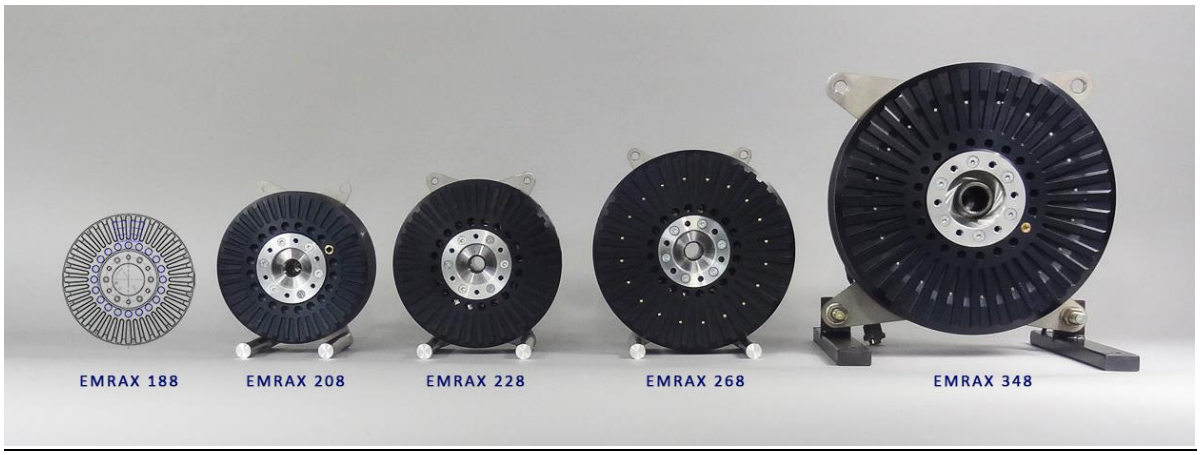
User's Manual for Advanced Axial Flux Synchronous Motors and Generators

EMRAX®
INNOVATIVE E-MOTORS



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Dear Customer,

Congratulations on your purchase of the EMRAX high performance electric motor.
This drive is a Slovenian product of a completely new type of pancake axial flux synchronous permanent magnet electric motor, which will keep its capability for a long time if treated properly. It can also work as a generator with the same performance characteristics. The drive was developed for airplanes, where reliability is extremely important. Therefore, our target was to build a reliable, low weight, high power direct drive electric motor with high efficiency.

The drive was developed and tested by Roman Sušnik, dipl. ing. (Company EMRAX d.o.o., till March 2016 company name was Enstroj d.o.o.). The first prototype was mounted onto the glider airplane Apis EA2 in 2005, when also the 1st electric flight in Slovenia and the 3rd in the world was made. The motor was also laboratory tested in Piktronik d.o.o in 2010, Siemens GmbH (May 2012) and Letrika d.d. (November 2014). Furthermore, our customers give us test results from their projects to confirm our test data. In February 2014 thermal tests were performed on EMRAX motors. The motor was exposed to shock tests from -40°C to +160°C for 17 days (24h/day), this means 408 hours non-stop. EMRAX passed this examination with excellent results, without any damages.

Meaning of EMRAX name:
- **EM** stands for the Electric Motor,
- **R** is the first letter of the innovator's name, who is Roman
- **AX** stand for the axial magnetic flux

EMRAX motor features:
- Axial Flux
- Permanent magnet synchronous motor
- Input type: sinusoidal three phase
- Lightweight - best in class power density (up to 10 kW/kg)
- High torque at low RPM
- Highly efficient (up to 98%)
- Reliable (developed and produced for the airplane industry, EV and for other applications)
- Compact and high-quality product
- IP21 or IP65
- EMC Compliant – E marked (complies with essential protection requirements of 89/336/EEC)
- Low cost
- 3 Cooling options (Air/Liquid/Combined)
- Low noise
- No vibrations
- Stacking capability (two same sized motors connected on the same shaft)

The EMRAX engine can achieve high power even at relatively low rotation speeds due to high torque. It allows a gearless drive without the usual step-down gear unit which causes power losses, additional weight, complexity and maintenance. In the case where the lower output rotation is needed the reduction drive can be used, which allows even higher torque (power stays the same).

The EMRAX motor ranks as the best high power density motor in the global market. Its power density is very high – up to 10 kW/kg. EMRAX motors have the best-in-class power density. The mechanical and no load electrical loses are very small, so EMRAX can run on high speed – in which case very high motor power can be achieved (up to 330 kWp – e.g. EMRAX 348 type). EMRAX motors use less material more efficiently to provide higher power densities than any comparable motor or generator.

Though many intensive tests have already been made and despite the parts being produced by modern CNC machines, the motor is become like series product. An way some manufacturing processes are still made by hand, which makes drive unique. Therefore, our customers are and will be part of the field test, thus we are already excited about the experiences they will make with the new motor.

First EMRAX engines as prototype have been sold since the year 2008. Through the years of experiences, we have made many improvements. The development is a never ending story, therefore improvements will still be made. The customer assumes responsibility to share the experiences made with the drive with the manufacturer, in order for the manufacturer to gather the know-how and identify possible weaknesses.

The usage of EMRAX motors is in automotive, motorsport, off road, marine, industrial, aerospace applications.

The orders are rising monthly, consequently we are prepared to raise the production quantity by multiplying the existing production cells and also start mass production. Even though motors are not made in high volumes, the advanced materials and proprietary construction techniques enable significant customer cost benefits. Therefore EMRAX motors have a very competitive price in their class.

Applications where EMRAX motors can be used:
- Traction motors for on, off-road, rail and marine transport (hybrid or full electric).
- Generators (especially where size and weight are important).
- Integrated starter Generators (ISG) (start, generate and power boost from a small volume).
- Hydraulic replacement (compact and efficient alternatives for hydraulic motors and starters).

Figure 1: EMRAX testing at Letrika d.d. Company

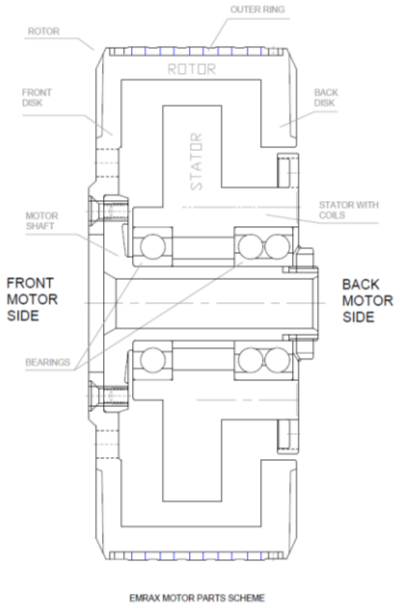


Figure 2: Scheme of EMRAX motor

1. Technical data of EMRAX motors

EMRAX motors/generators are **advanced axial flux synchronous (BLAC) electric motors/generators**. EMRAX motors are available in a range of torque and speed combinations and with variety of cooling options. EMRAX motor types (the number in the name means the diameter of the motor in mm):

EMRAX 188: This is the smallest motor. It is available for selling from beginning of 2017. Orders are being collected.
- High Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Medium Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Low Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)

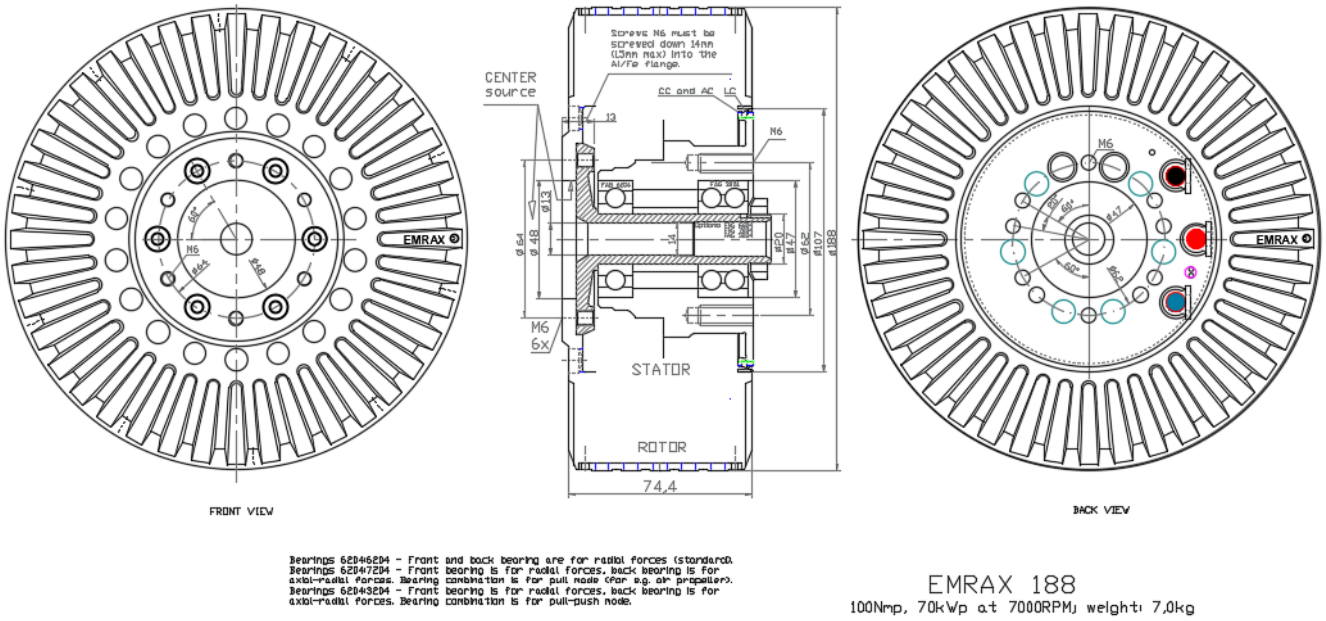


Figure 3: EMRAX 188 drawing

Figure 4: EMRAX 188 (IP21)

EMRAX 208: In production.
- High Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Medium Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Low Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)

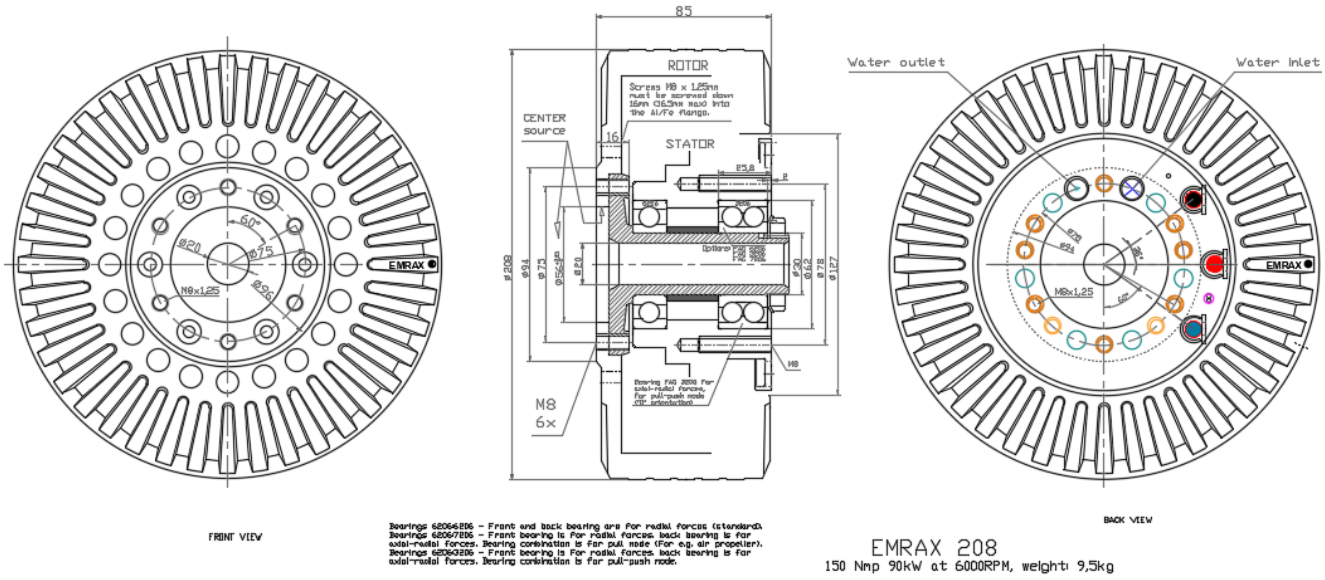


Figure 5: EMRAX 208 drawing

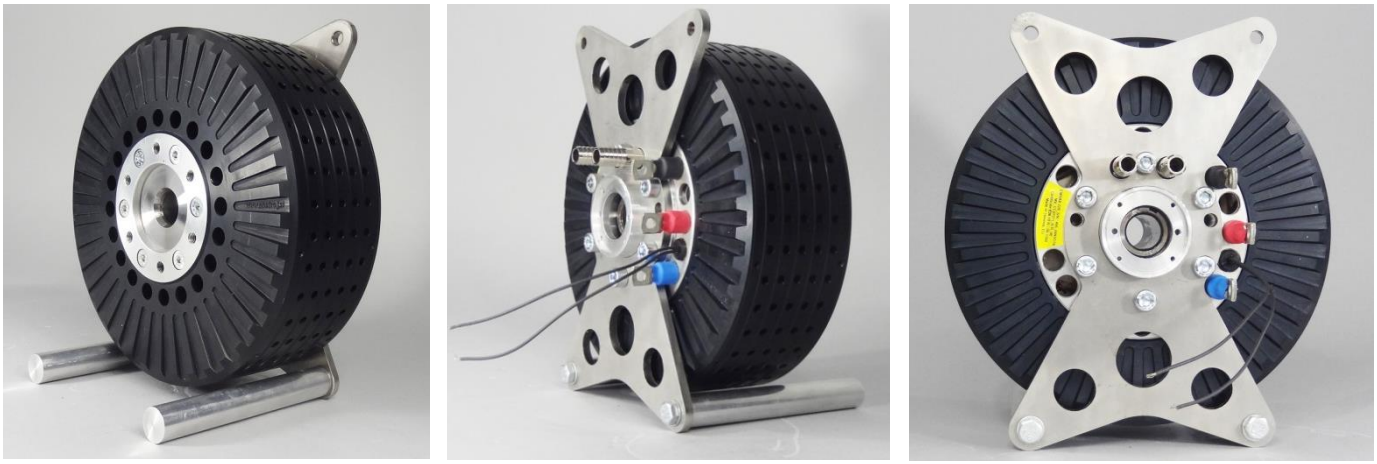


Figure 6: EMRAX 208 (IP65)

EMRAX 228: In production.
- High Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Medium Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Low Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)

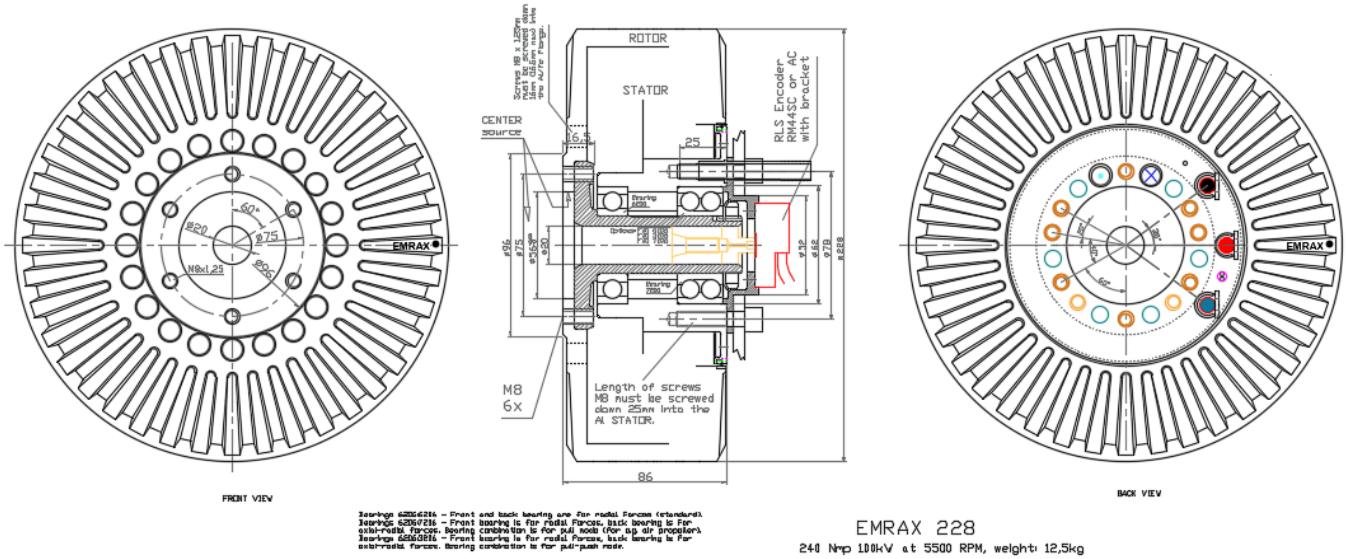


Figure 7: EMRAX 228 drawing

Figure 8: EMRAX 228 (IP21)

EMRAX 268: In production.
- High Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Medium Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Low Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)

*Customisations: EMRAX 268 Very High Mechanical Loads (VHML)

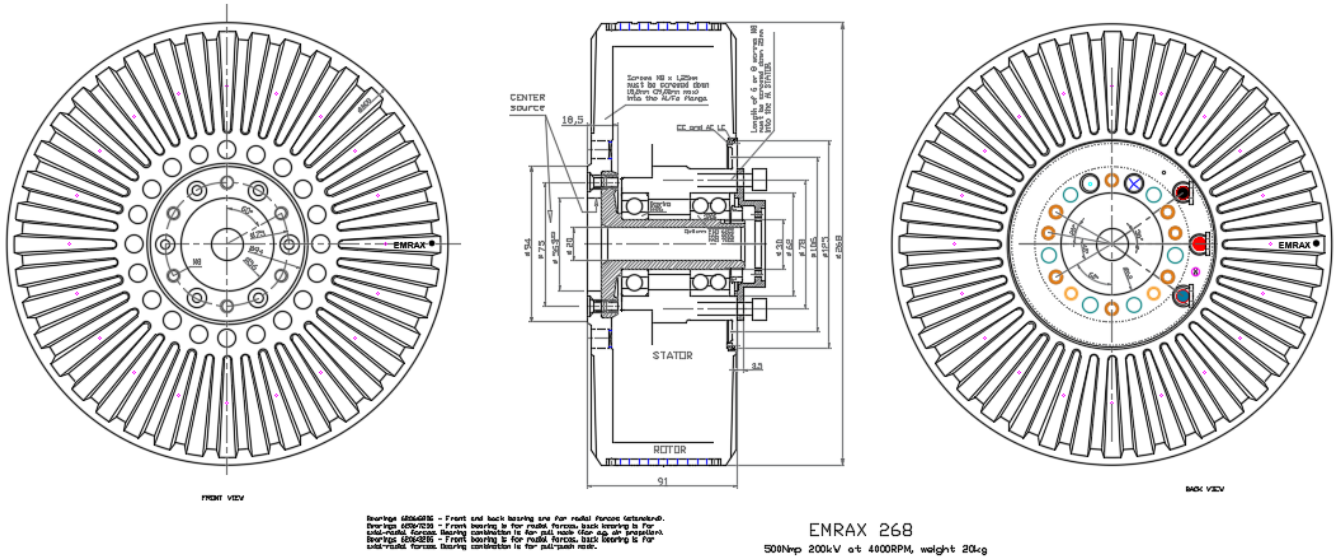


Figure 9: EMRAX 268 drawing

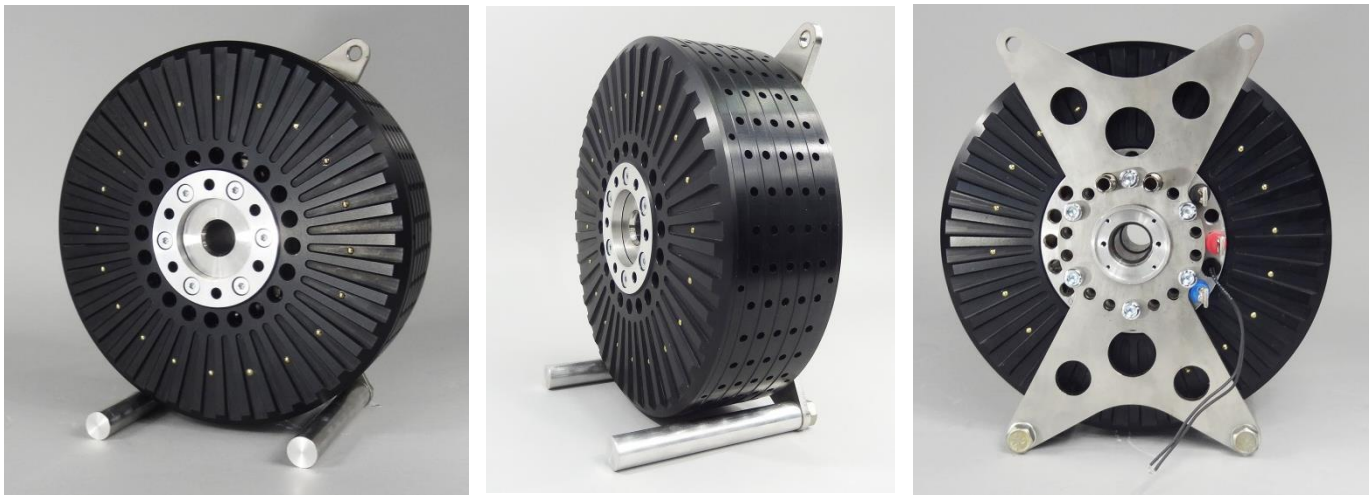


Figure 10: EMRAX 268 (IP21)

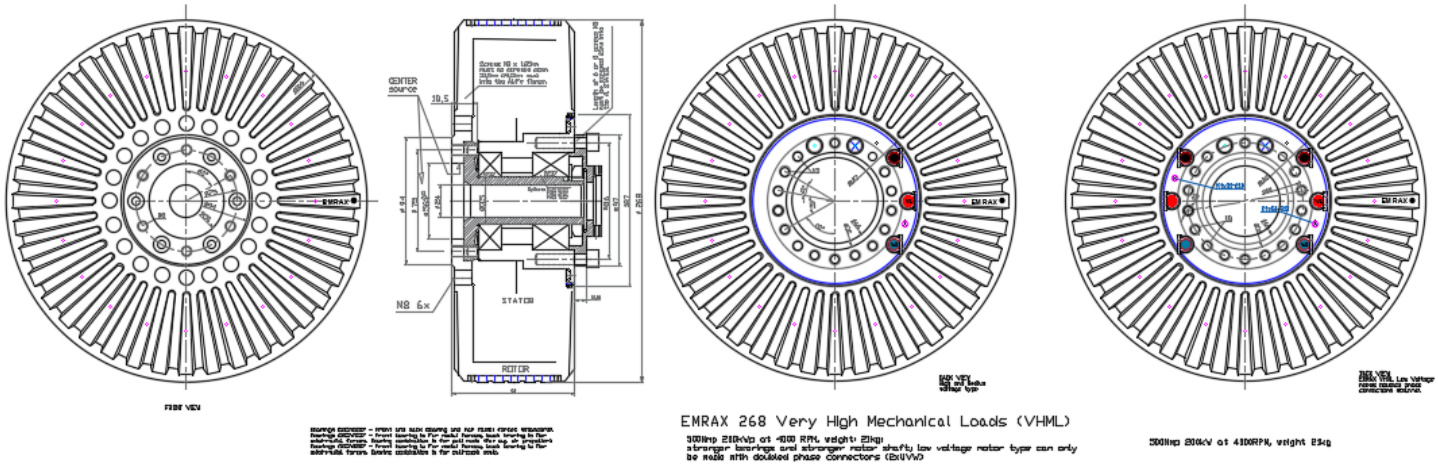


Figure 11: EMRAX Very High Mechanical Loads (VHML) drawing. EMRAX VHML Low Voltage needs doubled phase connectors (2xUVW).

