to plan a set of experimental points and regards the experimental points as the initial population of particles before executing the subsequent quantum-behaved particle swarm optimization. For the vehicle system considered in this paper, 6 suspension parameters, K_{px}, K_{py}, K_{sx}, K_{sy}, C_{sx} and $C_{sy.}$ are considered as control factors. Moreover, the number of particles is specified as 30. Thus, the uniform table $U^*_{30}(30^6)$ is chosen to construct the 30 particles of initial population. Table 1 shows the upper and lower bounds of suspension parameters. Table 2 shows the uniform table $U^*_{30}(30^6)$, where the integers represent the levels of parameters. To apply the uniform table $U^*_{30}(30^6)$, every suspension parameter must be divided into 30 levels between the parameter's upper and lower bounds. For each experiment, on the basis of Lyapunov's indirect method (Cheng [3]), critical hunting speed is evaluated three times under three different wheel conicites, λ=0.05, λ=0.07, and λ=0.09. The index for measuring robustness of the vehicle system is defined here by

$$R = 100 \times \frac{STD(V_1, V_2, V_3) + 1}{AVG(V_1, V_2, V_3)} \tag{10}$$

where $STD(V_1, V_2, V_3)$ and $AVG(V_1, V_2, V_3)$ denote respectively the standard deviation and the average of speeds V_1, V_2, and V_3. When the index R is decreased, critical hunting speeds can be advanced and sensitivity of speeds can be compressed. The lower the R is, the higher the robustness is. Table 3 shows the results of experiments, where the best solution occurs at the 30th experiment.

5.2 Quantum-behaved particle swarm optimization

particle swarm optimization (PSO) is a kind of swarm intelligence methods and is usually employed to solve global optimization problems. Inspired by the social behavior of bird flocking and fish schooling, Kennedy and Eberhart [7] proposed the particle swarm optimization (PSO) method in 1995. The main disadvantage of PSO is that the global convergence cannot be guaranteed. PSO is not a global optimization algorithm (van den Bergh and Engelbrecht [8]). To address this problem, Sun et al. [9, 10] introduced the quantum theory into PSO and proposed a quantum-behaved particle swarm optimization (QPSO) algorithm, which is a global convergence guaranteed method. As the experimental results reported in Ref.[9, 10] on some widely applied benchmark functions, QPSO works better than standard PSO. Unlike PSO, QPSO needs no velocity vectors for particles, and has fewer parameters to adjust, making it easier to implement. The QPSO algorithm has been applied to successfully solve a wide range of continuous optimization problems. Here, we also apply QPSO to search for the optimal solutions of suspension parameters. For the QPSO implemented here, the number of particles is 30 and linearly decreasing contraction-expansion coefficient strategy is used. The 30 experiments presented in the section 5.1 are regarded as the initial population of particles. The convergence history of the index R is shown in Figure 2, where the value of R is decreased from 1.51 to 0.22. Table 4 shows the optimal solutions for suspension parameters. After optimization, the critical hunting speeds under three different wheel conicities become the same, which means the critical hunting speed is no more sensitive to the noise factor, wheel conicity. Robustness of the vehicle system is increased successfully.

6. Conclusions

A new nonlinear creep model has been constructed and utilized to analyze the hunting stability of a high-speed railway vehicle during curving. The dynamics of the railway vehicle has been fully described utilizing a 14-DOF model. The suspension parameters of the vehicle system have been optimized. The optimization process is composed of two phases. The first phase is to execute a set of experiments planned by uniform design method. The second phase is to apply quantum-behaved particle swarm optimization to search for the optimal solutions for suspension parameters. After optimization, the vehicle's critical hunting speeds under three different wheel conicities have become totally the same value and equal to 457km/hr. This paper has shown that the integration of uniform design and quantum-behaved particle swarm optimization is a good strategy for advancing the robustness of a railway vehicle system.

Table 1 Lower and upper bounds for suspension parameters

Suspension parameter	K_{px} (N/m)	K_{py} (N/m)	K_{sx} (N/m)	K_{sy} (N/m)	C_{sx} (N-s/m)	C_{sy} (N-s/m)
Lower bound	300000	300000	50000	50000	50000	50000
Upper bound	2500000	2500000	2500000	2500000	1500000	1500000

Table 2 Uniform Table $U_{30}^{*}(30^{6})$

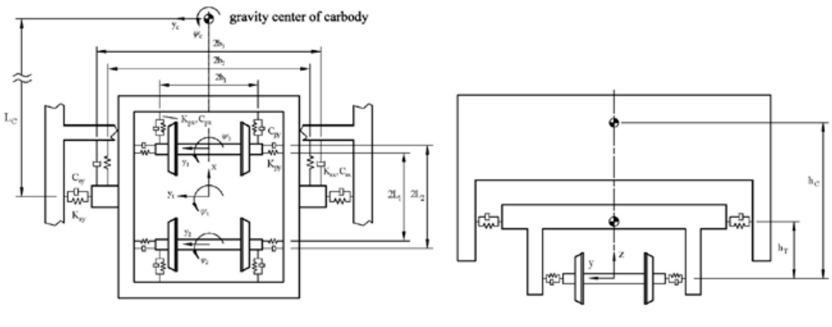
Exp.	K_{px}	K_{py}	K_{sx}	K_{sy}	C_{sx}	C_{sy}
1	1	4	10	14	18	25
2	2	8	20	28	5	19
3	3	12	30	11	23	13
4	4	16	9	25	10	7
5	5	20	19	8	28	1
6	6	24	29	22	15	26
7	7	28	8	5	2	20
8	8	1	18	19	20	14
9	9	5	28	2	7	8
10	10	9	7	16	25	2
11	11	13	17	30	12	27
12	12	17	27	13	30	21
13	13	21	6	27	17	15
14	14	25	16	10	4	9
15	15	29	26	24	22	3
16	16	2	5	7	9	28
17	17	6	15	21	27	22
18	18	10	25	4	14	16
19	19	14	4	18	1	10
20	20	18	14	1	19	4
21	21	22	24	15	6	29
22	22	26	3	29	24	23
23	23	30	13	12	11	17
24	24	3	23	26	29	11
25	25	7	2	9	16	5
26	26	11	12	23	3	30
27	27	15	22	6	21	24
28	28	19	1	20	8	18
29	29	23	11	3	26	12
30	30	27	21	17	13	6

