Design of High-speed Robots with Drastically Reduced Energy Consumption

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Context

The classical approach to decrease the energy consumption of high-speed robots is by lowering the moving elements mass in order to have a lightweight structure. Even if this allows reducing the energy consumed, the lightweight architecture affects the robot stiffness, worsening the accuracy of the mechanism.

Objective

In order to increase the energy efficiency of high-speed parallel robots while ensuring the accuracy, this work proposes the use of parallel arrangement of variable stiffness springs (VSS) and motors. The VSS are used as energy storage for carrying out the reduction of the energy consumption and their parallel configuration with the motors ensure the load balancing at high-speed without losing the accuracy of the robot.

Physical Background (Dynamics)

$$\boldsymbol{\tau} = \mathbf{M}\ddot{\mathbf{q}} + \mathbf{h}(\mathbf{q}, \dot{\mathbf{q}}) + \mathbf{K}(\mathbf{q} - \mathbf{q}_s)$$

$$\boldsymbol{\tau}_{\text{vsa}} = \mathbf{M}_s\ddot{\mathbf{q}}_s + \mathbf{h}_s(\mathbf{q}_s, \dot{\mathbf{q}}_s) - \mathbf{K}(\mathbf{q} - \mathbf{q}_s)$$

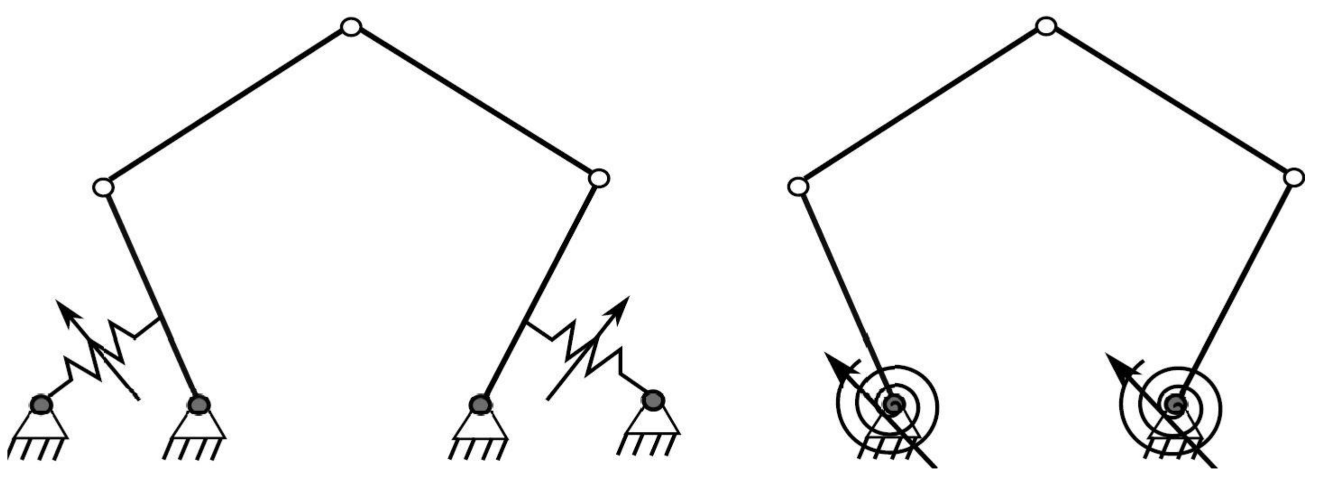

Fig. 1. Five-bar mechanism with variable stiffness linear and torsional springs in parallel arrangement with the actuated links (the grey circles denote the actuated joints).

