Appendix A
Sliding Friction Model

A.1 Model Overview

The model of friction that is used in the damper model of Chap. 5 is similar to the phenomenological model derived by Powell (1994) for the purpose of studying the response of an ER fluid subjected to oscillatory loadings. As shown in Fig. A.1, it is versatile and allows for modeling of complex dependencies often observed in friction data. Table A.1 contains model parameters used in the exemplary simulations. Here, for the purpose of modeling the friction at the interface between the floating gas cup and the cylinder tube in a damper the model was extended to allow for an additional asymmetry in friction forces that was observed experimentally in monotube dampers. The phenomenological model includes eight parameters for controlling the friction force magnitude and another six ones for modifying the force decay/rise with relative velocity. In the model the relationship between force and velocity is as follows

$$\dot{x} \geq 0 \mapsto F = \begin{cases} f_1 \left[1 + \frac{f_2 - f_1}{f_1} e^{(-c_1|\dot{x}|)}\right] \tanh c_3\dot{x}; & x \cdot \dot{x} > 0 \\ f_3 \left[1 + \frac{f_4 - f_3}{f_3} e^{(-c_2|\dot{x}|)}\right] \tanh c_3\dot{x}; & x \cdot \dot{x} < 0 \end{cases}$$

$$\dot{x} < 0 \mapsto F = \begin{cases} f_5 \left[1 + \frac{f_6 - f_5}{f_5} e^{(-c_4|\dot{x}|)}\right] \tanh c_6\dot{x}; & x \cdot \dot{x} > 0 \\ f_7 \left[1 + \frac{f_8 - f_7}{f_7} e^{(-c_5|\dot{x}|)}\right] \tanh c_6\dot{x}; & x \cdot \dot{x} < 0 \end{cases}$$

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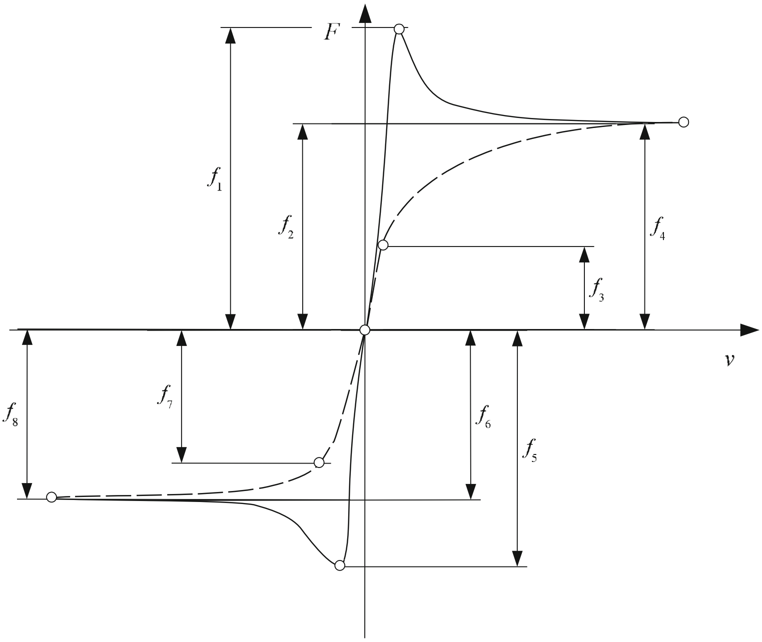

Fig. A.1 Friction model

Table A.1 Friction model parameters—c_i [s/m], f_i [N]

Figure		1	2	3	4	5	6	7	8
A.2(a)	c_i	7×10^4	7×10^4	7×10^4	7×10^4	7×10^4	7×10^4	–	–
	f_i	100	100	100	100	100	100	100	100
A.2(b)	c_i	7×10^4	7×10^4	2×10^5	7×10^4	7×10^4	2×10^5	–	–
	f_i	100	140	100	140	100	140	100	140
A.2(c)	c_i	7×10^4	7×10^4	2×10^5	7×10^4	7×10^4	2×10^5	–	–
	f_i	100	140	100	140	40	80	40	80
A.2(d)	c_i	7×10^4	7×10^4	2×10^5	7×10^4	7×10^4	2×10^5	–	–
	f_i	100	140	100	60	100	140	100	60

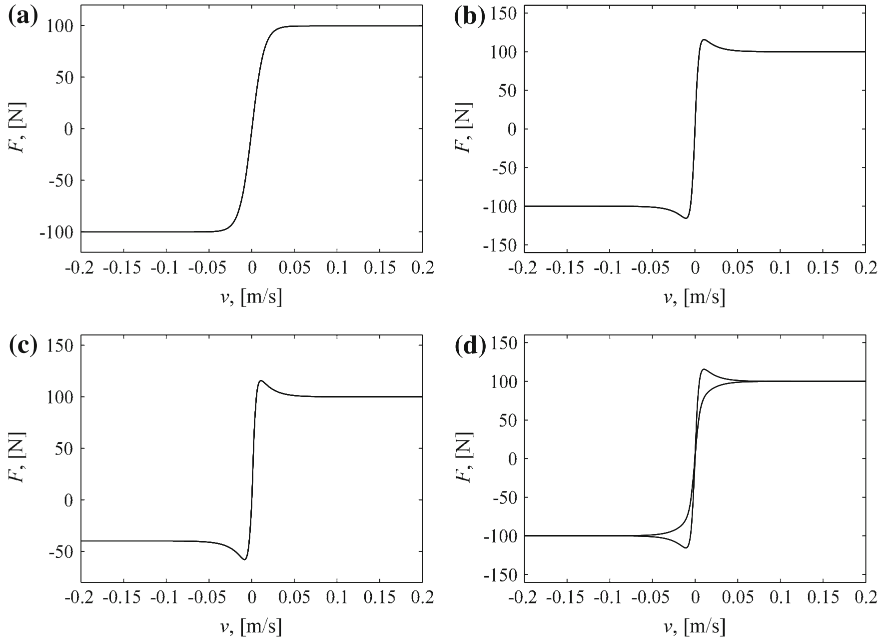

Fig. A.2 Friction model: force–velocity maps

Glossary

1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
ABS	Anti-lock Braking System
A/D	Analog/Digital
BP	Bingham Plastic
BPP	Bi-Plastic Bingham
BV	Bi-Viscous
CAN	Controller Area Network
CFD	Computational Fluid Dynamics
CI	Carbonyl Iron
CIP	Carbonyl Iron Powder
DAC	Data Acquisition
DAE	Differential Algebraic Equation
EMI	Electro-Magnetic Induction
EH–LMR	Energy Harvesting Linear (MR Damper)
ER	Electrorheological
FE	Finite-Element
I/O	Input/Output
LF	Left-Front
LR	Left-Rear
LDE	Life of a Device Estimate
MR	Magnetorheological
MagneRide	Magnetorheological Fluid-based Vehicle Suspension System
NVH	Noise, Vibration, Harshness
ODE	Ordinary Differential Equation
PDE	Partial Differential Equation
PI	Proportional-Integral
PID	Proportional-Integral-Derivative
PADM	Porsche Active Drivetrain Mount

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PM	Permanent Magnet
PWM	Pulse-Width Modulation
RF	Right-Front
RR	Right-Rear
RT	Real-Time
RMS	Root Mean Square
SCM	(Ferrari) Magnetorheological Suspension System
SMC	Soft Magnetic Composite
SMS	Smart Material System (or Structure)
TC	Traction Control
UDF	User-Defined Function

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