Dynamic analysis of planar mechanical system with clearance joints using a new nonlinear contact force model

Xupeng Wang, Geng Liu and Shangjun Ma

Journal of Mechanical Science and Technology 30 (4) (2016) 1537~1545

Assignment 2 : ME 748 Computer Aided Simulation of Machines | Prof. Anirban Guha

Presented by : Deepak Kumar Thakur (213101001)

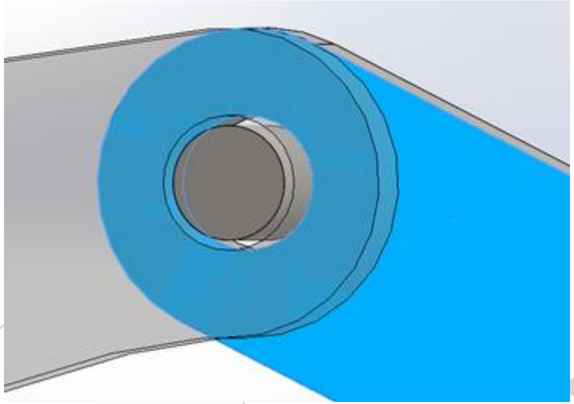
Link for paper: https://inis.iaea.org/search/search.aspx?orig_q=RN:47084707

Outlines

1. Introduction
2. Need for this model
3. What’s considered and not considered (New Nonlinear Contact force model)
4. Hertz Model And various development of contact law
5. New nonlinear contact force model
6. Comparison of new model with different other model and experimental values
7. Conclusion

1. Introduction

Mechanical systems consist of Kinematic joints with inevitable clearances.



With the demand of relative motions, clearance joints have many effects on mechanical system such as vibration, wear and noise

Reduces system reliability, kinematic accuracy and stability, even the life of mechanism

Hence modelling of an accurate contact force model for dynamic simulation of mechanical system with clearance joints is critical

2. Need for this model

Various contact force model proposed but all these models are purely elastic and do not consider the energy dissipation during contact process.

This drawback was solved using different models based on Hertz’s contact force models.

But these modified models works well for larger coefficient of restitution ($C_r \geq 1$)

3. What’s considered and not considered

- A nonlinear contact law with nonlinear contact stiffness
- Frictional effect measured by modified Coulomb friction

- Flexibility of links
- Lubrication action in the clearance joint
- Plastic deformation in the clearance joint

4. Hertz Model

- Hertz contact law is a purely elastic contact force
- It does not account for the energy dissipation during the impact process

$$F = K\delta^{n},$$

K - Generalized stiffness parameter,
n - Nonlinear power exponent (1.5 for metallic contact)
Δ - Relative deformation depth.

$$K = \frac{4}{3\pi(\sigma_1 + \sigma_2)}\sqrt{\frac{R_B R_J}{R_B - R_J}},$$

R_B and R_J - Radius of bearing and journal
σ_i - Material parameter

$$\sigma_1 = \frac{1 - \upsilon_i^2}{\pi E_i}, (i = 1, 2).$$

υ_i - Poisson's ratio
E_i - Young's modulus associated with journal and bearing

4. Various development of contact law

MODEL	CONTACT FORCE MODEL
Hunt and Crossley	Pure elastic Hertz's law, combined with a nonlinear viscoelastic element
Lankarani and Nikravesh	Based on Hunt and Crossley work, Frequently used contact force model
Bai et al.	A new hybrid contact force model, based on the Lankarani-Nikravesh model and the improved Winkler elastic foundation model,
Wang and Liu	Based on the contact force model of Liu et al. [7] and contact force model of Lankarani and Nikravesh

***** These modified models works well for larger coefficient of restitution ($C_r \geq 1$)**

5. New nonlinear contact force model

$$F_N' = \frac{\pi E^* L \delta^n}{2}\left(\frac{1}{2(c+\delta)}\right)^{1/2} = K_i \delta^n.$$

