UNIVERSITÀ DI PISA

DIPARTIMENTO DI FISICA "E.Fermi"
Corso di Dottorato in Fisica - XXX Ciclo
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PhD First Year Seminar

The stick-slip phenomenon in brake systems

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Presentation overview

- Brief description of stick-slip motion model;
- Stick-slip in a brake system;
- Main interests to study this kind of oscillation in a brake system;
- Some features and parameters of the system studied;
- Results and discussion;
- Some highlights and conclusions.

Stick-slip motion

Phenomenon characterized of a periodic cycle of alternating motion and arrest and is commonly taken to be the consequence of a lower friction force for a higher sliding velocity.

Stick-Slip motion is the basis for the description of a great variety of phenomena characterized by the presence of sliding friction between bodies with elastic features.

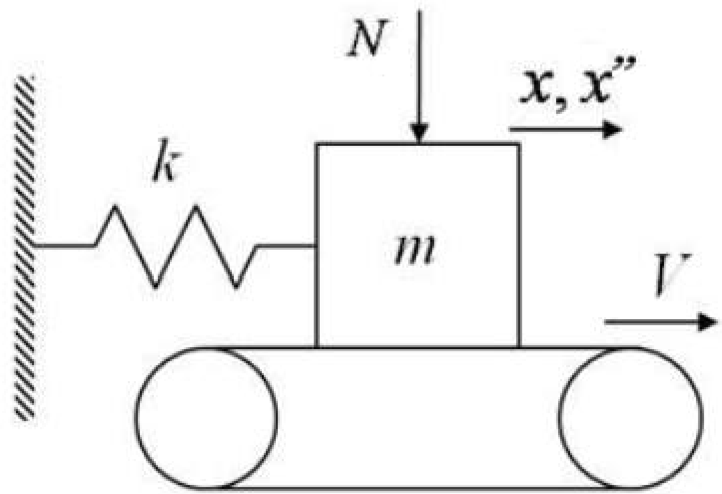
Stick-slip is present in:

- Sound emission mechanism of a violin;
- Squealing of a chalk on a blackboard;
- Sound of a windscreen wiper on a dry glass;

- Earthquake generation;
- Avalanche dynamics;
- Breaking of cars and trains.

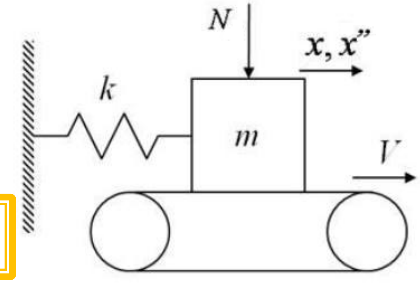
Stick-slip motion

A simple physical system that exhibits a stick-slip dynamics consists of a body having mass *m* connected to a wall by means of a spring, while a rough plan slides at constant speed under the body.



Stick-slip phenomena with very distinct aspects (even those observed in atomic-scale), despite the difference in each case, are studied from models based on the Strained Spring system above.

Stick-slip motion



For stick phase:

$x(t) = V.t$

For slip phase:

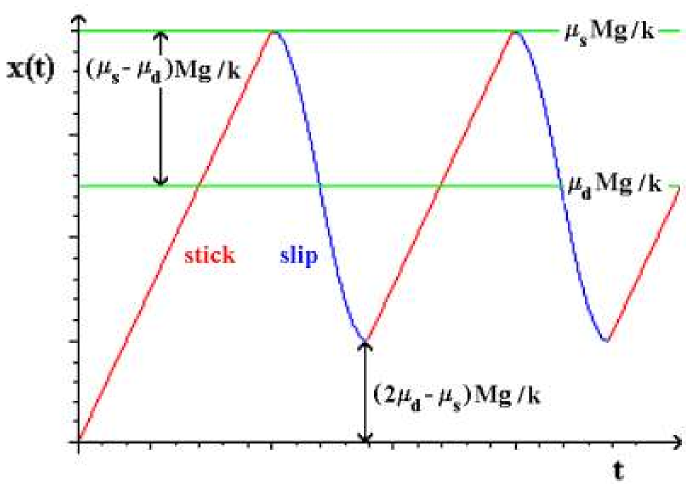
Condition: in $t = t_1$ $F_{el} = F_s \Rightarrow k.V.t = \mu_s.N$

Eq. of motion: $m.x''(t) = F_d - k.x(t)$; $F_d = \mu_d.N$

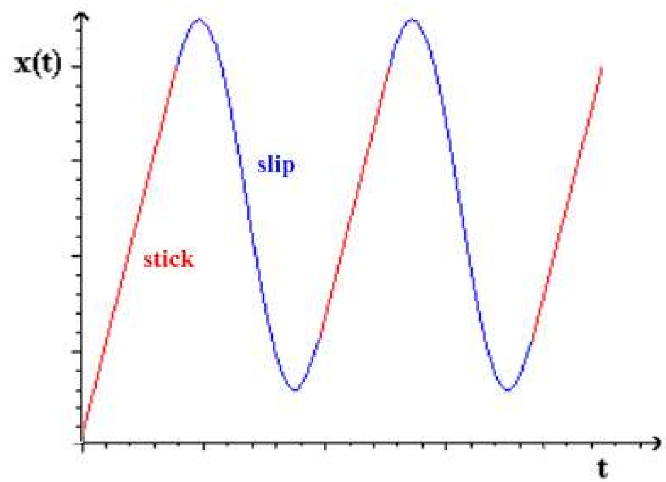
$x(t) = (\mu_d.N)/k + (\mu_s.N - \mu_d.N).cos(\omega.t)/k + (V/\omega).sen(\omega.t)$;

