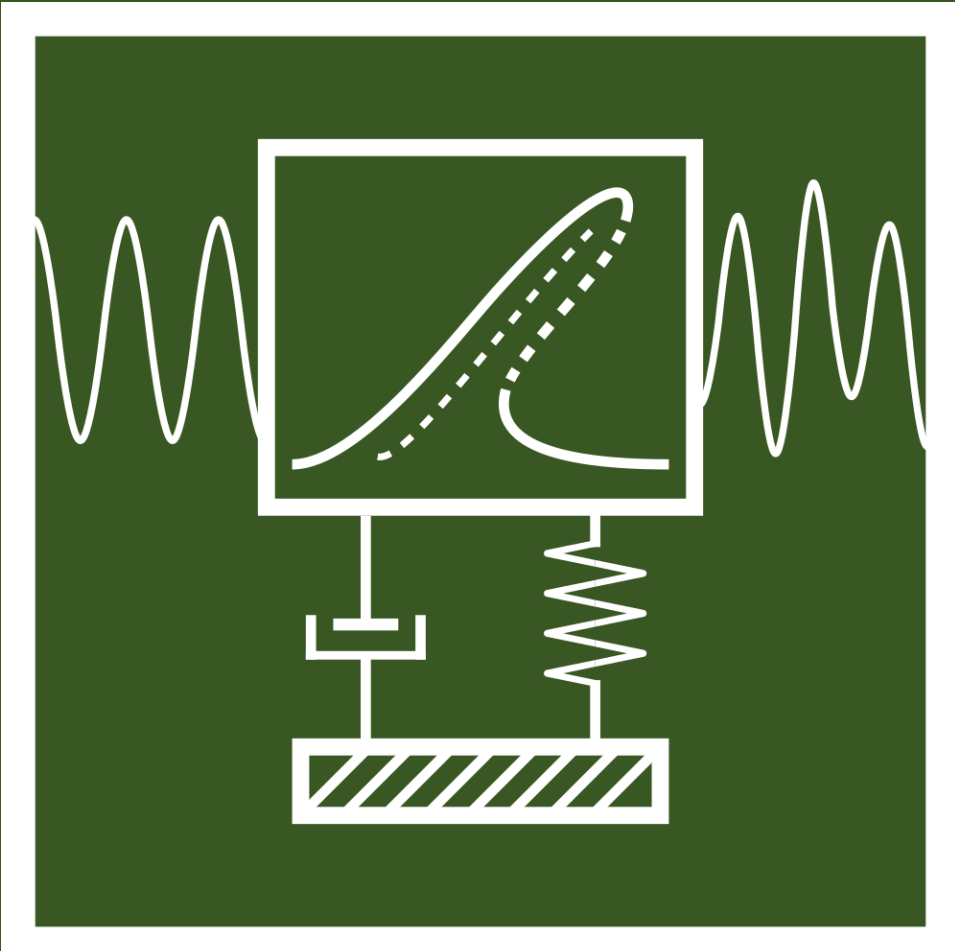


Speed and torque optimization of a two-module vibration-driven system with unbalanced rotors

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A Abstract

This numerical study jointly optimizes mean transport speed and combined RMS drive torque. A hybrid dry-friction model links two unbalanced rotors to contact loading and sticking. The selected 9 mN·m design increases speed by 108.25% and reduces RMS torque by 14.34% relative to a feasible reference.

01 Methods

Six design variables describe mass and unbalance allocation, excitation intensity, frequency tuning, damping and phase. A 2,048-point Sobol sample and differential evolution generate an approximate Pareto set. Independent event-driven integration checks 20 averaging cycles after 200 transient cycles.

02 Results

Steady-state comparison for the 0.55 kg system

Quantity	Reference B	Compromise C	Fastest found F
Mean speed (m/s)	0.06414	0.13356	0.40781
Combined RMS torque (mN·m)	10.501	8.995	30.947
Max. deformation (mm)	11.529	8.572	35.961
Positive energy / distance (J/m)	8.314	3.032	4.535
Min. contact reserve	0.4000	0.1983	0.1000

C: $\Omega = 0.79355$, $\delta = 179.50^\circ$, $k = 628.3$ N/m, $b = 0.5582$ N·s/m.
Positive input energy excludes braking-energy recovery.