K_i - Improved Generalized nonlinear stiffness coefficient,

$$D_i = \frac{3(1-c_r^2)e^{2(1-c_r)}\delta^n}{4\dot{\delta}^{(-)}}K_i.$$

Improved damping coefficient

Improved nonlinear contact force model

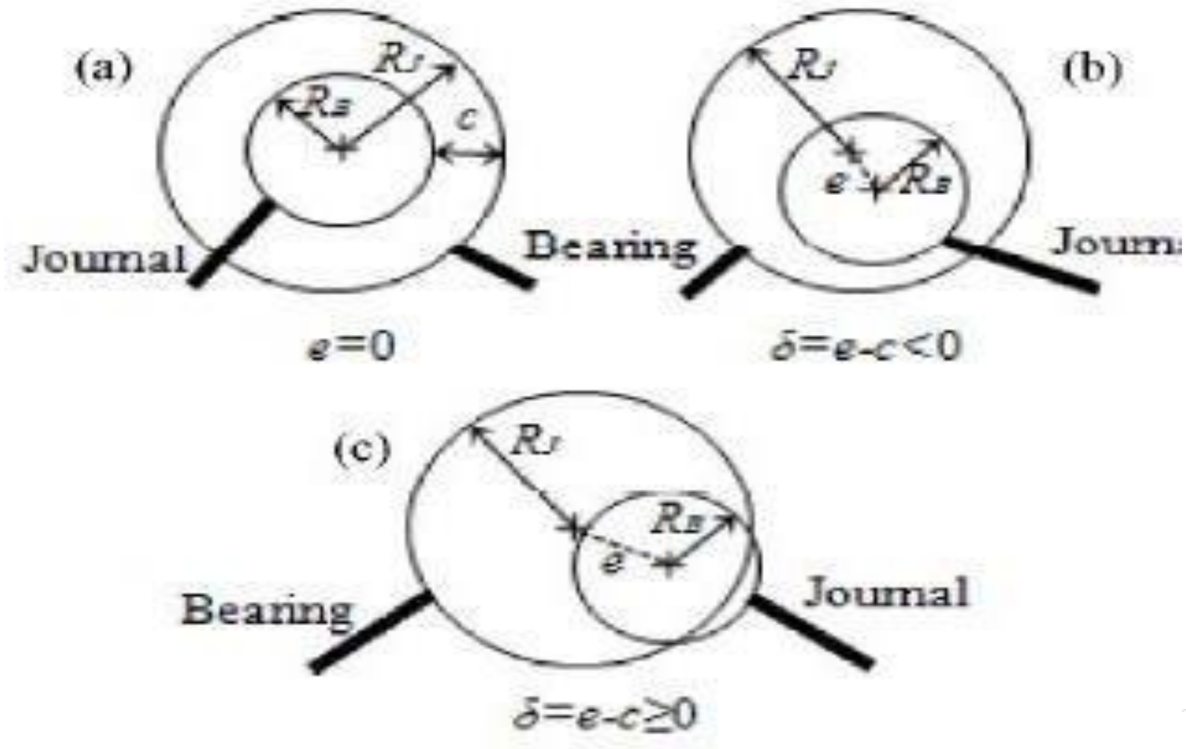
$$F_{Ni} = K_i\delta^n + D_i\dot{\delta}$$
$$= \frac{\pi E^* L \delta^n}{2}\left(\frac{1}{2(c+\delta)}\right)^{1/2}\left(1+\frac{3(1-c_r^2)e^{2(1-c_r)}\dot{\delta}}{4\dot{\delta}^{(-)}}\right).$$

Modified Coulomb friction force model to depict the friction effect in clearance joint

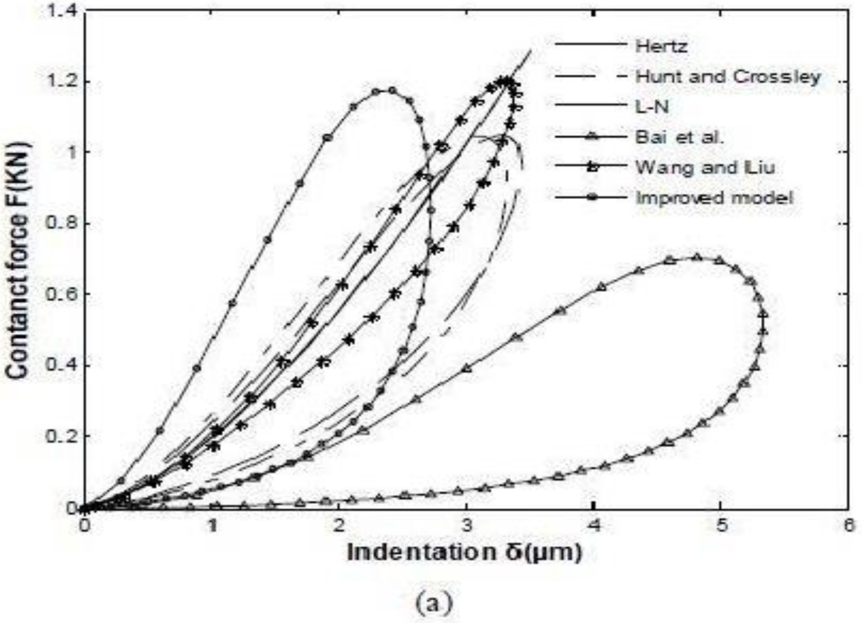
c_f - friction coefficient
F_N - Normal force
V_T - Relative tangential velocity
c_d -Dynamic correction coefficient

