Experimental Investigations on Hybrid System with Friction Damping to Analyse Stick-Slip Oscillations

Tintu Joseph
M. Tech Scholar, ME Department,
Saintgits College of Engineering,
Kottayam

Sreejith. R
Asst. Prof, ME Department,
Saintgits College of Engineering,
Kottayam

***Abstract*—The friction induced vibrations are analyzed with the help of a hybrid system which is a "mass on a moving belt". The system considered is a single-degree-of-freedom system which is acting under dry friction state. The system consists of a mass placed on a moving belt which is connected by a spring on one end whereas the other end is fixed. The Coulomb's force due to friction acts at the interface between the mass and the moving belt. The stick-slip regions due to the corresponding change in the mass are found out experimentally.**

Keywords— Friction; Hybrid System; Stick-Slip

I. INTRODUCTION

Dry friction is one of the most important topic were a lots of research has been going on in order to identify the cause of various irritating noises developed from car brakes, machine tool slide ways, wheel and rail etc. All the mechanical system is affected by friction which requires an appropriate model to analyse the dynamics of dry friction. When dry friction exists it leads to a phenomenon called stick-slip phenomenon. Stick-slip is nothing but a jerking motion that would occurs when two bodies slide each other.

Dry friction vibrations are non-linear in nature. Stick-slip are more in engineering applications as well as in day today life example noise from car brakes, squeaking sound from shoes, sound from violin, etc. the simplest model to analyse the stick-slip vibrations is a single degree of freedom system. There are various dry friction models explained by different authors. Different friction systems result in different stick slip phenomenon. All these are induced by dry friction [8]. Hence understanding dry friction and its models are important before we proceed for any analysis.

Henrik Olsson and Karl Johan, [6] conducted a comparative study on the dynamics of four different models of dry friction. Their results show that these models can bring contrasting effects to the stick slip behavior. There are two approaches to model dry friction macroslip and microslip. In macroslip the entire surface is assumed to stick or slip. Whereas microslip is at atomic level and requires computational investigation.

Andreaus and Casini studied the dynamics of friction excited oscillations [2] were their works focus on the study of base speed influence on the dynamics of the system. Closed form solutions were obtained with the assumption of Coulombs friction model with two distinct friction values. It is the first record of finding a critical velocity above which there is no stick-slip phenomenon. It also includes the influence of different friction models to the system output. Standard numerical methods are used to propose a law that permits the static coefficient of friction to decay exponentially towards the kinetic friction value. This paper helped in understanding the method to develop a friction model experimentally.

II. DRY FRICTION OSCILLATIONS

Tolstoi provided a theoretical proof to characterize the variation of friction coefficient with velocity. There are there three main phases involved on dry friction oscillations:

i. Stick-slip oscillations

ii. Pure slip oscillations

iii. No oscillations

The stick-slip oscillations are more common in engineering systems and day to day life. To understand these, various models were designed [12]. Thomsen and Fidlin demonstrated self-excited oscillations with a mass on moving belt setup. This work is a motivation from their novel approach to express approximate vibration amplitudes from the said experiment. There are a lot of researches going on to determine the conditions for stick-slip vibrations in order to avoid their presence in mechanical systems. Recent works are been carried out for linear guides as friction influences some important characteristics of machine tools and the provided data from the manufacturer's catalogue do not cover all the details of various working conditions, it is essential to investigate it thoroughly [10].

The present work will help to understand the amplitude variation as well as the frequency of occurrence of stick-slip. Further; the repeated experiments can also help develop friction models with the variation of belt velocity, that is, the relative velocity of the mass with respect to belt velocity.

A. Single Degree of Freedom Hybrid System

The stick slip vibrations are found out with the help of a single degree of freedom friction system to analyse the stick slip regions. Because of the researchers' various approaches to the problem and their different methods of description, in what follows only the most important models of static and dynamic friction have been distinguished and described. The static friction models describe the dependence of the friction force on the relative sliding velocity, whereas the dynamic friction models take the form of differential equations, which also describe the friction in the stick phase of the frictional elements, i.e., when the measured relative sliding velocity is equal to zero.

