ifas Institut für fluidtechnische Antriebe und Systeme | RWTH AACHEN UNIVERSITY

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Institute for Fluid Power Drives and Systems

Univ.-Prof. Dr.-Ing. Katharina Schmitz

Master's Thesis

Development of control strategies for a hydraulic inverse pendulum

by

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Field of activity:	Hydraulics, digitization

Aachen, January 16, 2023

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Development of control strategies for a hydraulic inverse pendulum

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Master's Thesis

by Dianming Lin B. Sc.
Student number: 412231

Development of control strategies for a hydraulic inverse pendulum

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The platform built by the Institute for Fluid Power Drives and Systems (ifas) is the subject of this thesis. An inverse pendulum consists of a pendulum and a sideways moving cart. Cart movement is controlled by a hydraulic system comprising of a hydraulic valve and a hydraulic linear motor for the lateral movement.

The purpose of controlling an inverted pendulum is to swiftly return it to balance while avoiding significant swings, extreme angles, and rapid motion. The system overcomes the random disturbances and maintains a stable position only after pendulum reaches the desired position.

The following subtasks are to be worked on for this:

-Familiarize the model topic and state of the art (3 weeks)
-Reference data and understand the model (4 weeks)
-Analyze data and build Simulation (6 weeks)
-Test bench adaptation and controller setup (2 weeks)
-Implementma test stand (3 weeks)
-Documentation (4 weeks)

Supervisor: Univ.-Prof. Dr.-Ing. Katharina Schmitz
Andreas Opgenoorth M. Sc.

Contents

Formula symbols and indices

Lower case latin letters as formula symbols

d_{piston}	m	Piston diameter
d_{pipe}	m	Pipe diameter
d_{rod}	m	Piston rod diameter
$d_{\dot{x}}$	$\frac{\mathrm{N\,s}}{\mathrm{m}}$	Damping coefficient of velocity
g	$\frac{\mathrm{m}}{\mathrm{s}^2}$	Gravitational acceleration
$l_{pendulum}$	m	total length of pendulum
l_{pipe}	m	length of pipe
l_{pole}	m	length of pendulum pole
l_{rod}	m	length of piston rod
m_{cart}	kg	mass of cart
$m_{cylinder}$	kg	mass of pendulum cylinder
m_{pole}	kg	mass of pendulum pole
$r_{cylinder}$	m	radius of pendulum cylinder
x	m	position of cart
$\dot{x}$	$\frac{\mathrm{m}}{\mathrm{s}}$	verlocity of cart
$\ddot{x}$	$\frac{\mathrm{m}}{\mathrm{s}^2}$	acceleration of pendulum cylinder

Upper case latin letters as formula symbols

A_{piston}	m^2	Area of piston
$C_{H,hydcyl}$	m^5/N	hydraulic cabarcity of hydraulic cylinder
$C_{H,pipe}$	m^5/N	hydraulic cabarcity of pipe
$C_{H,sum}$	m^5/N	hydraulic cabarcity of hydraylic cyliner and pipe
E_{pipe}	$\frac{N}{m^2}$	Young modulus of pipe
E_{oil}	$\frac{N}{m^2}$	Young modulus of oil
F	N	Extern force
J_{pen}	$kg\,m^2$	Moment of inertia of pendulum
$V_{Hyd.cyl}$	m^3	Volume of hydraulic cylinder(one side)
V_{Py}	bar/%	Pressure at opening point
V_{Qy}	$m^3/s/\%$	Flow characteristics at opening point
V_{Qp}	$\frac{m^3}{s\,Pa}$	Flow characteristics of pressure

Lower case greek letters as formula symbols

μ_{pen}	–	Friction coefficient of joint
μ_{cart}	–	Friction coefficient of cart
μ	–	Friction coefficient of gravitatinal force
μ_{cart}	–	Friction coefficient of cart
ϕ	°	angle

