CAE Analyst : Brake Moan Simulation and Testing

Objective

❑ To understand the mechanism of Brake Moan Noise

❑ To develop the procedure for simulation of Brake Moan Noise with MotionView

Process/Methodology

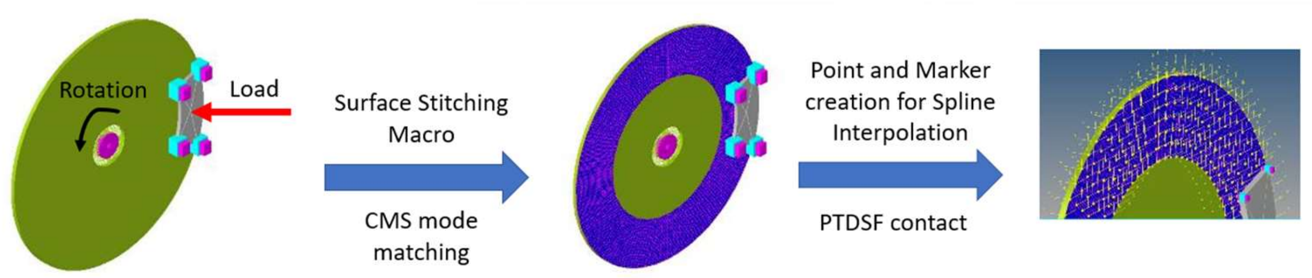
Basic Stick Slip Model ✓

Study of effect different parameters on the response ✓

Brake System Flexible Model ✓

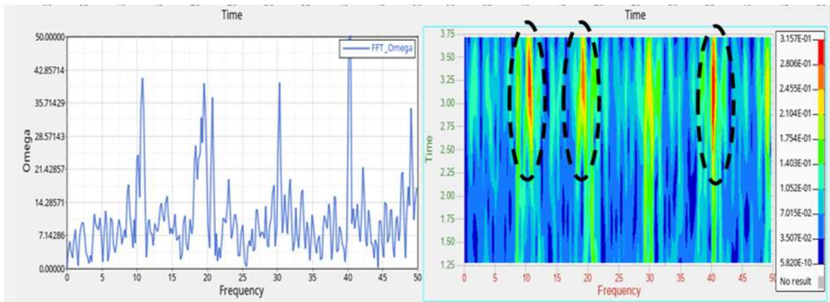
Python Script for Contact Model ✓

Subsystem Model build and Simulation setup



Simple Disc Brake Model

Simulation Results

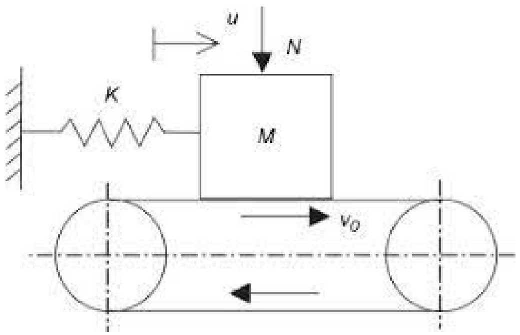


Status/Outcome/Results

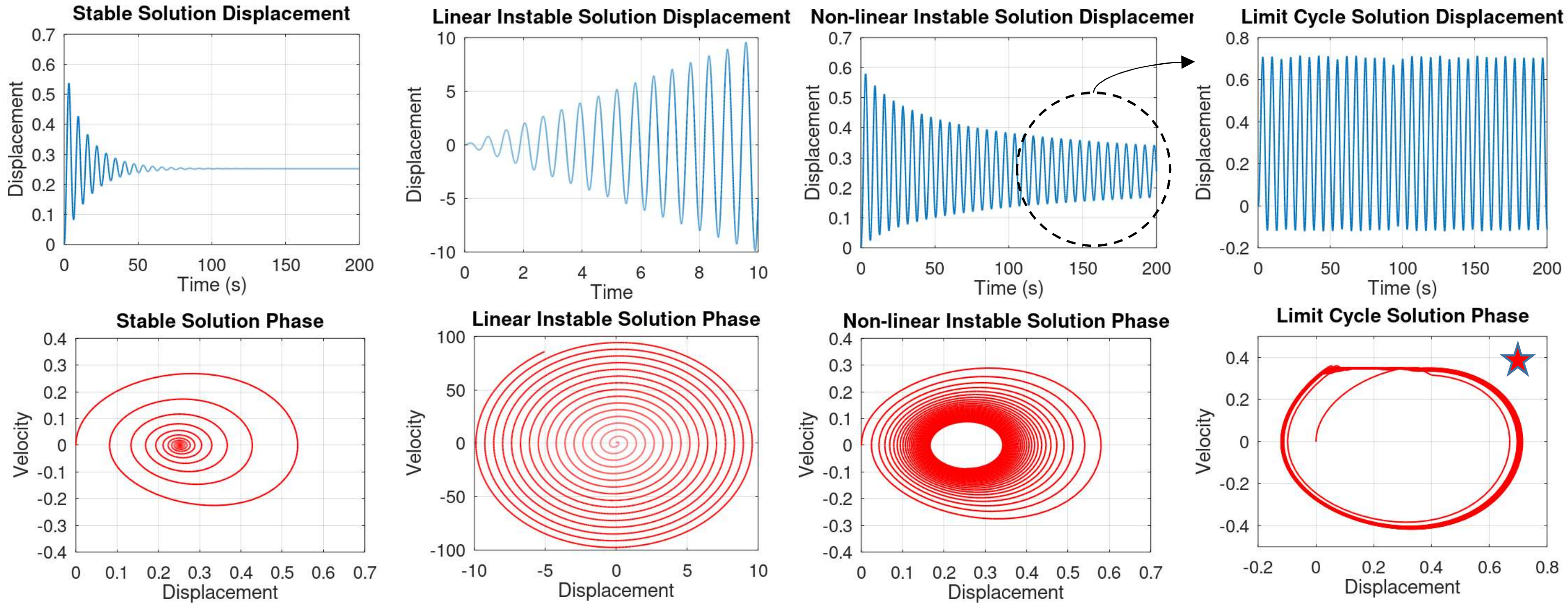
❑ Parameters are identified for simulation. Model is simulated with dummy values of friction. Tonal noise is simulated.

