Manual for EMRAX Motors / Generators

LIST OF CHANGES

Version	Reason and description for change	Changed pages	Date
5.4	//complete change of document//	/	5th of March 2020

Contents

Table of Figures

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. The first prototype was mounted onto the glider airplane Apis EA2 in 2008, 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. (2010), Siemens GmbH (May 2012) and Letrika d.d. now MAHLE Electric Drives Slovenia d.o.o. (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 and is committed to further development, testing and obtaining certificates.

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 motor
- Outrunner (outer part is rotating)
- Input type: sinusoidal three phase
- Lightweight - best in class power density (up to 10 kW/kg)
- Highly efficient (up to 98%)
- High torque at low RPM
- Reliable (developed and produced for the aerospace industry)
- Compact and high-quality product
- EMC Compliant – E marked (complies with essential protection requirements of 89/336/EEC)
- Low cost
- 3 cooling options Air (IP21), Combined (IP21) or Liquid (IP65)
- Low noise
- Stacking capability (two same sized motors connected on the same shaft)

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 420 kWp – e.g. EMRAX 348 type). EMRAX motors use less material more efficiently to provide higher power densities than any comparable motor or generator.

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).

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 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.

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

EMRAX motors can be used:
- as main traction motors for vehicles
- for hybrid powertrain integration
- as range-extending generators
- for generating electric power from wind/water turbines
- as integrated starter generators (ISG)
- for hydraulic replacement

Warranty for EMRAX motor is 12 months from the receiving date. EMRAX motor should be used with this manual, otherwise the warranty does not apply.

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 this manual. 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 take any responsibility on damages, injuries or other consequential losses caused by product failure of the user or any third person. Any responsibility of the EMRAX company expires in one year after the delivery of the motor.

Sales conditions of EMRAX are available on our web site: www.emrax.com.

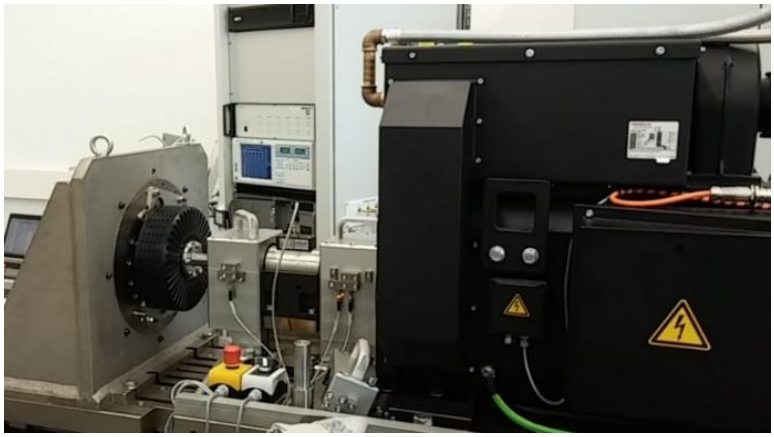


Figure 1: EMRAX motor testing at Letrika d.d.

1. Technical data of EMRAX motors

EMRAX motors/generators are **advanced axial flux synchronous 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:.

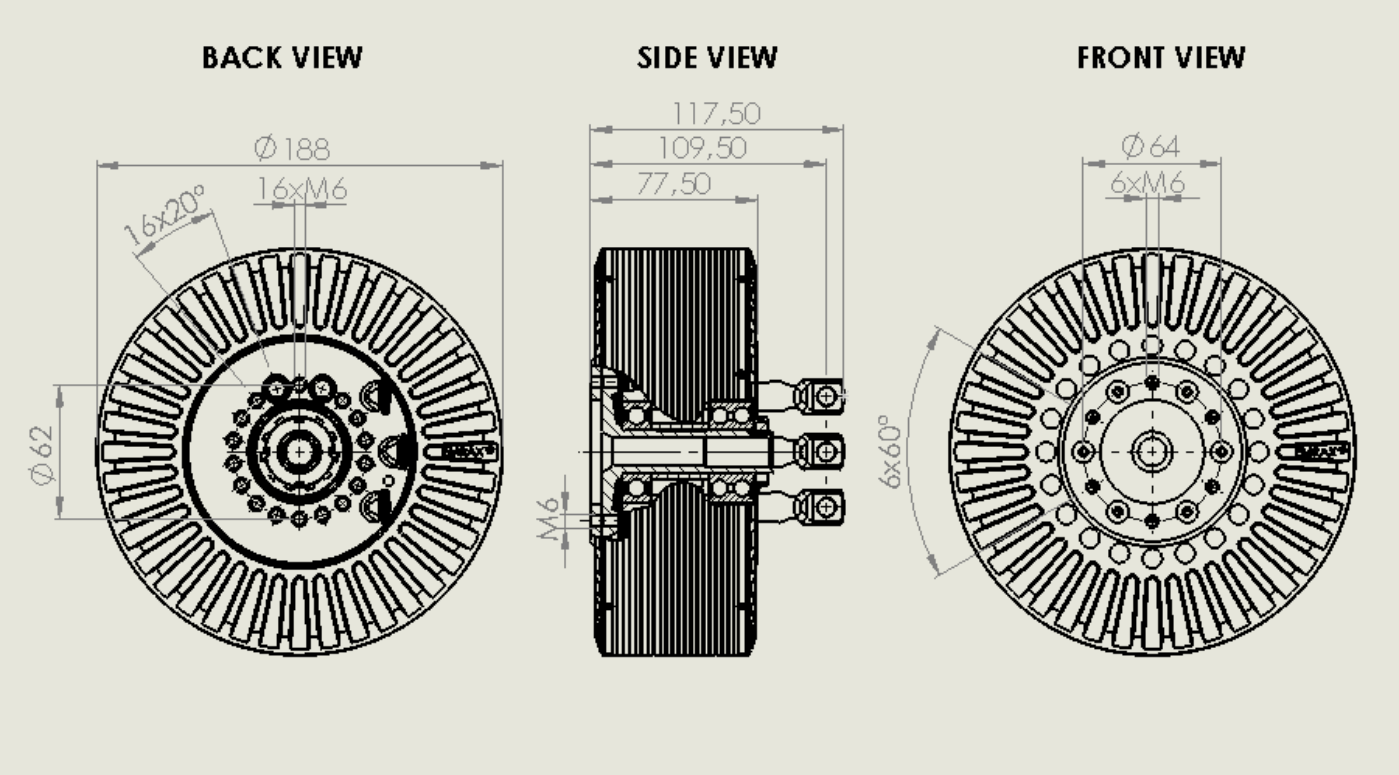


Figure 2: EMRAX 188 drawing

Figure 3: EMRAX 188 pictures

EMRAX 208:

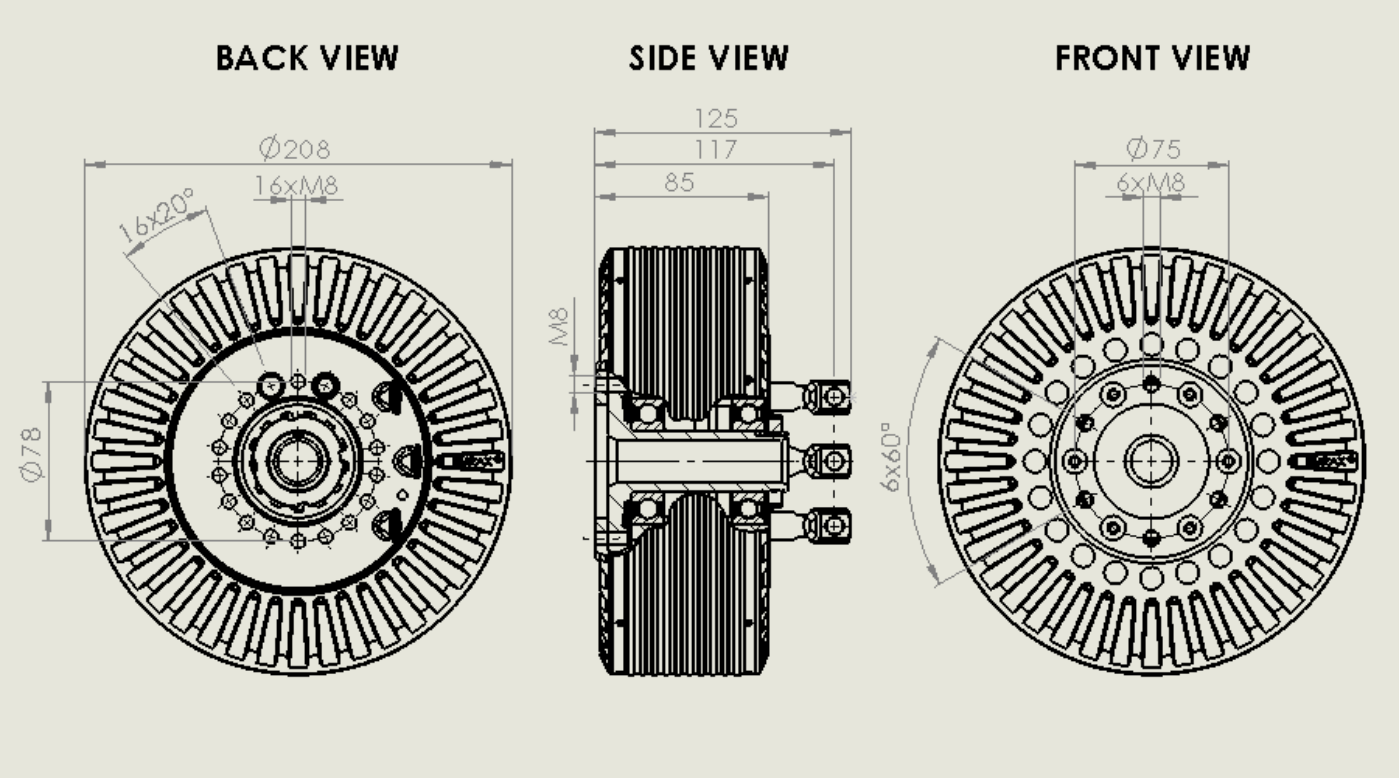


Figure 4: EMRAX 208 drawing

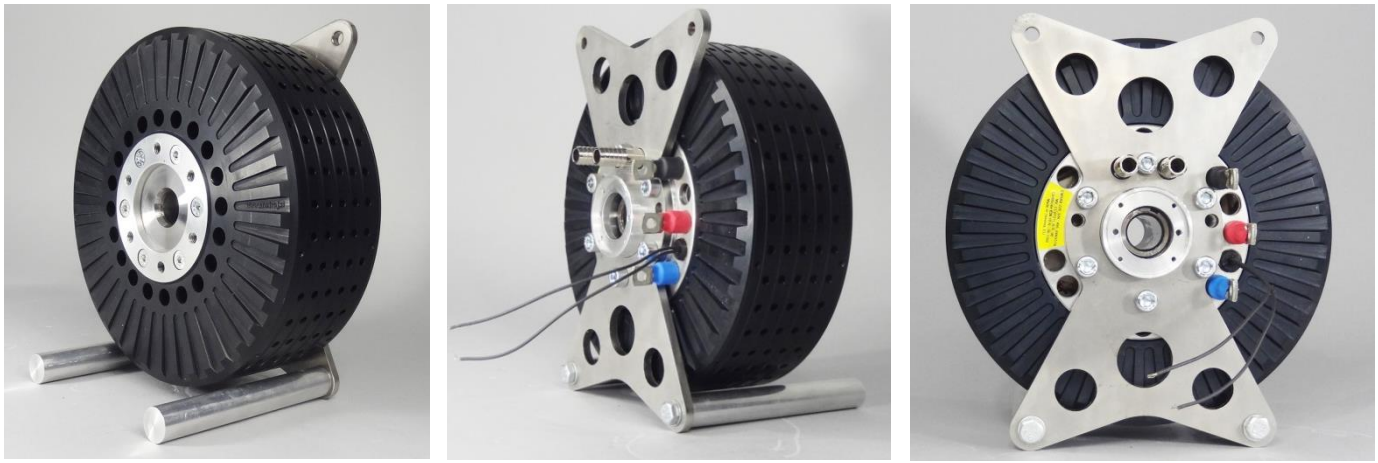


Figure 5: EMRAX 208 pictures

EMRAX 228:

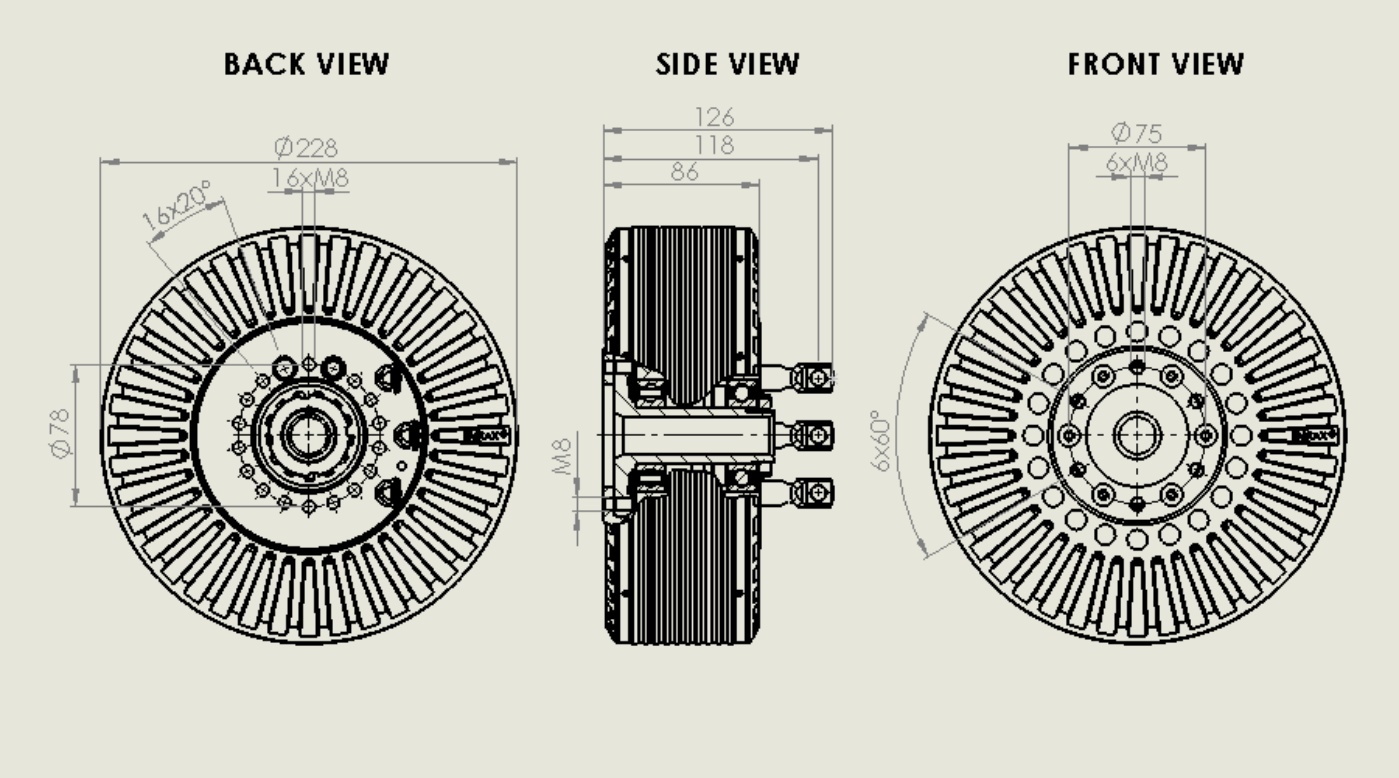


Figure 6: EMRAX 228 drawing

Figure 7: EMRAX 228 pictures

EMRAX 268:

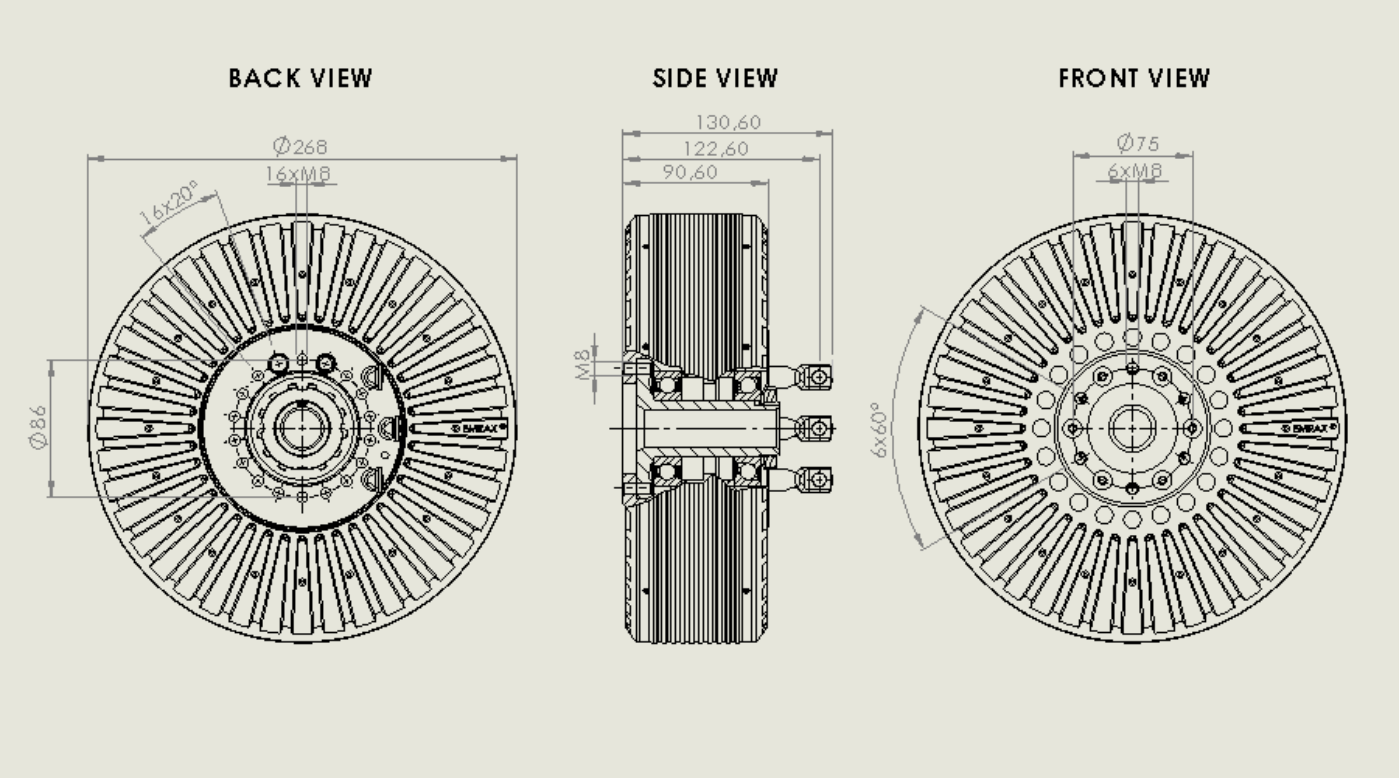


Figure 8: EMRAX 268 drawing

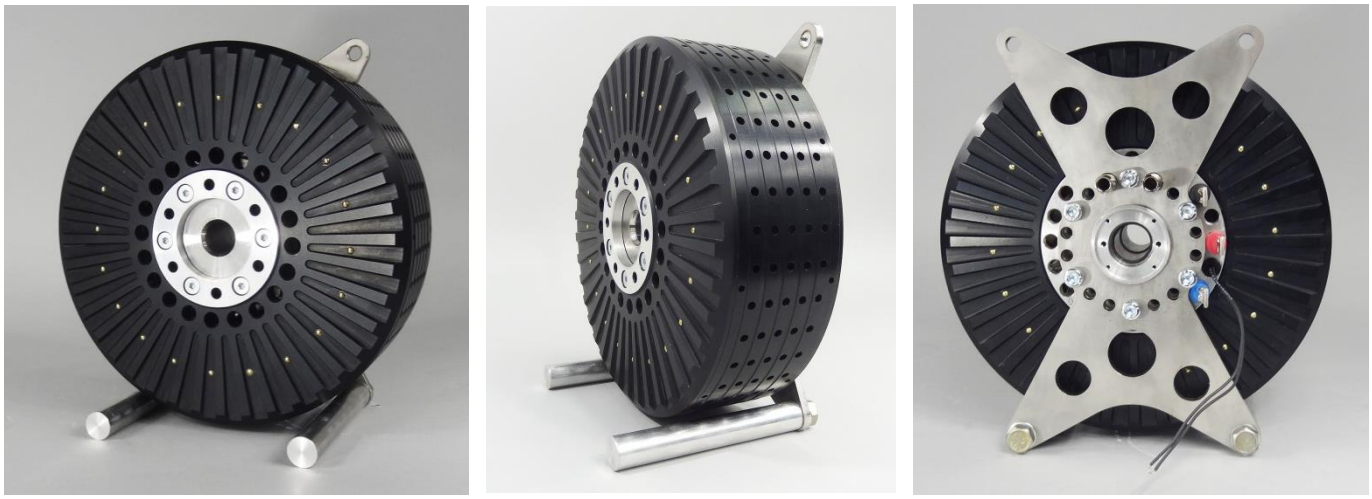


Figure 9: EMRAX 268 pictures

EMRAX 348:

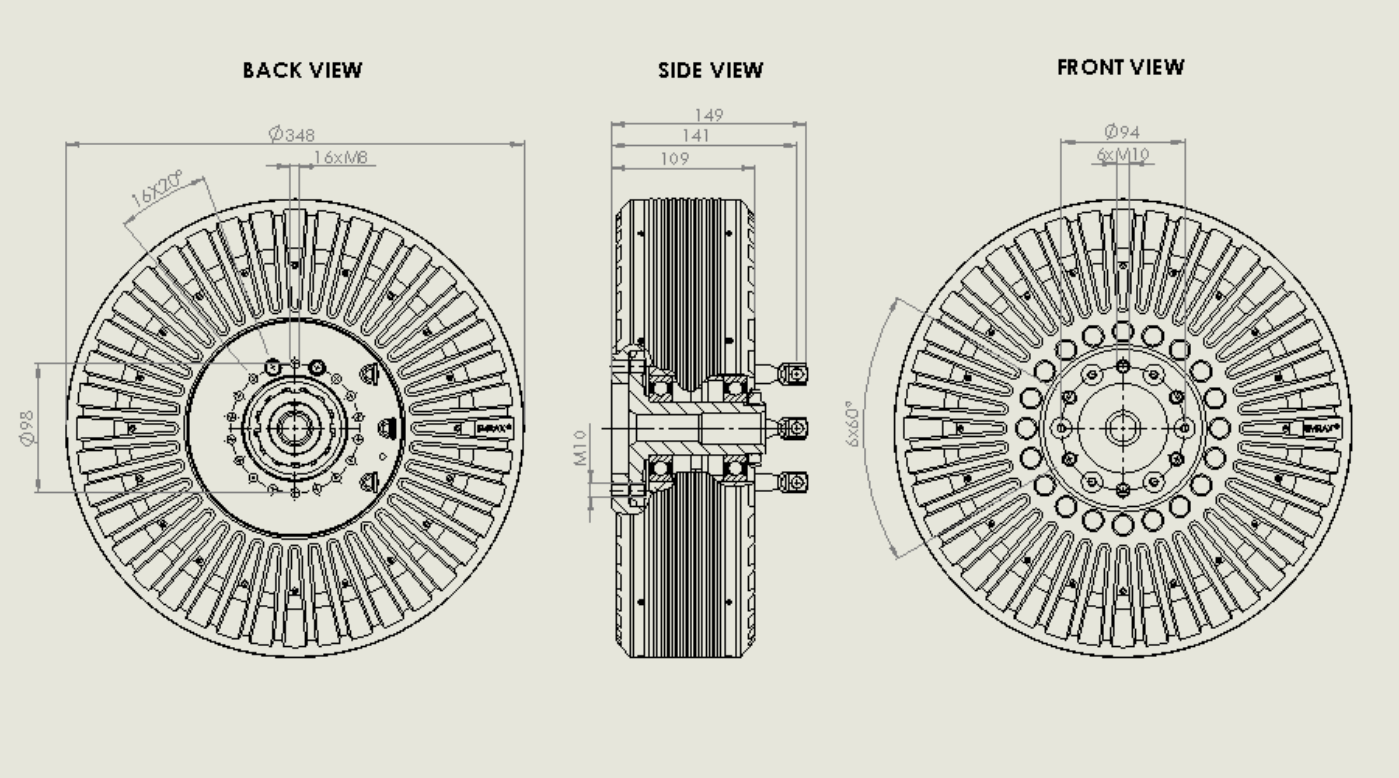


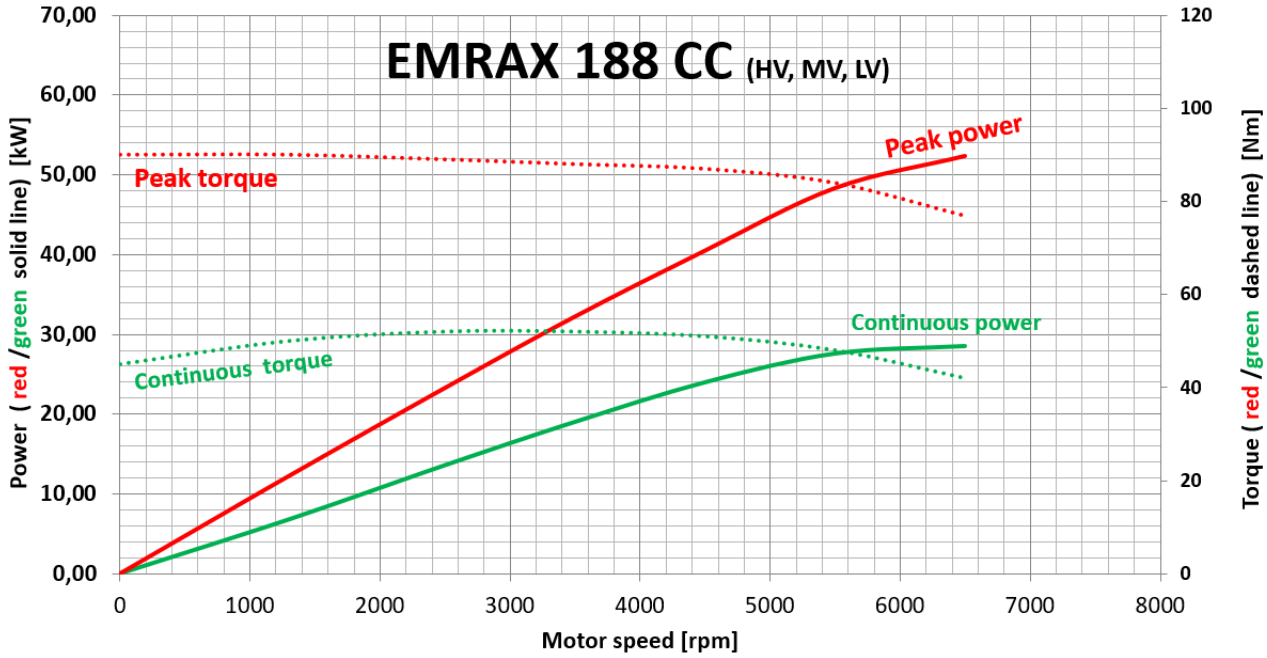
Figure 10: EMRAX 348 drawing

Figure 11: EMRAX 348 pictures

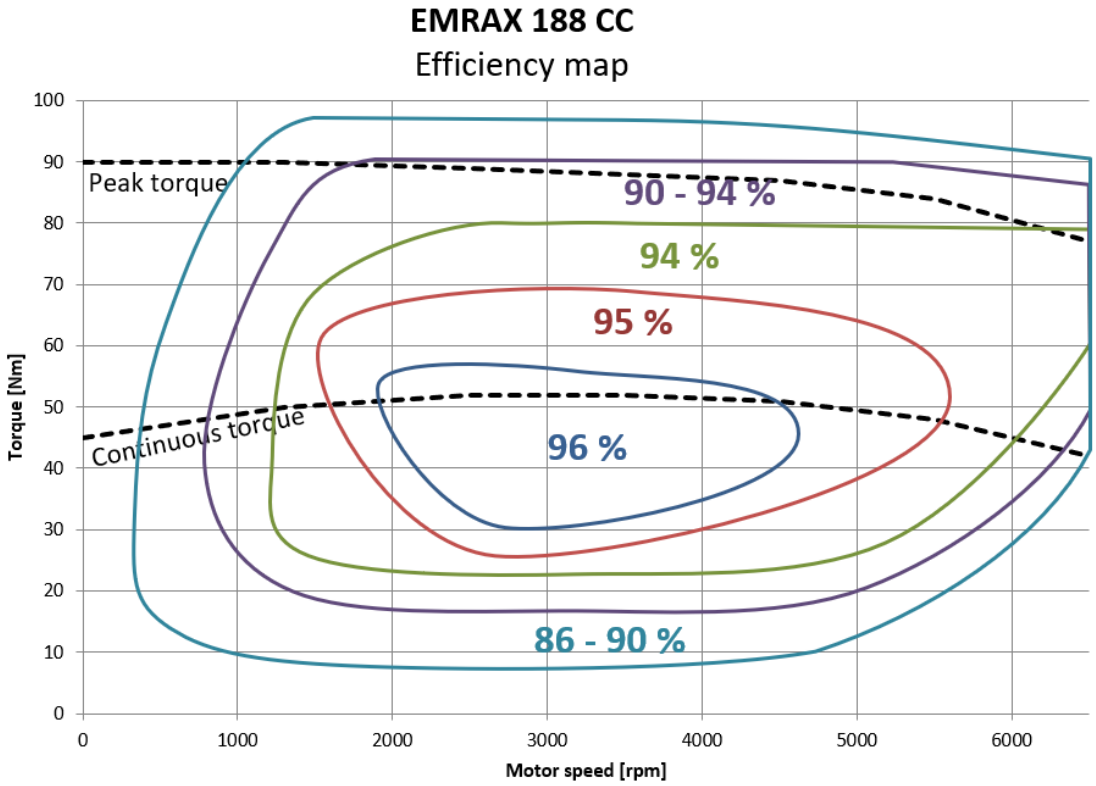
EMRAX 188 Technical Data Table

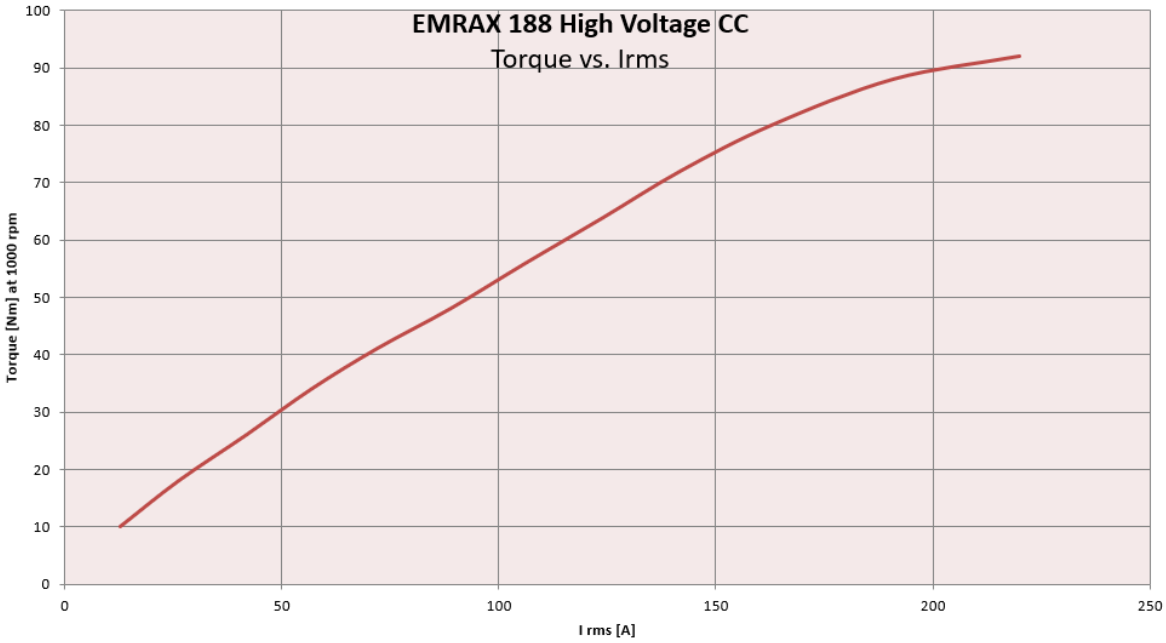
Type / Technical data	EMRAX 188 High Voltage			EMRAX 188 Medium Voltage			EMRAX 188 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	AC	LC	CC	AC	LC	CC	AC	LC	CC
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air 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]	7,0	7,3	7,2	7,0	7,3	7,2	7,0	7,3	7,2
Diameter ø / width [mm]	188 / 77								
Maximal battery voltage [Vdc] and max load RPM	430 Vdc (6500 RPM)			300 Vdc (6500 RPM)			110 Vdc (6500 RPM)		
Peak motor power at max load RPM (few min at cold start / few seconds at hot start) [kW]	52								
Continuous motor power (at 6500 RPM)	23	25	29	23	25	29	23	25	29
Maximal rotation speed [RPM]	6500 (8000 for a few seconds with magnetic field weakening)								
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]	90								
Continuous motor torque [Nm]	40	43	50	40	43	50	40	43	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]	12,0			5,0			0,8		
Input phase wire cross-section [mm²]	10,2			15,2			38,0		
Wire connection	star								
Induction Ld/Lq [µH] of 1 phase	92/102			40/44			5,4/6,0		
Controller / motor signal	sine wave								
AC voltage between two phases [Vrms/1RPM]	0,0384			0,0252			0,00923		
Specific idle speed (no load) [RPM/1Vdc]	19			28			75		
Specific load speed (max load) [RPM/1Vdc]	15			22			60		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100								
Magnetic flux – axial [Vs]	0,033			0,022			0,008		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor Inertia_ LC motor [kg*m²]	0,0134								
Bearings (front:back) - FAG	6204:3204 (for axial-radial forces; for pull-push mode, α=25°)								

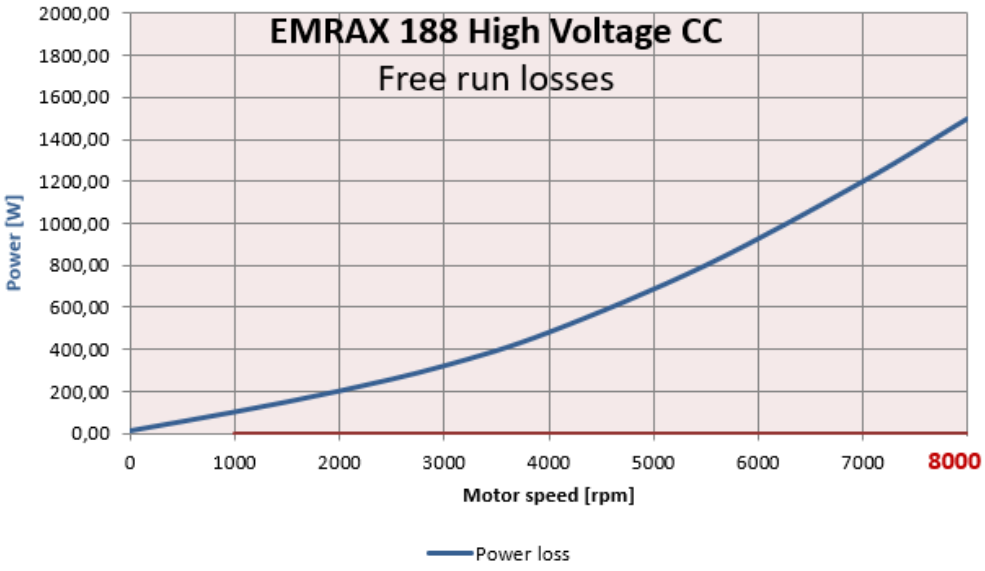
Graphs valid for EMRAX 188:



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)







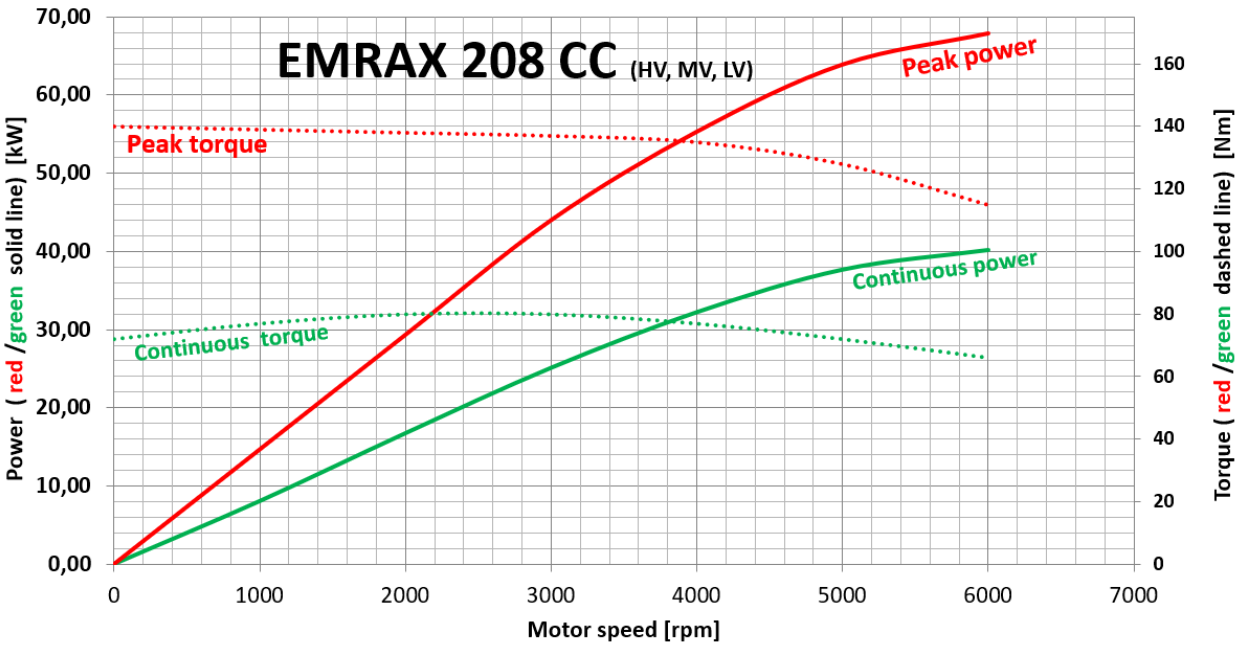
Graphs of EMRAX air cooled and liquid cooled type:
The continuous power and continuous torque for air cooled motor is 20% lower and for liquid cooled motor is 15% lower.

Graphs of the EMRAX 188 medium and low voltage motor type:
Graphs of EMRAX 188 low voltage and EMRAX 188 medium voltage are similar to graphs of EMRAX 188 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 188 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 188 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 188 high voltage motor.