$\omega^2 = k/m$

For low speed range:
$V/\omega = V.(m/k)^{1/2} << (\mu_s - \mu_d).N/k$

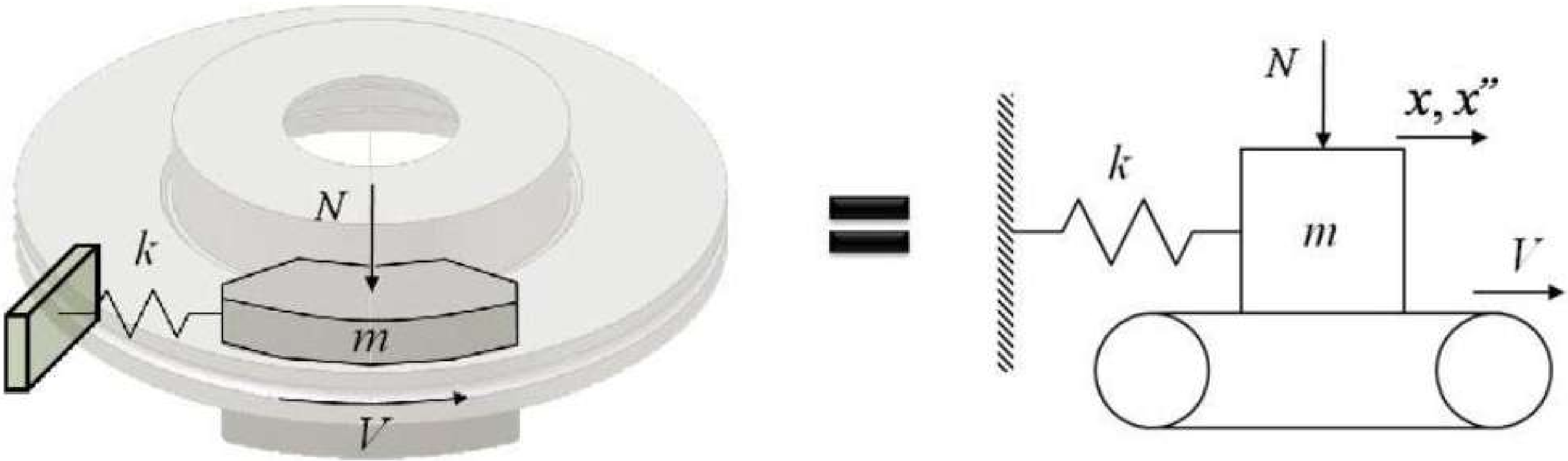


When the speed is not too low:
$V/\omega = V.(m/k)^{1/2} \geq (\mu_s - \mu_d).N/k$



Stick-slip – brake system

Brake system simplification to study the stick-slip.

