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# Analytical and Experimental Characterization of Friction Force in Belt Motion

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**ABSTRACT:** Dynamic friction force is the amount of force necessary to keep the two objects moving relative to each other. Till now only the analytical results regarding effect of relative velocity on dynamic friction are available which are based on several assumptions for simplifying the study. In this project, an effort has been made to characterize the dynamic friction force with relative velocity experimentally. In this project, we consider the classical “mass on a moving belt” model for describing friction-induced vibration. By using this model, we can study the stick-slip phenomena. In this work, an experimental setup is built to observe record and analyze friction damped oscillation. In this project, the dynamics of „mass on a moving belt“ is solved numerically and the effect of different parameters on the response is studied and these computational results are used to build up a model. A modified experimental setup is used for experimental study of stick-slip vibration which is used for characterizing friction with relative velocity. The experiments are conducted for different sets of parameters and it is found that the variation of friction force is linear with relative velocity.

**KEYWORDS:** Dynamic Friction, Stick-Slip, moving belt, Velocity.

## I. INTRODUCTION

Friction forces arising from the relative motion of two contacting surfaces are the main cause of energy dissipation. Sometimes friction forces are desirable e.g. brakes in automobiles, for producing sound in violin and sometimes these are undesirable e.g., friction in a bearing. Dynamic friction force is the amount of force necessary to keep two objects moving relative to each other. In 1781 Coulomb stated that the “Dynamic coefficient of friction is independent of relative velocity.” But at microscopic level dynamic coefficient of friction depends on the relative velocity. Friction induced vibrations are widespread phenomenon in technical devices and in engineering systems e.g. vibrations and noise induced due to the braking of vehicles by frictional forces, the squealing noise of railway vehicles passing narrow curves, gear noise, chatter of mechanical tools etc. In order to be able to compensate the effect of friction, it is necessary to describe the friction behaviour. The different friction behaviours are given in section (1.2.3). These frictional behaviours can be constructed through analytical study which is based on several assumptions adopted to simplify the analysis. Sufficient experimental models are lacking in the friction model. To validate the analytical results experimental data is needed. So to make an experimental model simulating the real conditions and to do experimental study is the main aim of this project.

The main focus of this project is to characterize the friction force with relative velocity experimentally. In this project work a mass on a moving belt model is studied analytically and experimentally; and both the results are compared. After comparing the results, we are in the position to characterize the friction behaviour. The effect of belt velocity and spring stiffness on dynamic friction force is also studied experimentally. These results and characterization of frictional behaviour can be applied to reduce the noise in mechanical system by controlling the friction force.

## II. RELATED WORK

Any motion that repeats itself after an interval of time is called periodic motion. The theory of vibration deals with the study of oscillatory motion of bodies and the associated force with them. In vibration there are different types of systems which are given below.

- Free Vibration Without damping
- Free vibration with damping

- Viscous damper
- 1. Under damped ( $\xi < 1$ )
- 2. Critically damped ( $\xi = 1$ )
- 3. Over damped ( $\xi > 1$ )
- Coulomb damper
- Other types of dampers
- Forced vibration without damping
- Forced vibration with damping

In this project first we focus on the vibration induced by the coulomb damping. Later through experimental work, model is constructed which is different from coulomb damping. Coulomb damping is the damping that occurs due to dry friction when two surface slides against each other. The direction of friction force is always opposite to the direction of velocity. In coulomb friction the minimum force required to start the sliding is directly proportional to normal force acting on the plane of contact. If the applied force is more than the static force then the body starts to slide. As the analytical result shows that, the dynamic friction force is depend on the relative velocity.

### III. METHODOLOGY

In this project, we consider the classical “mass on a moving belt” model for describing friction-induced vibration. By using this model we can study the stick-slip phenomena. In this work, an experimental setup is built to observe, record and analyse friction damped oscillation. In this project, the dynamics of „mass on a moving belt” is solved numerically and the effect of different parameters on the response is studied and these computational results are used to build up a model. Friction forces arising from the relative motion of two contacting surfaces are the main cause of energy dissipation. Sometimes friction forces are desirable e.g. brakes in automobiles, for producing sound in violin and sometimes these are undesirable e.g. friction in a bearing. In this project first we focus on the vibration induced by the coulomb damping.