❑ Friction measurement is done. More pads to be tested when BTB is available.

Summary of different solutions with the Basic Stick-Slip model in the Literature Survey

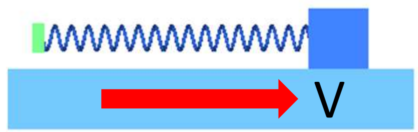


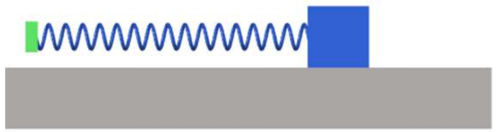
Basic Stick Slip Model

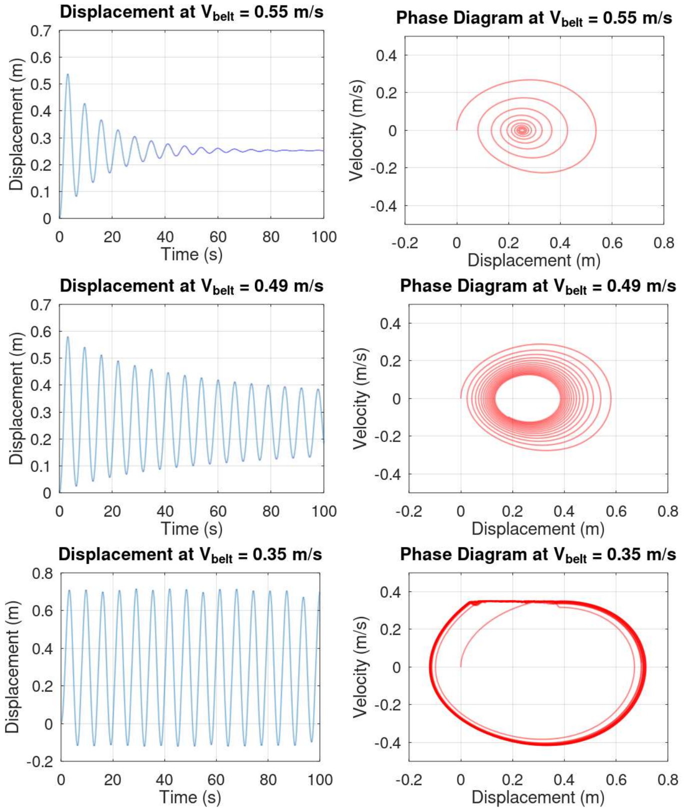


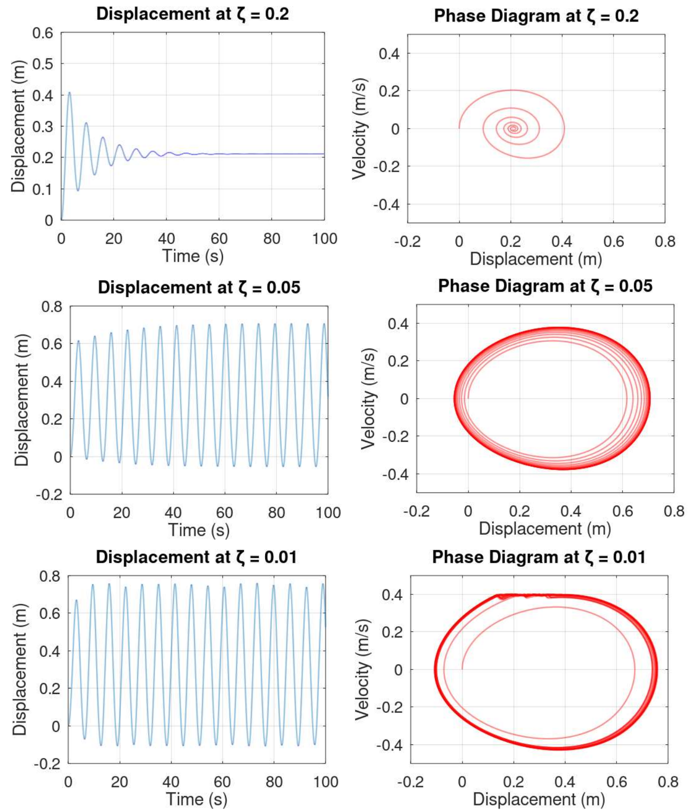
Stable Solution

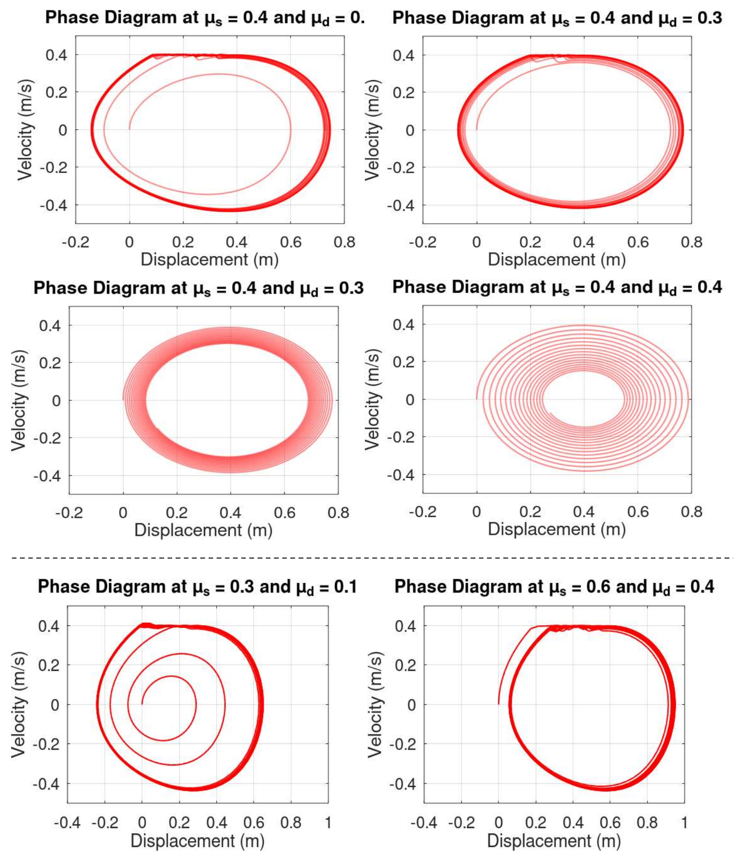
Limit Cycle






Displacement at V_{belt} = 0.55 m/s
Phase Diagram at V_{belt} = 0.55 m/s
Displacement at V_{belt} = 0.49 m/s
Phase Diagram at V_{belt} = 0.49 m/s
Displacement at V_{belt} = 0.35 m/s
Phase Diagram at V_{belt} = 0.35 m/s
Displacement (m)
Time (s)
Velocity (m/s)
Displacement (m)


Displacement at ζ = 0.2
Phase Diagram at ζ = 0.2
Displacement at ζ = 0.05
Phase Diagram at ζ = 0.05
Displacement at ζ = 0.01
Phase Diagram at ζ = 0.01
Displacement (m)
Time (s)
Velocity (m/s)
Displacement (m)

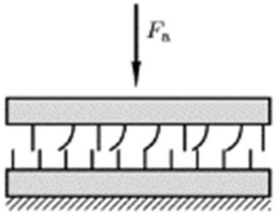

Phase Diagram at μ_s = 0.4 and μ_d = 0.
Phase Diagram at μ_s = 0.4 and μ_d = 0.3
Phase Diagram at μ_s = 0.4 and μ_d = 0.3
Phase Diagram at μ_s = 0.4 and μ_d = 0.4
Phase Diagram at μ_s = 0.3 and μ_d = 0.1
Phase Diagram at μ_s = 0.6 and μ_d = 0.4
Velocity (m/s)
Displacement (m)

Friction Stability ↑ →

- ↑ Disc Velocity
- ↑ Brake Pad Damping
- ↓ Static to Dynamic friction difference
- ↑ Axle Shaft Torsional Damping
- ↑ Transverse damping of Shims

LuGre Friction model