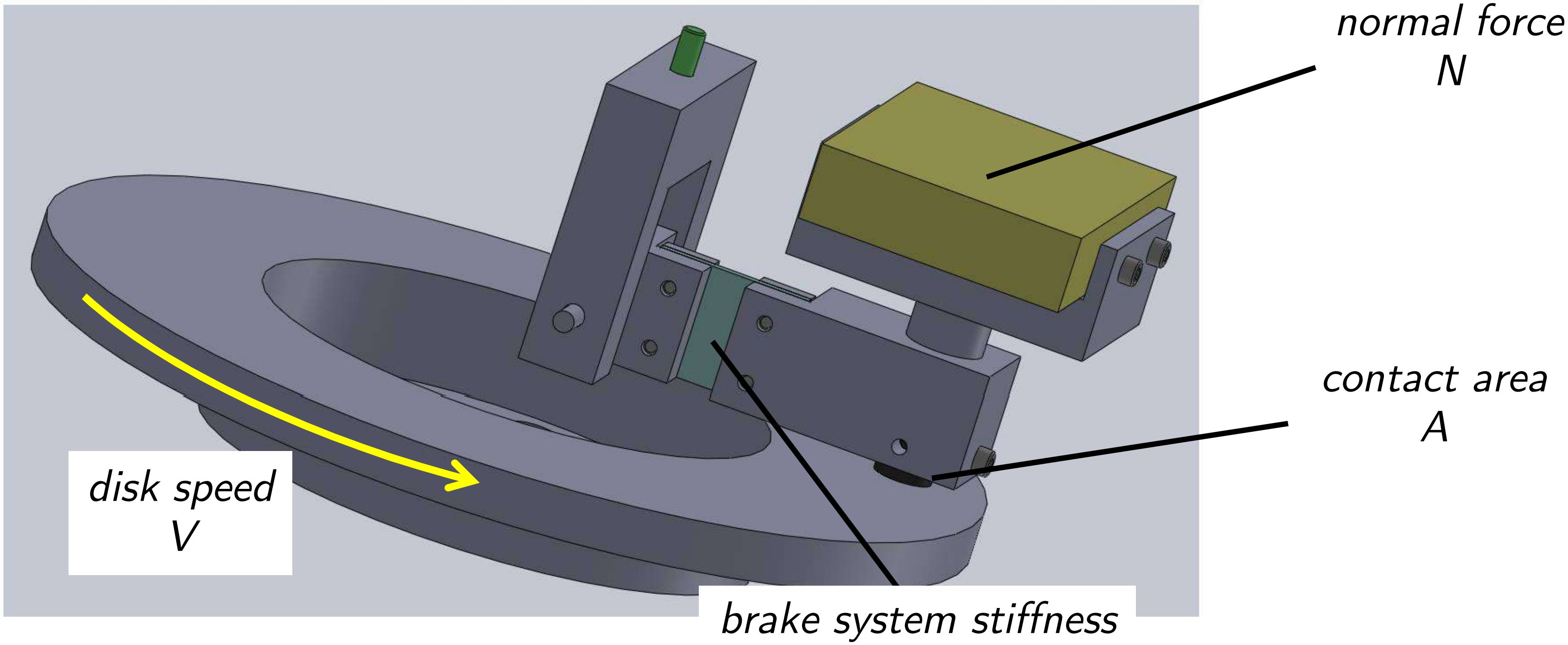


The studies of stick-slip in brake systems aim:

- ❑ Prevent unwanted oscillations that can cause fatigue;
- ❑ Predict when the oscillation causes an unwanted behavior of the mechanism;
- ❑ Minimize emission of audible noise when the system is triggered.

Stick-slip – brake system

The apparatus used in this work to investigate the stick-slip phenomena.



disc angular speed	
Speed1	100 rpm
Speed2	150 rpm
Speed3	200 rpm

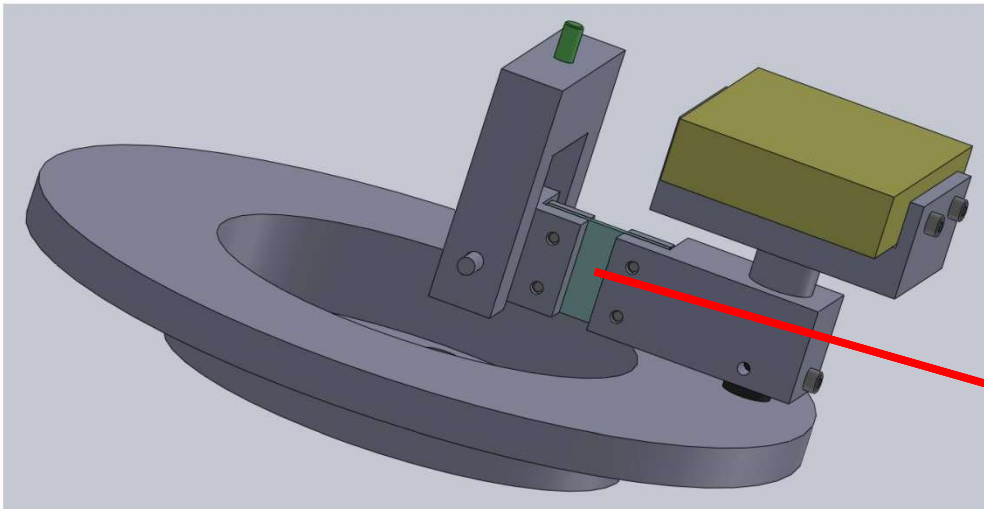
brake system stiffness (plate thickness)	
Plate 1	2 mm
Plate 2	3 mm

normal force	
Nforce1	40 N
Nforce2	80 N
Nforce3	135 N

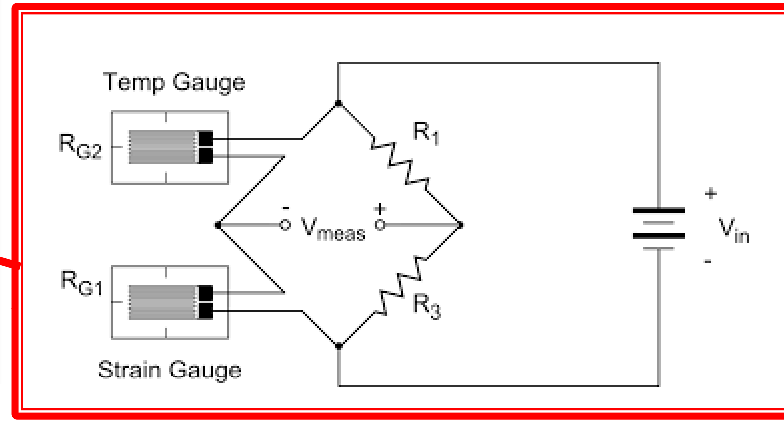
contact area (composite material)
Area1
12 mm^2

Stick-slip – brake system

Measurements of force in the plates with the following configuration:



Strain gauges in half bridge circuit

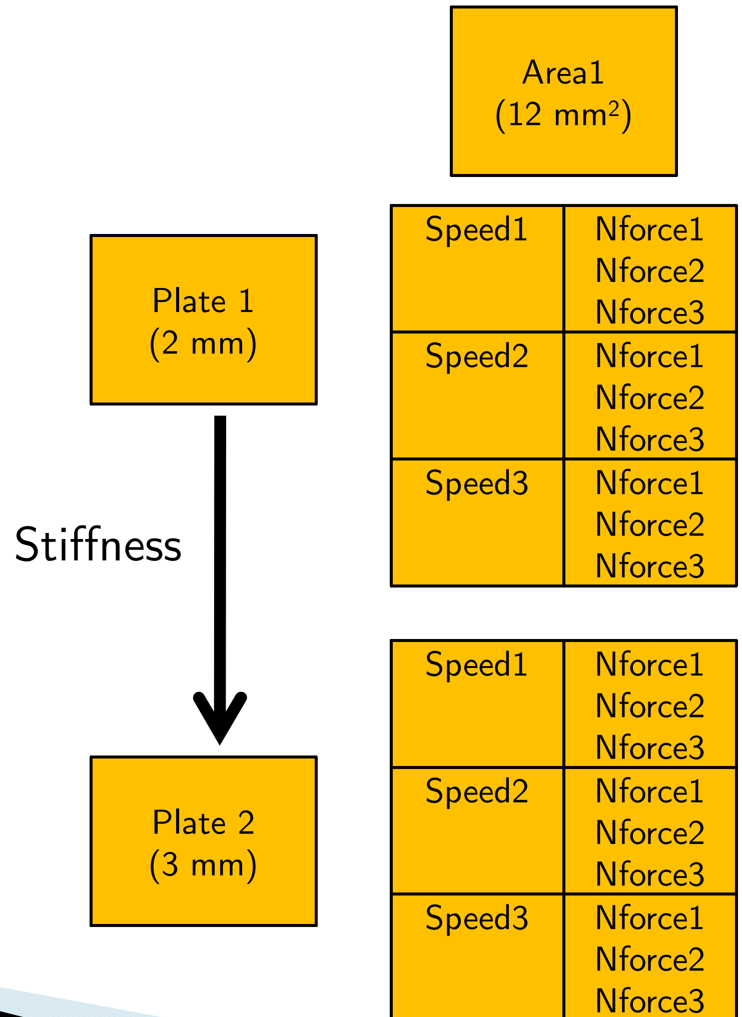


Strain gauges → Signal amplifier → Arduino board → PC and analysis

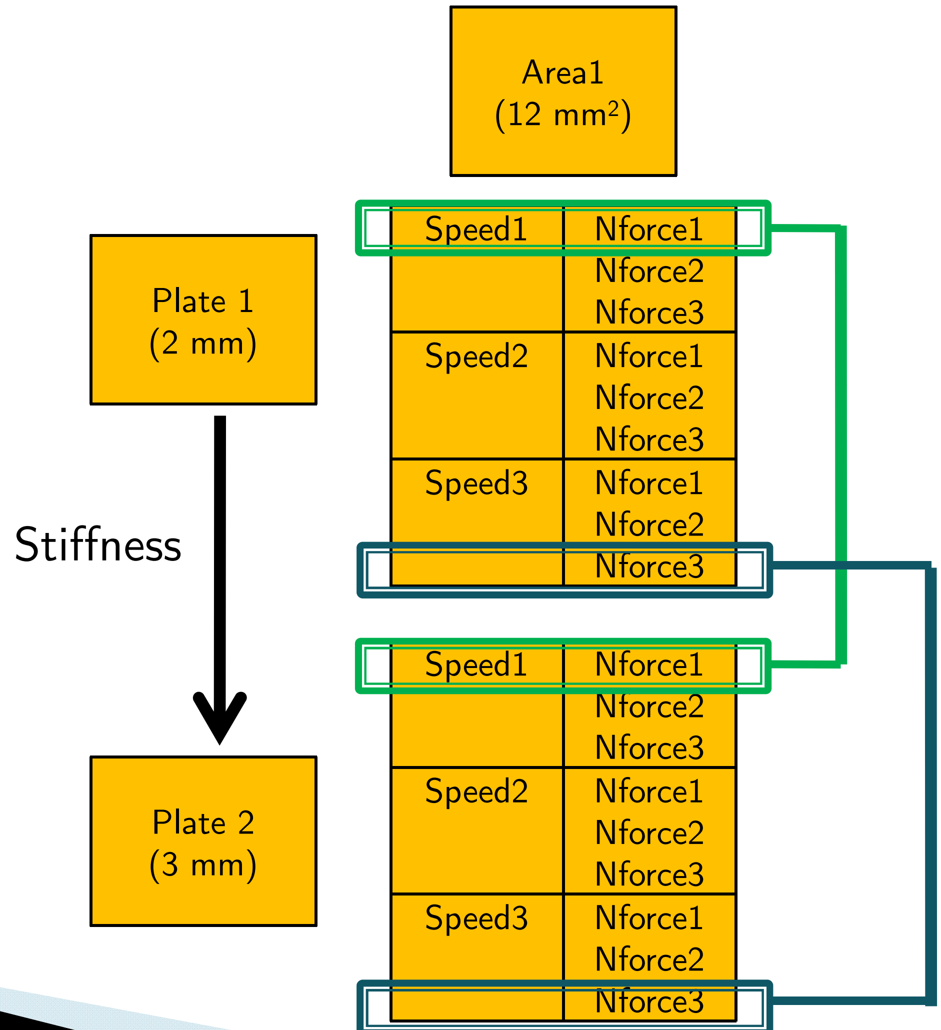
Arduino board

PC and analysis

Predicted experimental sequence



Predicted experimental sequence



Experiment (Speed1 – Nforce1)

