HHRI Paddles – Hardware Documentation

2022 paddle

Handling and usage precautions

1. Avoid touching the body of the motor while the paddle is powered, as it might be hot.
2. The paddle PCB is exposed. Please take care not to damage the board with electrostatic shocks. To do so, avoid touching the board. If you have to, touch the micro-USB connector first.
3. To avoid the inrush current at power-on (which causes sparks on the power connector and damages the contacts), the best practice is to connect the power supply to the board first, then plug it into the mains.
4. Make sure the steel cable never touches the board, or it may short-circuit it!
5. The two black rubber bumpers should always be present around the stop bits, to avoid damaging the motor ball bearings in case the paddle hits them.

Convention for the direction of rotation

The incremental encoder should output an increasing angle when the paddle is spinning counter-clockwise. The paddle should spin in the same direction with a positive torque/current target. If this is not the case, you should swap the two motor wires (the thicker red and black wires) in the terminal block of the board.

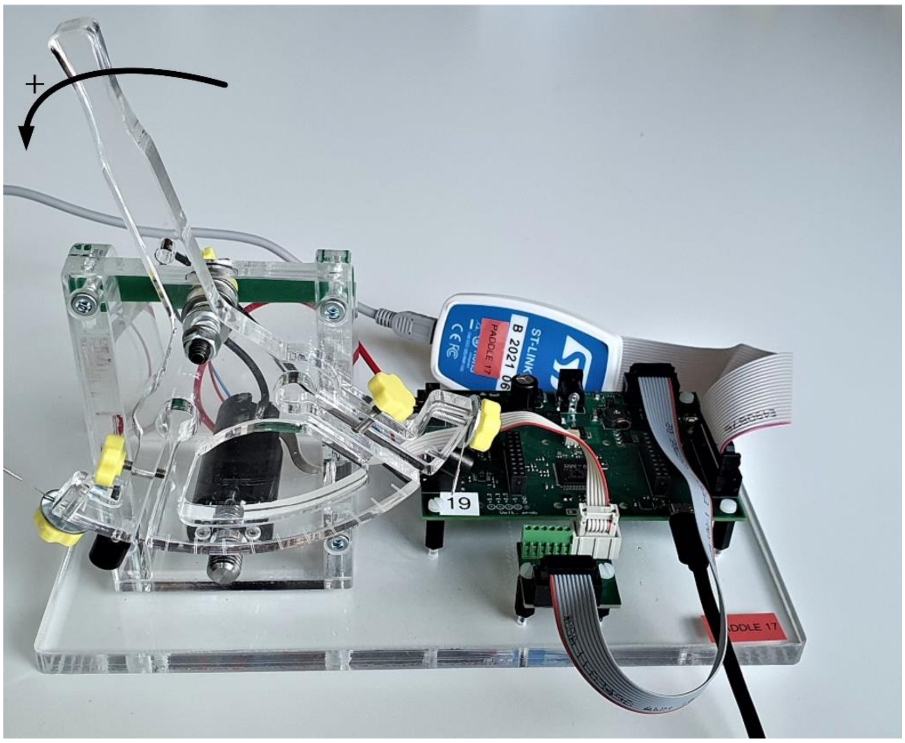


Figure 1: the rotation direction defined as positive

Mechanical parts

Paddle

Mass: 77 g.
Moment of inertia around the center of rotation: 205,404.- g·mm².

There are two screws on each side of the paddle (Figure 3). The "anchor screws" are used to hold the cable at the two ends of the paddle. The "tension screws" are used to adjust the amount of tension on the cables by changing the circumference of the curved part of the paddle.