$T_f = Friction\ Torque$
$T_s = Static\ friction\ Torque$
$T_c = Dynamic\ friction\ Torque$
$z\ = Bristle\ Deflection$
$\dot{z}\ = Bristle\ Velocity$
$\sigma_0 = Bristle\ Stiffness$
$\sigma_1 = Bristle\ Damping$
$\sigma_2 = Propostionality\ Constant$
$\omega_m = Motor\ rotational\ speed$
$\omega_s = Stick - slip\ transition\ speed$



Friction Torque Formulation

$$T_f = \sigma_0 \cdot z + \sigma_1 \cdot \dot{z} + \sigma_2 \cdot \omega_m$$

$$\dot{z} = \omega_m - \frac{|\omega_m|}{g(\omega_m)} \cdot z$$

$$\sigma_0 \cdot g(\omega_m) = T_c + (T_s - T_c) \cdot exp\left(-\left(\frac{\omega_m}{\omega_s}\right)^2\right)$$

Relative speed between the two surfaces is zero at steady rotor speed

$$Torque\,|_{Motor} = Inertia \cdot \cancel{\alpha} + Torque\,|_{Friction}$$

Experimental Setup [8]

- Angular acceleration is zero
- Relative bristle deflection zero
- Bristle Velocity is zero

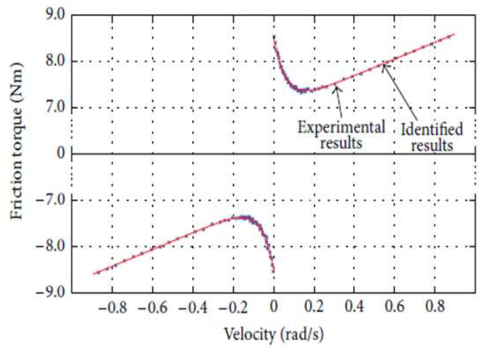
$$T_f = \sigma_0 \cdot z + \cancel{\sigma_1 \cdot} \dot{z} + \sigma_2 \cdot \omega_m \quad \Rightarrow \quad T_f = \sigma_0 \cdot z + \sigma_2 \cdot \omega_m$$

Friction Torque Estimation

$$\left[T_c + (T_s - Tc) \cdot exp\left(-\left(\frac{\omega_m}{\omega_s}\right)^2\right)\right] \cdot sgn(\omega_m) + \sigma_2 \cdot \omega_m$$

Steady State Parameters

$$\Omega_s = [T_c, T_s, \omega_s, \sigma_2]$$



Steady State Parameters

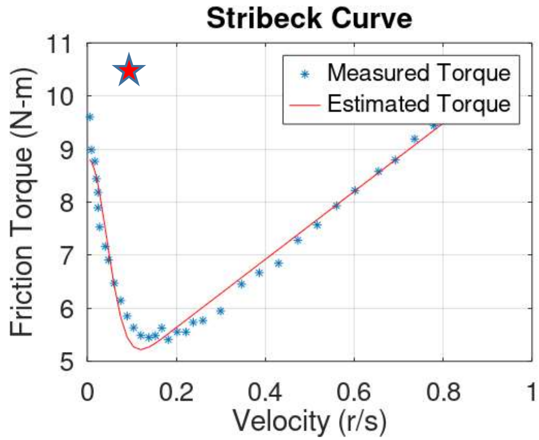
$$\Omega_s = [T_c, T_s, \omega_s, \sigma_2]$$

