

Development of Clunk Noise Numerical Model

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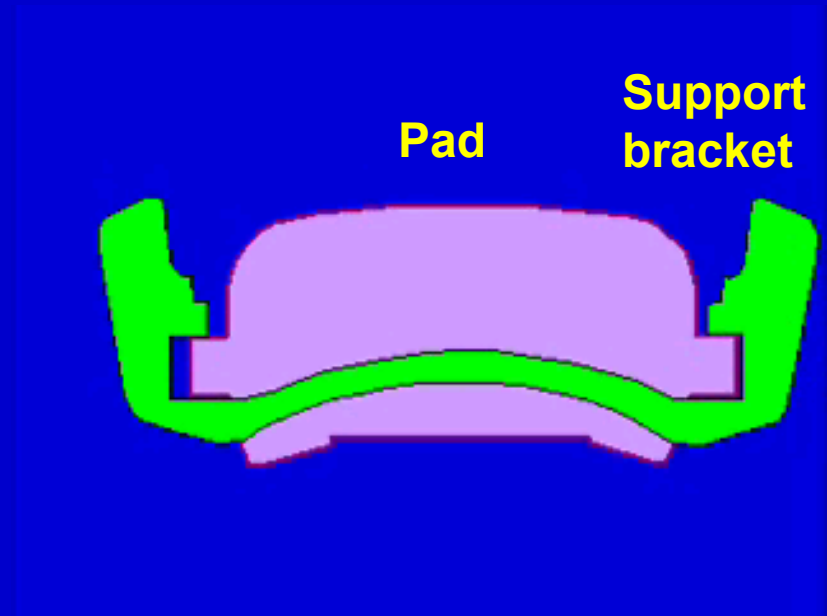
Explanation of clunk noise

- Brake clunk noise is a type of impact sound caused by movements of the disc pad impacting the anchor when the vehicle moves between forward and backward.



