

Bachelor Thesis

L^AT_EX -Template for Student Projects

Autumn Term 2018

Declaration of Originality

I hereby declare that the written work I have submitted entitled

Your Project Title

is original work which I alone have authored and which is written in my own words.¹

Author(s)

First name

Last name

Student supervisor(s)

First name

Last name

Supervising lecturer

Roland

Sieewart

With the signature I declare that I have been informed regarding normal academic citation rules and that I have read and understood the information on 'Citation etiquette' (<https://www.ethz.ch/content/dam/ethz/main/education/rechtliches-abschluesse/leistungskontrollen/plagiarism-citationetiquette.pdf>). The citation conventions usual to the discipline in question here have been respected.

The above written work may be tested electronically for plagiarism.

Place and date

Signature

¹Co-authored work: The signatures of all authors are required. Each signature attests to the originality of the entire piece of written work in its final form.

Contents

Preface	iii
Abstract	v
Symbols	vii
1 Introduction	1
2 Einige wichtige Hinweise zum Arbeiten mit L^AT_EX	3
2.1 Gliederungen	3
2.2 Referenzen und Verweise	3
2.3 Aufzählungen	3
2.4 Erstellen einer Tabelle	4
2.5 Einbinden einer Grafik	5
2.6 Mathematische Formeln	5
2.7 Weitere nützliche Befehle	6
Bibliography	7
A Irgendwas	9
B Datasheets	11

Preface

Bla bla ...

Abstract

Hier kommt der Abstact hin ...

Symbols

Symbols

ϕ, θ, ψ	roll, pitch and yaw angle
b	gyroscope bias
Ω_m	3-axis gyroscope measurement

Indices

x	x axis
y	y axis

Acronyms and Abbreviations

ETH	Eidgenössische Technische Hochschule
EKF	Extended Kalman Filter
IMU	Inertial Measurement Unit
UAV	Unmanned Aerial Vehicle
UKF	Unscented Kalman Filter

Chapter 1

Introduction

[1] [2] [3] [4] [5] [6] [7] [8] [9]

Chapter 2

Einige wichtige Hinweise zum Arbeiten mit L^AT_EX

Nachfolgend wird die Codierung einiger oft verwendeten Elemente kurz beschrieben. Das Einbinden von Bildern ist in L^AT_EX nicht ganz unproblematisch und hängt auch stark vom verwendeten Compiler ab. Typisches Format für Bilder in L^AT_EX ist EPS¹ oder PDF².

2.1 Gliederungen

Ein Text kann mit den Befehlen `\chapter{.}`, `\section{.}`, `\subsection{.}` und `\subsubsection{.}` gegliedert werden.

2.2 Referenzen und Verweise

Literaturreferenzen werden mit dem Befehl `\citep{.}` und `\citet{.}` erzeugt. Beispiele: ein Buch [?], ein Buch und ein Journal Paper [? ?], ein Konferenz Paper mit Erwähnung des Autors: ?].

Zur Erzeugung von Fussnoten wird der Befehl `\footnote{.}` verwendet. Auch hier ein Beispiel³.

Querverweise im Text werden mit `\label{.}` verankert und mit `\cref{.}` erzeugt. Beispiel einer Referenz auf das zweite Kapitel: chapter 2.

2.3 Aufzählungen

Folgendes Beispiel einer Aufzählung ohne Numerierung,

- Punkt 1
- Punkt 2

wurde erzeugt mit:

```
\begin{itemize}
  \item Punkt 1
  \item Punkt 2
\end{itemize}
```

¹Encapsulated Postscript

²Portable Document Format

³Bla bla.

Folgendes Beispiel einer Aufzählung mit Numerierung,

1. Punkt 1
2. Punkt 2

wurde erzeugt mit:

```
\begin{enumerate}
  \item Punkt 1
  \item Punkt 2
\end{enumerate}
```

Folgendes Beispiel einer Auflistung,

- P1** Punkt 1
- P2** Punkt 2

wurde erzeugt mit:

```
\begin{description}
  \item[P1] Punkt 1
  \item[P2] Punkt 2
\end{description}
```

2.4 Erstellen einer Tabelle

Ein Beispiel einer Tabelle:

Table 2.1: Daten der Fahrzyklen ECE, EUDC, NEFZ.

