SEMI-ACTIVELY CONTROLLED SUSPENSION OF RAILWAY VEHICLE

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Brno, 26. 9. 2024

INSTITUTE OF **MACHINE**
AND **INDUSTRIAL DESIGN**

CONTENT

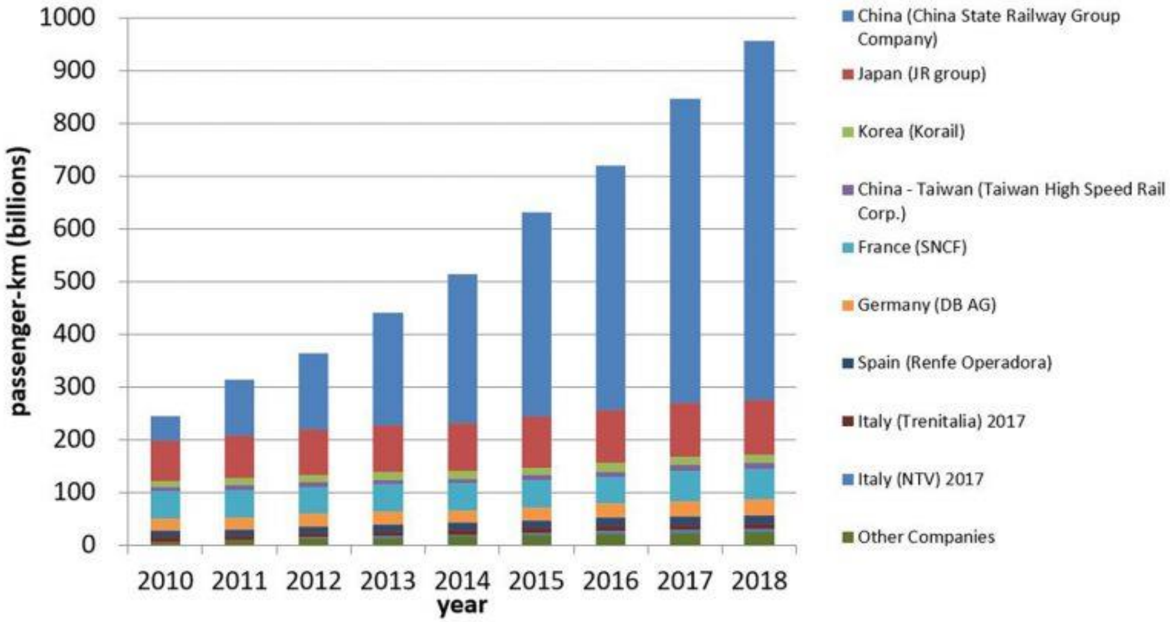
- Motivation
- State of the art
- Aim of the thesis
- Scientific questions and hypothesis
- Materials and methods
- Results
- Conclucion

wikipedia.org

MOTIVATION

- Developing high-speed rail in the world
  - ecological, economical

dopravadnes.cz



globalrailwayreview.com

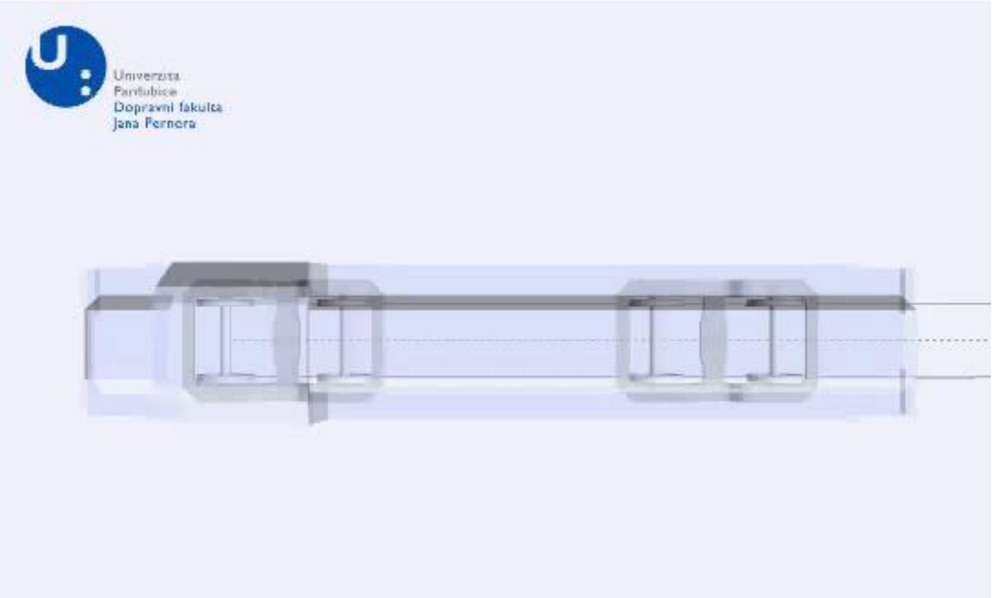
MOTIVATION

- Developing high-speed rail in the world
  - higher speeds

  → maintain safety, stability
  - passenger comfort

  → reduce carbody vibration

- increased demands on the suspension



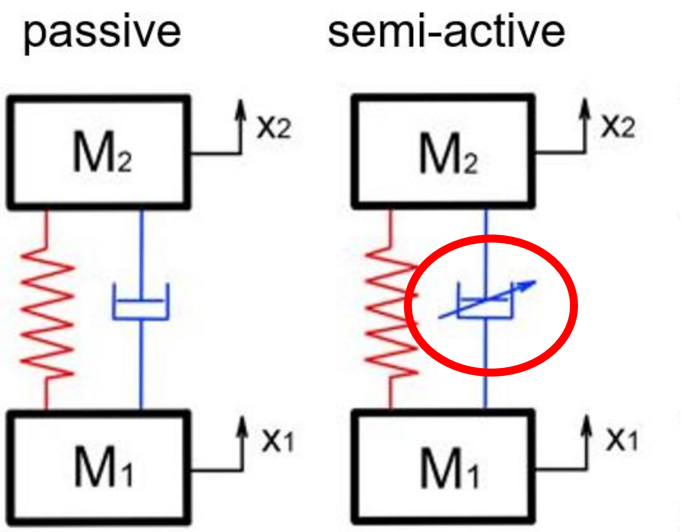
Unstable ride *youtube.com/DFJP*

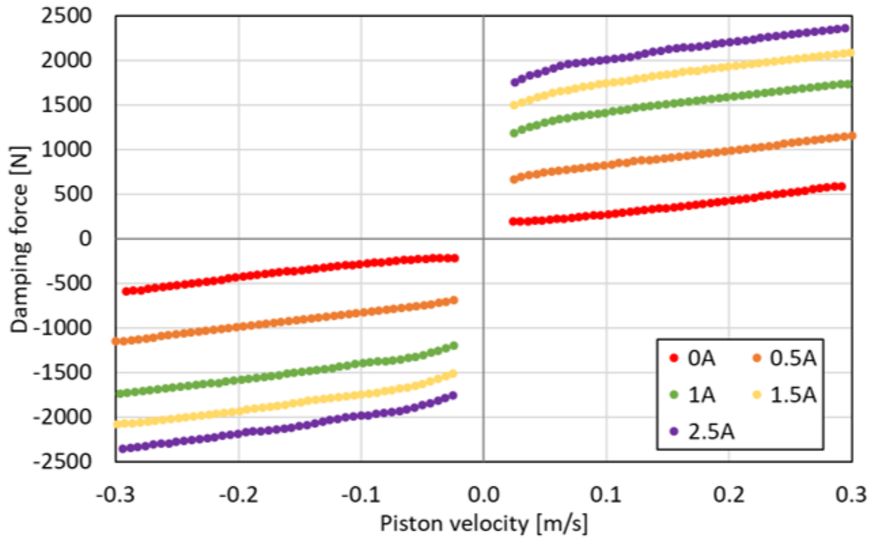
MOTIVATION

- Developing high-speed rail in the world
    - higher speeds
    → maintain safety, stability
    - passenger comfort
    → reduce carbody vibration

- increased demands on the suspension

→ **semi-active dampers can solve these problem**





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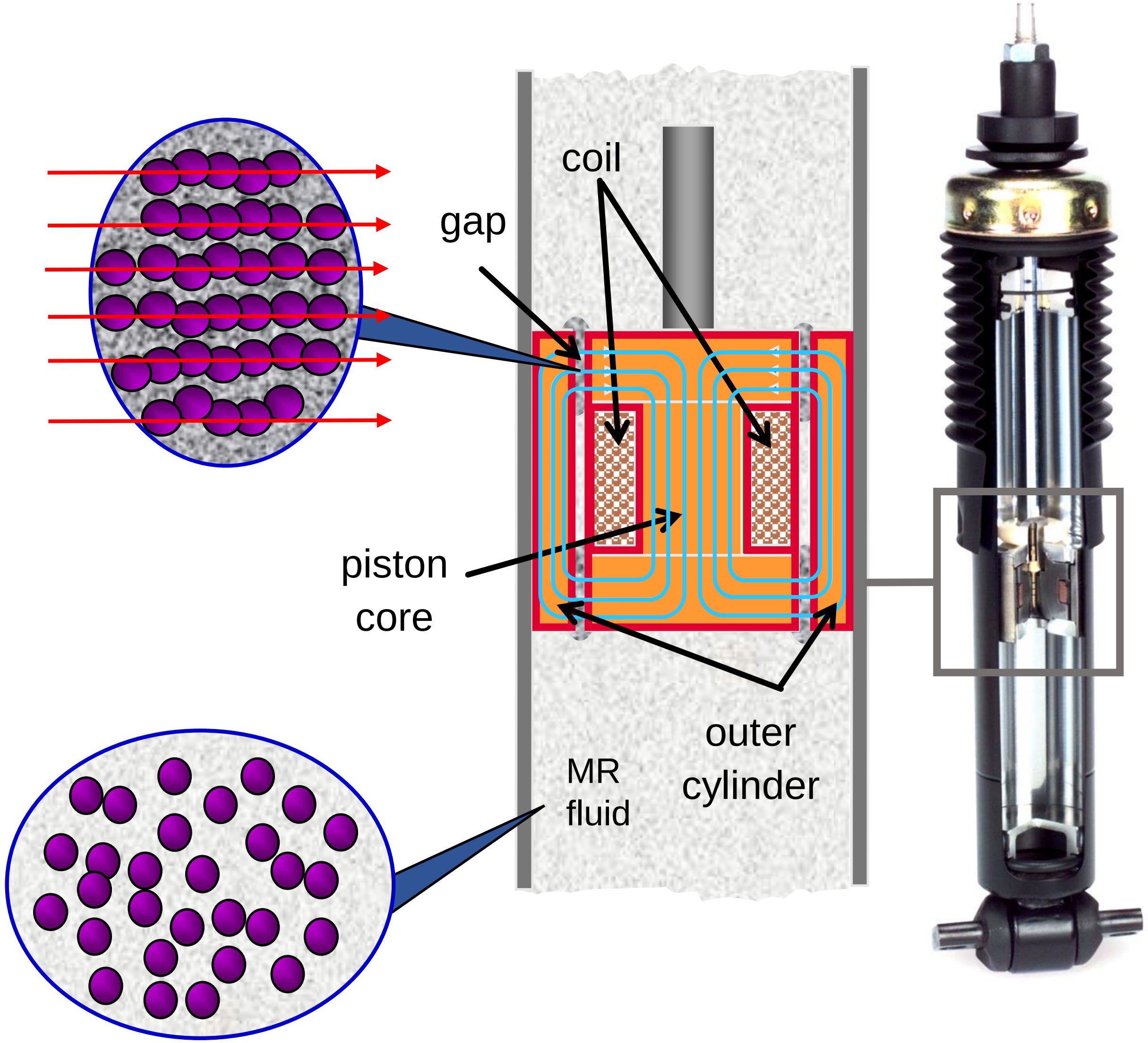
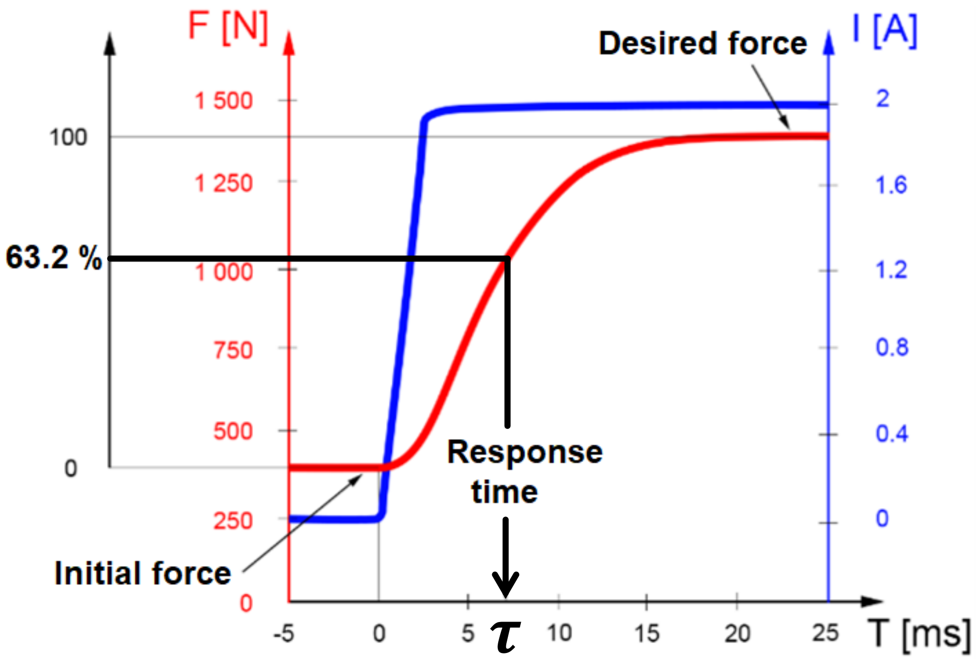
MAGNETORHEOLOGICAL DAMPER



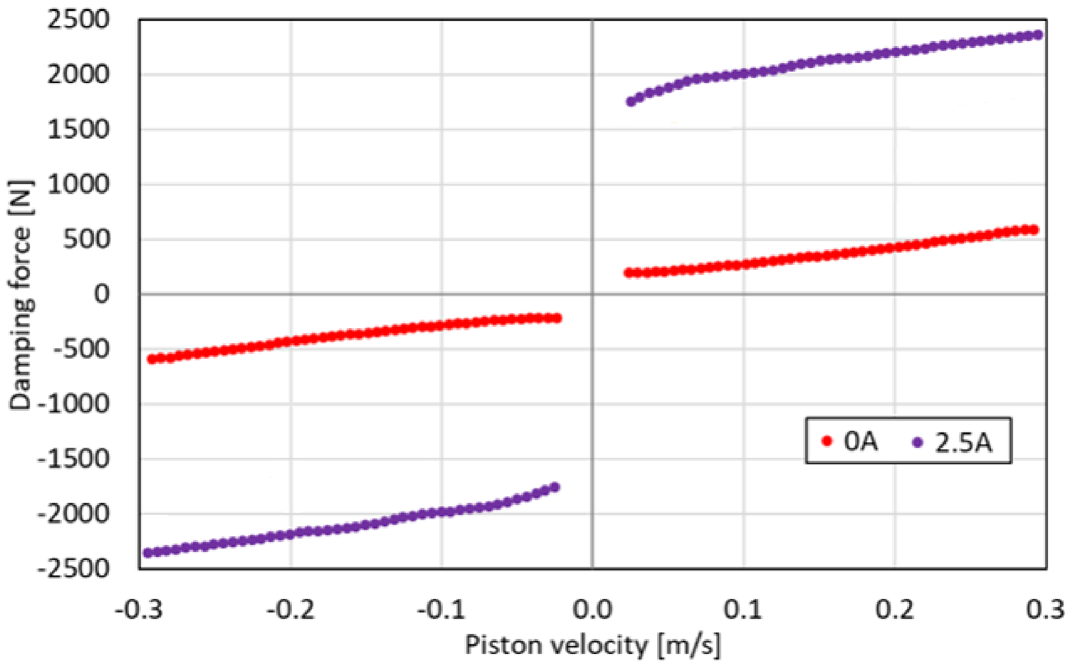
MAGNETORHEOLOGICAL DAMPER

MR damper dynamic behaviour

Force response time



Dynamic force range



ISSUES TO SOLVE

Motivation: improve running behaviour using semi-active dampers

How to control the MR damper and what dynamic parameters it must have?