EMRAX 348: Prototype is being tested. It is available from beginning of 2017. Orders are being collected.
- High Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Medium Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)
- Low Voltage (Air Cooled / Liquid Cooled (IP65) / Combined Cooled (IP21)

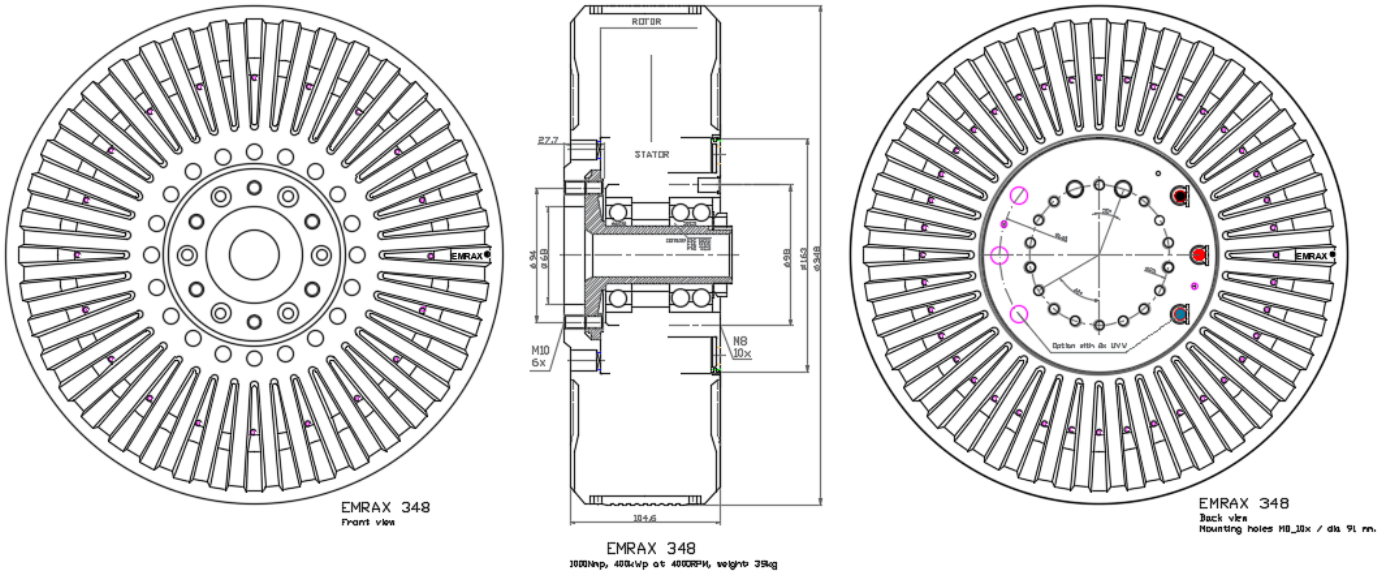


Figure 12: EMRAX 348 drawing

Figure 13: EMRAX 348 (IP65) with encoder

CUSTOM MADE EMRAX MOTORS

- Customized motor winding: Even though we offer low/medium/high voltage motors, we can still make some winding modification for the customers that need higher/lower RPM according to their battery voltage.
- Customized motor shaft:
  - hollow shaft with bigger hole diameter
  - shaft with multi splines.
- Special bearings for different magnitude and orientation of the force.
- Doubled phase connectors (2xUVW): One motor can be fitted with two controllers to gain enough motor current. In this case the motor also has a redundancy option.
- Longer phase connectors (UVW): Up to 250 mm.
- Phase connectors on the mirrored side (on the left side instead on the right side).
- Customized weight: Lighter motors for example aero applications.

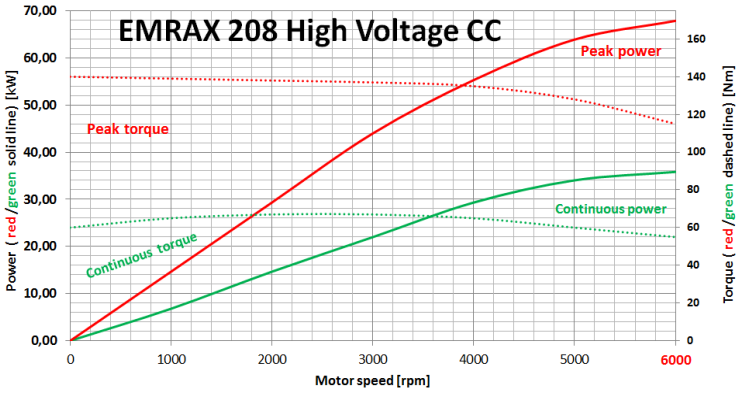
EMRAX 188 Technical Data Table

Type / Technical data	EMRAX 188 High Voltage			EMRAX 188 Medium Voltage			EMRAX 188 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Inlet Water/glycol Flow = WF; Ambient Air = AA) If inlet WF temperature and/or AA temperature are lower, then continuous power is higher.	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C
Weight [kg]	6,8	7,0	7,0	6,8	7,0	7,0	6,8	7,0	7,0
Diameter ø / width [mm]	188 / 77								
Maximal battery voltage [Vdc] and full load/no load RPM	400 Vdc (6400/7600 RPM)			270 Vdc (6750/7830 RPM)			100 Vdc (7000/7800 RPM)		
Peak motor power at max RPM (few min at cold start / few seconds at hot start) [kW]	**70**								
Continuous motor power (at 3000-6000 RPM) depends on the motor RPM [kW]	**15 - 28**	**15 - 30**	**17 - 35**	**15 - 28**	**15 - 30**	**17 - 35**	**15 - 28**	**15 - 30**	**17 - 35**
Maximal rotation speed [RPM]	**7000 (8500 peak for few seconds)**								
Maximal motor current (for 2 min if cooled as described in Manual) [Arms]	200			300			800		
Continuous motor current [Arms]	100			150			400		
Maximal peak motor torque [Nm]	**100**								
Continuous motor torque [Nm]	**50**								
Torque / motor current [Nm/1Aph rms]	0,60			0,39			0,15		
Maximal temperature of the copper windings in the stator and max. temperature of the magnets [°C]	120								
Motor efficiency [%]	92-98%								
Internal phase resistance at 25 °C [mΩ]	/			/			/		
Input phase wire cross-section [mm²]	10,2			15,2			38		
Wire connection	star								
Induction Ld/Lq [µH]	/			/			/		
Controller / motor signal	sine wave								
AC voltage between two phases [Vrms/1RPM]	0,0384			0,0252			0,0055		
Specific idle speed (no load RPM) [RPM/1Vdc]	19			29			78		
Specific load speed (depends on the controller settings) [RPM/1Vdc]	16 – 19			25 – 29			70 – 78		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100								
Magnetic flux – axial [Vs]	/			/			/		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor Inertia (mass dia=160mm, m=3,0kg) [kg*cm²]	/								
Bearings (front:back) - SKF/FAG	6204:6204 (for radial forces) or 6204:7204 (for axial-radial forces; for pull mode; focusing on very high axial load, e.g. for air propeller) or 6204:3204 (for axial-radial forces; for pull-push mode, α=25°); other bearings are possible (exceptionally)								

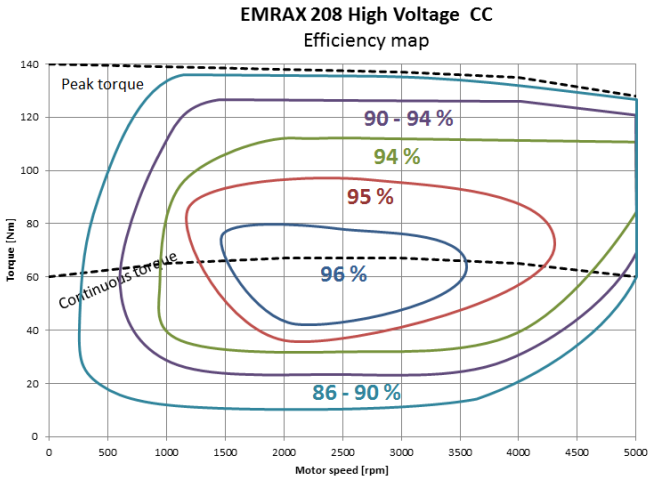
EMRAX 208 Technical Data Table (dynamometer test data)

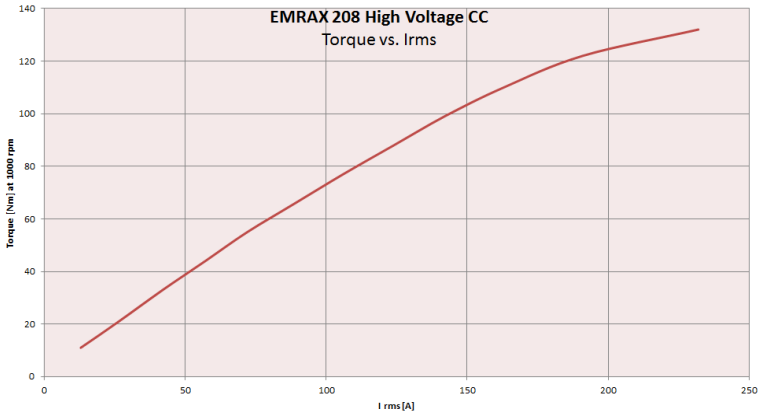
Type / Technical data	EMRAX 208 High Voltage			EMRAX 208 Medium Voltage			EMRAX 208 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Inlet Water/glycol Flow = WF; Ambient Air = AA) If inlet WF temperature and/or AA temperature are lower, then continuous power is higher.	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C
Weight [kg]	9,1	9,4	9,3	9,1	9,4	9,3	9,1	9,4	9,3
Diameter ø / width [mm]	208 / 85								
Maximal battery voltage [Vdc] and full load/no load RPM	470 Vdc (5170/7050 RPM)			320 Vdc (5760/7040 RPM)			125 Vdc (6250/7250 RPM)		
Peak motor power at max RPM (few min at cold start / few seconds at hot start) [kW]	**80**								
Continuous motor power (at 3000-5000 RPM) depends on the motor RPM [kW]	**20 - 32**	**20 - 32**	**25 - 40**	**20 - 32**	**20 - 32**	**25 - 40**	**20 - 32**	**20 - 32**	**25 - 40**
Maximal rotation speed [RPM]	**6000 (7000 peak for a few seconds)**								
Maximal motor current (for 2 min if cooled as described in Manual) [Arms]	200			320			800		
Continuous motor current [Arms]	100			160			400		
Maximal peak motor torque [Nm]	**150**								
Continuous motor torque [Nm]	**80**								
Torque / motor current [Nm/1Aph rms]	0,83			0,54			0,20		
Maximal temperature of the copper windings in the stator and max. temperature of the magnets [°C]	120								
Motor efficiency [%]	92-98%								
Internal phase resistance at 25 °C [mΩ]	12,0			5,7			0,8		
Input phase wire cross-section [mm²]	10,2			15,2			38		
Wire connection	star								
Induction Ld/Lq [µH]	125/130			52/56			7,2/7,5		
Controller / motor signal	sine wave								
AC voltage between two phases [Vrms/1RPM]	0,0487			0,0319			0,0117		
Specific idle speed (no load RPM) [RPM/1Vdc]	15			22			58		
Specific load speed (depends on the controller settings) [RPM/1Vdc]	11 – 15			18 – 22			50 – 58		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100								
Magnetic flux – axial [Vs]	0,0393			0,0257			0,095		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor Inertia (mass dia=160mm, m=4,0kg) [kg*cm²]	256								
Bearings (front:back) - SKF/FAG	6206:6206 (for radial forces) or 6206:7206 (for axial-radial forces; for pull mode; focusing on very high axial load, e.g. for air propeller) or 6206:3206 (for axial-radial forces; for pull-push mode, α=25°); other bearings are possible (exceptionally)								

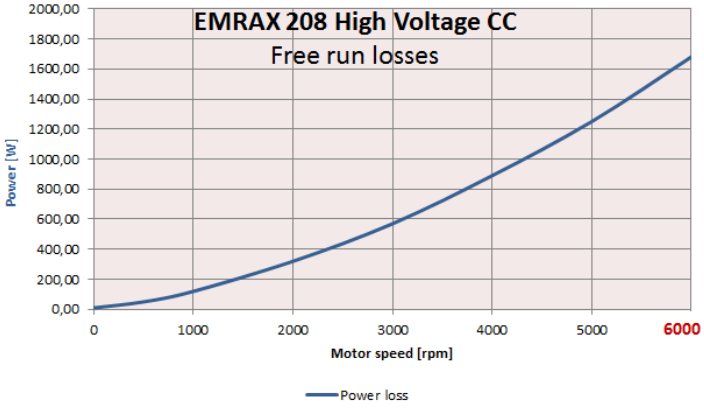
Graphs valid for EMRAX High Voltage Combined Cooled (CC) motor type:



Note 1: for determening peak or continuous power (kW) you should choose motor speed and than read power from chosen power curve (in the left graph side)
Note 2: for determening peak or continuous torque (Nm) you should choose motor speed and than read torque from chosen torque curve (in the right graph side)







Graphs of the EMRAX 208 Medium and Low voltage motor type:

Graphs of EMRAX 208 Low Voltage and EMRAX 208 Medium Voltage are similar to graphs of EMRAX 208 High Voltage. The only differences are the DC voltage and motor current. These two parameters can be read from the Technical data table for the EMRAX 208 Low and Medium Voltage motor.

Low Voltage motor needs 4 x higher motor current and 4 x lower DC voltage for the same power/torque and RPM, compared to EMRAX 208 High Voltage motor.

Medium Voltage motor needs 1.52 x higher motor current and 1/3 lower DC voltage for the same power/torque and RPM, compared to EMRAX 208 High Voltage motor.

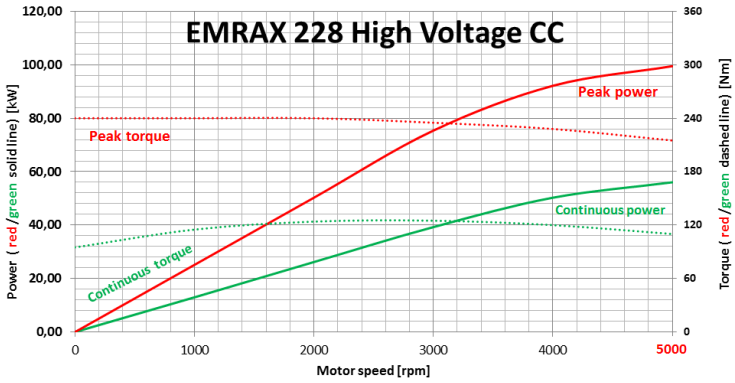
Graphs of the EMRAX 208 Liquid cooled (LC) and EMRAX 208 Air Cooled (CC):

Continuous power of the liquid cooled or air cooled motor is 20% lower than continuous power of the combined cooled motor. The peak power is the same. Data is presented in the Technical Data Table.

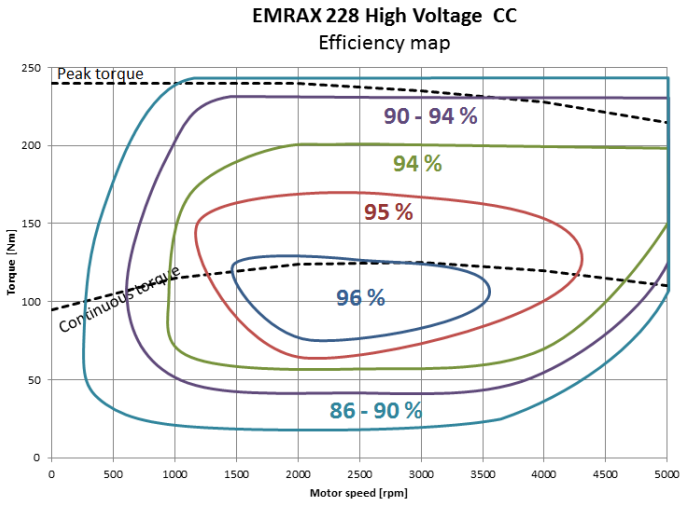
EMRAX 228 Technical Data Table (dynamometer test data)

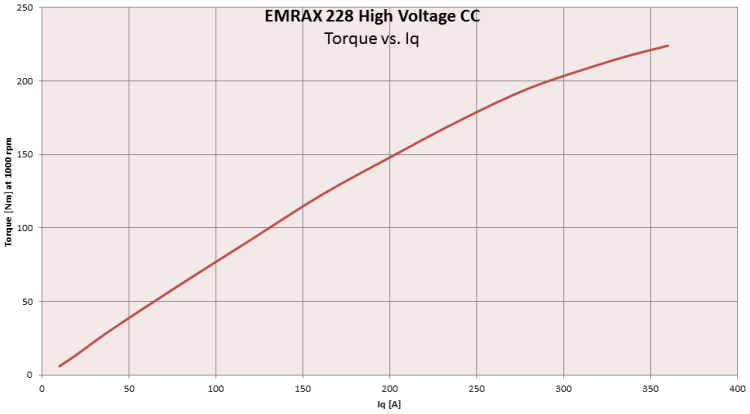
Type / Technical data	EMRAX 228 High Voltage			EMRAX 228 Medium Voltage			EMRAX 228 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Inlet Water/glycol Flow = WF; Ambient Air = AA) If inlet WF temperature and/or AA temperature are lower, then continuous power is higher.	AF=20m/s AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C
Weight [kg]	12,0	12,3	12,3	12,0	12,3	12,3	12,0	12,3	12,3
Diameter ø / width [mm]	228/86								
Maximal battery voltage [Vdc] and full load/no load RPM	670 Vdc (5300/6500 RPM)			470 Vdc (5170/6500 RPM)			130 Vdc (4400/5200 RPM)		
Peak motor power at max RPM (few min at cold start / few seconds at hot start) [kW]	**100**								
Continuous motor power (at 3000-5000 RPM) depends on the motor RPM [kW]	**28 - 42**	**28 - 42**	**35 - 55**	**28 - 42**	**28 - 42**	**35 - 55**	**28 - 42**	**28 - 42**	**35 - 55**
Maximal rotation speed [RPM]	**5500 (6500 RPM peak for a few seconds)**								
Maximal motor current (for 2 min if cooled as described in Manual) [Arms]	240			340			900		
Continuous motor current [Arms]	115			160			450		
Maximal motor torque (for a few seconds) [Nm]	**240**								
Continuous motor torque [Nm]	**125**								
Torque / motor current [Nm/1Aph rms]	1,1			0,75			0,27		
Maximal temperature of the copper windings in the stator and max. temperature of the magnets [°C]	120								
Motor efficiency [%]	92 – 98								
Internal phase resistance at 25 °C [mΩ]	18			8,0			1,12		
Input phase wire cross-section [mm²]	10,2			15,2			38		
Wire connection	star								
Induction in Ld/Lq [µH]	177/183			76/79			10,3/10,6		
Controller / motor signal	sine wave								
AC voltage between two phases [Vrms/1RPM]	0,0730			0,0478			0,0176		
Specific idle speed (no load RPM) [RPM/1Vdc]	9,8			14			40		
Specific load speed (depends on the controller settings) [RPM/1Vdc]	8 – 9,8			11 – 14			34 – 40		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100								
Magnetic flux – axial [Vs]	0,0542			0,0355			0,0131		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor inertia (mass dia=175mm, m=5,5kg) [kg*cm²]	421								
Bearings (front:back) - SKF/FAG	6206:6206 (for radial forces) or 6206:7206 (for axial-radial forces; for pull mode; focusing on very high axial load, e.g. air propeller) or 6206:3206 (for axial-radial forces; for pull-push mode, α=25°); other bearings are possible (exceptionally)								

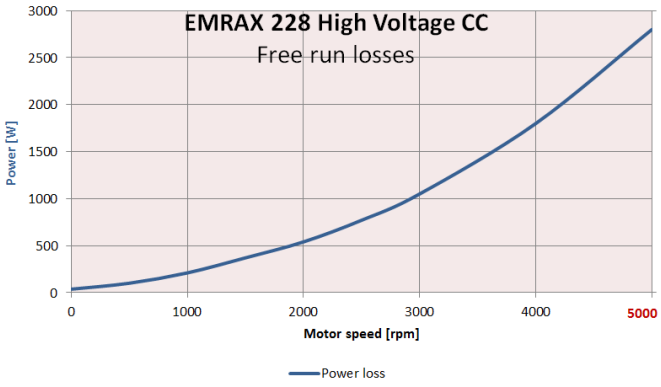
Graphs valid for EMRAX 228 High Voltage Combined Cooled (CC):



Note 1: for determening peak or continuous power (kW) you should choose motor speed and than read power from chosen power curve (in the left graph side)
Note 2: for determening peak or continuous torque (Nm) you should choose motor speed and than read torque from chosen torque curve (in the right graph side)







Graphs of the EMRAX 228 Medium and Low voltage motor type:
Graphs of EMRAX 228 Low Voltage and EMRAX 228 Medium Voltage are similar to graphs of EMRAX 228 High Voltage. The only differences are the DC voltage and motor current. These two parameters can be read from the Technical data table for the EMRAX 228 Low and Medium Voltage motor.
Low Voltage motor needs 4 x higher current and 4 x lower DC voltage for the same power/torque and RPM, compared to EMRAX 228 High Voltage motor.
Medium Voltage motor needs 1.52 x higher motor current and 1/3 lower DC voltage for the same power/torque and RPM, compared to EMRAX 228 High Voltage motor.

Graphs of the EMRAX 228 Liquid cooled (LC) and EMRAX 228 Air Cooled (CC):
Continuous power of the liquid cooled or air cooled motor is 20% lower than continuous power of the combined cooled motor. The peak power is the same. Data is presented in the Technical Data Table.