### IV. EXPERIMENTAL SETUP

Experimental setup consists of a spring-mass system in which a spring is fixed at one end and attached to mass at other end. The mass is placed on a moving belt whose velocity is assumed to be constant. The motion of belt is provided with the help of AC motor and worm-worm gear. An accelerometer is attached to the mass and is connected to ARDUINO to obtain the acceleration of mass in x-direction (direction of belt motion). An ultrasonic position sensor is used to obtain the position in between mass and ultrasonic position sensor. This ultrasonic position sensor is connected to the computer with the help of USB cable to collect the data .



(a) Schematic of experimental setup and its component  
(b) Connection to ARDUINO Board  
(c) AC motor and Worm-worm Gear

#### List of component

- Conveyor system
- Ultrasonic position sensor(hc-sr04)
- Accelerometer(adxl335)
- ARDUINO and its connection
- Spring
- Mass
- Wooden Block



- Speed Controller
- Motor and gear arrangement

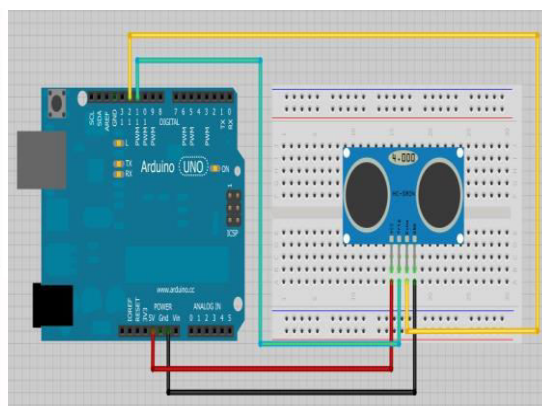
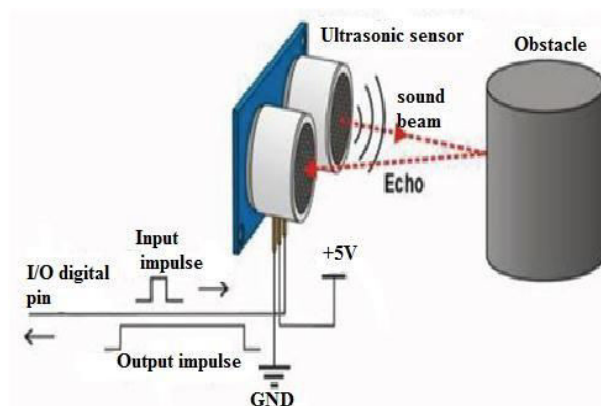
**CONVEYOR SYSTEM:** Conveyor system is electrically powered and operated by an AC motor. Conveyor system is connected to worm gear box which is responsible for driving the belt. The belt acts as a support for the spring mass system and can take a maximum weight of 5 kg without putting any extra stress on motor and belt. The belt also acts as a source for providing the force excitation to spring mass system. The velocity range is between 22 cm/s to 55 cm/s. As we know that, the dynamic coefficient of friction is depend on the relative velocity between the mass and belt. So the variation in belt velocity leads to the variation in relative velocity between the block and belt.

**ARDUINO BOARD (MEGA 2560):** It is a microprocessor which is used to process the data. For programming and processing 'ARDUINO 1.6.5' software is used. The codes for operating the accelerometer and position sensor are provided in appendix. ARDUINO software can be downloaded from ARDUINO website which is available for free. ARDUINO is easily connected to the laptop by using an USB cable.