Plate 3 mm – sample (contact area) 12 mm^2

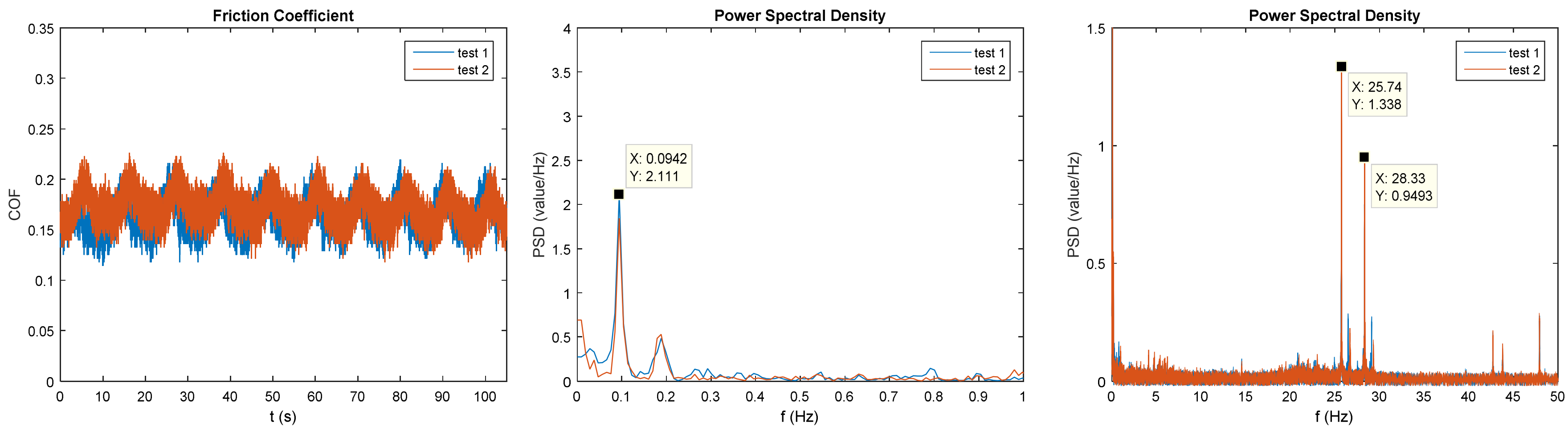
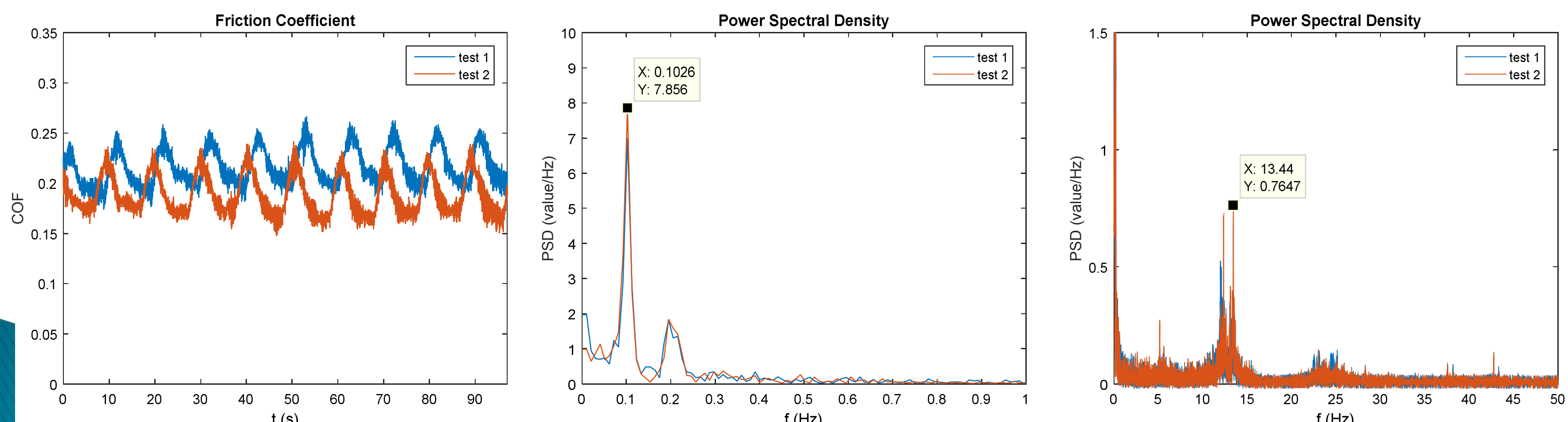


Plate 2 mm – sample (contact area) 12 mm^2



Experiment (Speed3 – Nforce3)

