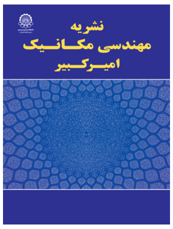

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Numerical analysis of chaotic dynamics in vehicle along with design of chaos controller using fuzzy fast terminal sliding mode control

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ABSTRACT: In this paper, chaos control in the vehicle during passaging of intermittent roughness has been investigated using a fuzzy fast terminal sliding mode control method. For this purpose, the nonlinear half model for the vehicle is considered due to the nonlinear behavior of the springs and dampers used in the suspension system and tires. Initially, the dynamical equations of motion are derived using the Newton-Euler laws and then are solved using the fourth-order Runge-Kutta method. To analyze the chaotic dynamics, the nonlinear dynamic system is studied by specific techniques for identifying the chaotic behaviors such as frequency response diagrams, bifurcation diagrams, frequency spectra, phase plane trajectories, Poincare′ section and max Lyapunov exponent. Therefore, using these methods, the chaotic zones along with the critical values in order to excite chaos based on the input force of the road surface are depicted on the uncontrolled model. Consequently, to eliminate this chaotic behavior, the control signals in the active suspension system are generated using the novel fuzzy fast terminal sliding mode control algorithm. According to the simulation results of the feedback system, the unwanted vibrations in the suspension system can be stabilized at a proper time via the efficient fuzzy fast terminal sliding mode controller besides the rejection of the irregular chaotic behaviors.

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1- Introduction

The vibrations in vehicles passing through the roughness cause to disturb the passengers' comfort and leads to a reduction in the lifetime of the vehicle's parts. Recently many studies have been done on the chaotic dynamics as well as chaos control of vehicle suspension that investigated chaos in a vehicle along with bifurcation and stability studies in the vehicle model [1-4].

The features of sliding mode control can be developed efficiently using the fast terminal algorithm. Therefore, using the fast terminal SMC, the convergence speed of the system is increased and by the use of the fuzzy inference system, the chattering phenomenon is eliminated in the system [5-8]. In this work, chaos controller based on the novel extended fast terminal SMC with fuzzy system is used to control the bounce vibrations in the active suspension system.

2- Dynamical Model and Chaos Analysis

In order to investigate the nonlinear phenomena such as chaos in a vehicle model, the mathematical model of the chassis is derived using Newton-Euler laws as the following formula and then is simulated using the Runge-Kutta method [2, 4].

$$\begin{aligned} M_b \ddot{\mathrm{X}}_{\mathrm{b}} = & -k_{f2}\,\mathrm{sgn}(\Delta_{bf2})\left|\Delta_{bf2}\right|^{n_{f2}} \\ & -c_{f2}\dot{\Delta}_{bf2} - k_{r2}\,\mathrm{sgn}(\Delta_{br2})\left|\Delta_{br2}\right|^{n_{r2}} \\ & -c_{r2}\dot{\Delta}_{br2} - M_b g + u_f + u_r \end{aligned} \tag{1}$$

After dynamic modeling, using the bifurcation diagrams, route to chaos via the periodic responses are observed. Figs. 1 and 2 show the influences of the time delay control parameter α and frequency of excited force from the road surface to the nonlinear dynamics.

In Fig. 3, the effects of the damping coefficient in the suspension system resulting the variation of the oil pressure in the active suspension is depicted on the nonlinear behavior of the system. Also using the power spectrum density based on the Fig. 4 and the diagrams of phase plane trajectories along with the Poincare' section according to Fig. 5, the occurrence of chaos is proved in the uncontrolled system. Furthermore, after calculation of the Lyapunov exponents using the wolf algorithm [9], the positive value for the maximum Lyapunov exponents satisfies the chaotic vibrations in the system.

3- Results of Chaos Control

In order to control the vertical model of the vehicle and rejection of the chaotic oscillations, the new Fuzzy Fast Terminal Sliding Mode Control (FFTSMC) algorithm is applied to the active suspension system. The novel control strategy involves the online calculation of the control parameters in the fast terminal SMC using fuzzy inference system according to Fig. 6.

The control system provides proper oil pressure for the hydraulic actuator in the active suspension, as a result of the forces acting on the vertical dynamics the vehicle are applied to the chassis. According to the control strategy, fuzzy logic

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is used to estimate the control gains of the fast terminal SMC involving the coefficients of K, p, and q. The fuzzy inference is based on the Mamdani system and the output of fuzzy is calculated using the gravity center method. The simulation results of the feedback systems are shown in Fig. 7 shows the rapid convergence of the responses of the states in the system along with the elimination of the chaotic vibrations in the vehicle.

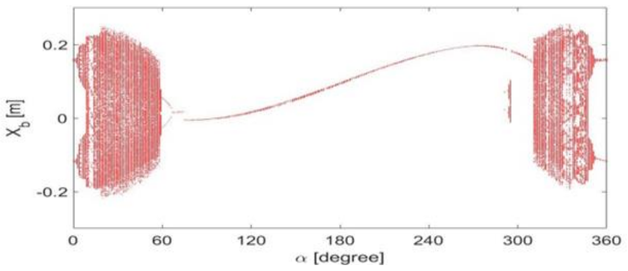

Fig. 1. Bifurcation diagrams of X_b relative to α

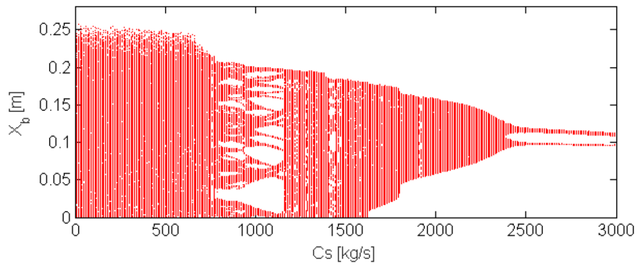

Fig. 3. Bifurcation diagrams of X_b with relative to equal damping coefficient of the active suspension system