EMRAX 268 Technical Data Table (dynamometer test data)

Type / Technical data	EMRAX 268 High Voltage			EMRAX 268 Medium Voltage			EMRAX 268 Low Voltage or EMRAX 268 Low Voltage**		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Inlet Water/glycol Flow = WF; Ambient Air = AA) If inlet WF temperature and/or AA temperature are lower, then continuous power is higher.	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C
Weight [kg]	19,9	20,3	20,3	19,9	20,3	20,3	19,9	20,3	20,3
Diameter ø / width [mm]	268/91								
Maximal battery voltage [Vdc] and full load/no load RPM	700 Vdc (3200/3800 RPM)			680 Vdc (4700/5500 RPM)			130 Vdc (2300/2900 RPM) 250 Vdc (4500/5500 RPM)		
Peak motor power at max RPM (few min at cold start / few seconds at hot start) [kW]	**160**			**230**			**115 (at 2300 RPM load); 220 (at 4500 RPM load)**		
Continuous motor power (at 2000-4000 RPM) depends on the motor RPM [kW]	**40 - 75**	**40 – 80**	**50 - 85**	**40 - 80**	**40 – 90**	**50 - 110**	**40 - 75**	**40 – 80**	**50 - 90**
Maximal rotation speed [RPM]	**4500 RPM (5500 RPM peak for a few seconds)**								
Maximal motor current (for 2 min if it is cooled as described in Manual) [Arms]	270			400			1000		
Continuous motor current [Arms]	125			190			500		
Maximal motor torque (for a few seconds) [Nm]	**500**								
Continuous motor torque [Nm]	**250**								
Torque / motor current [Nm/1Aph rms]	2,0			1,4			0,5		
Maximal temperature of the copper windings in the stator and max. temperature of the magnets [°C]	120								
Motor efficiency [%]	92 - 98								
Internal phase resistance at 25 °C [mΩ]	26			11,5			1,7		
Input phase wire cross-section [mm²]	10,2			15,2			38		
Wire connection	star								
Induction in Ld/Lq [µH]	292/273			126/118			17/15,9		
Controller / motor signal	sine wave								
AC voltage between two phases [Vrms/1RPM]	0,126			0,0825			0,0304		
Specific idle speed (no load RPM) [RPM/1Vdc]	5,4			8,2			22,2		
Specific load speed (depends on the controller settings) [RPM/1Vdc]	4,5 – 5,4			7 – 8,2			18 - 22,2		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100								
Magnetic flux – axial [Vs]	0,1014			0,0664			0,0245		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor inertia (mass dia=195mm, m=9,8kg) [kg*cm²]	932								
Bearings (front:back) – SKF/FAG	6206:6206 (for radial forces) or 6206:7206 (for axial-radial forces; for pull mode; focusing on very high axial load , e.g. for air propeller) or 6206:3206 (for axial-radial forces; for pull-push mode, α=25°); other bearings are possible (exceptionally)								
EMARX 268 Very High Mechanical Loads (VHML)	6207:6207 (for radial forces) or 6207:7207 (for axial-radial forces; for pull mode; focusing on very high axial load, e.g. for air propeller) or 7206:3207 (for axial-radial forces; for pull-push mode, α=25°); other bearings are possible (exceptionally)								

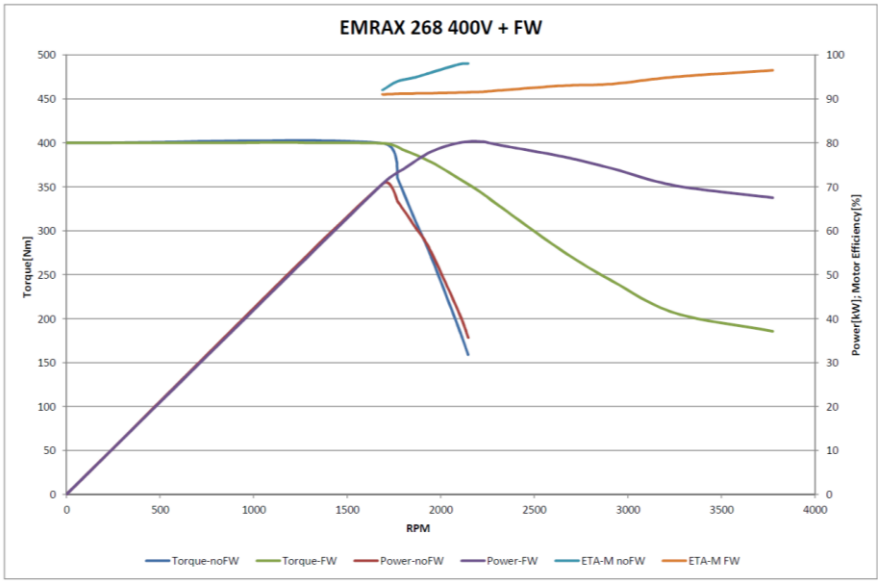
*EMRAX 268 VHML **Low Voltage** version always has 2 sequences of phase connectors (2x UVW).

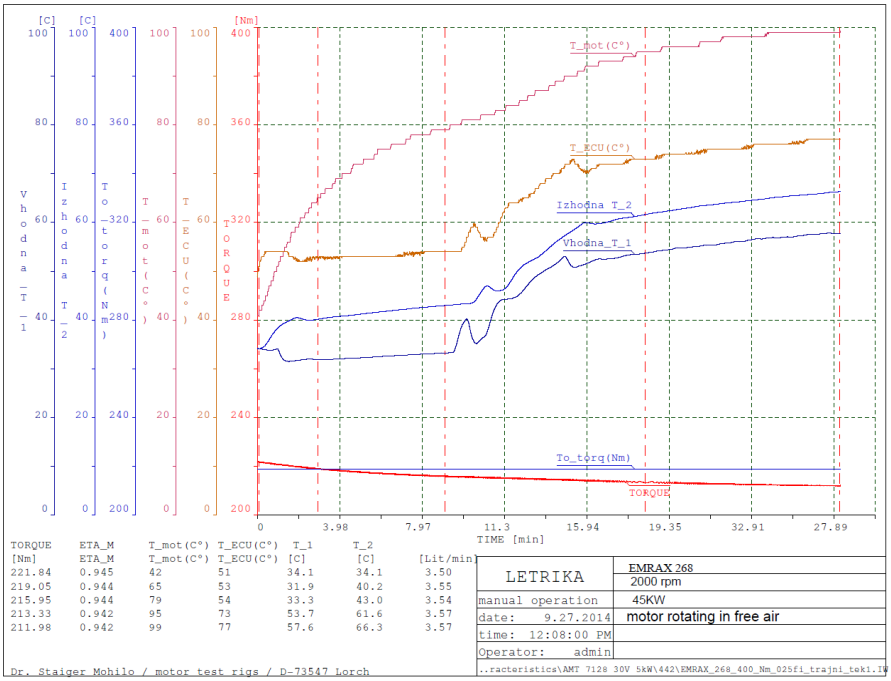
**Controller for EMRAX 268 Low Voltage motor should have very high peak and continuous motor current (1000 Arms peak and 500 Arms continuous). It is difficult to find such a high current controller in the global market. The most suitable is emDrive 500 from the Emsiso Company, which can deliver 500 Arms

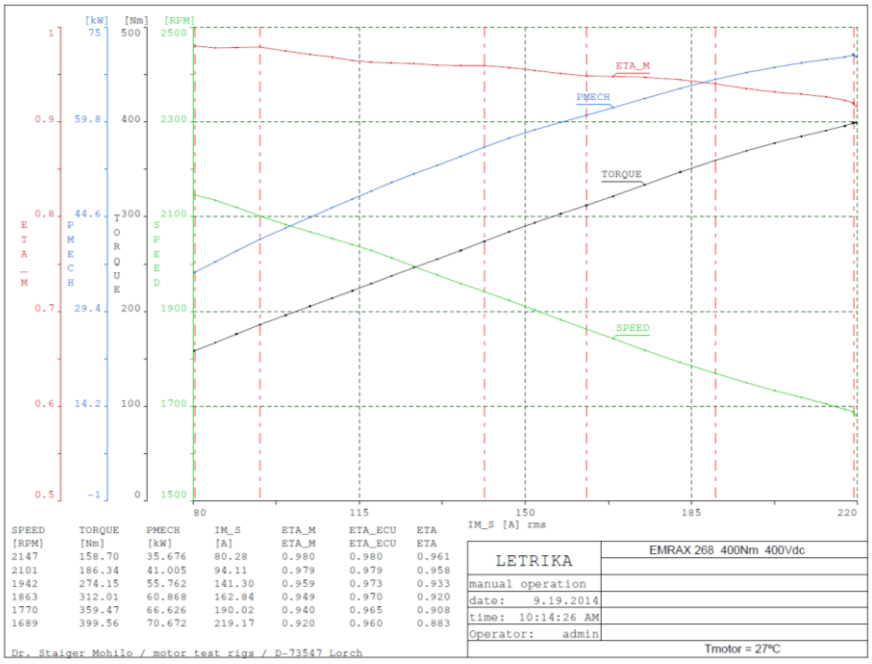
continuous and 800 Arms peak motor current. Another possibility to get a high enough motor current is to connect 1 motor with 2 controllers by using 2 set of phase connectors (2x UWV) on the motor. Winding correction with LV+50% mean 50% more winding turns on the coils, which bring the same speed (4500RPM)at doubled DC voltage. In this case EMRAX 268 can deliver even more than 200kWpeak power at ½ less motor current compared with LV motor.

Graphs valid for EMRAX 268 High Voltage Combined Cooled (CC):

Graphs were made from tests, which were made by Letrika d.d. in 2014. The motor was tested only up to 400 Nm of torque, because the opposite generator on the test bench generated only 400 Nm of torque. DC voltage from the batteries was 400 V, so we were able to run the EMRAX motor only at lower speed than the maximal motor speed. The motor was also tested with weakening magnetic field with special setting in the controller – in this case we achieve significantly higher speed at the same power. Water/glycol flow was only 3,5 l/min, but it should be 6-8 l/min as it is written in the Technical Data Table.



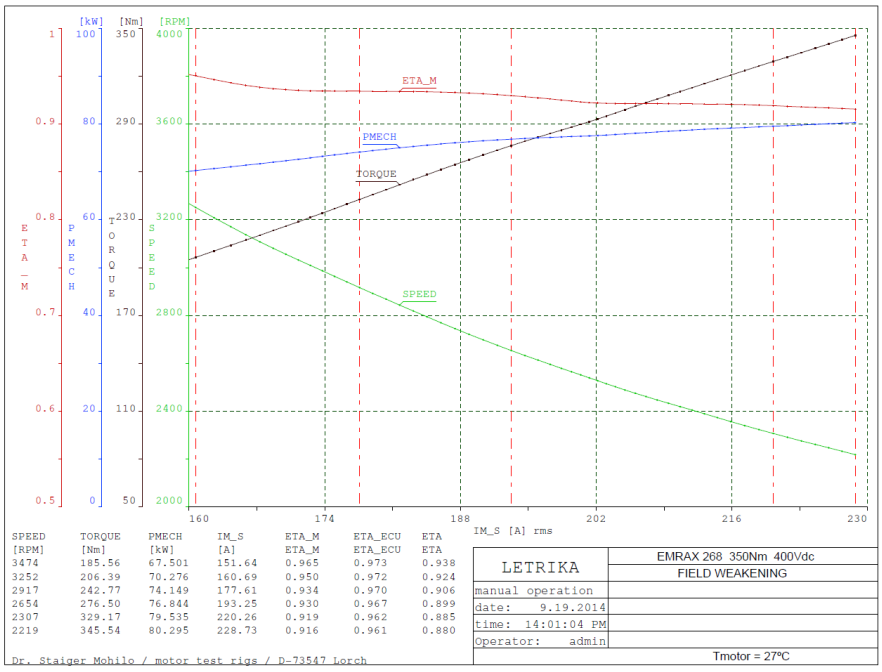




SPEED [RPM]	TORQUE [Nm]	PMECH [kW]	IM_S [A]	ETA_M	ETA_ECU	ETA
2147	158.70	35.676	80.28	0.980	0.980	0.961
2101	186.34	41.005	94.11	0.979	0.979	0.958
1942	274.15	55.762	141.30	0.959	0.973	0.933
1863	312.01	60.868	162.84	0.949	0.970	0.920
1770	359.47	66.626	190.02	0.940	0.965	0.908
1689	399.56	70.672	219.17	0.920	0.960	0.883

Dr. Staiger Mohilo / motor test rigs / D-73547 Lorch

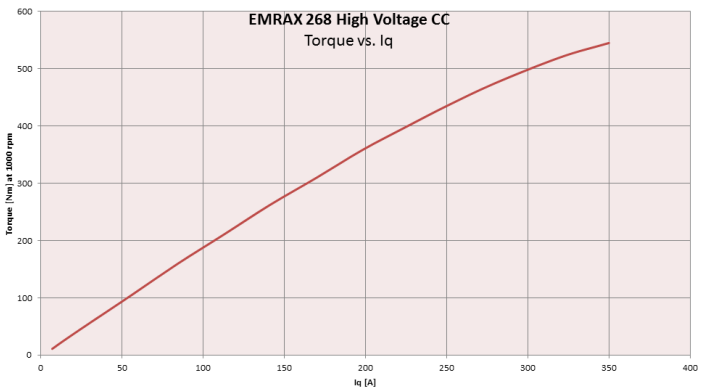
LETRIKA	EMRAX 268 400Nm 400Vdc
manual operation	
date: 9.19.2014	
time: 10:14:26 AM	
Operator: admin	
	Tmotor = 27°C

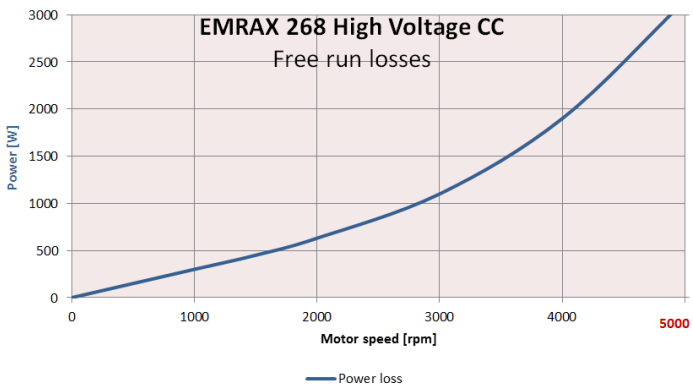


SPEED [RPM]	TORQUE [Nm]	PMECH [kW]	IM_S [A]	ETA_M	ETA_ECU	ETA
3474	185.56	67.501	151.64	0.965	0.973	0.938
3252	206.39	70.276	160.69	0.950	0.972	0.924
2917	242.77	74.149	177.61	0.934	0.970	0.906
2654	276.50	76.844	193.25	0.930	0.967	0.899
2307	329.17	79.535	220.26	0.919	0.962	0.885
2219	345.54	80.295	228.73	0.916	0.961	0.880

Dr. Staiger Mohilo / motor test rigs / D-73547 Lorch

LETRIKA	EMRAX 268 350Nm 400Vdc
	FIELD WEAKENING
manual operation	
date: 9.19.2014	
time: 14:01:04 PM	
Operator: admin	
	Tmotor = 27°C





Graphs of the EMRAX 268 Medium and Low voltage motor type:
Graphs of EMRAX 268 Low Voltage and EMRAX 268 Medium Voltage are similar to graphs of EMRAX 268 High Voltage. The only differences are in the DC voltage and motor current. These two parameters can be read from the Technical Data Table for the EMRAX 268 Low and Medium Voltage motor.
Low Voltage motor needs 4 x higher current and 4 x lower DC voltage for the same power/torque and RPM, compared to the EMRAX 268 High Voltage motor.
Medium Voltage motor needs 1.52 x higher motor current and 1/3 lower DC voltage for the same power/torque and RPM, compared to the EMRAX 268 High Voltage motor.

Graphs of the EMRAX 268 Liquid cooled (LC) and EMRAX 268 Air Cooled (CC):
Continuous power of the liquid cooled or air cooled motor is 20% lower than continuous power of the combined cooled motor. The peak power is the same. Data is presented in the Technical Data Table.

EMRAX 348 Technical Data Table

Technical data / Type	EMRAX 348 High Voltage			EMRAX 348 Medium Voltage			EMRAX 348 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**	**AC**	**LC**	**CC**
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Water/glycol Flow = WF – if inlet water/glycol temperature and/or ambient temperature are lower, then continuous power is higher)	AF=20m/s ; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s ; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s ; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C
Weight [kg]	39	40	40	39	40	40	39	40	40
Diameter ø / width [mm]	348/107								
Maximal battery voltage [Vdc] and full load/no load RPM	800 Vdc (1800/2200 RPM)			800 Vdc (2800/3400 RPM)			130 Vdc (1200/1500 RPM) 340 Vdc (3200/4000 RPM)		
Peak motor power at max RPM (few min at cold start / few seconds at hot start) [kW]	**190**			**290**			**125 kW (at 1200 RPM load #)** **330 kW (at 3200 RPM load ##)**		
Continuous motor power at load RPM [kW]	**90**	**100**	**100**	**140**	**150**	**170**	**70 at #; 170 at ##**	**70 at #; 180 at ##**	**80 at #; 200 at ##**
Maximal rotation speed [RPM]	4000 (with maximal battery voltage or magnetic field weakening)								
Maximal motor current (for 2 min if it is cooled as described in Manual) [Arms]	280			450			1100		
Continuous motor current [Arms]	140			210			550		
Maximal motor torque (for a few seconds) [Nm]	**1000**								
Continuous motor torque [Nm]	**500**								
Torque / motor current [Nm/1Aph rms]	**3,8**			**2,5**			**0,9**		
Cogging torque [Nm]	5								
Maximal temperature of the copper windings in the stator and max. temp. of the magnets [°C]	120								
Motor efficiency [%]	**92 - 98**								
Internal phase resistance at 25 °C [mΩ]	32			14			5		
Input phase wire cross-section [mm²]	10,2			15,2			38		
Wire connection	star								
Induction in Ld/Lq [µH]	418/452			180/195			24,3/26,3		
Controller / motor signal	sine wave								
AC voltage between two phases [Vrms/1RPM]	0,2320			0,1520			0,0560		
Specific idle speed (no load) [RPM/1Vdc]	**2,8**			**4,3**			**11,8**		
Specific - load speed (depends on the controller settings) [RPM/1Vdc]	**2,3 – 2,8**			**3,5 – 4,3**			**9,5 – 11,8**		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100 %								
Magnetic flux – axial [Vs]	N/A			N/A			N/A		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor inertia (mass dia=270 mm, m=20kg) [kg*cm²]	N/A								
Bearings (front:back) – SKF/FAG	6208:6208 (for radial forces) or 6208:7208 (for axial-radial forces; for pull mode; focusing on very high axial load, e.g. air propeller) or 7208:3208 (for axial-radial forces; for pull-push mode, α=25°); other bearings are possible (exceptionally)								

*Controller for EMRAX 348 Low Voltage should have very high peak and continuous motor current (1100 Arms peak and 550 Arms continuous). It is difficult to find such a high current controller in the global market. The most suitable would be the emDrive 500 from the Emsiso Company, which has 500 Arms continuous and 800 Arms peak motor current. Another possibility to get a high enough motor current is to connect 1 motor with 2 controllers by using 2 set of phase

connectors (2x UWV) on the motor. Winding correction with LV+50% mean 50% more winding turns on the coils, which bring the same speed (4000RPM)at doubled DC voltage (700Vdc). In this case EMRAX 348 can deliver even more than 300kWpeak power at ½ less motor current compared with LV motor.

2. Intended usage of the EMRAX motor/generator

Before selling the EMRAX motor, every EMRAX is tested at standard ambient and motor cooling conditions (described in Technical Data Tables) in our Company, operating as a generator and as a motor with the Unitek GmbH BAMOCAR D3 controller.

The drive is built according to the state of the art and approved safety-related rules. However, dangerous situations for the user or other parties as well as damages to the device or other material assets can arise.

Only use the system in technical soundness, safety-conscious, according to the intended usage and be aware of dangers! Especially faults that can affect safety should be cleared immediately!

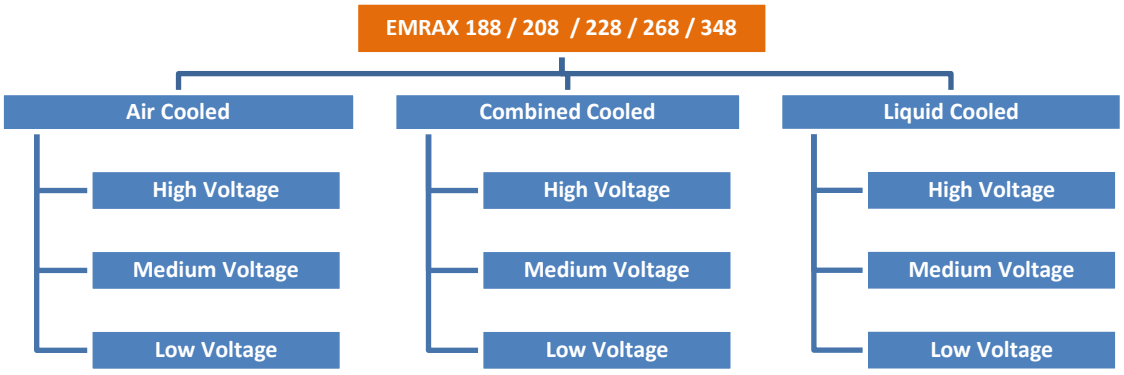
Avoid full throttle idle running at higher voltages. Speed (motor rotation) must be limited by the controller SW according to the Technical Data Table for each EMRAX type.

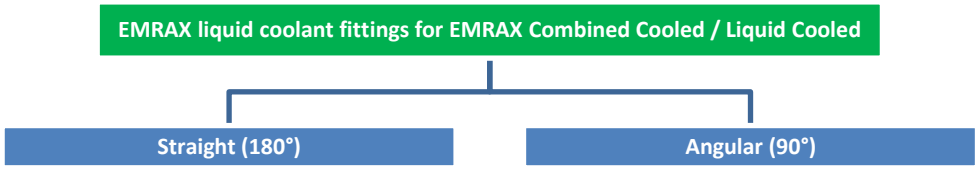
The EMRAX motor must be used in accordance with the ambient and motor cooling conditions, which are described in the Technical Data Table for each EMRAX motor type, otherwise the warranty does not apply.

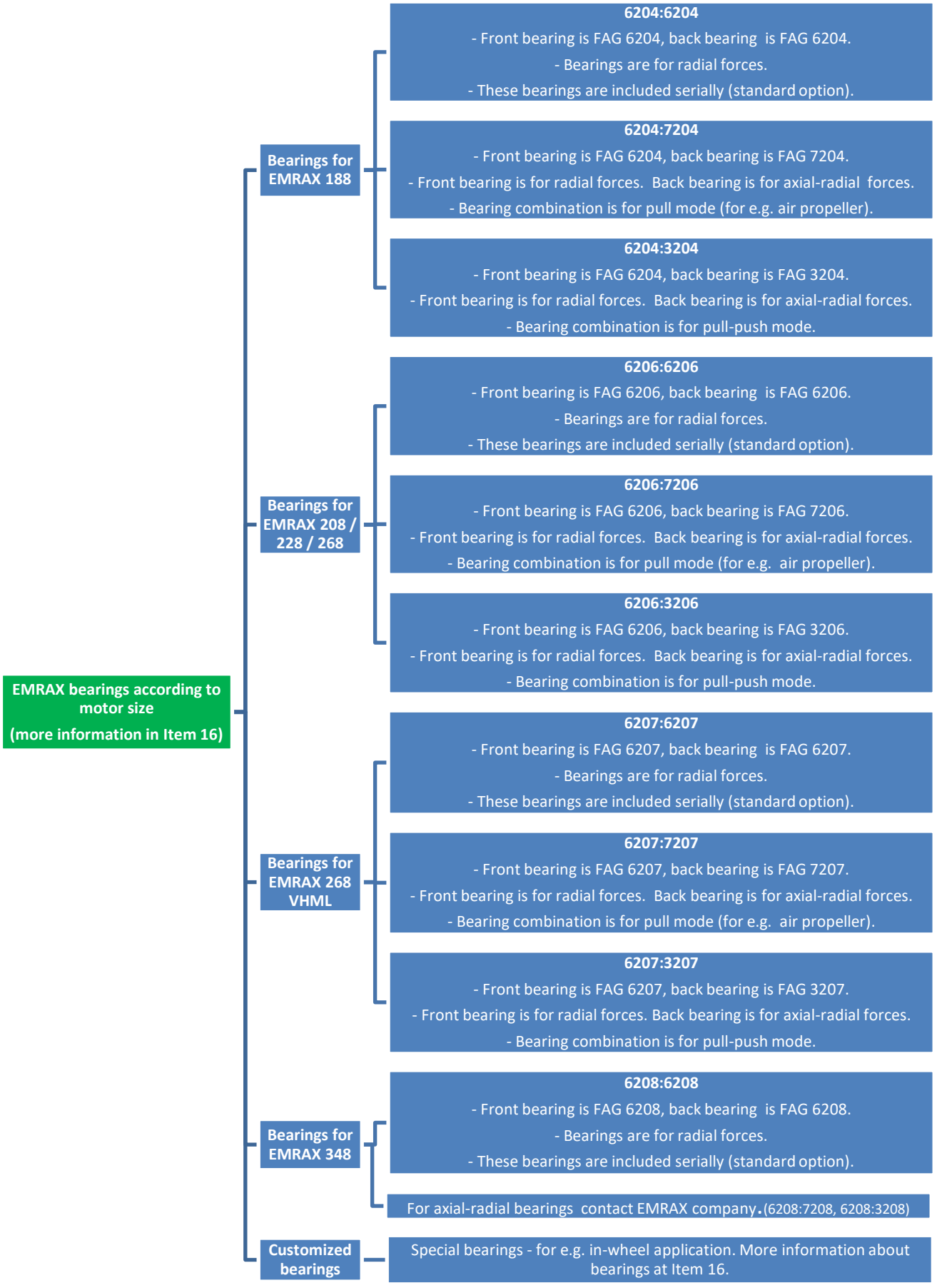
Do not to use the motor in direct salt environment.

