Biodynamic Response of Human Body Exposure to Vertical Motion on Vehicle

余慶雲、梁卓中

E-mail: 9225059@mail.dyu.edu.tw

ABSTRACT

Vehicle will subjected very high vertical acceleration under shock and impact environment, and which would result in severe human injuries. In this paper, Muksian's six degree of freedom oscillation -structure-human interaction model is adopted to study the biodynamic response of a vehicle suspension sitting subject to vehicle vertical motion induced by moving on an irregular terrain whrein, the human body is modeled using a lumped parameter system with the parameters obtained from corpse dynamic tensile tests. And the parameters and effectiveness of standard type suspension systems which provided to (i) both seat and front axle, (ii) seat only are determined, so that the response of the human body parts to vibration are minimized. It is found that the standard type suspension provided to the seat alone is better than the other type and effective in reducing vertical vibration level by 35% and 25% respectively, thus improving ride confort to a considerable extent. In addition, this paper proposed a shock-structure-human model to study the biodynamic response of a shipboard sitting person subject under vertical motion induced by underwater shock. Numerical results for the model are verified by living drop test (Liu et al., 1998). The simulation of sitting subject on shipboard structure under different shock intensity is, then, carried out to reveal the dynamic characteristics of human body. Furthermore, the injury criteria such as Federal Motor Vehicle Safety Standards, FMVSS 208, and Head Injury Criteria (HIC), etc, are taken into consideration to facilitate the injury assessment. From the simulation results, the part in direct contact with shipboard structure (such as pelvis) is much more vulnerable than others (such as head). Both structural damping and stiffness have more influence on the peak load acting on pelvis than that of on others. These results will be employed as a useful reference for the study of biodynamic response of vehicles in the further.

Keywords : Biodynamic Response ; Mass－Spring－Damping Human model ; Shock ; Vibration ; Vehicle Suspension System