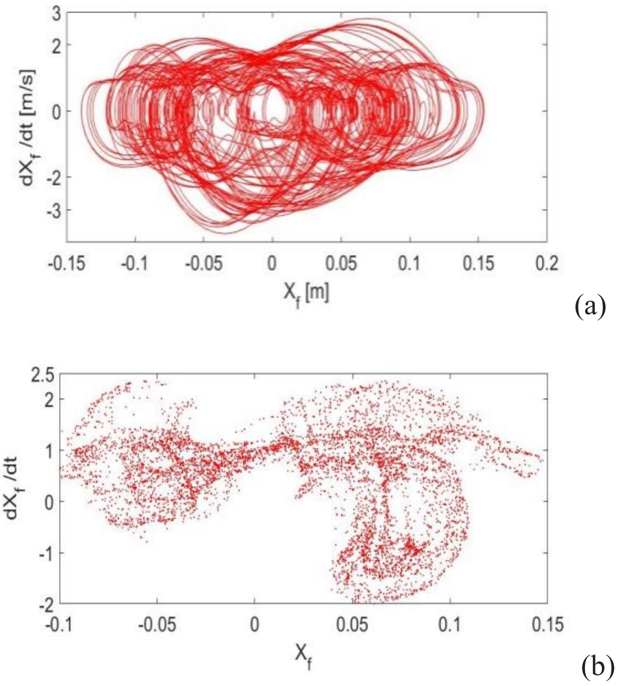

Fig. 5. Phase plane trajectories (a) and Poincare' section (b) of the chaotic system

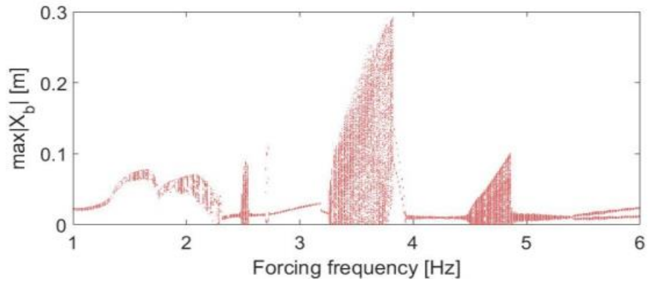

Fig. 2. Bifurcation diagrams of X_b with relative to Frequency of the excited force from road surface

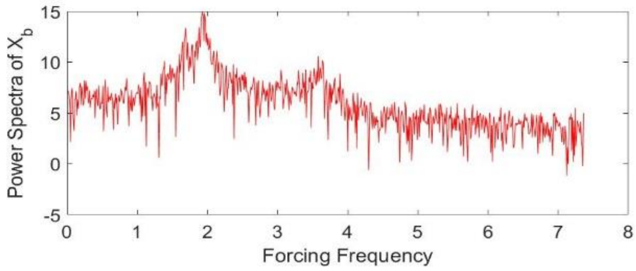

Fig. 4. Power spectrum density diagram of the displacement in the body of vehicle

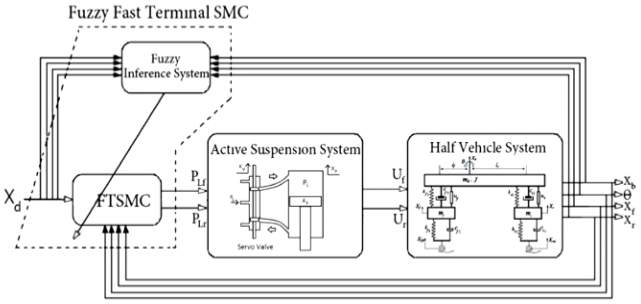

Fig. 6. Block diagram of the fuzzy fast terminal SMC for the half. vehicle model with active suspension

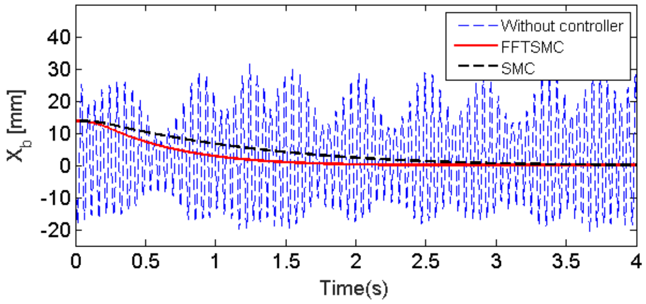

Fig. 7. Simulation results of the feedback system under the fuzzy fast terminal SMC

4- Conclusions

In this work, the chaotic behaviors of the vehicle model are considered using the bifurcation diagram, frequency spectrum, phase trajectories, Poincare' section and Lyapunov exponent numerically. Then a novel fuzzy fast terminal sliding control method has been used to control and eliminate these irregular vibrations. In order to improve the performance of a fast terminal-SMC system, its control gains have been computed online using fuzzy inference systems. Comparing the results of the fast terminal SMC with the conventional SMC shows a 60% decrease in sitting time and a 47% decrease in energy consumption. Also, comparing the results of this study with [10] while reducing the settling time by 10%, indicates the elimination of overshoots in the responses. Comparison of the control input signals with [10] also indicates a significant reduction in the amplitude of the control input, which while reducing energy consumption, completely eliminates the problem of saturation in suspension operators.

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