Backward ← → Forward

A Clunk noise movie

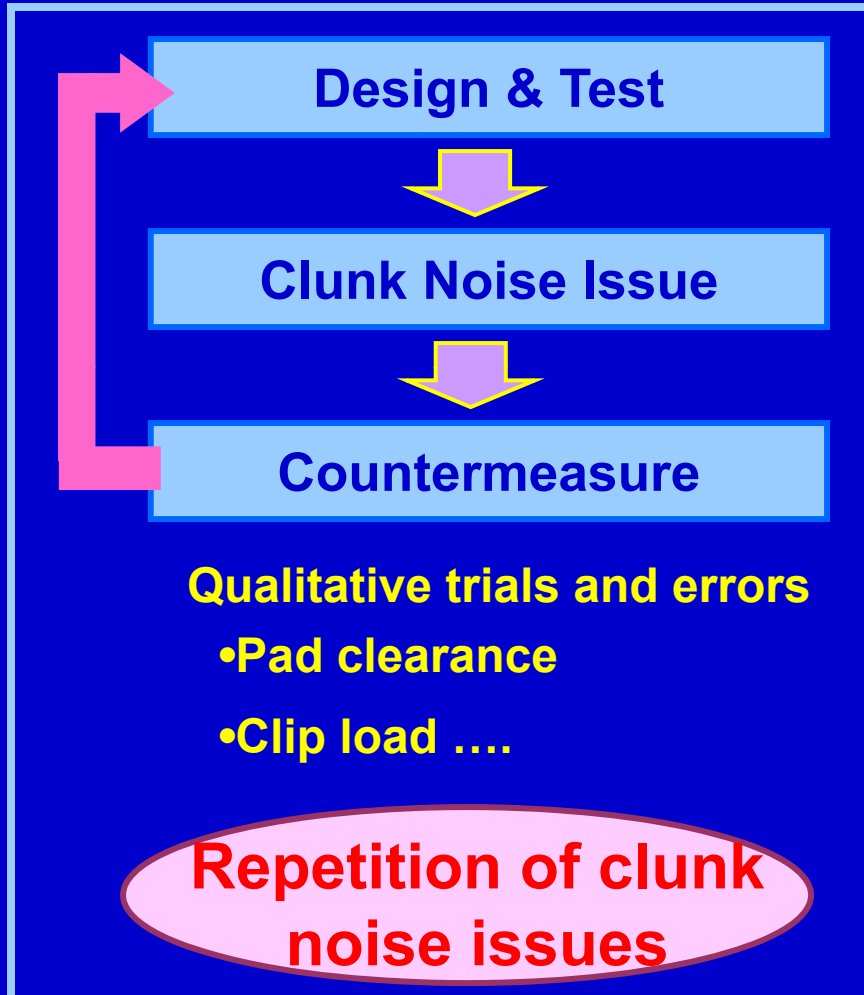


Backward ← → Forward

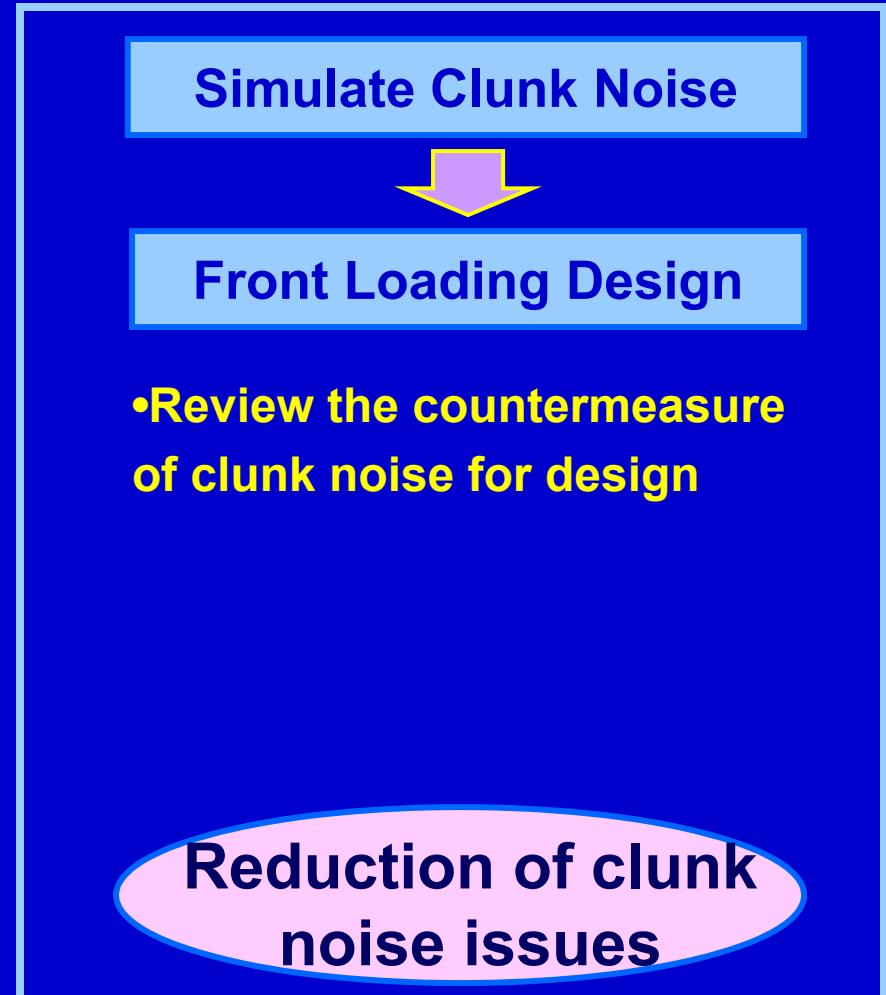
Image

Objective of this research

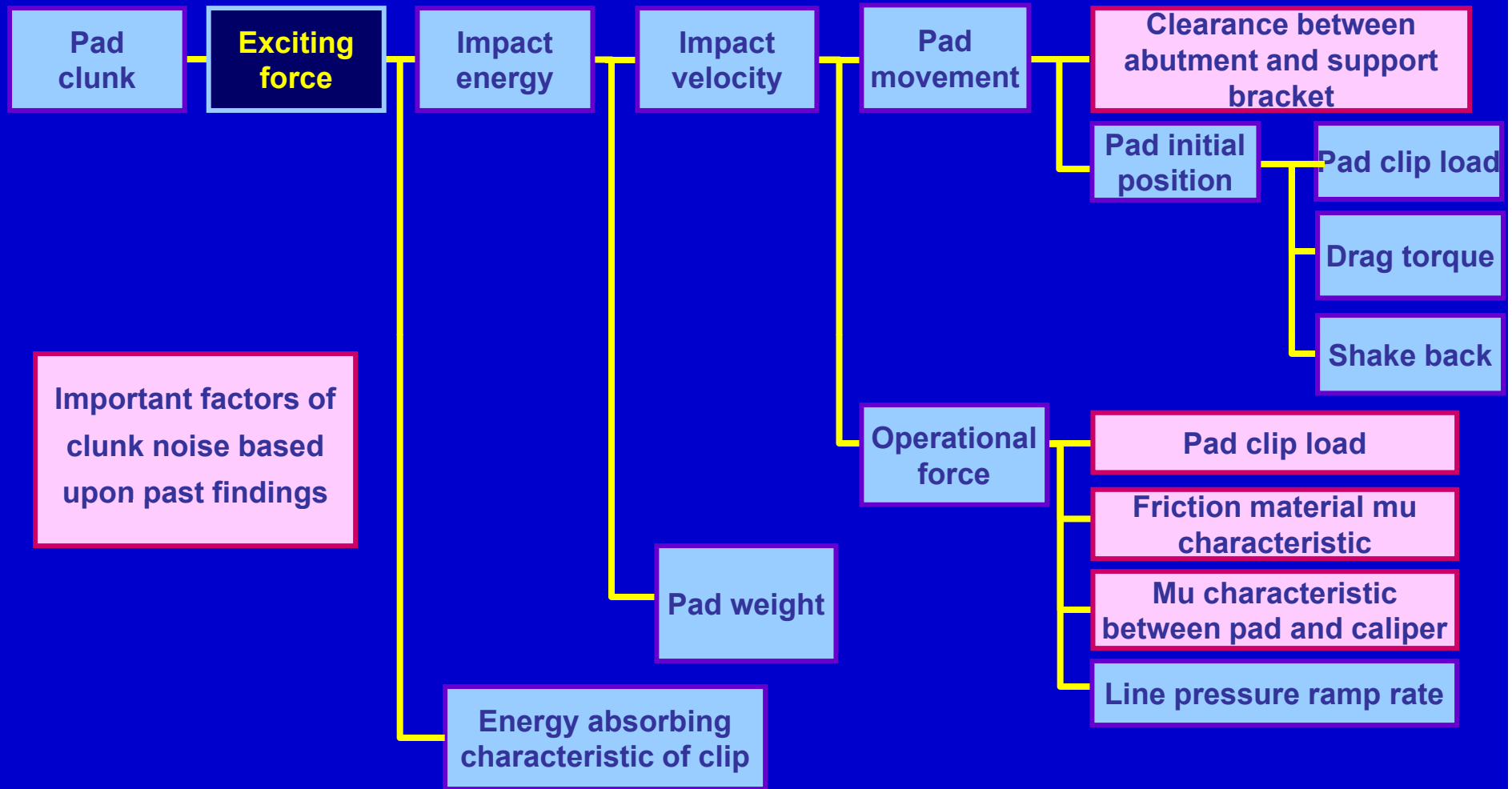
Conventional Development Process



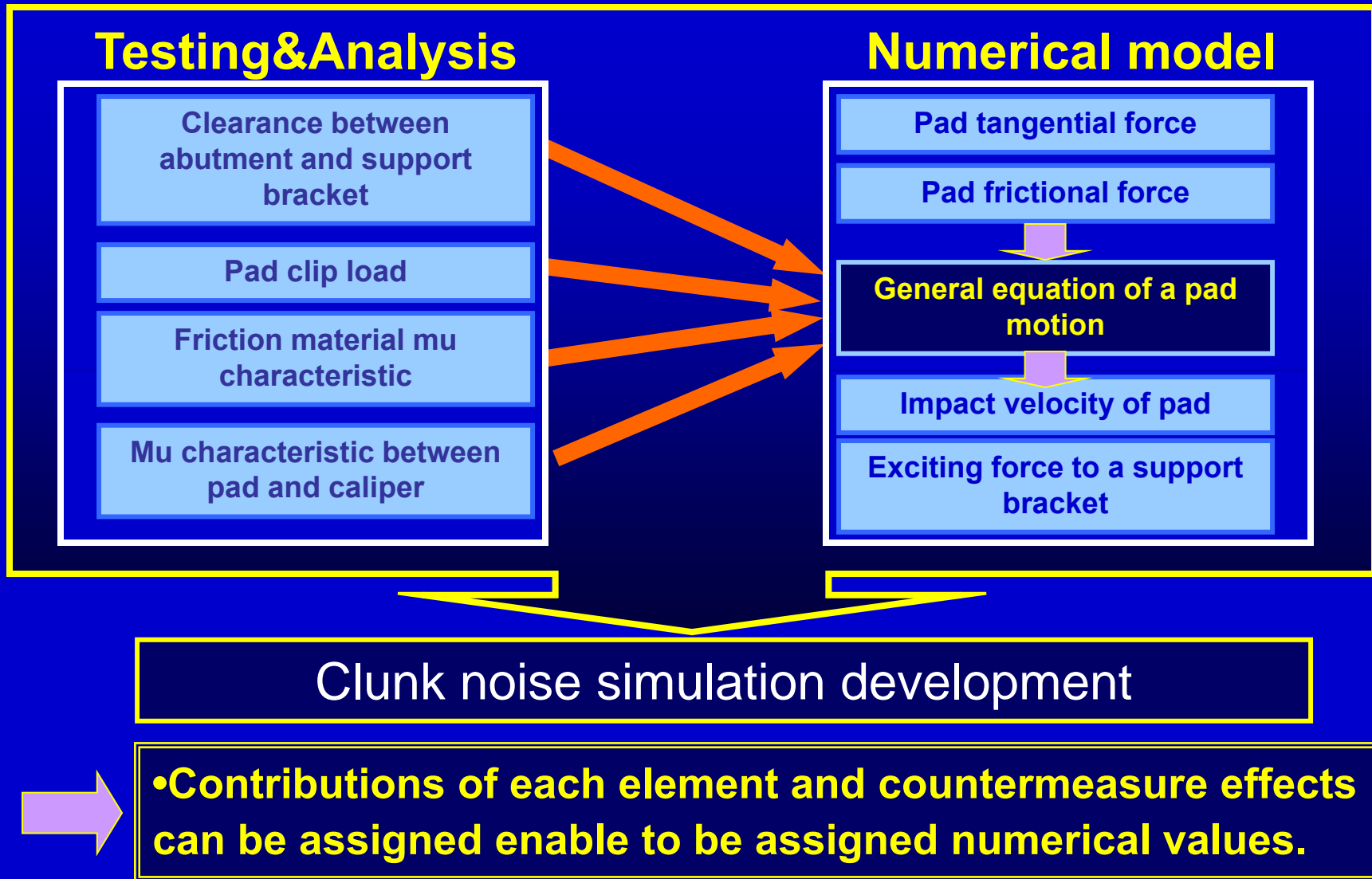
Future Development Process