Kennzahl	Einheit	ECE	EUDC	NEFZ
Dauer	s	780	400	1180
Distanz	km	4.052	6.955	11.007
Durchschnittsgeschwindigkeit	km/h	18.7	62.6	33.6
Leerlaufanteil	%	36	10	27

Die Tabelle wurde erzeugt mit:

```
\begin{table}[h]
\begin{center}
\caption{Daten der Fahrzyklen ECE, EUDC, NEFZ.}\vspace{1ex}
\label{tab:tabnefz}
\begin{tabular}{ll|ccc}
\hline
Kennzahl & Einheit & ECE & EUDC & NEFZ \\ \hline
Dauer & s & 780 & 400 & 1180 \\
Distanz & km & 4.052 & 6.955 & 11.007 \\
Durchschnittsgeschwindigkeit & km/h & 18.7 & 62.6 & 33.6 \\
Leerlaufanteil & \% & 36 & 10 & 27 \\
\hline
\end{tabular}
\end{center}
\end{table}
```

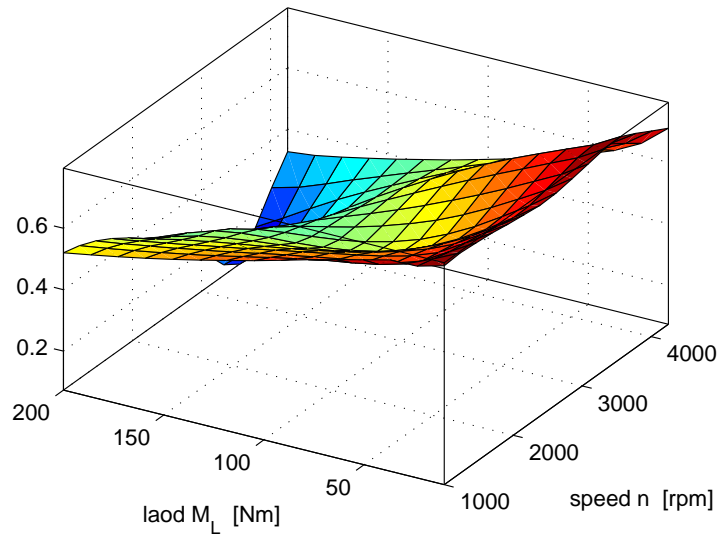


Figure 2.1: Ein Bild

2.5 Einbinden einer Grafik

Das Einbinden von Graphiken kann wie folgt bewerkstelligt werden:

```
\begin{figure}
  \centering
  \includegraphics[width=0.75\textwidth]{images/k_surf.pdf}
  \caption{Ein Bild.}
  \label{fig:k_surf}
\end{figure}
```

oder bei zwei Bildern nebeneinander mit:

```
\begin{figure}
  \begin{minipage}[t]{0.48\textwidth}
    \includegraphics[width = \textwidth]{images/cycle_we.pdf}
  \end{minipage}
  \hfill
  \begin{minipage}[t]{0.48\textwidth}
    \includegraphics[width = \textwidth]{images/cycle_ml.pdf}
  \end{minipage}
  \caption{Zwei Bilder nebeneinander.}
  \label{pics:cycle}
\end{figure}
```

2.6 Mathematische Formeln

Einfache mathematische Formeln werden mit der equation-Umgebung erzeugt:

$$p_{me0f}(T_e, \omega_e) = k_1(T_e) \cdot (k_2 + k_3 S^2 \omega_e^2) \cdot \Pi_{\max} \cdot \sqrt{\frac{k_4}{B}}. \quad (2.1)$$

Der Code dazu lautet:

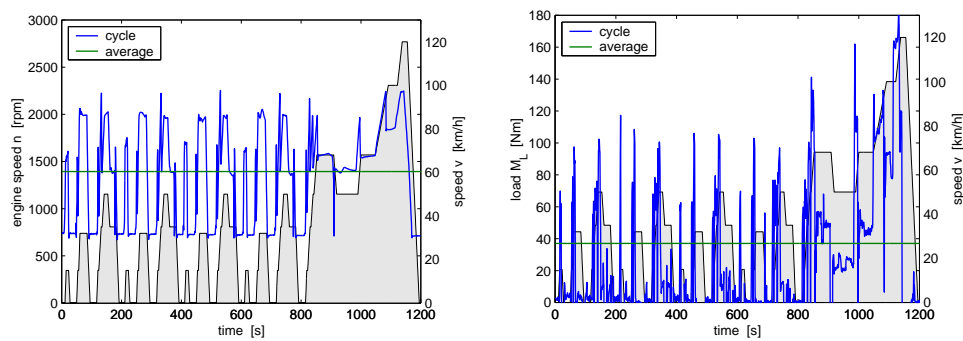


Figure 2.2: Zwei Bilder nebeneinander

```
\begin{equation}
p_{me0f}(T_e,\omega_e) \setminus = \setminus k_1(T_e) \setminus cdot (k_2+k_3 S^2
\omega_e^2) \setminus cdot \Pi_{max} \setminus cdot \sqrt{\frac{k_4}{B}} \setminus , .
\end{equation}
```