Table 3 Results of critical hunting speeds

Exp.	V_1(km/h) λ=0.05	V_2(km/h) λ=0.07	V_3(km/h) λ=0.09	R
1	94	86	78	10.47
2	111	283	89	66.60
3	133	116	103	13.67
4	148	129	112	14.66
5	345	339	291	9.41
6	176	152	130	15.73
7	168	145	125	15.42
8	208	326	288	22.35
9	202	366	321	28.93
10	415	353	332	12.04
11	214	196	149	18.55
12	316	236	170	30.79
13	332	467	191	42.12
14	227	314	192	26.12
15	538	453	437	11.61
16	198	288	139	36.50
17	484	449	376	12.86
18	284	300	328	7.65
19	198	188	149	15.08
20	573	496	450	12.47
21	484	465	453	3.56
22	351	516	492	19.90
23	370	293	464	23.06
24	366	300	437	18.91
25	497	466	447	5.58
26	222	527	174	62.55
27	315	474	459	21.34
28	550	295	516	30.74
29	299	358	509	28.12
30	479	471	467	1.51

Table 4 Optimal solutions for suspension parameters and critical hunting speeds

K_{px}(N/m)	K_{py}(N/m)	K_{sx}(N/m)	V_1(km/h)	V_2(km/h)	V_3(km/h)	R
2040723	1567538	2500000	457	457	457	0.22
K_{sy}(N/m)	C_{sx}(N-s/m)	C_{sy}(N-s/m)				
1230013	1052827	1111631				



(a) Top view (b) Front view

Figure 1. Car body model

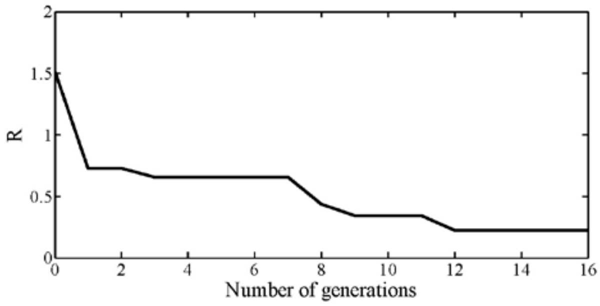


Figure 2. History of search of the objective function R

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Appendix

Calculation of the semi axes lengths of the contact area between rails and wheels

Following Hertz contact theory, the shape of contact areas between rails and wheels is assumed to be elliptical. According to the notation used by Garg and Dukkipati **[4]**, the semi axes lengths, $\overline{a}$ and $\overline{b}$ are given by

$$\overline{a} = m\left[\frac{3\pi N^{*}\left(K_1+K_2\right)}{4K_3}\right]^{1/3},\quad \overline{b} = n\left[\frac{3\pi N^{*}\left(K_1+K_2\right)}{4K_3}\right]^{1/3} \tag{11}$$

where N^{*} is the normal force between rails and wheels. In this paper, assuming static force equilibrium in the vertical direction, the normal force N^{*} is equal to N_{Lz} and N_{Rz} given by Cheng [3]. Therefore, the semi axes lengths, $\overline{a}$ and $\overline{b}$ vary with railway vehicle speeds. $K_1 \sim K_3$ are given by Cheng [3].

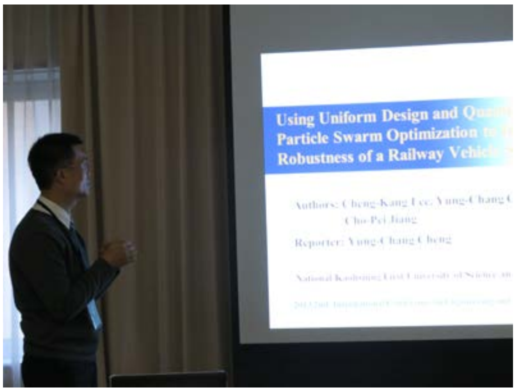
The coefficients, m and n, are given by Garg and Dukkipati **[4]**. By using the curve fitting technique in the curve fitting toolbox of MATLAB software, m and n can be shown in terms of θ and given by

$$m = 37.44\theta^{-0.7236} - 0.451 \tag{12a}$$

$$n = \frac{6.868\times10^{-5}\theta^{5} - 0.00082070\theta^{4} + 0.8561\theta^{3} + 6.708\theta^{2} - 2.288\theta - 0.5623}{\theta^{3} + 37.27\theta^{2} + 13.11\theta - 15.28} \tag{12b}$$

where θ is defined and given by Garg and Dukkipati **[4]**.

(2)照片



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