Table of Contents

REFERENCES

[1] Harris, C.M., "Shock and Vibration Handbook"3rd ed., Mc GRAW-Hill Book Company, pp.44-1~44-58 (1988).
[2] Resele and Laimbock, F., "Safety and Crash Behavior", Da-Yeh Institute of Technology, AE & ICE Series, Vol.21, pp.1-74 (1993).
[3] 美國通用汽車公司， http://www.gm.com。
[4] Coermann R.R., "The mechanical impedance of the human body in sitting and standing positions at low frequencies", Human Factors, Vol.4, pp.227-253 (1962).
[5] Suggs, C.W., Abrams, C.F. and Stikeleather, L.F., "Application of a damped spring-mass human vibration simulator in vibration testing of vehicle seats", Ergonomics, Vol.12, pp.79-90 (1969).
[6] Cheng H. and Rizer A. L., "Articulated Total Body Model Version V: User's Manual", Biodynamics and Protection Division, Human Effectiveness Directorate, Air Force Research Laboratory (1998).
[7] Cesari, D. and Ramet, M., "Pelvic Tolerance and Protection Criteria in Side Impact", SAE Paper No.821159 (1982).
[8] Alem, N.M., NushoHz, G.S. and Melvin, J.W., "Head and Neck Response to Axial Impacts", SAE Paper 841667 (1984).
[9] British Standard 6841, "Measurement and evaluation of human exposed to whole-body mechanical vibration and repeated shock" (1987).
[10] Amirouch, F.M.L, and Ider, S.K., "Simulation and analysis of a biodynamic human model subjected to low accelerations-a correlation study", Journal of Sound and Vibration, Vol.123, pp.281-292 (1988).
[11] Panjabi, M.M., Andersson, G.B.J., Torneus, L.L., Huet, E. and Maltson, L., "In vivo measurements of spinal column vibrations", Journal of Bone Joint Surgery, Vol.68A, pp.695-702 (1986).
[12] Pradko, F., Orr, T.R. and Lee, R.A., "Human vibration analysis", SAE Paper No.650426 (1978).
[13] Sandover J., "Modelling human responses to vibration, Aviation, Space, and Environmental Medicine", Jan., pp.335-339 (1978).
[14] Griffin, M.J., Lewis, C.H., Parsons, K.C. and Whitham, E.M., "The biodynamic response of the human body and its application to standards", NATO Advisory Group for Aerospace Research & Development (AGARD) Conference Proc. No.253, pp.A25-1-A28-18 (1979).
[15] Pintar, F.A. and Yoganandan, N., "Kinematic and Anatomical Analysis of the Human Cervical Spinal Column Under Axial Loading", SAE Paper No.892436 (1989).
[16] Rakheja, S., Afework, Y. and Sankar, S.,"An analytical and experimental investigation of the driver-seat-suspension system", Vehicle System Dynamics, Vol.23, pp.1513-1531 (1994) [17] Nightingale, R.W., McElhaney, J.H. and Richardson, W.J., "Dynamic responses of the head and cervical spine to axial impact loading", Journal of Biomechanics, Vol.29, No.3, pp.307-318 (1996).