Mathematische Ausdrücke im Text werden mit $\$formel\$$ erzeugt (z.B.: $a^2+b^2=c^2$). Vektoren und Matrizen werden mit den Befehlen $\backslash vec\{.\}$ und $\backslash mat\{.\}$ erzeugt (z.B. \mathbf{v} , \mathbf{M}).

2.7 Weitere nützliche Befehle

Hervorhebungen im Text sehen so aus: *hervorgehoben*. Erzeugt werden sie mit dem $\backslash epmh\{.\}$ Befehl.

Einheiten werden mit den Befehlen $\backslash unit[1]\{m\}$ (z.B. 1 m) und $\backslash unitfrac[1]\{m\}\{s\}$ (z.B. 1 m/s) gesetzt.

Bibliography

- [1] D. Brescianini and R. D'Andrea, "Design, modeling and control of an omnidirectional aerial vehicle," in *2016 IEEE International Conference on Robotics and Automation (ICRA)*, May 2016, pp. 3261–3266.
- [2] A. Nikou, G. C. Gavridis, and K. J. Kyriakopoulos, "Mechanical design, modelling and control of a novel aerial manipulator," in *2015 IEEE International Conference on Robotics and Automation (ICRA)*, May 2015, pp. 4698–4703.
- [3] M. Kamel, S. Verling, O. Elkhatab, C. Sprecher, P. Wulkop, Z. Taylor, R. Siegwart, and I. Gilitschenski, "Voliro: An Omnidirectional Hexacopter With Tilttable Rotors," *arXiv:1801.04581 [cs]*, Jan. 2018, arXiv: 1801.04581.
- [4] M. Tognon and A. Franchi, "Omnidirectional Aerial Vehicles with Unidirectional Thrusters: Analysis, Optimal Design, and Motion Control," *IEEE Robotics and Automation Letters*, p. 11, 2018.
- [5] S. Rajappa, M. Ryll, H. H. Bühlhoff, and A. Franchi, "Modeling, control and design optimization for a fully-actuated hexarotor aerial vehicle with tilted propellers," in *2015 IEEE International Conference on Robotics and Automation (ICRA)*, May 2015, pp. 4006–4013.
- [6] R. Rashad, P. Kuipers, J. Engelen, and S. Stramigioli, "Design, Modeling, and Geometric Control on $SE(3)$ of a Fully-Actuated Hexarotor for Aerial Interaction," *arXiv:1709.05398 [math]*, Sep. 2017, arXiv: 1709.05398.
- [7] S. Park, J. Her, J. Kim, and D. Lee, "Design, modeling and control of omnidirectional aerial robot," in *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Oct. 2016, pp. 1570–1575.
- [8] M. Ryll, H. H. Bühlhoff, and P. R. Giordano, "Modeling and control of a quadrotor UAV with tilting propellers," in *2012 IEEE International Conference on Robotics and Automation*, May 2012, pp. 4606–4613.
- [9] M. Burri, J. Nikolic, H. Oleynikova, M. W. Achtelik, and R. Siegwart, "Maximum likelihood parameter identification for MAVs," in *2016 IEEE International Conference on Robotics and Automation (ICRA)*, May 2016, pp. 4297–4303.

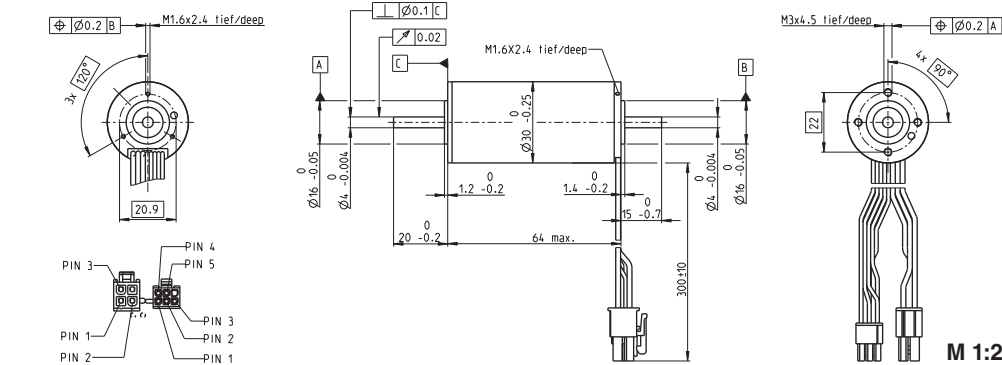
Appendix A

Irgendwas

Bla bla ...