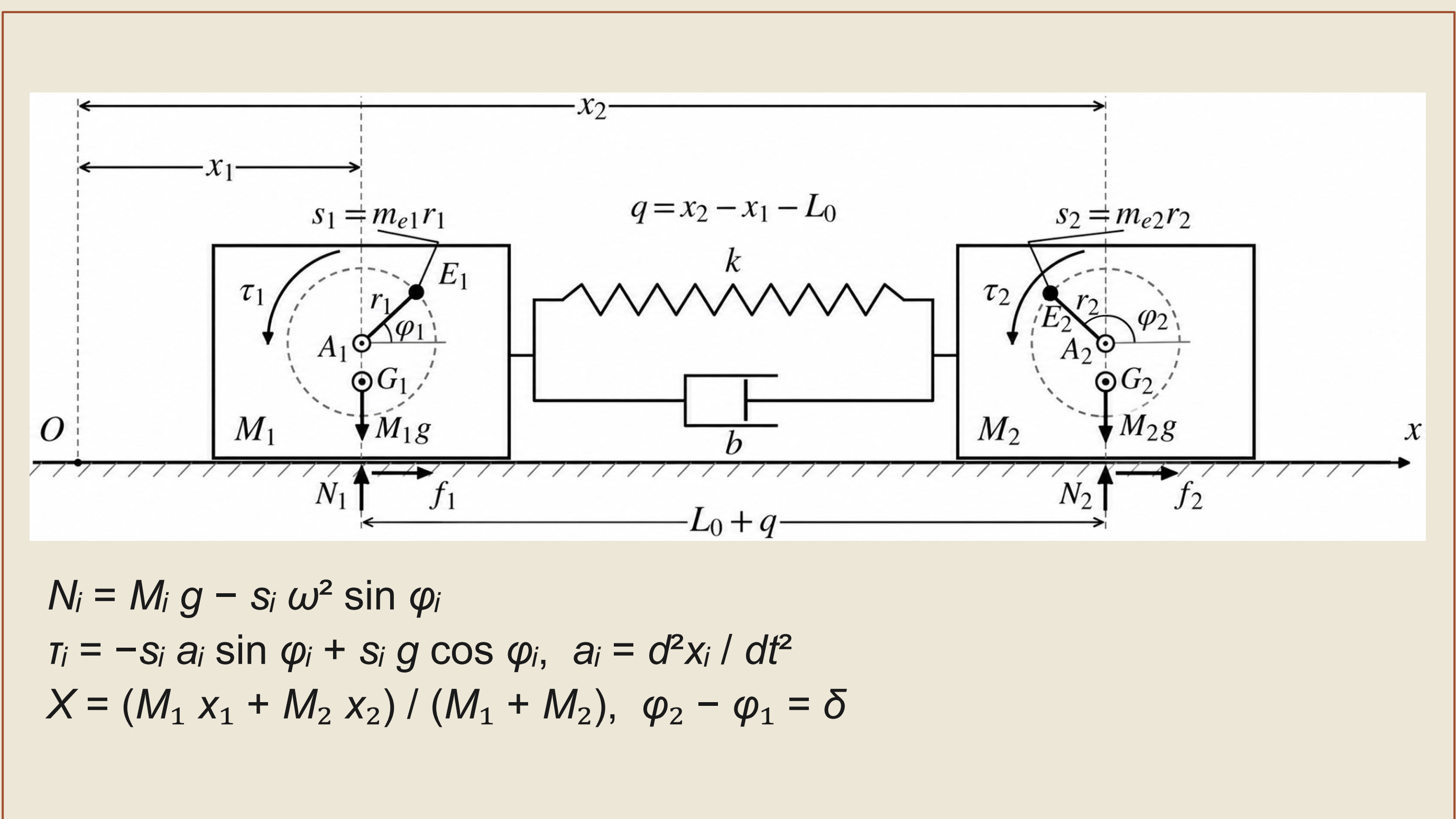


Fig. 1. Model with constant-speed rotors and explicit stick–slip contact.