Error Formulation

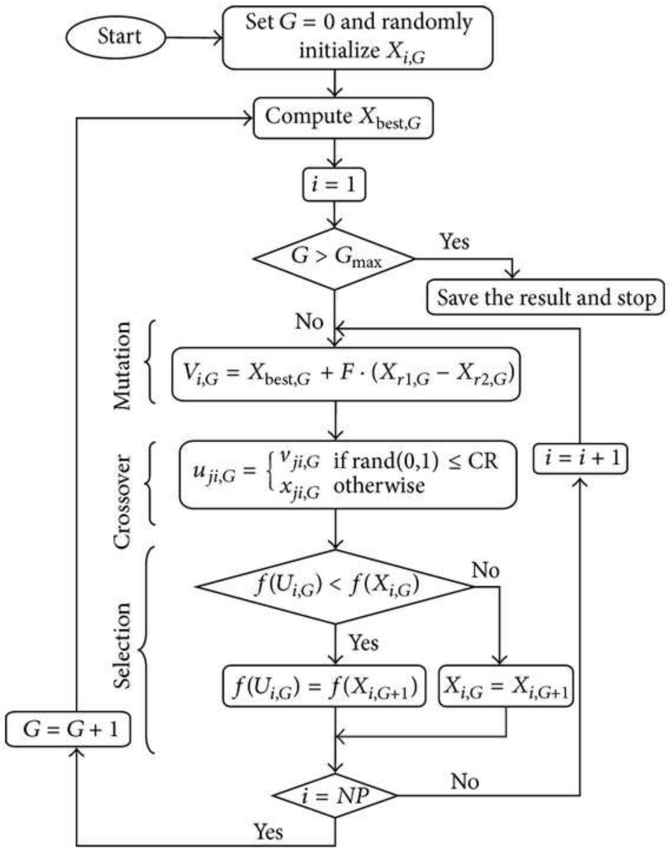
$$Erf(i) = T_{measured}(i) - T_{estimated}(\Omega_s, \omega_m, i)$$

Objective Function

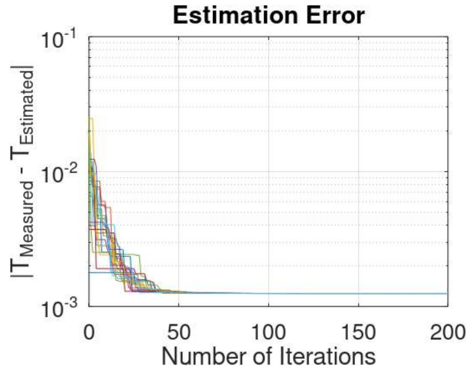
$$Objective\ Function = \frac{1}{2}\sum (Erf(i))^2$$



Differential Evolution Algorithm



Repeatability



Computer Specification

G = 200
Serial Computing
Ram = 128 GB
CPU = 2.4 GHz
Time ~ 12.5 s

Parameter	Paper (TVM)	OCTAVE code (DE)
Dynamic Torque (N-m)	6.975	4.352
Static Torque (N-m)	8.558	8.802
Sigma_2	1.819	6.416
Sliding Speed (r/s)	0.06109	0.0613
Population	-	50
Cross Over Probability	-	0.8
Selection Probability	-	0.85
Mutation Probability	-	-

Friction Torque Formulation

$$T_f = \sigma_0 \cdot z + \sigma_1 \cdot \dot{z} + \sigma_2 \cdot \omega_m$$

$$\dot{z} = \omega_m - \frac{|\omega_m|}{g(\omega_m)} \cdot z$$

$$\sigma_0 \cdot g(\omega_m) = T_c + (T_s - T_c) \cdot exp\left(-\left(\frac{\omega_m}{\omega_s}\right)^2\right)$$

Dynamic Parameters

$$\Omega_d = [\sigma_0, \sigma_1]$$

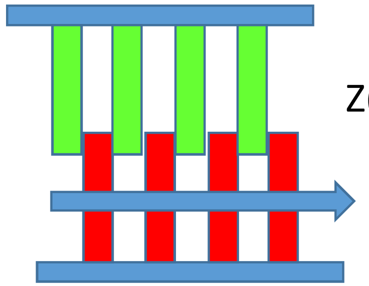
Error Formulation

$$Erf(i) = T_{measured}(i) - T_{estimated}(\Omega_s, \omega_m, i)$$

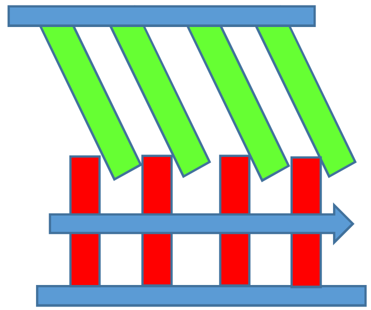
Objective Function

$$Objective\ Function = \frac{1}{2}\sum (Erf(i))^2$$

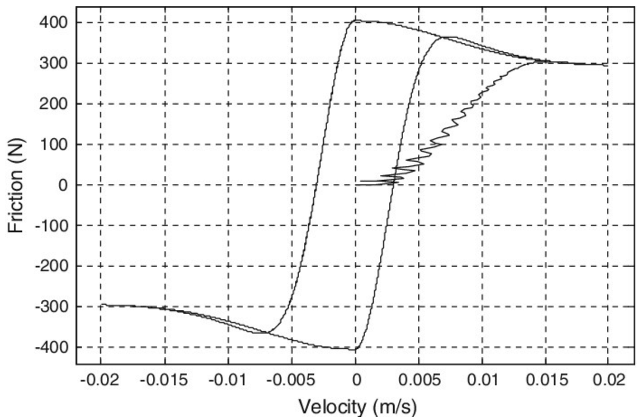
$$Torque\,|_{Motor} = Inertia \cdot \cancel{\alpha} + Torque\,|_{Friction}$$



Z(0) = 0



Z(T)



- In the literature, torque is given as input and velocity is measured
- We are measuring friction hysteresis by velocity cycle input
- Measurement to be taken in pre-sliding region