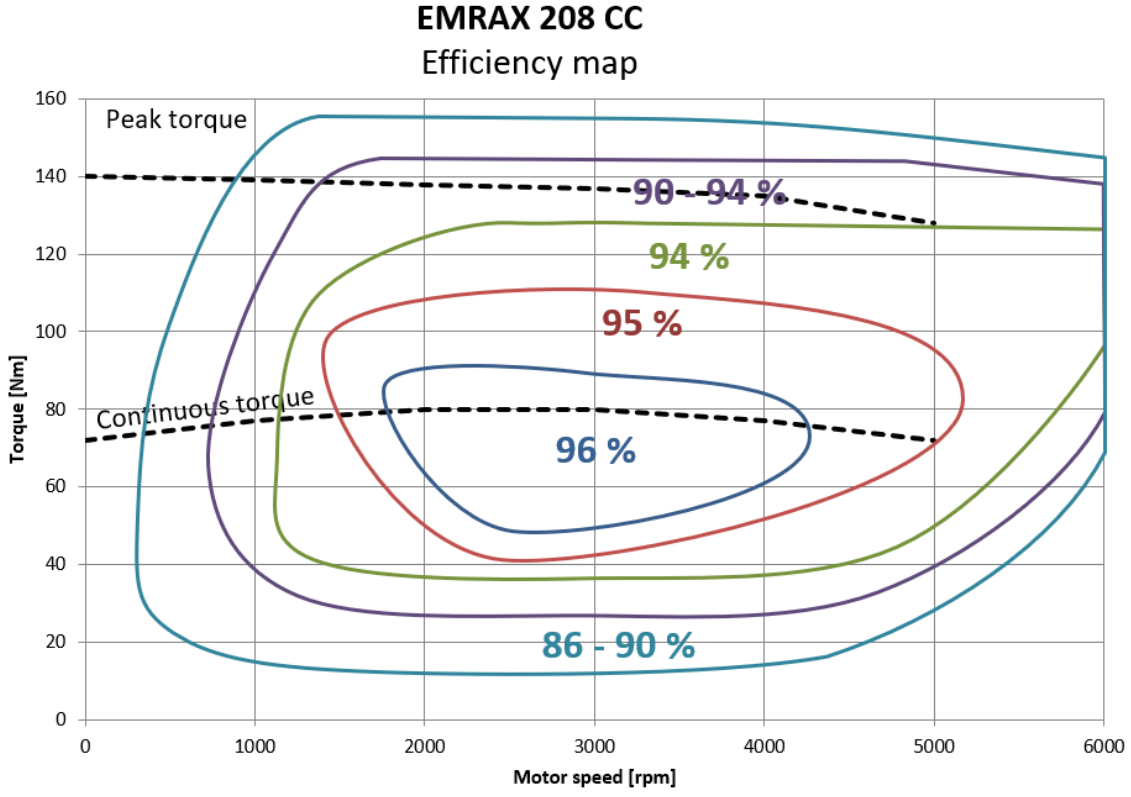
EMRAX 208 Technical Data Table (dynamometer test data)

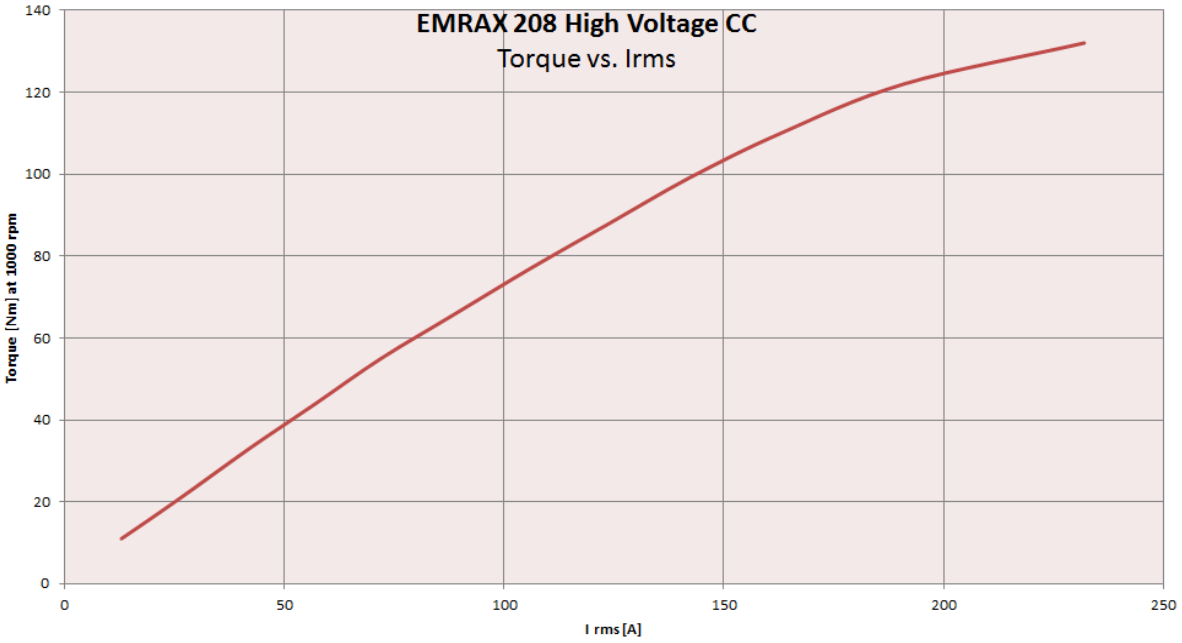
Type / Technical data	EMRAX 208 High Voltage			EMRAX 208 Medium Voltage			EMRAX 208 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	AC	LC	CC	AC	LC	CC	AC	LC	CC
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air 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 max load RPM	550 Vdc (6000 RPM)			350 Vdc (6000 RPM)			120 Vdc (6000 RPM)		
Peak motor power at max load RPM (few min at cold start / few seconds at hot start) [kW]	68								
Continuous motor power (at 6500 RPM)	33	35	41	33	35	41	33	35	41
Maximal rotation speed [RPM]	6000 (7000 for a few seconds with magnetic field weakening)								
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]	140								
Continuous motor torque [Nm]	64	68	80	64	68	80	64	68	80
Torque / motor current [Nm/1Aph rms]	0,80			0,50			0,19		
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			5,0			0,9		
Input phase wire cross-section [mm²]	11,4			17,0			42,5		
Wire connection	star								
Induction Ld/Lq [µH] of 1 phase	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/1Vdc]	15			22			58		
Specific load speed (max load) [RPM/1Vdc]	11			17			50		
Magnetic field weakening (for higher RPM at the same power and lower torque) [%]	up to 100								
Magnetic flux – axial [Vs]	0,0393			0,0257			0,0095		
Temperature sensor on the stator windings	kty 81/210								
Number of pole pairs	10								
Rotor Inertia LC motor [kg*m²]	0.023								
Bearings (front:back) - FAG	6206:3206 (for axial-radial forces; for pull-push mode, α=25°)								

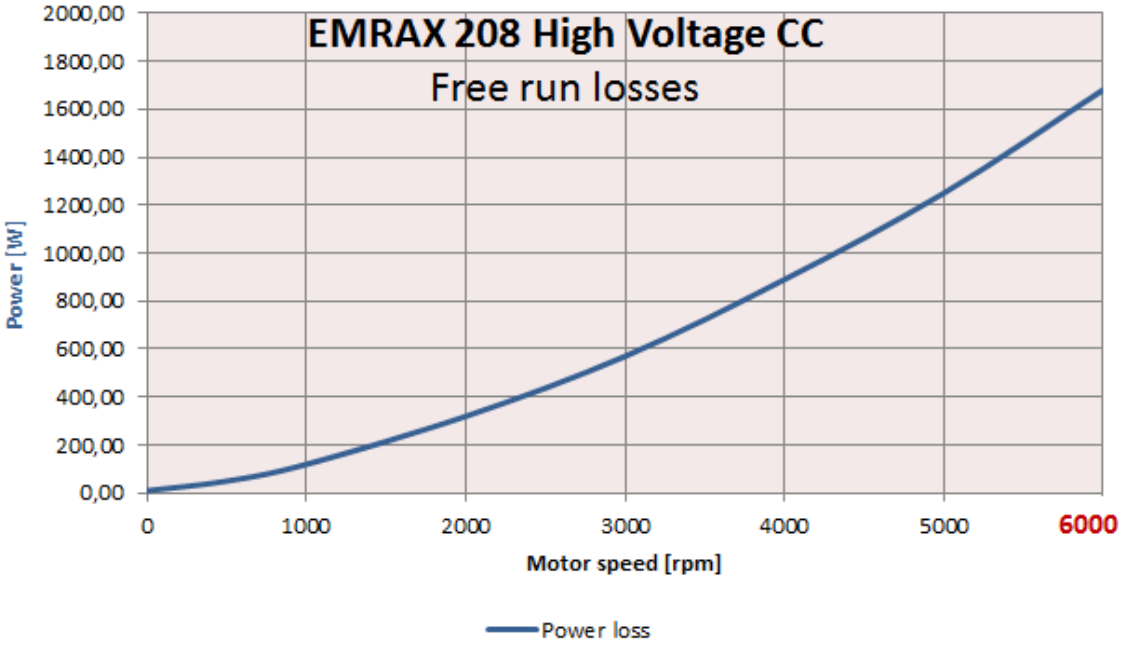
Graphs valid for EMRAX 208:



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)







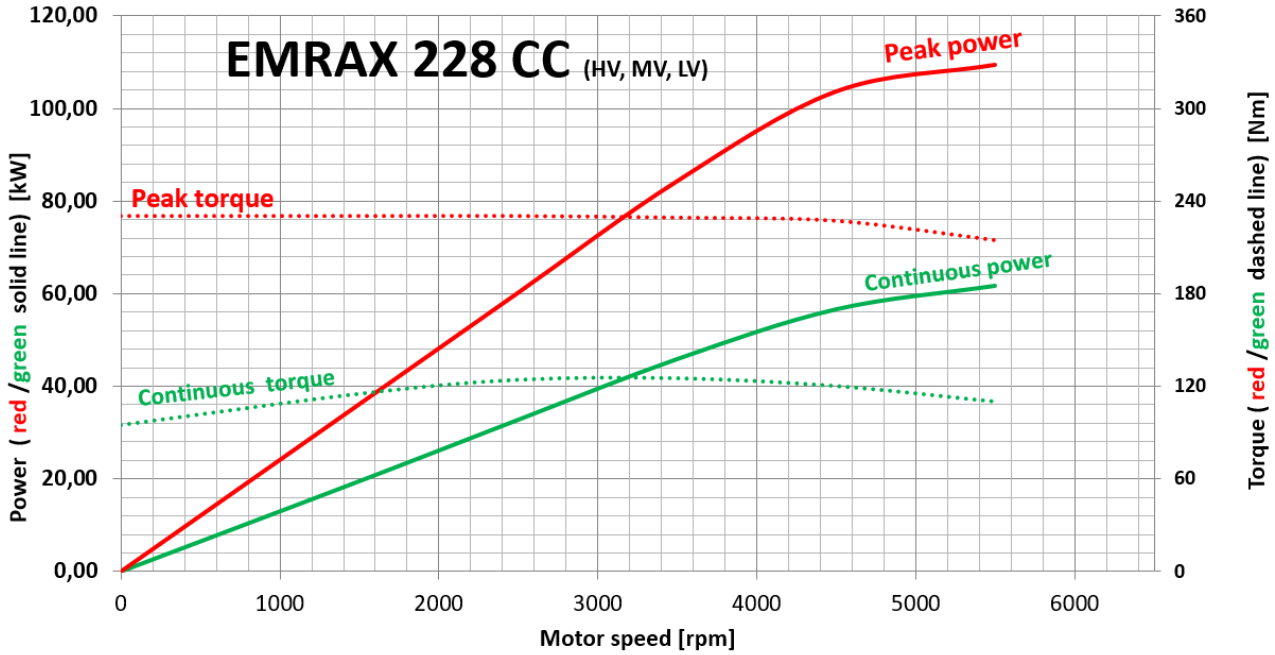
Graphs of EMRAX air cooled and liquid cooled type:
The continuous power and continuous torque for air cooled motor is 20% lower and for liquid cooled motor is 15% lower.

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.

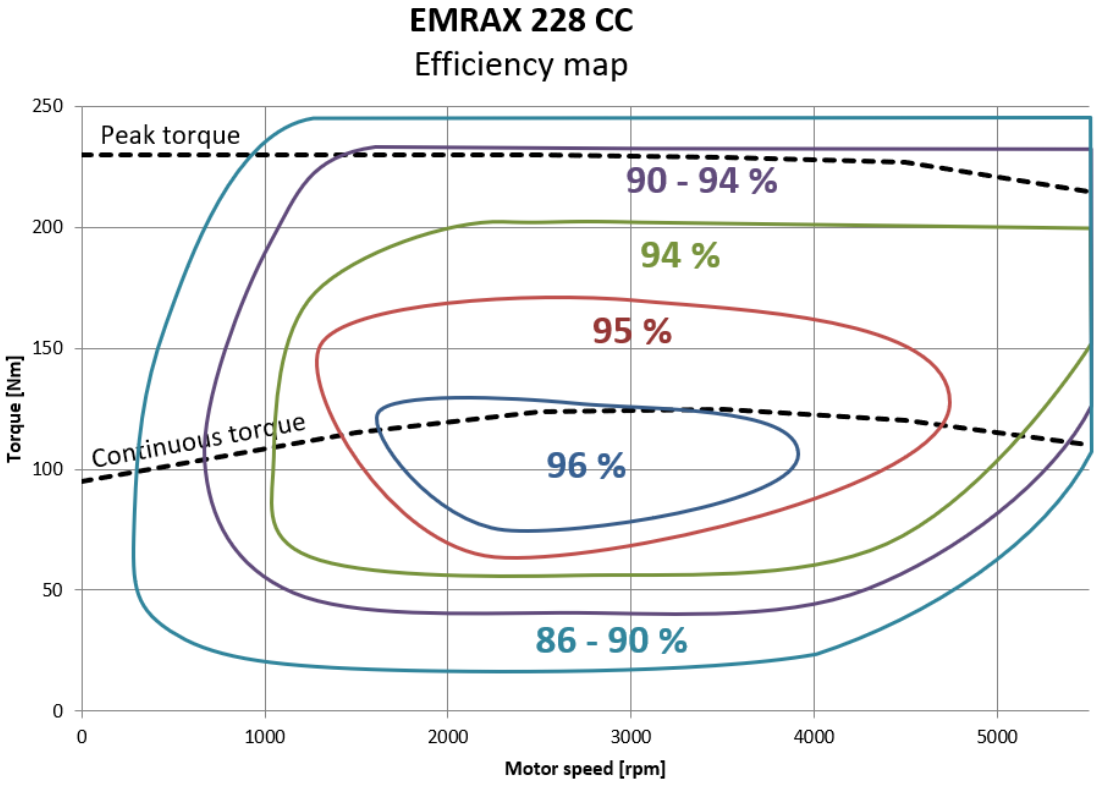
EMRAX 228 Technical Data Table (dynamometer test data)

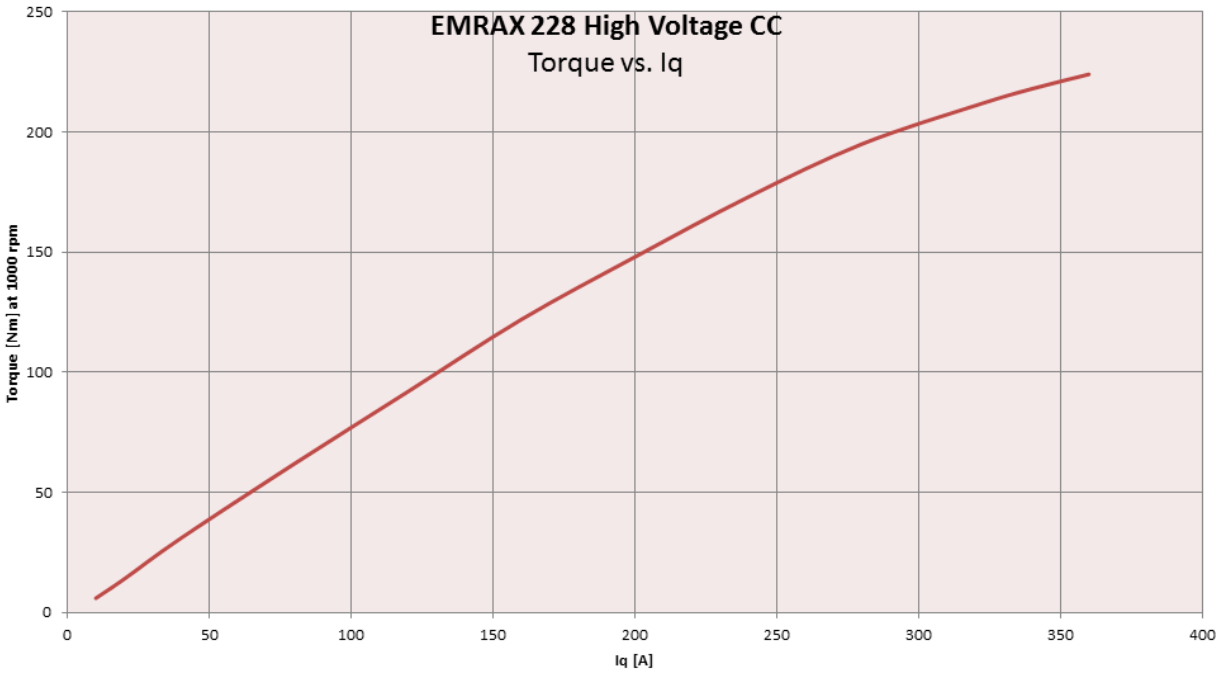
Type / Technical data	EMRAX 228 High Voltage			EMRAX 228 Medium Voltage			EMRAX 228 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	AC	LC	CC	AC	LC	CC	AC	LC	CC
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air 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	12,4	12,3	12,0	12,4	12,3	12,0	12,4	12,3
Diameter ø / width [mm]	228 / 86								
Maximal battery voltage [Vdc] and max load RPM	680 Vdc (5500 RPM)			500 Vdc (5500 RPM)			160 Vdc (5500 RPM)		
Peak motor power at max load RPM (few min at cold start / few seconds at hot start) [kW]	109								
Continuous motor power (at 5500 RPM)	50	53	62	50	53	62	50	53	62
Maximal rotation speed [RPM]	5500 (6500 for a few seconds with magnetic field weakening)								
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]	230								
Continuous motor torque [Nm]	96	102	120	96	102	120	96	102	120
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]	16,7			7,0			1,1		
Input phase wire cross-section [mm²]	11,4			17,0			42,5		
Wire connection	star								
Induction in Ld/Lq [µH] of 1 phase	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/1Vdc]	9,8			14			40		
Specific load speed (max load) [RPM/1Vdc]	8			11			34		
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 LC motor [kg*m²]	0,0383								
Bearings (front:back) - FAG	6206:3206 (for axial-radial forces; for pull-push mode, α=25°)								

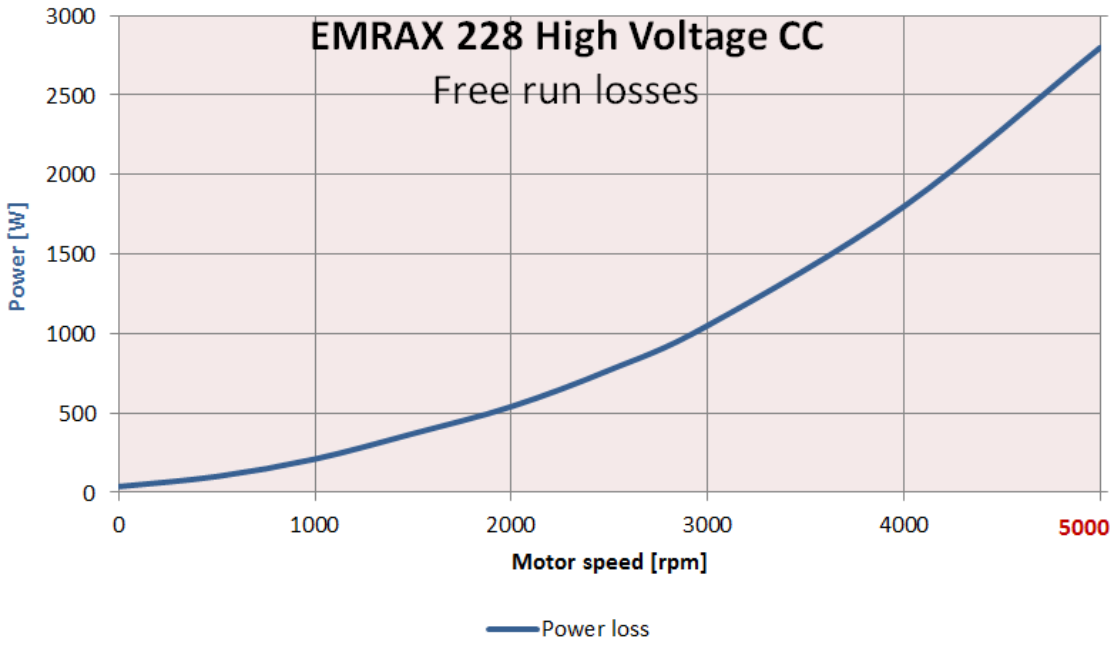
Graphs valid for EMRAX 228:



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 EMRAX air cooled and liquid cooled type:
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Graphs of the EMRAX 228 medium and low voltage motor type:
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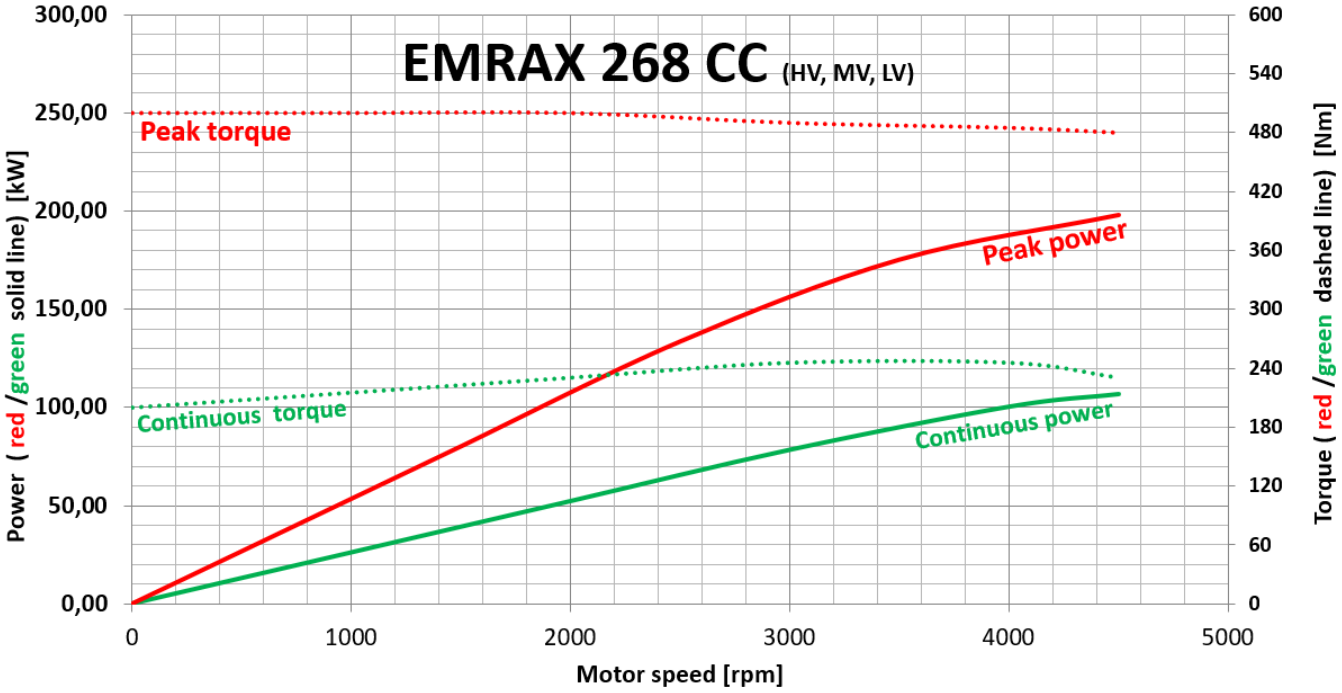
EMRAX 268 Technical Data Table

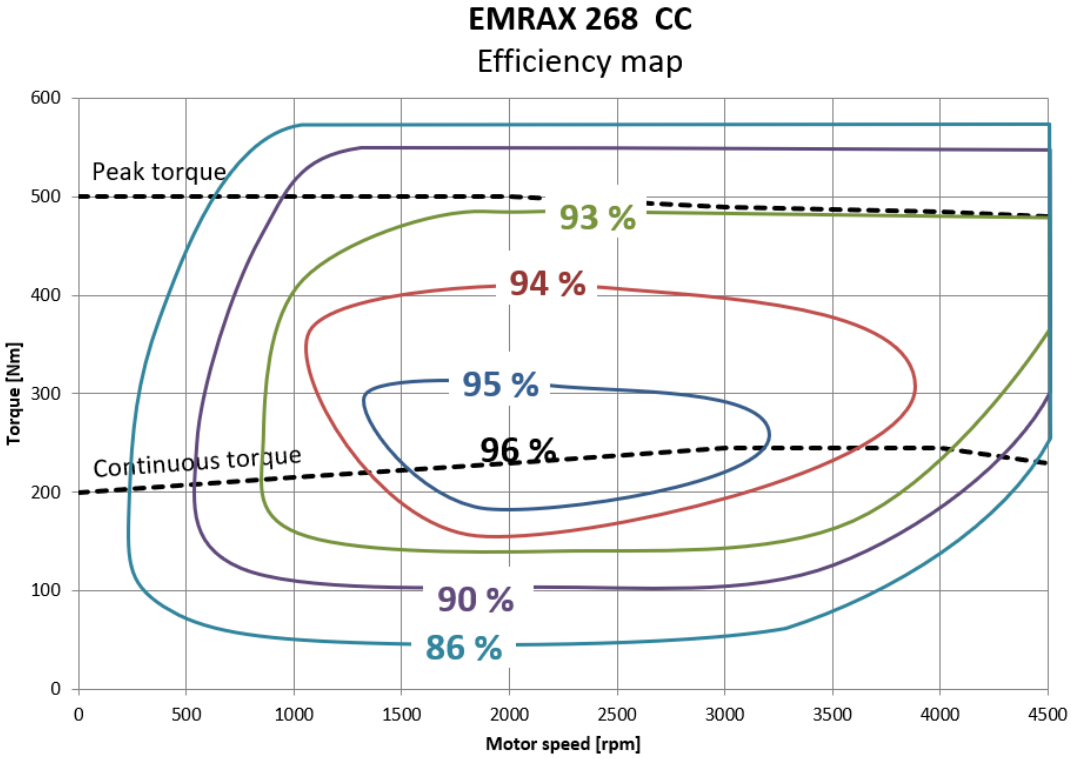
Type / Technical data	EMRAX 268 High Voltage			EMRAX 268 Medium Voltage			EMRAX 268 Low Voltage*		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	AC	LC	CC	AC	LC	CC	AC	LC	CC
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air 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]	20,0	20,5	20,3	20,0	20,5	20,3	20,0	20,5	20,3
Diameter ø / width [mm]	268 / 91								
Maximal battery voltage [Vdc] and max load RPM	800 Vdc (3600 RPM)			650 Vdc (4500 RPM)			250 Vdc (4500 RPM)		
Peak motor power at max load RPM (few min at cold start / few seconds at hot start) [kW]	160			200			200		
Continuous motor power (at 2000-4000 RPM) depends on the motor RPM [kW]	67	73	86	86	91	107	86	91	107
Maximal rotation speed [RPM]	4500 (5500 for a few seconds with magnetic field weakening)								
Maximal motor current (for 2 min if it is cooled as described in Manual) [Arms]	250			400			1000		
Continuous motor current [Arms]	125			190			500		
Maximal motor torque (for a few seconds) [Nm]	500								
Continuous motor torque [Nm]	200	213	250	200	213	250	200	213	250
Torque / motor current [Nm/1Aph rms]	1,90			1,30			0,46		
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]	22,9			10,5			1,8		
Input phase wire cross-section [mm²]	11,4			17			42,5		
Wire connection	star								
Induction in Ld/Lq [µH] of 1 phase	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/1Vdc]	5,4			8,2			22,0		
Specific load speed (max load) [RPM/1Vdc]	4,5			7			18		
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 LC motor [kg*m²]	0,0922								
Bearings (front:back) – FAG	7206:3207 (for axial-radial forces; for pull-push mode, α=25°)								

*EMRAX 268 low voltage version always has 2 sequences of phase connectors (2xUVW).

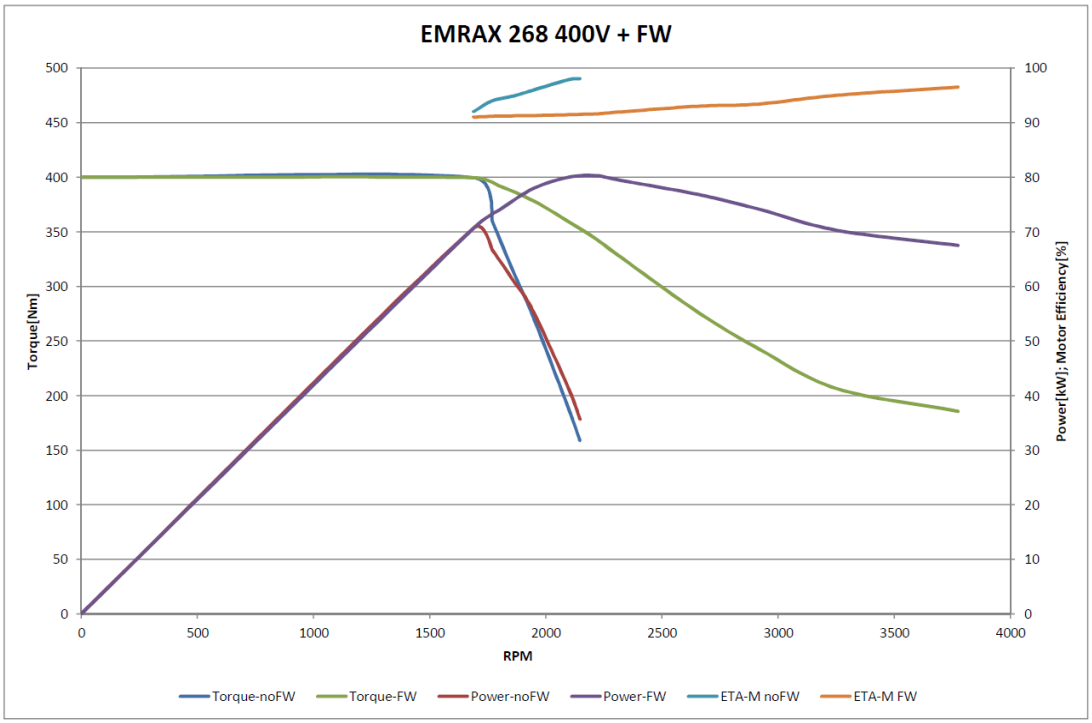
Graphs valid for EMRAX 268:

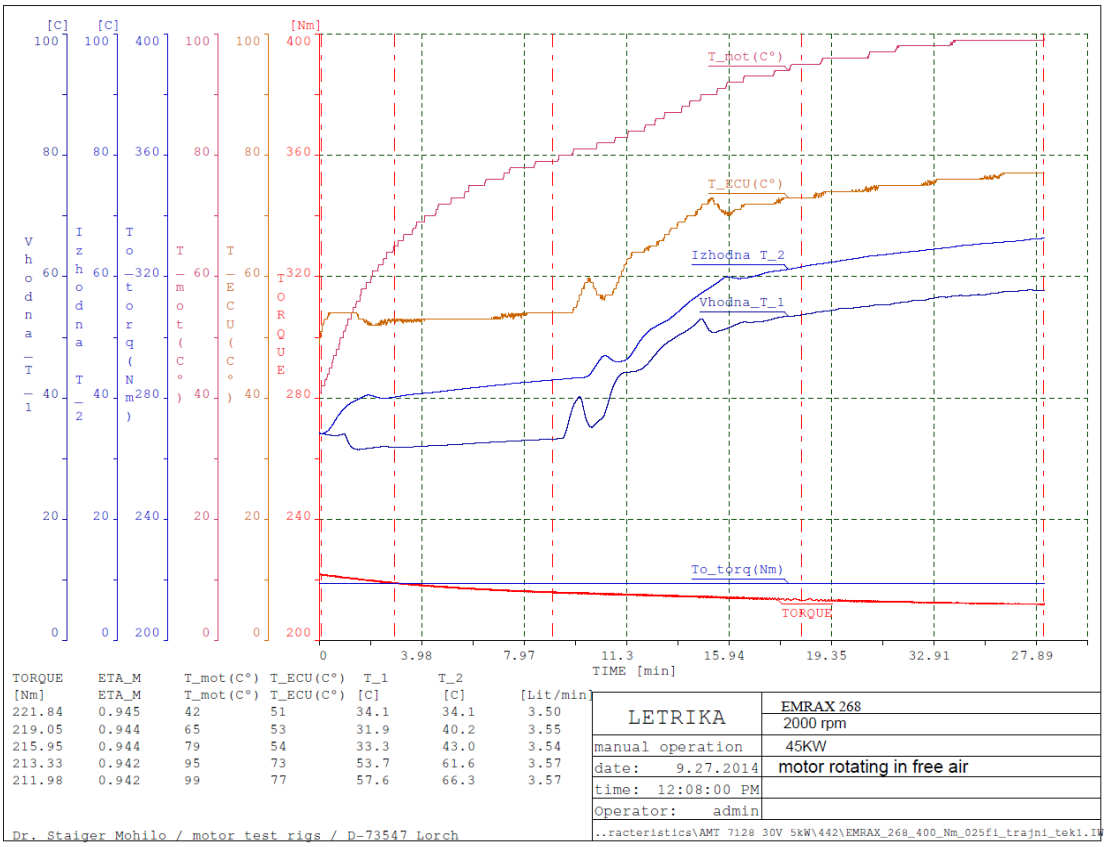


Note 1: for determening peak or continuous power (kW) you should choose motor speed and than read power from chosen power curve (in the left graph side)
Note 2: for determening peak or continuous torque (Nm) you should choose motor speed and than read torque from chosen torque curve (in the right graph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

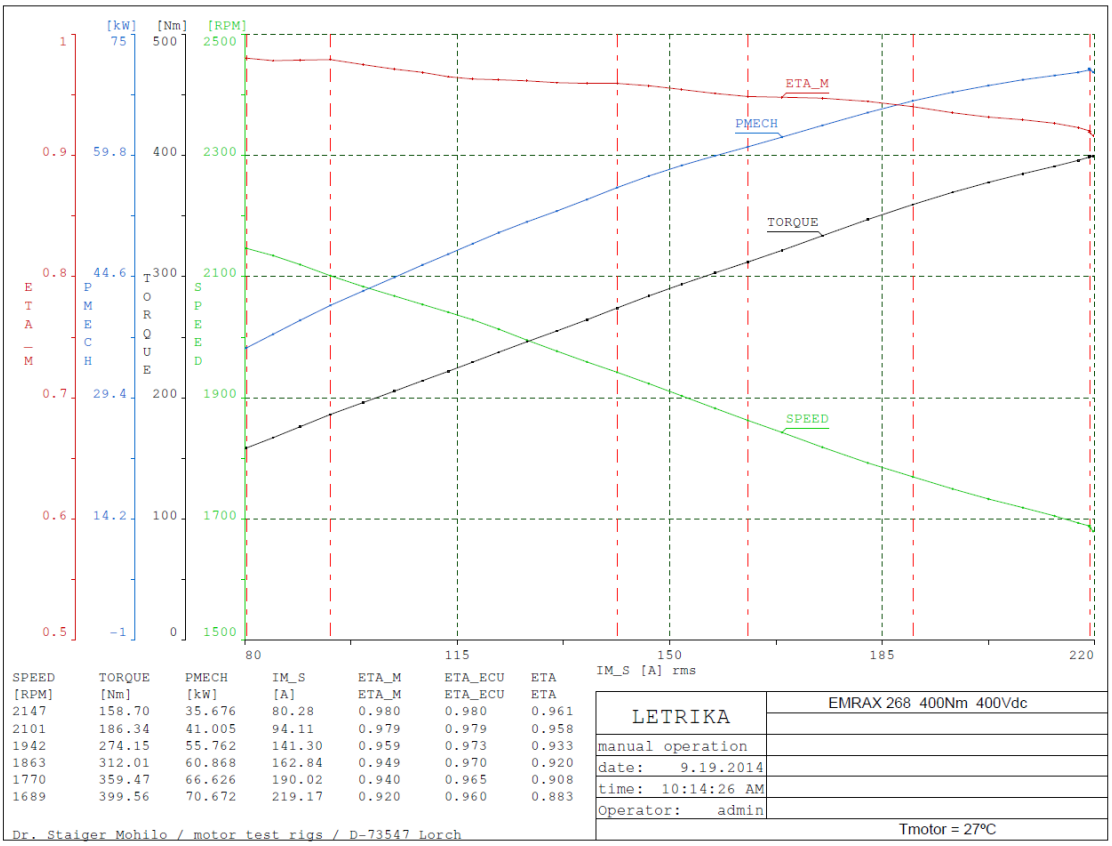


***Graphs from testing in Letrika (2014):**





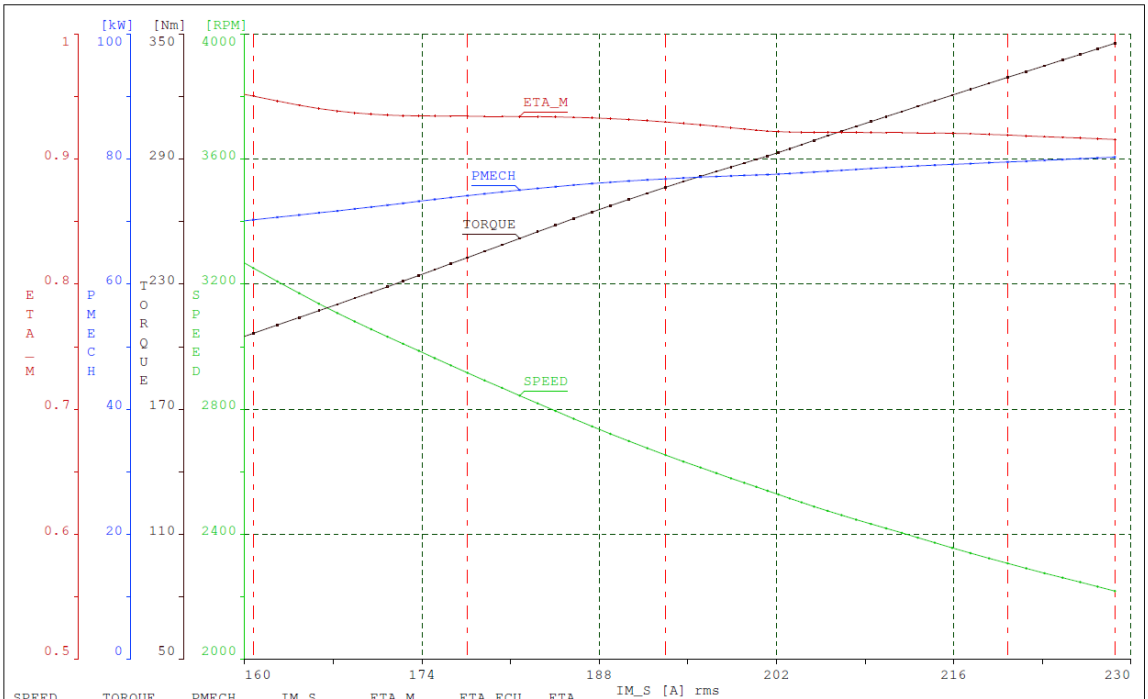
TORQUE [Nm]	ETA_M	T_mot(C°)	T_ECU(C°)	T_1 [C]	T_2 [C]	[Lit/min]
221.84	0.945	42	51	34.1	34.1	3.50
219.05	0.944	65	53	31.9	40.2	3.55
215.95	0.944	79	54	33.3	43.0	3.54
213.33	0.942	95	73	53.7	61.6	3.57
211.98	0.942	99	77	57.6	66.3	3.57



