# Circumvention of Friction-Induced Stick-Slip Vibration by Modeling and Simulation

**Jitendra Yadav and Geeta Agnihotri**

**Abstract** Present works deal with the insight into the friction-induced stick-slip vibration which takes place by virtue of the difference in the values of static and kinetic friction between the rubbing surfaces, which causes decrease in friction force with velocity. The produced intermittent motion is objectionable as it is the cause of serious nuisance, power loss, quadrant glitch, limit cycle, inaccuracy in control, etc. A comprehensive description of this phenomenon by capturing the effect of influencing parameter has become challenging research task for system dynamics especially for control. In present work, the motion of mass on rough surface, being dragged at constant velocity, is studied by stiction model. In this research work, it has been tried to capture the effect of influencing parameters to define the acceptable and optimum criteria of selecting them to ensure motion without stick slip. The study is performed by varying relevant parameters like coefficient of friction, viscous damping, driving velocity, ratio of static friction to kinetic friction. The outcome of this study is the range of these parameters and their combinations, for which friction-induced disturbances are the minimum. The results obtained in this work may be used as a generalized guide line for reducing and avoiding these disturbances.

**Keywords** Stick slip · Sticking time · Damping · Friction · Modeling

**Notations**

| | |
|---|---|
| $c$ | Damping coefficient |
| $F_c$ | Coulomb kinetic friction |
| $F_f$ | Friction force |
| $Fs$ | Coulomb static friction |

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| | |
|---|---|
| $k$ | Spring constant |
| $m$ | Mass of the moving body |
| $x$ | Displacement of mass |
| $\dot{x} = v$ | Velocity of mass |
| $y$ | Displacement of the wall |
| $\dot{y} = u$ | Driving velocity (velocity of wall) |
| $\mu$ | Coulomb friction coefficient |
| $\zeta$ | Damping ratio |

## 1 Introduction

Proper depiction and explanation of friction phenomena are very important to capture the correct system dynamics. Stick slip is one of the phenomena of friction. Stick slip has an adverse effect on system performance and very importantly considered while dealing with the control systems to maintain the control accuracy. Bumpy motion, disquiet, aggravation, and physical damage are some of the effect of stick slip. The proper understanding of stick-slip vibration has indeed become very important for the systems under friction. In past, researchers attempted to capture the facets of these vibrations but quite a well remained untouched for its characterization. Aabdulgalil and Siguerdidjane [1] presented a novel approach to compensate the nonlinear friction of drillstring system by bearing in mind stick-slip behavior at the bit of bottom whole assembly. Di Bernardo et al. [2] ascertained the evidence of stick-slip oscillations in resonant power converters. Huang et al. [3] suggested the control of drive devices with noteworthy stick-slip oscillations. Owen et al. [4] prescribed a solution of friction circumvention. Niemann and Ehrlensp [5] and Rowson [6] analyzed stick-slip motion. Korycki [7] has worked on mathematical modeling of the stick slip. In spite of solving the complex mathematical equation, the effect of sick slip can be obtained directly by simulation [8]. Tool slide ways in machines, extrusion process, and hydraulic cylinder exhibit stick slip at low speeds [9, 10].

There is a research gap found to establish generalized explanation for the effect of influencing parameter and their significance on stick-slip vibrations which is the motive of present work. In the present work, it is tried to observe the effect of parameters on sticking time which is the measure of intensity of stick-slip vibrations.

## 2 Problem Formulation

The dynamic system for the analysis is modeled in form one degree of freedom system comprises of spring-mass-damper and draged at constant velocity as shown in Fig. 1. As the spring is pulled by a tension force, it slides with constant velocity. Static friction is for more than kinetic friction. After a unit pulling of distance, when the enough tension is generated in spring, mass starts sliding. Because of the difference of friction in these two phases, the block moves at a faster rate than that of spring, restoring spring to its unscratched length that bring the block to rest thus starting entire process again. In spite of other scenario, this model is selected to make it simplest one for the sake of the feasibility of experimental validation. This model is quite able to capture the stick-slip behavior of many mechanical systems, e.g., piezoelectric actuator and similar machines having sliding motion between parts. The problem is generalized to capture the stick slip by dynamic response of the system as shown in Fig. 1. The governing equations, defining the motion, are Eq. (1).