[18] Yoganandan, N., Pintar, F.A. and Maiman, D.J., "Human Head-Neck biomechanics under axial tension", Medical Engineering and Physics, Vol.18, No.4, pp.289-294 (1996).
[19] Boileau, P.E. and Rakheja, S., "Whole-body vertical biodynamic response characteristics of the seated vehicle driver Measurement and model development", International Journal of Industrial Ergonomics, Vol.22, pp.449-472 (1998).
[20] Wei, L. and Griffin, J., "The prediction of seat transmissibility from measures of seat impedance", Journal of Sound and Vibration, Vol.214, No.1, pp.121-137 (1998).
[21] Hoviattalab, M. and Varziri, M.S., "Investigations on the behavior of the body in response to vertical vibration", Proceedings of ESDA2002: 6th Biennial Conference on Engineering Systems Design and Analysis, ESDA2002 / APM-015 (2002).
[22] Zong, Z. and Lam, K.Y.,"Biodynamic response of shipboard sitting subject to ship shock motion", Journal of Biomechanics, Vol.35, pp.35-43 (2002).
[23] Liu, X.X., Shi, J. and Li, G.H., "Biodynamic response and injury estimation of ship personnel to ship shock motion induced by underwater explosion", Proceedings of 69th Shock and Vibration Symposium, St. Paul, Vol.18, pp.1-18 (1998).
[24] Low, T.C. and Prasad, P., "Dynamic Response and Mathematical Model of the Side Impact Dummy", SAE Paper No.902321 (1990).
[25] 朱健源，"車輛後撞中人體動態反應模擬"，碩士論文，成功大學醫學工程所，台南 (1994)。
[26] 賈維中，"農用搬運車椅座懸掛系統之研究與設計"，碩士論文，中興大學農業機械工程學系，台中 (1994)。
[27] 周正賓，"人體動態有限元素分析"，碩士論文，成功大學醫學工程研究所，台南 (1995)。
[28] Moss,S. and Huang, Y., "Development of an Advanced Finite Element Model Database of the Hybrid III Crash Test Dummy Family", SAE Paper No.971042 (1997).
[29] 陳建宏，"數值模擬法對於人體脊椎及股骨生物力學問題之研究"，碩士論文，中原大學應用物理研究所，中壢 (1997)。
[30] Linder, A., "A new mathematical neck model for a low-velocity rear-end impact dummy: evaluation of components influencing head kinematics", Accident analysis and Prevention, Vol.32, pp.261-269 (2000) [31] 楊秉文，"車禍事故中人體頭頸部之損傷分析"，碩士論文，國防大學中正理工學院兵器系統工程研究所，桃園 (2002)。
[32] Bostrom, O., Fredriksson, R., Haland, Y., Jakobsson, L., Krafft, M., Lovsund, P., Muser, M.H. and Svensson, Y.,"Comparison of car seats in low speed rear-end impacts using the BioRID dummy and the new neck injury criterion (NIC)", Accident analysis and Prevention, Vol.32, pp.321-328 (2000).
[33] Zander, T., Rohlmann, A., Calisse, J. and Bergmann, G.,"Estimation of muscle forces in the lumbar spine during upper-body inclination",