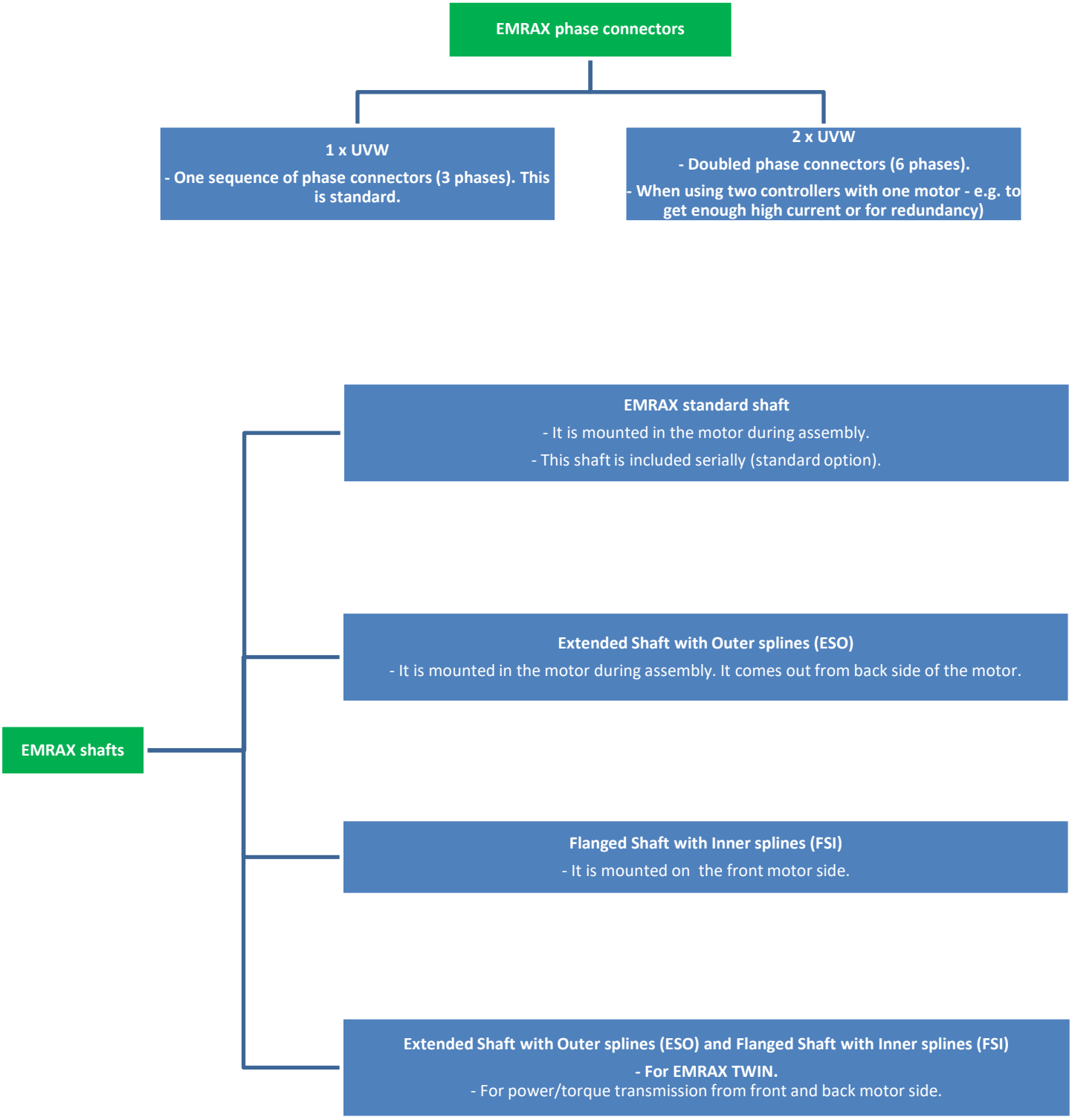
3. Motor types and additional motor parts

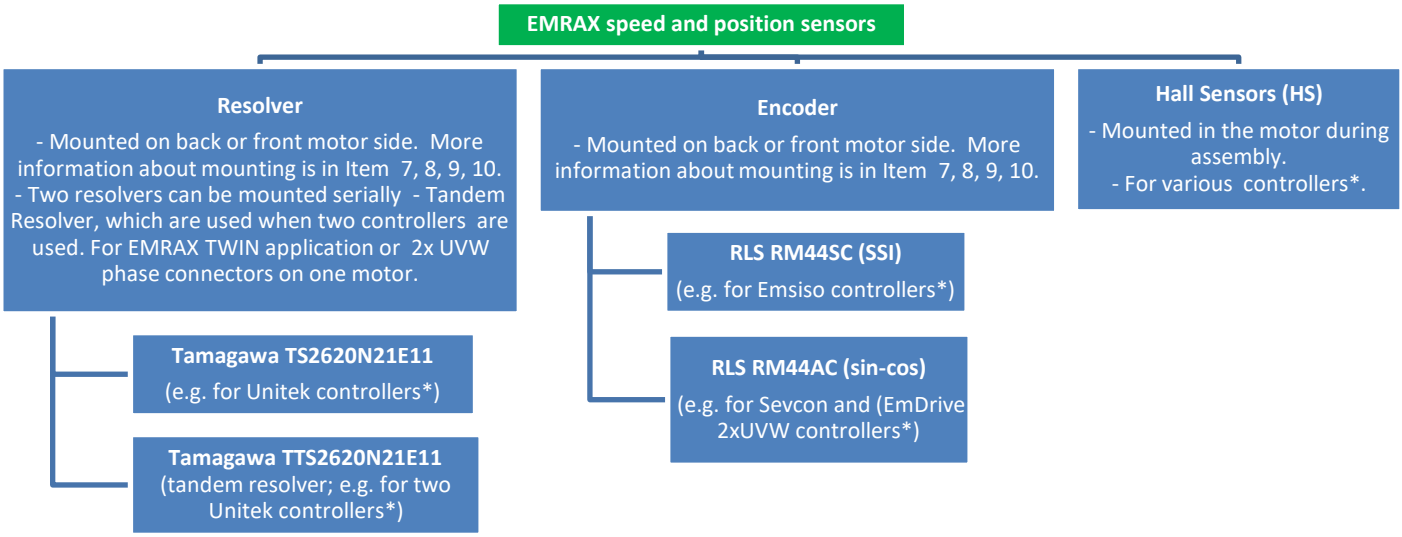
The EMRAX motor family consists of 5 different motor sizes: 188 mm, 208 mm, 228 mm, 268 mm and 348 mm diameter. Each motor size can be air, combined or liquid cooled and each of them can also be made for high, medium or low voltage system.





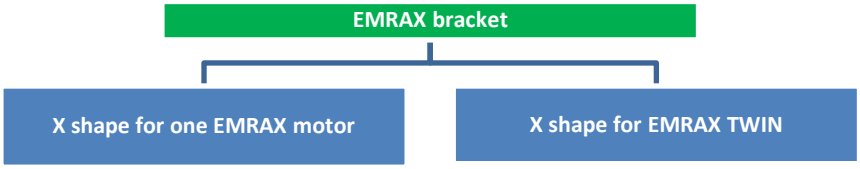

EMRAX bearings according to motor size
(more information in Item 16)
Bearings for EMRAX 188
6204:6204
- Front bearing is FAG 6204, back bearing is FAG 6204.
- Bearings are for radial forces.
- These bearings are included serially (standard option).
6204:7204
- Front bearing is FAG 6204, back bearing is FAG 7204.
- Front bearing is for radial forces. Back bearing is for axial-radial forces.
- Bearing combination is for pull mode (for e.g. air propeller).
6204:3204
- Front bearing is FAG 6204, back bearing is FAG 3204.
- Front bearing is for radial forces. Back bearing is for axial-radial forces.
- Bearing combination is for pull-push mode.
Bearings for EMRAX 208 / 228 / 268
6206:6206
- Front bearing is FAG 6206, back bearing is FAG 6206.
- Bearings are for radial forces.
- These bearings are included serially (standard option).
6206:7206
- Front bearing is FAG 6206, back bearing is FAG 7206.
- Front bearing is for radial forces. Back bearing is for axial-radial forces.
- Bearing combination is for pull mode (for e.g. air propeller).
6206:3206
- Front bearing is FAG 6206, back bearing is FAG 3206.
- Front bearing is for radial forces. Back bearing is for axial-radial forces.
- Bearing combination is for pull-push mode.
Bearings for EMRAX 268 VHML
6207:6207
- Front bearing is FAG 6207, back bearing is FAG 6207.
- Bearings are for radial forces.
- These bearings are included serially (standard option).
6207:7207
- Front bearing is FAG 6207, back bearing is FAG 7207.
- Front bearing is for radial forces. Back bearing is for axial-radial forces.
- Bearing combination is for pull mode (for e.g. air propeller).
6207:3207
- Front bearing is FAG 6207, back bearing is FAG 3207.
- Front bearing is for radial forces. Back bearing is for axial-radial forces.
- Bearing combination is for pull-push mode.
Bearings for EMRAX 348
6208:6208
- Front bearing is FAG 6208, back bearing is FAG 6208.
- Bearings are for radial forces.
- These bearings are included serially (standard option).
For axial-radial bearings contact EMRAX company.(6208:7208, 6208:3208)
Customized bearings
Special bearings - for e.g. in-wheel application. More information about bearings at Item 16.


EMRAX phase connectors
1 x UVW
- One sequence of phase connectors (3 phases). This is standard.
2 x UVW
- Doubled phase connectors (6 phases).
- When using two controllers with one motor - e.g. to get enough high current or for redundancy)
EMRAX shafts
EMRAX standard shaft
- It is mounted in the motor during assembly.
- This shaft is included serially (standard option).
Extended Shaft with Outer splines (ESO)
- It is mounted in the motor during assembly. It comes out from back side of the motor.
Flanged Shaft with Inner splines (FSI)
- It is mounted on the front motor side.
Extended Shaft with Outer splines (ESO) and Flanged Shaft with Inner splines (FSI)
- For EMRAX TWIN.
- For power/torque transmission from front and back motor side.



With RMS controllers goes 5 pole pair Tamagawa resolver **TS2620N1095E161**

*For more information about suitable sensors, for each controller, contact the controller producer.



4. Order codes, tariff (HTS) codes, weights of EMRAX motors and additional motor parts

Sample of order code: EMRAX_228_HV_LC(IP65)_ R _TS_180

Item code:	Explanation:	Weight (kg)	Tariff (HTS) codes and description
EMRAX	Motor name	**7 / 9 / 12 / 20 / 40**	**8501.52.9; electric motor**
188 / 208 / 228 / 268 / 348	Motor diameter in mm		
LV / MV / HV	Voltage type (**L**ow **V**oltage / **M**edium **V**oltage / **H**igh **V**oltage)		
LC(IP65) / CC(IP21) / AC(IP21)	**L**iquid **C**ooled (**IP65**) / **C**ombined **C**ooled (**IP21**) / **A**ir **C**ooled (**IP21**)		
R	Bearings for radial forces.		
P	Front bearing is for radial forces. Back bearing is for axial-radial forces, focusing on very high axial load. Bearing combination is for **pull mode**. For e.g. air propeller.		
PP	Front bearing is for radial forces. Back bearing is for axial-radial forces. Bearing combination is for **pull-push mode**.		
2xUVW	2 sequences of phase connectors (6 motor phases). When using one motor with two controllers to get a high enough current.		
VHML	Bearings and motor shaft made for Very High Mechanical Loads (VHML). Stronger bearings and stronger shaft. Possible only for EMRAX 268.		
TS(back)	Resolver Tamagawa 1PP: **TS2620N21E11** (e.g. for Unitek Bamocar D3 controller). And Tamagawa 5PP: **TS2620N1095E161** (e.g. RMS controller) with bracket mounted on back side of the motor.	0,2	**9031.80.98; speed and position sensor**
TS(front)	Resolver **TS2620N21E11 or TS2620N1095E161** mounted on the front motor side by a special bracket. This bracket has to be connected with X shape bracket, which is mounted on the back motor side. Special bracket, X shape bracket and connecting parts are included.	0,3	

TTS	**T**andem resolver **TS2620N21E11** (e.g. for two Unitek Bamocar D3 controllers) with bracket mounted on the back side of the motor. For EMRAX TWIN (mounted on back side of the second motor) and when using two controllers with one motor (in this case two sequences of phase connectors are needed; 2xUVW).	0,3	
RLS RM44SC(back)	Encoder **RLS RM44SC** (SSI; e.g. for Emsiso controller) with bracket mounted on back side of the motor.	0,2	
RLS RM44SC(front)	Encoder **RLS RM44SC** (SSI; e.g. for Emsiso controller) mounted on the front motor side by a special bracket. This bracket has to be connected with X shape bracket, which is mounted on the back motor side. Special bracket, X shape bracket and connecting parts are included.	0,3	
RLS RM44AC(back)	Encoder **RLS RM44AC** (sin-cos; e.g. for Sevcon controller) with bracket mounted on back side of the motor. Encoder **RLS RM44AC** (sin-cos; e.g. for EmDrive controller) with bracket for 2xUVW phase connectors	0,2	
RLS RM44AC(front)	Encoder RLS RM44AC (sin-cos; e.g. for Sevcon controller, EmDrive for 2xUVWmotor connectors) mounted on the front motor side by a special bracket. This bracket has to be connected with X shape bracket, which is mounted on the back motor side. Special bracket, X shape bracket and connecting parts are included.	0,3	
HS	**H**all **S**ensors mounted inside the motor. Suitable for Emsiso (EmDrive) controllers; cable length is 0,6m.	0,2	
180	Coolant fittings - **180°** (straight tubes). Two in one package (for 1 motor).	0,1	**7411.21.90; coolant fittings**
90	Coolant fittings - **90°** (angular tubes). Two in one package (for 1 motor).	0,1	
ESO	**E**xtended motor **S**haft with **O**uter splines comes out from back motor side (mounted in the motor during assembly). Possibilities for mounting the sensors: **- Resolver / encoder should be mounted on the front motor side by a special bracket, which can be ordered at EMRAX Company.** **- Resolver / encoder can be mounted on the tailored elongated shaft (adapter shaft), which is added to ESO. Resolver / encoder is mounted after drive wheel (for pulley, chain etc.) at the end of adapter shaft by tailor made bracket, which has to be provided by a customer.** **- A special resolver / encoder with bigger internal diameter of the rotor can be mounted on the ESO. This special sensor* has to be provided by a customer.** **- Instead of resolver / encoder hall sensors can be used.** * Resolvers / encoders with bigger inner diameter of the rotor are bigger and a lot more expensive. These bigger sensors also need more space for mounting.	1,1	**8483.10.95; shaft**
FSI	**F**langed **S**haft with **I**nner splines is mounted on front motor side.	0,6	
ESO and FSI	**E**xtended motor **S**haft with **O**uter splines comes out from back motor side (mounted in the motor during assembly) and **F**langed **S**haft with **I**nner splines is mounted on front motor side. **In case both shafts are mounted in one motor:** **- Hall sensors should be used.** **- Resolver / encoder is mounted at the end of tailored elongated shaft (adapter shaft) after the drive wheel (for pulley, chain etc.) on the back or front motor side (on the FSO or ESO) by using a tailor made bracket. This adapter shaft and bracket have to be provided by a customer.** **- A special resolver / encoder with bigger internal diameter of the rotor can be mounted on the ESO. This special sensor* has to be provided by a customer.** * Resolvers / encoders with bigger inner diameter of the rotor are bigger and a lot more expensive. These bigger sensors also need more space for mounting. **In case of EMRAX TWIN:** **- In case using ESO in the second motor both motors should use hall sensors.** **- Tandem resolver (TSS) or encoder can be mounted at the end of tailored elongated shaft (adapter shaft) after the drive wheel (for pulley, chain etc.) on the back or front motor side (on ESO or FSI) by a tailor made bracket. Tailored shaft and bracket have to be provided by a customer.** **- Special tandem resolver or encoder with bigger internal diameter of the rotor can be mounted on the ESO. These special sensors* have to be provided by a customer.** * Resolvers / encoders with bigger inner diameter of the rotor are bigger and a lot more expensive. These bigger sensors also need more space for mounting.	1,7	
X	X shaped iron bracket. For one motor 1 pc is needed. For EMRAX TWIN 2 pcs are needed.	1	**7326.90.98; steel bracket**

5. 3D drawings of EMRAX motors

EMRAX 3D drawings, base URF files, pdf files with tech data tables for encoders, resolvers, and Hall Sensor can be downloaded from www.emrax.com

6. Mounting the motor

Only use the drive if properly mounted on threaded bores intended for in the stator. Take a look at EMRAX drawings, where you can see mounting holes for each EMRAX model. EMRAX has an external rotor, which must not under any condition, not even for testing, be connected to the frequency converter or the power source, if the motor is not fixed in the manner described above. Propeller, Flanged Shaft with Inner Splines (FSI) some other drive shaft can be mounted on the front motor side with sixM8/M10 threaded bores intended for in the rotor. These screws must be screwed down into the rotor:

- at least 14 mm and not more than 15 mm – for EMRAX 188 (M6 threaded boreholes)
- at least 15 mm and not more than 16,0 mm - for EMRAX 208 (M8 threaded boreholes)
- at least 15,5 mm and not more than 16,5 mm - for EMRAX 228 (M8 threaded boreholes)
- at least 17,5 mm and not more than 18,5 mm - for EMRAX 268 (M8 threaded boreholes)
- at least 27 mm and not more than 28 mm – for EMRAX 348 (M10 threaded boreholes)

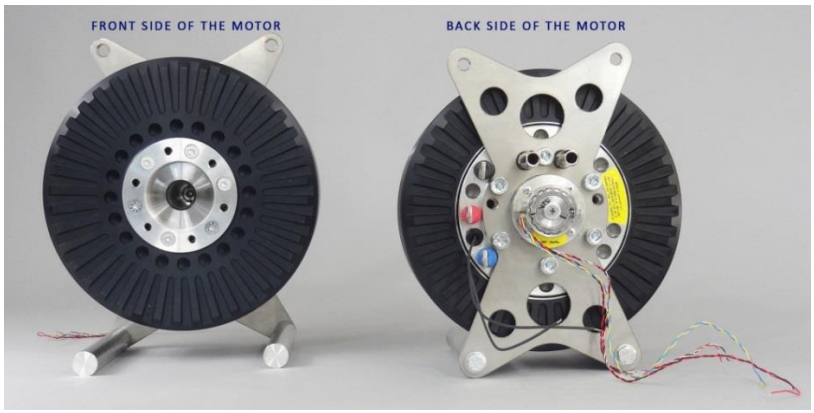


Figure 14: Mounting holes on front and back side of the motor

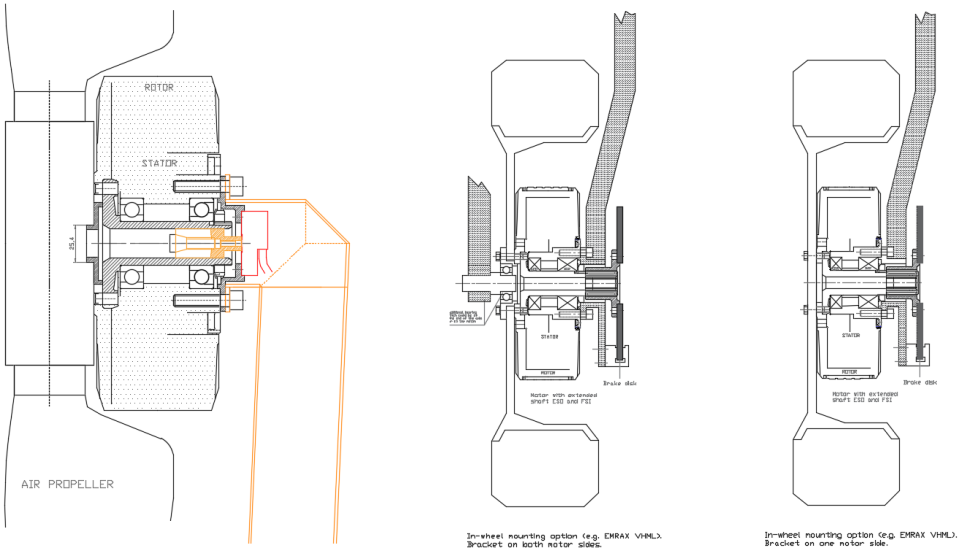


Figure 15: Mounting options (air propeller / in-wheel)

Brackets for mounting EMRAX motors are X shape brackets or they can be custom made. The X shape bracket is available for any motor size. It is made from stainless steel. Two X shape brackets can be connected together and used for mounting the EMRAX TWIN.

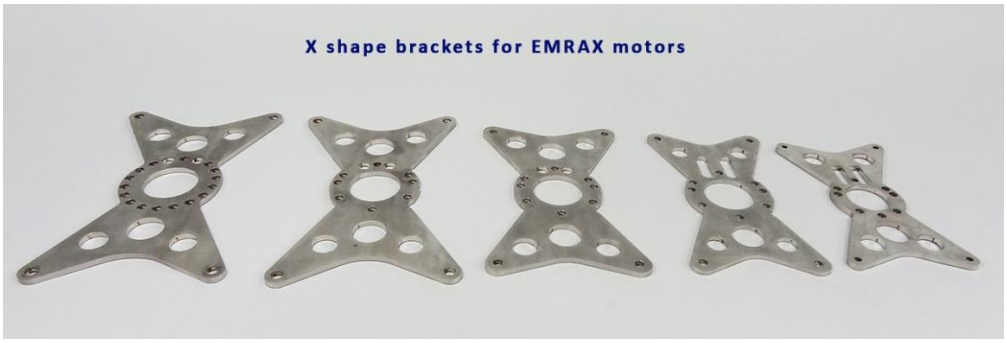


Figure 16: X shape brackets for EMRAX motors

7. Power/torque transmission and shafts

Every EMRAX motor has a serially included standard shaft. In this case the power/torque must be transmitted by using flanged shaft on the front motor side. All shafts for EMRAX motors are hollow. Therefore EMRAX motors have trough-shaft mounting and stacking capability.