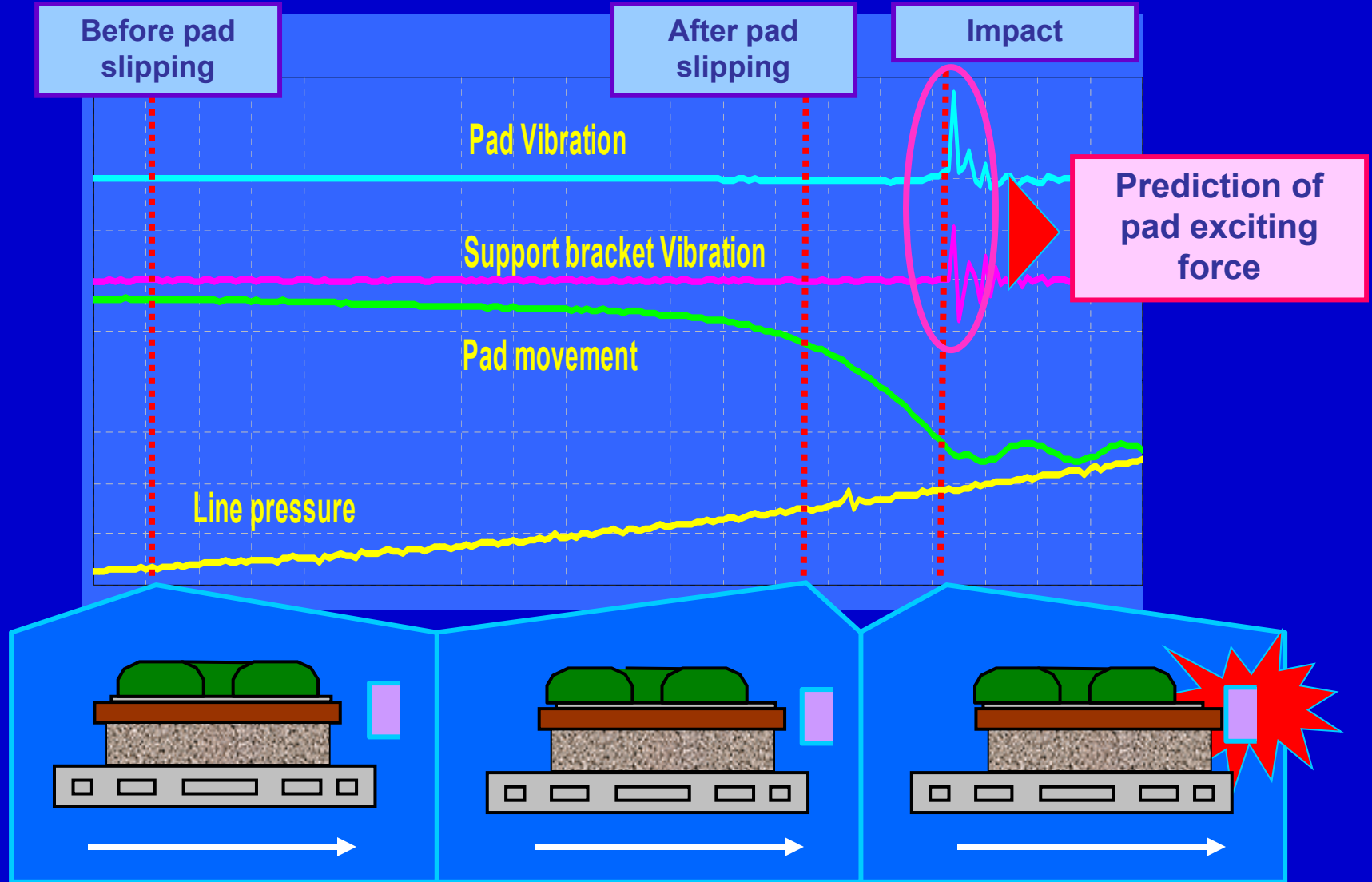
Clunk noise occurrence factor chart



Clunk noise simulation development flow

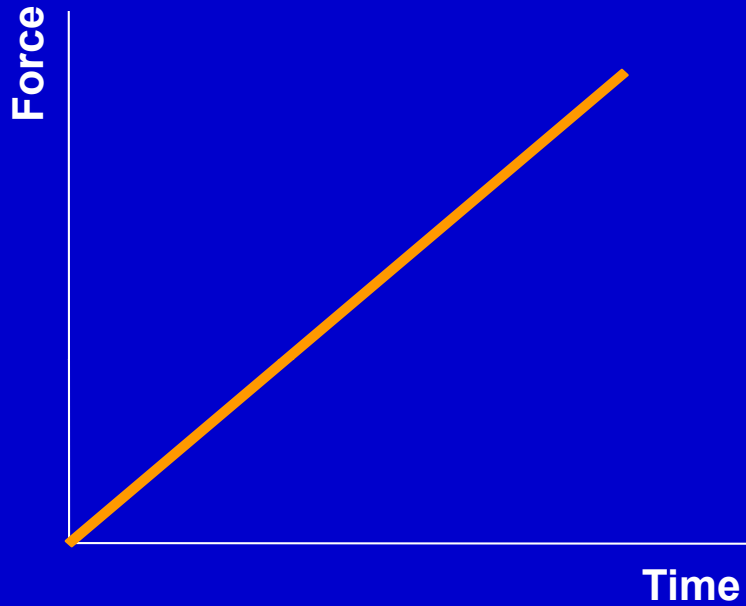


Basic idea of clunk noise

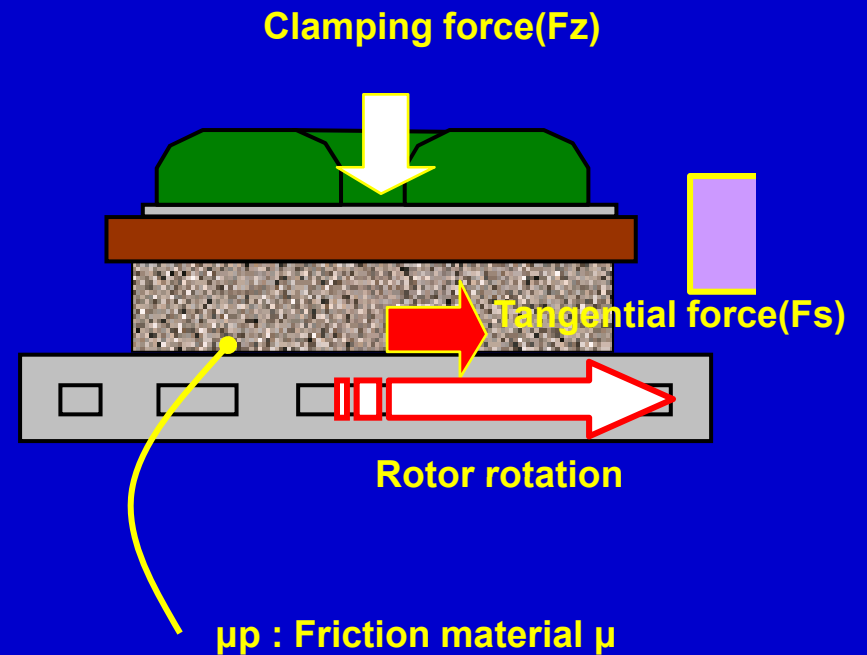
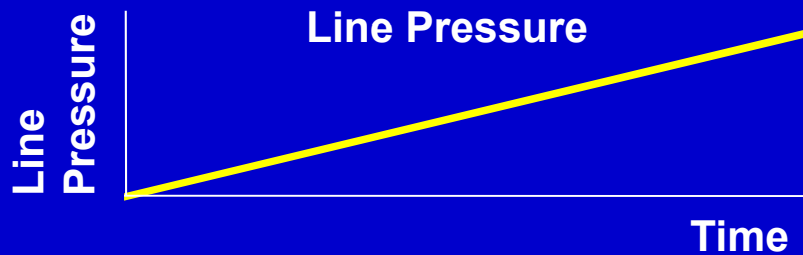


Numerical model of clunk noise

Pad tangential force (F_s)