Dynamic Parameters

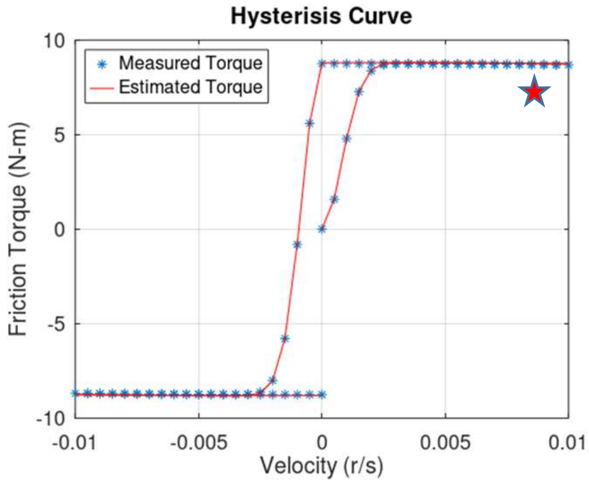
$$\Omega_d = [\sigma_0, \sigma_1]$$

Error Formulation

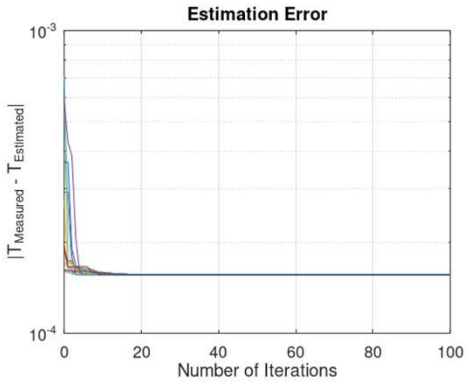
$$Erf(i) = T_{measured}(t, i) - T_{estimated}(\Omega_d, \omega_m, t, i)$$

Objective Function

$$Objective\ Function = \frac{1}{2}\sum (Erf(i))^2$$



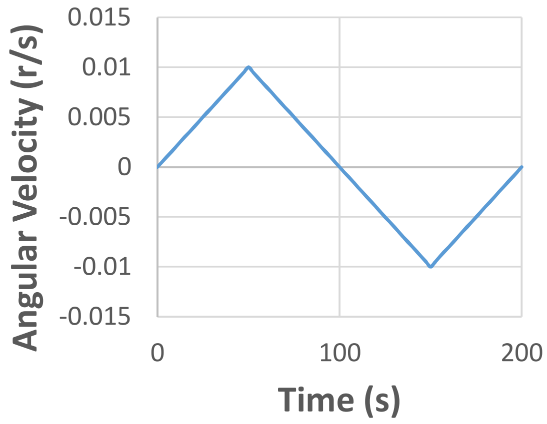
Repeatability

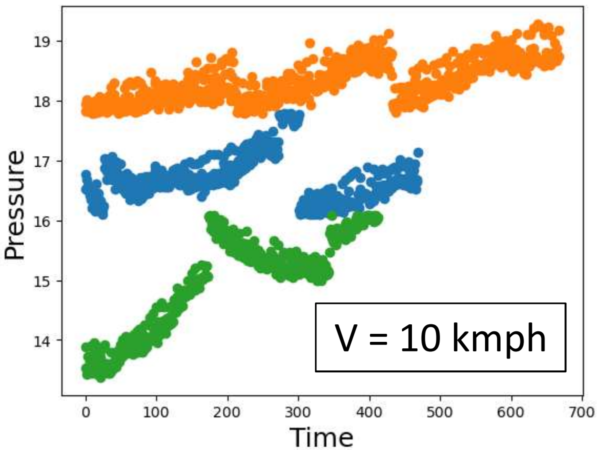


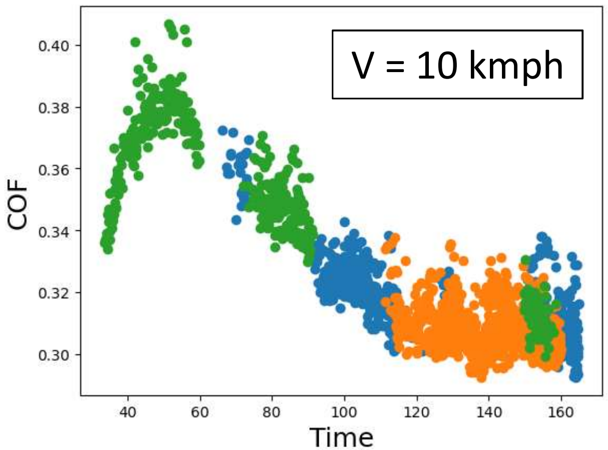
Computer Specification

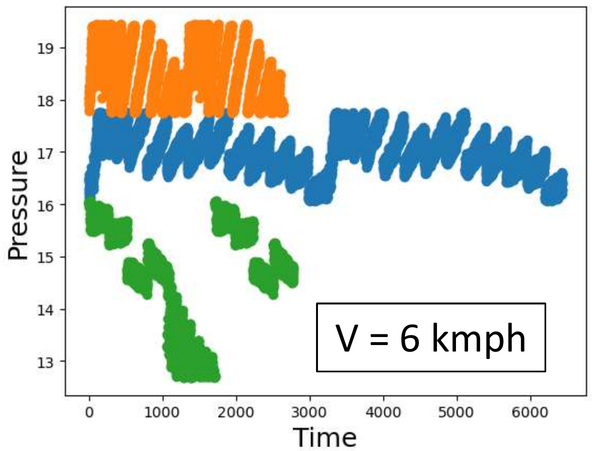
G = 100
Time steps : 83
Serial Computing
Ram = 128 GB
CPU = 2.4 GHz
Time ~ 30 mins