The motor power/torque transmission can be made from the front side and/or back side of the motor:

- If the power/torque transmission is from front side of the motor, then the Flanged Shaft with Inner splines (FSI) is needed. It can be ordered from the EMRAX Company or the customer provides it in case custom made splines are needed (inner, outer etc.). The shaft is mounted on the front motor side with six screws (M6/M8/M10 – depends on the motor size).
- If the power/torque transmission is from back side of the motor the customer needs the Extended motor Shaft with Outer splines (ESO). It can be ordered from the EMRAX Company. If the custom made shaft is needed, the customer can provide it. In this case the extended motor shaft from back motor side must be sent to the EMRAX Company before the motor assembly (this shaft has to be made precisely for EMRAX motors according to drawings, which are sent to customer by email). Before sending the shaft the customer must contact the EMRAX Company.

  !Note: If the extended shaft from back motor side is used the six screws (M6/M8/M10 – depending on the motor size) must be screwed down into the rotor on the front side of the motor, because they carry the torque from the rotor disks to the extended shaft. Screws must be screwed down in the rotor as it is described in Item 6.

  !Note: If the power/torque transmission is from the back motor side ESO should be mounted in the motor during motor assembly. Possibilities for mounting the sensors in case of ESO:

  - Resolver / encoder should be mounted on the front motor side by a special bracket, which can be ordered at EMRAX Company.

- Resolver / encoder can be mounted on the tailored elongated shaft (adapter shaft), which is added to ESO. Resolver / encoder is mounted after drive wheel (for pulley, chain etc.) at the end of adapter shaft by tailor made bracket, which has to be provided by a customer.

- A special resolver / encoder with bigger internal diameter of the rotor can be mounted on the ESO. This special sensor* has to be provided by a customer.

- Instead of resolver / encoder hall sensors can be used.

* Resolvers / encoders with bigger inner diameter of the rotor are bigger and a lot more expensive. These bigger sensors also need more space for mounting.

- If the motor power/torque transmission is from the front and back motor side, then the motor needs a flanged shaft with 6 inner splines (FSI) from the front motor side and an extended motor shaft (ESO) from back motor side. These shafts can be ordered from the EMRAX Company. If custom made shafts are needed, the customer can be provided with them – in this case the extended motor shaft from back motor side must be send to the EMRAX Company before the motor assembly (this shaft has to be made precisely for our motors according to drawings that are sent to the customer). Before sending the shaft the customer must contact the EMRAX Company.

  !Note: If the power/torque transmission is from front and back motor side ESO should be mounted during motor assembly and FSI should be mounted afterwards on the front motor side.
  Possibilities for mounting the sensors in case of ESO and FSI:

  - Hall sensors should be used.

  - Resolver / encoder is mounted at the end of tailored elongated shaft (adapter shaft) after the drive wheel (for pulley, chain etc.) on the back or front motor side (on the FSO or ESO) by using a tailor made bracket. This adapter shaft and bracket have to be provided by a customer.

  - A special resolver / encoder with bigger internal diameter of the rotor can be mounted on the ESO. This special sensor* has to be provided by a customer.

  * Resolvers / encoders with bigger inner diameter of the rotor are bigger and a lot more expensive. These bigger sensors also need more space for mounting.

Figure 17: EMRAX transmission shafts

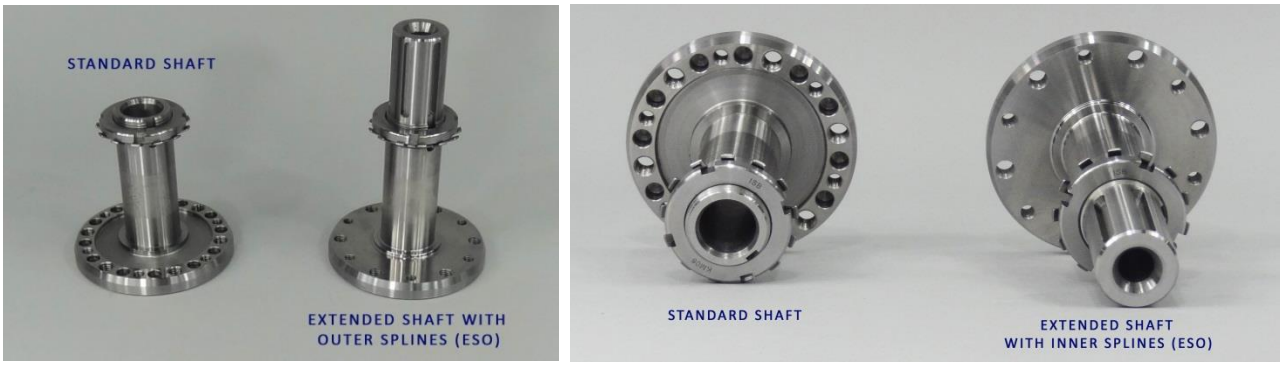


Figure 18: Standard motor shaft vs. extended shaft with outer splines (ESO)

Figure 19: ESO and FSI

Figure 20: Standard motor shaft vs. EMRAX 268 VHML shaft

Figure 21: FSI

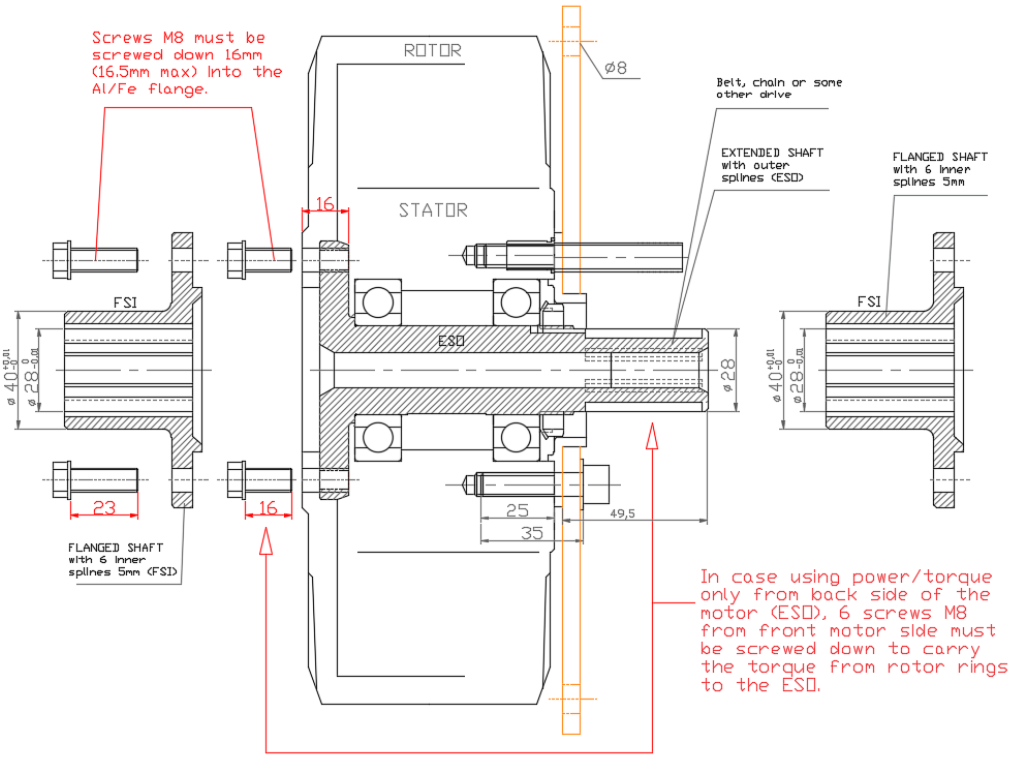


Figure 22: EMRAX with ESO and FSI

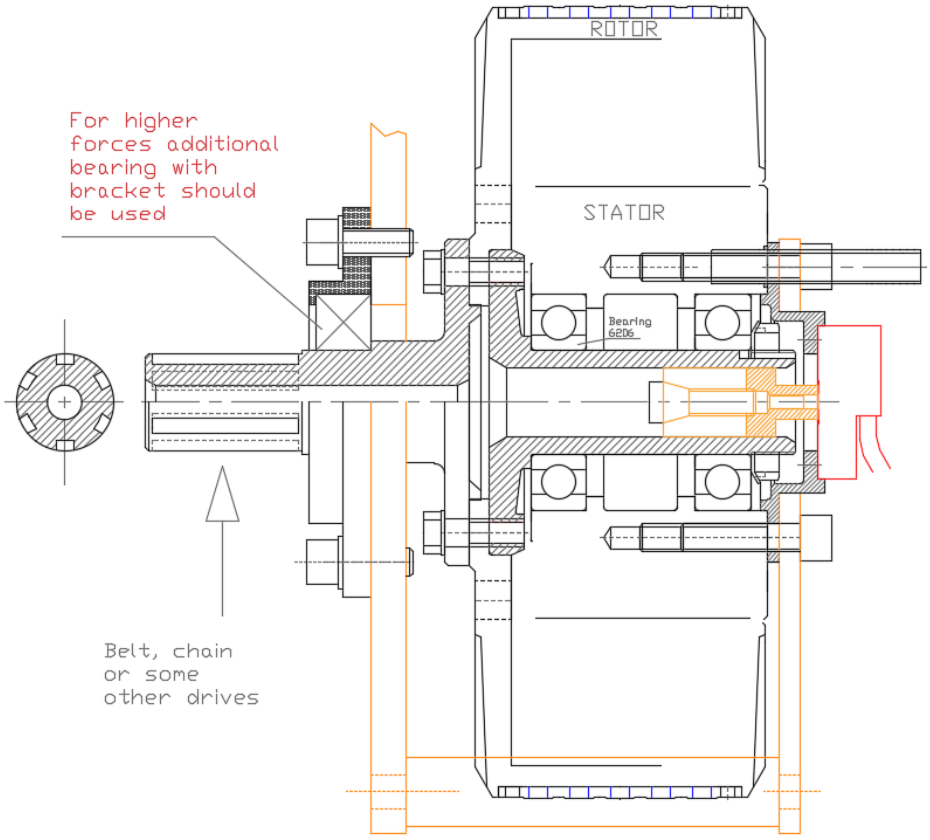


Figure 23: Power/torque transmission from front motor side

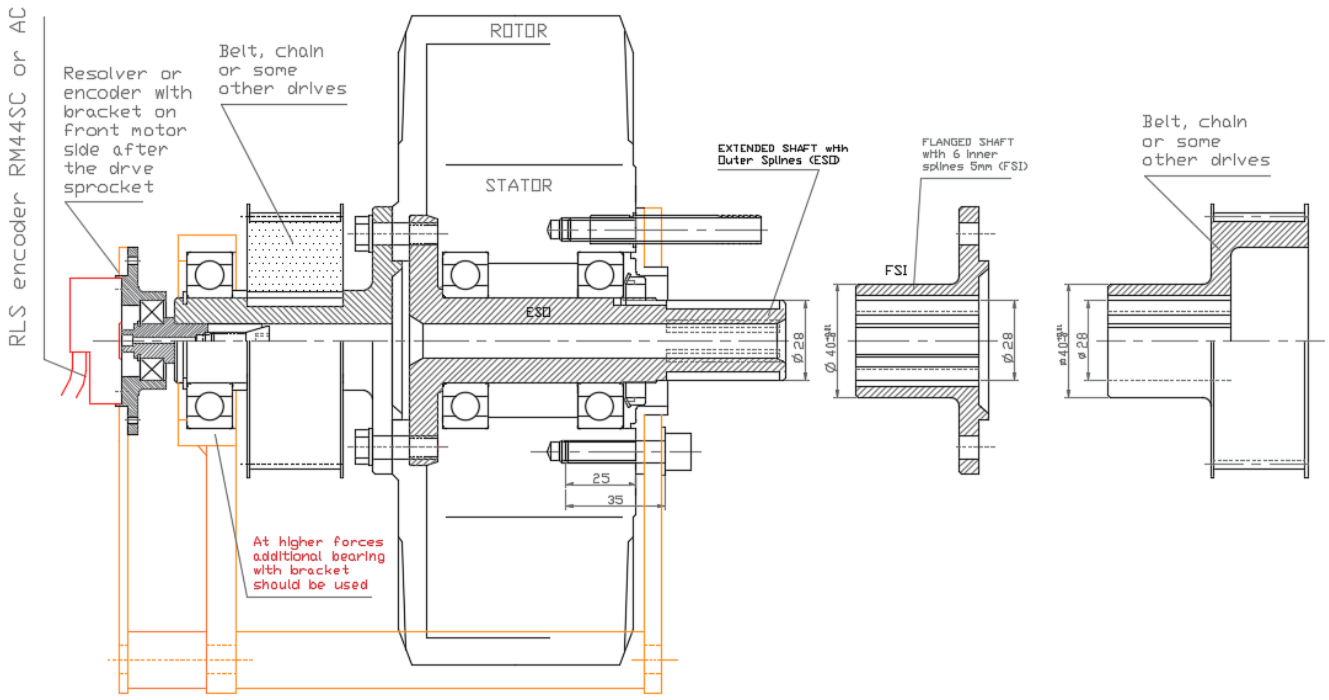


Figure 24: Power/torque transmission from front (FSI) and/or back motor side (ESO)

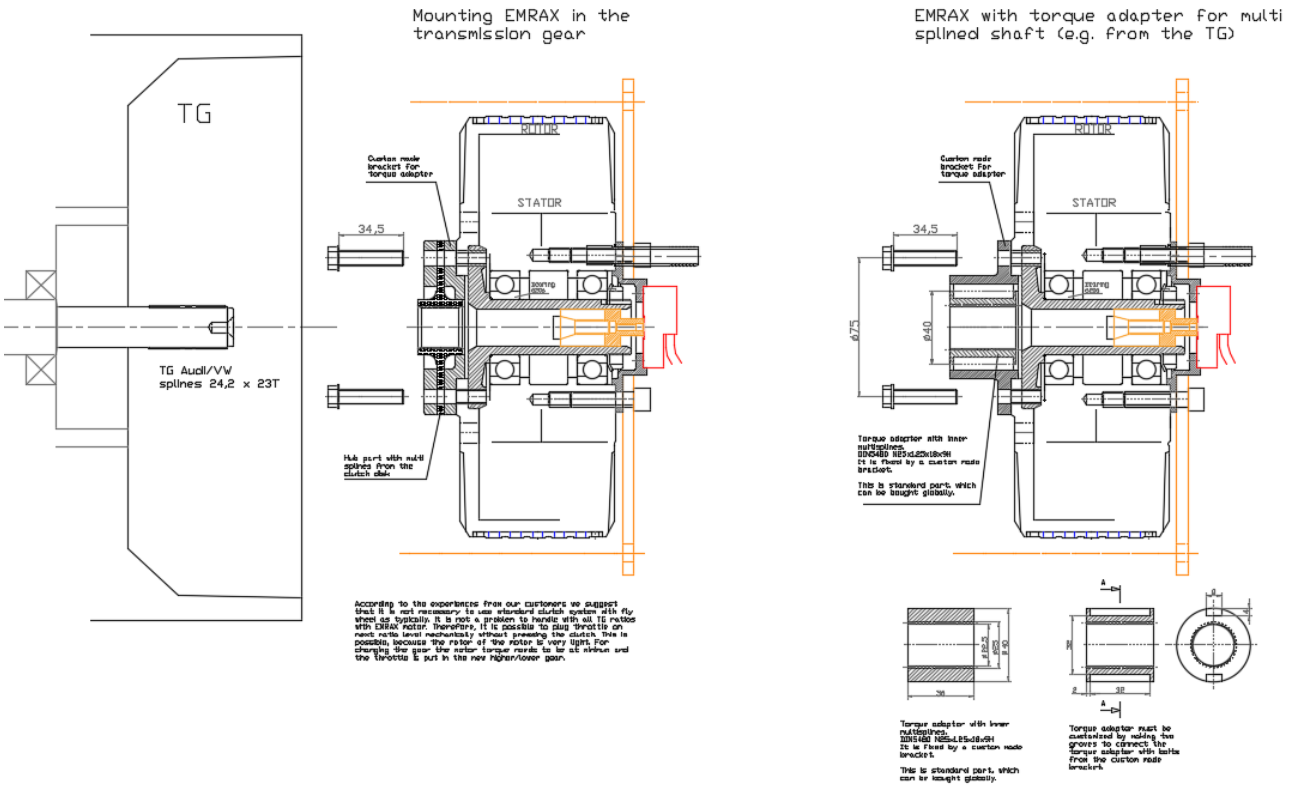


Figure 25: Power/torque transmission from front motor side to the transmission gear

The extended motor shaft and the standard motor shaft cannot be replaced once the motor is assembled.
Emrax shafts are made from hardened steel (42CrMo4QT).

If custom made shafts are needed, customer can provide a shaft, which must be made precisely according to EMRAX drawings. The customer can provide a motor shaft or an extended motor shaft. The shaft dimensions must be discussed with the EMRAX Company before sending the shaft and mounting it in the motor during assembly. The customer can also make a special flanged shaft for the motor (e.g. with special splines). Another option is to use standard torque adapter (globally available) and mount it in on the front side of the motor by using special brackets.

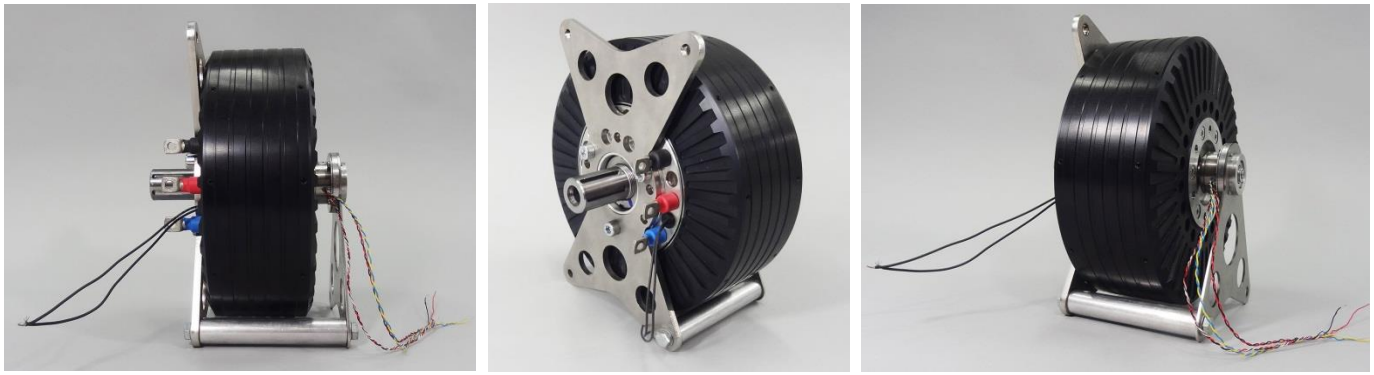


Figure 26: Motor with extended shaft from back motor side

8. Controlling direction, position and rotation speed of EMRAX motors

a) Drive control with sensor:
- For controlling direction, position and rotation speed of the motor a sensor should be used. Sensor types that can be used are: resolvers, encoders or hall sensors.
- Sensors must be used for e.g. electric vehicles and propellers that have to stop at the exact position (glider planes, where the propeller has to be put into the fuselage).
- Resolver/encoder has to be precisely mounted onto the motor by a special bracket. Hall sensors have to be mounted in the motor during assembly of the motor. Sensors with brackets can be ordered from the EMRAX Company, where they are also mounted. If sensors are not mounted in the EMRAX Company no warranty applies.

!Note:
- It is important that auto tuning (synchronising the electrical and mechanical motor angle) and pre-setting of controller software is done first. Here is a video, which shows auto-tuning EMRAX motor with Unitek controller: https://youtu.be/yuyPS_RCWQ8
- For every motor one sensor (encoder/resolver/hall sensors) is needed if the motor is used with one controller. When one motor is used with two controllers (2 sequences of motor phase connectors – 2xUVW) then two sensors should be used (e.g. tandem resolver). This is when a very high motor current has to be ensured. **Hall Sensors** doesn't goes with doubled 2xUVW connectors.
- In case EMRAX with 2xUVW and controller EmDrive from Emsiso is needed the position sensor – the encoder RM44AC type.
- For the EMRAX TWIN application two sensors (tandem resolver mounted on the second motor) and two controllers are needed to fit each motor. Some controllers (rare controllers) have an option to split the signal from two controllers in only one sensor (usually encoder), which is mounted on the second motor.
- For more information about sensors, please consult with the controller producers.