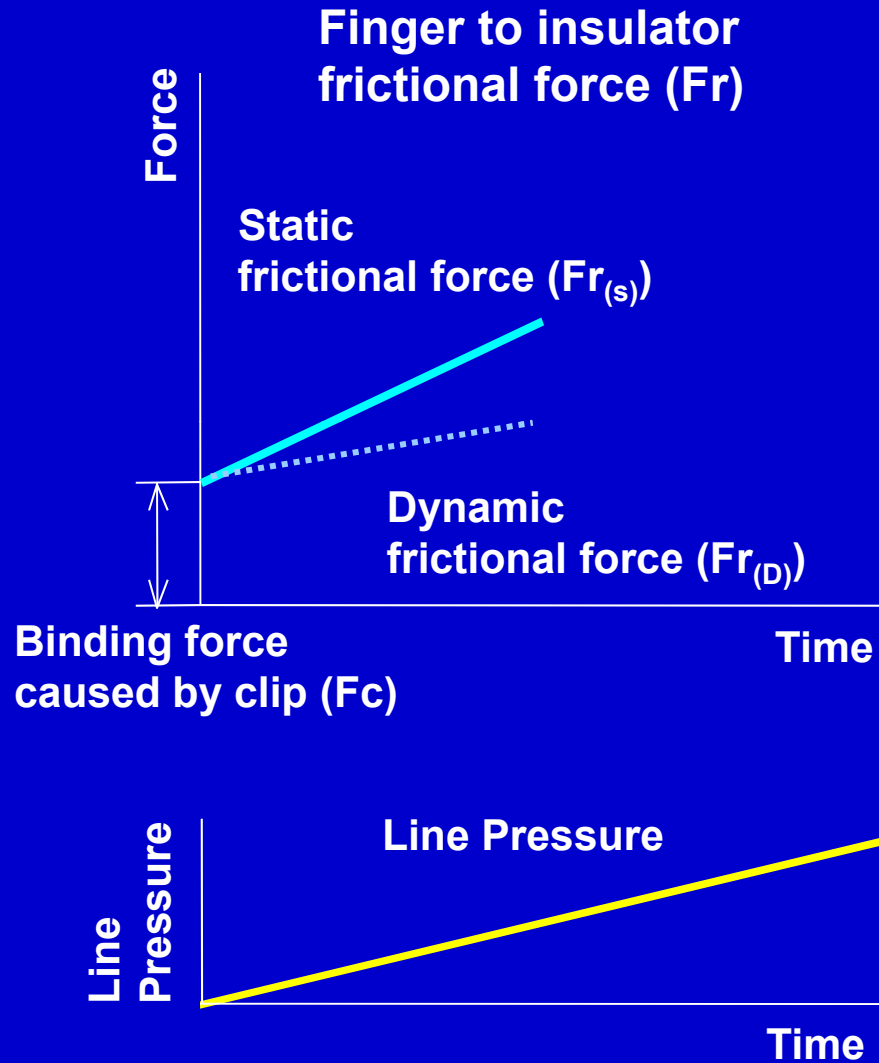


$$F_s = F_z \times \mu_p$$

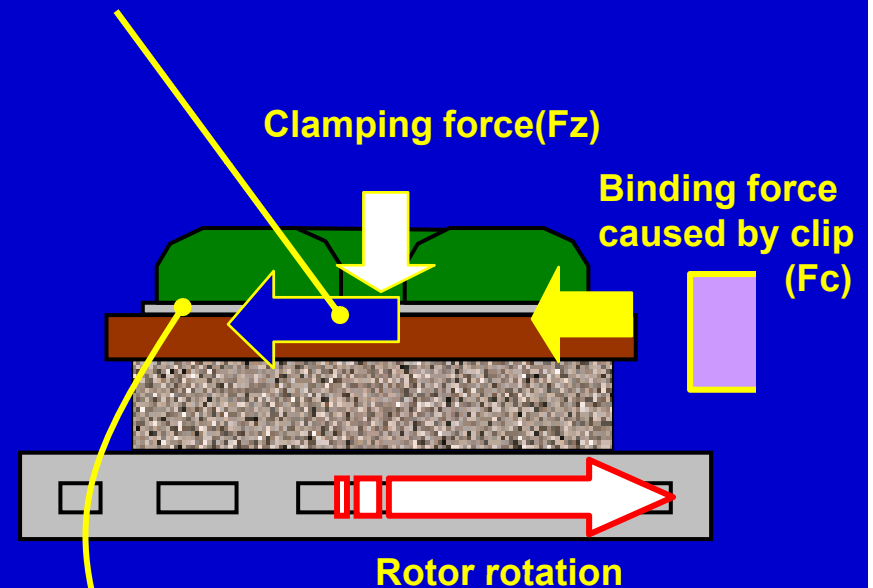


Numerical model of clunk noise

$$Fr_{(s)} = Fz \times \mu_{i(s)}$$



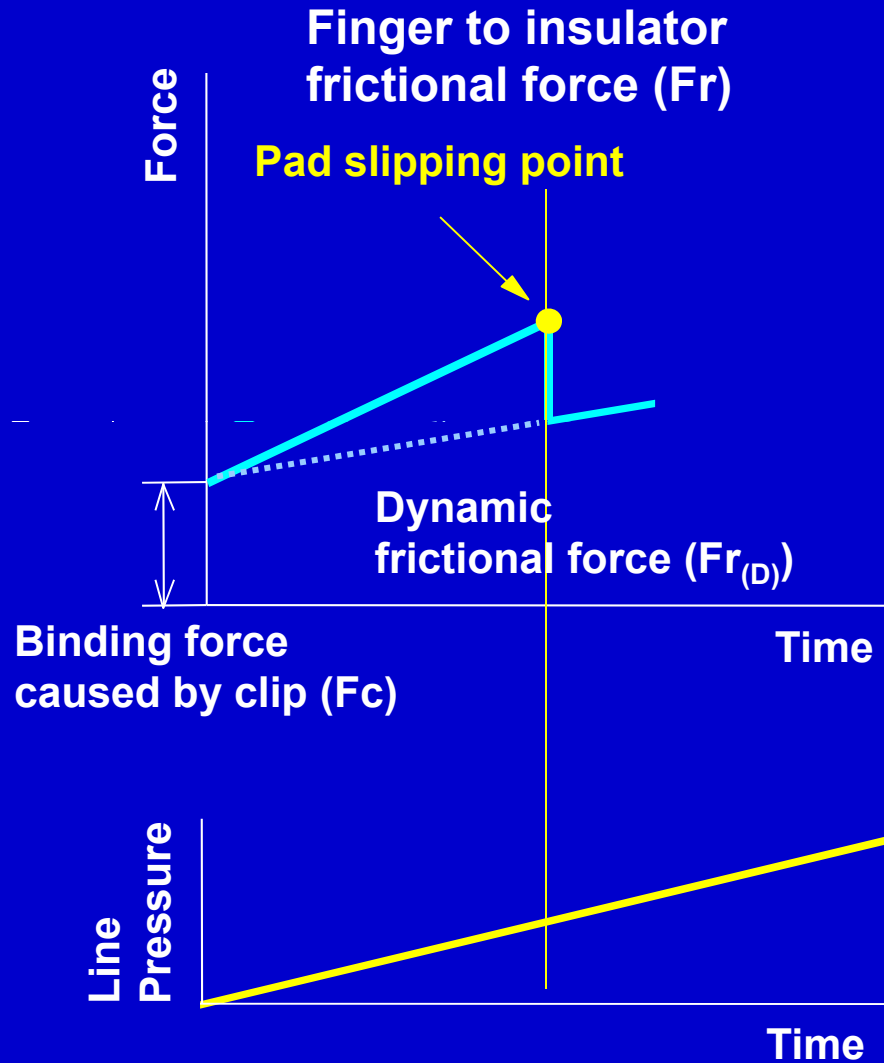
Static frictional force ($Fr_{(s)}$)



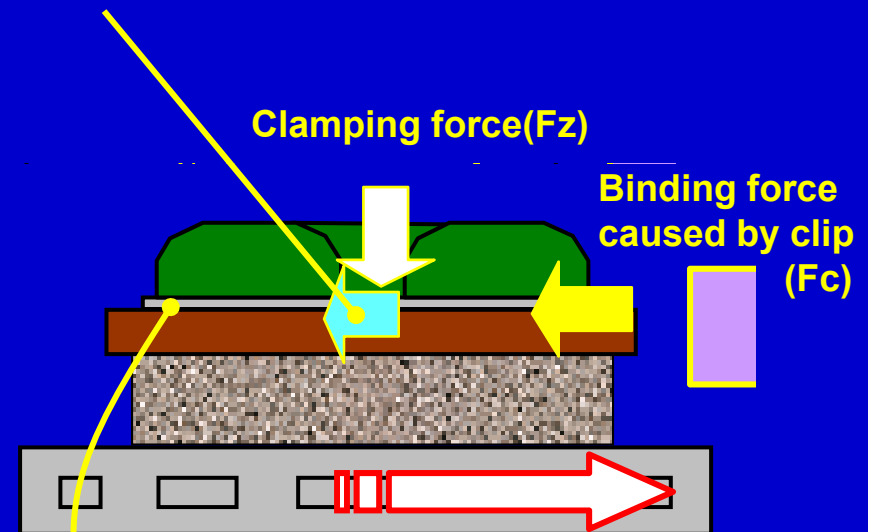
$\mu_{i(s)}$: Static Insulator surface μ

Numerical model of clunk noise

$$Fr_{(D)} = Fz \times \mu_{i(D)}$$



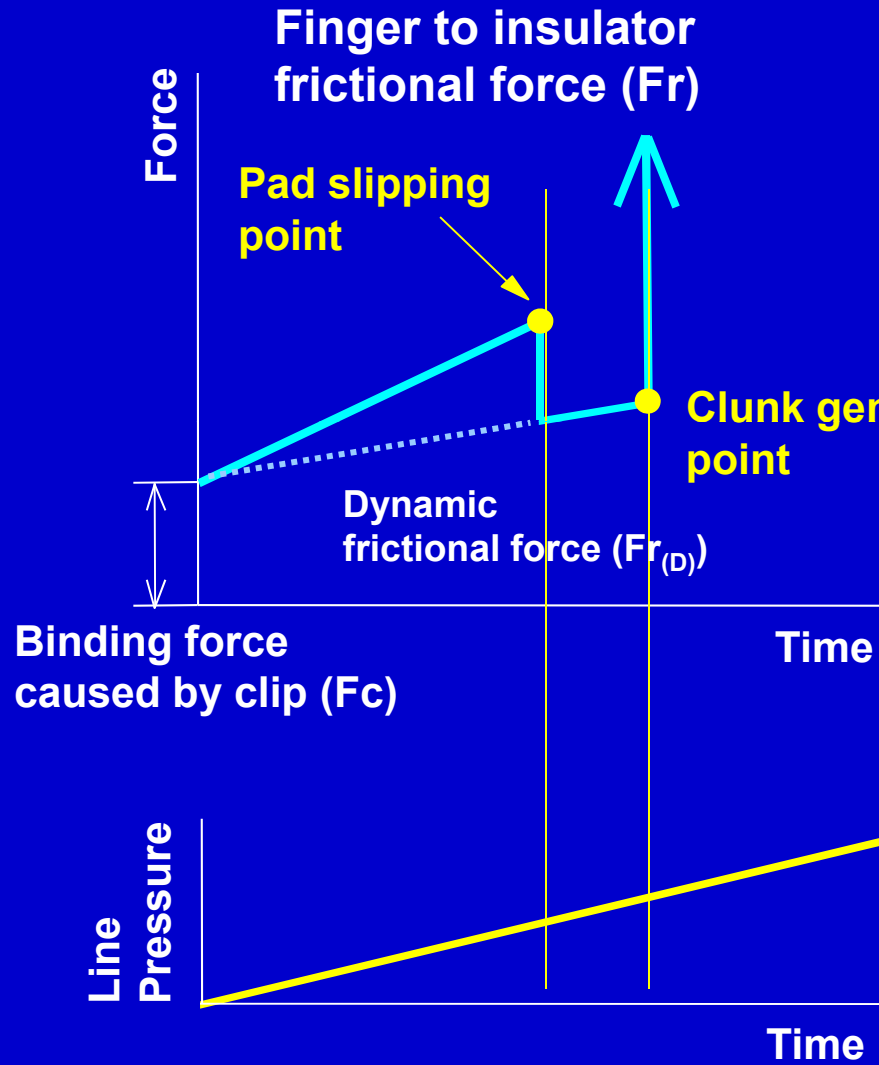
Dynamic frictional force ($Fr_{(D)}$)



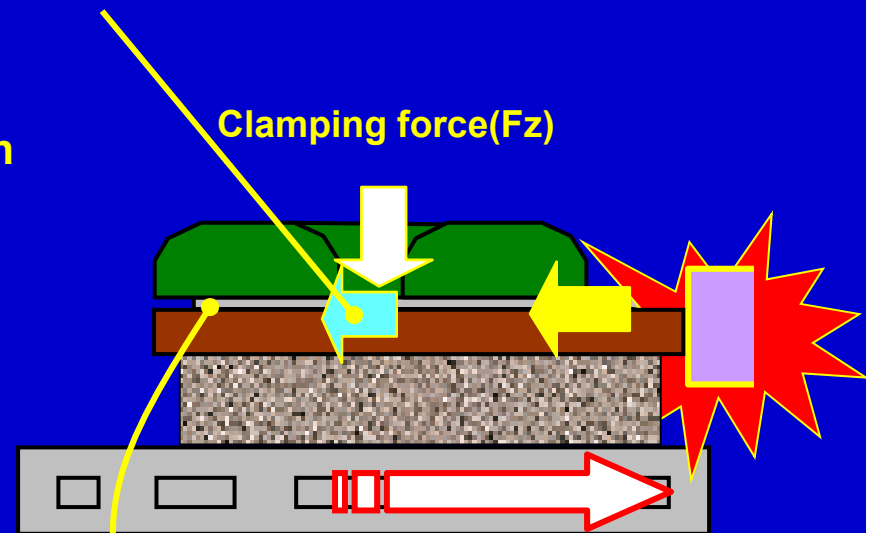
$\mu_{i(D)}$: Dynamic Insulator surface μ