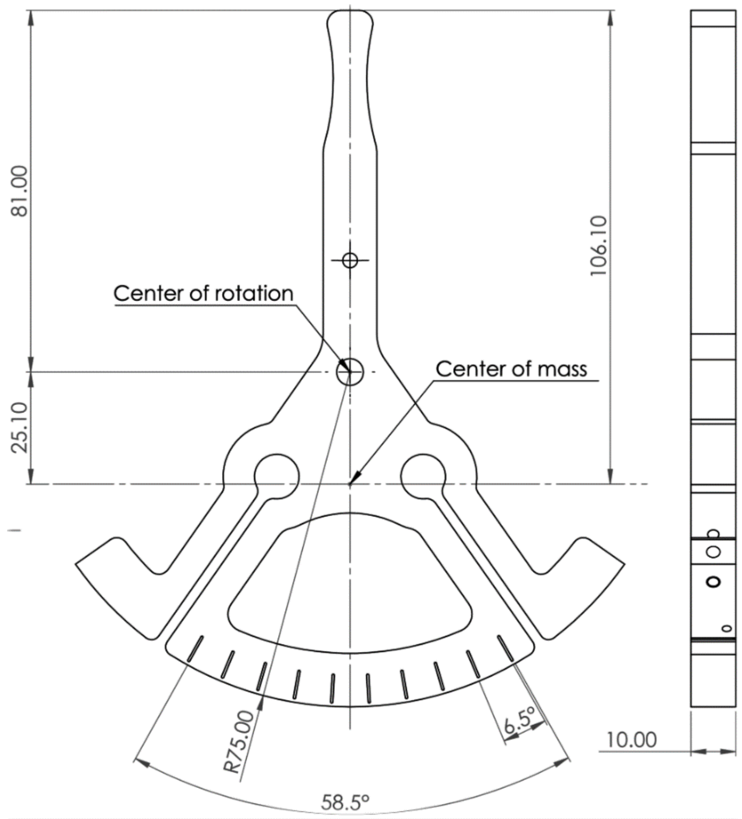


Figure 2: paddle part dimensions (length unit: [mm])

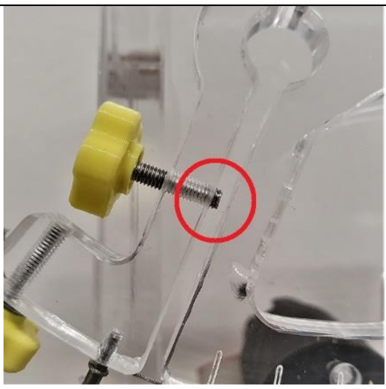
Figure 3: the screws on each side of the paddle

Worm screw

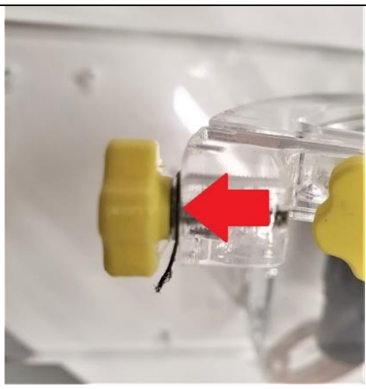
Moment of inertia about the axis of rotation: 1.44 g·cm^2.

Nominal radius: 5 mm.
=> Transmission ratio motor/paddle: (75/5=) 15.

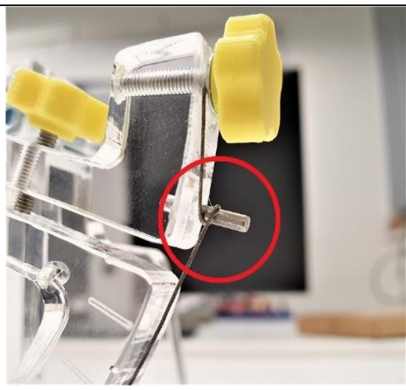
Procedure to mount the cable on the paddle



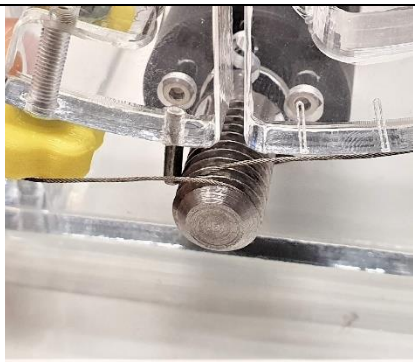
1. Unscrew the tension screws on both sides of the paddle, such that its tip does not touch the surface in front of it.