Fig. 1 represent the mathematical model of a stick-slip phenomenon were it consists of a mass 'm' placed on a moving belt attached to a spring with stiffness "k' as shown. The mass bottom is in contact with the moving belt as a result friction does exist [13].

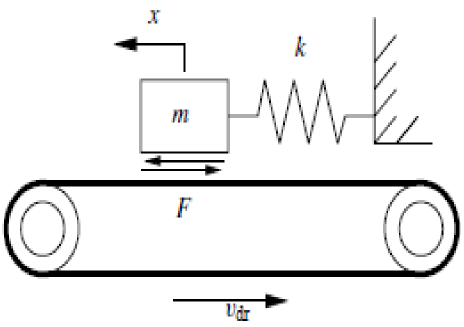


Fig. 1: Single Degree of Freedom Hybrid System

The equation of motion for the system is:

$$m\ddot{x} + kx = F \qquad (1)$$

F is the frictional force

The equation resembles that the system is nonlinear due to the alternate change in friction force with the relative velocity. The process of external dry friction that occurs in various junctions of machines and mechanisms has been investigated with the utmost attention these days. The attempts to come up with a qualitative explanation of it by means of an appropriate mathematical notation face numerous difficulties related to the contact surface's complex structure, heat emission, and wear processes.

Therefore, an analytical and experimental explanation of the character and the mechanisms of their occurrence is a priority in the investigation of discontinuous dynamic systems. That is why, in order to develop a friction model, mathematical equations that describe the frictional contact are formulated and experiments on true real systems with friction are conducted.

III. EXPERIMENTAL SET UP

The mass on moving belt is a mechanical system to understand the dynamic behavior of friction damping in mechanically vibrating systems an arrangement is shown in *Fig. 2*. The presence of dry friction during the motion of the mass on the belt results in a non smooth vibration system. Stick slip occurs when there is a transition from static to dynamic coefficient of friction. Also the value of static friction is found to be too large compared with dynamic friction.

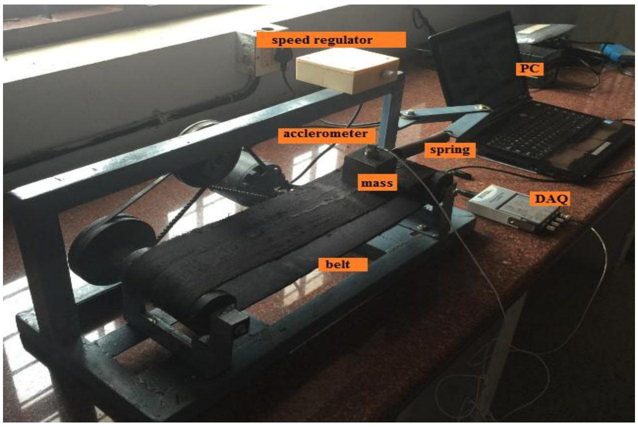


Fig. 2: Experimental Set Up

The purpose of the setup is to analyze the vibration characteristics like stick-slip period, amplitude, acceleration and velocity profile with the variation of input parameters. The input parameters that can be controlled are mass, spring constant, coefficient of maximum static friction and most importantly the belt velocity. The acceleration sensor is used to retrieve the acceleration values from the spring-mass system.

IV. RESULTS

The various outputs that have been got from the sensor corresponding to the change in mass are as follows:

A. *Frequency Plot*

The natural frequency is main cause of squeal they appear at frequency equal to the system natural frequency. Therefore they should be calculated in order to avoid the squeal.