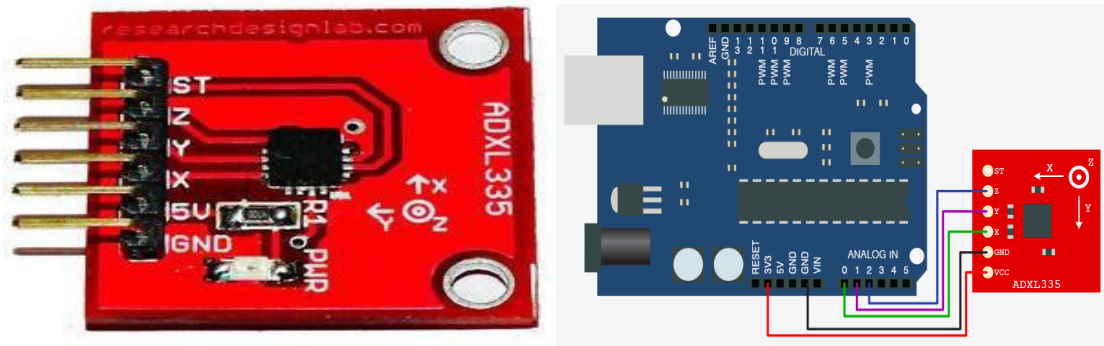


Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage	7-12V
(recommended) Input	6-20V
Voltage (limits)	54 (of which 14 provide PWM output)
Digital I/O Pins	16
Analog Input Pins	40 mA
DC Current per I/O Pin	50 mA
DC Current for 3.3V Pin	256 KB of which 8 KB used by boot loader
Flash Memory	8 KB

**ULTRASONIC POSITION SENSOR:** It is a device that measure the time spent by a beam of sound waves emitted from a source to come back again, after they had been reflected by an obstacle. We can understand it by Fig . Connections of ultrasonic position sensor to ARDUINO are given in Fig



**ACCELEROMETER (ADXL335):** An accelerometer is an electromechanical device that is used to measure the acceleration, a force obtained due to the phenomenon of weight exerted by an object that is kept in the frame of reference of the accelerometer. Now days mostly MEMS (micro-electro-mechanical-system) accelerometers are used. It measures the acceleration in all the three directions. An accelerometer, which is used for measuring the acceleration, is given in Fig . Connections of accelerometer to ARDUINO are given in Fig .



**EXPERIMENTAL FRICTION MODEL:** For obtaining the characteristic of coefficient of friction with relative velocity between block and belt, friction force and the relative velocity is required. Friction force can be obtained by the equation given below and velocity of block can be obtained by using the accelerometer reading.

Equation of motion

(5.1)

Where,

$k$  = Stiffness of the spring

$m$  = Mass of the block

$x$  = Deflection of spring

$a$  = Acceleration of block  $F$  = Friction force

For obtaining the friction force, mass of the block, stiffness of spring, acceleration of block and the deflection in spring are required. Mass of the block and stiffness of spring is known. Acceleration can be obtained by using accelerometer and deflection in spring obtained by using ultrasonic position sensor.

Example

$m=1$  Kg

$k= 100$  N/m

Acceleration reading =  $10$  m/

Position sensor reading =  $20$  mm =  $0.020$  m Friction force =  $1 \cdot 10 + 100 \cdot 0.02 = 12$  N

**READING FROM POSITION SENSOR:** Position sensor gives the distance between the sensor head to block.

Sensor measure the time taken by a sound wave to travel between sensor head and obstacle. Ultrasonic position sensor measures the time in microsecond.

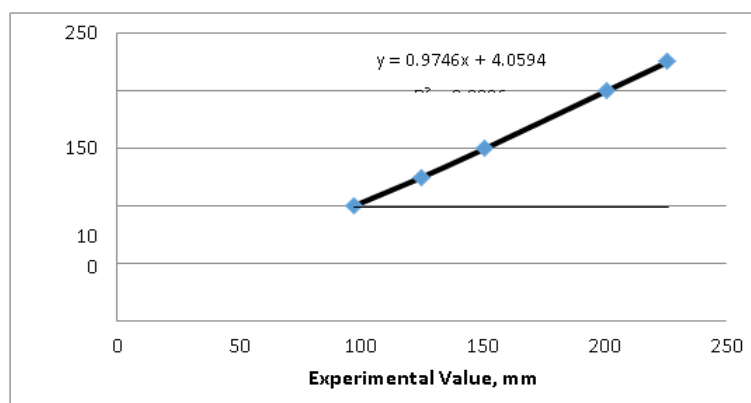
Distance calculation for Sensor:

Velocity of sound ( ) =  $343.3$  / (at  $20^\circ\text{C}$ ) =  $343.3/10000$

=  $1/58$  cm/ $\mu\text{s}$

Distance travelled by the sound wave =  $t = (1/58) \cdot t$  cm (5.2)