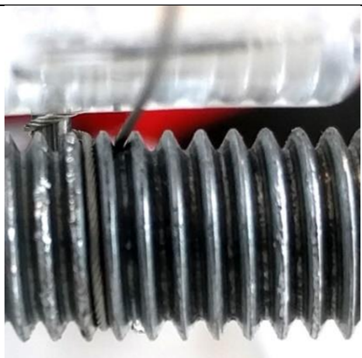
2. Make half a turn around the right anchor screw with the cable, and tighten the screw. The cable should be pressed between the paddle surface and the washer.



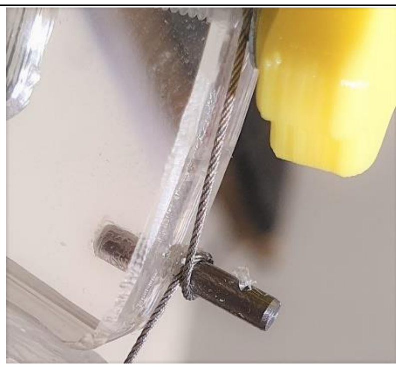
3. Surround the pin with the cable, as shown on the picture. The cable should “enter” and “leave” the pin on its inner side.



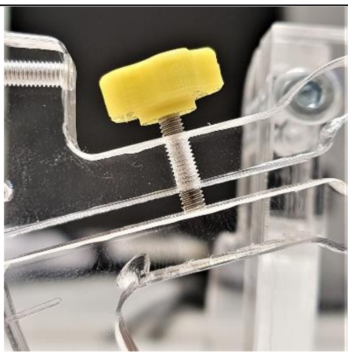
4. Push the left pin of the paddle against the motor screw. Surround the motor wormscrew with the cable. Keep the cable tightened with your hand, to avoid that the cable goes out of the wormscrew.



5. Keeping the cable softly tightened, push the right pin of the paddle against the motor wormscrew. Then, spin the motor screw with your fingers, until the cable “enters” the screw close to the right pin.

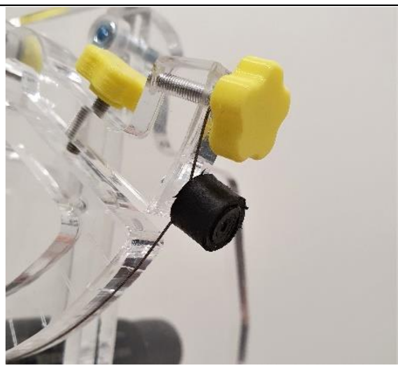


6. Surround the left pin with cable, then surround the left anchor screw, tighten the cable, and tighten the screw. The cable should “enter” and “leave” the pin on its inner side, and should be pressed between the paddle surface and the washer of the anchor.



7. Gradually tighten the tension screws, until the cable does not easily slip on the motor shaft. You do not necessarily need to screw all the way to the end.

8. Move the paddle back-and-forth, and make sure there is no friction noise when approaching the ends of the range. If this is the case, go back to step 5.



9. Put the rubber bumpers back on both pins.

Motor specifications

The paddle is driven by a Faulhaber 2642W024 CR brushed PM DC motor. The full datasheet is included in the last page of this document.
The motor shaft is connected to an incremental encoder, more details below.

The haptic paddle board will limit its torque to the nominal torque (0.032 N.m), so no overload is possible.

Incremental encoder Faulhaber IE3-1024

Two channels with quadrature square waves, 1024 periods per revolution. This leads to 4096 transitions (usable steps) per revolution.
One index line (one short pulse per turn), currently unused.