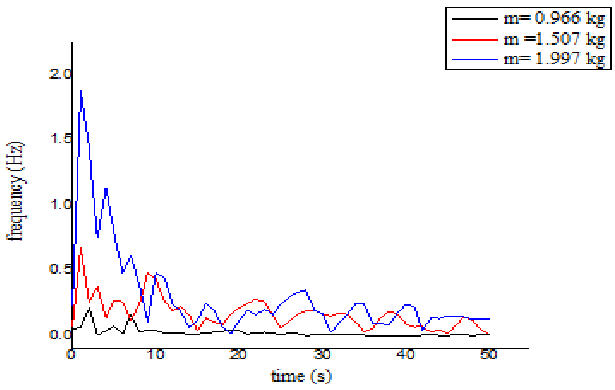


Fig. 3: Frequency Plot

Fig. 3 shows the frequency plot for all the three mass that has been considered in which the blue colour line represents the plot for mass m=1.997 kg, red colour line represents the plot for mass m=1.507 kg and the black colour line for the mass m=0.966 kg. From *Fig. 3* the peak frequency has been found to be occurred at 1 Hz for the maximum amplitude of 1.89 mm for 1.997 kg whereas 1.2 Hz for the maximum amplitude of 0.73 mm for 1.509 kg and 1.56 Hz for an amplitude of 0.21 mm for 0.966 kg. As the mass increases the amplitude at which natural frequency occurs also increases.

B. Amplitude time plot

The stick slip affect has been shown in the displacement graph were the effect of jerking occurs, the stick slip phenomenon acts and is shown the graph with the peak values. Similar to the frequency plot the amplitude plot for the corresponding mass has been shown as follows:

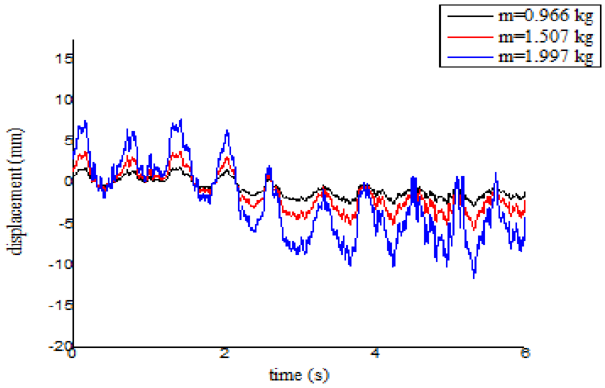


Fig. 4: Amplitude Time Plot for mass 0.996, 1.507 and 1.997 kg

By comparing the *Fig 3* and *Fig 4* it can be clearly state that the system vibrates at natural frequency above 1.8788 mm within a time of 1.839 second for a mass of 1.997 kg. By comparing the *Fig 3* and *Fig 4* it can be clearly state that the system vibrates at natural frequency above 0.6753 mm within a time of 1.12 second for a mass of 1.509 kg and from the *Fig 3* and *Fig 4* it can be clearly state that the system vibrates at natural frequency above 0.2339 mm within a time of 0.257 second for a mass of 0.966 kg.

C. Velocity plot

The velocity plot for the corresponding set up according to the various mass are shown in fig