Numerical model of clunk noise

$$Fr_{(D)} = Fz \times \mu_{i(D)}$$

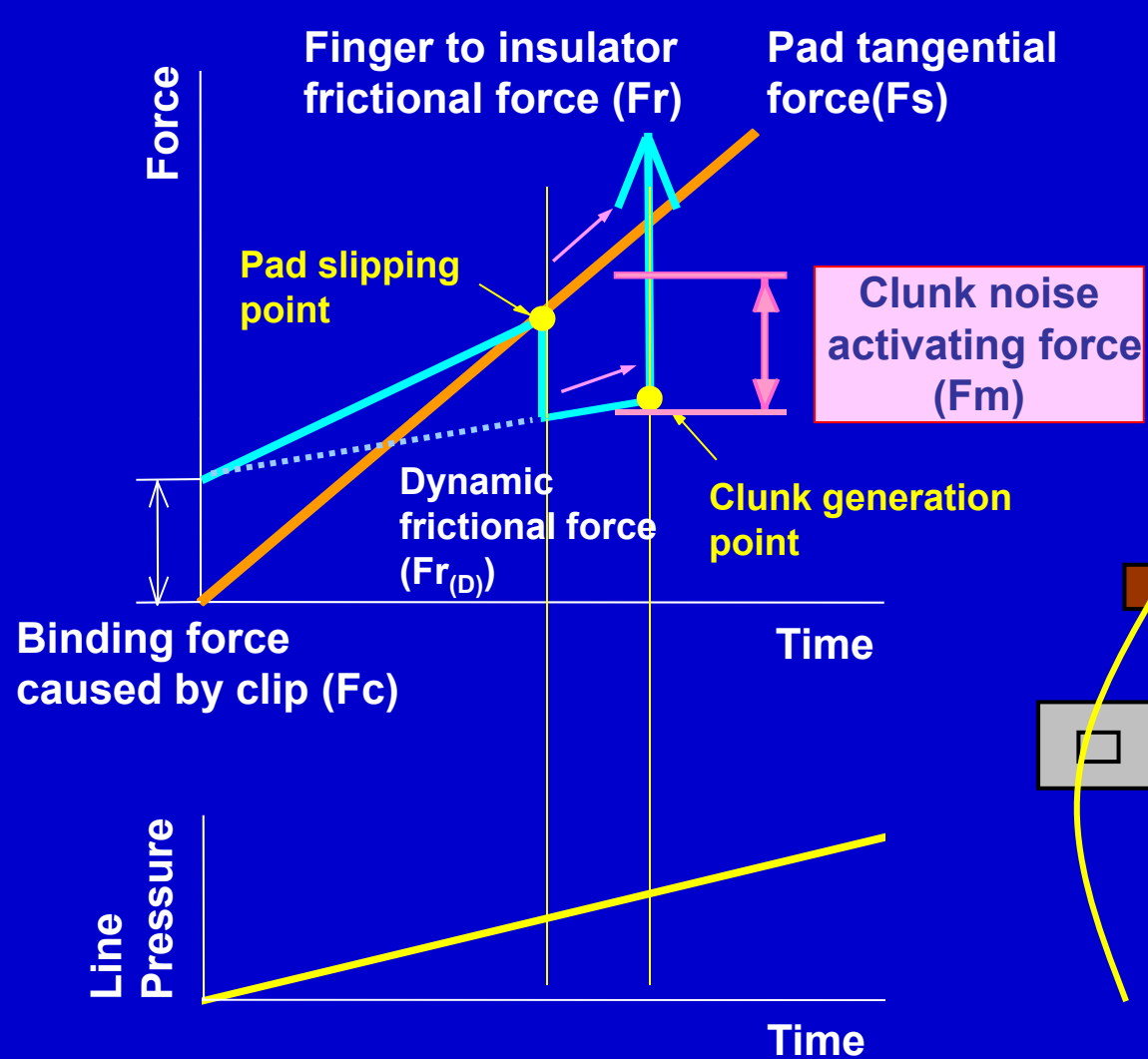


Dynamic frictional force ($Fr_{(D)}$)



$\mu_{i(D)}$: Dynamic Insulator surface μ

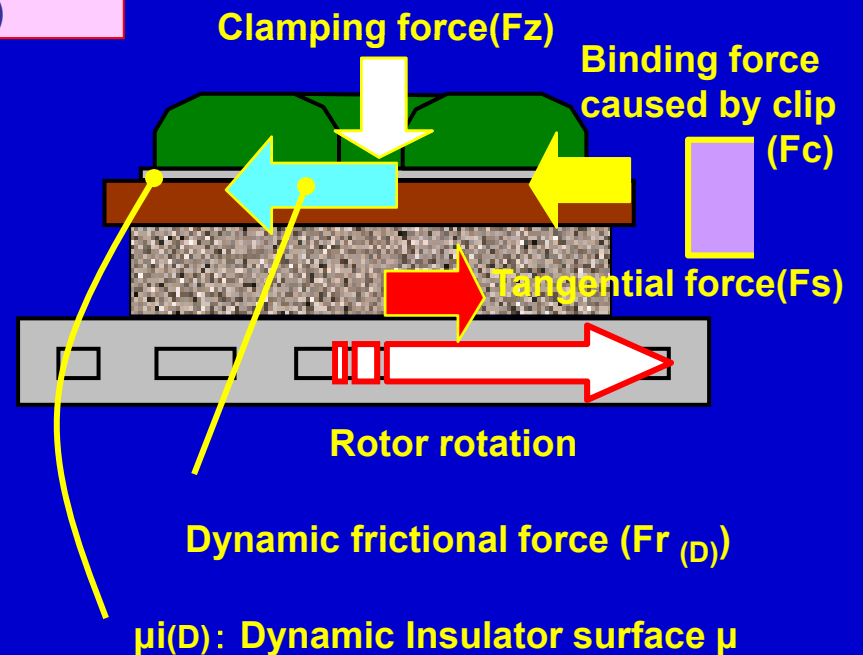
Numerical model of clunk noise



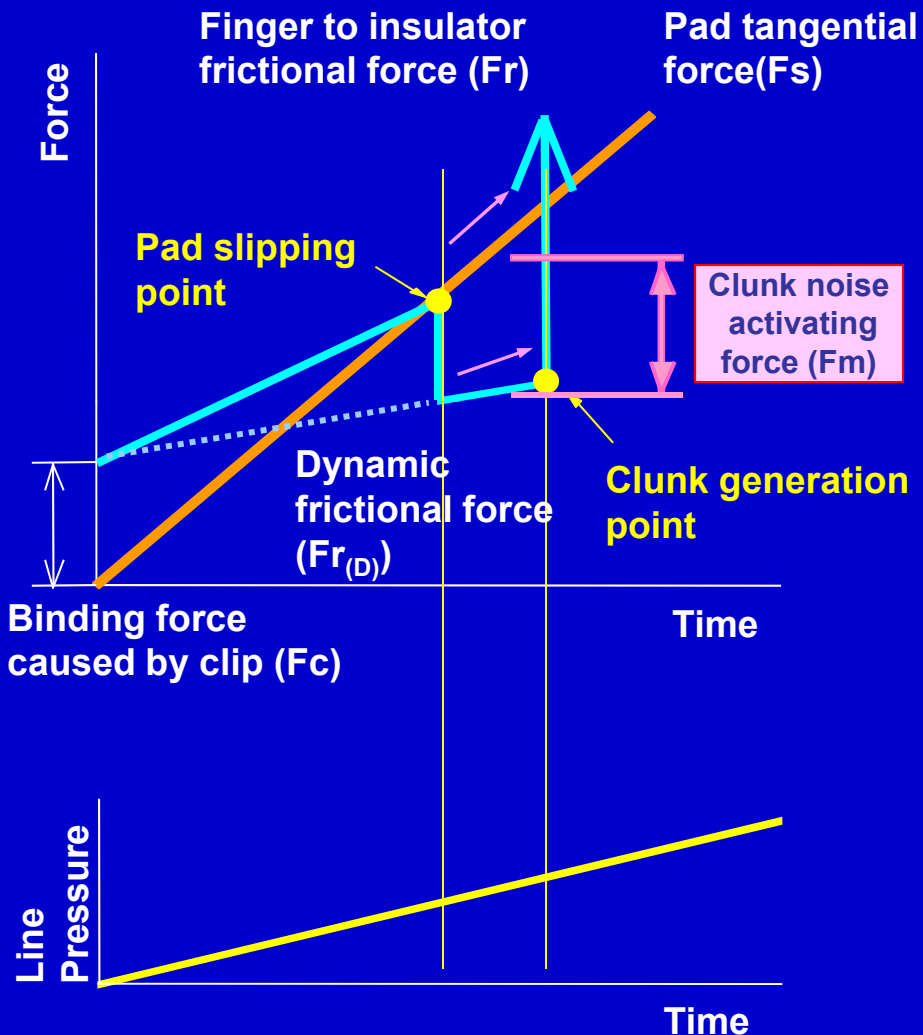
$$F_m = F_s - F_r - F_c$$

$$= m_p \times \alpha$$

F_m : Clunk noise activating force
 m_p : Pad mass
 α : pad acceleration



Numerical model of clunk noise



F_s : Pad tangential force
 F_z : Clamping force
 μ_p : Friction material μ

$$F_s = F_z \times \mu_p$$

F_r : Finger to insulator frictional force
 $\mu_i(S)$: Static Insulator surface μ
 $\mu_i(D)$: Dynamic Insulator surface μ

$$\left\{ \begin{array}{l} F_r = F_z \times \mu_{i(S)} \\ F_r = F_z \times \mu_{i(D)} \end{array} \right.$$