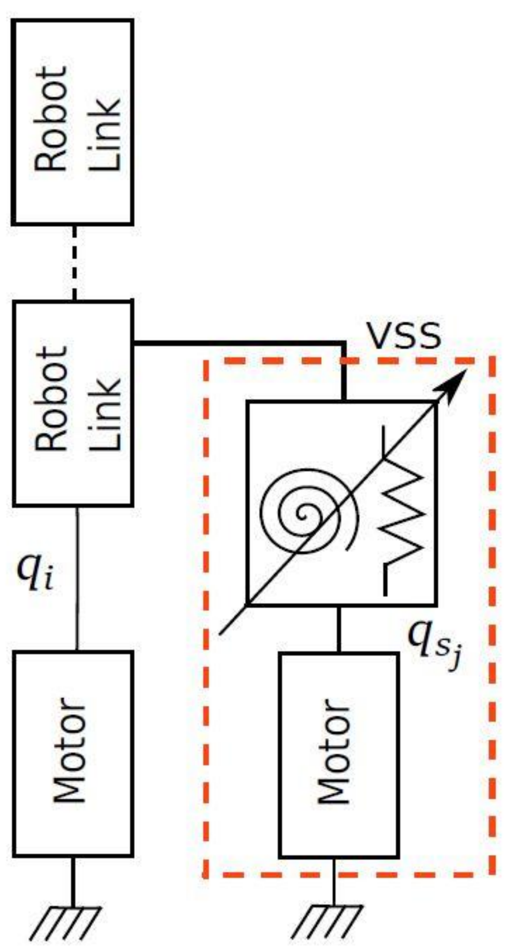

Fig. 2. Variable stiffness springs in parallel to the motors. q_i and q_{sj} represent the parallel robot joints and variable stiffnes joints respectively.

Physical Background (Power consumption)

Motor electromechanical losses:

$$P_{losses} = P_{motor} + P_{brake} + P_{damp} + P_{cond} + P_{switch} + P_{rectifier}$$

Dynamics vs Power consumption: Methods and Results

Cost function: minimize $J = \int_0^{tf} P_{losses} dt$

Method 1 Optimal motion generation: Reduction of 40%

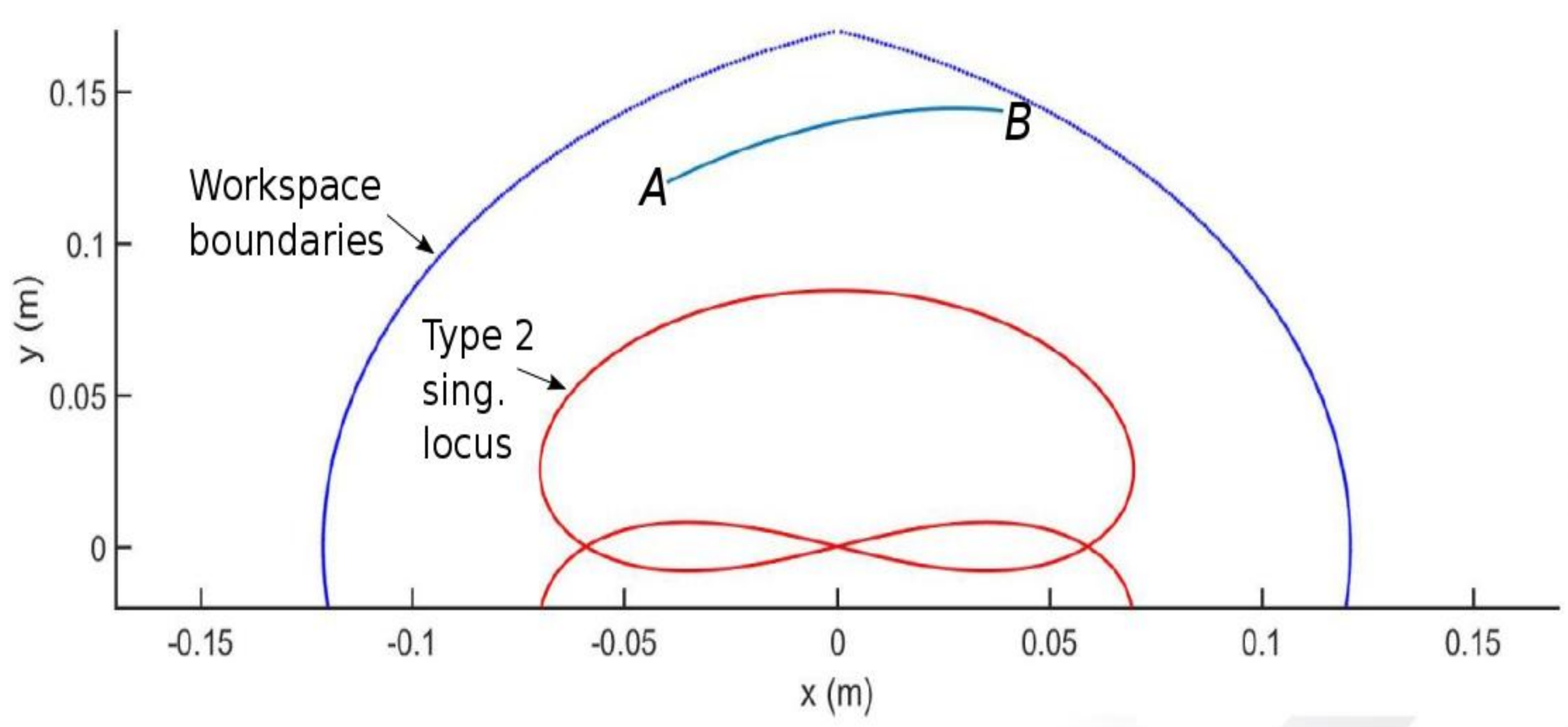

Fig. 3. Desired trajectory points sequence from *A* to *B* multiple times, with travel times of 0.07s between desired points.