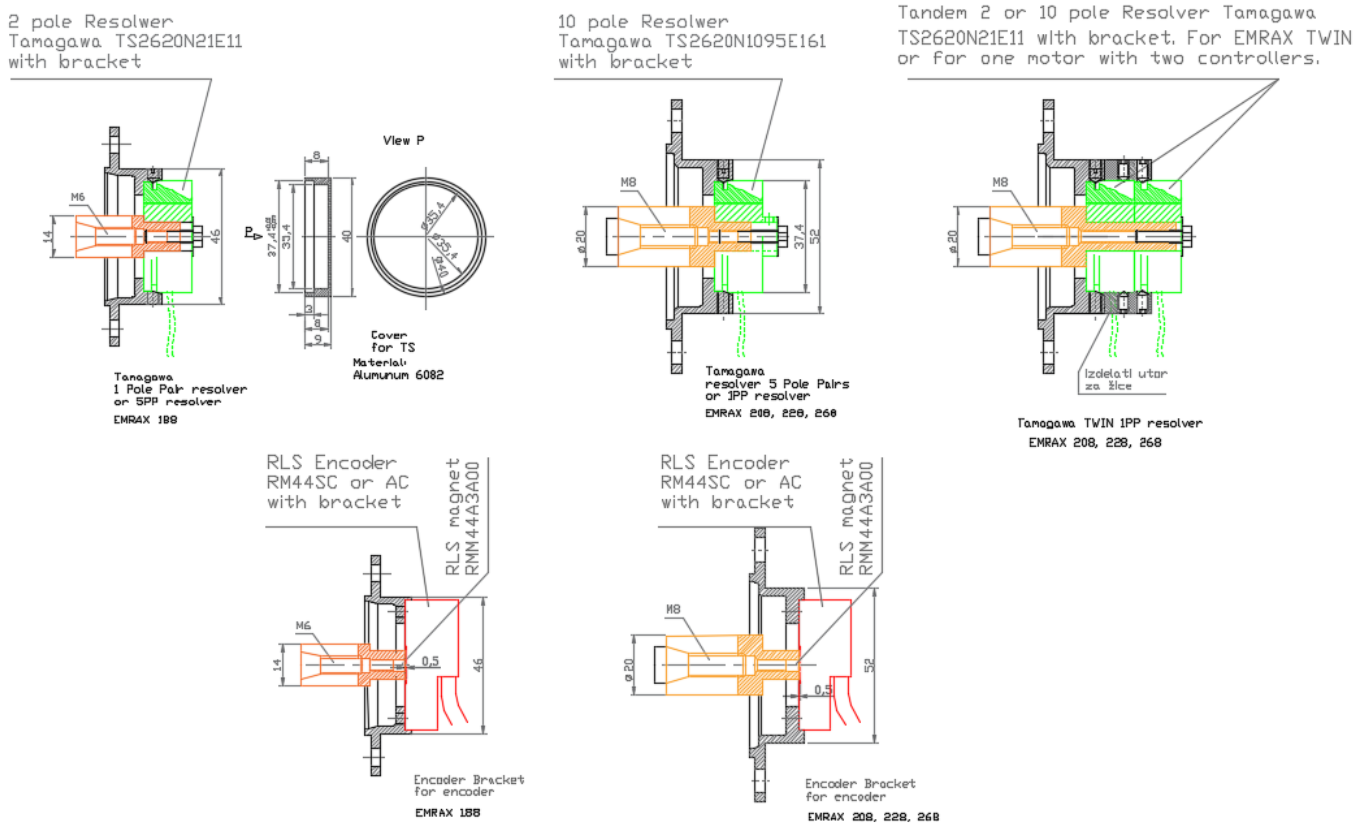


Figure 27: Resolver / encoder on back motor side

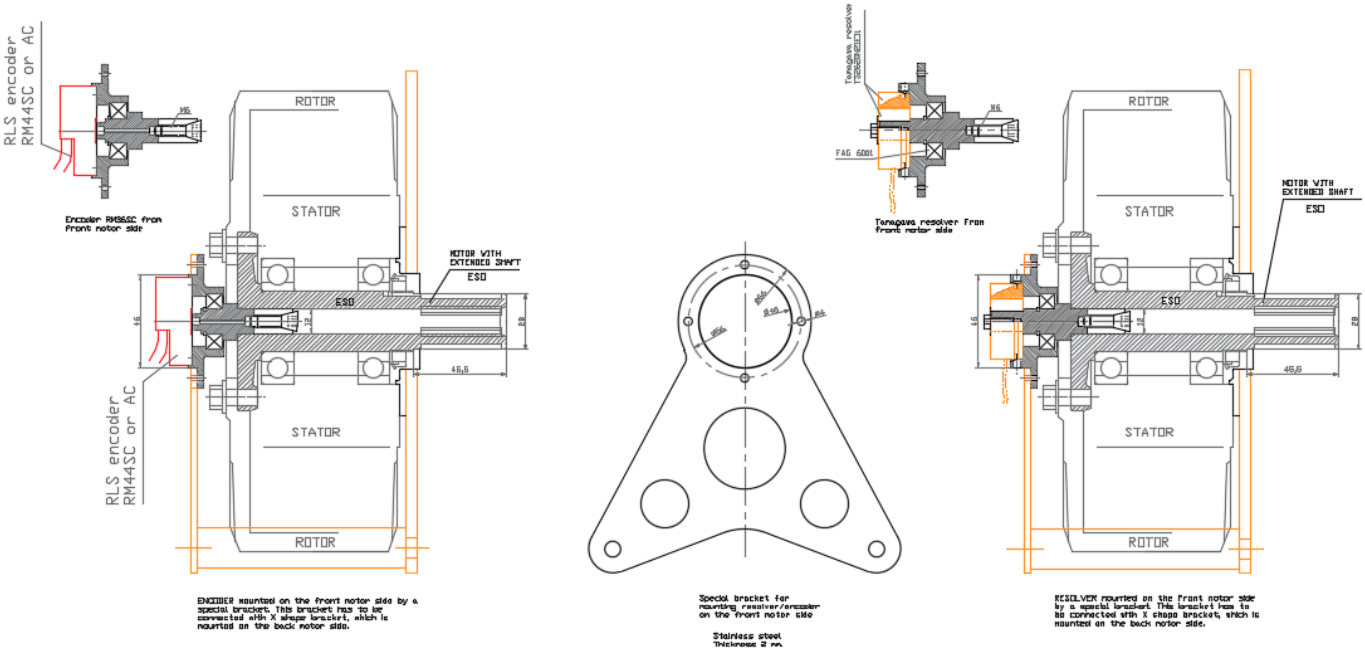


Figure 28: Resolver / encoder on front motor side

Figure 29: Encoder with bracket

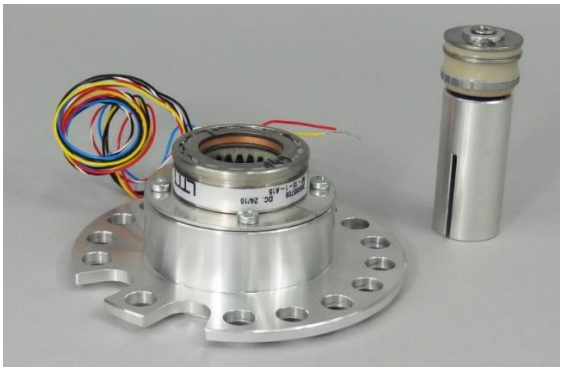
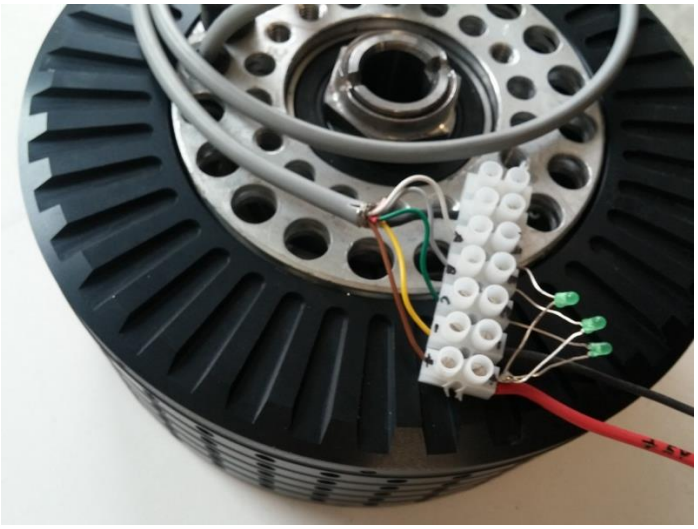


Figure 30: Resolver LTN (on the photo) with bracket (Tamagawa resolver is used from May 2017)



Hall sensors type:	SS411P

Power supply wires:	
BROWN	+ 5 V
YELLOW	- 5 V

Hall sensors signal wires:	
WHITE	A
GRAY	B
GREEN	C

Figure 31: EMRAX with hall sensors HS

b) Drive control without sensor (sensor-less):
- Direction of motor rotation (clockwise/counter clockwise) can also be defined without a sensor, if the controller has a sensor-less option. It can be defined by pole reversal, which can be achieved by a change of two motor phase cables. Three phase power connectors UVW are shown below in this Item. Position and rotation speed cannot be defined without a sensor.
- Sensor-less can be used for e.g. boats, airplanes and for applications that do not need a high torque at the start (applications with propellers).

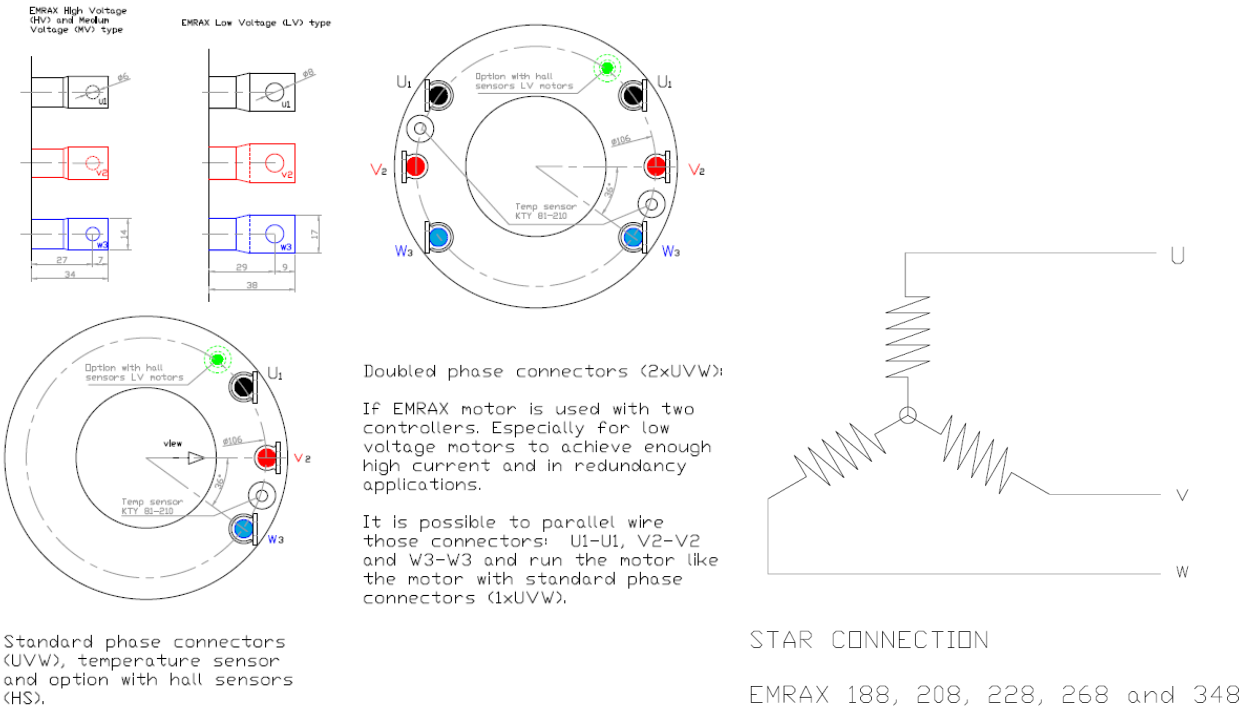


Figure 32: Motor phase connectors – normal (UVW) and doubled (2xUVW)

9. Suitable controllers for EMRAX motors

Controllers have to be bought directly from the producers. The most suitable controllers for EMRAX motors are from the following companies:

- Unitek GmbH, Germany
- Emsiso d.o.o., Slovenia
- Sevcon Ltd., United Kingdom
- Rinehart Motion Systems LLC (RMS), USA

The controller has to be selected according to the Technical Data Table of each motor (high motor current and voltage is very important). For EMRAX motor different sizes is needed to find suitable controller in the global market. It is difficult to find a controller with enough high current, which enables for low voltage motors performances listed in the Technical Data Tables. If the motor current is not high enough, then performances are inferior to the performances in the Technical Data Tables. For this reason here is an option with two controllers which can be used with one motor, therefore the motor can perform with its full performance. In this case the motor windings are wind in two phase sequences (2xUVW). The customer has to order doubled phase connector sequences on one motor when placing an order. Stator windings are tested at 1500 Vac at 50Hz.

EMRAX motors should be used with the **sin signal commutation** controllers. If the controller with trapezoidal commutation is used, the motor would not work at its best performance, and it would also be louder.

Every motor is tested with the Unitek Bamocar D3 (or EmDrive) controller before dispatch. In the table below controllers are listed that are recommended for each motor type (performances of the motor should be calculated according to controller characteristics – current, voltage!):

Motor type	Recommended controller
EMRAX 188 High Voltage	Unitek; Sevcon;
EMRAX 188 Medium Voltage	Unitek (Bamocar D3 400 V; Sevcon
EMRAX 188 Low Voltage	Sevcon; Emsiso (2x emDrive 200 or 1x emDrive 500)
EMRAX 208 High Voltage	Unitek (Bamocar D3 400 V) Emsiso (emDrive H300) Sevcon; RMS
EMRAX 208 Medium Voltage	Unitek (Bamocar D3 400 V); Emsiso (emDrive H300) Sevcon; RMS
EMRAX 208 Low Voltage	Emsiso (emDrive 500) Sevcon; RMS
EMRAX 228 High Voltage	Unitek (Bamocar D3 700 V) Sevcon; RMS
EMRAX 228 Medium Voltage	Unitek (Bamocar D3 400 V) Emsiso (emDrive H300) Sevcon; RMS
EMRAX 228 Low Voltage	Emsiso (emDrive 500) Sevcon; RMS
EMRAX 268 High Voltage	Unitek (Bamocar D3 700 V) Emsiso (emDrive H300, for up to 450Vdc - for high torque at lower RPM) Sevcon; RMS
EMRAX 268 Medium Voltage	Unitek (Bamocar D3 700 V) Emsiso (emDrive H300) Sevcon; RMS
EMRAX 268 Low Voltage	Emsiso (emDrive 500 - only up to 130 Vdc→lower RPM→lower power or 2x emDrive H300) Unitek (2x Bamocar D3 400 V)

	Sevcon, RMS
EMRAX 348 High Voltage	Unitek (2x Bamocar D3 700 V) Sevcon; RMS
EMRAX 348 Medium Voltage	Emsiso (emDrive H300 - only up to 450 Vdc power RPM lower power) Unitek (2x Bamocar D3 700V) Sevcon; RMS
EMRAX 348 Low Voltage	Emsiso (2x emDrive 500 - up to 1200 RPM), (2x emDrive H300 for higher speed)

!Note: For the correct type of the controller consult with the controller producer – especially for Sevcon and RMS controllers.

Most controllers use sensors for controlling position, direction and rotation speed of the motor. If the controller has the sensor-less option, then a sensor is not needed, but in this case only the direction of motor rotation can be defined (by changing positions of two phase cables). More information about sensors is written in Item 8.

Recommended sensors for different controllers:

- Most controllers can drive the EMRAX motor with encoder, 2 poles resolver, 10 poles resolver or hall sensors. Sensors that are available from the EMRAX Company are (they are mounted on the motor by a special bracket or in the motor):
  - **TS2620N21E11** (2 poles **Tamagawa** resolver) for Unitek Bamocar D3 controller
  - **T-TS2620N21E11** (2 poles tandem resolver) for two Unitek Bamocar D3 controllers; when using two controllers with one motor (doubled phase connectors - 2xUVW are needed) or for EMRAX TWIN
  - **RLS RM44SC** (encoder) for Emsiso emDrive 500 and emDrive H300 (with EMRAX 1xUVW).
  - **RLS RM44AC** (encoder) for Sevcon controllers, or in case EMRAX 2xUVW with Emsiso controllers
  - **HS SS411P** three hall sensors HS (Emdrive controller). **HS** doesn't goes with motor which has doubled 2xUVW connectors. Instead of HS with 2xUVW the encoder RM44AC (EmDrive) or tandem resolver (Bamocar D3) is useable.
- Some controllers (e.g. **RMS**) require 5 pole pair resolvers **TS2620N1095E161**, which are more accurate and can deliver a better signal with their controllers. In this case the controller can deliver a better current commutation to the motor. These sensors are especially required for higher speeds. The 1 pole pair resolver can be replaced by the 5 poles resolver by using the same resolver bracket. 5 pole pair (5PP) resolvers are more expensive than 1 pole pair (1PP) resolvers. Tamagava resolvers should be covered from the back side with cover to achieve IP65 ingress protection.

For more information about suitable sensors, consult with the controller producer.
Every sensor has to be mounted on the motor by a special bracket. If the resolver/encoder is bought from the EMRAX Company it is already precisely mounted on the motor by a special bracket when the customer receives the motor. Hall sensors are mounted in the motor during the motor assembly.

!Note:

- Controllers can usually deliver very high peak power and lower continuous power, especially if the controller is air cooled.
- Performance of the motor also depends on the controller boost current and voltage (especially peak).
- Batteries should have very high C (Current) rating – very high boost discharging current from the batteries at high motor load.
- For EMRAX TWIN application two sensors (tandem resolver mounted on the second motor) and two controllers are needed. Some controllers (rare controllers) have an option to split the signal from two controllers in only one sensor (usually encoder), which is mounted on the second motor.
- Separated EMRAX motors which are not connected together mechanically (are not on the same shaft), cannot be driven with one controller.

Motor RPM depends on battery DC voltage and magnetic field weakening:

Maximal battery DC voltage delivers maximal motor RPM which should not be exceeded. Take a look at specific load speed in the Technical Data Table – **RPM/1Vdc**. In case of using the magnetic field weakening MFW option with the controller settings the higher or maximal motor RPM can be achieved at the same motor power, even at lower DC voltage from the batteries.

Achieving higher RPM with magnetic field weakening (MFW):

Most controllers have an option to set the magnetic field weakening in the controller software program. This setting enables the motor to achieve higher RPM at the same battery voltage. All EMRAX motors can weaken the magnetic field up to 100%. In this case the rotation speed increases, but the power stays at the same level. Torque is lower at higher speed. Efficiency drops only for 1-2 %.

Magnetic field weakening can be set in the controller software. EMRAX motors have 10 pole pairs, therefore it is recommended to weaken the magnetic field 15-20% to achieve better performance. With higher % of magnetic field weakening the motor can run faster with very good efficiency, which drops only for 1, 5% at 80% MFW. We recommend MFW only for a short time (few min in case of full motor power), because of a very high phase current between the motor and controller.

!Note:
- Maximal motor RPM should not be exceeded. Maximal motor RPMs are listed in the Technical Data Tables for each motor type.
- EMRAX motor has 10 pole pairs, which results in very high motor rotation frequency, especially at higher motor speed. Therefore the controller for an EMRAX motor has to be made for high rotation frequencies.
For example: at 6000 RPM the rotation frequency is 1000 HZ. Consequently, the controller must deliver a stable and smooth signal even at a high rotation frequency with high PWM. $RPM = 60 * Hz/PP$.

10. Two same sized EMRAX motors connected serially (EMRAX TWIN) – stacking capability of EMRAX motors

Two same sized EMRAX motors can be connected serially – this is EMRAX TWIN. All EMRAX motor types can be connected into TWIN.

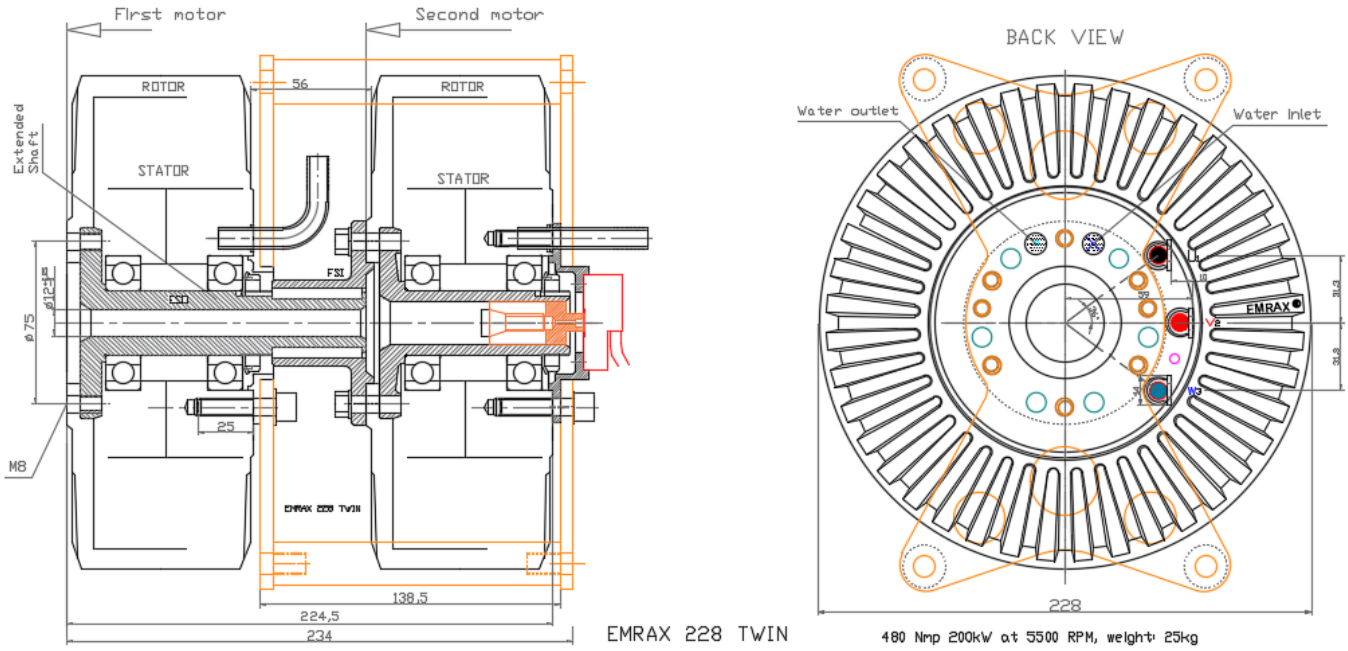


Figure 33: EMRAX TWIN drawing

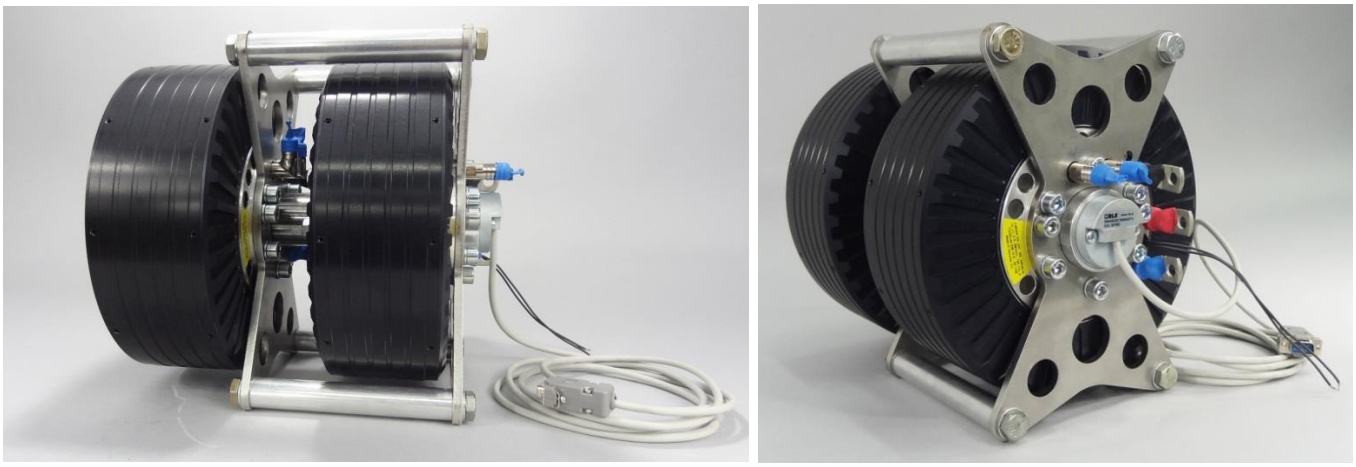


Figure 34: EMRAX TWIN with encoder RM44AC. The signal can be split with the second controller, which drive the first motor

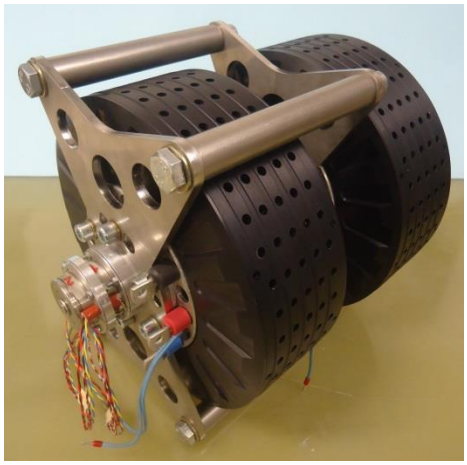


Figure 35: EMRAX TWIN with tandem resolver (each resolver drive independent controller)

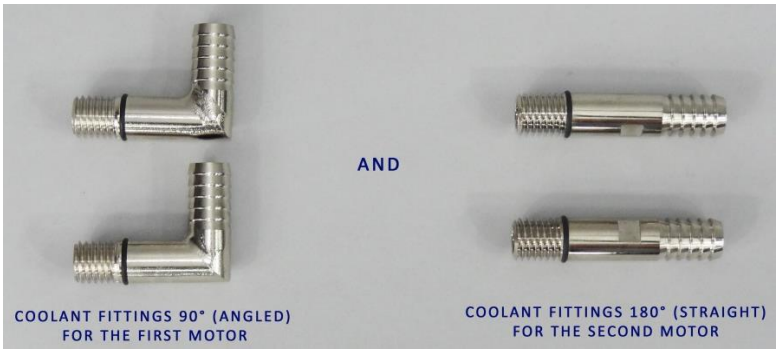


Figure 36: Coolant fittings for EMRAX TWIN (the new CF are made without threat)

Parts for EMRAX TWIN:
- First motor needs the Extended shaft with outer splines (ESO)
- Second motor needs the Flanged shaft with inner splines (FSI)
- 2 pcs of X shape brackets made from stainless steel and connectors between the X carriers.
- If direction, position and rotation speed of the motor need to be controlled sensors are needed (more information in Item 8). Sensors that can be used are: tandem resolver (two resolvers wired serially – recommended), one encoder if the controller has an option to split the signal (rare controllers - EmDrive) or hall sensors in every motor. For more information about sensors, please consult with controller producers.