How to achieve acceptable damper dynamic behaviour?

What to do in the case of a power failure?

SEMI-ACTIVE DAMPING

What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

1973 — 2011 — 2012 — 2014

Karnopp et al.

- design of control strategy Shyhook

Hudha et al.

- simulations
- 39% comfort improve

Spelta et al.

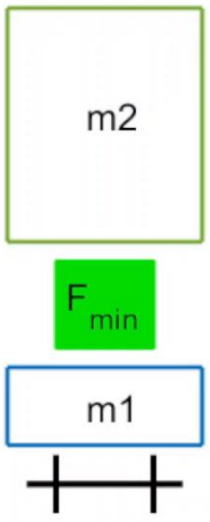
- simple real model
- 34% comfort improve

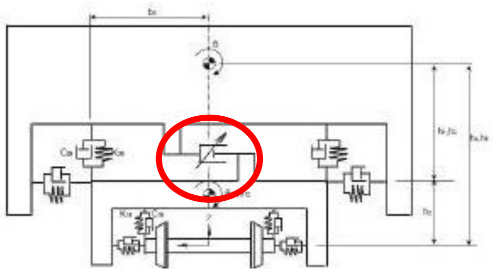
Shin et al.

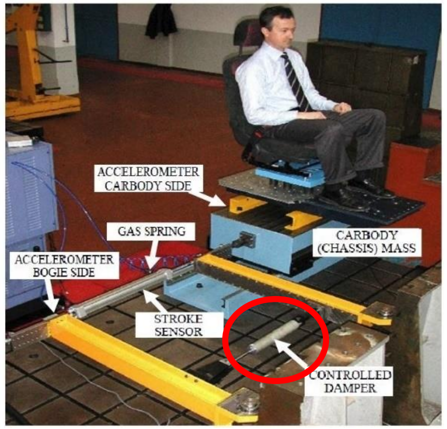
- simple real model
- 67% comfort improve (natural frequency)

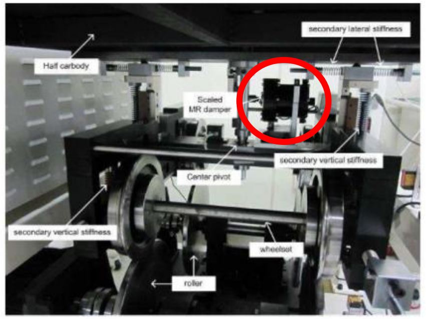
<u>Sumary:</u>

- lateral dampers
- Skyhook
- comfort improve approx. 40 %
- not verified on real vehicle
- response time neglected or unstated
- **unknown influence of damper dynamic behaviour**









STATE OF THE ART

MAGNETORHEOLOGICAL DAMPER

What dynamic parameters damper must have?

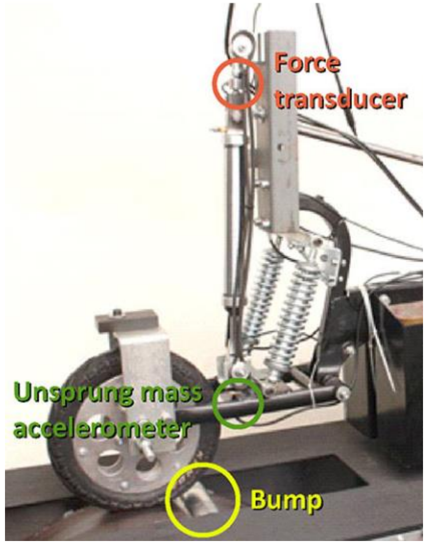
How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

2014 | 2015

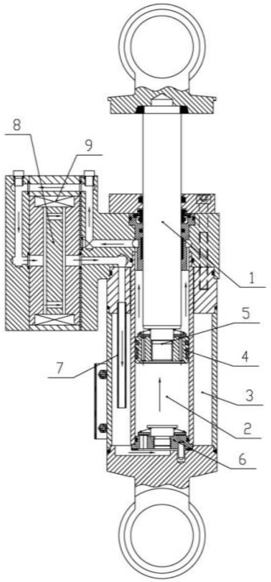
Strecker et al.

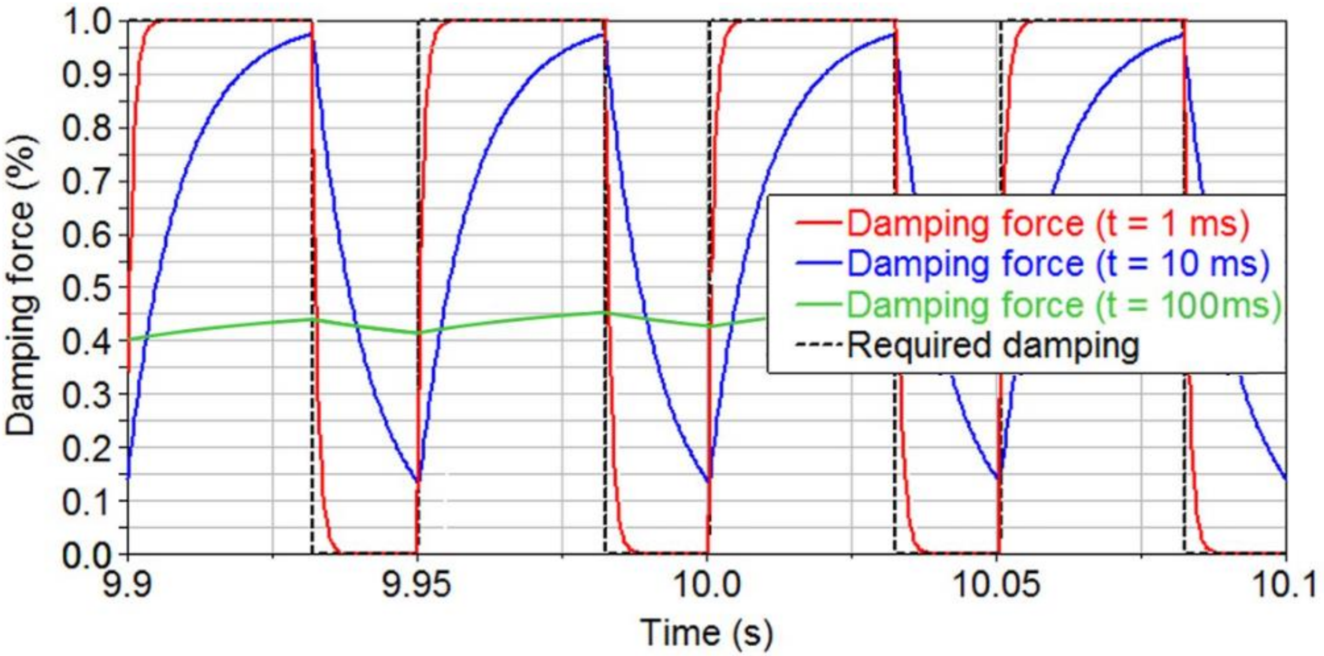
- exp. trolley
- τ = 9 ms
- dr = 9



Guo et al.

- railway damper
- τ = **300** ms
- dr = 6





MAGNETORHEOLOGICAL DAMPER

2014

2015

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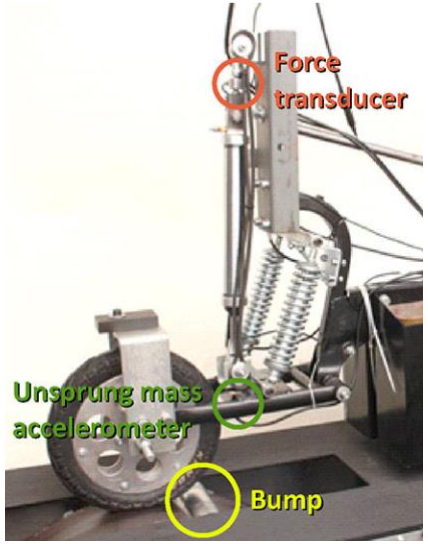

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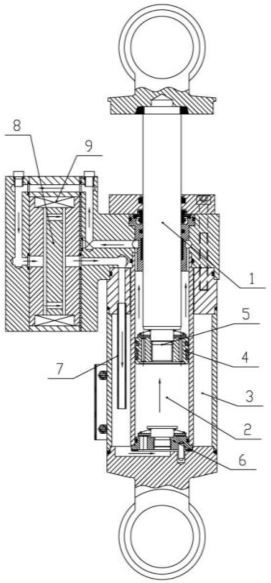
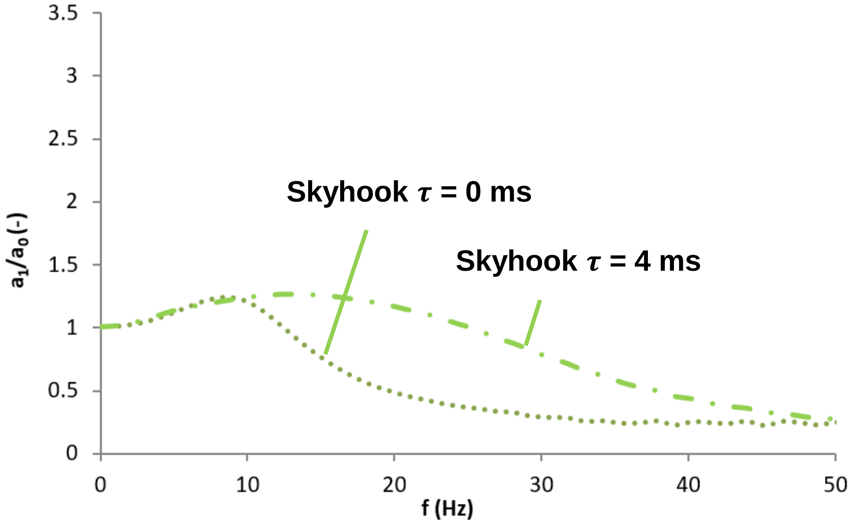
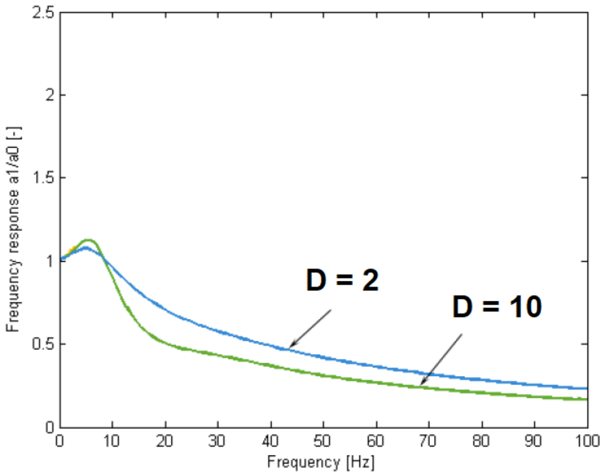




Strecker, 2018 (modificated)



Machacek, 2017 (modificated)