$$F_T = -c_f c_d F_N \,\mathrm{sgn}(V_T).$$

5. New nonlinear contact force model



6. Comparison of new model with different other model and experimental values



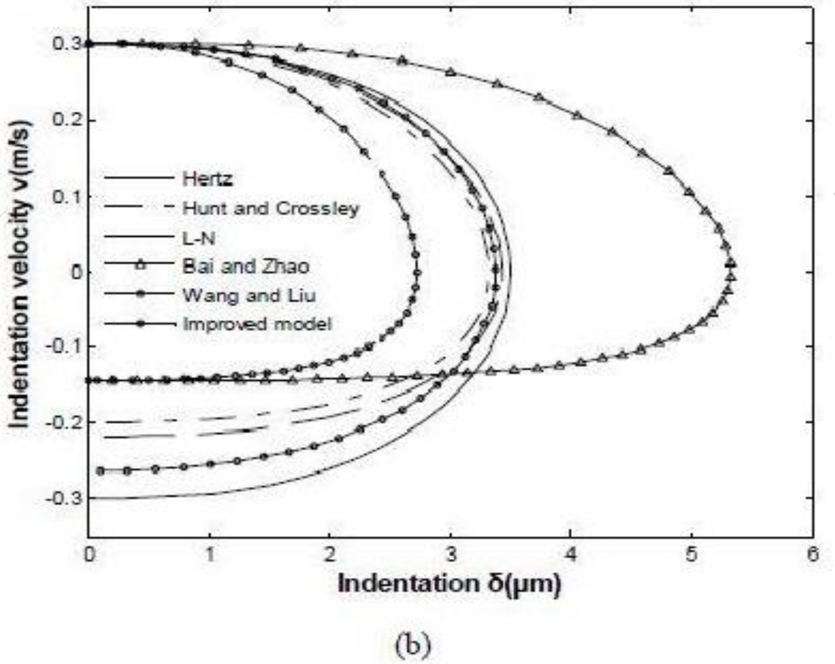


Fig. (a) Force-indentation relation; (b) velocity indentation relation for different contact force models For journal and bearing