List of abbreviations

General abbreviations

FFT	Fast-Fourier-Transformation
IQR	Interquartilsabstand
ML	Machine Learning
PC	Personal Computer
PCA	Hauptkomponentenanalyse

1 Abstract

I don’t know if we need this wenn we already have the issue.
So will also be finishd at the end of the objects.

kjals

2 Introduction

3 Fundamental

Inverted pendulums, as indicated at the issue's outset, are common scientific items and find usage in various practical contexts. Model system construction by ifas is described in detail in Sections 3.1 and 3.2 of this chapter. Then, the fundamentals of mechanics and hydrodynamics for a realistic model are implemented in Section 1.3. The controller design is explored in detail in Section 1.4.

3.1 Mechanical system

The pendulum consists of a cylinder and a pole, one end of the pole is inserted into the cylinder, and the other end is connected to the cart via a revolute joint, this joint allows the pendulum to rotate at least 360° during the movement of the cart. A rail which runs across the cart ensures that the cart's motion is restricted sideways sliding only. As seeing from Fig 3.1.

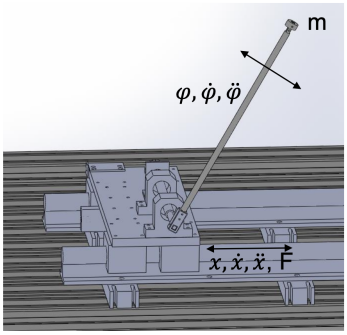

Fig. 3.1. sketch of inverse pendulum (/Fin15/)

A sensor mounted on the joint measures the angle of the pendulum, and the sensor data is sent to the controller for claculate until the angle ϕ reaches vertical equilibrium, aka. 0°.

3.2 Hydraulic system

The hydraulic system is built by ifas. This system consists of a pump, a tank, a hydraulic cylinder, a capsule accumulator, and a 4/3 servo valve as its primary components.
A hydraulic cylinder, also known as a linear hydraulic motor, is powered by the incompressible liquid hydraulic fluid compressed within the cylinder. By altering the pressure on both sides of the piston, the piston is pushed to move from side to side, therefore propelling the piston rod. Sketc.h will be showen form Fig 3.2.

Why would a hydraulic system be used to drive a cart instead of an electric motor? Hydraulics provides a simple yet effective method for generating a great deal of force in a small area,

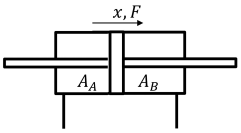

Fig. 3.2. Sketch of hydraulic cylinder

which was designed fairly early on and requires just a very tiny apparatus to raise 1 or 2 tons of objects with using the hydraulic force. Due to the incompressibility of hydraulic oil, the oil in the cylinder resembles a solid at high pressure, which gives the Hydraulic cylinder excellent dynamic properties.

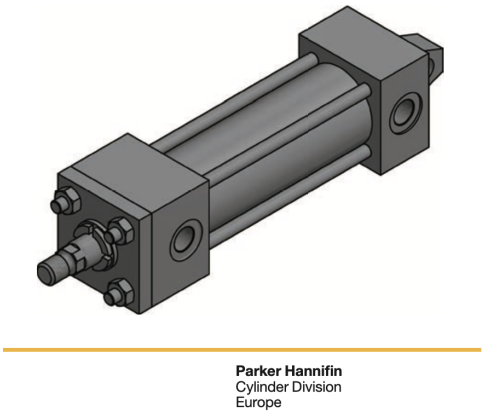

Fig. 3.3. Parker® hydraulic cylinder HMI-ME6(/Par/)

Existing hydraulic cylinder can provide working pressure up to 700bar. The hydraulic cylinder in the unit is supplied by Parker® and the model HMI-ME6 can work up to 210 bar.

4 Description

4.1 Description of system

5 Outlook

Hier kann man dann schreiben,was alles noch kommt.