Distance of obstacle = (Distance travelled by the sound wave)/2



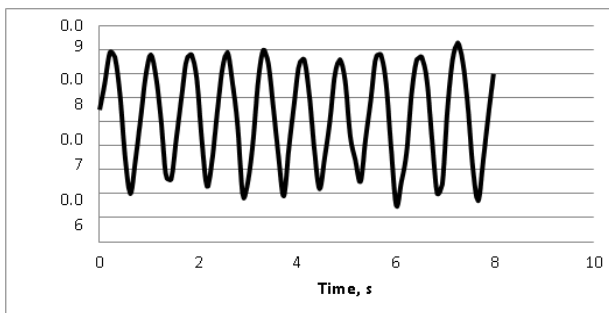
Calibration plot for position sensor

## V. EXPERIMENTAL RESULTS

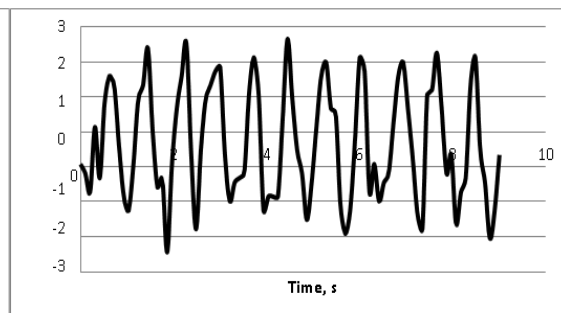
An experiment was conducted for finding the friction force versus relative velocity graph. The parameters used in experimental setup are given below. We can see that the mass is being taken as 1.94 in order to maintain proper range of amplitude. Spring stiffness can be found by plotting the graph between spring force and deflection in the spring. Slope of the spring force versus deflection in the deflection graph gives the stiffness of the spring. For finding the static coefficient of friction experimental trial and error method is used. The value of this static coefficient of friction for the experimental setup is given in Appendix A4.

Experimental parameters

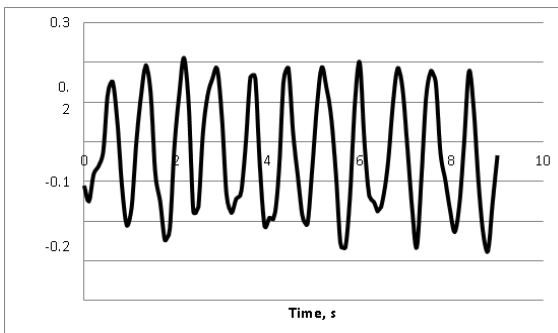
- $k=140/$
- $=1.94$
- $=0.25/$
- $=0.38 \pm 0.04$



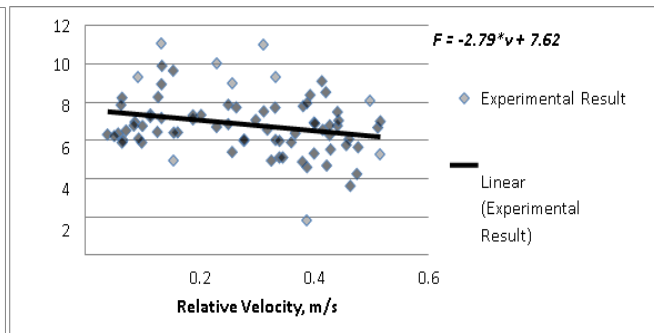
Displacement versus time plot



Acceleration versus time plot



Velocity versus time plot



Friction force versus relative velocity plot

## VI. CONCLUSION

A friction induced vibration model is simulated in MATLAB. It is observed that as we increase the value of spring stiffness, mass and static coefficient of friction and reduce the velocity of belt, ratio of stick to slip time increases which indicates stick dominates over slip phenomenon. Experimental characterization is done for friction in the mass on a moving belt. The experiments are conducted for 8 sets of parameters and it is obtained that the variation of friction force is linear with relative velocity. After modification in block and taking the average of experimental value fluctuation in friction force gets reduced by 30.7%. It is observed that the friction force depends on the belt velocity and doesn't depend on spring stiffness. Y-intercept of friction force versus relative velocity plot gives the static friction force. Error in the static coefficient of friction found is -6% to 11% of the value obtained from the trial and error method. FFT analysis shows that, frequency obtained from experiment differs from that obtained through simulation. This variation is present in the frequencies obtained from FFT analysis is due to the assumptions in our model.



## VII. SCOPE OF FUTURE WORK

The experiment results are not showing any stick region, this is because of time interval for stick reason is 110 ms which is very less. In experiment, time step is varying between 103 ms to 105 ms. If we reduce the time step then it may be possible that we will get a stick region. By using USB based data acquisition (DAQ) and control device time step can be reduced and it will give better results.

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