- unknown acceptable values for railway suspension

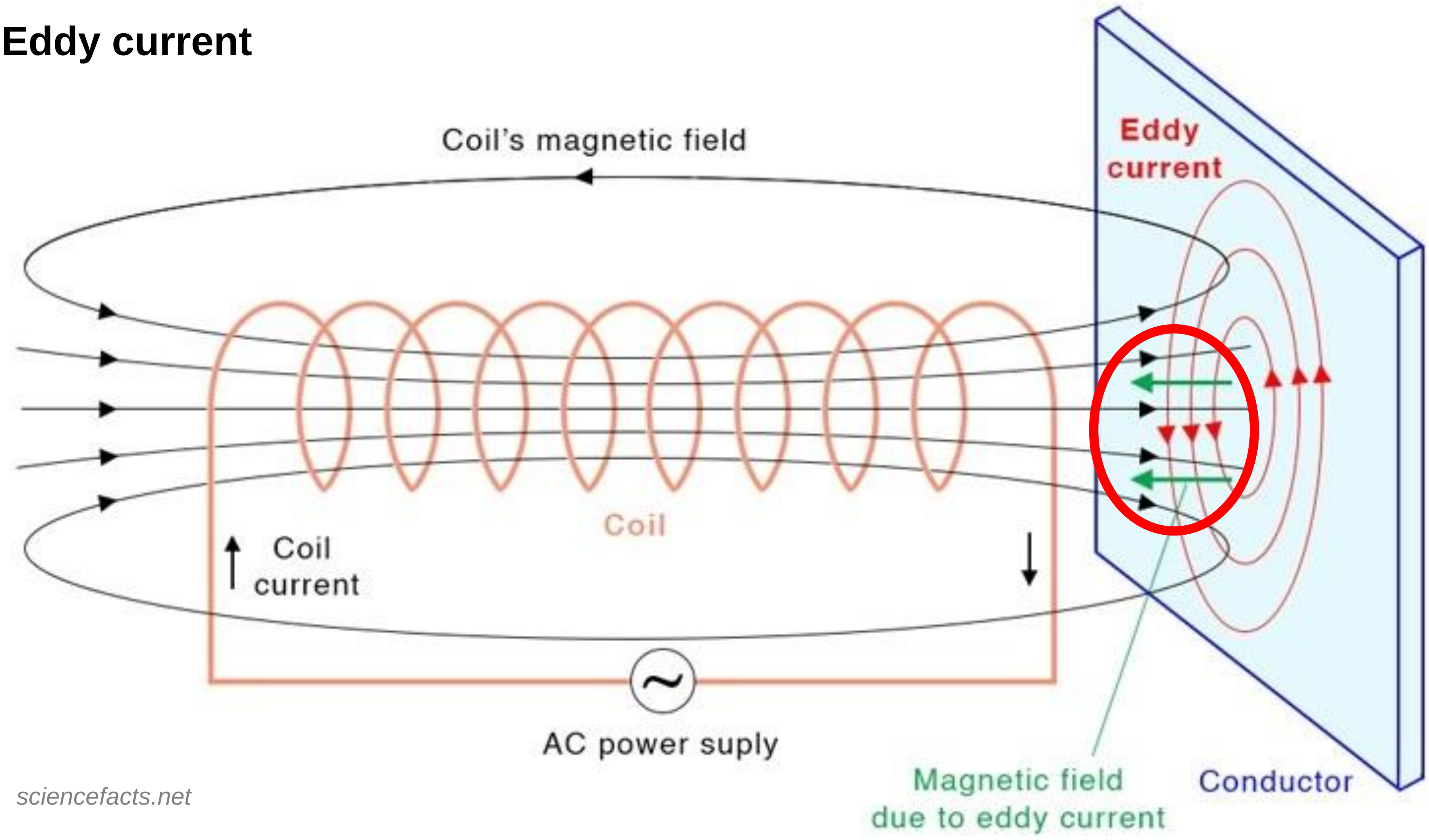
MAGNETORHEOLOGICAL DAMPER

What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

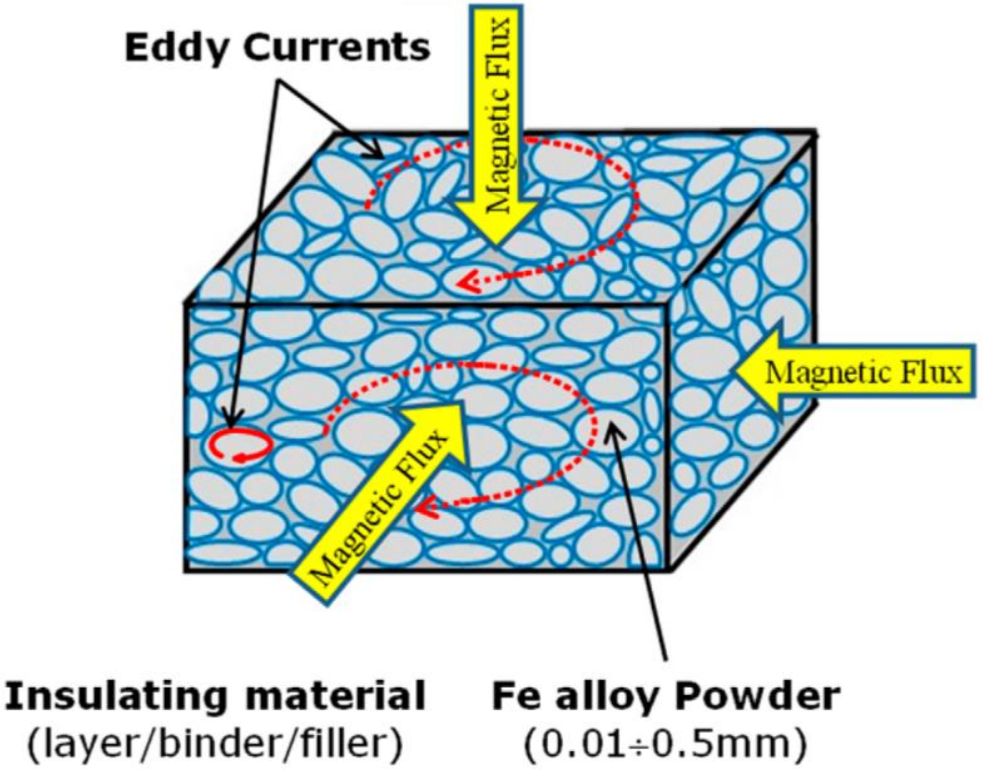
Eddy current

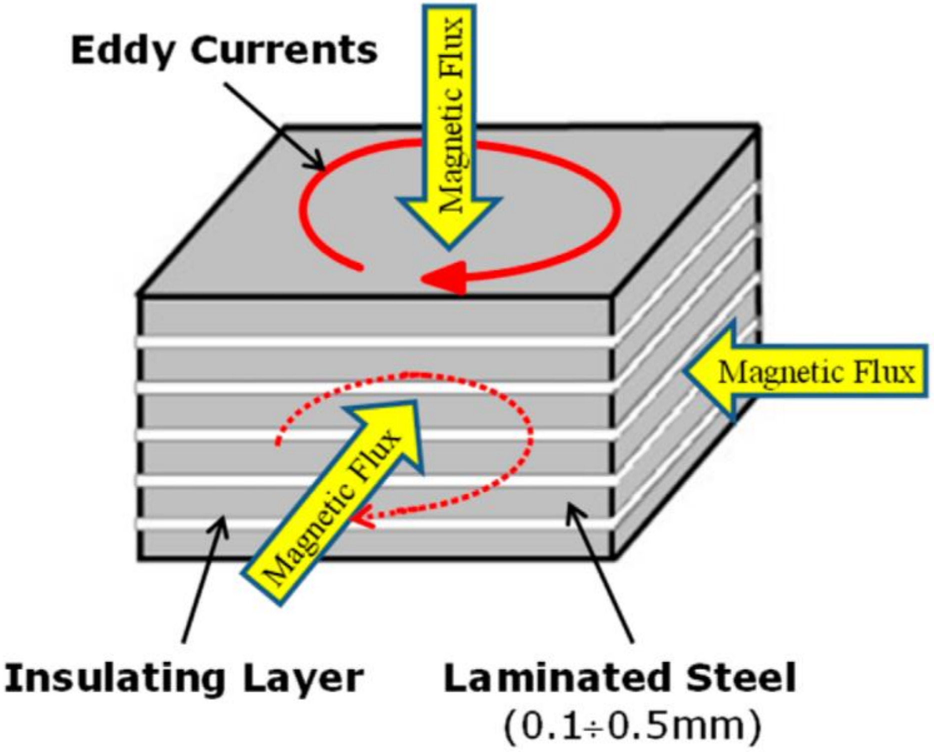


sciencefacts.net

MAGNETORHEOLOGICAL DAMPER

Material approach X Shape approach





magneticsmag.com

MAGNETORHEOLOGICAL DAMPER

What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

2014 | 2015 | 2017 | 2019

Strecker et al.

- exp. trolley
- τ = 9 ms
- dr = 9

Guo et al.

- railway damper
- τ = **300** ms
- dr = 6

Kubík et al.

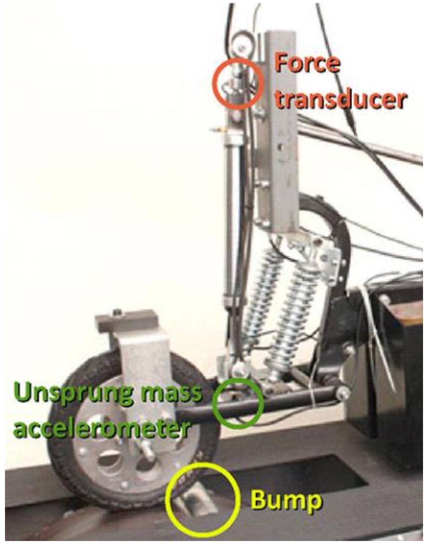
- external MR valve
- feritte (iron oxid)
- τ = 4 ms, dr = 8

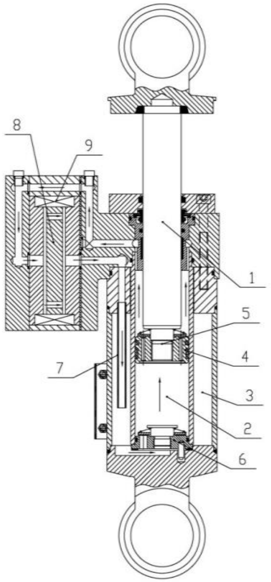
Choi et al.

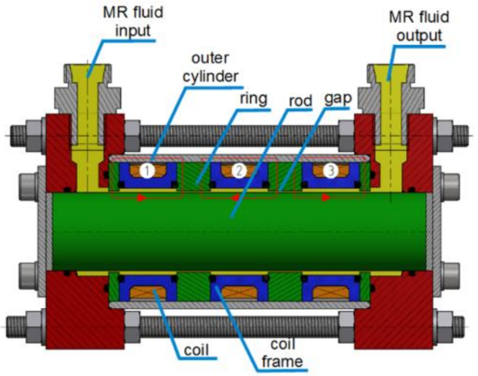
- grooved
- τ = 2 ms
- dr = 2.5

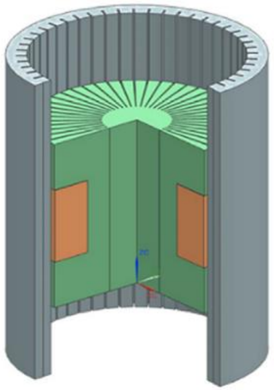
Sumary:

- unknown influence of different materials and shapes of magnetic circuit on damper dynamic behaviour





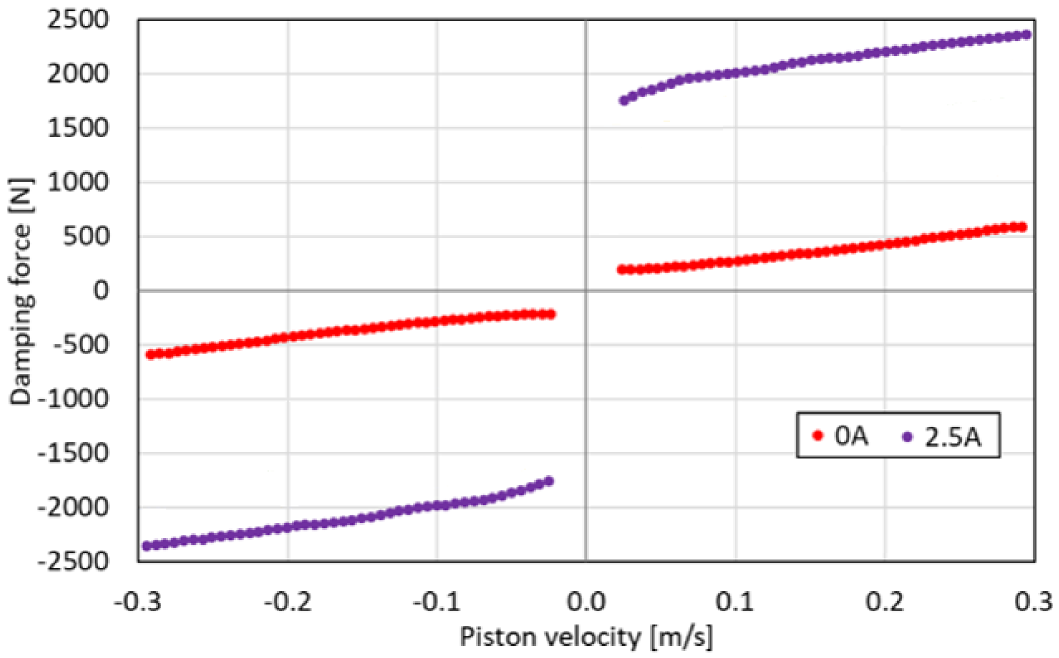


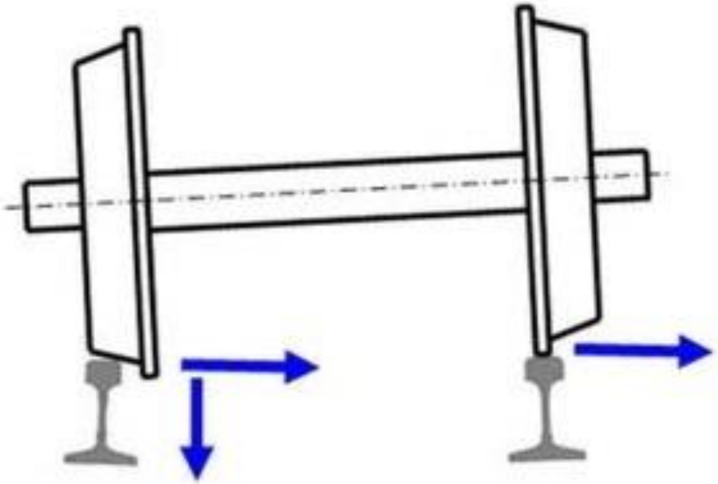


FAIL-SAFE MR DAMPER

Power failure → low damping → dangerous situation (derailment)

→ **Fail-safe** mode is required





FAIL-SAFE MR DAMPER

What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

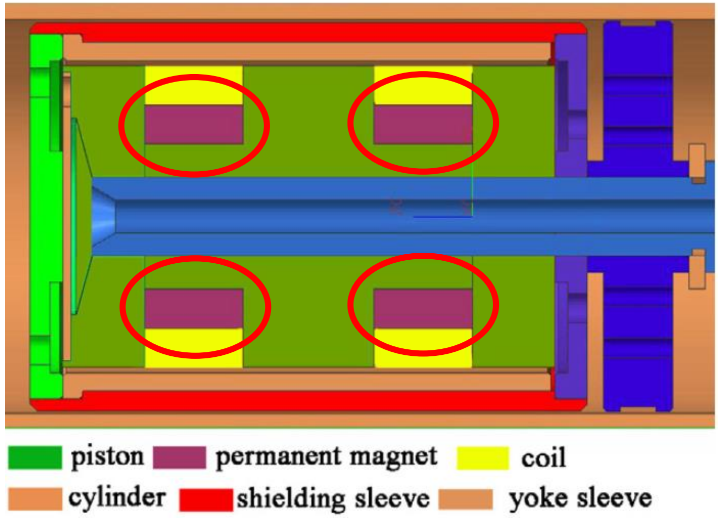
What to do in the case of a power failure?

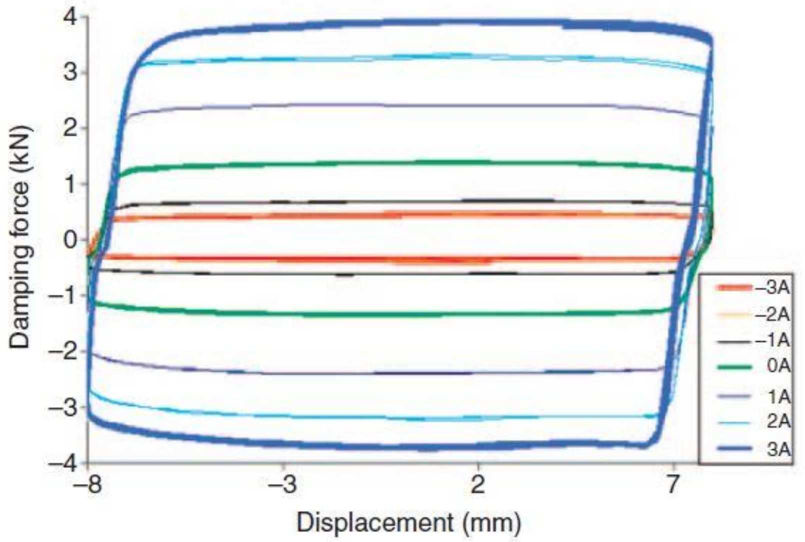
Power failure → low damping → dangerous situation (derailment)

→ **Fail-safe** mode is required

2007 — 2010 — 2011

Zhang et al. **Boese et al.** **Wei-ming et al.**



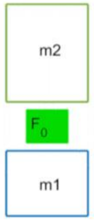


Sumary:

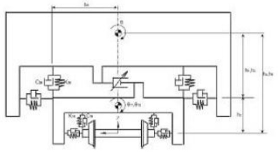
- permanent magnet in piston core
- fail-safe force – 1/3 of max. force
- **unknown damper dynamic behaviour**

LACK OF KNOWLEDGE

1973
Karnopp et al.

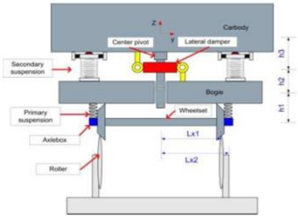


2011
Hudha et al.

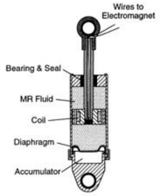


2012
Spelta et al.

2014
Shin et al.

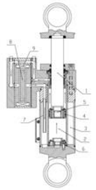


1996
Spencer et al.

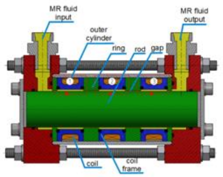


2014
Strecker et al.

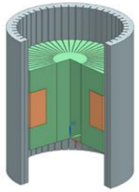
2015
Guo et al.