SPEED [RPM]	TORQUE [Nm]	PMECH [kW]	IM_S [A]	ETA_M ETA_M	ETA_ECU ETA_ECU	ETA 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

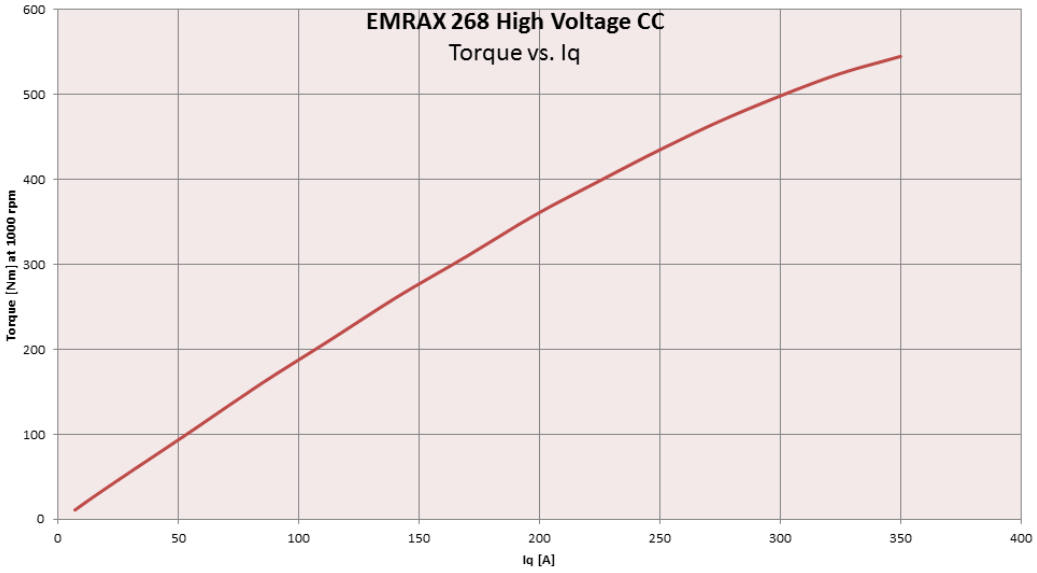
LETRIKA	EMRAX 268 400Nm 400Vdc
manual operation	
date: 9.19.2014	
time: 10:14:26 AM	
Operator: admin	
	Tmotor = 27ºC

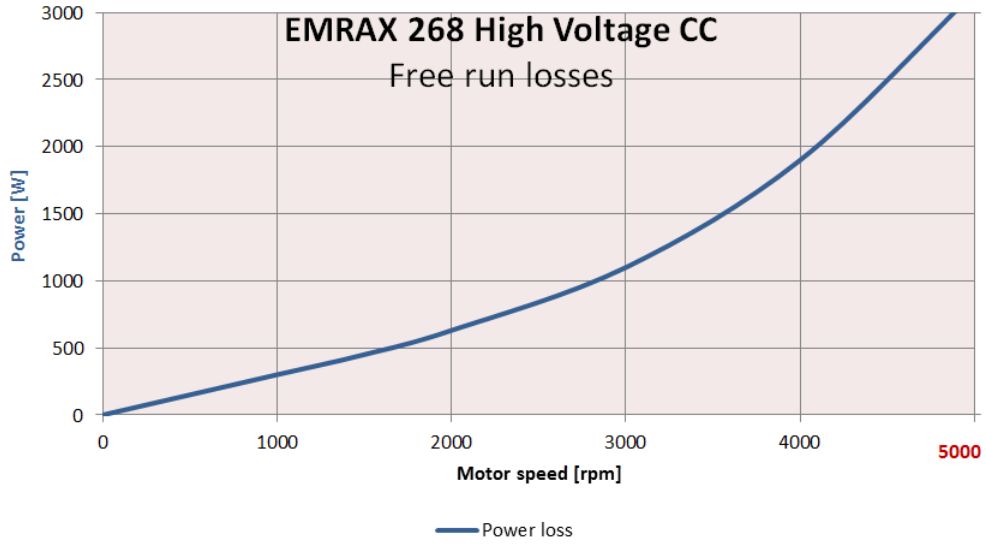


SPEED [RPM]	TORQUE [Nm]	PMECH [kW]	IM_S [A]	ETA_M ETA_M	ETA_ECU ETA_ECU	ETA ETA
3474	185.56	67.501	151.64	0.965	0.973	0.938
3252	206.39	70.276	160.69	0.950	0.972	0.924
2917	242.77	74.149	177.61	0.934	0.970	0.906
2654	276.50	76.844	193.25	0.930	0.967	0.899
2307	329.17	79.535	220.26	0.919	0.962	0.885
2219	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 = 27ºC





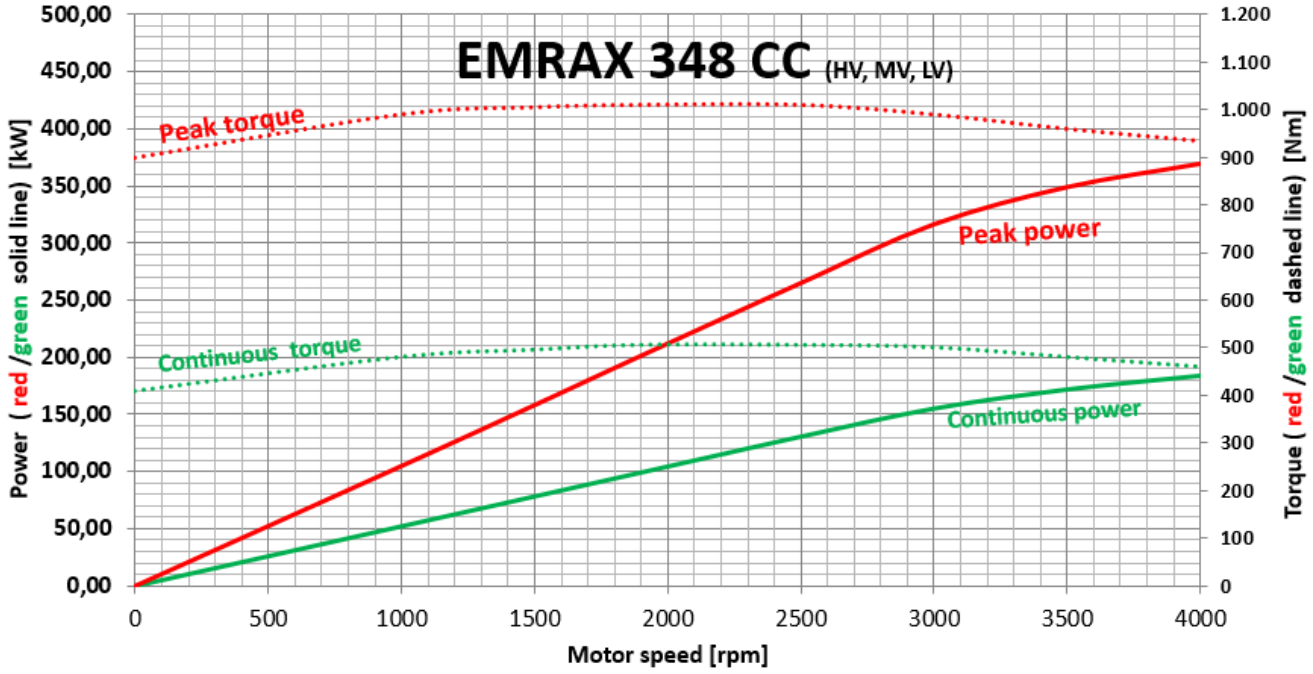
Graphs of EMRAX air cooled and liquid cooled type:
The continuous power and continuous torque for air cooled motor is 20% lower and for liquid cooled motor is 15% lower.

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.

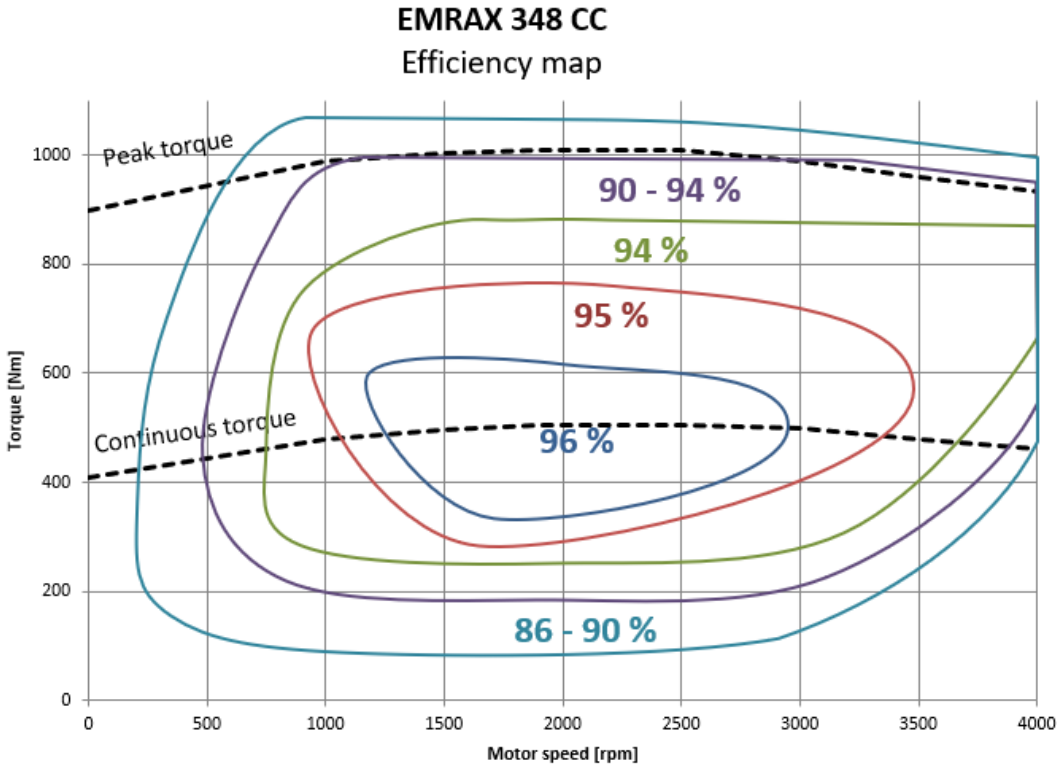
EMRAX 348 Technical Data Table

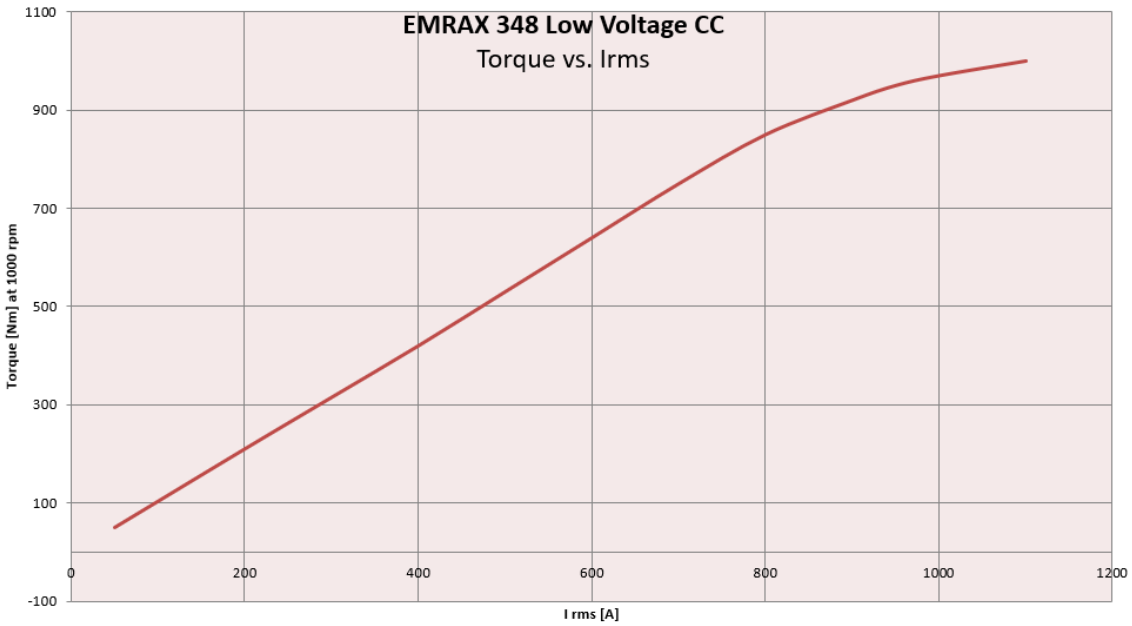
Technical data / Type	EMRAX 348 High Voltage			EMRAX 348 Medium Voltage			EMRAX 348 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	AC	LC	CC	AC	LC	CC	AC	LC	CC
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Water/glycol Flow = WF – if inlet water/glycol temperature and/or ambient temperature are lower, then continuous power is higher)	AF=20m/; 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]	41	42	41,5	41	42	41,5	41	42	41,5
Diameter ø / width [mm]	348 / 107								
Maximal battery voltage [Vdc] and max load RPM	800 Vdc (1840 RPM)			800 Vdc (2800 RPM)			420 Vdc (4000 RPM)		
Peak motor power at max RPM (few min at cold start / few seconds at hot start) [kW]	170			260			380		
Continuous motor power at load RPM [kW]	68	72	85	103	110	129	170	189	210
Maximal rotation speed [RPM]	4000 (4500 for a few seconds with 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]	400	425	500	400	425	500	400	425	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]	30			12,3			4,4		
Input phase wire cross-section [mm²]	11,4			17,0			42,5		
Wire connection	star								
Induction in Ld/Lq [µH] of 1 phase	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 (max load) [RPM/1Vdc]	2,3			3,5			9,5		
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 LC motor [kg*m²]	0,3654								
Bearings (front:back) – FAG	7208:3208 (for axial-radial forces; for pull-push mode, α=25°)								

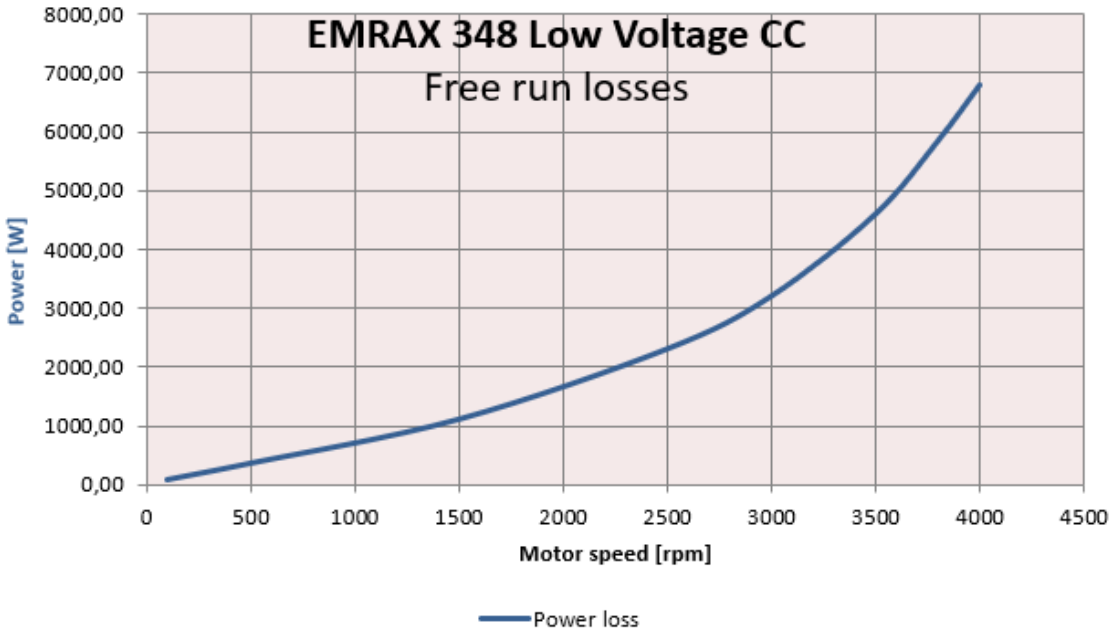
Graphs valid for EMRAX 348:



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)



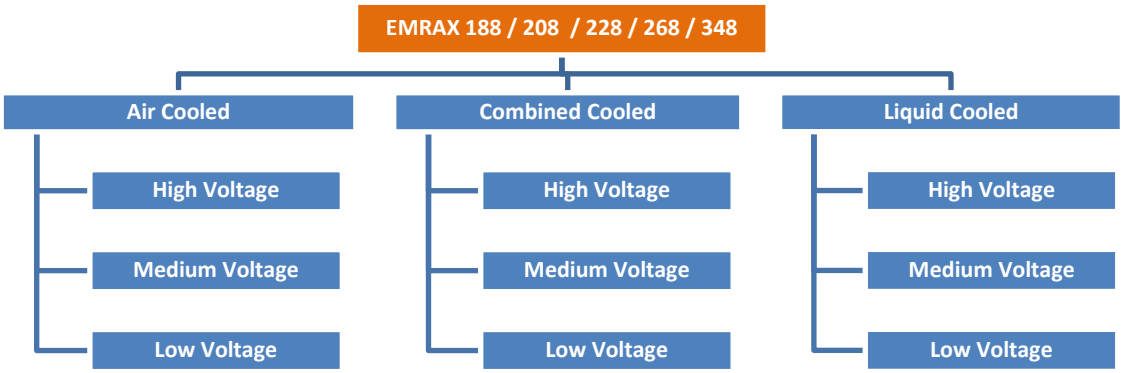


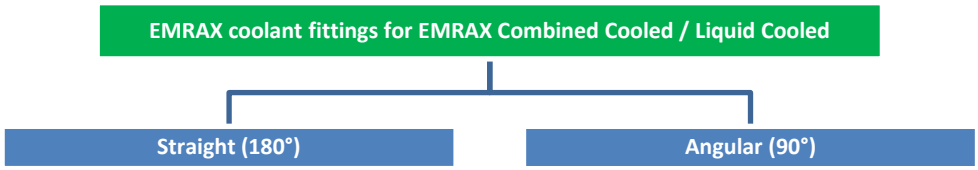


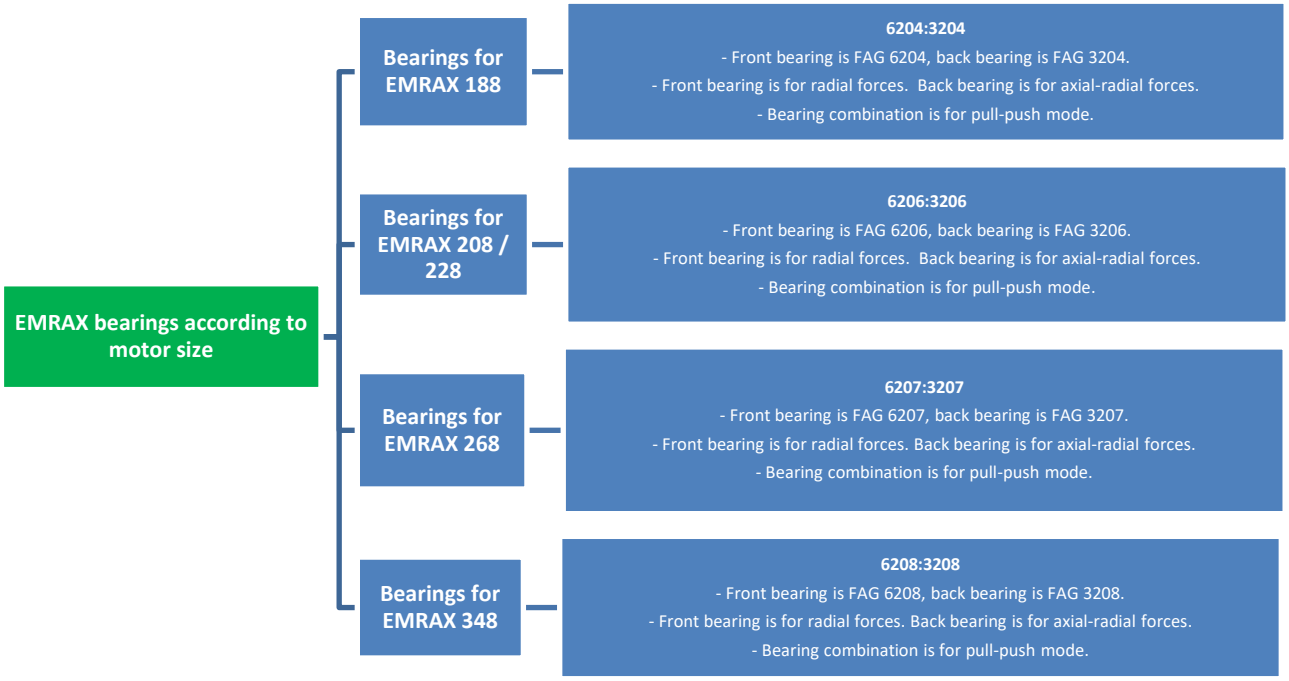
Graphs of EMRAX air cooled and liquid cooled type:

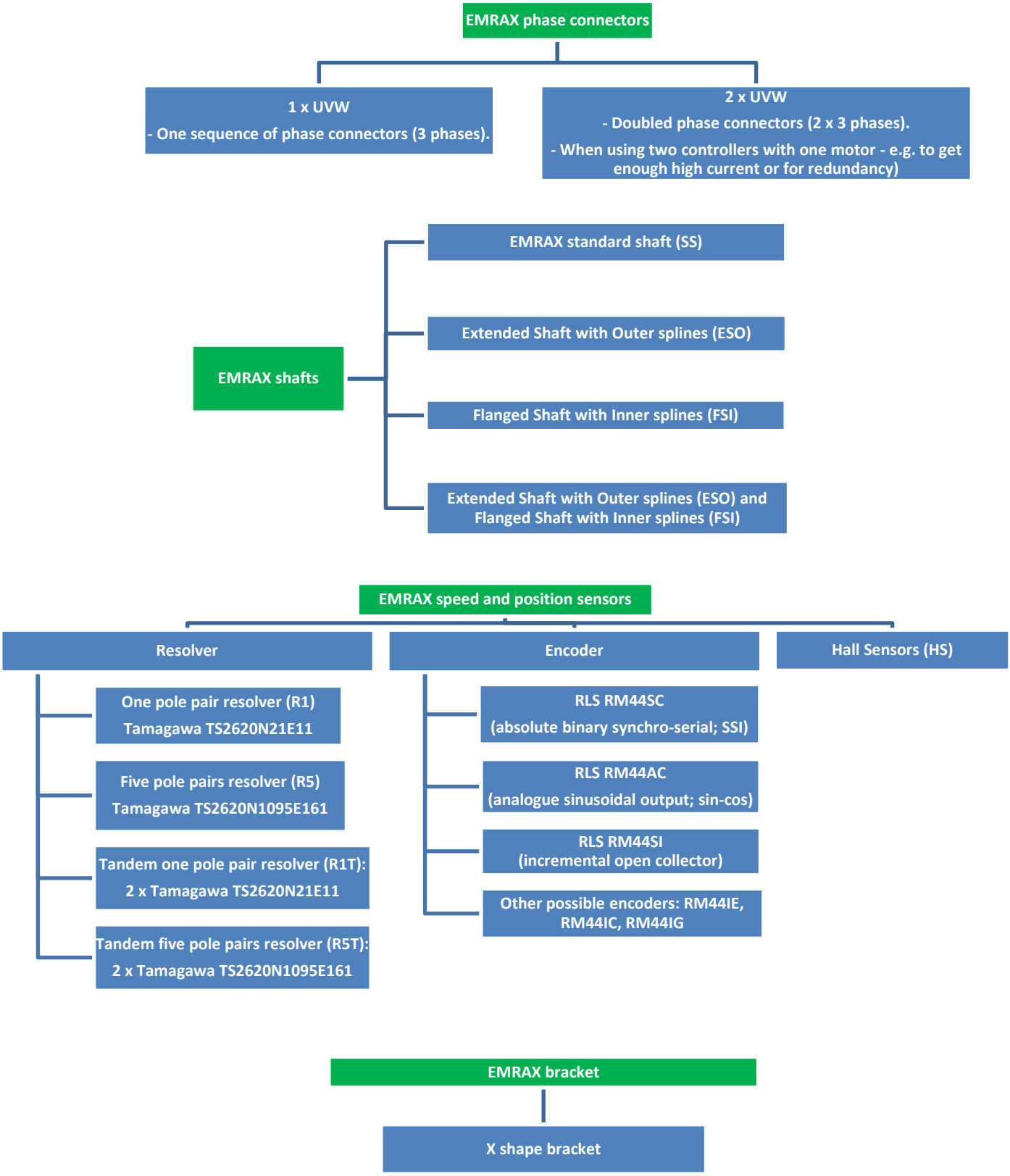
The continuous power and continuous torque for air cooled motor is 20% lower and for liquid cooled motor is 15% lower.

2. Motor types and additional motor parts








EMRAX phase connectors
1 x UVW
- One sequence of phase connectors (3 phases).
2 x UVW
- Doubled phase connectors (2 x 3 phases).
- When using two controllers with one motor - e.g. to get enough high current or for redundancy)
EMRAX shafts
EMRAX standard shaft (SS)
Extended Shaft with Outer splines (ESO)
Flanged Shaft with Inner splines (FSI)
Extended Shaft with Outer splines (ESO) and Flanged Shaft with Inner splines (FSI)
EMRAX speed and position sensors
Resolver
Encoder
Hall Sensors (HS)
One pole pair resolver (R1) Tamagawa TS2620N21E11
Five pole pairs resolver (R5) Tamagawa TS2620N1095E161
Tandem one pole pair resolver (R1T): 2 x Tamagawa TS2620N21E11
Tandem five pole pairs resolver (R5T): 2 x Tamagawa TS2620N1095E161
RLS RM44SC (absolute binary synchro-serial; SSI)
RLS RM44AC (analogue sinusoidal output; sin-cos)
RLS RM44SI (incremental open collector)
Other possible encoders: RM44IE, RM44IC, RM44IG
EMRAX bracket
X shape bracket

3. 3D drawings of EMRAX motors

EMRAX 3D drawings can be downloaded from www.emrax.com

4. Mounting the motor

Motor can only be mounted from back side and with at **least 6 bolts**.

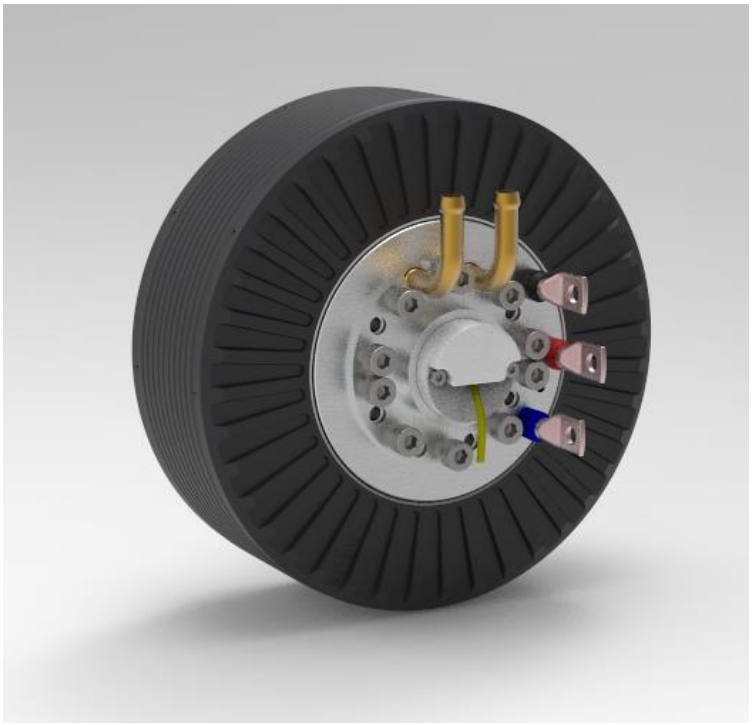


Figure 12: Motor mounting only from back side

Motor needs to be mounted **with at least 6 bolts** that are screwed down into the stator (measured from stator's plane surface):

- at least 15 mm and not more than 21 mm - for EMRAX 188 (M6 threaded boreholes)
- at least 20 mm and not more than 25 mm - for EMRAX 208 (M8 threaded boreholes)
- at least 20 mm and not more than 25 mm - for EMRAX 228 (M8 threaded boreholes)
- at least 24 mm and not more than 27,5 mm - for EMRAX 268 (M8 threaded boreholes)
- at least 28 mm and not more than 34 mm - for EMRAX 348 (M8 threaded boreholes)

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) or some other drive shaft can be mounted on the front motor side with 6 threaded bores intended for this in the rotor. The same bolt requirements apply when customer decides to take ESO (Extended Shaft with Outer Splines). In order to withstand torque, ESO must be additionally fixed with 6 bolts.

These **6 bolts** bolts must be screwed down into the rotor:

- at least 13 mm and not more than 13,8 mm - for EMRAX 188 (M6 threaded boreholes)
- at least 16 mm and not more than 16,8 mm - for EMRAX 208 (M8 threaded boreholes)
- at least 16 mm and not more than 16,8 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)

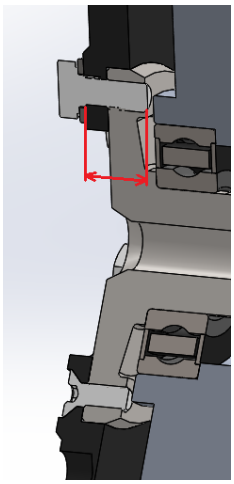


Figure 13: ESO shaft; bolts for ESO shaft

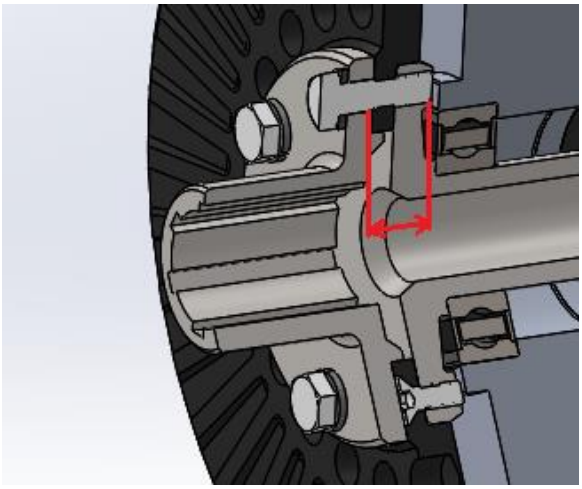


Figure 14: FSI shaft; bolts for FSI+SS shaft

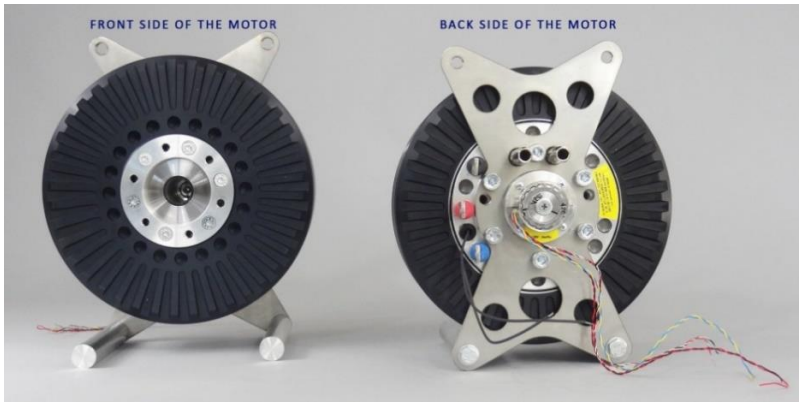


Figure 15: Mounting holes on front and back side of the motor

Brackets for mounting EMRAX motors are X shape brackets. The size of the bracket depends on the motor size. It is made from stainless steel. Two X shape brackets are used for mounting the EMRAX TWIN.

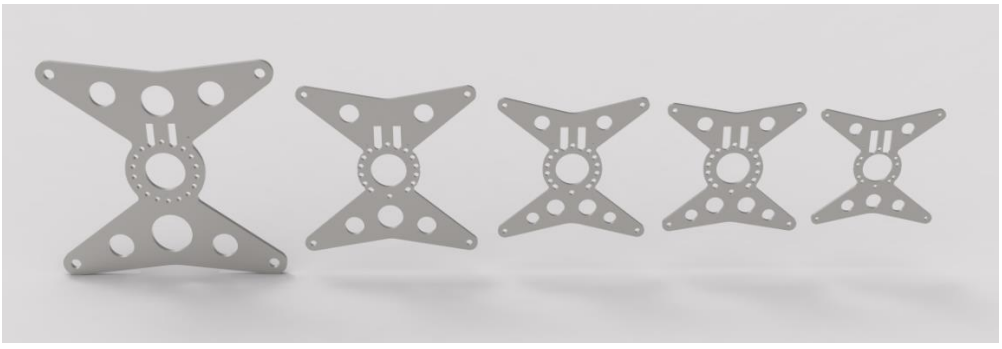


Figure 16: X brackets

5. Power/torque transmission and shafts

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

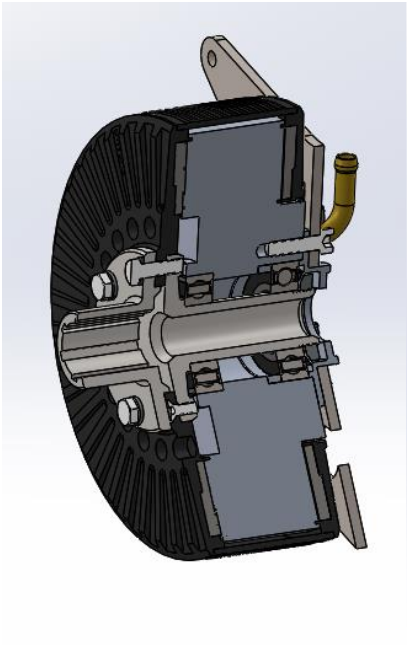


Figure 17: SS+FSI (front power output);

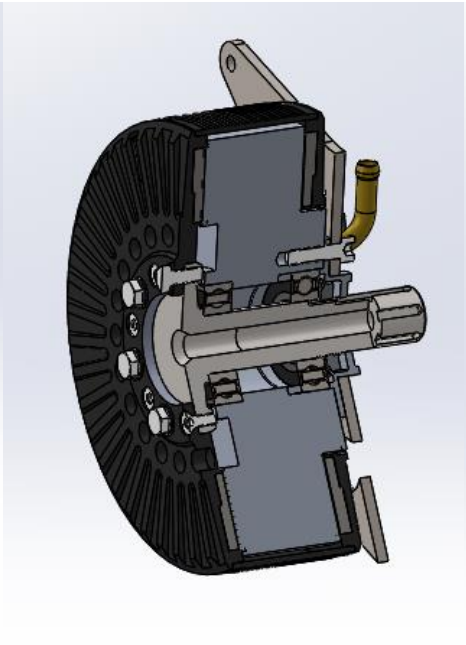


Figure 18: ESO (back power output);

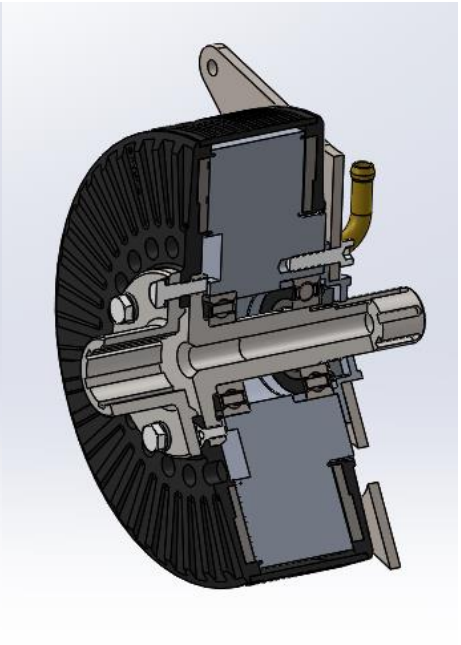


Figure 19: ESO+FSI (back and front power output)

!Note: If the ESO is used, then 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 described in the chapter Mounting the motor – check here.

!Note: In case of choosing ESO, the resolver / encoder can not be mounted on the back motor side. In this case we offer hall sensors, which are installed in the motor.

Figure 20: EMRAX power transmission shafts

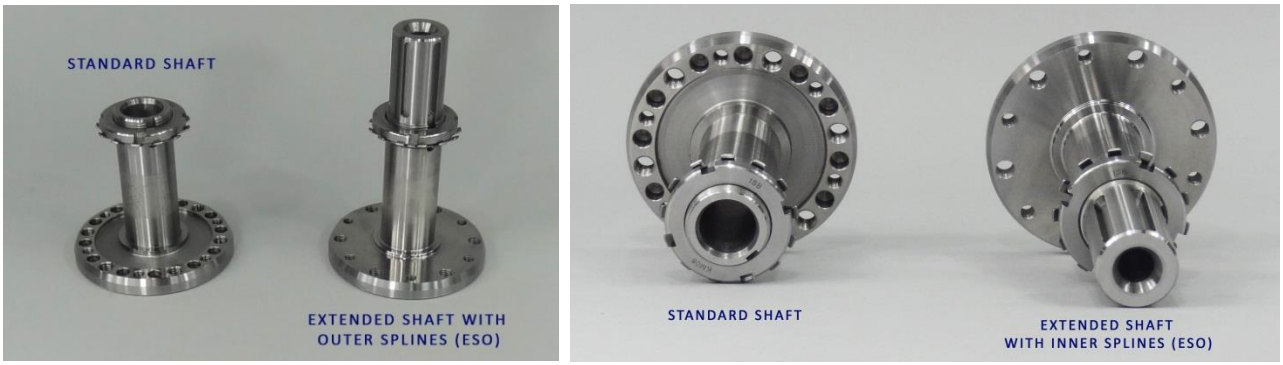


Figure 21: Standard motor shaft vs. extended shaft with outer splines (ESO)

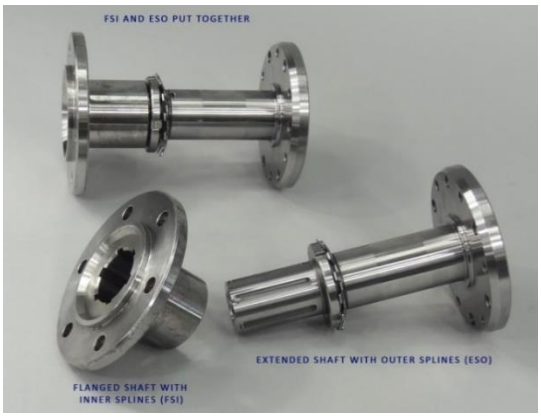


Figure 22: ESO and FSI

Figure 23: FSI

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).

Customer can make its own flanged shaft (FSI) according to required specifications.