6. Comparison of new model with different other model and experimental values

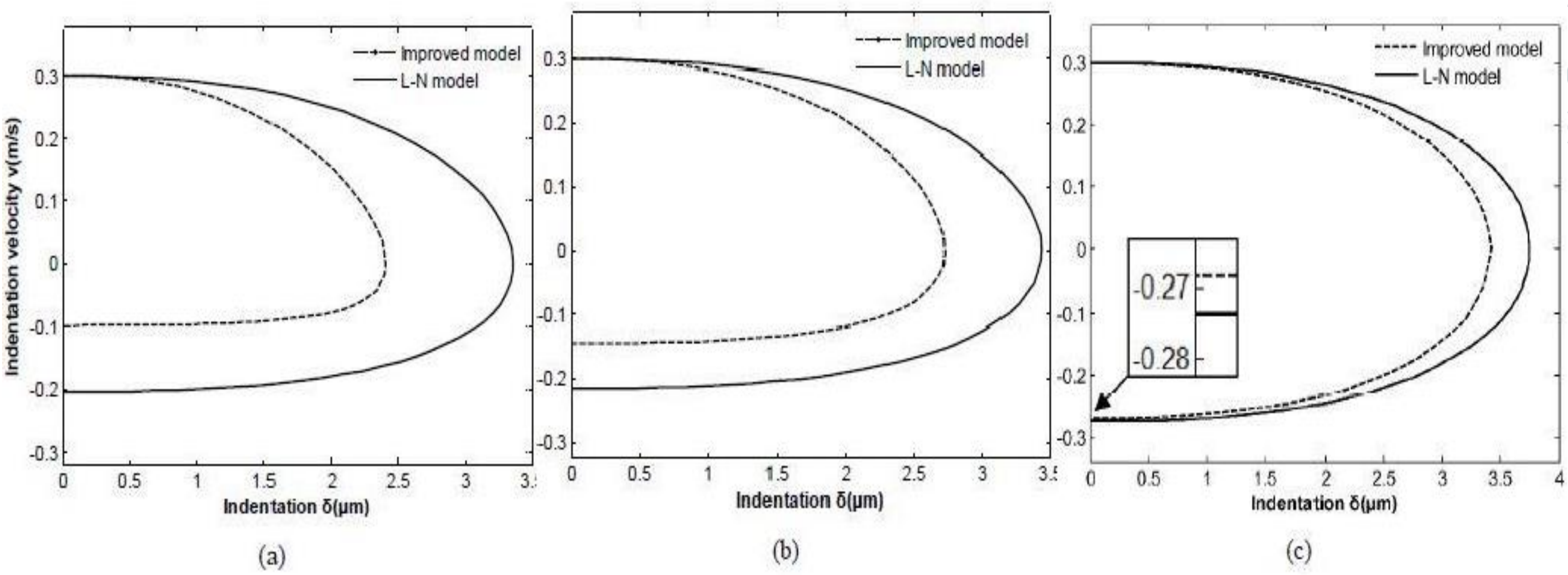


Fig. Velocity-indentation curves with improved model and Lankarani and Nikravesh models: (a) $C_r = 0.3$; (b) $C_r = 0.5$; (c) $C_r = 0.9$.

6. Comparison of new model with different other model and experimental values

Application Case : Slider crank mechanism

Table 4. Mass and inertia properties of slider-crank mechanism.

Body	Length [m]	Mass [kg]	Moment of inertial [kgm^2]
Crank	0.05	17.900	0.460327
Connecting rod	0.30	1.130	0.015300
Slider	-	1.013	0.000772

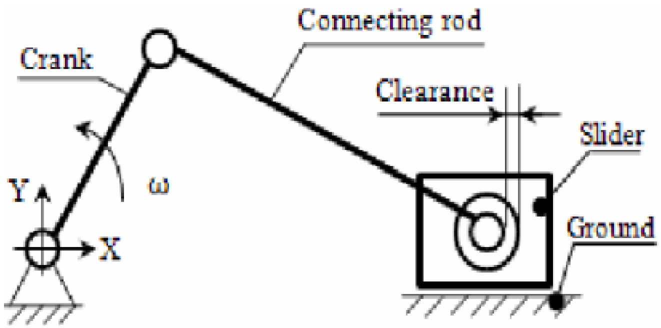


Fig. 6. Slider-crank mechanism with a revolute clearance.

6. Comparison of new model with different other model and experimental values

Table 1. Simulation results with fixed c_r, $\delta'(-)$ and varied c.

Name	c	0.01	0.1	0.5	1
M_{Imp}	$\delta'^{(+)}$(m/s)	0.1448	0.1448	0.1448	0.1448
	c_r'	0.4827	0.4827	0.4827	0.4827
	Error	3.46%	3.46%	3.46%	3.46%
$M_{L\text{-}N}$	$\delta'^{(+)}$(m/s)	0.2176	0.2176	0.2176	0.2176
	c_r'	0.7253	0.7253	0.7253	0.7253
	error	45.06%	45.06%	45.06%	45.06%

Table 2. Simulation results with fixed c, $\delta'^{(-)}$ and varied c_r.

Name	c_r	0.3	0.5	0.9	1
M_{Imp}	$\delta'^{(+)}$(m/s)	0.098	0.1448	0.2687	0.3
	c_r'	0.3267	0.4827	0.8957	1
	Error	8.889%	3.467%	0.482%	0
$M_{L\text{-}N}$	$\delta'^{(+)}$(m/s)	0.2053	0.2176	0.274	0.3
	c_r'	0.6843	0.7253	0.9133	1
	Error	128.1%	45.06%	1.48%	0

6. Comparison of new model with different other model and experimental values

Table 3. Simulation results with fixed c, c_r and varied δ'(-).