Possibilities for mounting the sensors in case of EMRAX TWIN:

- In case using ESO in the second motor both motors should use hall sensors.

- Tandem resolver (T-Tamagawa) or encoder can be mounted at the end of tailored elongated shaft (adapter shaft) after the drive wheel (for pulley, chain etc.) on the back or front motor side (on ESO or FSI) by a tailor made bracket. Tailored shaft and bracket have to be provided by a customer.

- Special tandem resolver or encoder with bigger internal diameter of the rotor can be mounted on the ESO. These special sensors* have to be provided by a customer.

* Resolvers / encoders with bigger inner diameter of the rotor are bigger and a lot more expensive. These bigger sensors also need more space for mounting.

The first motor is connected to the second motor by using the ESO shaft, FSI shaft and two X shape brackets with 4 connectors between X carriers. ESO and FSI shaft must be made by the EMRAX Company, otherwise the warranty does not apply.

Figure 37: EMRAX TWIN shafts – ESO is mounted in the first motor and FSI on the front side of the second motor

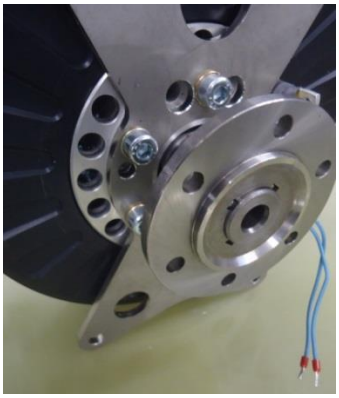


Figure 38: Motor with extended shaft and flanged shaft on the extended shaft (for EMRAX TWIN)

11. Redundancy

2 options:
- EMRAX TWIN, which needs to be driven with two controllers and needs a tandem resolver or hall sensors in every motor. In case of one controller/motor failure the others are still working.
- One EMRAX motor can be driven with two controllers. In this case the EMRAX motor needs doubled phase connectors (2xUVW). In case of one controller failure, the other still drives the motor (performances are lower). Sensors: tandem resolver, encoder if the controller can split the signal (EmDrive)
Redundancy may be considered for airplane applications.

12. EMRAX motor working as a generator and its integration into the hybrid system

EMRAX motors can be used as generators for electricity production. The same performance characteristics can be achieved in the motor and generator modes of operation. Technical data and graphs for the generator application are the same as for the motor application if the generator is driven by the controller. In case the generator is driven without a controller the power / torque is approximately 50% lower, because there is no control of the correct electrical-mechanical angle at load. Also an additional controller for converting generator three phase alternating signal to grid signal (230V/50Hz) is needed.

The EMRAX motor can be used in a hybrid propulsion system as a generator, which generates energy and charge the batteries in regeneration mode by using the controller and battery management system (BMS). The controller and BMS at the same time drive the diesel engine on the right power/RPM for charging the batteries at optimal level. At the end of charging BMS also balance the battery cells and turn off the diesel engine.

13. EMRAX motor ingress protection (IP CODE)

- **IP21:**

  a) Air Cooled (AC): only air cooled

  b) Combined Cooled (CC): air and liquid cooled (water/glycol mixture)

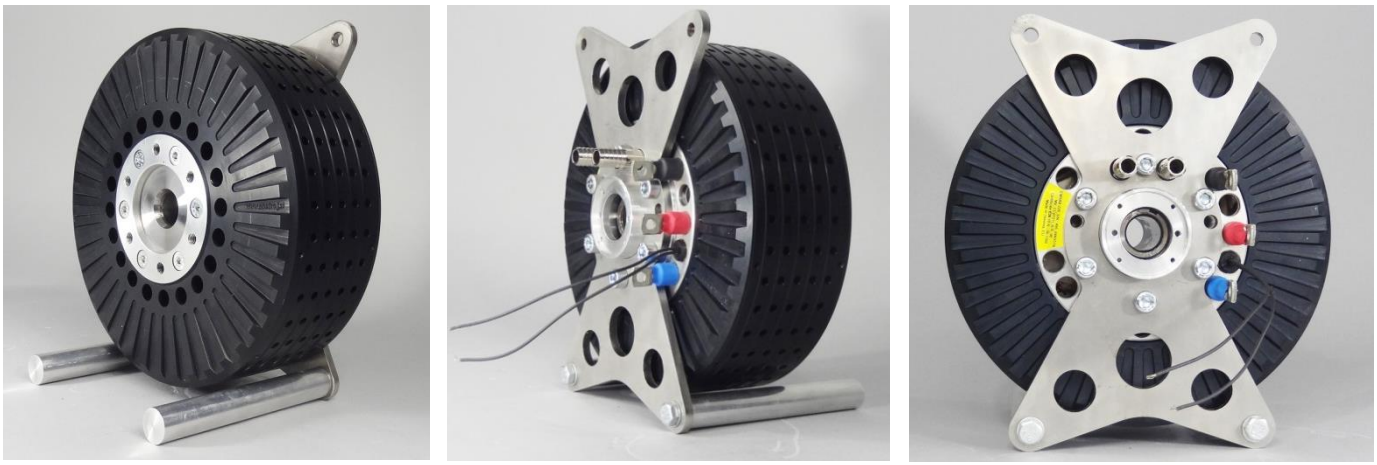


Figure 39: EMRAX IP21

- **IP65**:
  Liquid cooled (LC): Totally closed motor. Dimensions and weight of this motor are the same as for EMRAX with IP21. Continuous power / torque are up to 20% lower, peak is the same compared to EMRAX with IP21.

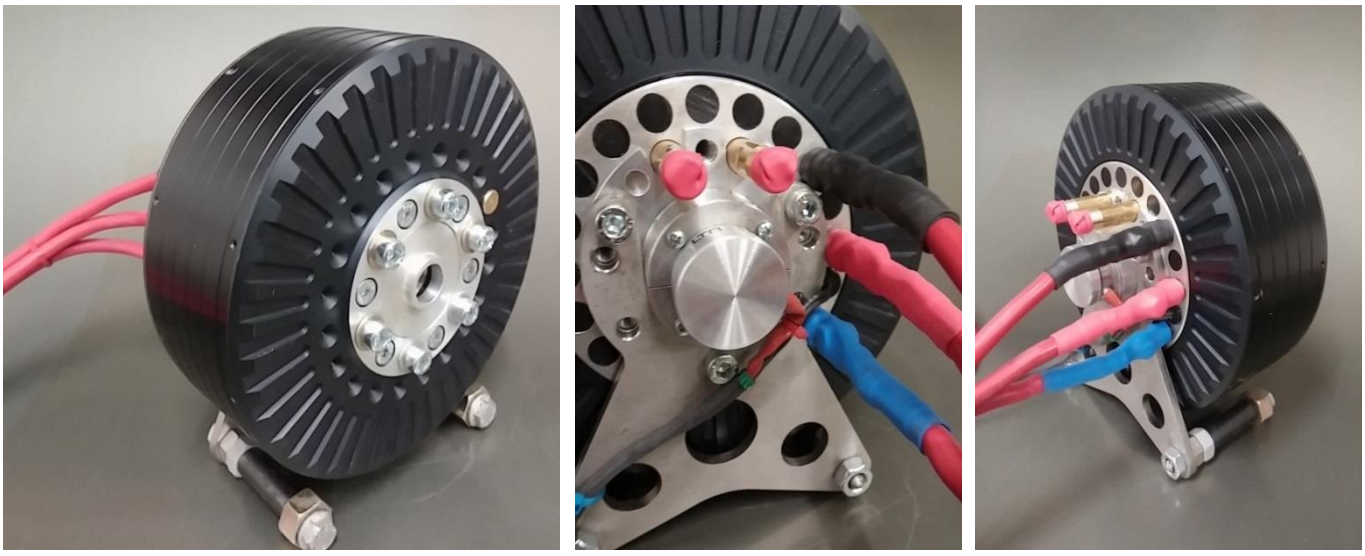


Figure 40: EMRAX IP65

14. Motor cooling

It is important to enable sufficient cooling of the motor at any time. In every case, the temperature sensor that is mounted in the controller must be connected to the controller. This sensor protects the motor from overload. In case temperature is too high and not stable the controller drives the motor with lower current until the temperature becomes stable under the limit. The standard temperature sensor mounted into the motor is KTY 81-210. Other types can be mounted (e.g. PT1000) if the customer consults with the EMRAX Company in advance. EMRAX motors can be air cooled (IP21), liquid cooled (IP65) or combined cooled (IP21).

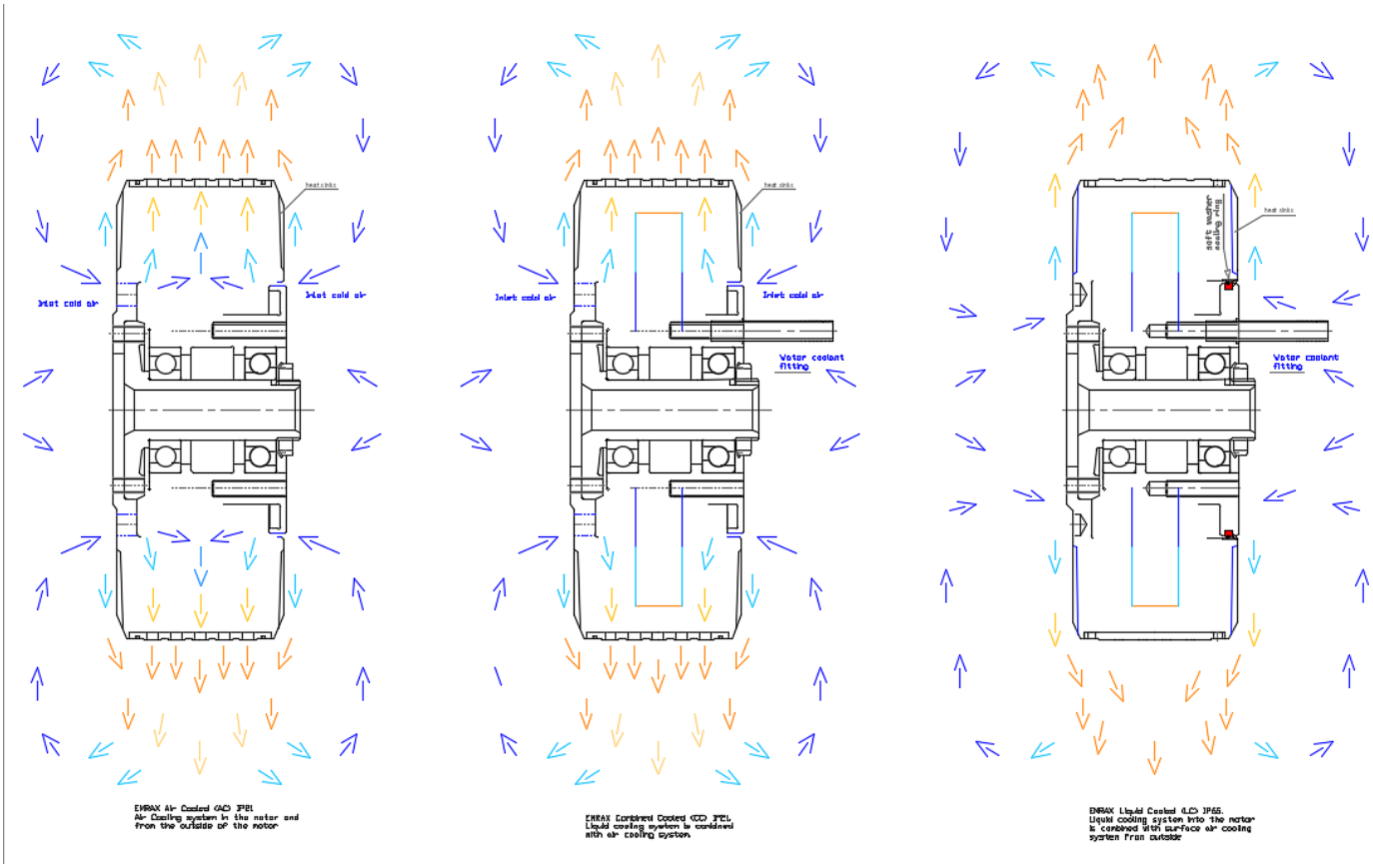


Figure 41: Motor cooling options

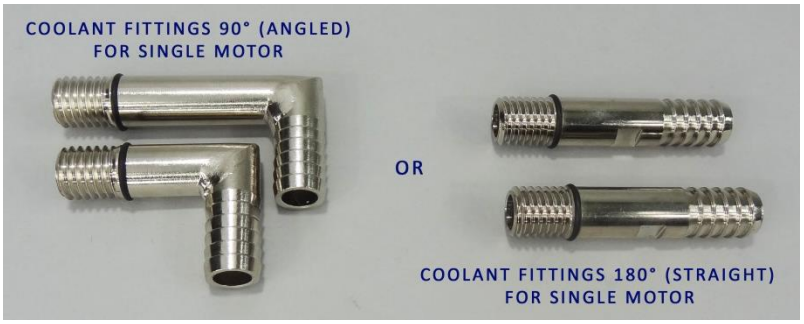


Figure 42: Motor Coolant Fittings for one motor (the new CF are made without threat)

EMRAX motors have to be used under ambient and motor cooling conditions, which are described in the Technical Data Tables. Failure to comply with these conditions will void the warranty.

- The EMRAX motor **must not exceed the temperature below -40°C and above 120°C on cooper windings and on the magnets. These values are also valid for the bearings**. If the temperature exceeds these values, it causes a void of warranty. The indicator for exceeded temperature is placed in the motor. In case of disconnection of the temperature sensor, which has to be on the cooper windings, the controller has to stop the motor. The motor temperature sensor detector in the controller must always be enabled, during motor operation. **The temperature sensor in the motor only measures the temperature of the stator, not the temperature of the magnets, consequently the magnets' temperature (outer/surface temperature of the motor) has to be measured with the thermal camera.** It must be considered that the surface temperature is lower compared to the magnet temperature – difference is approximately 10-20 °C (depends on the load).
- **IP21 motor:**
  - **EMRAX Air Cooled AC (air cooled):**
    Fresh air has to be served to the drive symmetrically and sufficiently. Air speed must be **20 m/s at maximal 25°C air temperature and at maximal 200 kPa pressure**. This has to be ensured by intake ports or other air conduction measures. The motor can be protected with some net against the dirt.
  - **EMRAX Combined Cooled CC (air and liquid cooled):**
    Liquid cooling flow must be **6 to 8 litres per minute at maximal 50 °C inlet water/glycol temperature and ambient air temperature has to be 25°C or less**. Inlet water/glycol temperature and ambient temperature can also be lower – in this case the continuous motor power is higher. This is valid for all EMRAX motor sizes.

    To achieve a good inlet water/glycol flow rate which is recommended (from 6 to 8 l/min) the inlet pressure for the different motor types must be:

Motor size	Water/glycol flow pressure (pressure drop)	Water/glycol flow rate
188 CC	0,5 bar	7 l/min
208 CC	0,6 bar	7 l/min
228 CC	0,9 bar	7 l/min
268 CC	1,0 bar	6 l/min
348 CC	1,0 bar	6 l/min

    !Note:
    - Maximum inlet water/glycol flow pressure must not exceed 2 bars.
    - Inlet water/glycol flow pressures are valid if the tube length between the motor coolant fittings and the pump is up to 2 meters (diameter is 10 to 12 mm). If the tube is longer higher pressure in accordance with the pressure drop must be used.
    - For the combined cooled motor it is important that beside liquid cooling also air cooling is assured – this means that the air around the motor must be exchanged (air circulation) and that the ambient air temperature must be 25°C or less (as described in the Technical Data Tables) to achieve the best motor performance.
    - The motor must **not be closed** into some box without possibility of exchanging the air. Liquid cooling system

is important for the stator, air cooling system is important for the rotor. The motor can be protected with some net against the dirt.
- Liquid flow must be filtered through the filter which openings' diameter or diagonal must not exceed 2 mm.
- We recommend original coolant fittings, which have a special O sealing ring. If the tubes are sealed with some other sealing material, we do not guarantee that the system is waterproof.
- We do not recommend cooling the motor direct with salt water, because long-term exposure of the motor cooling system might lead to mineral deposits. Therefore we recommend a heat exchanger. Motors were not tested in a salt environment and cooled with salt water.

- **IP65 motor:**
  - **EMRAX Liquid Cooled LC (liquid cooled):**
    This motor is totally closed. Liquid cooling flow must be **6 to 8 litres per minute at maximal 50 °C inlet water/glycol temperature and ambient air temperature has to be 25°C or less**. Inlet water/glycol temperature and ambient temperature can also be lower – in this case the continuous motor power is higher. This is valid for all EMRAX motor sizes.

    To achieve good inlet water/glycol flow rate the recommended (from 6 to 8 l/min) inlet pressure for the different motor types must be:

Motor size	Water/glycol flow pressure (pressure drop)	Water/glycol flow rate
188 LC	0,5 bar	7 l/min
208 LC	0,6 bar	7 l/min
228 LC	0,9 bar	7 l/min
268 LC	1,0 bar	6l/min
348 LC	1,0 bar	6 l/min

    !Note:
    - Maximum inlet water/glycol flow pressure must not exceed 2 bars.
    - Inlet water flow pressures are valid if the tube length between the motor coolant fittings and the pump is up to 2 meters (diameter is 10 to 12 mm). If the tube is longer higher pressure in accordance with the pressure drop must be used.
    - Even though the motor is liquid cooled only the ambient temperature is an important factor for achieving high constant power. The ambient temperature must be 25°C or less (as described in Technical Data Tables).
    - The motor must not be closed into some box without the possibility of exchanging air.
    - Liquid flow must be filtered through the filter which openings' diameter or diagonal must not exceed 2 mm.
    - We recommend original coolant fittings, which have a special O sealing ring. If the tubes are sealed with some other sealing material, we do not guarantee that the system is waterproof.
    - We do not recommend cooling the motor direct with salt water, because long-term exposure of the motor cooling system might lead to mineral deposits. Therefore we recommend a heat exchanger. Motors were not tested in a salt environment and cooled with salt water.

15. EMRAX motor materials, quality and reliability

EMRAX motors are quality made and consist of quality advanced materials. Materials are able to withstand extremely high power / torque (high temperature resistant, shatterproof, stiff) and are corrosion resistant.

Stator part, outer ring, front and rear disk are made of aluminium quality 6082. Minimum aluminium thickness is 3.0 mm, which is on the outer ring. The outer ring, front and rear aluminium disk are anodized in black.

Even though rotors with magnets represent approximately 40% of the motor weight, the direction of motor rotation can be changed in a fraction of a second. This is possible due to a very high quality materials for all components like the motor shaft, which is made from hardened steel (42CrMo4QT) and quality bearings, which are chosen for long time duration.
Stator with cooper windings has an additional epoxy coating.
Magnets are made with high qualita material with UH grade, which means that they are resistant up to 180°C. They are chemically and mechanically fixed on the back iron, therefore EMRAX motors are very reliable.

EMRAX motors are sold to the airplane industry where reliability is extremely important. Due to adequate fixation of the magnets and quality advanced materials as well as motor design, the smallest sized EMRAX motors can be rotated even up to 8000 RPM.

The generated voltage of EMRAX may vary for 1-2% at the same rotation speed. This is due to the difference of the magnetic field of the magnets (tolerance 1-2%). The difference in voltage also depends on the other materials of the motor.

16. EMRAX motor bearings and life expectancy

Bearings of the rotor are not qualified for forces higher than bearings of the EMRAX motors included can transfer. Bearings used are FAG or SKF models, which are listed in the Technical Data Tables for every EMRAX type and in Item 3. All technical information about listed bearings is publicly available.

Every EMRAX motor includes two bearings – front and back. The distance between the front and back bearing can be measured from drawings. The bearing type depends on the load (direction and amplitude of the force applied on the motor shaft).

Bearings for EMRAX motors are listed in the tree structure of Item 3 and in the table below this paragraph. Bearing types, which are described, are used for most applications. If special bearings are needed (e.g. for in-wheel application), customer must consult with the EMRAX technical support before placing an order. Bearings are mounted in the motor during motor assembly. The bearing type must be calculated and selected by customer.

EMRAX motor size	Bearings for EMRAX motors (FAG bearings)		
	For radial forces (standard) (R)	For radial-axial	
		For pull mode (P)*	For pull-push mode (PP)**
188	6204:6204	6204:7204	6204:3204
208 / 228 / 268	6206:6206	6206:7206	6206:3206
268 VHML	6207:6207	6207:7207	6207:3207
348	6208:6208	6208:7208	6208:3208

* Front bearing is for radial forces. Back bearing is for axial-radial forces, focusing on very high axial load. Bearing combination is for pull mode. Suitable for e.g. air propeller.

** Front bearing is for radial forces. Back bearing is for axial-radial forces. Bearing combination is for pull-push mode.

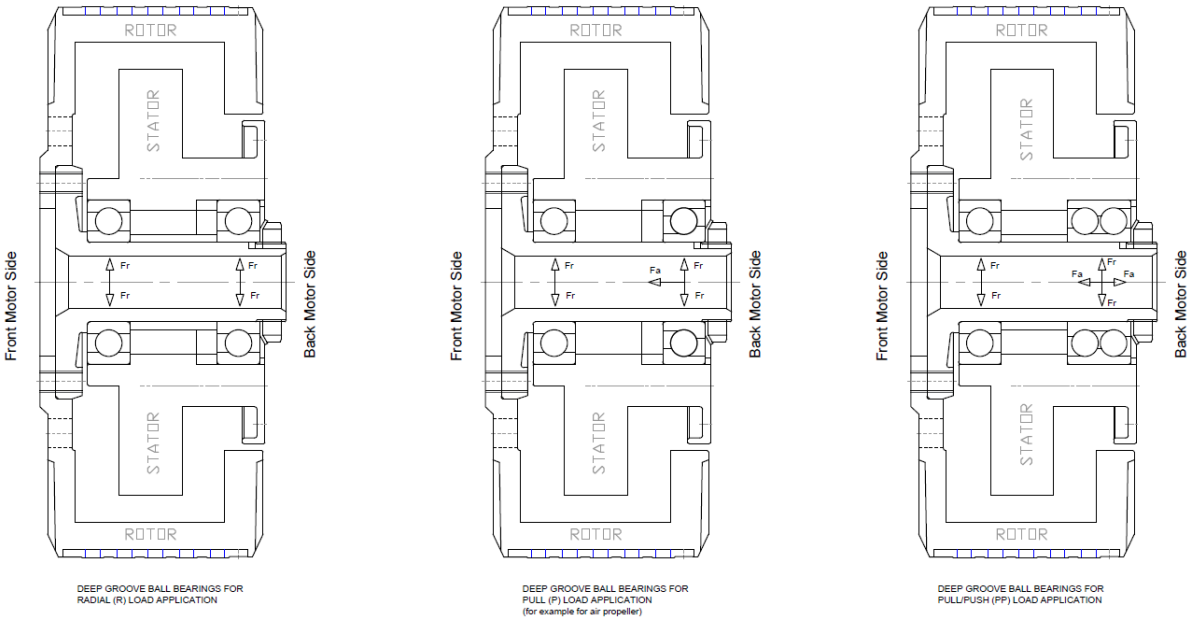


Figure 43: Combinations of bearings for EMRAX motors

To choose the correct bearings, the calculator on the link below should be used. Size of the bearing must be correct (according to EMRAX motor drawings). We offer FAG and SKF bearings.