Specific sensors

Hall sensor

A1324LUA-T from Allegro.
Senses the vertical component of the magnetic field of the diametrically polarized magnet.

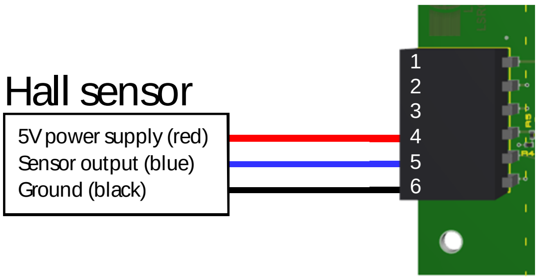


Figure 4: connection of the Hall sensor to the board

Extension boards and sensors

These boards are not mounted on the paddles by default. They may be added later for some final projects.

Generic amplifier

This generic differential amplifier board can be used to measure the voltage of many sensors. The voltage gain can be set from 10x to 1280x, and the bandwidth is 10 kHz. It has a voltage reference, adjustable with an integrated potentiometer.

To obtain the value of the amplified voltage in your code, use:
`adc_GetChannelVoltage(ADC_CHANNEL_6)`

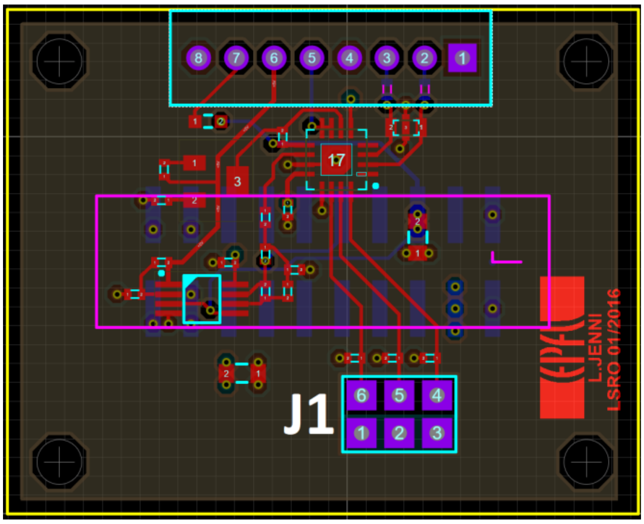


Figure 5: generic amplifier extension board (top view)

Connector pinout

- Pin 1&8: ground
- Pin2&3: Diff. inputs
- Pin5: Adjustable middle point ref. (2.5V+/-300mV trough T1 potentiometer)
- Pin6: 5V
- Pin7: Fixed 2.5V ref.

The amplifier gain is set by the jumper on J1:

Gain	x10	x20	x40	x80	x160	x320	x640	x1280
Jumpers layout	321 (none)	321	321	321	321	321	321	321 (all set)

IMU

MPU-6050 from Invensense: 3-axes accelerometer, 3-axes gyroscope, temperature sensor.
It communicates with the board with the I2C bus. This sensor is not mounted on the paddles by default, but can be added later for some final projects of the course.

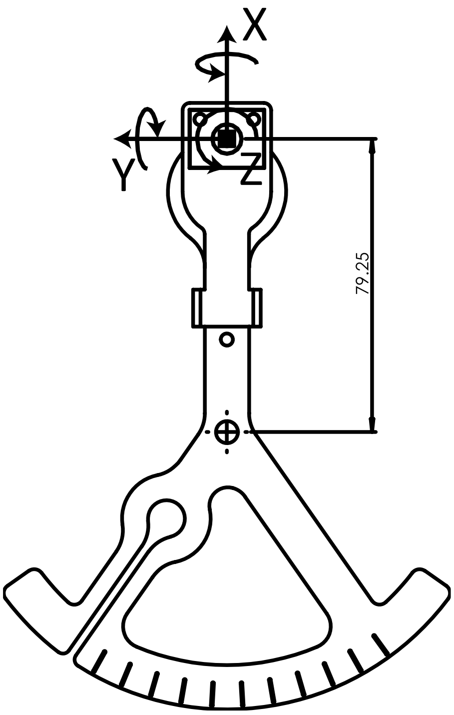


Figure 6: axes of the IMU paddle extension (length unit: [mm])

Tachometer wiring

Use the lowest gain (x10). It may even be necessary to use a voltage divider to avoid saturation at high speed.