F_m : Clunk noise activating force
 m_p : Pad mass
 α : pad acceleration

$$\begin{aligned} F_m &= F_s - F_r - F_c \\ &= m_p \times \alpha \end{aligned}$$

V : Approximate expression for pad impact velocity
 S : effective clearance

$$V = \sqrt{2\alpha \cdot S}$$

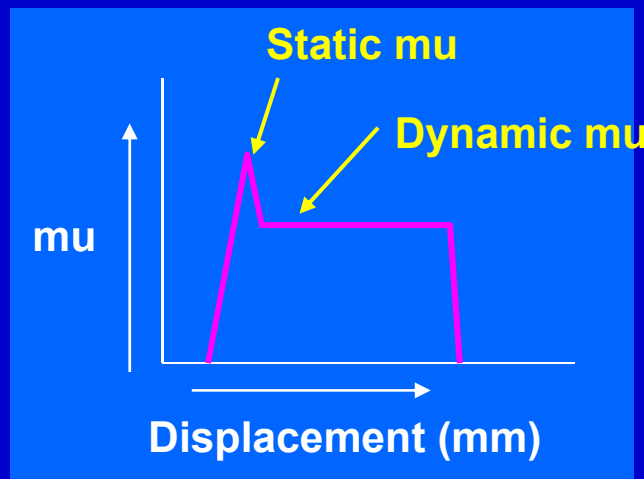
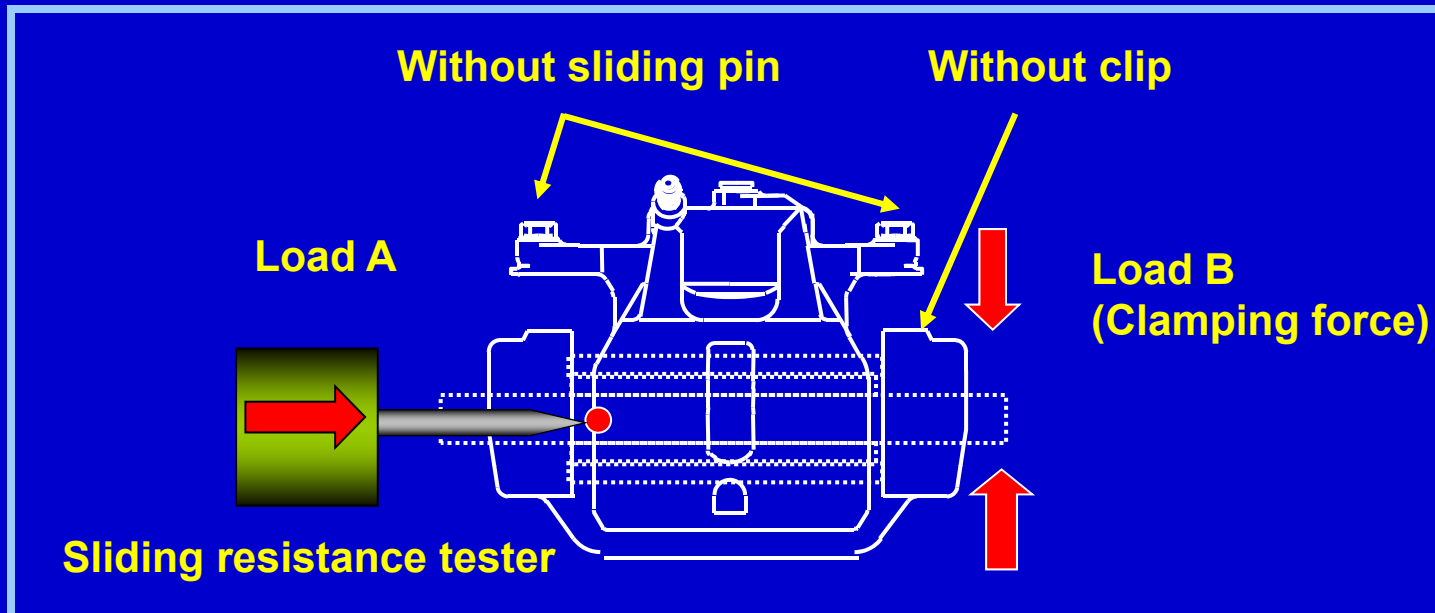
β : Impact acceleration
 T_s : Contact duration

$$\beta = \frac{V}{t_s}$$

F_β : Exciting force for support bracket

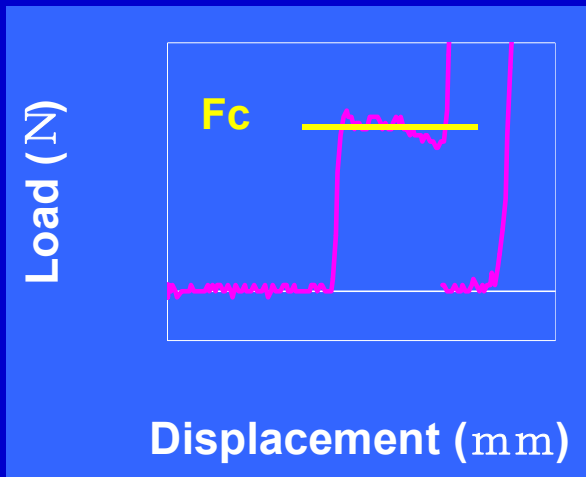
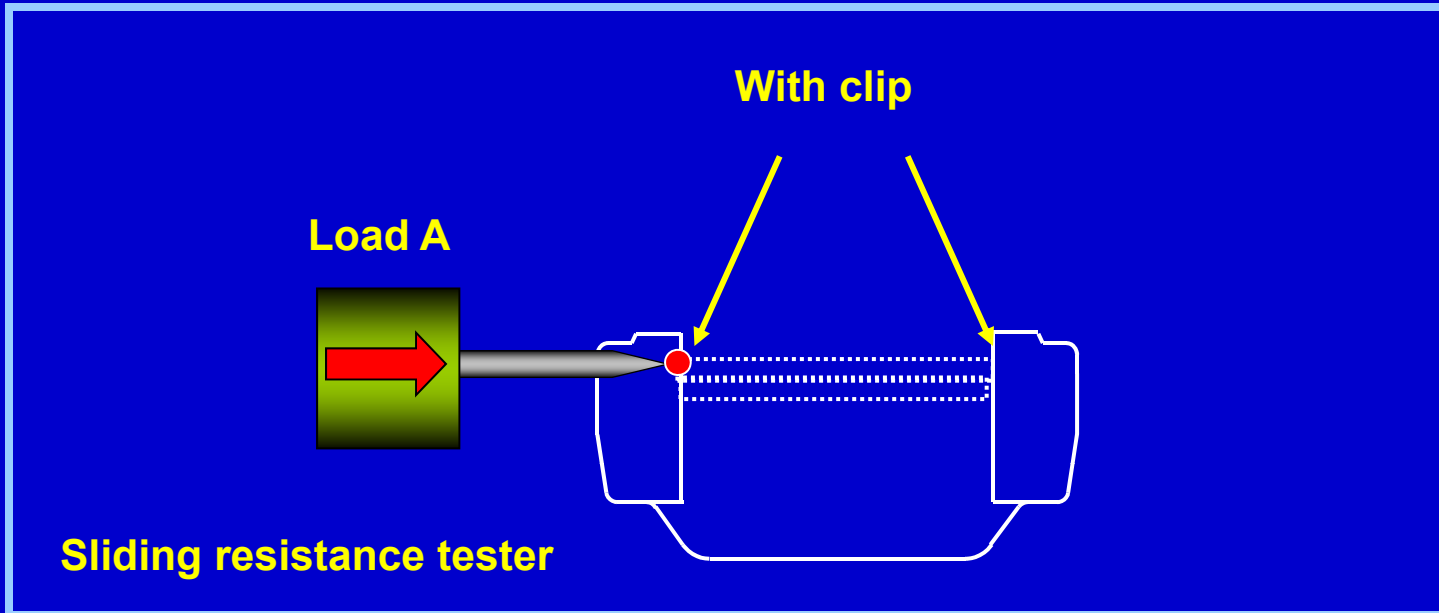
$$F_\beta = m_p \times \beta$$

Definition of noise Insulator surface mu



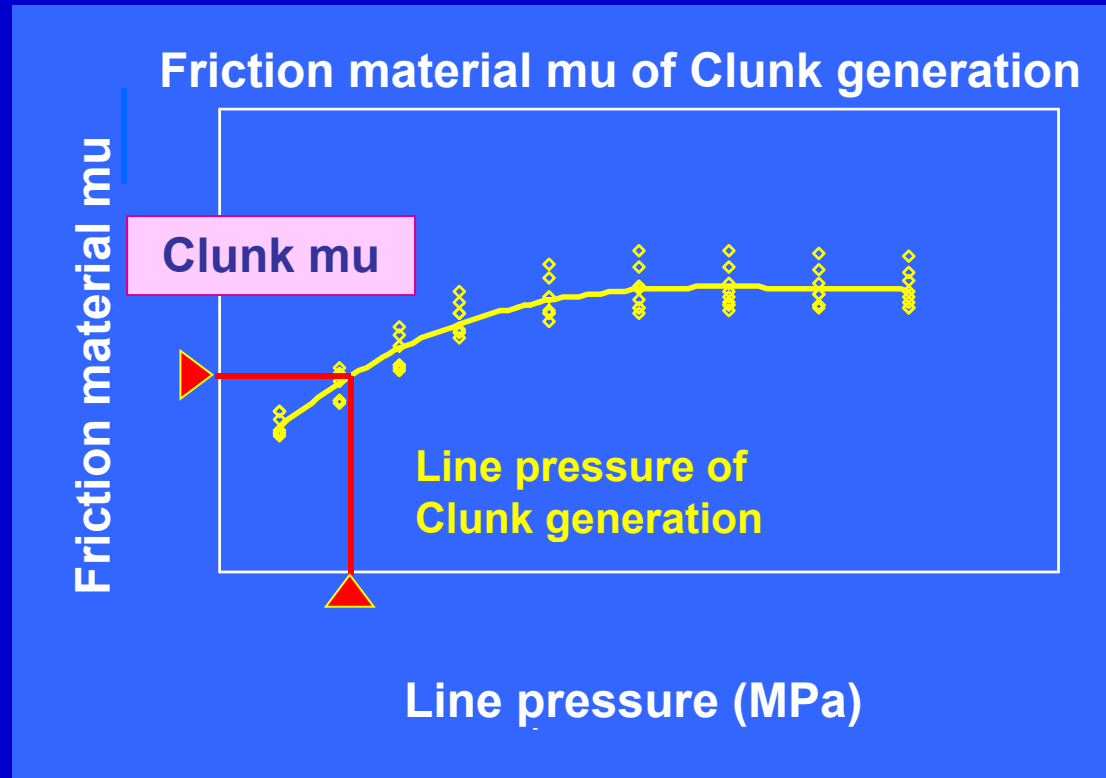
$$\mu = \frac{\text{Load A}}{\text{Load B}}$$