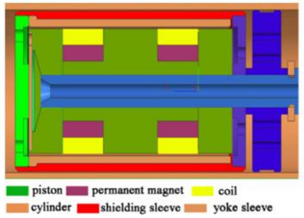
2017
Kubík et al.



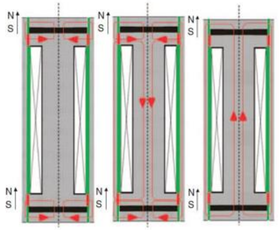
2019
Choi et al.



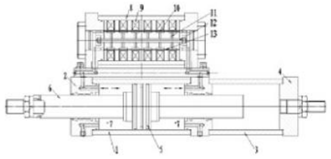
2007
Zhang et al.



2010
Boese et al.



2011
Wei-ming et al.



? Influence of damper dynamic behaviour on S/A control efficiency

? Influence of different materials and shapes of magnetic circuit on damper dynamic behaviour

? Dynamic behaviour of MR damper with permanent magnet

AIM OF THE THESIS

Investigate the effect of damper dynamic behaviour on the performance of the semi-actively controlled suspension of railway vehicle.

Investigate the possibilities of improving the MR damper dynamic behaviour.

Scientific questions:

Q1: What is an acceptable damper force response time and dynamic range for effective S/A control of railway lateral MR dampers?

Q2: How does the material and shape of the MR damper magnetic circuit affect damper behaviour?

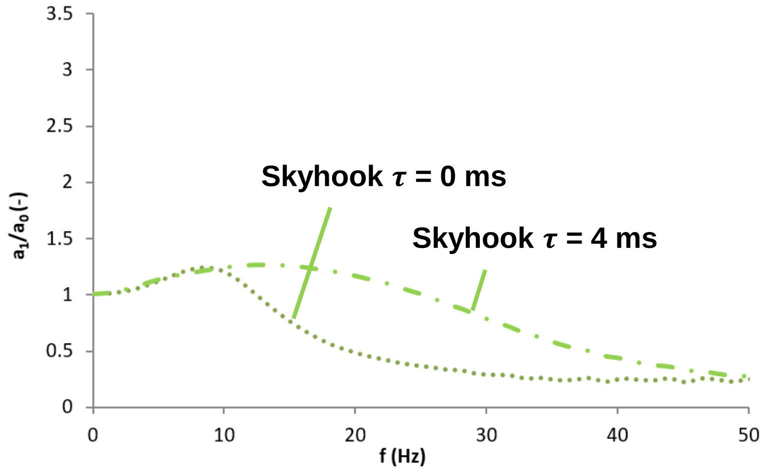
Q3: Will the permanent magnet in the MR damper affect the response time?

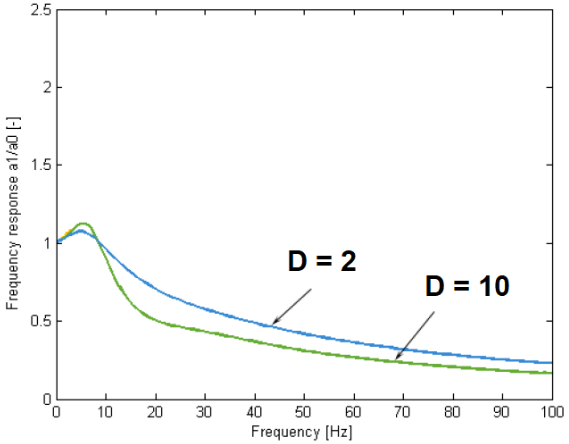
Q1

QUESTION 1

Q1: How does the damper behaviour affect the S/A control efficiency in the case of railway vehicle lateral secondary MR dampers? What are the acceptable values of damper force response time and dynamic range for this control?

H1: An acceptable force **dynamic range** is assumed to be about **10**. An acceptable **force response time** is assumed to be about **10 ms**, due to the low vibration frequency of railway vehicle carbody.



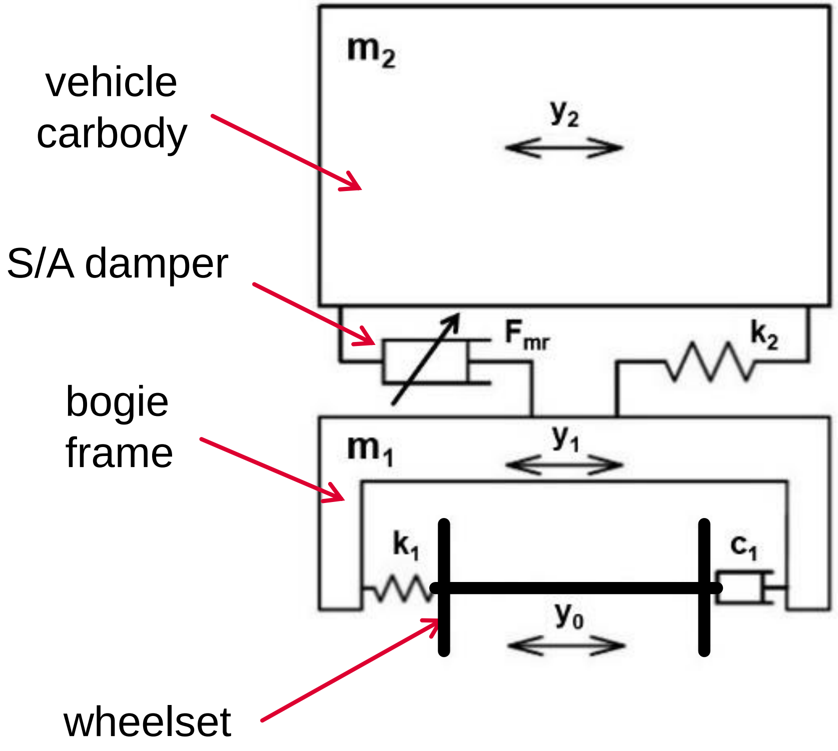


MATERIALS AND METHODS

Vehicle model

- lateral movement of railway vehicle suspension
- 2 degrees of freedom
- 1 wheelset, ½ of bogie frame, ¼ of vehicle carbody
- kinematic excitation y_0, straight track, 160 km/h
- 1:5 scale

Parameter	Symbol	Original	1:5 scale
½ bogie frame weight	m1	5000 kg	1000 kg
¼ carbody weight	m2	13,750 kg	2750 kg
wheelset-bogie frame bond stiffness	k1	10 kN/mm	2 kN/mm
bogie frame-carbody bond stiffness	k2	1 kN/mm	0.2 kN/mm
wheelset-bogie frame bond damping	c1	10 kNs/m	2 kNs/m

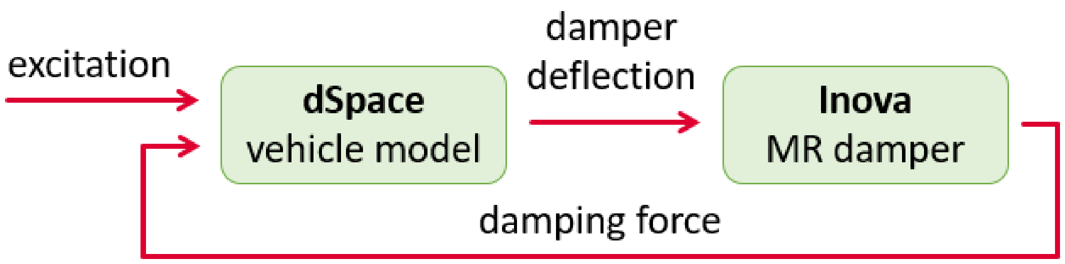


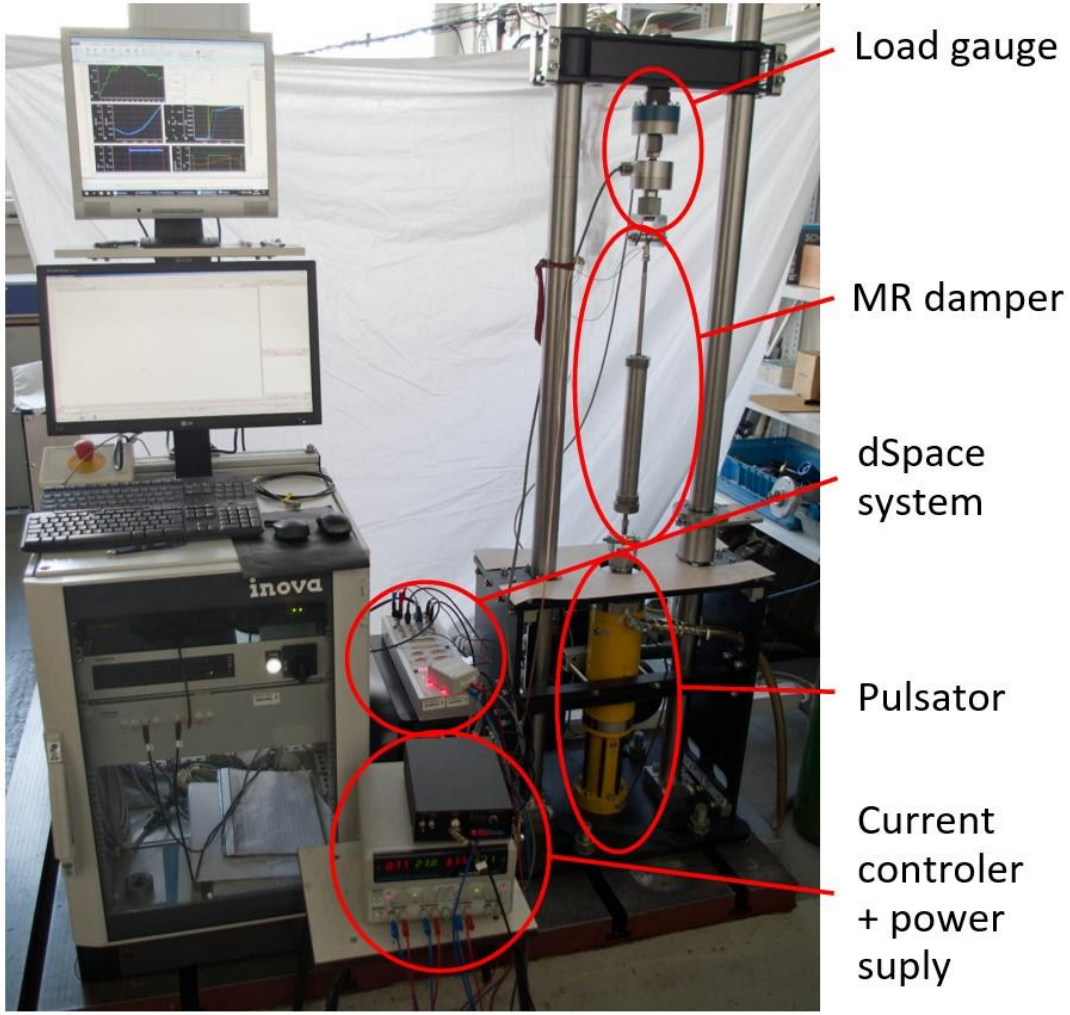
Q1: What damper force response time and dynamic range are acceptable for S/A control?

MATERIALS AND METHODS

Hardware-in-the-loop simulation

- real damper on pulsator
- virtual model on dSpace





Q1: What damper force response time and dynamic range are acceptable for S/A control?

Q1

MATERIALS AND METHODS

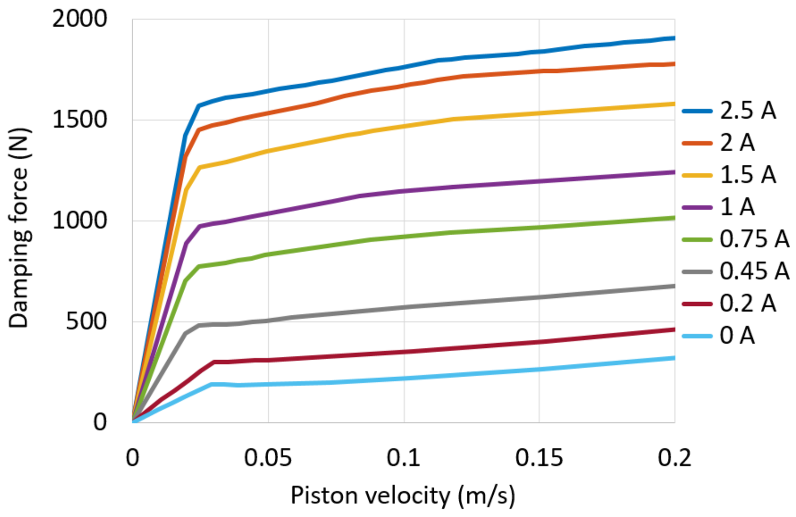
What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

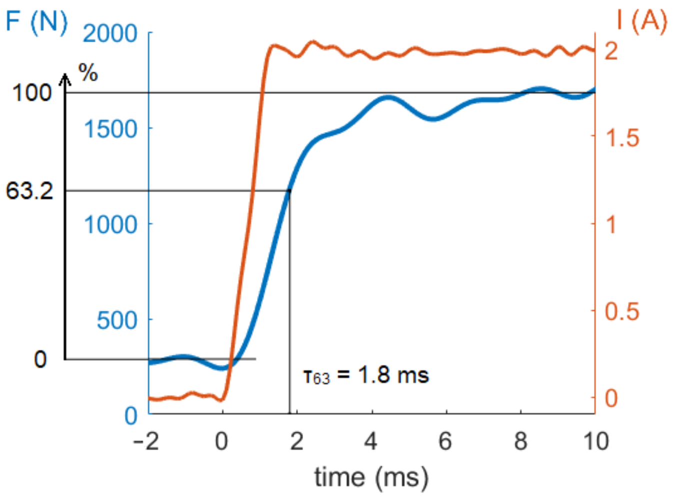
MR damper

- magnetic circuit from SMC
- dynamic range of 7.6 (0.1 m/s)
  - tested: 2 – 7.6
- response time
  - rise: 1.8 ms, drop: 1.1 ms
  - tested: 1.8 ms – 56 ms



Semi-active control

- Shyhook: 2-states, linear



Q1: What damper force response time and dynamic range are acceptable for S/A control?

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Q1

RESULTS AND DISCUSIONS

What dynamic parameters damper must have?

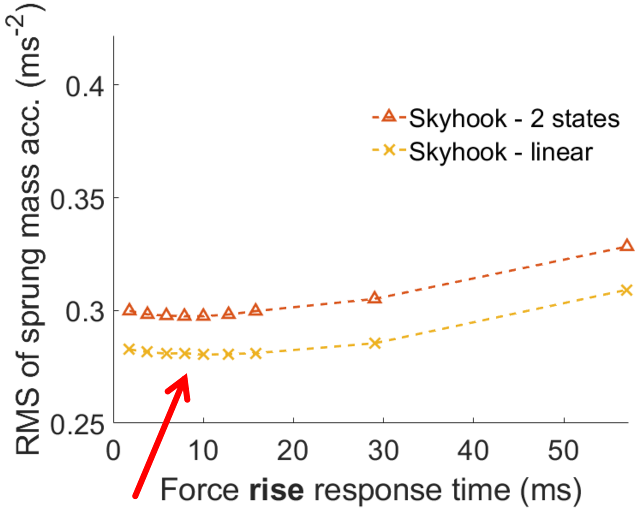
How to achieve acceptable damper behaviour?