The governing equation is given as below:

$$m\ddot{x} + c(\dot{y} - \dot{x}) + k(y - x) - F_f = 0 \tag{1}$$

where

- $m$ mass of the block;
- $c$ damping coefficient;
- $k$ stiffness;
- $x$ displacement of mass;
- $y$ displacement of the wall;
- $\dot{x}$ $v$ velocity of mass;
- $\dot{y}$ $u$ velocity of wall.

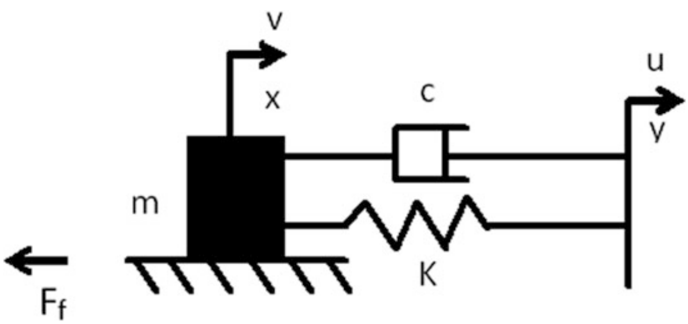


**Fig. 1** Spring mass damper system

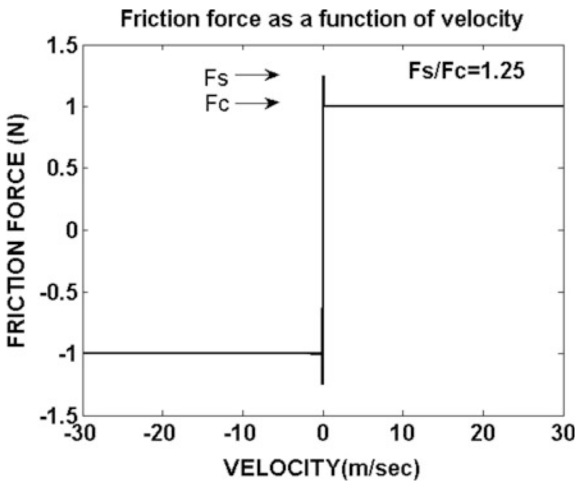


**Fig. 2** Stiction model

## 3 Modeling of Friction Force

Stiction models deal with the two different regimes of operating friction, i.e., static friction at stagnation and Coulomb friction at motion. The friction imposed by the surfaces at rest is always higher than that of in motion, i.e., kinetic force or Coulomb friction. To initiate the relative motion between the surfaces from rest, an external force more than the force of stiction is needed. During the motion, the friction persisting between the surfaces is the kinetic or Coulomb friction and that causes the motion to be intermittent, known as stick-slip motion. Friction at rest is not only defined by only the velocity but the external force ($F_e$) too which in deed expressed mathematically by Eq. 2

$$F_f = \begin{cases} F_e & \text{if } v = 0 \quad \text{and } |F_e| < F_s \\ F_s \text{sgn}(F_e) & \text{if } v = 0 \quad \text{and } |F_e| \geq F_s. \end{cases} \tag{2}$$

The friction force in Eq. 2 is made as a continuous function of velocity as shown in Fig. 2.

## 4 System Parameters

System parameters selected for the simulation are shown in table.

| Parameter | Value |
|---|---|
| $m$ | 1 kg |
| $K$ | 2 N/m |
| $\mu$ | 0.1–0.5@ 0.1 |
| Fc | μ*m* g N |
| Fs/Fc | 1.10, 1.25, 1.40, 1.55 and 1.80 |
| $\zeta$ | 0, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.9 and 1.1 |
| $u$ | 0.10, 0.20 and 0.30 m/s |

## 5 Results of Simulation

The response of the system is found in terms of displacement versus time and velocity versus time plots for various combinations of influencing parameters.

The sample results for the proposed model are obtained for Fs/Fc = 1.5, $\mu$ = 0.1, $u$ = 0.1 m/s, and $\zeta$ = 0.141, as shown in Fig. 3.