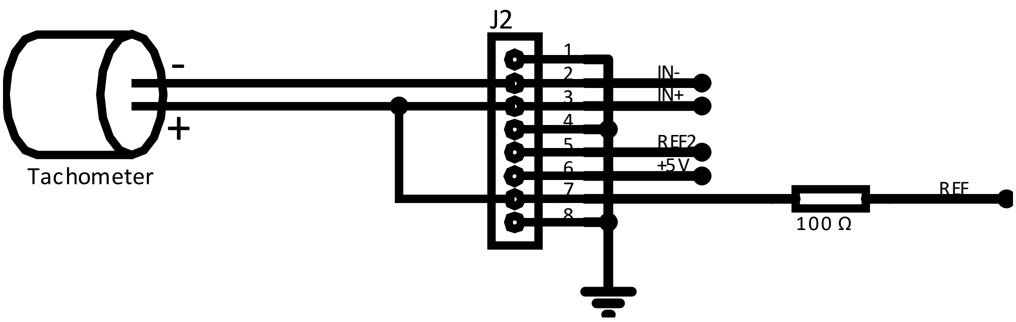


Figure 7: tachometer wiring to the amplifier board

Strain gauges wiring

The adjustable reference is feedback to one of the inputs (through an optional resistor that has same impedance as the gauge) and used to trim the 0 point.

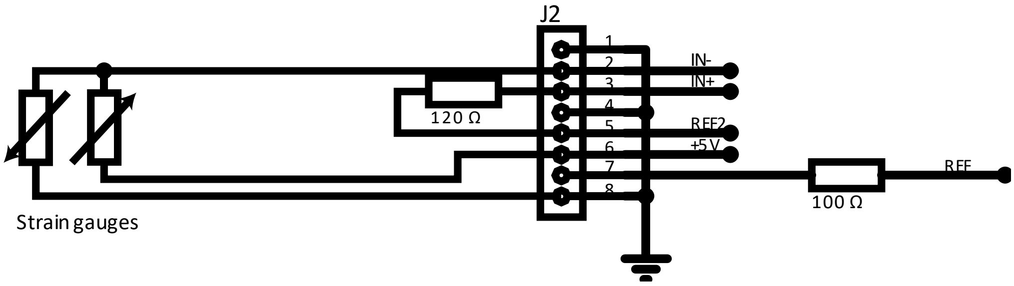


Figure 8: wiring of the strain gauges to the amplifier board (3-wires)

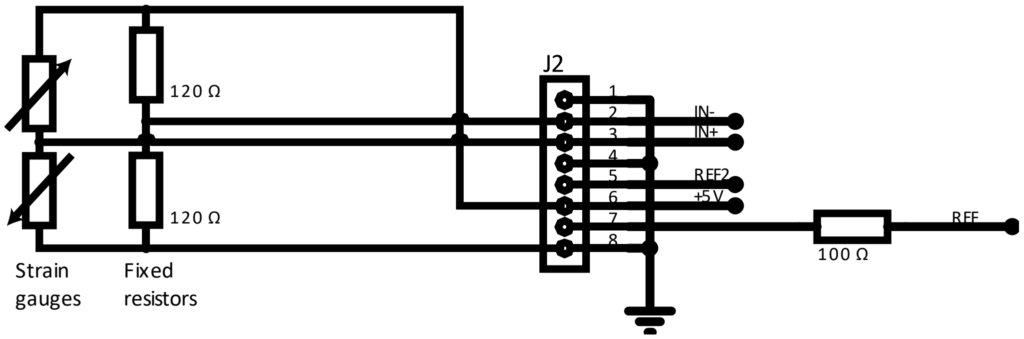


Figure 9: wiring of the strain gauges to the amplifier board (4-wires)

Digital breakout board

The goal of this board is to provide an easy access to the digital signals, so that cables can be soldered directly on it. This allows to interface with any external digital peripheral.