Name	δ'(-)	δ'(-)	$3\delta'$(-)	$5\delta'$(-)	$10\delta'$(-)
M_{Imp}	$\delta'^{(+)}$(m/s)	0.1448	0.4343	0.7239	1.4478
	c_r'	0.4827	0.4826	0.4826	0.4826
	Error	3.46%	3.48%	3.48%	3.48%
$M_{L\text{-}N}$	$\delta'^{(+)}$(m/s)	0.2176	0.6527	1.0879	2.1757
	c_r'	0.7253	0.7252	0.7253	0.7252
	Error	45.06%	45.04%	45.06%	45.04%

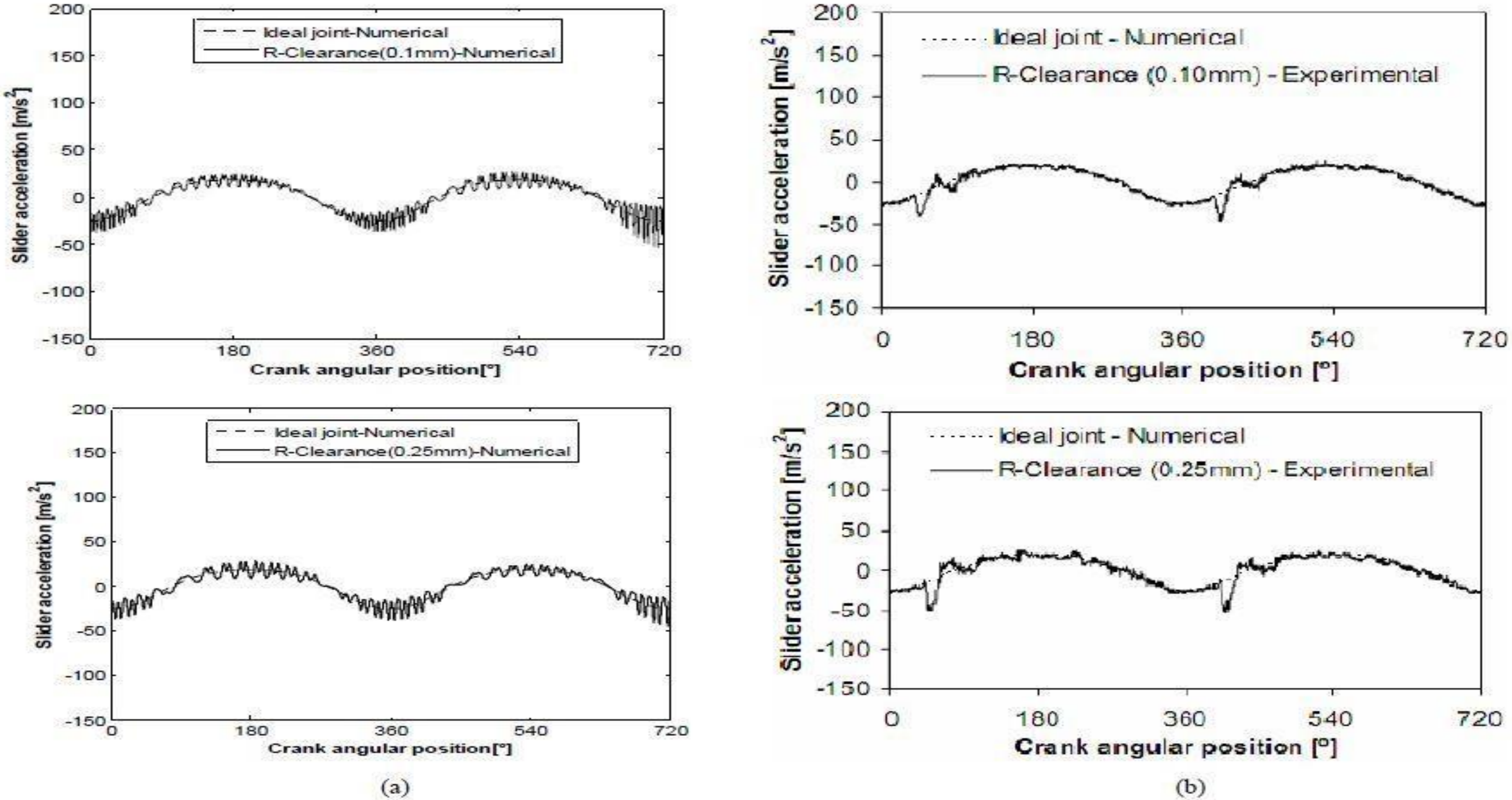


Fig. Slider accelerations with clearance size c = 0.1 mm (top) and c = 0.25 mm (bottom) from (a) simulation; (b) experiment