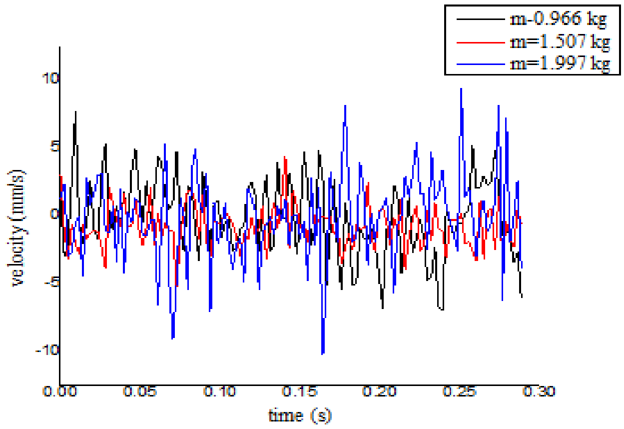


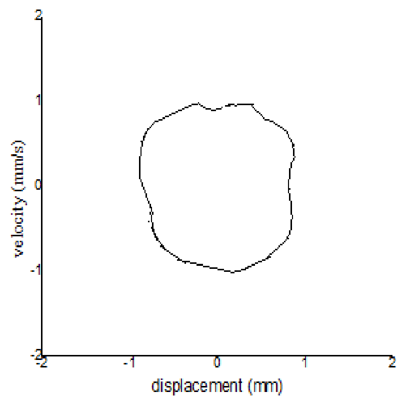
Fig. 5: Velocity versus Time Plot for mass m=1.997, 1.507 and 0.966 kg

The system shows peak in the velocity curve its because the motion changes from slip to stick and it indicate the tendency of the mass to continue slipping. From *Fig 5* it can be found that increasing the belt velocity the number of oscillations also increases also corresponding the slip period alo increases. The system shows peak in the velocity curve its because the motion changes from to slip to stick. Form the *Fig 5*, as the system changes from stick to slip the velocity of the mass increasers to the maximum amplitude and then decreases. This indicates the extreme position of te mass after which it is trying to return back to zero position

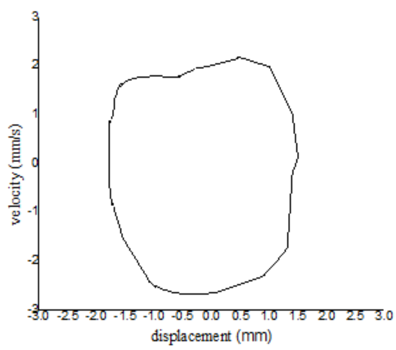
D. Phase plot

The graphical representation between displacement and velocity as the coordinate axes represent the phase plot. A phase portrait is a geometric representation of the trajectories of the system in the phase plane. Each set of initial conditions are represented by a different curve, or point according to the phase.

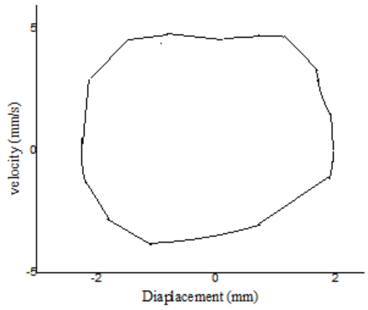
They consist of a plot of special trajectories in the state space. The stick mostly appears when the velocity is zero as long as the position of mass changes linearly with time. The phase plots for the corresponding mass used in the experimental analysis are as follows:



(a)



(b)



(C)

Fig. 6: Phase Plot for mass a) 0.966 kg b) 1.507 kg and c) 1.997 kg

The velocity versus displacement plot has been shown from *Fig 6(a)* which the stick slip range has been found out to be 0.48671 mm where the sticking stops and the mass continues to slip. From *Fig 6(b)* the displacement is 1.0352 mm the sticking stops and the mass starts to slip for a mass of 1.509 kg. When the displacement is 1.4873 mm the sticking stops and the mass starts to slip which is shown in *Fig6(c)* for the mass of 0.966 kg.

V. CONCLUSIONS

The friction mechanism yields self-excited vibrations in mechanical systems with dry friction. The dynamic effect has got more importance in the behavior of such systems. The first main purpose of this work was to investigate the effect of various vibration characteristics on the hybrid system. The second main purpose was to find out the frequencies of the system based on particular changes in the input parameters. Experimental investigations of the system that has been considered are conducted by varying the amount of mass. This works explains that, the transition between each of the motions strongly depends on various parameters such as the frequencies and amplitudes. In all mechanical system, Stick-Slip motion is considered as harmful effects. So that too many researches are concentrated to diminish amplitude of vibration which can directly affect stresses and thus the life of the system and our results have potentially an equally wide range of applications in engineering.

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