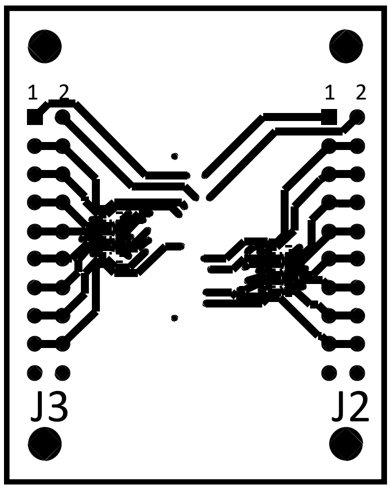


Figure 10: digital breakout board connectors (top view)

J3				J2			
1	+5.25 V	+3.3V	2	1	+5.25V	+3.3V	2
3	PE1		4	3	PD4		4
5	PE0		6	5	PD3		6
7	PB9 (I2C1_SDA)		8	7	PD2 (UART5_RX)		8

9	PB8 (I2C1_SCL)	10	9	PD1	10
11	PB7 (I2C1_SDA, UART1_RX)	12	11	PD0	12
13	PB6 (I2C1_SCL, UART1_TX)	14	13	PC12 (SPI3_MOSI, UART5_TX)	14
15	PB5 (SPI3_MOSI)	16	15	PC11 (SPI3_MISO, UART4_RX, UART3_RX)	16
17	PD7	18	17	PC10 (SPI3_CLK, UART5_TX, UART3_TX)	18
19	GND	20	19	GND	20

EMG amplifier

This extension board measures the electrical activity of the muscle, across the surface of the skin. Compared to the generic amplifier, it has a high-pass filter (to remove the offset) and an active voltage reference input (to minimize the common-mode noise).

To obtain the value of the amplified voltage in your code, use:
`adc_GetChannelVoltage(ADC_CHANNEL_6)`

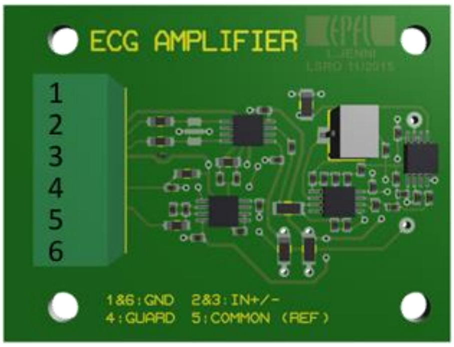


Figure 11: EMG amplifier extension board (top view)

Pinout:

- Pin 1&6: ground (should normally not be used).
- Pin 2&3: electrodes located on the muscle.
- Pin 4: cable shielding (if any).
- Pin 5: active voltage reference. The corresponding electrode should be placed on the body, on a region with no electrical activity (e.g. on the elbow).

Specification:

- Variable gain: 70-760V/V
- Bandwidth: 0.05-156 [Hz] (AC coupled)