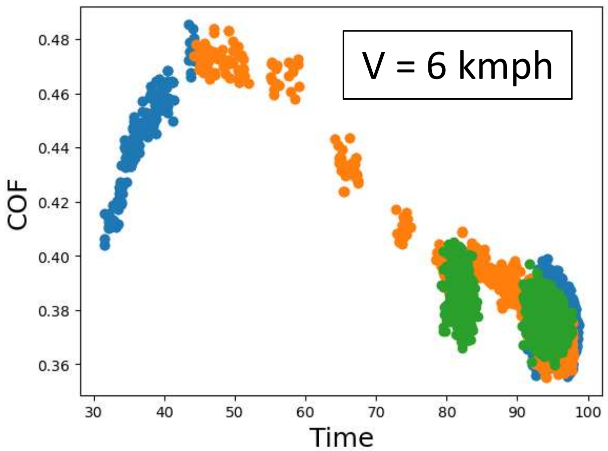
Parameter	Paper (TVM)	OCTAVE code (DE)
Sigma_0	2750	2695.83
Sigma_1	45.2	174.04
Population	-	50
Cross Over Probability	-	0.8
Selection Probability	-	0.85
Mutation Probability	-	-









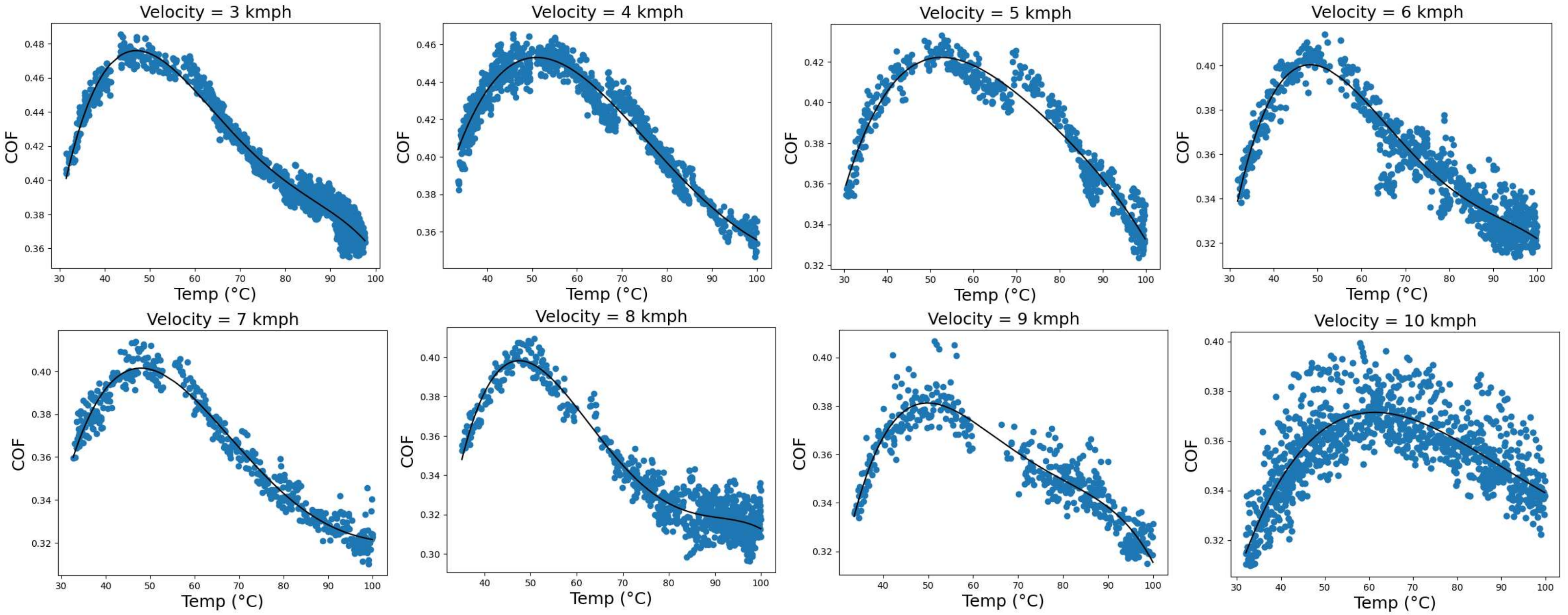


- Although the pressure is different the Coefficient of Friction varying mainly due to temperature change

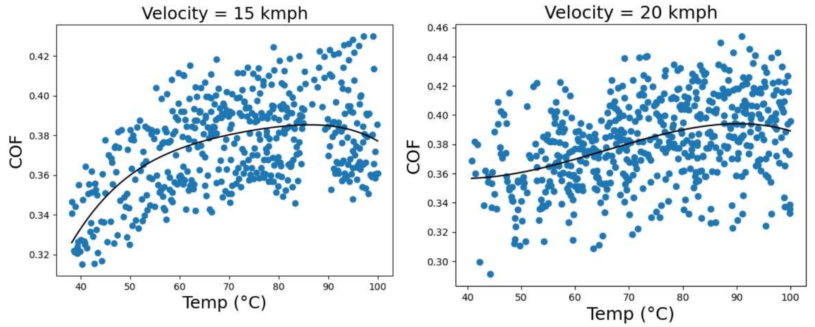
- The input lever force governs how fast the temperature changes. At high lever force the temperature rise is high. This could be possible reason in panic brake condition.

	vel	T_cor	F_lever	T_SG	press	temp	pos	mu
vel	1.000000	-0.209661	-0.273443	-0.272209	-0.046012	0.051890	0.087503	-0.146159
T_cor	-0.209661	1.000000	0.134834	0.844547	0.652304	0.149819	-0.585756	-0.152297
F_lever	-0.273443	0.134834	1.000000	0.160211	0.304707	0.468732	0.295984	-0.264239
T_SG	-0.272209	0.844547	0.160211	1.000000	0.637414	0.140634	-0.535206	-0.015946
press	-0.046012	0.652304	0.304707	0.637414	1.000000	0.742944	-0.170720	-0.778188
temp	0.051890	0.149819	0.468732	0.140634	0.742944	1.000000	0.484158	-0.858661
pos	0.087503	-0.585756	0.295984	-0.535206	-0.170720	0.484158	1.000000	-0.232458
mu	-0.146159	-0.152297	-0.264239	-0.015946	-0.778188	-0.858661	-0.232458	1.000000