To check if the bearing is suitable for forces applied on the shaft you can use publicly available FAG bearing calculator: http://medias.ina.de/medias/en!hp.ec/1_R*0*C

1. First, enter the type of the bearing in the box on the right side (e.g. 6206).
2. New window opens with the search results. Choose the product (e.g. 6206-2z, which means that it is closed from the front and back side).
3. Now you can choose the *Calculation* tab.
4. Double click on *Loadcase 1* on the right side of the window.
5. In the window that opens enter the magnitude of axial force (F_a), magnitude of radial force (F_r), rotation speed and operating temperature. Click on the calculator icon in the top row (5^{th} icon from the left). Under the picture of bearing you will see the rating life in hours.

Life expectancy of the EMRAX motor is the same as life expectancy of the bearings that are mounted in the motor. If the bearings are overloaded than the bearing life time is shorter. They can be replaced.

In case of doubt, the circumstances of operation shall be discussed with the manufacturer of the bearings or the EMRAX Company. If the radial or axial load is higher than the bearings can bear, then the system must have an additional shaft with stronger bearings (belt transmission, chain transmission, gear transmission, direct drive applications). The EMRAX Company can insert some customized bearings' combinations (e.g. with tapered rolling bearings with additional sealing rings). This has to be discussed by the EMRAX Company in advance.

A static redundant dimensioning caused by the thrust bearing must be avoided in any case. Certain resilience in the mount of the drive or the thrust bearing is satisfactory. Required is a clean rotation of the extension shaft. The shaft must be able to rotate smoothly and easily by hand after mounting.

Tapered bearings must be lubricated according to the bearings lubrication instructions from the bearing producer.

Bearings are mounted in the motor during assembly. They can be replaced only at the EMRAX Company. Any opening and/or bearing replacement not done by the EMRAX Company causes a void of warranty! Also opening an EMRAX motor can cause health damage. Therefore please avoid opening the motor.

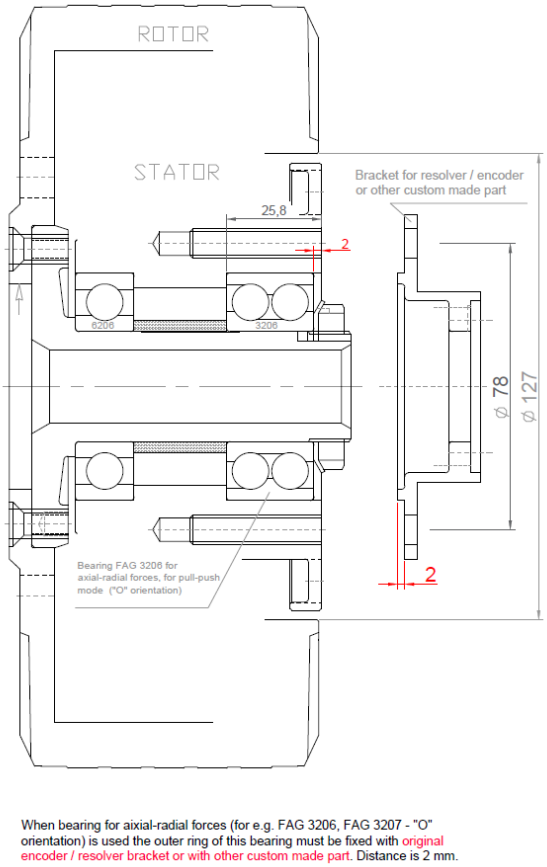


Figure 44: Pull-push (PP) bearing outer ring fixation

17. EMRAX motors as in-wheel motors

All EMRAX motor types can be used as in-wheel motors. Important considerations before placing an order are:
- Bearings selection according to forces applied on the shaft (torque, weight of the vehicle) – more information about bearings in Item 16.
- Motor shaft selection according to forces applied on the shaft (torque, weight of the vehicle) – more information in Item 7.

EMRAX motor for in-wheel application must be totally closed (IP65; Liquid cooled).

For most in-wheel applications EMRAX 268 VHML is appropriate. In every case forces that will be applied to the shaft and bearings should be discussed before placing an order.

In-wheel mounting options for EMRAX can be seen in Item 6.

18. Maintenance and protection of EMRAX motor against environmental disturbances

- The drive does not need any maintenance during lifetime. The lifetime of EMRAX motors is the same as the lifetime of the bearings that are included in each motor.
- However it has to be considered that no foreign objects at all can enter the interior of the drive. This is especially important for EMRAX motors with IP21 (Air Cooled and Combined Cooled). Furthermore, it is necessary to protect the motor from humidity, dirt, paint, glues, salt, iron particles, etc. If this is ignored, a proper functionality of the motor cannot be guaranteed and irreparable damages are possible. To prevent objects falling inside the motor (especially iron chips, iron fillings), **the motor ventilation holes (ring and side holes) MUST be protected with some tape during the time the motor is being assembled into the system and during the time the drive is not in use. The drive must be**

protected from these objects even when it is already mounted in the system (especially if the motors are mounted close to the ground and if there are iron particles). In this case the motor should be protected with some fine net in order for the cooling to remain sufficient at the same time! In the event a foreign object enters the motor, do not by any means simply keep on using the drive! In this case contact the EMRAX Company and explain what happened. Unintended handling leads to secondary damages. **Opening or disassembling of the motor causes a void of warranty!** Also for opening the motor, special tools are needed to prevent any damages to the motor and to the person who opens the motor. Opening of the motor must be avoided in any case. The EMRAX Company can remove the foreign object from the motor and also checks the interior of the motor at the same time as well as protects it again. Removing particles from the motor, inspection and protection of the stator costs approximately 190 euros per motor. The customer also has to pay shipping costs and duty costs that may incur.

- In case of damage, ship the drive back to the EMRAX Company for repairs. It is important, that you contact the EMRAX Company before sending the motor back.
- Keep magnetic memory cards or electronic devices out of the rotor's close range, because the alternating magnetic field can cause a delete of data. Be careful with medical devices (e.g. pacemakers) which are sensitive to alternating magnetic fields.

19. Starting EMRAX motor (connecting the motor with controller):

1. **Firstly, it is important to read the manuals for the EMRAX motors and for the controllers!**
2. **Be aware of the following safety instructions before starting:**
    - It is essential to permanently check the loads driven by the motor for damages, cracks etc. The use of damaged loads can lead to heaviest injuries.
    - The frequency converter needs to be mounted jacked up, so that a vibration free use is unconditionally guaranteed. If this is not the case, vibrations can cause contact faults and furthermore the breakdown of devices. This may lead to damages to the electronic system or to components in its environment.
3. **Connecting the EMRAX motor, controller and batteries:**
    - Before starting, the right direction of rotation has to be checked and if necessary changed – motor connectors UVW must be set according to the controller phase positions. UVW (1, 2, and 3) connectors of the motor are parallel to UVW output phases from the controller. If sensor (encoder / resolver / hall) is used it has to be properly connected to the controller. Instructions can be provided by the sensor producer or the controller producer. For connecting instructions of the RLS encoder / LTN resolver / hall sensors please contact the EMRAX Company.
      The drive should be, if possible, directly connected to the frequency controller, without any inserted connectors. If this is not possible, only use high current capable, low-impedance, best quality connectors. Shoddy connectors lead to voltage peaks and can destroy the frequency converter. Oftentimes unplugging the connector can cause contact problems which may also lead to a destruction of the converter. We also recommend a main vacuum switch between the batteries and controller and a suitable DC fuse.

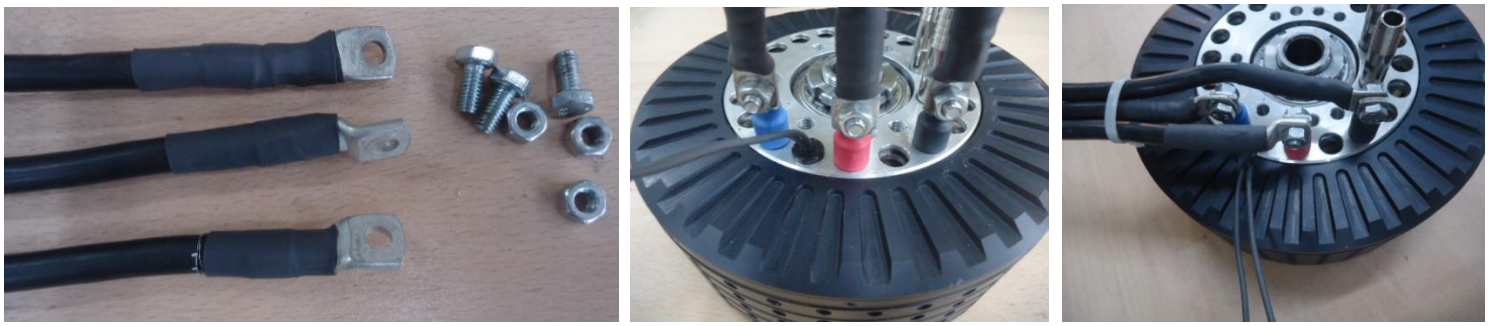


Figure 45: Straight connection of motor phase connectors to controller cables.

Figure 46: Angular connection of motor connectors to controller cables. Connections must be isolated with shrink hose!

- Only use high current connector systems between the motor, converter and the battery. The connectors have to be checked before every use. If the coating is used up, the internal discs and the jacks may be damaged or lose their resilience, and they have to be replaced.
- Shoddy or used up connectors are the most common reason for destructions of the drive, the controller and possible components around it.
- **The electric connectors and cables must be connected professionally and have to be isolated with a shrink hose.**

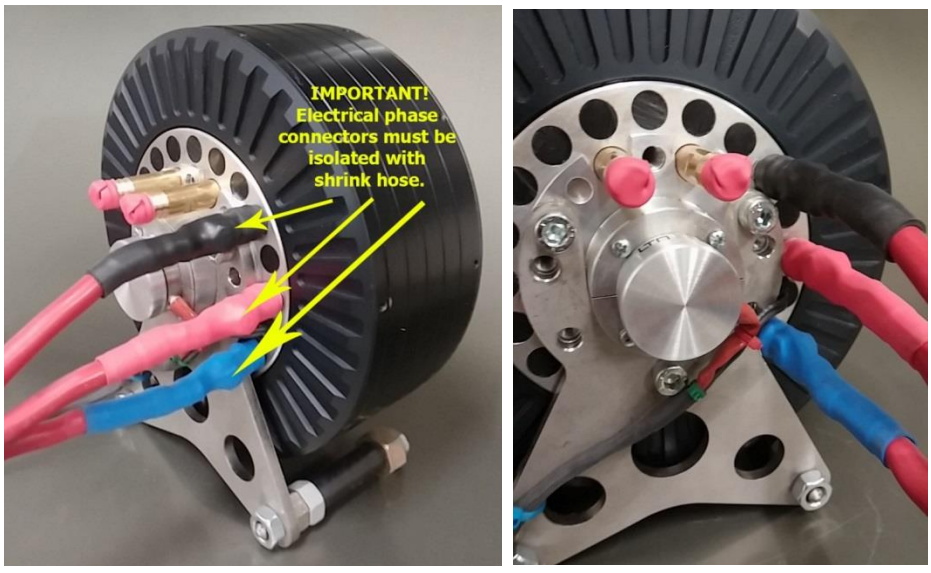


Figure 47: Isolation of electrical phase connectors with shrink hose

- Mixing up the polarity of the battery or a short circuit leads to a destruction of the drive and means an acute fire hazard and danger of life!

- The cables should be as short as possible. For longer cables the diameter of the cable must be bigger. **Power cables must be shielded and grounded. Distant of those cables must be enough from the communication cables**.

4. **Setting the controller software:**
   - Basic controller software settings must be set in the controller software. Basic controller settings are published on our web site: link. These files are for the Unitek controller. Other controllers use similar parameters, which can be set by using these parameters and the Technical Data Table of the motor.
   - Afterwards auto-tuning must be made. This means automatic adjustment of electrical angle according to the mechanical rotor position. This is a very important step for proper operation of the engine! When auto-tuning starts the motor slowly rotates for 360 mechanical degrees. Every controller has different system for automatic adjustment of electrical angle, so make sure you read the manual of the controller or consult with the controller producer. Here is a video, which shows auto-tuning EMRAX motor with Unitek controller: https://youtu.be/yuyPS_RCWQ8
   - Now you can start the motor and adjust software parameters according to your application. Be sure you enter the parameters that are in accordance with the Technical Data Table! Otherwise it causes a void of warranty.

20. How to choose the correct EMRAX motor type for every application:

1. First you need to know what RPM and torque you will need for your application. You have to make sure, that the desired RPM and torque (without transmission gear) do not exceed maximal RPM and torque listed in the Technical Data Table for the specific EMRAX motor. You also need to make sure, to consider the Torque/RPM graph! The torque also depends on the controller current of the motor, therefore the controller needs to have enough high phase current to get enough high torque from the motor.

2. In the Technical Data Table you can find Specific load speed **(RPM/1Vdc).** With this data you can calculate how many RPM you will get at desired battery voltage (Vdc) at load application.
   *It is possible to achieve higher RPM with magnetic field weakening (MFW). You can use magnetic field weakening when torque is at maximal value. At magnetic field weakening the torque slightly decreases, but the RPM rises and consequently the power stays the same (take a look at the equation below). Magnetic field weakening can be set in the controller software. EMRAX motors have 10 pole pairs, therefore it is recommended to weaken the magnetic field for 15-20% to achieve the best performances. With higher % of magnetic field weakening the motor can run faster with very good efficiency, which drops only for 1% to 2% at 80% MFW. We recommend MFW only for a short time (few min in case full motor power), because of a very high phase current between the motor and the controller.

3. Now you can calculate the power, using this equation:

$$P\,[kW] = n\,[RPM] * Mt\,[Nm] / 9550$$

   At a lower RPM (motor rotation), you can expect lower motor power at the same torque. At a higher motor speed you can expect higher motor power at the same torque.

   Mt……torque [Nm]
   P……power [kW]
   n……motor rotation [RPM]
   In case you need higher power we recommend you to increase battery voltage (Vdc) instead of increasing motor current – because cables with bigger diameter are needed and consequently the weight is bigger. It is better to use a High Voltage motor if you need higher motor speed (RPM).

4. **Example for 228 MV**:

   Customer has battery voltage 365 Vdc at load.

228 MV motor can deliver 11 to 14 RPM per 1 Vdc at no load. At full load it can deliver 11 RPM/1Vdc.

This means that you can get $365\ [Vdc] * 11 = 4015\ [RPM]$.
Therefore at 180 Arms peak from controller from Bamocar D3, the motor power is:

$4015\ [RPM] * 180\ Nm \div 9550 = 75^{\cdot}[kW]$ This is the maximum which you can expect with this controller. If you
want more power you need higher dc voltage to get higher RPM and also higher motor current. You need app 280 Arms peak (which gives app 230 to 240 Nm of torque with EMRAX 228 size). So if you can increase the current you will be closer to 100 kW. But we recommended that you increase the battery voltage to get higher RPM and consequently higher power.

21. Usage of EMRAX motors for electric vehicles (EV)

How to calculate power and torque for EV?

1. First you have to calculate the torque that will be needed for the vehicle (torque on the wheels):

   Example:

EV weight:	G = 1700 kg
Acceleration time from 0 km to 100 km/h (= 27,78 m/s):	t = 5 sec

   Acceleration:

$$a = v \div t = 27{,}778\ m/s \div 5\ s = 5{,}55\ m/s^2$$

   Force for acceleration:

$$F = 1700\ kg * 5{,}55\ m/s^2 = 9444{,}5\ N$$

   Torque on the wheels (wheel diameter 0,64 m):

$$Mt = 9444{,}5\ N * 0{,}32\ m = 3022{,}2\ Nm$$

   3000 Nm is a torque on the wheels, which is needed to accelerate the vehicle (EV weight is 1700 kg) from 0 km/h to 100km/h.

2. Now you need to consider the transmission gear (TG) ratio and calculate the torque:

   Example:

   Differential ratio is approximately 3:1, TG ratio is approximately 4:1. Therefore total ratio with the first gear is:

$$total\ ratio = 3 * 4 = 12$$

   For example, one EMRAX 228 motor can deliver 240 Nm peak torque and 120 Nm continuous torque. Therefore peak torque on the wheels with the first gear is:

$$total\ peak\ torque\ on\ the\ wheels\ with\ the\ first\ gear = 12 * 240\ Nm = 2880\ Nm$$

   In this case this is close to 3000 Nm of peak torque in first gear can be expected. In the second gear the torque is lower. Only higher gear can deliver higher and finally end speed of EV.

End speed also depends on the maximal battery voltage (Vdc) and magnetic field weakening (MFW) – more information in Item 9. Final EV speed can be even higher if magnetic field of the motor is weakened. This can be done in the controller settings. Power stays the same at higher speed.

Power of EV is rising at higher speed because of the air drag.

EV needs enough high torque for starting EV and driving up the hill. 15% slope is minimal for torque calculation.

3. Torque, power calculation:

$$\boldsymbol{P\ [kW]\ =\ n\ [RPM] * Mt\ [Nm]\ /\ 9550}$$

At lower RPM (motor rotation), you can expect lower motor power at the same torque. At higher motor speed you can expect higher motor power at the same torque.

Mt……torque [Nm]
P……power [kW]
n……motor rotation [RPM]
Very important considerations when calculation power and torque for EV:

- acceleration
- air drag at higher speed
- driving up the hill

Usually there is no need to add higher torque for climbing up the hill, because there is enough high torque in the first gear in the case of using TG. Only the EV speed is lower. Normally we do not need to drive up the hill at full speed.

EV must start with good acceleration even at very low RPM or at zero speed. Therefore the most important are motor torque and reduction drive ratio (belt drive, chain drive, differential or transmission gear etc.).

Mounting options of EMRAX motor for electric car EV:

- In-wheel (in Item 6)
- On the differential
- In the transmission gear (TG).

Firstly, you should know how much torque you need on the driven wheels.

1.) If you use the transmission gear then one EMRAX 208 gives enough power:
1900 Nm peak / 900 Nm continuous in the first gear.

2.) EMRAX 228 mounted in the TG is better option. You can expect much better EV acceleration, also you will be able to drive up the hill at higher gear:
3800 Nm peak / 1900 Nm continuous in the first gear .

3.) EMRAX 228 is useable for lighter EV if mounted directly on the differential:
nearly 1000 Nm peak / 500 Nm continuous on the wheels at full range of motor RPM.

4.) EMRAX 268 is useable for heavier vehicles if mounted directly on the differential:
approximately 1600 Nm peak / 800 Nm continuous on the wheels at full range of motor RPM.

5.) If EMRAX 268 is mounted in the TG, than you can expect very high torque:
6000 Nm peak / 3000 Nm continuous on the wheels at full range of motor RPM.
You can also use EMRAX TWIN (torque/power is doubled). Peak torque means that the power lasts 1-2

minutes.

Example of calculation for electric Audi ETT:

Engine:	1x EMRAX 268 MV CC(IP21)
Differential gear ratio:	i = 2,65 (BMW differential)
EV weight:	G = 1500 kg
Peak / continuous motor torque:	500 Nm / 250 Nm
Wheel diameter:	D = 0,64 m
Battery capacity:	Qbat = 30 kWh

Acceleration:

Maximal torque on the front wheels:

$$Mw = 500\ Nm * 2{,}65 = 1325\ Nm$$

Force that is needed for this torque:

$$F = M\ \div r = 1325\ Nm\ \div 0{,}32\ m = 4140{,}6\ N$$

Acceleration is:

$$a = F\ \div m = 4140{,}6\ N\ \div 1500\ kg = 2{,}76\ m/s^2$$

Acceleration time from 0 to 100 km/h (=27, 77 m/s):

$$t = v\ \div a = 27{,}77\ m/s \div 2{,}76\ m/s^2 = 10\ s$$

Final EV speed:

Nominal DC battery voltage:	384 Vdc
Specific load motor speed:	7,5 RPM/1Vdc at full load

Maximal motor RPM according to specific load motor speed:

$$N_{mot} = 348\ Vdc * 7{,}5\ RPM/1Vdc = 2880 RPM$$

Maximal wheel rotating at full load:

$$Nw = 2880\ RPM\ \div 2{,}65 = 1087\ RPM$$

Circumference of the wheel:

$$Cr = 2 * 3{,}14 * 0{,}32\ m = 2{,}01\ m$$

Maximal EV speed without magnetic field weakening:

$$V_{max} = 1087\ RPM * 60 * 2{,}01\ m\ \div 1000 = 131{,}1\ km/h$$

!Note: Maximal EV speed can be much higher at the same power with magnetic field weakening (MFW). This setting can be made in the controller software.

Travel range with 30 kWh of battery capacity:

Average power, which is needed to drive EV approximately 100 km/h, is approximately 14 kW motor power. Therefore theoretically expected travel range is at least to 200 km with one charging of the batteries. In practice the producer of the batteries does not recommend 100% discharging of the batteries, therefore 180 km is what can be expected in reality.

22. EMRAX Certificates

EMRAX motors are in the process of obtaining certificates.
Until now the EMRAX motor obtained the EMC certificate (E26) – electromagnetic field testing. This means that the motor complies with essential protection requirements of EMC Directive 2014/30/EU. EMRAX approval number is: **E26 10 R 05 1160**. EMC certificate is important for electric vehicles.

23. EMRAX disclaimer

The EMRAX Company does not assume any responsibility for difficulties, which are the result of inappropriate configuration, electric system structure and settings that are not in accordance with the latest version of the Manual for EMRAX motors. Every motor is tested before shipping at ambient conditions and parameters, which are described in the Technical Data Tables. If EMRAX motors are not used in accordance with this manual it causes a void of warranty. Products of the EMRAX Company have been developed for usage on electric vehicles, planes, boats, power plants. Company EMRAX assumes no liability in case a customer uses components for the purposes for which they have not been developed or tested, and especially not for the purpose of presenting a direct threat to human life or health. The EMRAX Company does not assume any responsibility for damages caused by using the motors for testing purposes in circumstances which differ from standard usage of the motor. Any responsibility of the EMRAX Company expires in one year after the delivery of the motor. For maintenance and usage standards see Manual for EMRAX motors. The EMRAX Company does not take any responsibility on damages, injuries or other consequential losses caused by product failure of the user or any third person.

General Terms and Conditions of the EMRAX Company are available here: www.emrax.com

24. Service

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We now wish you lots of fun and success with your high performance EMRAX engine.