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Research paper

Active control of contact force for high-speed railway pantograph-catenary based on multi-body pantograph model

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ABSTRACT

Active control of pantograph is a promising approach in improving the current collection quality of high-speed railway pantograph-catenary system. To address the shortcomings of the lumped-parameter pantograph model used in previous studies, a multi-body model of pantograph is established, and two configurations of installing actuators on a multi-body pantograph are presented. In combination with a nonlinear finite element model of catenary, the control performance is evaluated through several numerical simulations. First of all, the effect of control gains on the control performance is analyzed. Then considering more realistic conditions, the controller time-delay and the limitation of controller sensitivity are included, whose influence on the control performance is investigated. At last, considering realistic external disturbance (strong wind load and locomotive vibration) to pantograph-catenary system the control performance is evaluated in decreasing the fluctuation in contact force as well as eliminating the contact loss. The results indicate that the proposed controller with larger control gains has better performance in decreasing the fluctuation of the contact force between the multi-body pantograph and the nonlinear finite element catenary, but has lower robustness against the controller time-delay. The reduction of controller sensitivity results in a fluctuating degradation of the control performance.

1. Introduction

A railway overhead line (also called catenary), as shown in Fig. 1, is a cable structure constructed along a railway, which is responsible for the transmission of electric energy to high-speed train via a pantograph installed on the roof of a locomotive. As well known, pantograph-catenary systems are widely used in modern electrified railway industries. The sliding contact between pantograph and catenary is the most vulnerable part in a traction power system, which directly determines the transmission quality of electric energy from catenary to locomotive. In recent years, the increase of train speed results in a significant increase of the fluctuation of the contact force between the catenary and pantograph, which has brought huge challenges to the stable current collection quality of pantograph-catenary systems. This issue has been one of the key

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Nomenclature

m_1	Mass of lower link
m_2	Mass of lower arm
m_3	Mass of upper arm
k_E	Equivalent stiffness of framework
m_E	Equivalent mass of framework
c_E	Equivalent damping of framework
z_E	Equivalent uplift of framework
m_h	Mass of pantograph head
c_h	Damping of pantograph head
k_h	Stiffness of pantograph head
J_1	Moments of inertia of lower link
J_2	Moments of inertia of lower arm
J_3	Moments of inertia of upper arm
l_1	Length of lower link
l_2	Length of lower arm
l_3	Length of upper arm
l_5	Length of FA
l_6	Length of GB
l_7	Length of PC
C_A	Damping of revolute joints A
C_B	Damping of revolute joints B
C_C	Damping of revolute joints C
C_D	Damping of revolute joints D
α	Rising angle of pantograph
M_0	Static uplift moment
$z_E(t)$	Displacement of the upper framework
$z_h(t)$	Displacement of the pantograph collector
m_h	Mass of pantograph collector
k_h	Stiffness of pantograph collector
c_h	Damping of pantograph collector
l_e	Vertical distance between two joints A and B on the base
l_f	Horizontal distance between two joints A and B on the base
δ	Fixed angle from the upper arm to arm CD
f_c	Contact force between pantograph collector and contact wire
L	Difference between kinetic energy and potential energy
Q_1	Generalized forces acting on α
Q_2	Generalized forces acting on $z_h(t)$
$\ddot{\mathbf{u}}(t)$	Acceleration vector of catenary
$\dot{\mathbf{u}}(t)$	Velocity vector of catenary
$\mathbf{u}(t)$	Displacement vector of catenary
$\mathbf{M}_c$	Mass matrix of catenary
$\mathbf{C}_c$	Damping matrix of catenary
$\mathbf{K}_c(t)$	Stiffness matrix of catenary
$\mathbf{F}_c(t)$	External force vector
z_1	Vertical displacement of the contact wire at the contact point
K_S	Contact stiffness
$f_{con}(t)$	Control force
$M_{con}(t)$	Control moment
$f^*_{con}(t)$	Generalized control force
f_{ob}	Target value of contact force
f_{mean}	Mean value of contact force
$\Delta f_c(t)$	Difference between f_{ob} and $f_c(t)$
f_0	Static uplift force of pantograph
q_p	Proportional control gain
q_d	Derivative control gain
s	Laplace constant
$H_{MI}(s)$	Mechanical impedance of pantograph collector