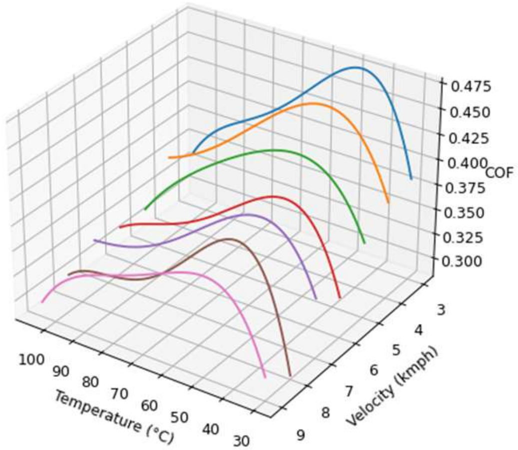
Co-relation matrix at fixed velocity



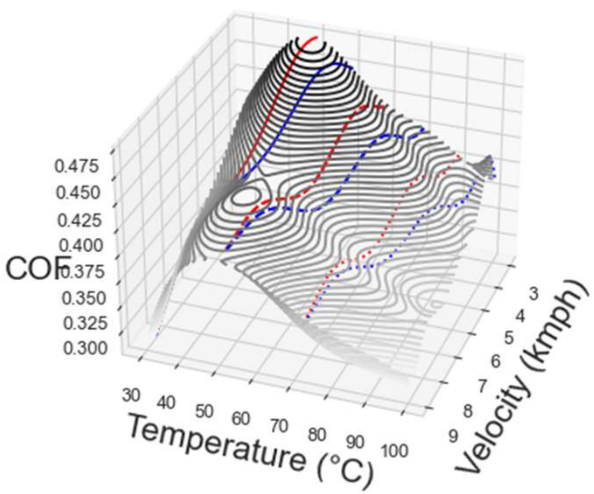
Velocity = 3 kmph
Velocity = 4 kmph
Velocity = 5 kmph
Velocity = 6 kmph
Velocity = 7 kmph
Velocity = 8 kmph
Velocity = 9 kmph
Velocity = 10 kmph
COF
Temp (°C)



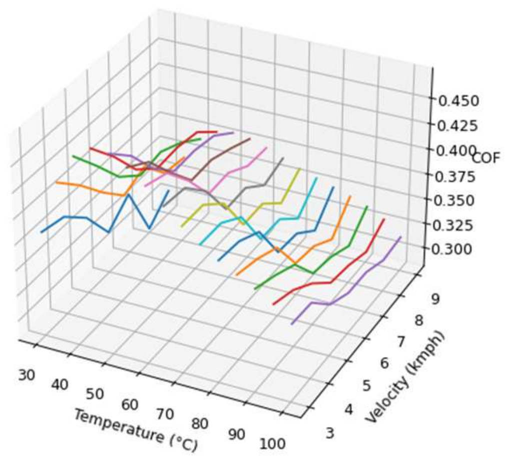
Velocity = 15 kmph
Velocity = 20 kmph
COF
Temp (°C)



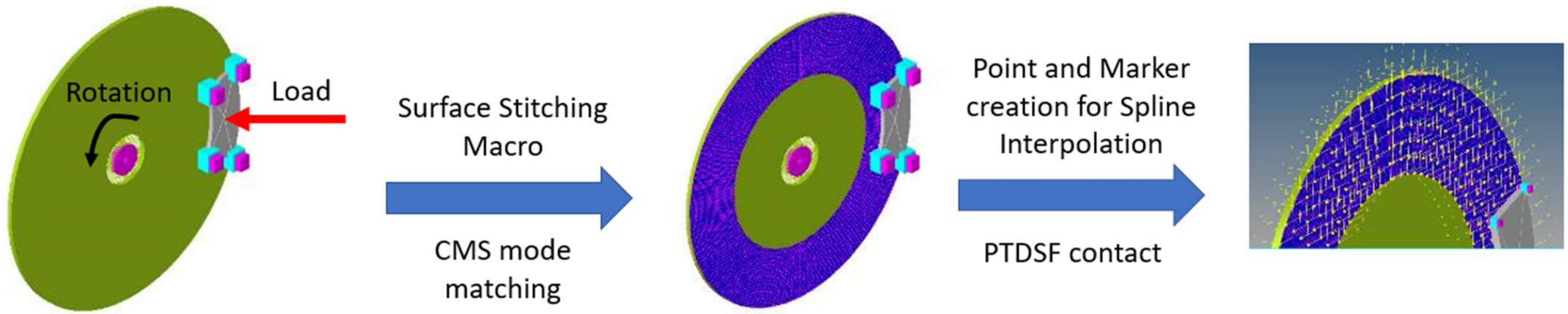
COF
Temperature (°C)
Velocity (kmph)



COF
Temperature (°C)
Velocity (kmph)