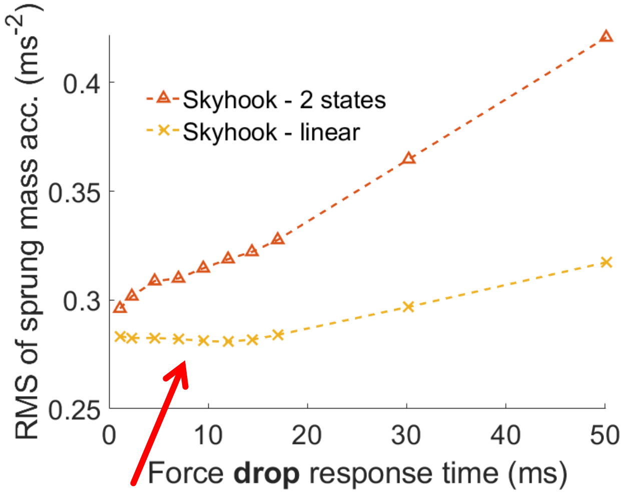
What to do in the case of a power failure?

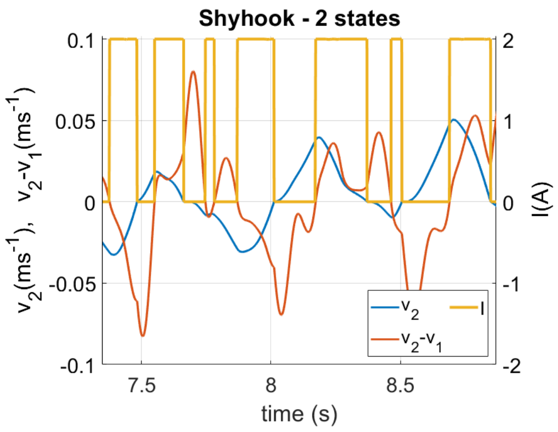
Results

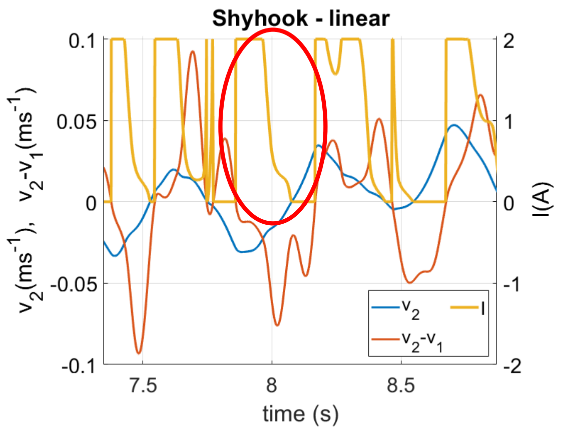
- ideal force response time about **τ = 8 ms**
- suitable to increase dynamic range above **7.6**

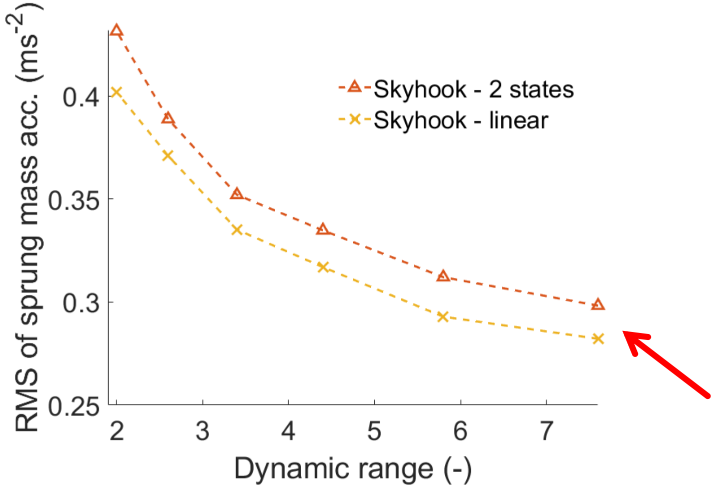
- H1: verified











Q1: What damper force response time and dynamic range are acceptable for S/A control?

Q1

RESULTS AND DISCUSIONS

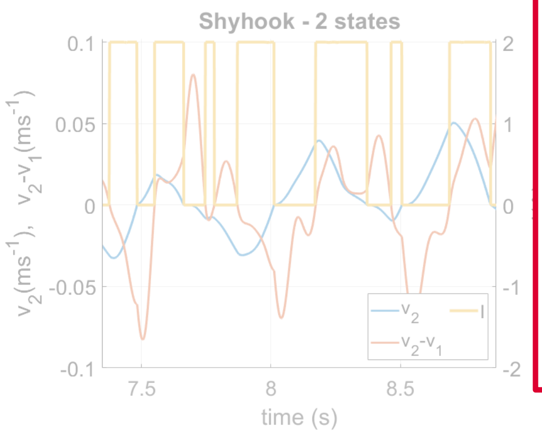
What dynamic parameters damper must have?

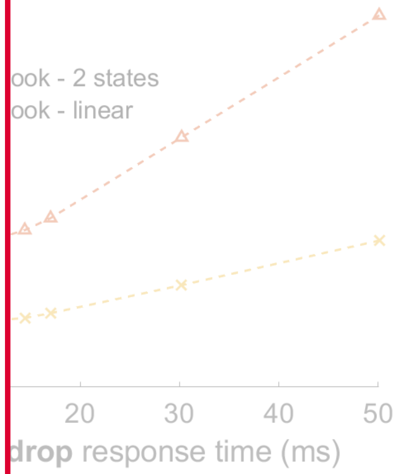
How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

Results

- ideal force response time τ = 8 ms
- suitable to increase dynamic range above 7
- H1: verified





time (s)

actuators

MDPI

Article

Effect of the Magnetorheological Damper Dynamic Behaviour on the Rail Vehicle Comfort: Hardware-in-the-Loop Simulation

Filip Jeniš [1,*], Michal Kubík [1], Tomáš Michálek [2], Zbyněk Strecker [1], Jiří Žáček [1] and Ivan Mazůrek [1]

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[2] Department of Transport Means and Diagnostics, Faculty of Transport Engineering, University of Pardubice, Studentska 95, 532 10 Pardubice, Czech Republic
* Correspondence: filip.jenis@vutbr.cz; Tel.: +420-541-143-216

Abstract: Many publications show that the ride comfort of a railway vehicle can be significantly improved using a semi-active damping control of the lateral secondary dampers. However, the control efficiency depends on the selection of the control algorithm and the damper dynamic behaviour, i.e., its force rise response time, force drop response time and force dynamic range. This paper examines the influence of these parameters of a magnetorheological (MR) damper on the efficiency of S/A control for several control algorithms. One new algorithm has been designed. Hardware-in-the-loop simulation with a real magnetorheological damper has been used to get close to reality. A key finding of this paper is that the highest efficiency of algorithms is not achieved with a minimal damper response time. Furthermore, the force drop response time has been more important than the force rise response time. The Acceleration Driven Damper Linear (ADD-L) algorithm achieves the highest efficiency. A reduction in vibration of 34% was achieved.

Keywords: hardware-in-the-loop; Acceleration Driven Damper; response time; dynamic range; semi-active; magnetorheological; damper; railway vehicle; lateral vibration

check for updates

Q1: What damper force response time and dynamic range are acceptable for S/A control?

QUESTION 2

Q2: How does the material and geometry of the MR damper magnetic circuit affect force response time and dynamic range?

H2:

The highest electrical resistivity

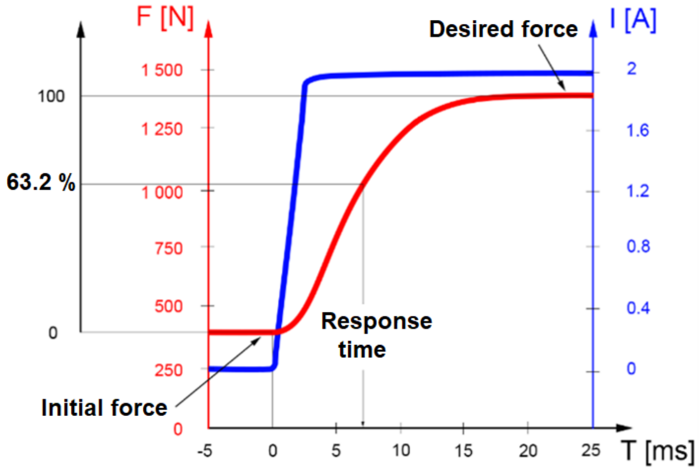
→ the shortest response time.

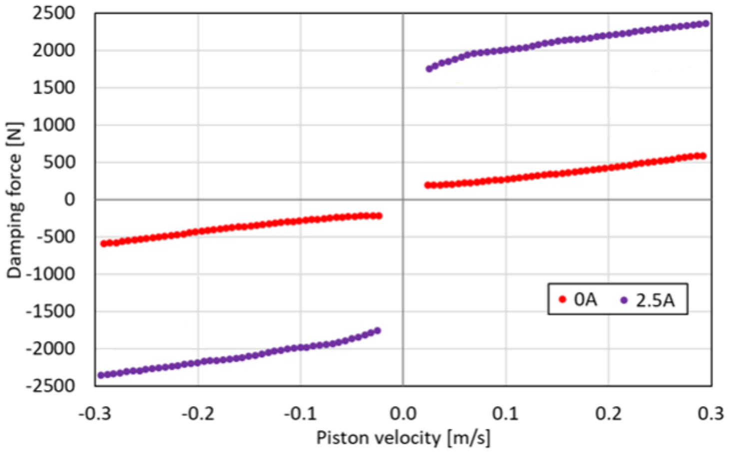
The highest magnetic saturation

→ the highest dynamic range

Shape approach

→ 5 times shorter response time





MATERIALS AND METHODS

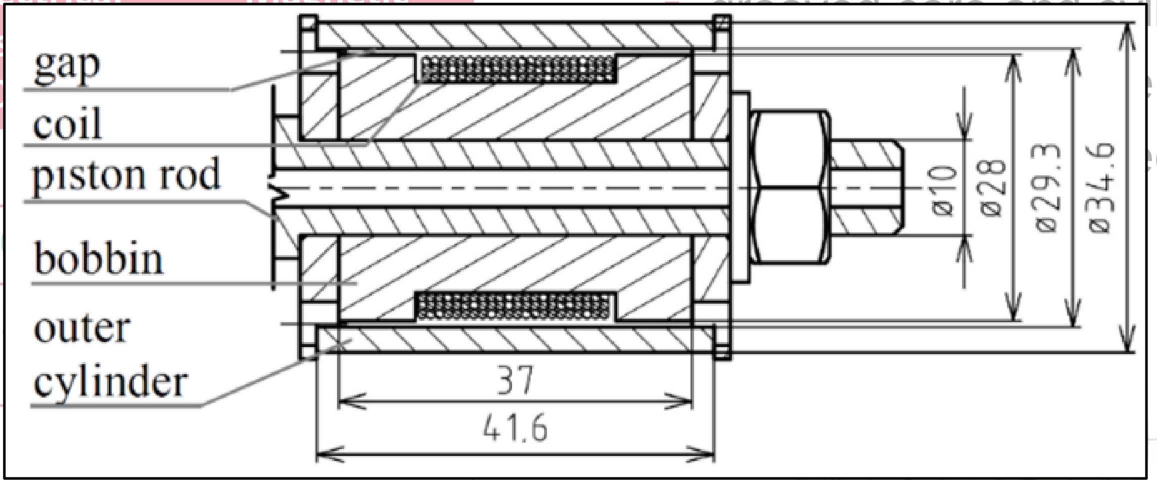
What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

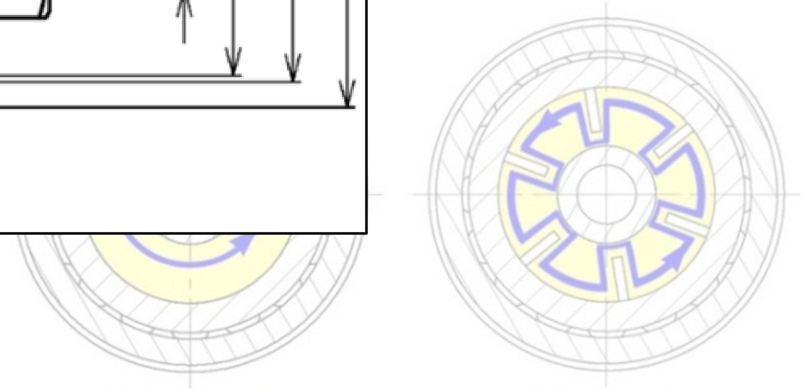
Material approach

Material	Electrical res... (10...	Magnetic...
11SMn30 – cutting steel		
N87 ferrite – iron oxide	10,...	
Sintex SMC – soft magnetic composites		
AISI 420A – stainless steel		
Pure iron – SLM	0.13	1.7
Vacoflux 50 – CoFe alloy	0.42	2.35



Shape approach

- for materials with low electrical resistivity
- ...linder of damper piston
- ...e flow of eddy curents
- ...ected using FEM analysis



Q2: What is the effect of the material and the shape approach?

Q2

MATERIALS AND METHODS

What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

Material approach

Material	Electrical resistivity (10^{-6} Ω·m)	Magnetic saturation (T)
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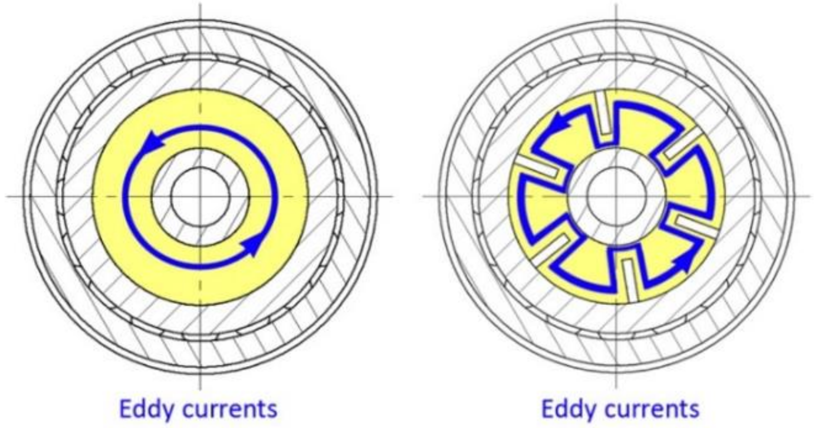
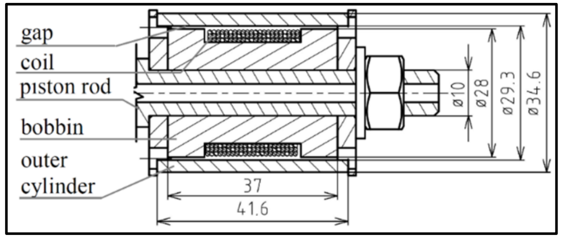
N87 ferrite – iron oxide	**10,000,000**	**0.5**
Sintex SMC – soft magnetic composites	2800	1.45
AISI 420A – stainless steel	0.5	1.6
Pure iron – SLM	**0.13**	1.7
Vacoflux 50 – CoFe alloy	0.42	**2.35**

Shape approach

- for materials with low electrical resistivity
- grooved core and cylinder of damper piston
- grooves intersect the flow of eddy curents
- final variant was selected using FEM analysis





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Q2

MATERIALS AND METHODS

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Q2: What is the effect of the material and the shape approach?