Clinical Biomechanics, Vol.16 (Supplementary), No.1, pp.S73-S80 (2001).
[34] Noureddine, A., Eskandarian, A. and Digges, K., "Computer Modeling and Validation of a HybridIII Dummy for Crashworthiness Simulation", Mathematical and Computer Modelling, Vol.35, pp.885-893 (2002).
[35] 黃世疇，"多體系統動力學的應用研究－車輛碰撞中人體動力分析"，行政院國家科學委員會研究報告，NSC83-0420-E151-001 (1991)。
[36] Bayazitoglu, T.O. and Chace, M.A., "Methods of Automated Dynamic analysis of Discrete Mechanical Systems", Journal of Applied Mechanics, Vol.40, pp.809-819 (1973).
[37] Bayazitoglu, T.O. and Chace, M.A., "Dynamic Analysis of a Three Dimensional Vehicle Model Undergoing Large Deflections", SAE Paper No.770051 (1977).
[38] Chace, M.A. and Smith, D.A., "DAMN－Dynamic Digital Computer Program for the Dynamic Analysis of Generalized Mechanical Systems", SAE Transactions, Vol.80, pp.969-983 (1971).
[39] Denavit, J. and Hartenberg, R.S.,"A Kinematic Notation for Lower－Pair Mechanisms Based on Matrices", Journal of Applied Mechanics, pp.215-221 (1956).
[40] Denavit, J., Hartenberg, R.S., Razi, R.S. and Uicker Jr., J., J."Velocity, Acceleration and Static－Force Analysis of Spatial Linkages", Journal of Applied Mechanics, Vol.32, pp.903-910 (1965).
[41] Dix, R.C. and Lehman, T.L.,"Simulation of the Dynamics of Machinery", Journal of Engineering for Industry, Vol.94, pp.433-438 (1972).
[42] Haug, E.J., Wehage, R.A. and Barman, N.C.,"Design Sensitivity Analysis of Planar Mechanism and Machine Dynamics", Journal of Mechanical Design, Vol.103, pp.560-570 (1981).
[43] Kane, T.R. and Levinson, D.A.,"Formulation of Equations of Motion for complex Spacecraft", Journal of Guidance and control, vol.3, No.2, pp.99-112 (1980).
[44] Nikravesh, P.E., "Computer－Aided Analysis of Mechanical Systems, Prentice Hall, Englewood Ciffs, NJ (1998).
[45] Paul, B.,"Analytical Dynamics of Mechanisms－A Computer Oriented Overview", Mechanism and Machine Theory, Vol.10, pp.481-507 (1975).
[46] Paul, B., "Kinematics and Dynamics of Planar Machinery", Prentice Hall, Englewood Cliffs, NJ (1979).
[47] Uicker, J.J., Denavit Jr., J. and Hartenberg, R.S.,"An Iterative Method for the Displacement Analysis of Spatial Mechanisms", Journal of Applied Mechanics, Vol.31, pp.309-314 (1964).
[48] Vukobratovic, M., "Dynamics of Articulated Mechanisms and Synthesis of Artificial Motion", Mechanism and Machine Theory, Vol.13, pp.1-18 (1978).
[49] Huston, R.L., Hessel, R.E. and Winget, J.W.,"Dynamics of a Crash-Victim-A Finite Segment Model", AIAA Journal, Vol.14, No.2, pp.173-178 (1976).
[50] Huston, R.L., Passerello, C.E. and Harlow, M.W.,"UCIN Vehicle-Occupant /Crash-Victim Simulation Model", Structural Mechanics software Series, Vol. II , University Press of Virginia, Charlottesville, VA, pp.131-150 (1978).
[51] 黃世疇，"車輛碰撞中人體動力反應模擬模型的探討"，第十五屆全國力學會議，工業技術研究院機械工業研究所，新竹，第1205-1211頁(1991)。
[52] Huston, R.L.,"Multibody Dynamics", Butterworth-Heinemann Ltd., ISBN 957-00-6167-7 (1995).
[53] 劉永生，"人體模型之動力系統分析"， 行政院國家科學委員會研究報告，NSC86-2212-E035-010 (1995)。
[54] 陳燕梅，"人體模型建立與應用"，碩士論文，逢甲大學機械研究所，台中 (1997) [55] 張凱敦，"人體模型之動力系統分析"，碩士論文，逢甲大學機械研究所，台中 (1997)。
[56] Komura, T. Shinagawa, Y. and Kunii, T., "Creating and retargeting motion by the musculoskeletal human body model", The Visual Computer, Vol.16, pp.254-270 (2000).
[57] Troy, J.J., "Haptic Control of a Simplified Human Model with Multibody Dynamics", Fifth PHANTOM Users Group Workshop (PUG2000) Final Proceeding, PUG '00 Final Proceedings and Individual Papers (2000).
[58] Kasai, T., Yahagi, S. and Shimura, K., "Effect of vibration-induced postural illusion on anticipatory postural adjustment of voluntary arm movement in standing humans", Gaitand Posture, Vol.15, pp.94-100 (2002).
[59] Fregly, B. J., Bei, Y., and Sylvester, M. E.,"Experimental evaluation of a multibody dynamic model to predict contact pressures in knee replacements", Journal of Biomechanics, accepted (2003).
[60] Muksian, R., "A model for the response of seated humans to sinusoidal displacements of the seat", Journal of Biomechanics, Vol.7, pp.209-215 (1974).
[61] Muksian, R. and Nash, C.D., Jr., "On frequency Dependent damping coefficients in lumped parameter models of human beings", Journal of Biomechanics, Vol.9, pp.339-342 (1976).
[62] Patil, K.M. and Palanichamy, M.S., "Dynamic Response of Human Body Seated on a Tractor and Effectiveness of Suspension System", SAE Paper No.770932 (1977).
[63] Mizrahi, J. and Susak, Z., "In-Vivo Elastic and Damping Response of the Human Leg to Impact Forces", Journal of Biomechanical