Plate 3 mm – sample (contact area) 12 mm^2

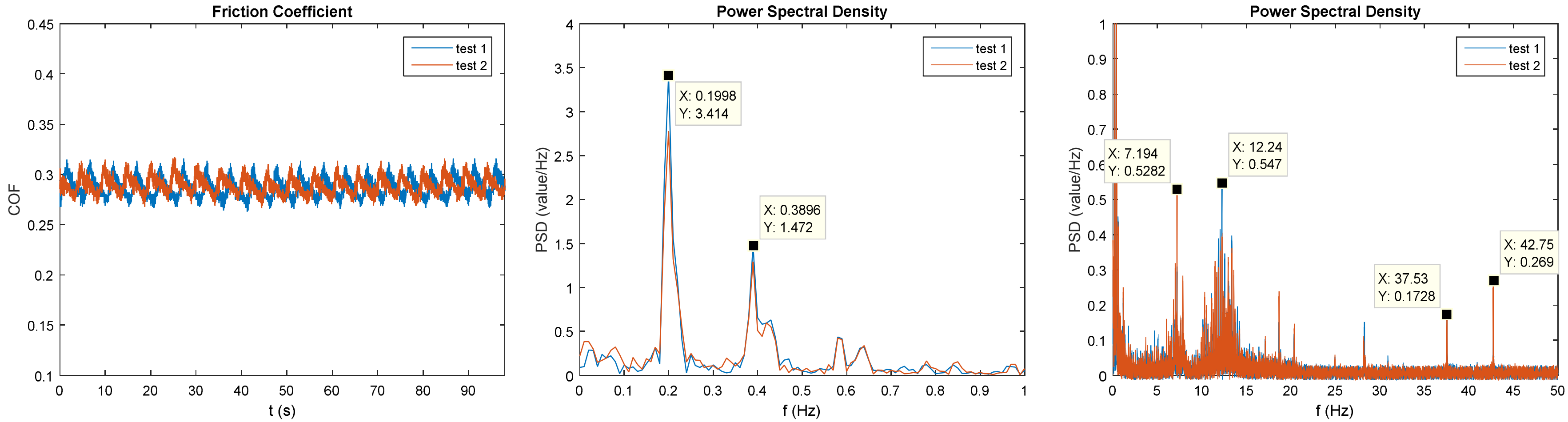
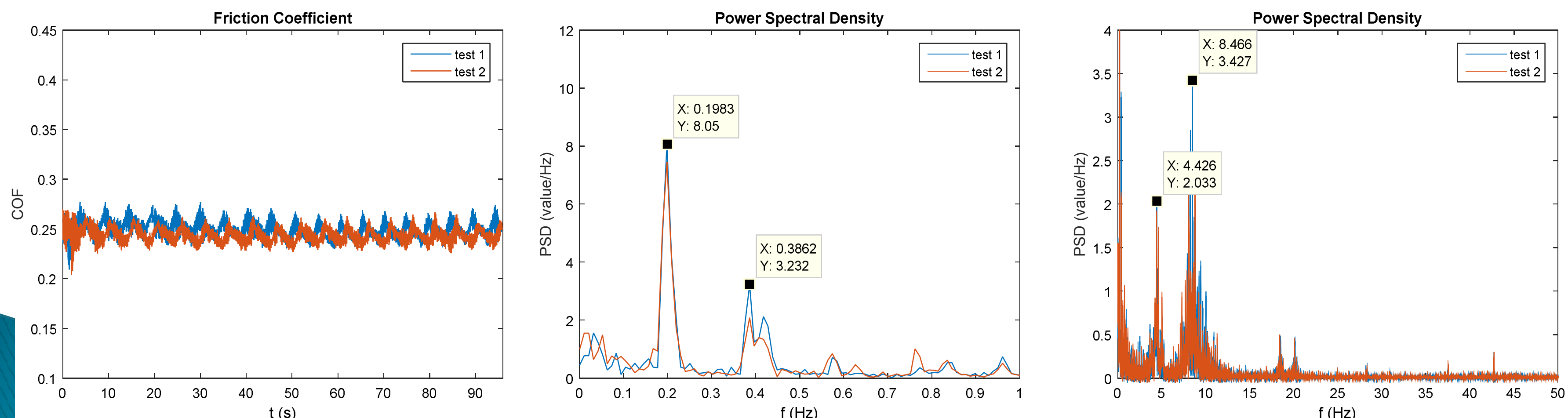


Plate 2 mm – sample (contact area) 12 mm^2



Kinect friction coefficient

Statistical analysis for all experiments

Plate 3 mm – sample (contact area) 12 mm²

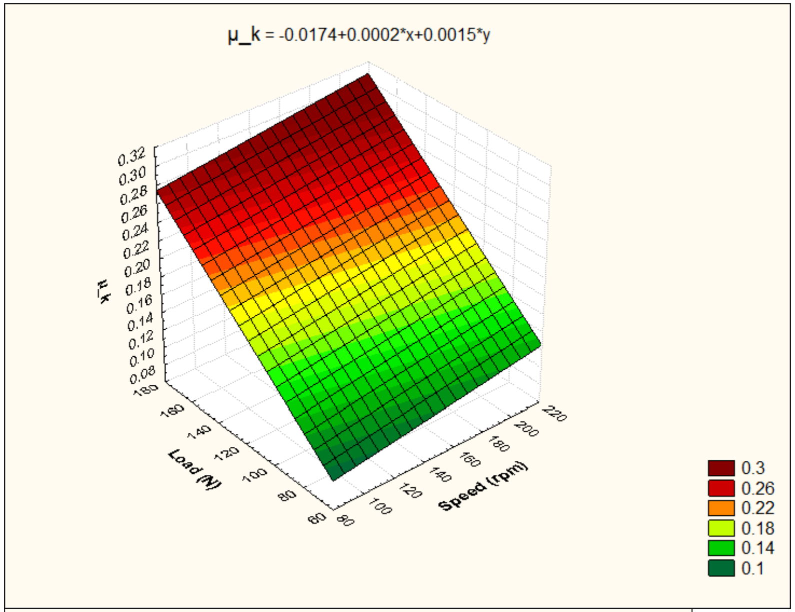
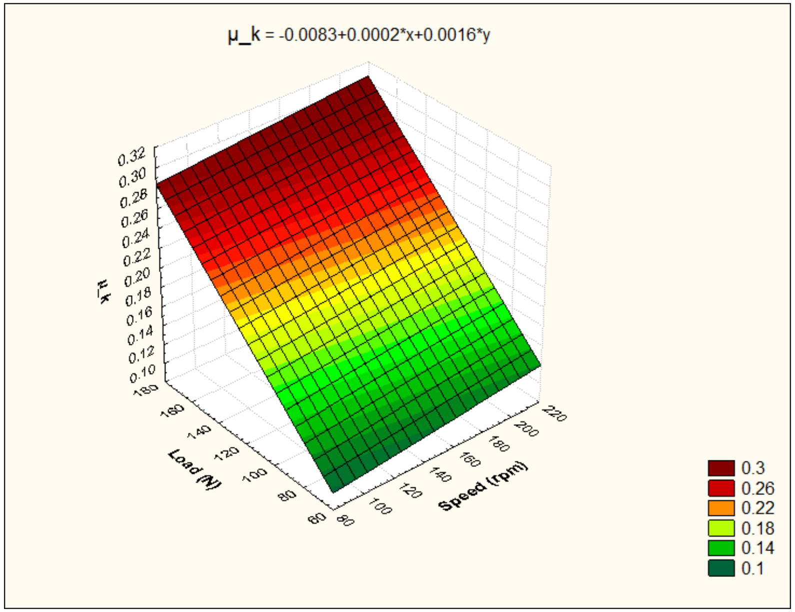
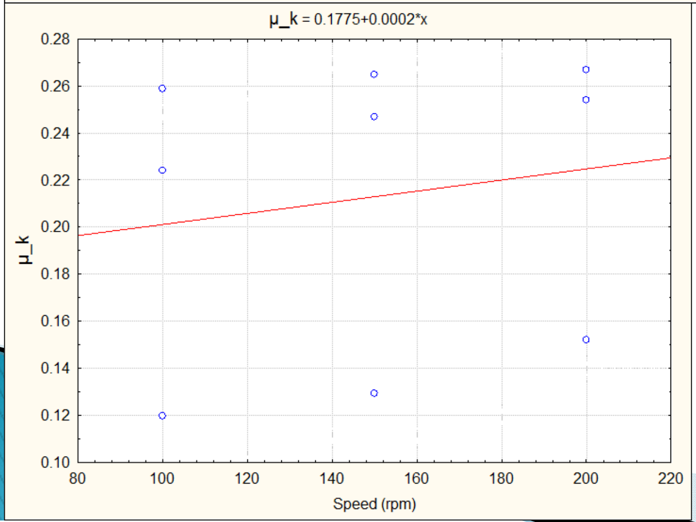