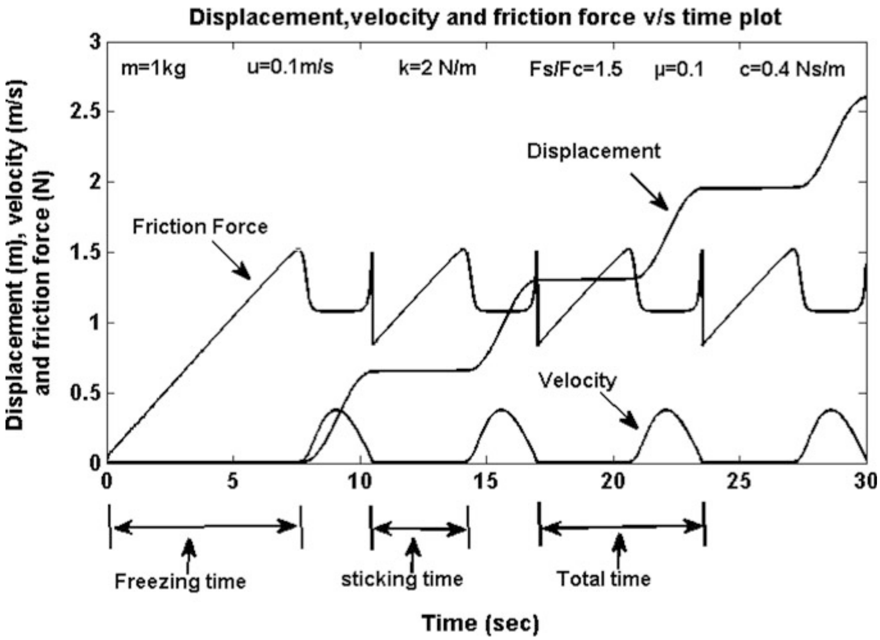


**Fig. 3** Sample results

## 6 Validation of Model

The sample results as shown in Fig. 3 are in perfect compliance with the results of generic paper for LuGre model [10] (refer section D and Table 1). The sample results are obtained with same input parameters as of the LuGre model paper. Viscous damping(c) in the present work has been taken as a lumped parameter of the system, whereas in LuGre model paper it has been considered in the friction force expression itself in the form of the parameter $\sigma_2$; however, this is not affecting the system dynamics. Thus, the proposed model herein is validated and can be adopted for simulation.

## 7 Discussion

The results for different values of prevailing parameters, Fs/Fc, driving velocity damping ratio, and coefficient of friction are obtained. The stick slip can be examined by different findings like velocity peak (maximum amplitude of velocity), freezing time (time delayed for the starting of block after the driving force is applied on the wall), sticking time (Ts) (time for which the mass adhere to the surface during the course of motion), and frequency (reciprocal of time period (Tt)) (total time required for complete one cycle of velocity reversal). In the present work, the stick slip is estimated by the sticking time only by the perception that higher the sticking time higher will be the stick slip in the system. Three-dimensional graphs are plotted for variation of two input parameters keeping other constant, to have their effects on the characteristic parameters of stick-slip motion that is the sticking time.

It can be understood from Fig. 4 that the sticking time for constant value of coefficient of friction and driving velocity decreases linearly with the increase of value of damping ratio. The sticking time increases somewhat linearly with the increase of Fs/Fc ratio for all the values of damping ratio. So higher the damping in the system lower will be the sticking time that means the damping has a worst effect on stick slip.

It is clear from Fig. 5 that the sticking time for constant value of coefficient of friction and Fs/Fc ratio decreases linearly with the increase of value of damping ratio for all the values of driving velocity and decreases somewhat linearly with the increase of driving velocity. It is also observed that the sticking time is zero at higher values of damping ratio and driving velocity. So the stick slip diminishes with the higher values of driving velocity and damping ratio.

It is evident from Fig. 6 that the sticking time for constant value of driving velocity and Fs/Fc ratio decreases somewhat exponentially with the increase of value of damping ratio for all the values of coefficient of friction up to the elimination of stick slip and linearly increases with the incremental values of coefficient of friction for all the values of damping ratio.