Engineering, Vol.104, pp.63-65 (1982).
[64] Nigam, S.P., Malik, M., "A study on a vibratory model of a human body", Journal of Biomechanical Engineering, Vol.109, No.2, pp.148-153 (1987).
[65] Paddan, G.S. and Griffin, M.J., "The transmissional seat vibration to the head－Ⅰ. Vertical Seat vibration", Journal of Biomechanics, Vol.21, No.3, pp.191-197 (1988).
[66] Patil, M. K. and Palanichamy, M. S., "A mathematical model of tractor-occupant system with a new seat suspension for minimization of vibration response", Appl. Math. Modelling, Vol.12, pp.63-71 (1988).
[67] Fairley, T.E. and Griffin, M.J., "The apparent mass of the seated human body: vertical vibration", Journal of Biomechanics, Vol.22, pp.81-94 (1989).
[68] Berger, E. and Gilmore, B. J., "Seat Dynamic Parameters for Ride Quality", SAE Paper No.930115 (1993).
[69] Boileau, P. E., Wu, X. and Rakheja, S., "Definition of a Range of Idealized values to Characterize seated body Biodynamic Response under Vertical Vibration", Journal of Sound and Vibration, Vol.215, No.4, pp.841-862 (1998).
[70] Tewari, V.K. and Prasad, N., "Three DOF modeling of tractor seat－operator system", Journal of Terramechanics, Vol.36, pp.207-219 (1999).
[71] Younggun C. and Yoon, Y.S., "Biomechanical model of human on seat with backrest for evaluating ride quality", International Journal of Industrial Ergonomics, No.27, pp.331-345 (2001).
[72] 梁卓中，鄧作樑，江基風，余慶雲， "船艦座椅上之人體在垂向爆震運動下之生物動態響應分析"，中華民國第二十六屆全國力學會議，第K001-1~K001-12頁 (2002)。
[73] 鄭質， "汽車安全系統之發展與分析－過去、現在與未來"，駕馭e行動時代汽車尖端科技論壇，福特六和汽車股份有限公司 (2000)。
[74] Gurdjian E.S., Lange W.A., Patrick L.M. and Thomas L.M., "Impact injury and crash protection", Thomas, C.C., Springfield, IL, pp.308-349 (1970).
[75] Gadd C.W., "Use of a Weighted-Impulse Criterion for Estimating Injury Hazard", Proceedings of The 10th Stapp Conference, SAE Paper No.660793 (1966).
[76] Hodgson, V.R. and Thomas, L.M., "Comparison of head acceleration injury indices in cadaver skull fracture", SAE Paper No.710854 (1971).
[77] Versace J., "A Review of the Severity Index," Proceedings of The 10th Stapp Conference No.710881 (1971).
[78] Sances Jr., A. and Yoganandan, N., "Human head injury tolerance", In: Sances Jr. (Ed.), Mechanisms of Head and Spine Trauma, Aloray, Goshen, NY, pp.189-215 (1986).
[79] Mertz, J.H., "Anthropomorphic test devices", In: Nahum, A.M., Melvin, J.W. (Eds.), Accidental Injury: Biomechanics and Prevention, Springer, New York, pp.66-84 (1993).
[80] Rouhana, S.W., "Biomechanics of abdominal trauma", In: Nahum, A.M., Melvin, J.W. (Eds.), Accidental Injury: Biomechanics and Prevention, Springer, New York, pp.391-428 (1993).
[81] Cory, C.Z., Jones, M.D., James, D.S., Leadbeatter, S. and Nokes, L.D.M.,"The potential and limitations of utilizing head impact injury models to assess the likelihood of significant head injury in infants after a fall", Forensic Science International, Vol.23, pp.89-106 (2001) [82] Mackenzie, E.J., "Injury Severity Scales: Overview and Directions for Future Research", Am. J. Emergency Med, Vol.2, pp.537-549 (1984) [83] 美國國家公路交通安全管理局， http://www.nhtsa.gov。
[84] NHTSA, "Federal Moter Vehicle Safety Standards: Side Impact Protection", Code of Federal Regulations, 49CFR571.214, Washington, D.C. (1997).
[85] McElhaney, J.H. and Myers, B.S., "Biomechanical aspects of cervical trauma", In: Nahum, A.M., Melvin, J.W. (Eds.), Accidental Injury: Biomechanics and Prevention, Springer, New York, pp.311-361 (1993).
[86] Pintar, F.A., Yogananda, N. and Voo, L., "Effect of age and loading rate on human cervical spine injury threshold", Spine, Vol.23, pp.1957-1962 (1998).
[87] Griffin, M.J., "Handbook of Human Vibration", London: Academic Press, ISBN:0-12-303040-4 (1996).
[88] Goldman, D.E. and von Gierke, H.E.,"The Efects of Shock and Vibration on Man", Naval Medical Research Institute Report No.60-3, Betheda (1960).
[89] Pradko, F., Lee, R. and Kaluza, V.,"Theory of human vibration response", ASME Paper No.66-WA/BHF-15, In:Winter Annual Meeting and Energy Systems Esposition, New York, 21 November-1 December 1996, The American Society of Mechanical Engineers (1966).
[90] 彭新勝，"車輛底盤懸吊與傳動軸整體構件最佳化之振動分析"，碩士論文，中央大學機械工程研究所，桃園 (2000)。
[91] Radke, A.O., "Vehicle vibration…man's environment,", ASME Paper, Vol.57-A, No.54, pp.1-8 (1957).
[92] 梁卓中， "爆震環境下船艦上裝備與結構之反應"，技術報告，國防大學中正理工學院造船系，第3-1~3-6頁 (1992)。