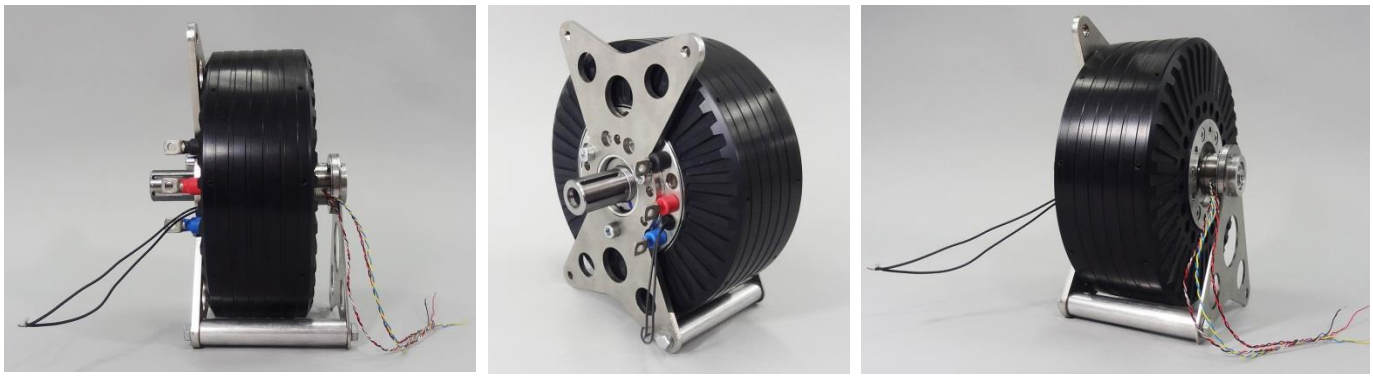
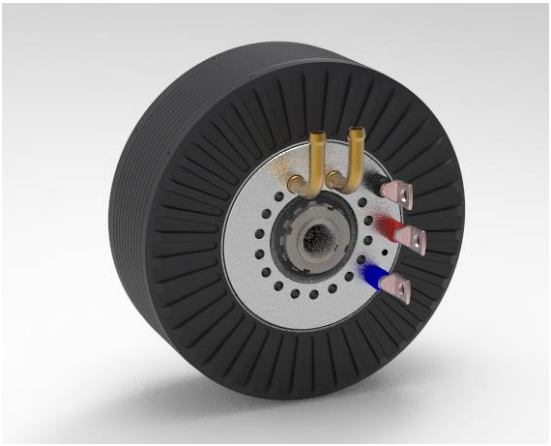


Figure 24: Motor with extended shaft from back motor side

6. Motor phase connectors (UVW)

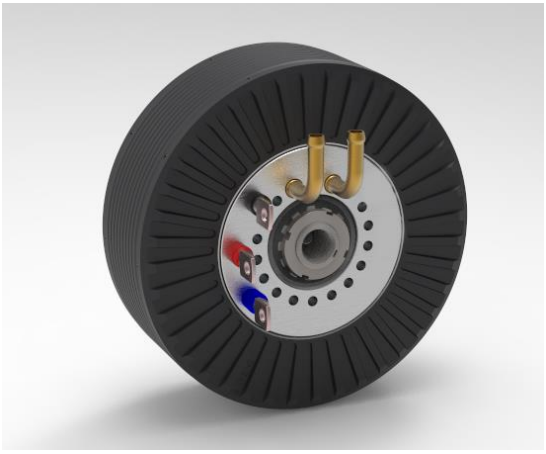
Options:

1x UVW standard connectors (one sequence of motor phase connectors)



One sequence of motor phase connectors on right side of the motor.
In this case one controller can be connected with one motor.

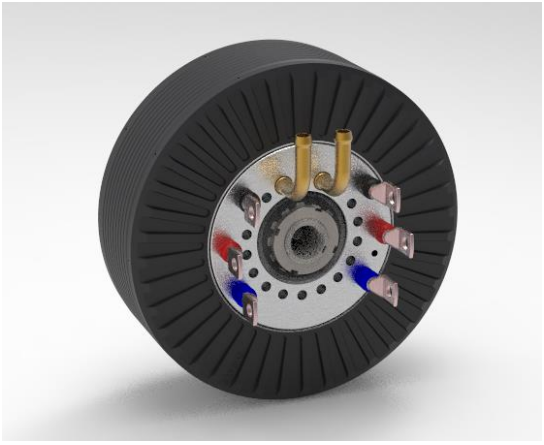
Figure 25: 1x UVW standard connectors



One sequence of motor phase connectors on left side of the motor.
In this case one controller can be connected with one motor.

Figure 26: 1x UVW mirrored connectors

2x UVW connectors (two sequences of motor phase connectors)



Two sequences of motor phase connectors, one on left side and one on right side of the motor.
In this case two controllers can be connected with one motor.

This version can be used:

- In case of redundancy (check the chapter about Redundancy here).
- In case one controller has too low electrical current. (check the chapter about Controllers here).

Figure 27: 2x UVW connectors

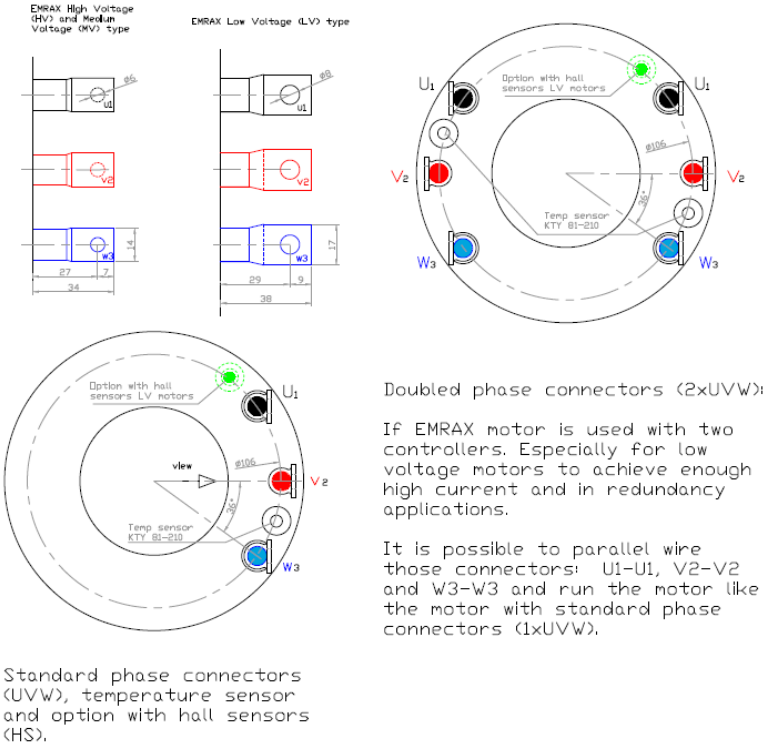


Figure 28: UVW connectors scheme

7. 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.
- Sensor types are listed here.
- 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).
- In case of 2xUVW connectors, HS cannot be used. In this case the customer must choose tandem resolver in order to achieve accurate communication between motor and controller.

You can download Excel table with recommended controllers and sensors here.

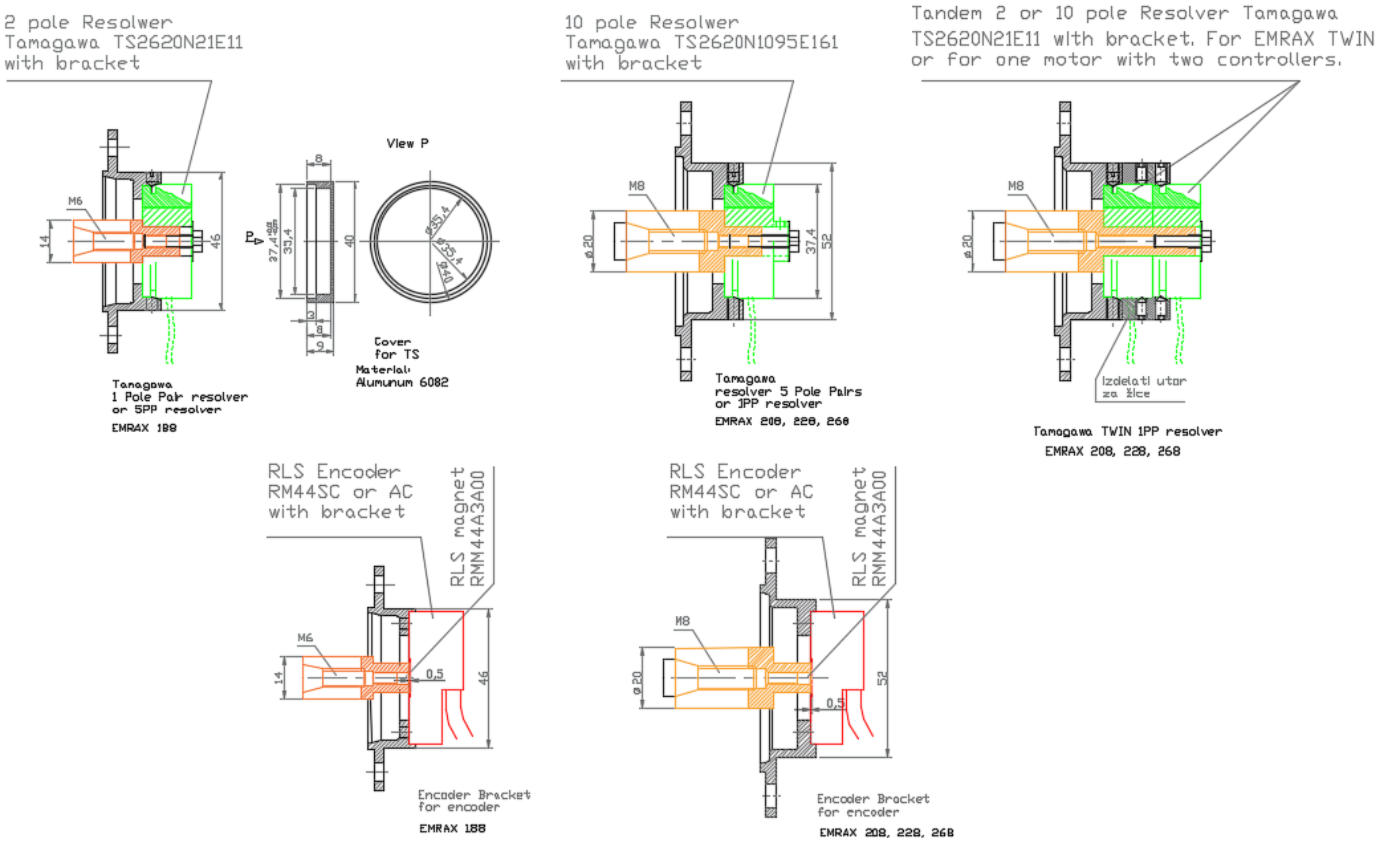


Figure 29: Resolver / encoder with mounting bracket to the back motor side

Figure 30: Encoder with bracket

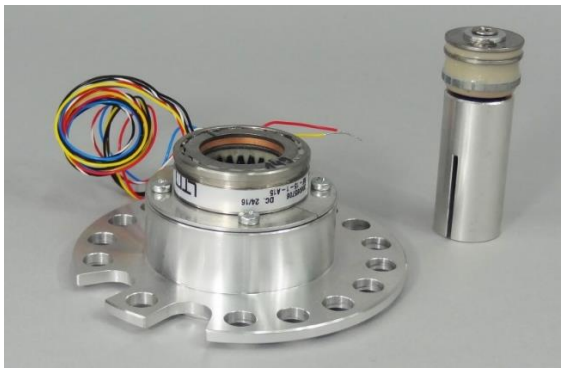


Figure 31: Resolver with bracket

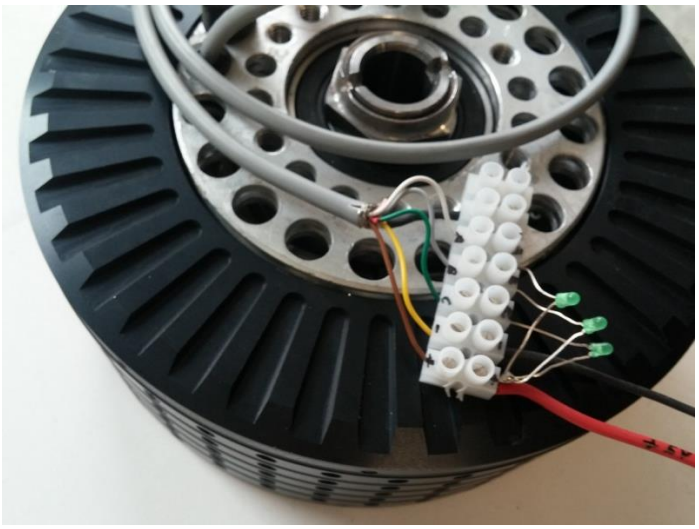


Figure 32: EMRAX with hall sensors HS

Hall sensors type:	SS411P

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

Hall sensors signal wires:	
WHITE	A – 1. HS
GRAY	B – 2. HS
GREEN	C – 3. HS

!NOTE: In case using Hall sensors the motor is not able to provide full range of torque and power. Continuous torque/power can be achieved, but only with a suitable controller and very good settings. Peak torque and power cannot be delivered in full, only up to 50% which is approximately the same as continuous power.

Here you can check the specifications for HS.

Here you can check the installation guide of encoder.

Here you can check the data sheet of encoder, resolver 1 pole pair, resolver 5 pole pair.

Every motor sensor has to be mounted on the motor by a special bracket. If the resolver/encoder is ordered 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.

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. 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) and accurate position.

Figure 33: Motor with sensorless (left) configuration and motor with encoder (right)

8. Suitable controllers and settings recommendation for EMRAX motors

Excel table with recommended controllers and sensors is available here.
EMRAX motors must be used with the **sinusoidal signal commutation** controllers. The controller with trapezoidal commutation should not be used with EMRAX motors. In this case the warranty does not apply.

The controller has to be selected according to the Technical Data Table of each motor.
Performances of the motor should be calculated according to controller characteristics – current, voltage.

Batteries should have very high C (Current) rating – very high boost discharging current from the batteries at high motor load.

Every EMRAX motor is tested with the DTI controller or Emsiso EmDrive controller before dispatch.
Stator windings are tested at 1500 Vac at 50Hz.

Controller settings have to be set according to Technical data table for each motor.
It is important that maximal motor RPM (listed in Technical Data Table) should not be exceeded. Take a look at specific load speed in the Technical Data Table – **RPM/1Vdc**.

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.

Separated EMRAX motors which are not connected together mechanically (are not on the same shaft), cannot be driven with one controller.

Setting the magnetic field weakening in the controller software

Maximal motor RPM can be achieved even at lower DC voltage than listed in Technical Data Tables in case of magnetic field weakening.

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 (a few min in case of full motor power), because of a very high phase current between the motor and controller.

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. $RPM = 60 * Hz/PP$.

9. 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 configuration to achieve doubled power / torque.

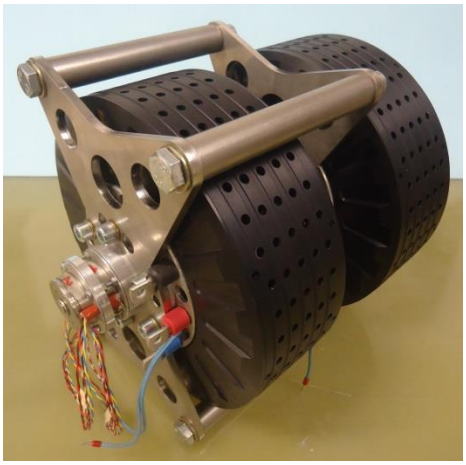


Figure 34: EMRAX TWIN with tandem resolver (each resolver is connected with one controller)

If direction, position and rotation speed of the motor need to be controlled sensors are needed (more information here). Sensors that can be used are: tandem resolver (two resolvers wired serially) or hall sensors in each motor.

TWIN motor cooling:
In case of liquid or combine cooled version each of the stacked two motors is cooled with liquid coolant. Therefore, it has coolant fittings (check here) for first and second motor in stack. First motor always has 90 degrees coolant fittings, second motor has optional 90° or 180° pipes.

TWIN motor mounting:
Twin motors come with integrated X-brackets (one per each motor), which are connected with 4 rods by 8 bolts (4 per each X-bracket), like it is marked on below pictures. Brackets and rods are made from steel.

!NOTE: X-brackets are used only for connection between two motors. They should not be used as a primary mounting place for TWIN motor. Therefore, the customer should make another bracket for mounting the TWIN motor in the customer's system.

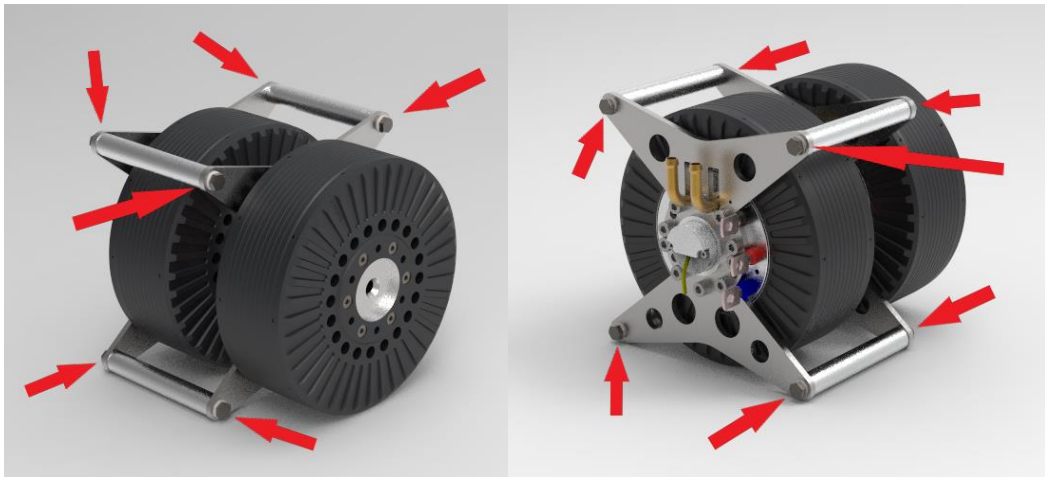


Figure 35: EMRAX TWIN - connection between two motors

10. Redundancy

2 options:

- EMRAX TWIN motor with 1xUVW and tandem resolver/hall sensors. EMRAX TWIN 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 other one is still working.

- EMRAX SINGLE motor with 2xUVW and tandem resolver/hall sensors. In this case the motor is driven with two controllers. In case of one controller failure, the other still drives the motor (performances of the motor are lower).

11. EMRAX motor 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. Note that 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.