Plate 2 mm – sample (contact area) 12 mm²





Linear friction-velocity relationship gives rise to stick-slip vibration

Static friction coefficient

Statistical analysis for all experiments

Plate 3 mm – sample (contact area) 12 mm^2

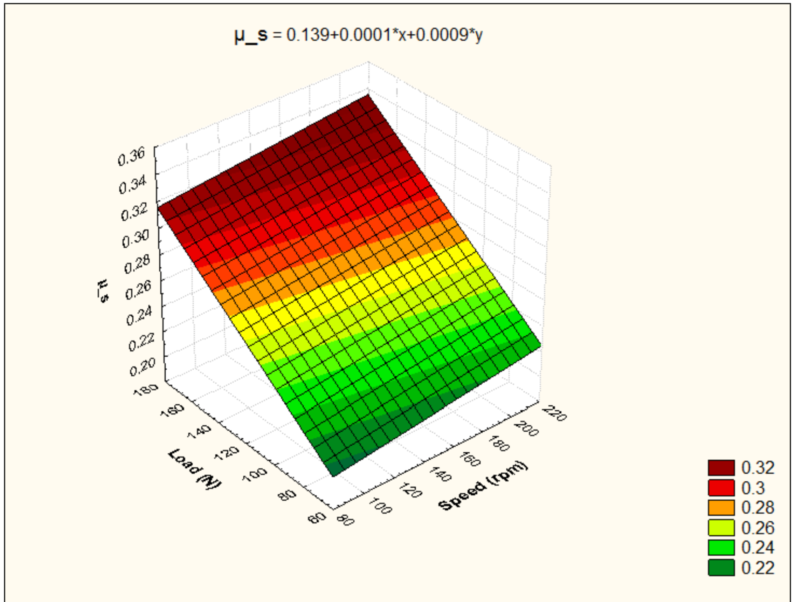
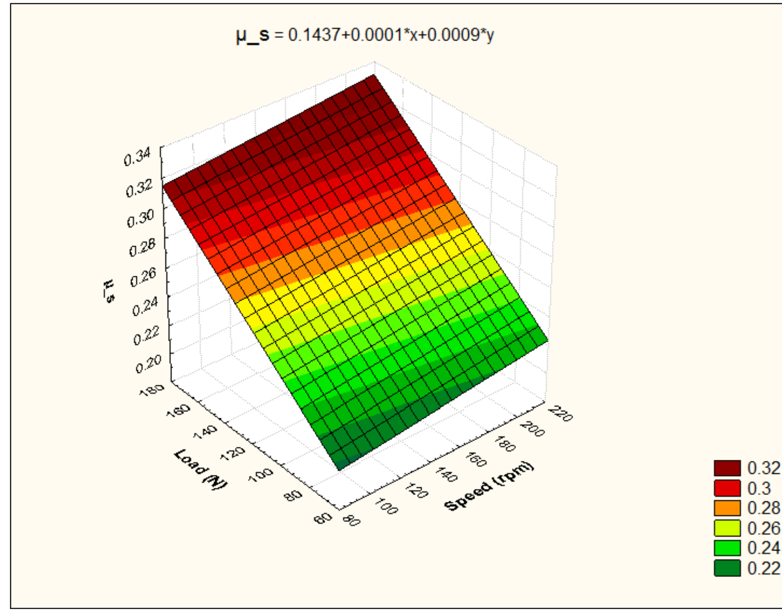
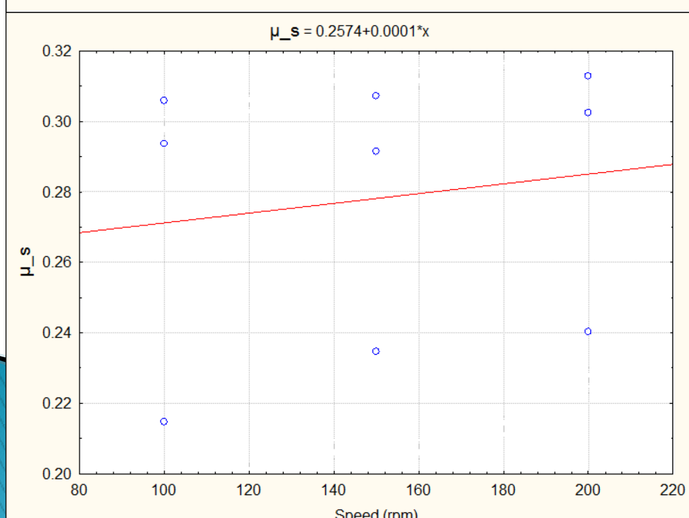