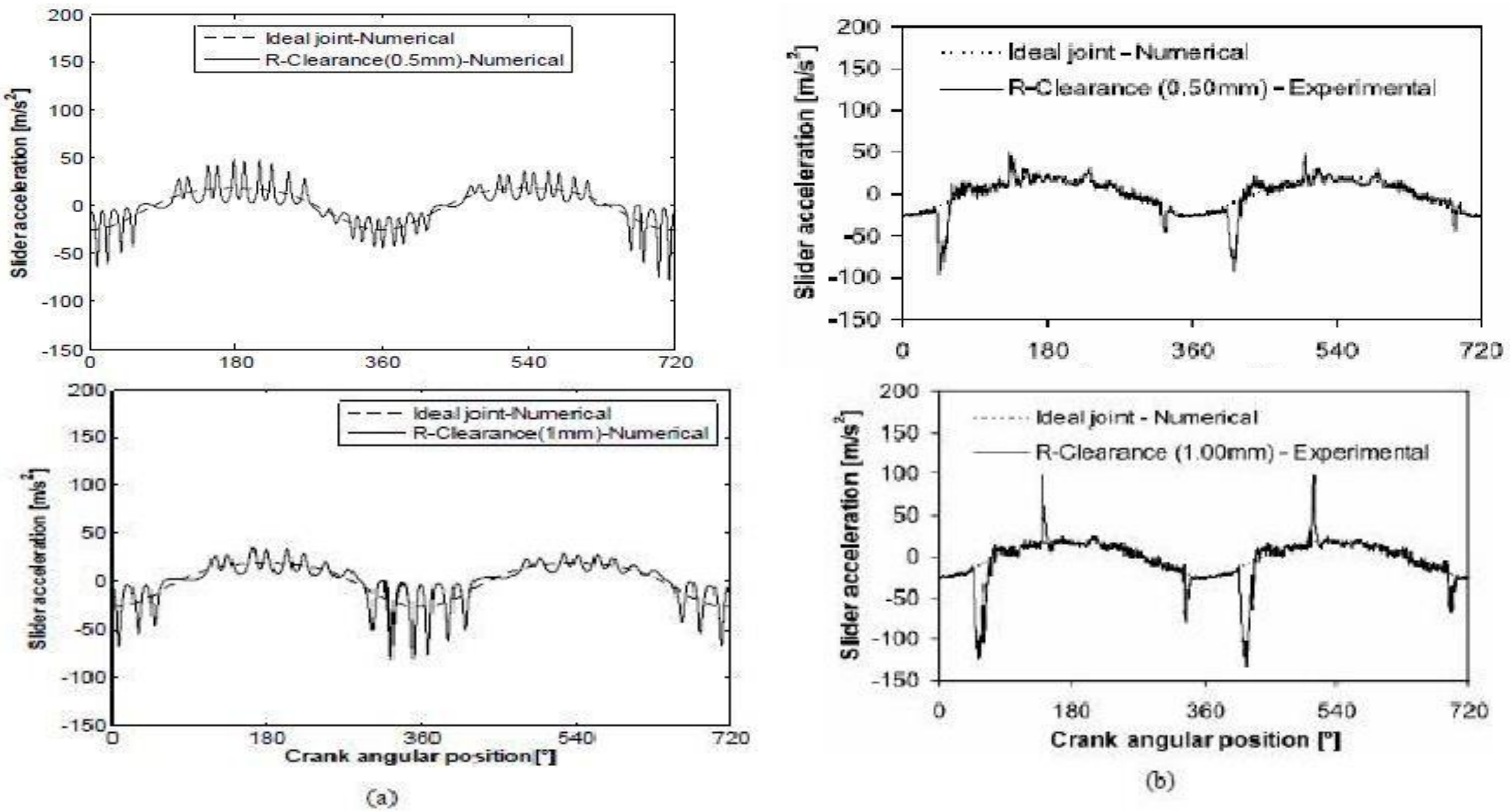


Fig. Slider accelerations with clearance size c = 0.5 mm (top) and c = 1 mm (bottom) mm from (a) simulation; (b) experiment

7. Conclusion

Reasons for the small difference in experimental and new model values

- The clearance size is assumed to be equal and without change during simulation
- Small variations on restitution and friction coefficient during simulation
- the flexibility of links, and lubrication action and the plastic deformation in the clearance joint

Neglected in the numerical simulations which explains

A combination of a nonlinear contact law with nonlinear contact stiffness

The dynamic response of slider acceleration using new nonlinear contact force model is similar to the experimental results published and has least error for $C_r \leq 1$.

Thanks!

Any question?

You can find me at:

213101001@iitb.ac.in

All references from https://inis.iaea.org/search/search.aspx?orig_q=RN:47084707