Method 2 Control of oscillations (Limit cycles): Reduction between 60% to 65%

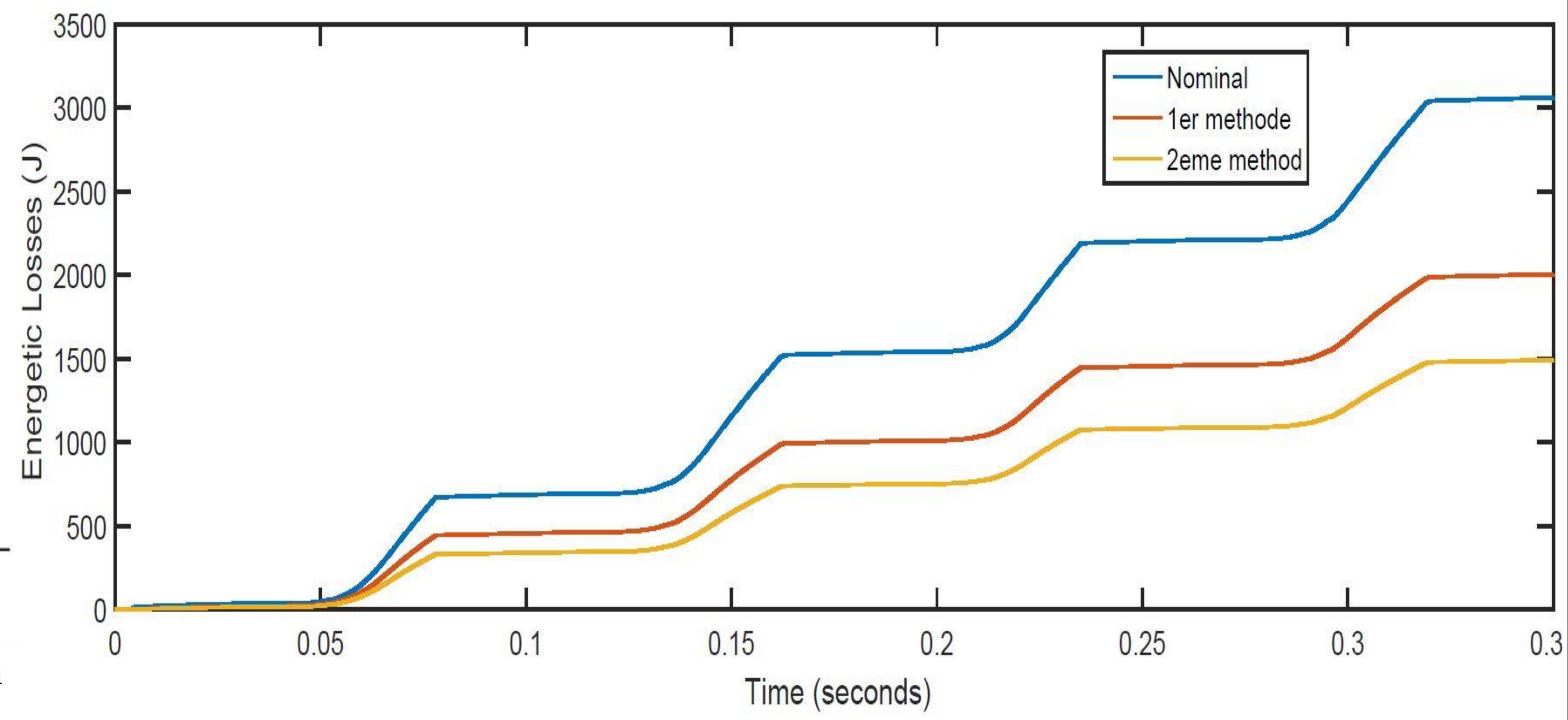

Fig. 4. Energetic losses for the desired trajectory points sequence.

Conclusions:

- Results show that the reduction of energy consumption can reach up to 40% by using optimal motion generation and 65% by using limit cycles, being the latter the method showing the major energy reduction due to the exploitation of the dynamic model through the storage elements.
- Next work on this subject includes experimental validation.

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