Definition of Clip load



Definition of Friction material mu

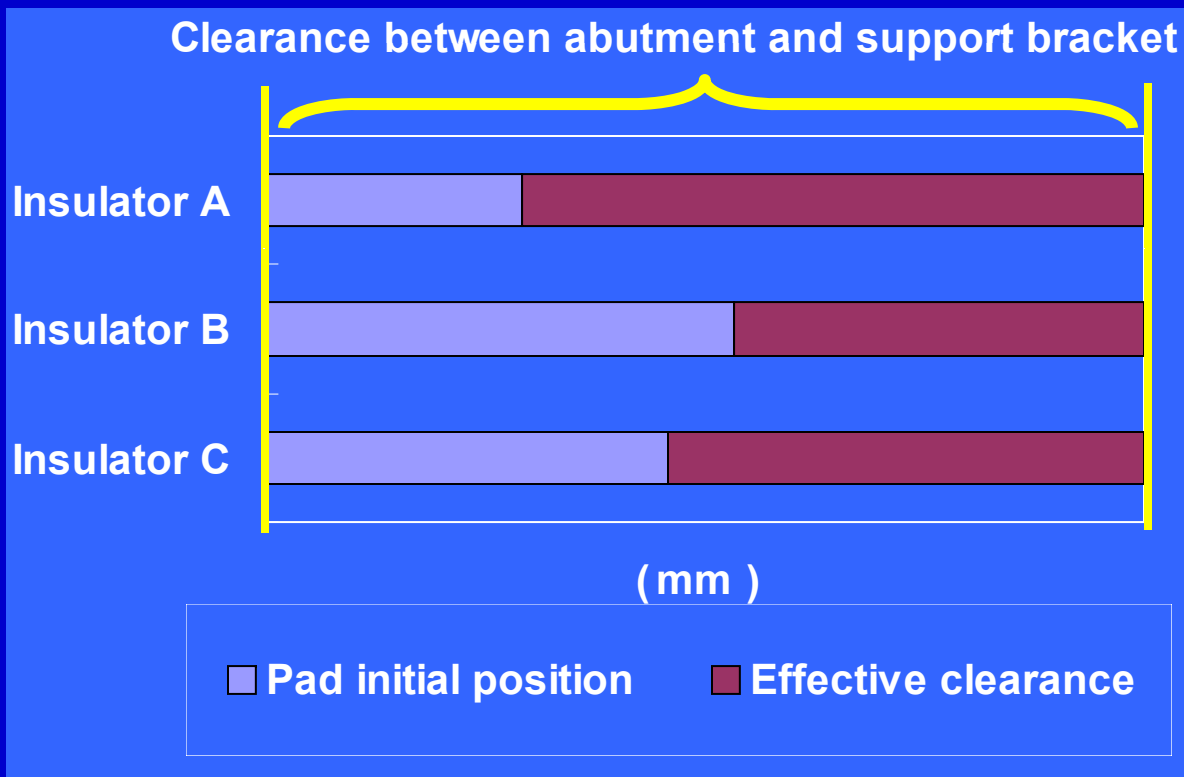
- Finding the friction material mu based on line pressure during clunk generation on dynamometer.



- Friction material mu at which clunk mu occurs is dependent on insulator type.

Definition of effective clearance

$$\text{Effective clearance} = \text{Clearance between pad abutment and support bracket} - \text{Pad initial position}$$

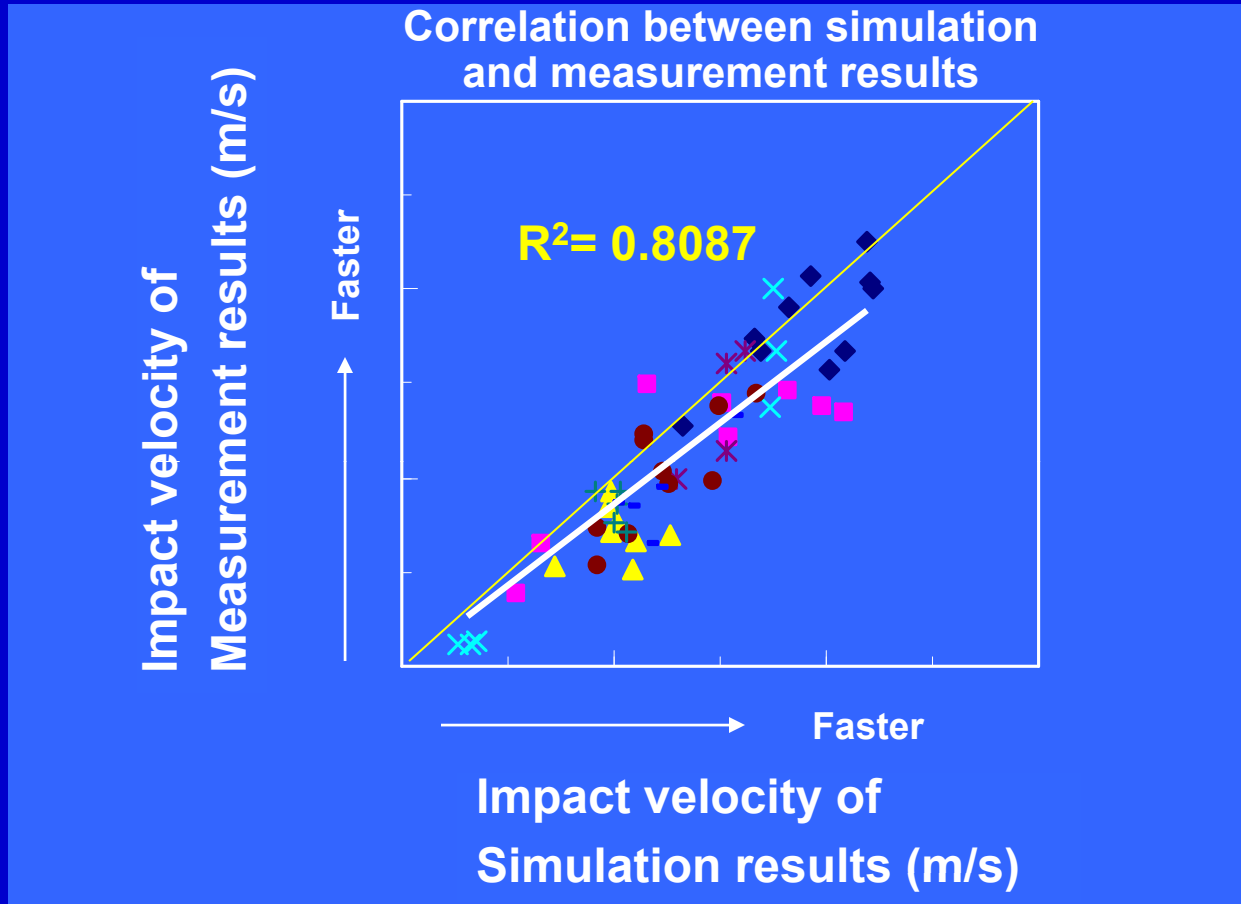


• Pad initial position is influenced by Insulator types.

Parameters list

F_c	Binding force caused by clip	Experimental
Mu_i	Noise Insulator surface mu	Experimental
mu_p	Friction material mu	Experimental
S	<p>Effective Clearance</p> <p>= (Clearance between pad abutment and support bracket)</p> <p>- (Pad initial position)</p>	Experimental
m_p	Pad weight	Measured
T_s	<p>Contact duration</p> <p>=Time between impact and pad stop</p>	Experimental

Correlation between simulation and measurement results



Configuration list

	Clearance	Clip load	Insulator type
◆	L	L	A
■	L	L	B
▲	L	L	C
×	L	S	A
*	L	M	A
●	L	L	A
+	S	L	A
-	S	L	B

L:Large
M:Medium
S:Small

•Impact velocity is duplicated by this simulation.

Summary until this point

- ◆ Previously no satisfactory clunk noise numerical model existed.
- ◆ A simulation with high accuracy was obtained by using detailed elemental investigation results.
- ◆ As a result of factor analysis, individual countermeasure effectiveness can be quantified.

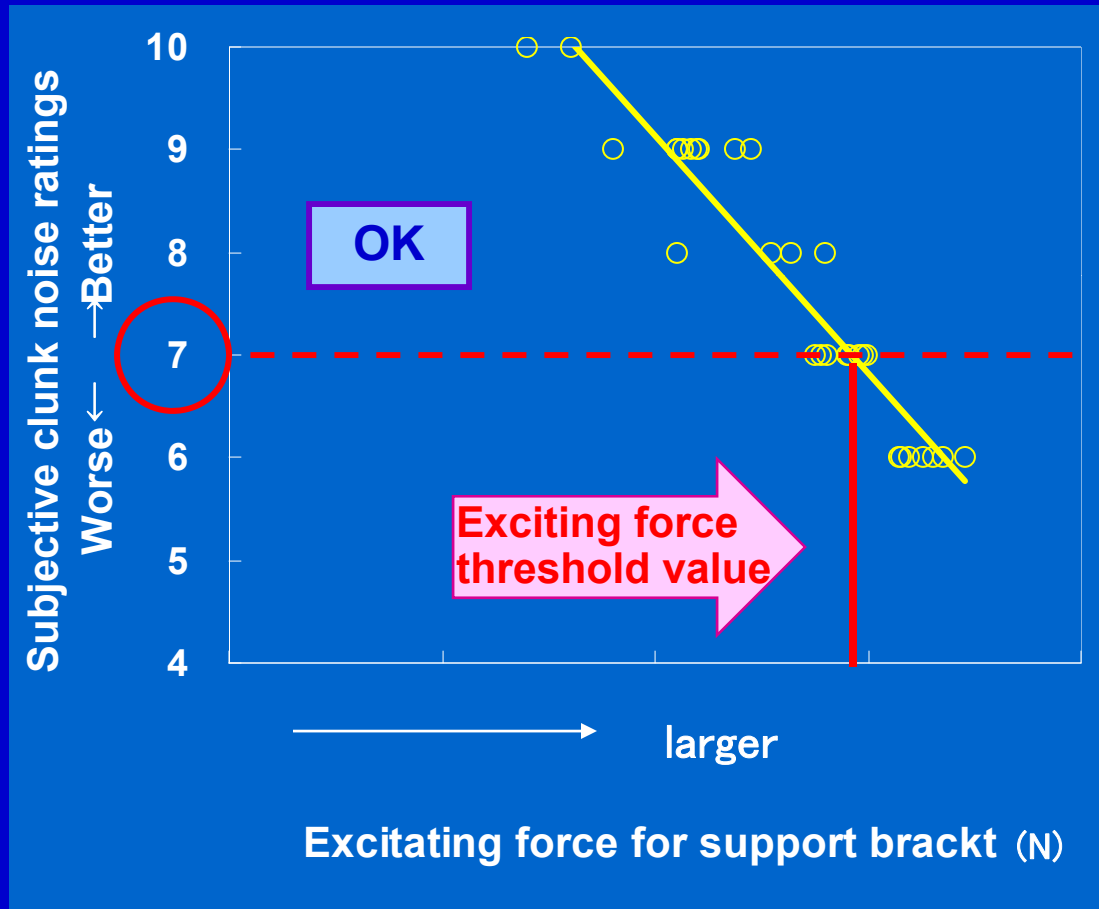
A countermeasure case study

Brake Spec.