Plate 2 mm – sample (contact area) 12 mm^2





Linear friction-velocity relationship gives rise to stick-slip vibration

Stick-slip frequency

Statistical analysis for all experiments

Plate 3 mm – sample (contact area) 12 mm^2

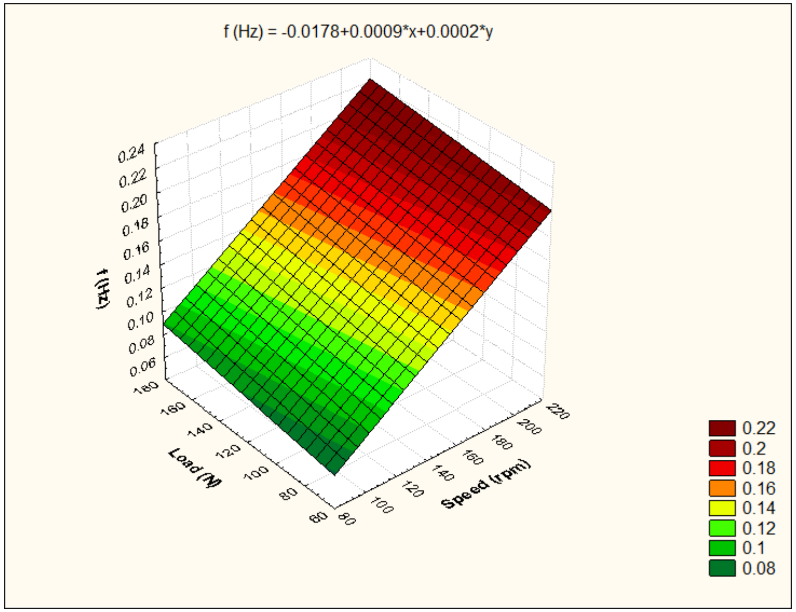
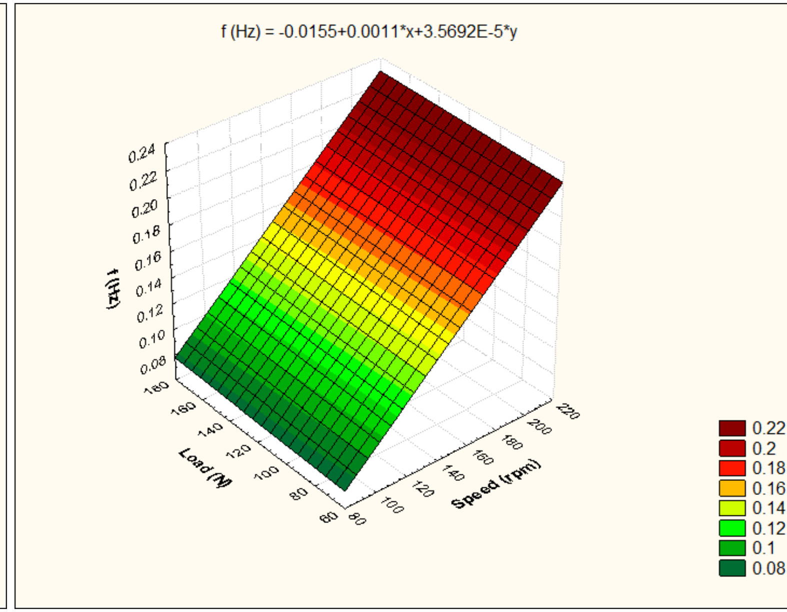


Plate 2 mm – sample (contact area) 12 mm^2



The experiments have shown a stable and predictable behavior.

If each studied configuration corresponded to an actual application for this supposed brake system, its operation would be reliable.

Highlights and conclusions

Stick-slip is an intermittent motion characterized by alternating of *static* phases, where the system accumulates potential energy, and *dynamic* phases, where this energy is transformed in kinetic energy.

This kind of motion play an important role in brake systems and it has to be taken into account in the design phase to achieve a stable and secure functioning of the mechanism.

The presented system provides a stick-slip dynamic rather predictable, with a linear friction-velocity relationship, for the different applied speeds in this study. No significant changes in friction coefficient for different normal forces applied.

In the PSD graphs, besides the peak referred to the stick-slip frequency, there are other peaks most likely related to the system vibration as a whole. In each test, these peaks appears for different frequencies. It is important to observe these frequencies to avoid quasi-harmonic or resonant vibration.