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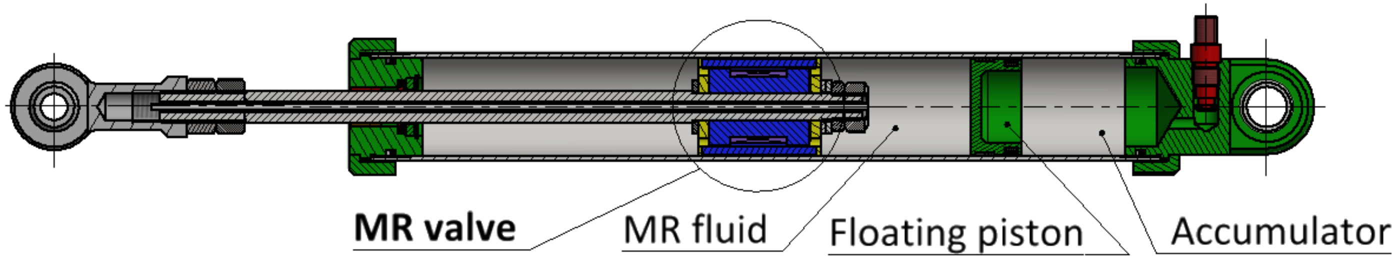
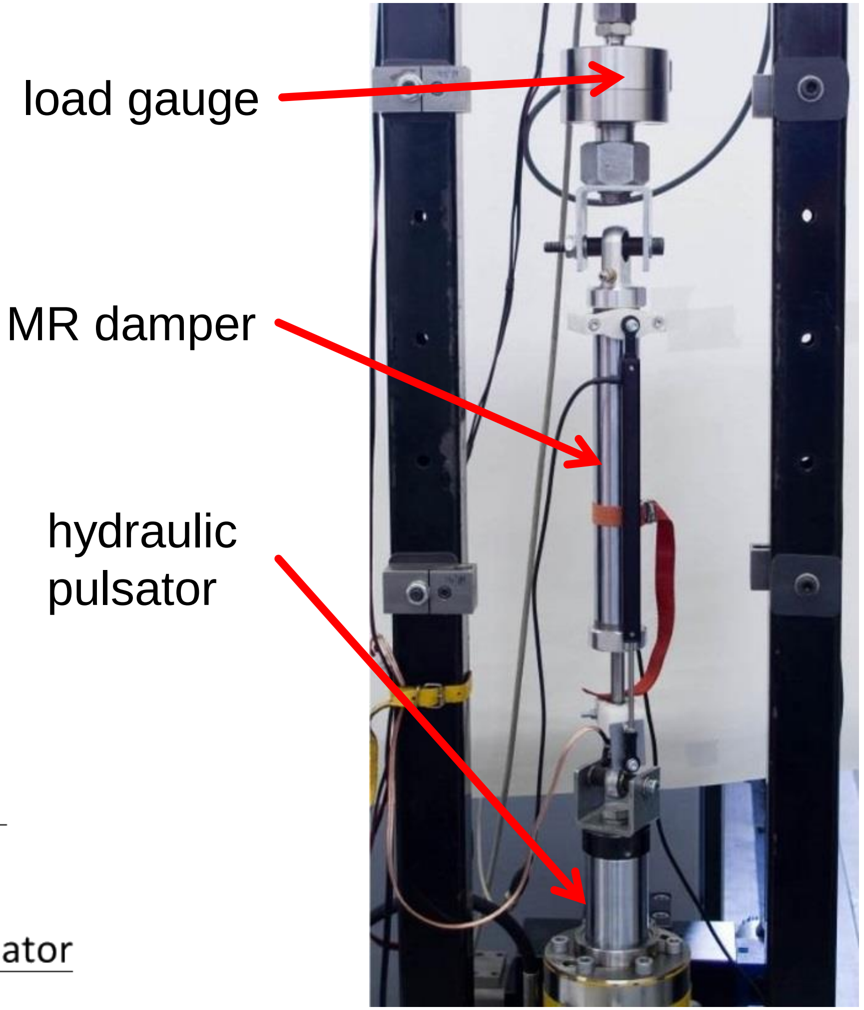
MATERIALS AND METHODS

Measuring MR damper dynamic behaviour

- Dynamic range and force response time
  - pistons → MR damper





Q2

RESULTS AND DISCUSIONS

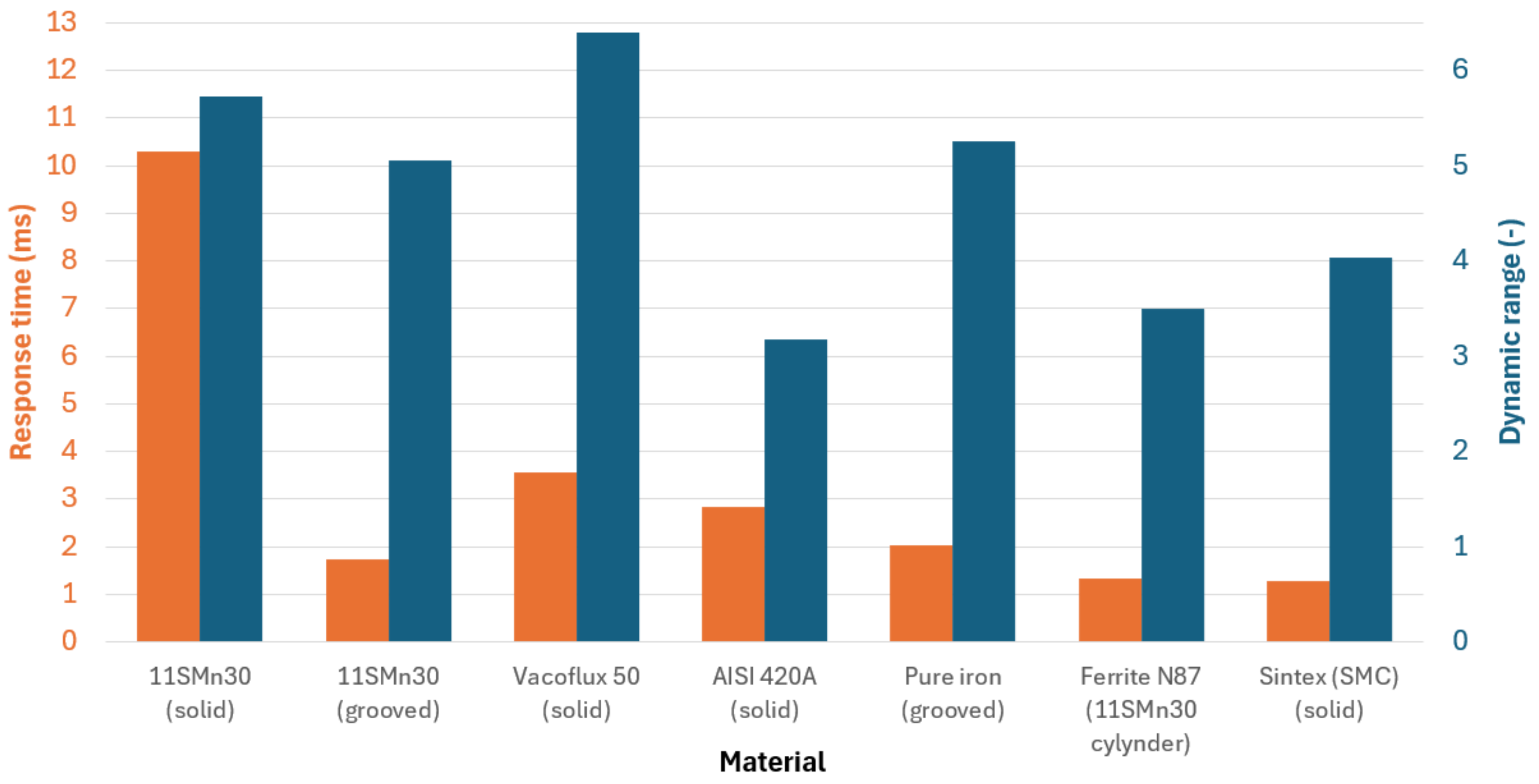
What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

Damper force response time and dynamic range

- Ferrite and SMC: the shortest force response time
  - the highest electric resistivity
  - bad mechanical properities
- Vacoflux: the highest dynamic range
  - the highest magnetic saturation
- 11SMn30 – 6 times shorter force response time by grooves



Conclusion

- H2: verified
- Best option: SMC, grooved cutting steel (11SMn30)

Q2: What is the effect of the material and the shape approach?

Q2

RESULTS AND DISCUSIONS

What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

Damper force respons[e] and dynamic range

- Ferrite and SMC: the sh[...] force response time
  - the highest electric[...]
  - bad mechanical pr[...]
- Vacoflux: the highest dy[...]
  - the highest magnet[...]
- 11SMn30 – 6 times sho[...] force response time by g[...]

Conclusion

- H2: verified
- Best option: SMC, groo[...]

materials

MDPI

Article

Novel Approaches to the Design of an Ultra-Fast Magnetorheological Valve for Semi-Active Control

Zbyněk Strecker [1,*], Filip Jeniš [1], Michal Kubík [1], Ondřej Macháček [1] and Seung-Bok Choi [2,*]

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2 Department of Mechanical Engineering, The State University of New York at Korea (SUNY Korea), Incheon 21985, Korea

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Abstract: This article presents a list of suitable techniques and materials leading to the design of an ultra-fast magnetorheological (MR) valve. Two approaches for achieving the short response time are proposed: (a) by means of material, and (b) by means of the shape. Within the shape approach, the revolutionary technique of 3D metal printing using a selective laser melting (SLM) method was tested. The suitability of the materials and techniques is addressed based on the length of the response time, which is determined by the FEM. The simulation results determine the response time of the magnetic flux density on the step signal of the current. Subsequently, the response time is verified by the measurement of the simple magnetorheological valve. The following materials were tested: martensitic stainless steel AISI 420A (X20Cr13), cutting steel 11SMn30, pure iron for SLM, Sintex SMC STX prototyping material, ferrite N87, and Vacoflux 50. A special technique involving grooves was used for preventing eddy currents on materials with a high electrical conductivity. The simulation and experimental results indicate that a response time shorter than 2.5 ms can be achieved using materials such as Sintex SMC prototyping, ferrite N87, and grooved variants of metal pistons.

Keywords: magnetorheological valve; response time; eddy currents; magnetic simulations; SMC material

check for updates

Citation: Strecker, Z.; Jeniš, F.; Kubík, M.; Macháček, O.; Choi, S.-B. Novel Approaches to the Design of an Ultra-Fast Magnetorheological Valve for Semi-Active Control. *Materials* **2021**, *14*, 2500. https://doi.org/10.3390/ma14102500

Q2: What is the effect of the material and the shape approach?

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Q3

QUESTION 3

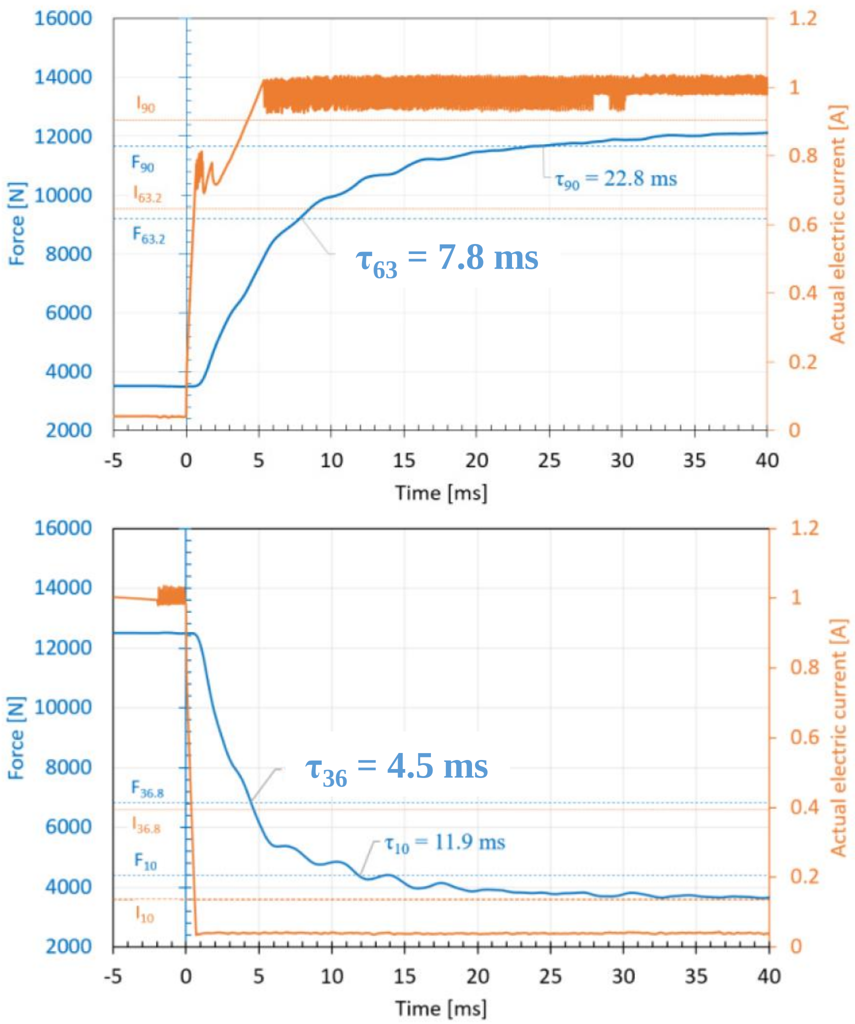
What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

Q3: Will the permanent magnet in the MR valve affect the response time of the MR damper? Will the response time of the force rise and force drop be different?

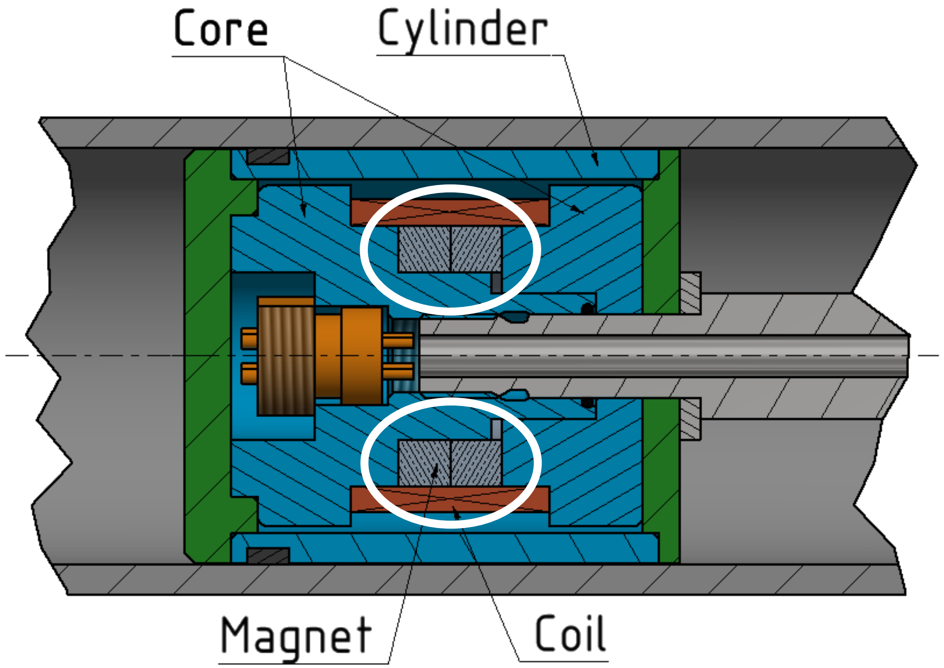
H3: Permanent magnet don‘t affect generation of the magnetic field in the magnetic circuit. Response time of the force rise will be slower than the response time of the force drop.