Beispielkapitel

Dieses Beispielkapitel dient der Darstellung häufig verwendeter Elemente in LaTeX wie Aufzählungen, Abbildungen, Tabellen oder Gleichungen. Es hat keinen Anspruch auf Vollständigkeit und kann gerne erweitert werden. Eine ausführliche Beschreibung der LaTeX-Befehle kann der Befehlsübersicht entnommen werden. Die Beispiele können kopiert und dann angepasst werden.

Aufzählungen

Aufzählungen mit Punkten

- Körper
- Bindungselemente
- Koppelelemente

5.0.1 Aufzählungen mit Zahlen

1. Körper
2. Bindungselemente
3. Koppelelemente

Abbildungen

Fig. 5.1. Eine Abbildung (lange Abbildungsunterschrift mit Quelle, Quelle: /Mus12, p. 1/)

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ection*{Abbildungen}
abel{sec:abbildungen}

egin{figure}[htbp]
  \centering
  \includegraphics[width = 0.5\textwidth]{Contents/Resources/superc.jpeg}
  \caption[Eine Abbildung (kurze Abbildungsunterschrift ohne Quelle)]{Eine Abbildung (lange Abbildu
  \label{fig:eine_abbildung}
nd{figure}

egin{figure}[htbp]
  \centering
  \begin{subfigure}[t]{0.46\textwidth}
      \includegraphics[width = 1\textwidth]{Contents/Resources/superc.jpeg}
      \caption{Bild 1}
      \label{fig:bild1}
  \end{subfigure}
  \begin{subfigure}[t]{0.46\textwidth}
      \includegraphics[width = 1\textwidth]{pendulum.png}
      \caption{Bild 2}
      \label{fig:bild2}
  \end{subfigure}
  \caption[Zwei Abbildungen]{Bild 1 (a) und Bild 2 (b)}
  \label{fig:mehrere_abbildungen}
nd{figure}
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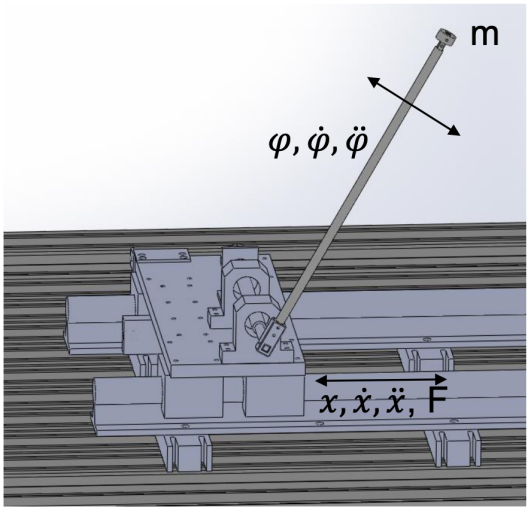

(a) Bild 1 **(b)** Bild 2

Fig. 5.2. Bild 1 (a) und Bild 2 (b)

Tabellen

Table 5.1: Tabelle mit automatischer Ausrichtung

l	c	r
a	b	c
aa	bb	cc
aaa	bbb	ccc

Table 5.2: Tabelle mit Ausrichtung an Trennungszeichen

a	b
1234.000,	1234
1234.000,	123
1234.000,	12
1234.000	1

Table 5.3: Tabelle mit Zellen über mehrere Zeilen oder Spalten

l	c	r
ab		c
aa	bb	cc
	bbb	ccc

Gleichungen

Newton hat folgenden Zusammenhang entdeckt:

$$F = ma \tag{5.1}$$

Das war das mit dem Apfel und so.

Anführungszeichen

Es gibt mehrere Möglichkeiten deutsche Anführungszeichen einzufügen:
„test“
"‘test"’

Zitationen

Zitation einer Quelle: /Mus12/
Zitation einer Quelle mit Seitenangabe: /Mus12, pp. 12–16/
Zitation mehrerer Quellen: /Mus12; Mus11/
Zitation mehrerer Quellen mit Seitenangabe: /Mus12, pp. 12–16; Mus11, p. 3/

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/Par/ Parker®
HMI/HMD Hydraulic Cylinders.

List of Tables

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