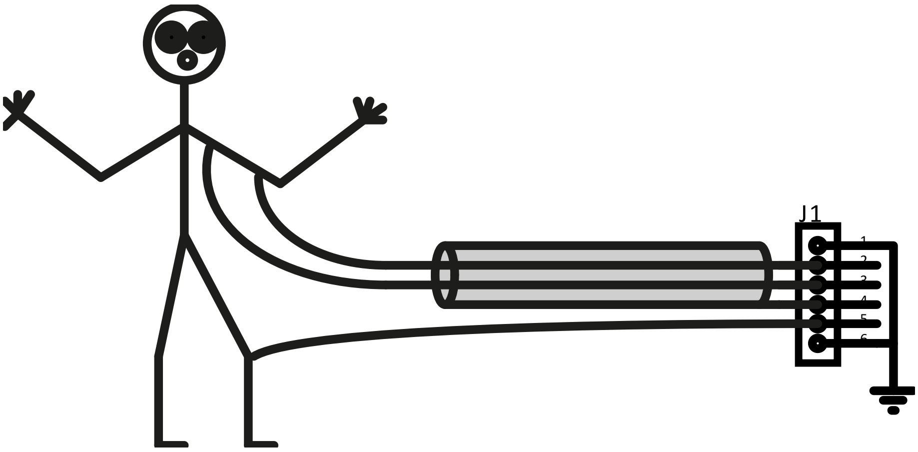


Figure 12: wiring of the EMG amplifier on the human body (picture credits: Laurent Jenni)

DC-Micromotors

Graphite Commutation

32 mNm

28 W

Series 2642 ... CR

	Values at 22°C and nominal voltage	2642 W		012 CR	018 CR	024 CR	036 CR	048 CR	
1	Nominal voltage	U_N		12	18	24	36	48	V
2	Terminal resistance	R		1,45	3,1	5,78	13,6	23,8	Ω
3	Efficiency, max.	$\eta_{max.}$		78	76	79	76	79	%
4	No-load speed	n_0		6 400	6 400	6 400	6 500	6 400	min⁻¹
5	No-load current, typ. (with shaft ø 4 mm)	I_0		0,118	0,079	0,058	0,039	0,029	A
6	Stall torque	M_H		132	144	139	134	137	mNm
7	Friction torque	M_R		2	2	2	2	2	mNm
8	Speed constant	k_n		565	370	276	183	137	min^{-1}/V
9	Back-EMF constant	k_E		1,77	2,7	3,62	5,47	7,31	mV/min^{-1}
10	Torque constant	k_M		16,9	25,8	34,6	52,2	69,8	mNm/A
11	Current constant	k_I		0,059	0,039	0,029	0,019	0,014	A/mNm
12	Slope of n-M curve	$\Delta n/\Delta M$		48,5	44,5	46	47,7	46,7	min^{-1}/mNm
13	Rotor inductance	L		130	300	550	1 200	2 200	µH
14	Mechanical time constant	τ_m		5,4	5,4	5,4	5,4	5,4	ms
15	Rotor inertia	J		11	12	11	11	11	gcm^2
16	Angular acceleration	$\alpha_{max.}$		120	120	120	120	120	$\cdot 10^3 rad/s^2$
17	Thermal resistance	R_{th1} / R_{th2}	2,1 / 11						K/W
18	Thermal time constant	τ_{w1} / τ_{w2}	10 / 510						s
19	Operating temperature range:								
	– motor		-30 ... +125						°C
	– winding, max. permissible		+155						°C
20	Shaft bearings		ball bearings, preloaded						
21	Shaft load max.:								
	– with shaft diameter		4						mm
	– radial at 3 000 min⁻¹ (3 mm from bearing)		20						N
	– axial at 3 000 min⁻¹		2						N
	– axial at standstill		20						N
22	Shaft play:								
	– radial	≤	0,015						mm
	– axial	=	0						mm
23	Housing material		steel, black coated						
24	Mass		114						g
25	Direction of rotation		clockwise, viewed from the front face						
26	Speed up to	$n_{max.}$	7 000						min⁻¹
27	Number of pole pairs		1						
28	Magnet material		NdFeB						

	Rated values for continuous operation								
29	Rated torque	M_N		30	32	32	31	32	mNm
30	Rated current (thermal limit)	I_N		2,2	1,5	1,1	0,74	0,56	A
31	Rated speed	n_N		4 390	4 490	4 370	4 340	4 330	min⁻¹