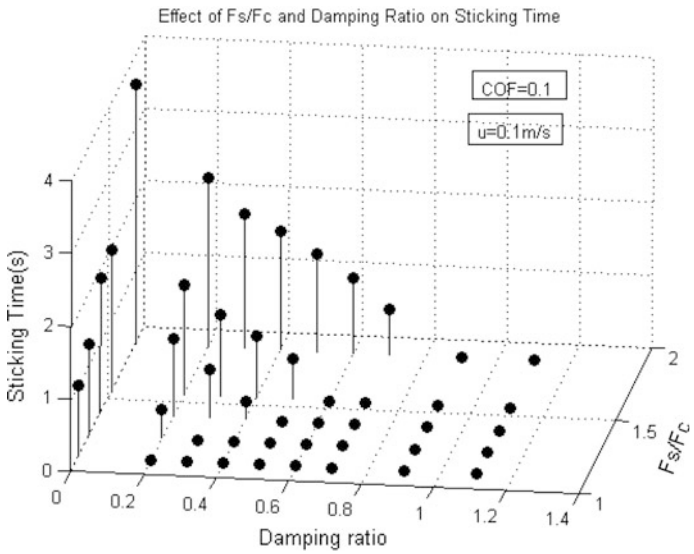


**Fig. 4** Effect of Fs/Fc and damping ratio on sticking time for constant value of *u* and $\mu$, with damping

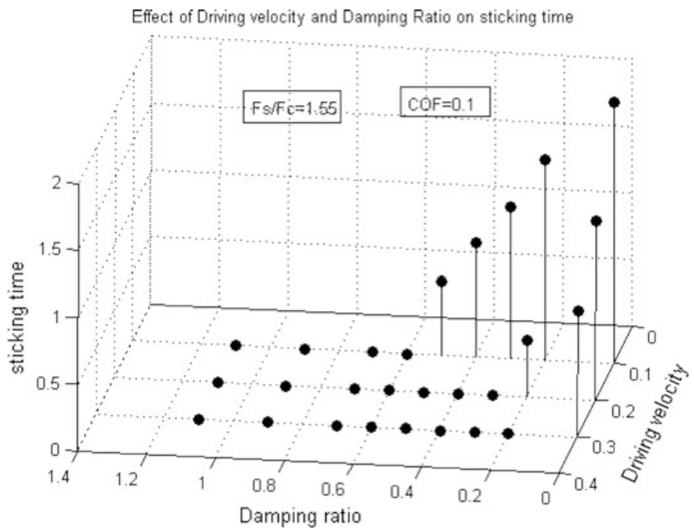


**Fig. 5** Effect of driving velocity and damping ratio on sticking time for constant value of Fs/Fc and $\mu$, with damping

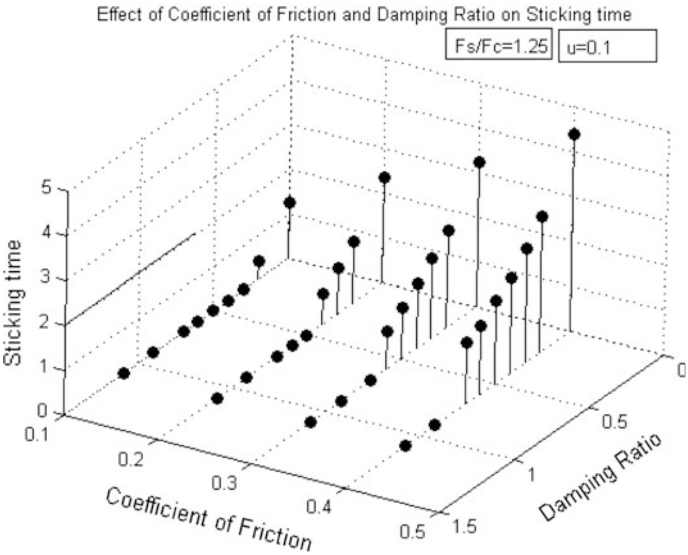


**Fig. 6** Effect of $\mu$ and damping ratio on sticking time for constant value of Fs/Fc and $u$, with damping

It can also be observed from Figs. 4, 5, and 6 that there is a combination of the system parameter for which the sticking time is zero. Therefore, by selecting the proper combination of the system parameters the system can be made to be performing without stick slip.

# 8 Conclusion

It can be concluded that:

1. The sticking time decreases linearly with increase in damping ratio so damping plays a worst role against the stick slip, but the frequency of vibration first increases up to a certain value of damping ration (that is the point of elimination of stick slip from the system) and then decreases with further increase in the value of damping ratio.
2. The sticking time increases linearly with increase in Fs/Fc ratio, and therefore Fs/Fc is favorable to stick slip and it should be kept minimum as possible as to ensure the system free from stick slip.
3. The sticking time decreases with increase in driving velocity, and therefore the stick slip can be decreased by driving the system at higher velocity.
4. The sticking time increases with the increase in coefficient of friction between the rubbing surfaces so the friction plays a positive role for stick slip. Therefore,

to minimize the stick slip the coefficient of friction between the rubbing surfaces should be kept as minimum as possible.

Sometime, the system might have constraints that do not allow the change in system parameters like coefficient of friction, driving velocity, stiffness, and Fs/Fc though there is an alternative option available to ensure the stick-slip free performance of the system and that is integrating the system with proper viscous damping. Furthermore, it is palpable from the study that by selecting the proper combination of the influencing parameters the system can be kept free from stick slip.

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