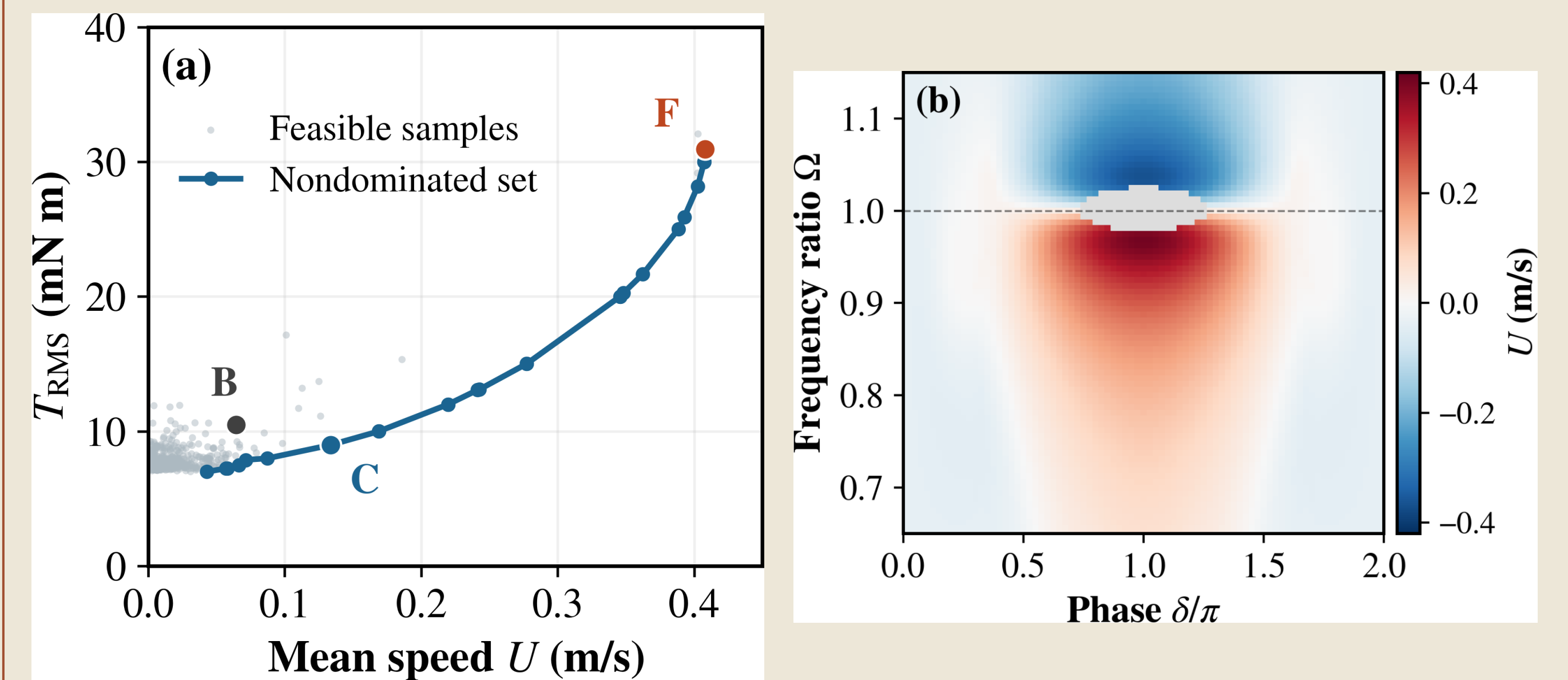
Maximize $U = -\text{mean}(\ddot{X})$, with $T_{\text{RMS}} = \sqrt{\text{mean}(\tau_1^2 + \tau_2^2)} \leq T_{\text{lim}}$.
 $N_i \geq 0.10 M_i g$; $\max|q| \leq 40$ mm; $\max|\tau_i| \leq 80$ mN·m.

03 Discussion

Compromise C operates below nominal resonance ($\Omega = 0.794$), with nearly balanced masses and antiphase excitation. F approaches the 10% contact reserve and requires greater torque and stroke. Proportional mass-unbalance allocation maximizes contact capacity, not necessarily speed.

04 Conclusions

Joint mechanical and excitation tuning improves the speed-torque compromise. C reduces positive mechanical energy per distance by 63.53%. These numerical gains depend on the stated bounds and assumed friction. Experimental validation of contact and drive losses remains necessary.



Map: $\alpha = \beta = 0.5$, $\Gamma = 0.8$, $\zeta = 0.03$. Gray: inadmissible.