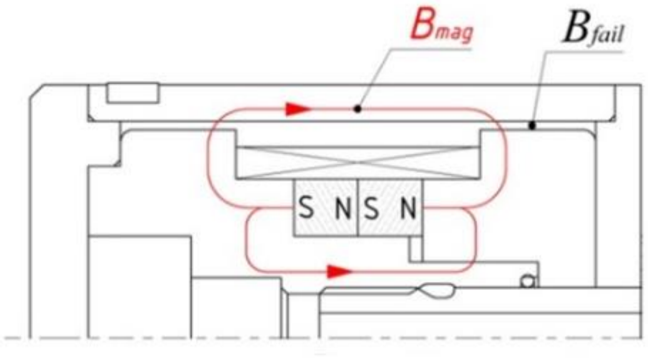


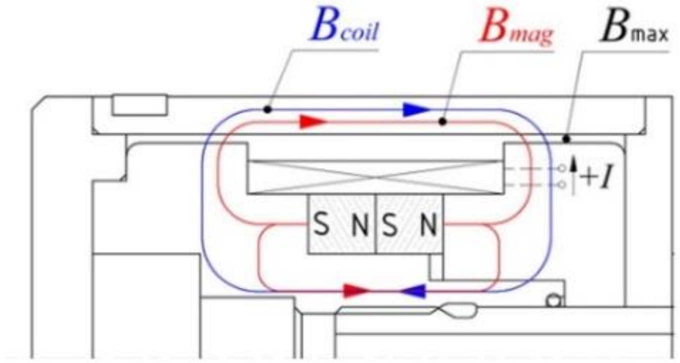
Kubík, 2011

MATERIALS AND METHODS

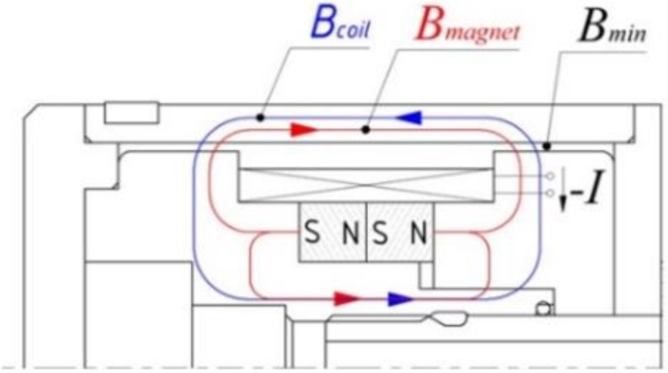
- two neodymum magnets in the magnetic circuit







$$B_{fail} = B_{mag}$$
$$B_{max} = B_{mag} + B_{coil}$$
$$B_{min} = B_{mag} - B_{coil}$$

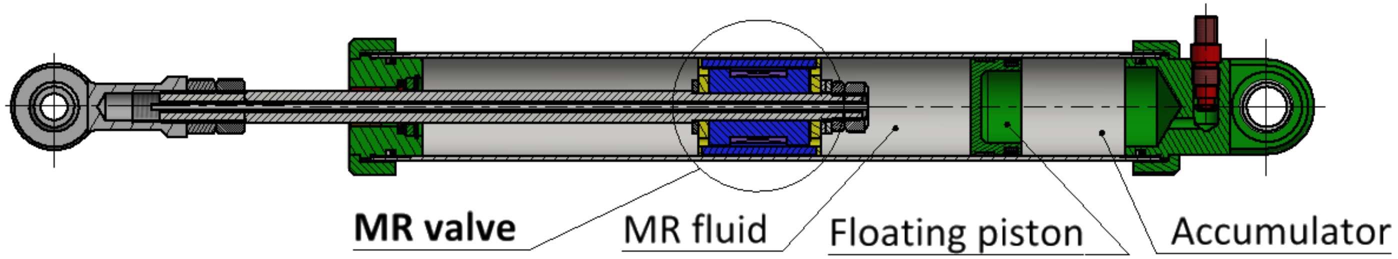


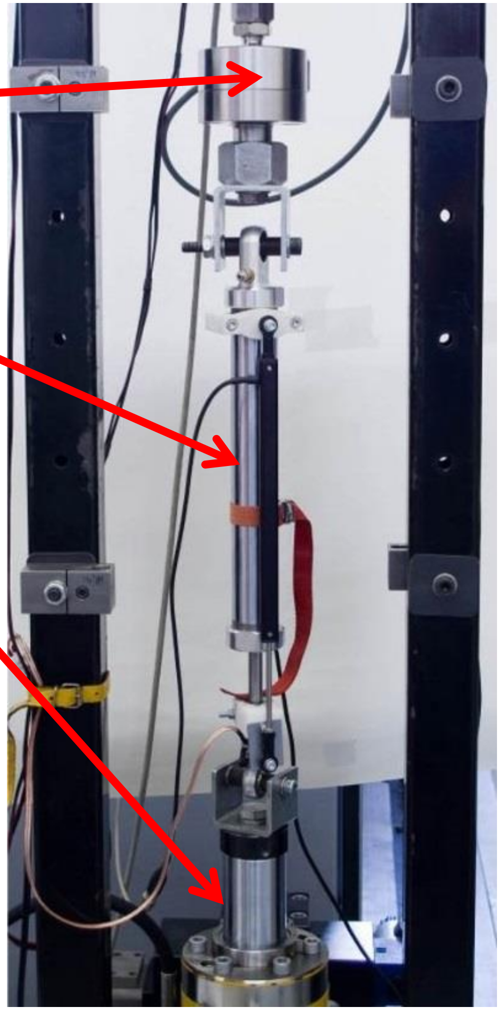
Q3: What is the effect of the permanent magnet in the fail-safe MR damper?

MATERIALS AND METHODS

Measuring MR damper dynamic behaviour

- Dynamic range and force response time
  - pistons → MR damper



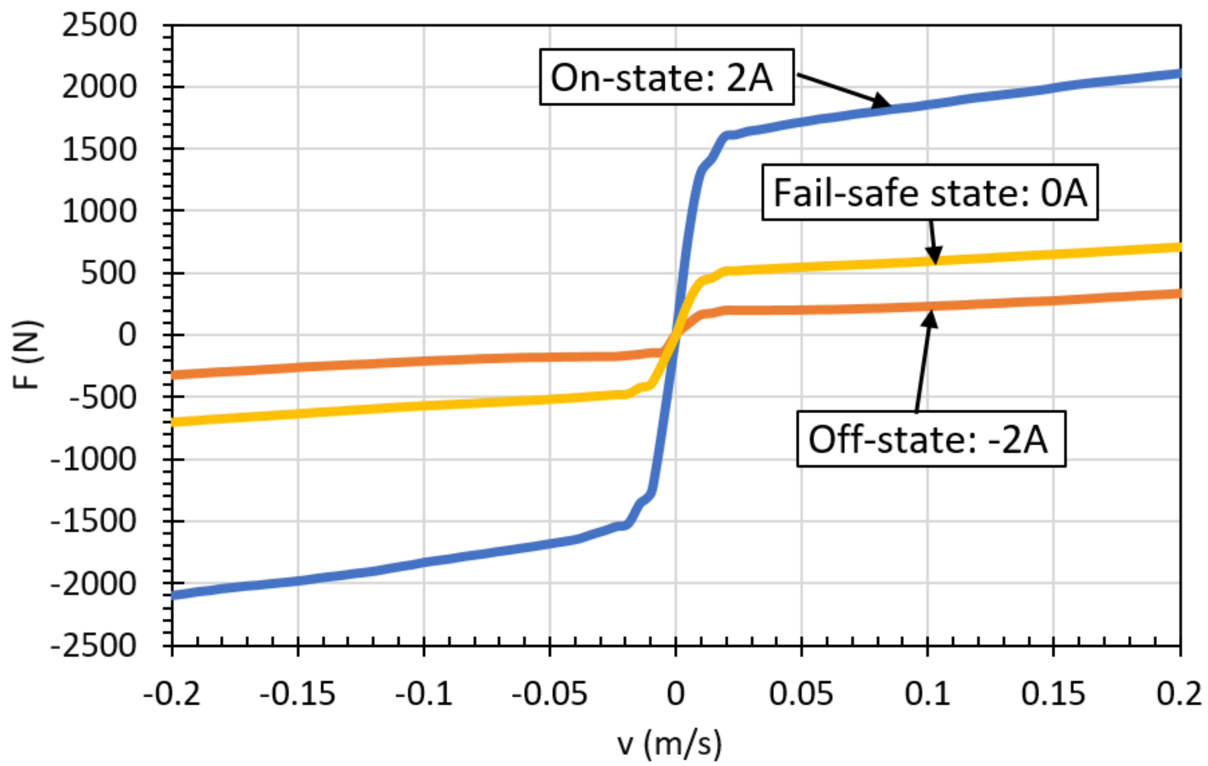


Q3: What is the effect of the permanent magnet in the fail-safe MR damper?

RESULTS AND DISCUSIONS

Damper dynamic behaviour

- fail-safe force is 1/3 of on-state force
- dynamic range of **8.5**



Q3: What is the effect of the permanent magnet in the fail-safe MR damper?

Q3

RESULTS AND DISCUSIONS

What dynamic parameters damper must have?

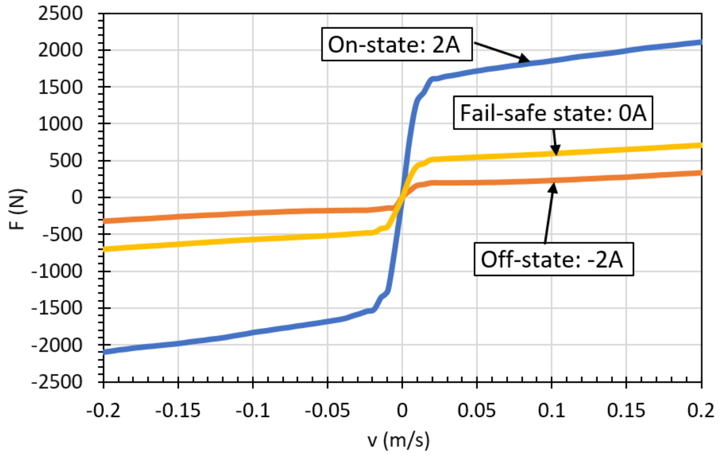
How to achieve acceptable damper behaviour?

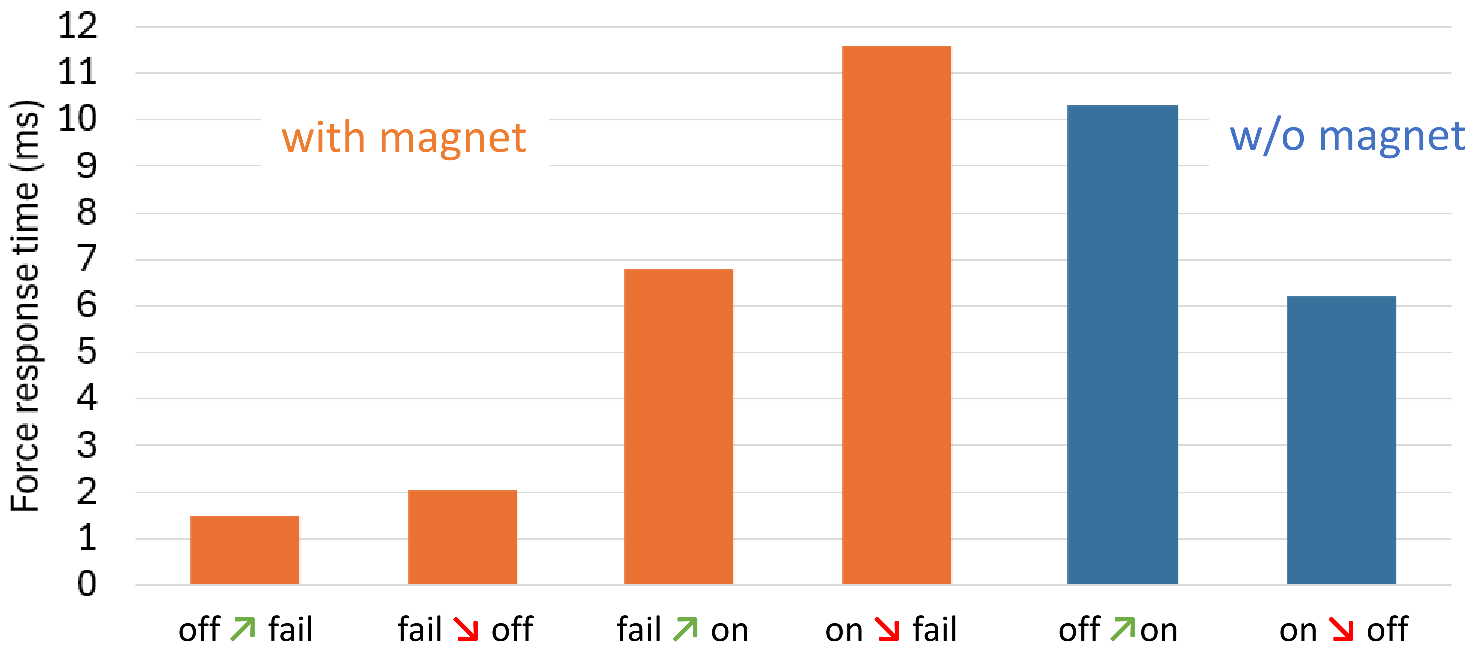
What to do in the case of a power failure?