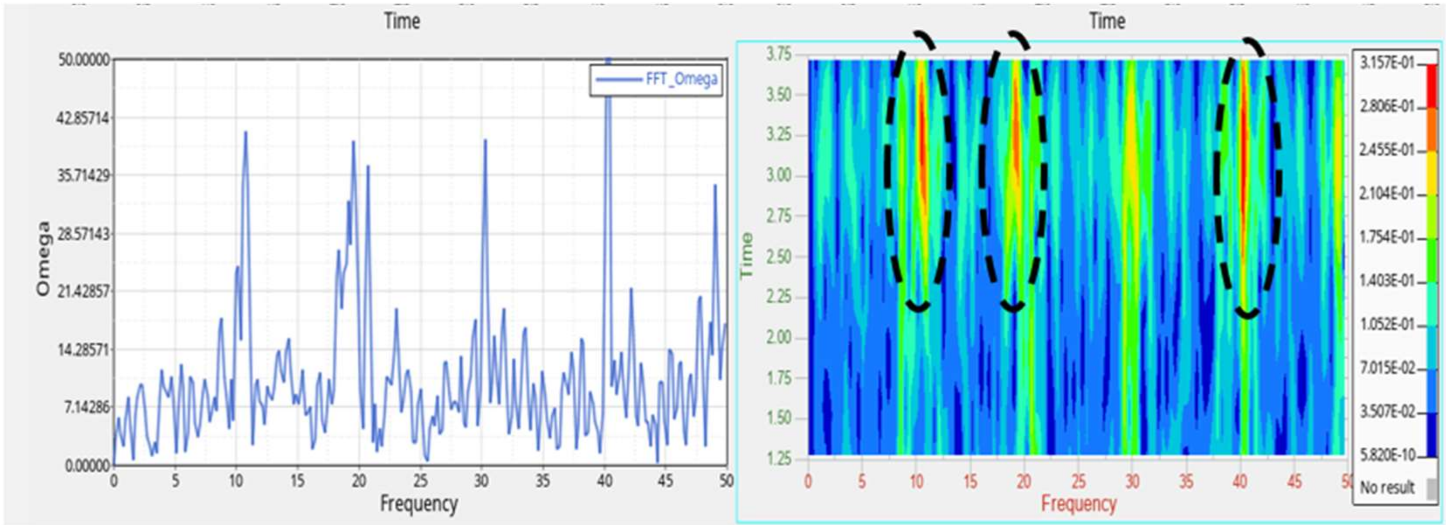


COF
Temperature (°C)
Velocity (kmph)

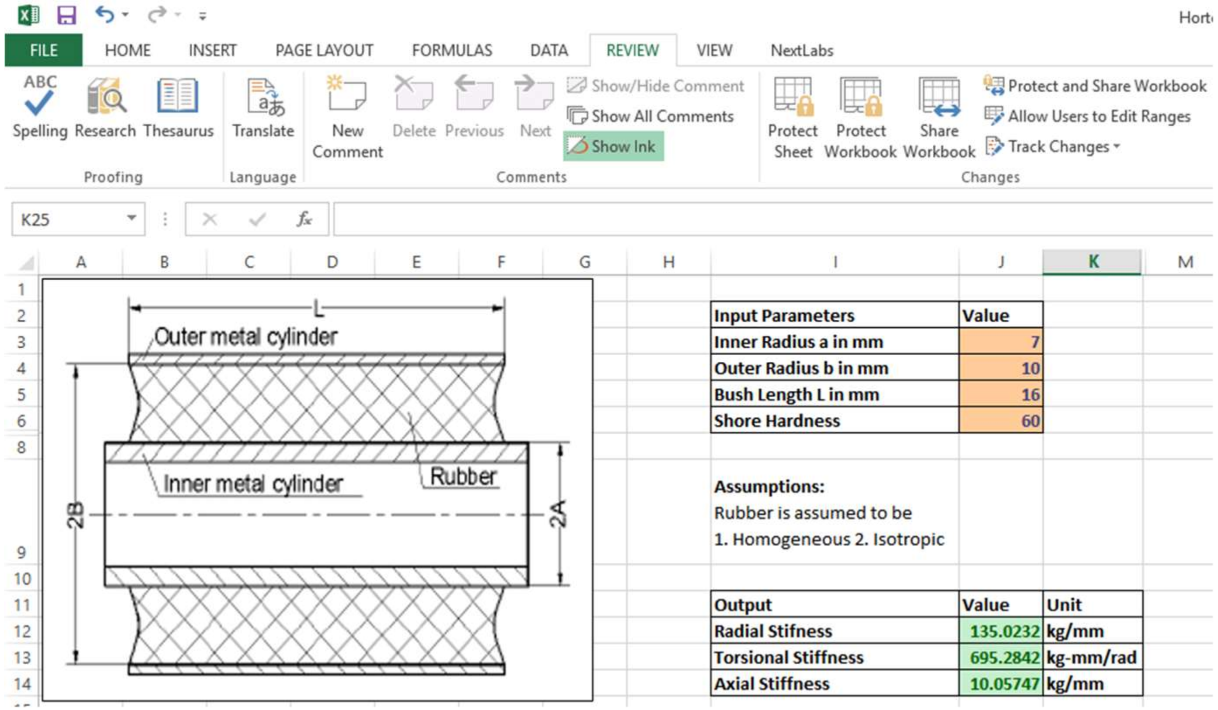


Simple Disc Brake Model

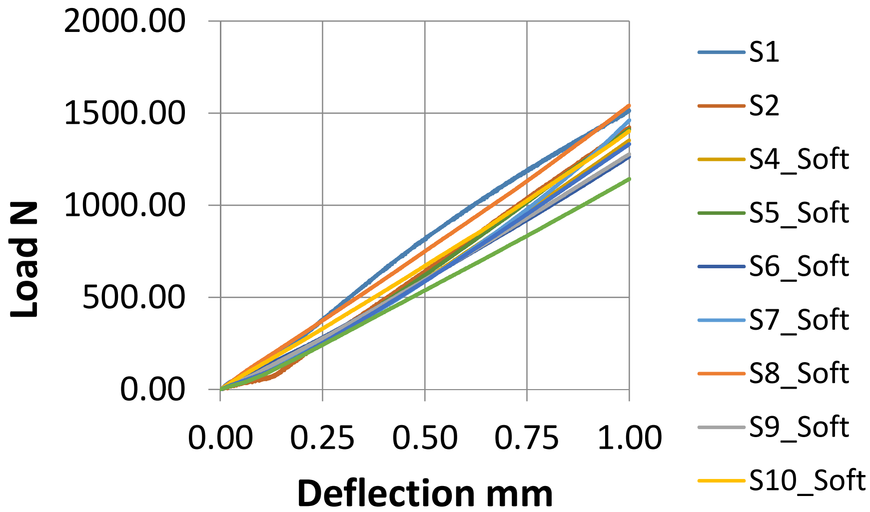
Simulation Results



Rubber Bush Radial Stiffness Prediction



Excel Sheet Prediction of Cylindrical Rubber Bush Stiffness



Measured Values of Radial Stiffness

$$K_{Measured} = 133.15 \pm 17\ Kg/mm$$
$$K_{Predicted} = 135.05\ Kg/mm$$