TYPE	Floating 1POT
Bore Size	57mm
Clearance	Medium
Clip load	Medium
Insulator	Type-A

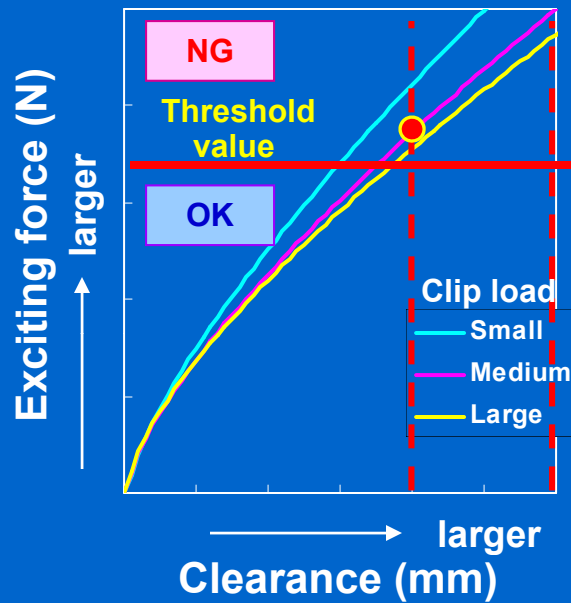
Subjective rating of a vehicle test

- A border line is decided by relationship between exciting force on support bracket and subjective clunk noise ratings.

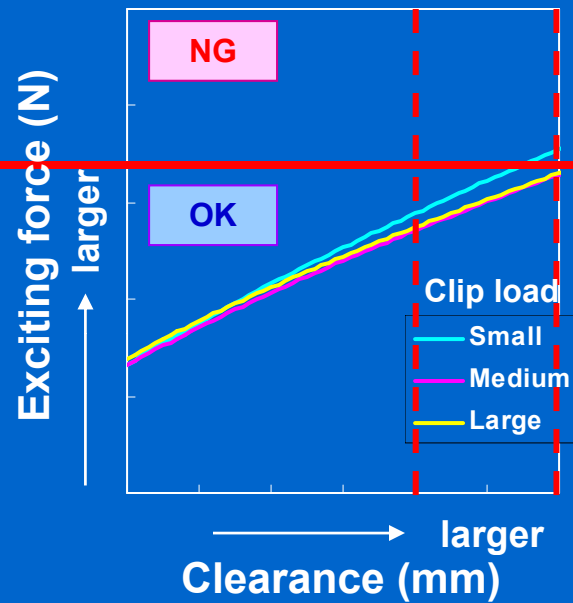


Simulation analysis summary

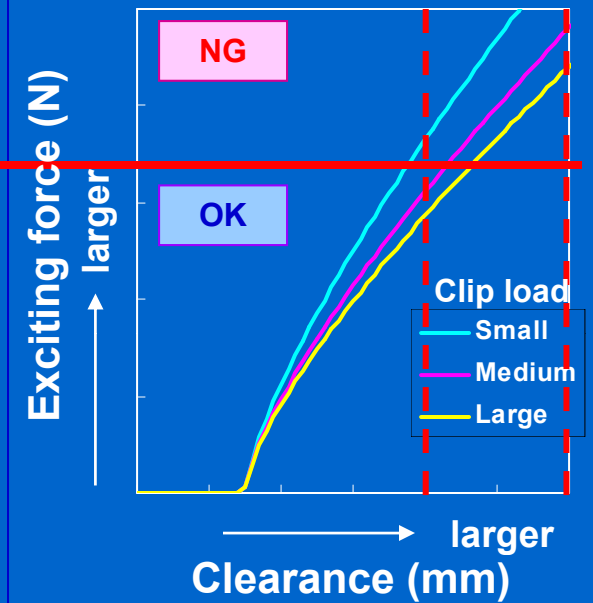
Insulator type-A



Insulator type-B



Insulator type-C



Clearance	Medium	Large
Clip load Small	NG	NG
Clip load Medium	NG	NG
Clip load Large	NG	NG

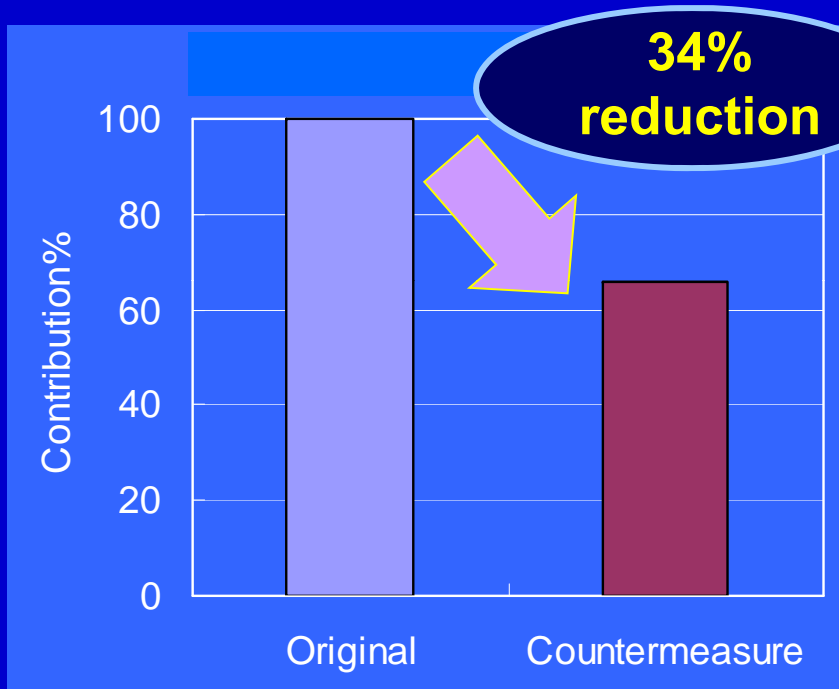
Clearance	Medium	Large
Clip load Small	OK	NG
Clip load Medium	OK	OK
Clip load Large	OK	OK

Clearance	Medium	Large
Clip load Small	NG	NG
Clip load Medium	OK	NG
Clip load Large	OK	NG

Countermeasure Results

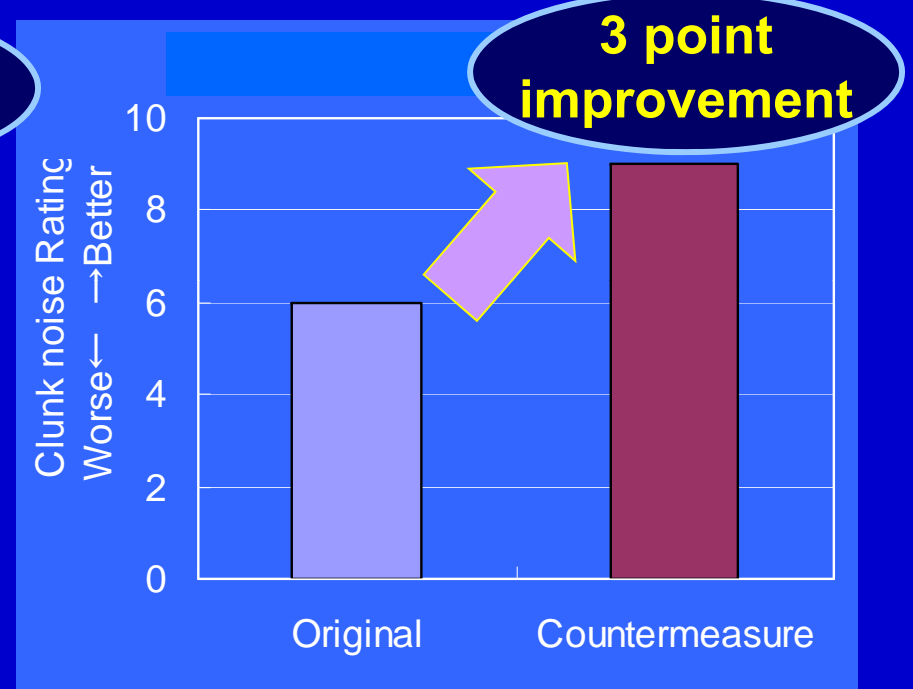
Simulation

Exciting force for support bracket



Vehicle test

Clunk noise Rating



•Reduction of clunk noise is confirmed on a vehicle test.

Conclusion

- **Succeeded to develop the clunk noise simulation by constructing experimental analysis and the numerical model.**
- **Clarified brake elements which affect clunk noise significantly and made it possible to do quantitative analysis for a design.**

<Future challenges>

- **Investigate parameters for other vehicles and summarize those.**

Thank you very much for your attention