Damper dynamic behaviour

- fail-safe force is 1/3 of on-state force
- dynamic range of **8.5**
- acceptable response time
- **force rise is faster than force drop**

→ H3: falsified





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RESULTS AND DISCUSIONS

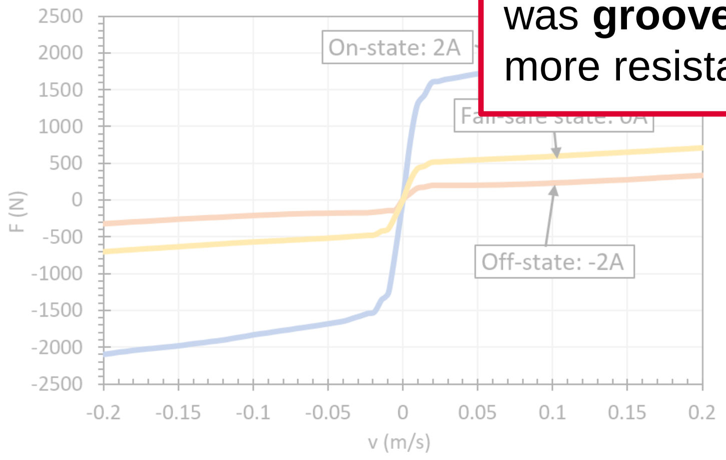
Damper dynamic behaviour

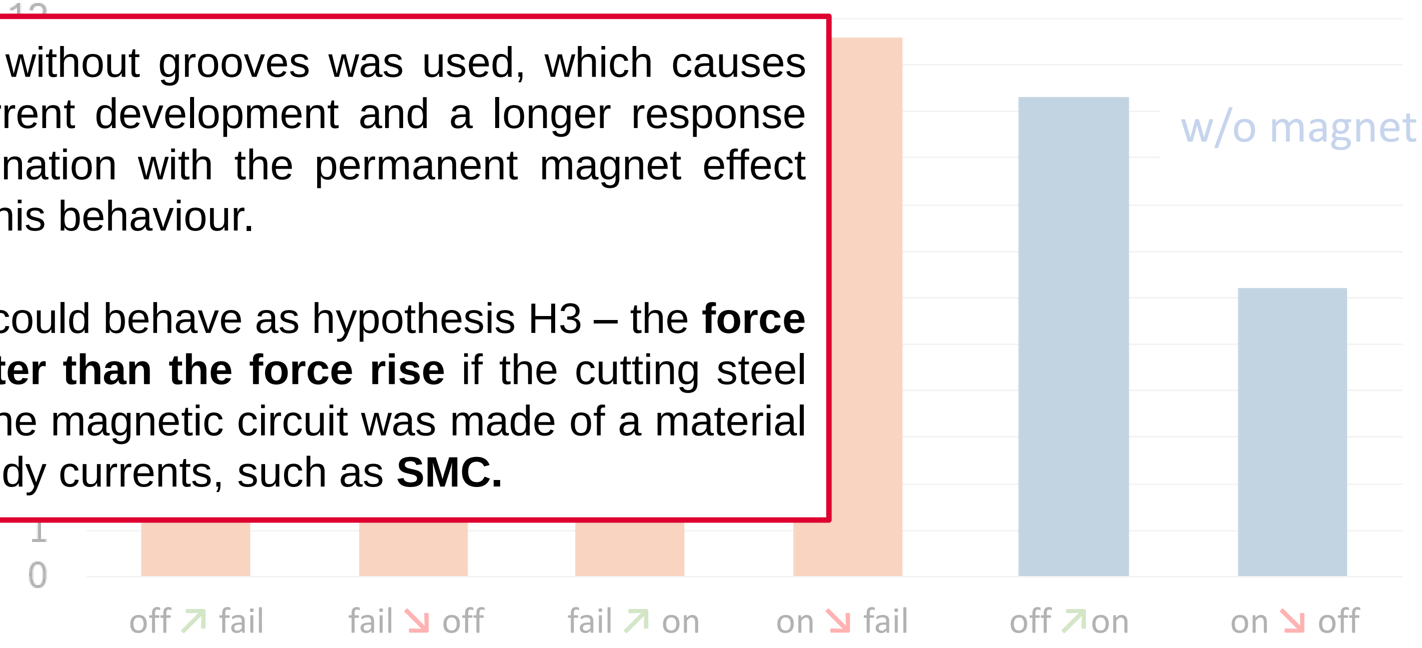
- fail-safe force is 1/3 of on-state force
- dynamic range of **8.5**
- acceptable response tim
- **force rise is faster thar**

→ H3: falsified

H3.2: Cutting steel without grooves was used, which causes excessive eddy current development and a longer response time. And in combination with the permanent magnet effect it probably causes this behaviour.

The response time could behave as hypothesis H3 – the **force drop could be faster than the force rise** if the cutting steel was **grooved** or if the magnetic circuit was made of a material more resistant to eddy currents, such as **SMC.**





Q3: What is the effect of the permanent magnet in the fail-safe MR damper?

Q3

RESULTS

What dynamic
ters damper
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How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

Damper dynamic behav

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- acceptable response time
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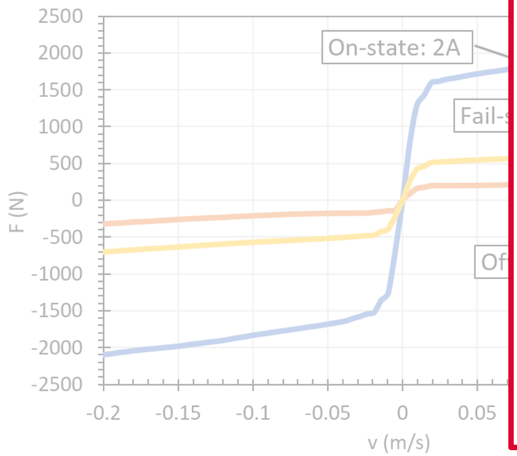
→ H3: falsified



IOP Publishing Smart Materials and Structures

Smart Mater. Struct. **30** (2021) 017004 (12pp) https://doi.org/10.1088/1361-665X/abc26f

Technical Note

Insight into the response time of fail-safe magnetorheological damper

F Jeniš, M Kubík, O Macháček, K Šebesta and Z Strecker

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E-mail: filip.jenis@vutbr.cz

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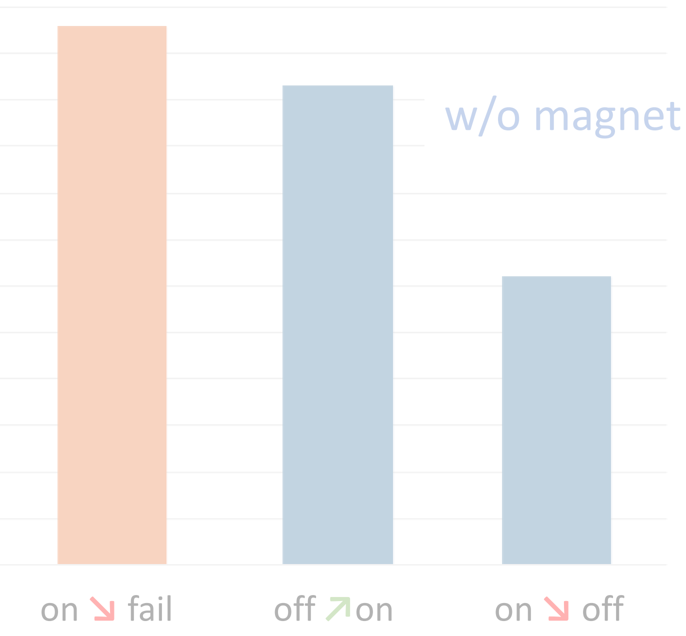
Published 9 December 2020

CrossMark

Abstract

The significant problem of magnetorheological (MR) dampers is their poor fail-safe ability. In the case of power supply failure, the damper remains in a low damping state which is dangerous for several technical applications. This can be solved by accommodating a permanent magnet to the magnetic circuit of the damper. Currently, the MR dampers are used in progressive semiactive (S/A) control of suspension systems. The dynamics (force response time) of the damper is an important parameter that affects the performance of S/A control. The main goal of this paper is to introduce the dynamic behavior of MR damper with a permanent magnet. The damper design with the permanent magnet in the magnetic circuit, transient magnetic simulation including magnetic hysteresis and eddy currents, and experiments are presented. The magnetic field response time and MR damper force response time are measured and also determined from magnetic simulation. The permanent magnet significantly influences the MR damper dynamics. The decrease of the damping force from a fail-safe state–medium damping to off-state–low damping is significantly faster (2 ms, −1 A) than the increase to on-state–high damping (12 ms, 1 A). The exact value is depending on the electric current magnitude and piston velocity. The damper achieved fail-safe damping force approximately 1/3 of the maximum damping force. The exact value of the fail-safe force is magnetization history-dependent. The maximum dynamic force range is 8.5 which is comparable with the common design of MR damper.

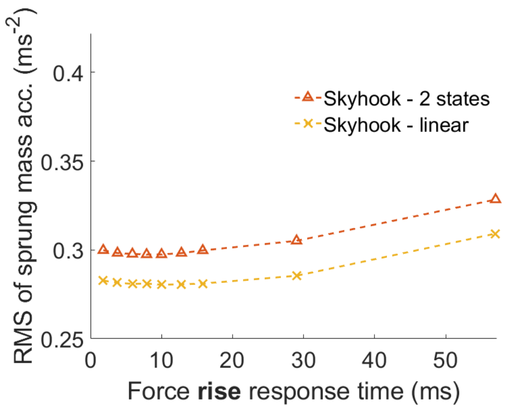
Keywords: magnetorheological valve, MR damper, response time, permanent magnet, fail-safe, transient response, damper dynamics

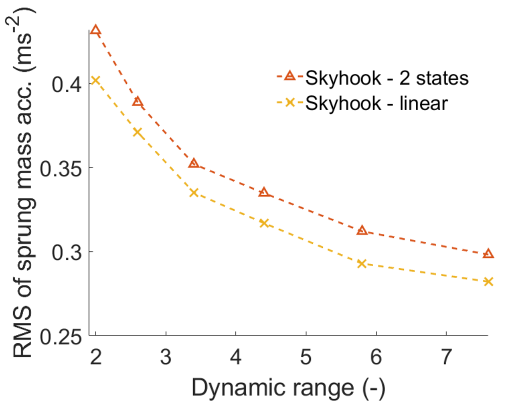


Q3: What is the effect of the permanent magnet in the fail-safe MR damper?

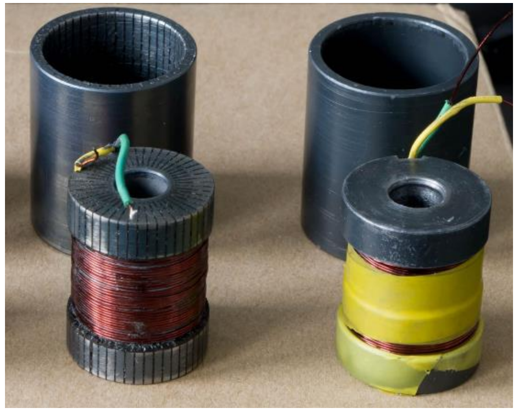
CONCLUSION

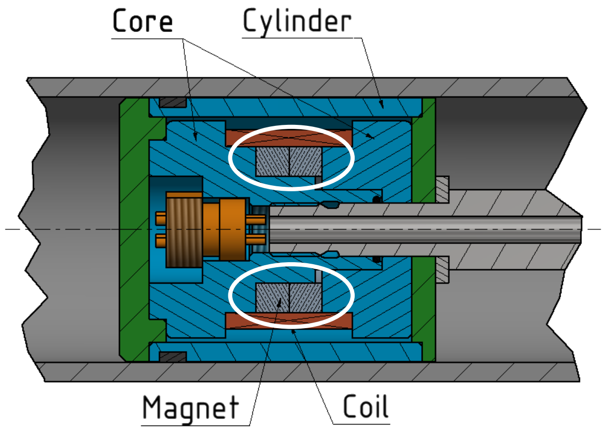
- Ideal response time τ = **8** ms
  dynamic range above **7.6**





- Best option of magnetic circuit:
  grooved cutting steel, SMC





- Fail-safe damper is applicable
  for S/A control

It is possible to design an MR damper for efficient control of the railway bogie

LIST OF PUBLICATIONS

What dynamic parameters damper must have?

How to achieve acceptable damper behaviour?

What to do in the case of a power failure?

Papers published in journals with impact factor

- **JENIŠ, Filip**; KUBÍK, Michal; MICHÁLEK, Tomáš; STRECKER, Zbyněk; ŽÁČEK, Jiří; MAZŮREK, Ivan. Effect of the magnetorheological damper dynamic behaviour on the rail vehicle comfort: hardware-in-the-loop simulation. *Actuators,* 2023, **12**(47), 1-14. **(IF 2.6)**
- STRECKER, Zbyněk; **JENIŠ, Filip**; KUBÍK, Michal; MACHÁČEK, Ondřej; CHOI, Seung Bok. Novel Approaches to the Design of an Ultra-Fast Magnetorheological Valve for Semi-Active Control. *Materials,* 2021, **14**(10), 1-20. **(IF 3.4)**
- **JENIŠ, Filip**; KUBÍK, Michal; MACHÁČEK, Ondřej; ŠEBESTA, Karel; STRECKER, Zbyněk. Insight into the response time of fail-safe magnetorheological damper. *Smart Materials and Structures*, 2020, **30**(1), 1-13. **(IF 4.1)**

- **JENIŠ, Filip**; MICHÁLEK, Tomáš; KUBÍK, Michal; HÁBA, Aleš; STRECKER, Zbyněk; ŽÁČEK, Jiří; MAZŮREK, Ivan. Semi-active yaw dampers in locomotive running gear: New control algorithms and verification of their stabilising effect. *Journal of Vibration and Control*, 2024. **(IF 2.6)**
- **JENIŠ, Filip**; MICHÁLEK, Tomáš; KUBÍK, Michal; STRECKER, Zbyněk; ŠLAPÁK, Jiří; MAZŮREK, Ivan. The Influence of Semi-actively Controlled Magnetorheological Bogie Yaw Dampers on Guiding Behaviour of a Railway Vehicle in an S-Curve: Simulation and On-track test. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. 2024 **(IF 2.2)**

- ŽÁČEK, Jiří; ŠEBESTA, Karel; MOHAMMAD, Housam; **JENIŠ, Filip**; STRECKER, Zbyněk; KUBÍK, Michal. Experimental Evaluation of Modified Groundhook Car Suspension with Fast Magnetorheological Damper. *Actuators*, 2022, **11**(12), 1-14. **(IF 2.6)**
- KUBÍK, Michal; VÁLEK, Josef; ŽÁČEK, Jiří; **JENIŠ, Filip**; BORIN, Dmitry; STRECKER, Zbyněk; MAZŮREK, Ivan. Transient response of magnetorheological fluid on rapid change of magnetic field in shear mode. *Scientific Reports*, 2022, **12**(1), 1-10. **(IF 4.6)**
- KUBÍK, Michal; ŠEBESTA, Karel; STRECKER, Zbyněk; **JENIŠ, Filip**; GOLDASZ, Janusz; MAZŮREK, Ivan. Hydrodynamic response time of magnetorheological fluid in valve mode: model and experimental verification. *Smart Materials and Structures*, 2021, **30**(12), 1-13. **(IF 4.1)**
- ROUPEC, Jakub; **JENIŠ, Filip**; STRECKER, Zbyněk; KUBÍK, Michal; MACHÁČEK, Ondřej. Stribeck Curve of Magnetorheological Fluid within Pin-on-Disc Configuration: An Experimental Investigation. *Materials*, 2020, **13**(20), 1-11. **(IF 3.4)**

12 papers in conference proceedings

FOLLOW UP RESEARCH

MR damper for raiway vehicle

- grooved cutting steel 11SMn30
- dynamic range of **25 – 8.5**
- response time τ = **7.8** ms

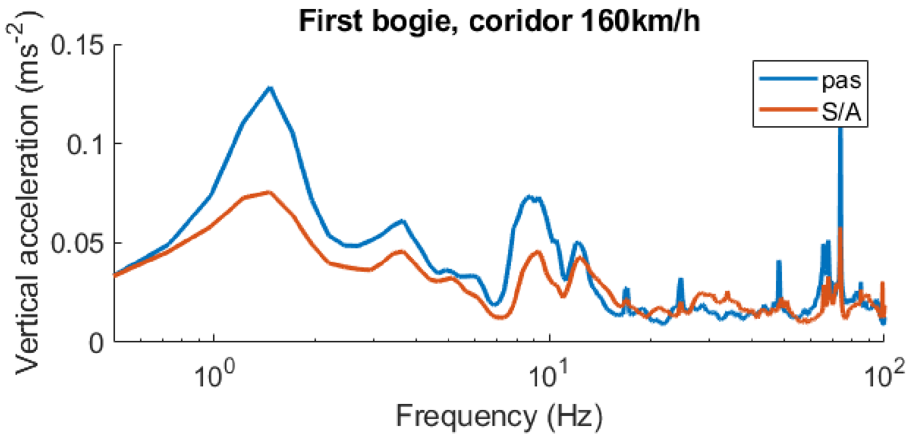
  (Guo 2015, 300 ms)

- <u>suitable for use on a railway vehicle!</u>

FOLLOW UP RESEARCH

MR lateral and vertical damping system

- real vehicle
- modified Shykook linear
- comfort increased up to **34%** (EN 12299)



THANK YOU FOR YOUR ATTENTION

Filip Jeniš

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