Appendix B

Datasheets

EC-max 30 Ø30 mm, brushless, 60 Watt

■ Stock program
 □ Standard program
 ■ Special program (on request)

Part Numbers

272762 272763 272764 272765

Motor Data**Values at nominal voltage**

1 Nominal voltage	V	12	24	36	48
2 No load speed	rpm	7980	9340	9490	9350
3 No load current	mA	302	191	130	95.4
4 Nominal speed	rpm	6590	8040	8270	8130
5 Nominal torque (max. continuous torque)	mNm	63.6	60.7	63.7	64.1
6 Nominal current (max. continuous current)	A	4.72	2.66	1.88	1.4
7 Stall torque	mNm	381	458	522	519
8 Starting current	A	26.8	18.8	14.5	10.7
9 Max. efficiency	%	80	81	82	82

Characteristics

10 Terminal resistance phase to phase	Ω	0.447	1.27	2.48	4.49
11 Terminal inductance phase to phase	mH	0.049	0.143	0.312	0.573
12 Torque constant	mNm/A	14.2	24.3	35.9	48.6
13 Speed constant	rpm/V	672	393	266	197
14 Speed/torque gradient	rpm/mNm	21.2	20.6	18.4	18.2
15 Mechanical time constant	ms	4.86	4.73	4.21	4.17
16 Rotor inertia	gcm ²	21.9	21.9	21.9	21.9

Specifications**Thermal data**

17 Thermal resistance housing-ambient	7.4 K/W
18 Thermal resistance winding-housing	0.5 K/W
19 Thermal time constant winding	2.76 s
20 Thermal time constant motor	1000 s
21 Ambient temperature	-40...+100°C
22 Max. permissible winding temperature	+155°C

Mechanical data (preloaded ball bearings)

23 Max. permissible speed	15000 rpm
24 Axial play at axial load < 6.0 N	0 mm
24 Axial play at axial load > 6.0 N	0.14 mm
25 Radial play	preloaded
26 Max. axial load (dynamic)	5 N
27 Max. force for press fits (static) (static, shaft supported)	98 N
28 Max. radial loading, 5 mm from flange	1300 N
	25 N

Other specifications

29 Number of pole pairs	1
30 Number of phases	3
31 Weight of motor	305 g

Values listed in the table are nominal.

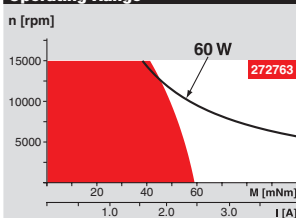
Connection motor (Cable AWG 20)	
red	Motor winding 1 Pin 1
black	Motor winding 2 Pin 2
white	Motor winding 3 Pin 3
N.C.	N.C. Pin 4

Connector	Part number
Molex	39-01-2040

Connection Sensors (Cable AWG 26)	
yellow	Hall sensor 1 Pin 1
brown	Hall sensor 2 Pin 2
grey	Hall sensor 3 Pin 3
blue	GND Pin 4
green	V _{DD} 3...24 VDC Pin 5
N.C.	N.C. Pin 6

Connector	Part number
Molex	430-25-0600

Wiring diagram for Hall sensors see p. 35

Operating Range**Comments**

■ **Continuous operation**
 In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
 = Thermal limit.
 □ **Short term operation**
 The motor may be briefly overloaded (recurring).
 — **Assigned power rating**