Fig. 2. Approximate Pareto set (a) and frequency–phase speed map (b).

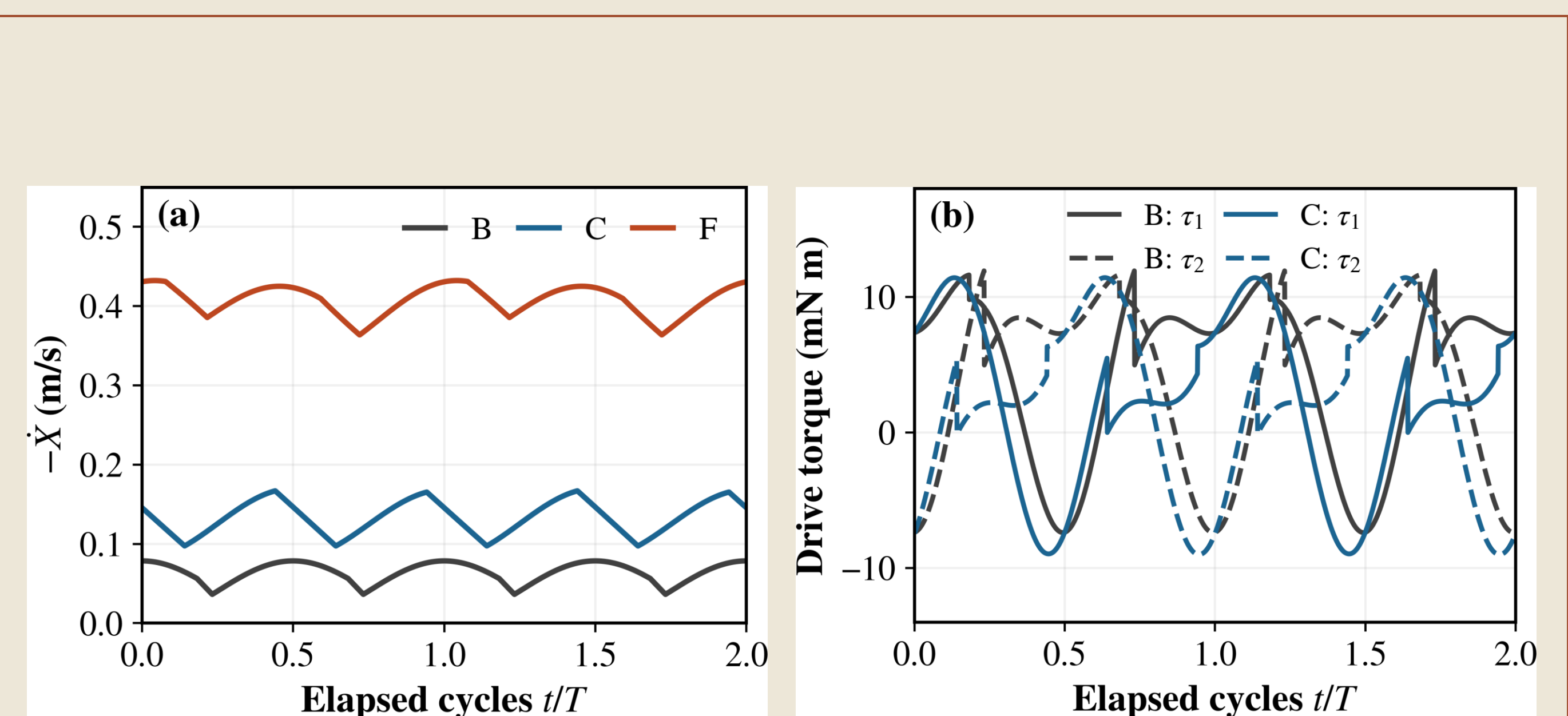


Fig. 3. Velocity (a) and signed drive torques (b) over two cycles.

$M = 0.55$ kg, $S = 1.5 \times 10^{-3}$ kg·m, $\eta = 0.03$ m.
Assumed friction: $\mu_s = 0.35$, $\mu_k = 0.30$. No lift-off or pitch.
The computed Pareto set does not prove global optimality.

Research information

Lviv Polytechnic National University, Lviv, Ukraine.
Data are available from the corresponding author on request.

Selected references

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