maxon Modular System**Planetary Gearhead**

Ø32 mm

8.0 Nm

Page 266

Koaxdrive

Ø32 mm

1.0 - 4.5 Nm

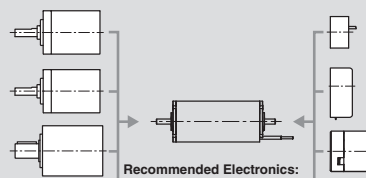
Page 268

Planetary Gearhead

Ø42 mm

3 - 15 Nm

Page 271

**Recommended Electronics:**

ESCON 36/3 EC Page 320

ESCON 50/5, Module 50/5 321

ESCON 70/10 321

DECS 50/5 324

DEC Module 24/2 325

DEC Module 50/5 325

EPOS2 24/5, 50/5 331

EPOS2 P 24/5 334

EPOS3 70/10 EtherCAT 337

Notes 24

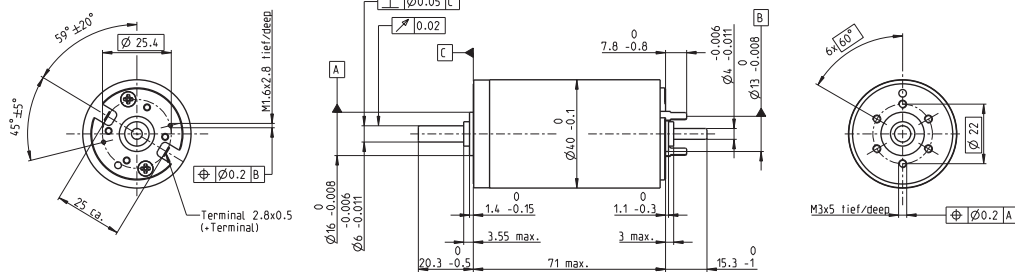
Overview on page 20 - 25

Encoder MR
 500/1000 CPT,
 3 channels
 Page 302
Encoder HEDL 5540
 500 CPT,
 3 channels
 Page 308
Brake AB 20
 24 VDC
 0.1 Nm
 Page 346

RE 40 Ø40 mm, Precious Metal Brushes, 25 Watt

NEW

maxon DC motor



M 1:2

■ Stock program
 □ Standard program
 ▨ Special program (on request)

Part Numbers

Motor Data		448588	448589	448590	448591	448592
Values at nominal voltage						
1 Nominal voltage	V	9	18	24	42	48
2 No load speed	rpm	2850	2850	2780	2920	2690
3 No load current	mA	49.7	24.8	18.1	11	8.62
4 Nominal speed	rpm	2610	2600	2480	2640	2410
5 Nominal torque (max. continuous torque)	mNm	87.8	87.8	88.2	87.6	87.6
6 Nominal current (max. continuous current)	A	2.96	1.48	1.09	0.65	0.524
7 Stall torque	mNm	873	956	794	895	818
8 Starting current	A	29	15.9	9.66	6.53	4.81
9 Max. efficiency	%	92	92	92	92	92
Characteristics						
10 Terminal resistance	Ω	0.311	1.14	2.49	6.43	9.97
11 Terminal inductance	mH	0.0624	0.33	0.613	1.7	2.62
12 Torque constant	mNm/A	30.2	60.3	82.2	137	170
13 Speed constant	rpm/V	317	158	116	69.7	56.2
14 Speed / torque gradient	rpm/mNm	3.27	2.98	3.51	3.27	3.3
15 Mechanical time constant	ms	4.85	4.29	4.36	4.14	4.13
16 Rotor inertia	gcm ²	142	137	119	121	120

Specifications

Thermal data	
17 Thermal resistance housing-ambient	4.65 K/W
18 Thermal resistance winding-housing	1.93 K/W
19 Thermal time constant winding	41.5 s
20 Thermal time constant motor	809 s
21 Ambient temperature	-20...+85°C
22 Max. permissible winding temperature	+100°C

Mechanical data (ball bearings)	
23 Max. permissible speed	3330 rpm
24 Axial play	0.05 - 0.15 mm
25 Radial play	0.025 mm
26 Max. axial load (dynamic)	5.6 N
27 Max. force for press fits (static) (static, shaft supported)	110 N
28 Max. radial loading, 5 mm from flange	1200 N
	28 N

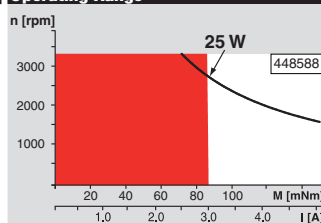
Other specifications	
29 Number of pole pairs	1
30 Number of commutator segments	13
31 Weight of motor	480 g

Values listed in the table are nominal.
Explanation of the figures on page 71.

Option

Preloaded ball bearings

Operating Range



Comments

Continuous operation
 In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
 = Thermal limit.

Short term operation
 The motor may be briefly overloaded (recurring).

Assigned power rating

maxon Modular System

Overview on page 20 - 25