12. EMRAX motor ingress protection (IP CODE)

- **IP21:**

  a) Air Cooled (AC): air cooled only

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

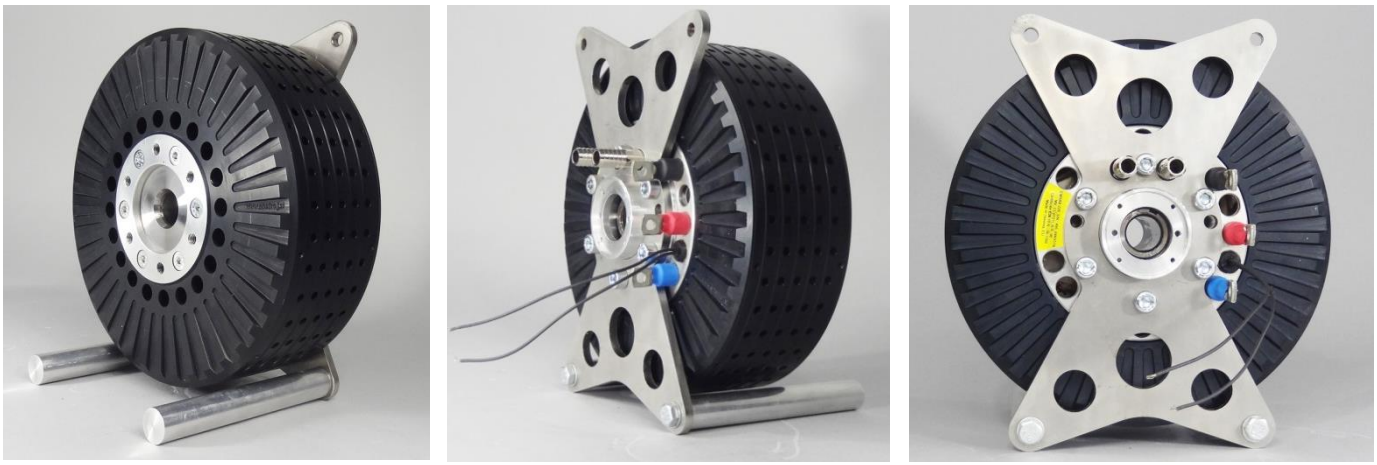


Figure 36: EMRAX IP21

- **IP65:**

  Liquid Cooled (LC):

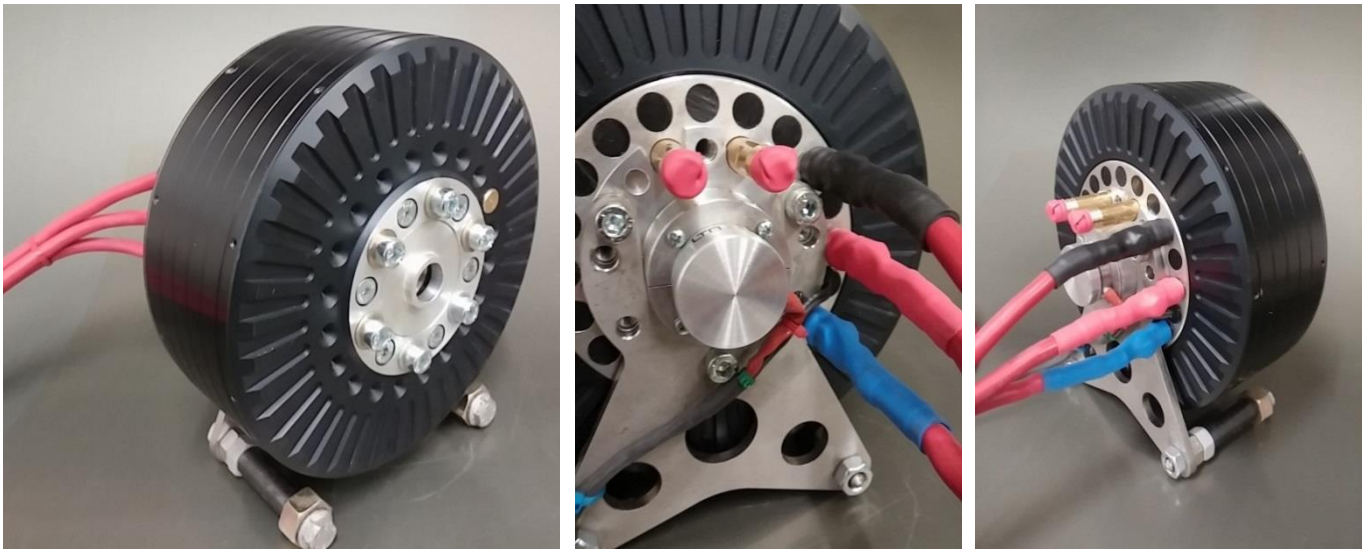


Figure 37: EMRAX IP65

!NOTE: Every EMRAX motor needs a sufficient air, that is circulating around the motor – this is valid also for Liquid Cooled motor. The motor should not be closed into the chamber. It can be protected with some net or chamber with enough holes, that enable the air to exchange and circulate. If the motor does not have the ambient conditions as described in Technical data tables, the continuous power / torque are expected to be lower.

13. 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 motor 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. You can access the sensor specifications here. EMRAX motors can be air cooled (IP21), liquid cooled (IP65) or combined cooled (IP21).

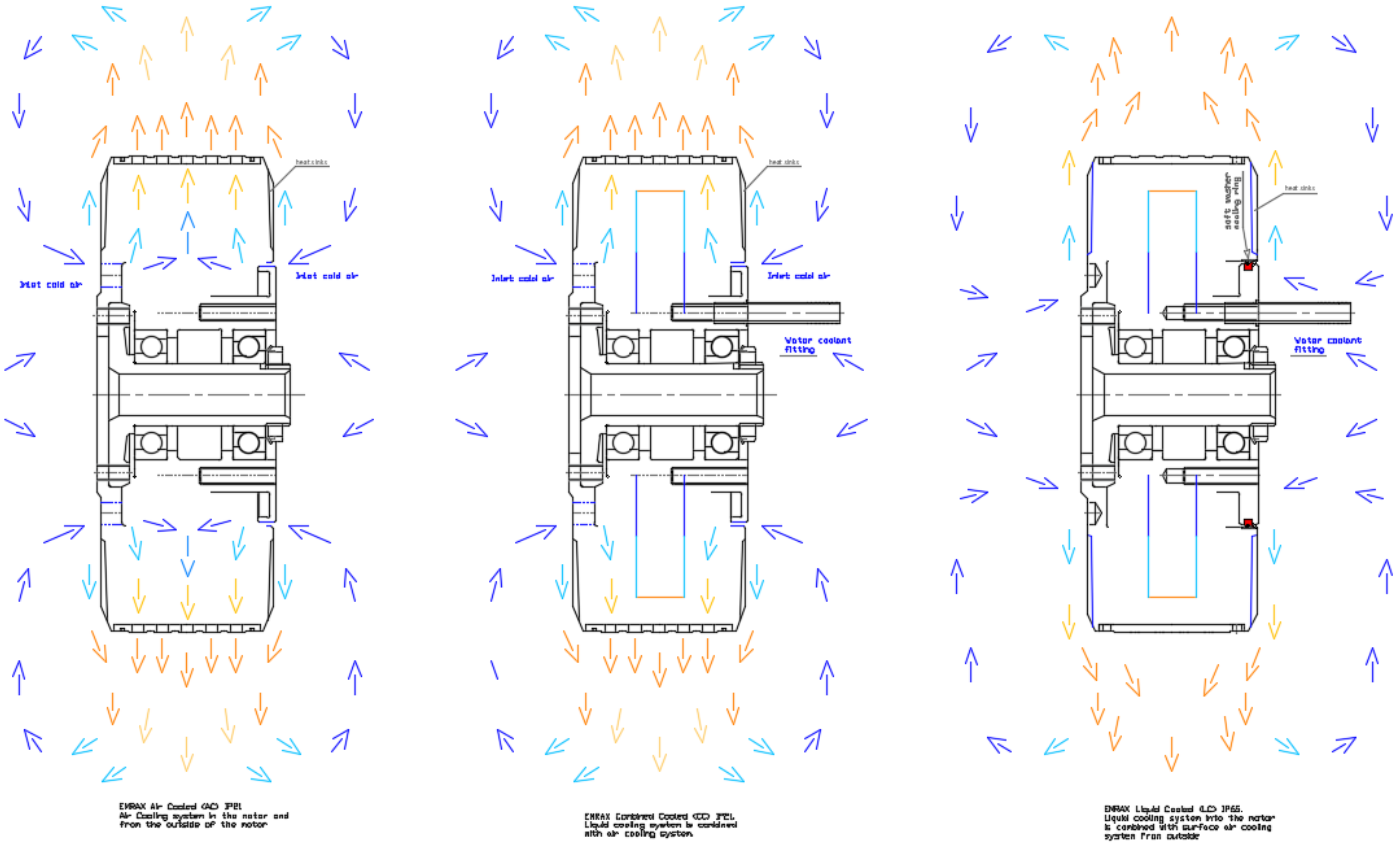


Figure 38: Motor cooling options

Options for motor coolant fittings (for combined cooled and liquid cooled motors):

- Angled (90°)
- Straight (180°)

In case of replacing or disassembling, coolant pipes must be precisely mounted, to ensure proper sealing of coolant. O-ring sealing must be placed onto the pipe and lubricated with small amount of grease or other lubricant. Coolant fitting is then placed into the coolant hole. Sealing should be neatly pressed between pipe's bulge and stator's inner wall. It is very important that the o-ring is not rolled, twisted, scratched, broken or injured in any way.

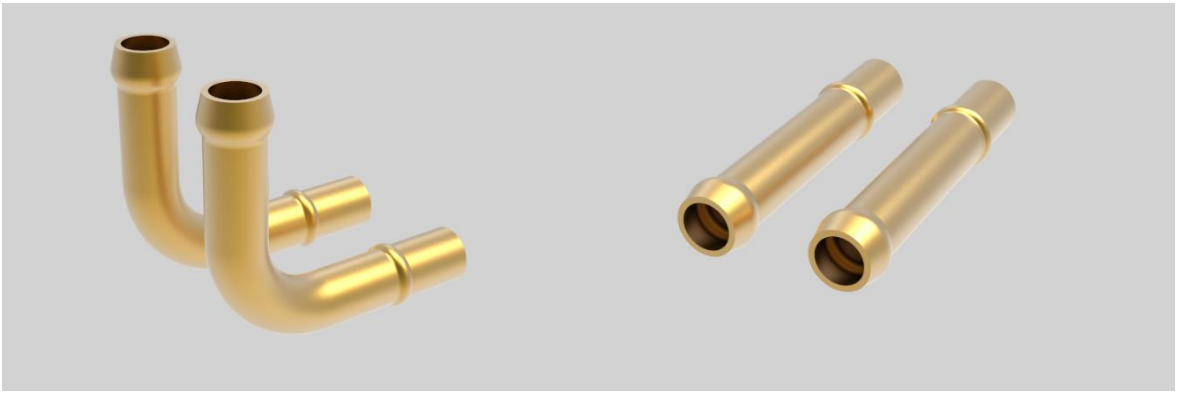


Figure 39: Motor coolant fittings set - angled (90°) or straight (180°)

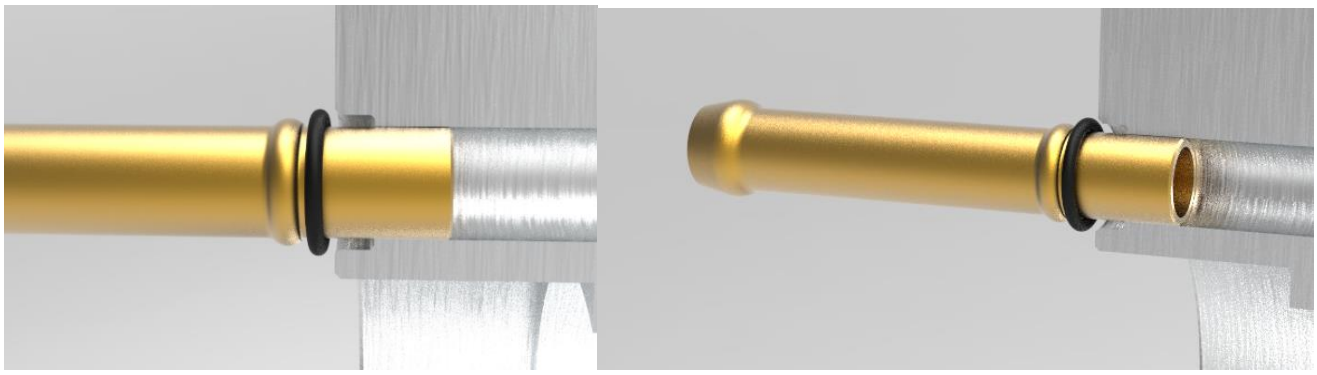


Figure 40: Motor coolant fittings mounting

After the pipe is placed, the bracket has to be mounted over the pipes to ensure o-ring compression and sealing properties. Look at the picture below.

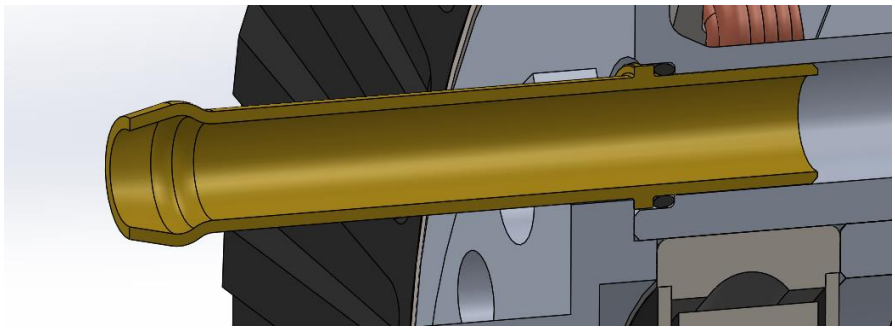


Figure 41: Motor coolant fittings mounting with bracket

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. 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.

- **EMRAX air cooled (AC; IP21):**
  Fresh air has to be served to the drive symmetrically and sufficiently. In any way the motor should not be closed in the chamber without air exchange. The recommendation for the air speed is **20 m/s at maximal 25°C air temperature**. This has to be ensured by intake ports or other air conduction measures.

- **EMRAX combined cooled (CC; IP21) and EMRAX liquid cooled (LC; IP65):**
  Recommended liquid cooling flow is **6 to 8 litres per minute at maximal 50 °C inlet coolant temperature at ambient air temperature 25°C or less**. Inlet coolant temperature and ambient temperature can also be lower – in this case the continuous motor power/torque is higher. In any way the motor should not be closed in the chamber without air exchange.

  Air cooled (AC) and Combined cooled (CC) motors must not be used in the environment a high risk of entering small particles (i. e. iron particles, stones, dust, liquids) into the motor is present. The motor must be protected against the dirt – for example with net.

  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	0,5 bar	7 l/min
208	0,6 bar	7 l/min
228	0,9 bar	7 l/min
268	1,0 bar	6 l/min
348	1,0 bar	6 l/min

!NOTE:
- Maximum inlet water/glycol flow pressure must not exceed 2 bars.
- Liquid flow must be filtered through the filter which openings' diameter or diagonal must not exceed 2 mm.
- We do not recommend cooling the motor directly with salt water, because long-term exposure of the motor cooling system might lead to mineral deposits. Therefore, we recommend a heat exchanger.

14. EMRAX motor materials, quality and reliability

EMRAX motors are quality made and consist of quality advanced materials. Materials can 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. 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 from high quality material with UH grade. They are chemically and mechanically fixed, making EMRAX motors are very reliable.

15. EMRAX motor bearings and life expectancy

Bearings used in EMRAX motors are FAG, which are listed in the Technical Data tables for every motor type. All technical information about listed bearings is publicly available here.

Every EMRAX motor includes two bearings – front and back. 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 here and in the table below this paragraph. Bearings are mounted in the motor during motor assembly, which requires special procedure and tools.

EMRAX motor size	Bearings for EMRAX motors (FAG bearings) are made for axial-radial forces; pull-push mode (PP); front bearing : back bearing
188	6204-2Z : 3204-BD-2Z-TVH-XL
208 / 228	6206-2Z : 3206-BD-2Z-TVH-XL
268	6207-2Z : 3207-BD-2Z-TVH-XL
348	6208-2Z : 3208-BD-2Z-TVH-XL

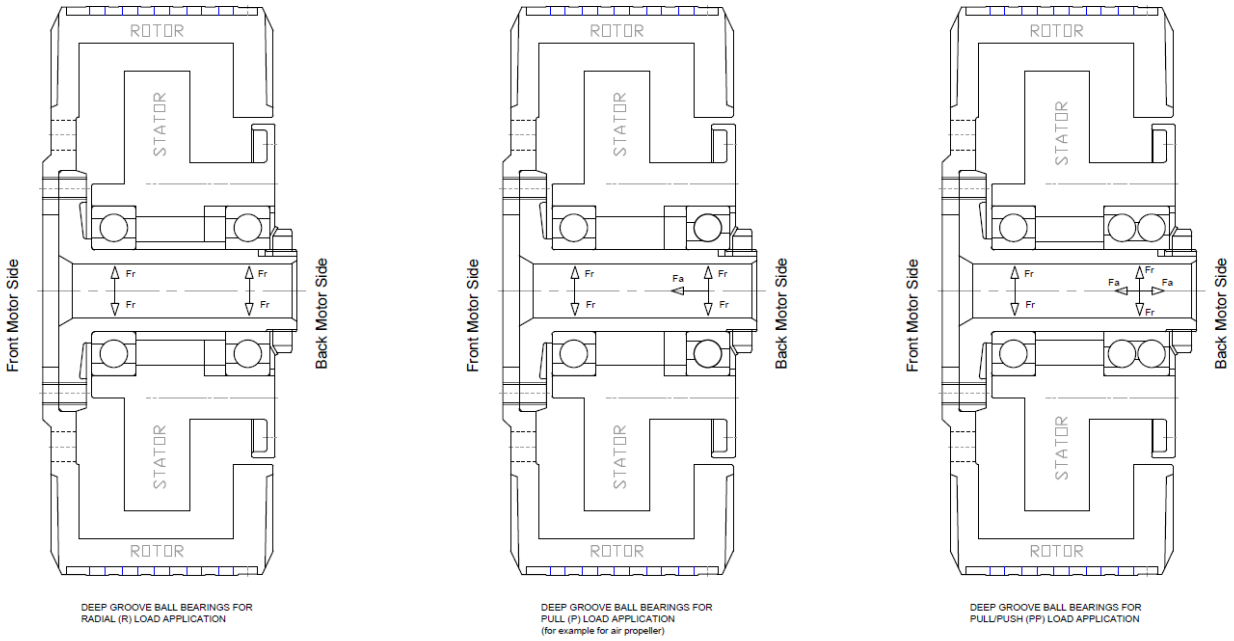


Figure 42: Combination of bearings for EMRAX motors

Life expectancy of the EMRAX motor is the same as life expectancy of the bearings that are mounted in the motor. Bearings 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 damage to the motor or person disassembling it. Therefore, please avoid opening the motor.

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).

16. 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 this motor type 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! Check here about the cooling conditions for EMRAX motor. 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. For the opening of 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 check the interior of the motor at the same time as well as restore the damages whenever possible.

For removing the parts that enter the motor or in case of damage go to our website to see the instructions for return. Do not ship the motor back to us without informing us in any case!

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.

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

The drive is built according to the state of the art and approved safety-related rules.

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 motor 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. Cooling conditions are also described here.

Do not to use the motor in direct salt environment.

Procedure:

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 motor and controller need to be mounted in a way 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 must 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 must be properly connected to the controller. Instructions can be provided by the sensor producer or the controller producer.
   The drive should be, if possible, directly connected to the 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 controller. 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.

   !NOTE: Connector cables should not be bent.

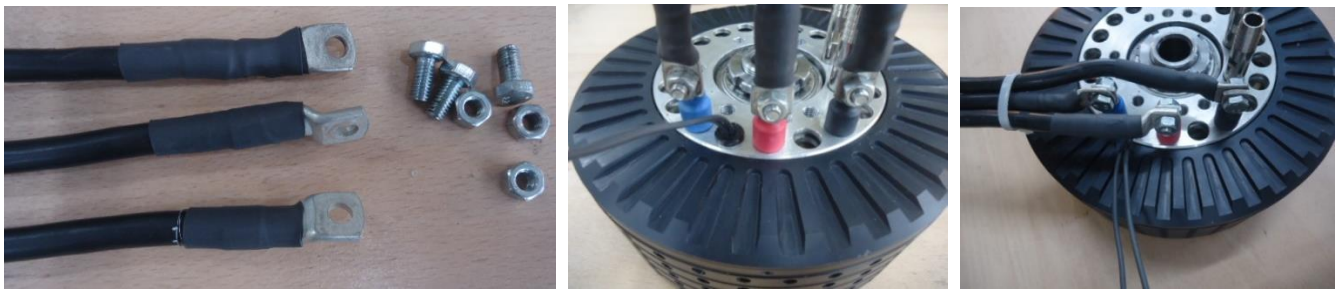


Figure 43: Straight connection of motor phase connectors to controller cables. It must be isolated with shrink hose!

Figure 44: Angular connection of motor connectors to controller cables. It must be isolated with shrink hose!

Only use high current connector systems between the motor, converter and the battery. The connectors must 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 must be replaced. Shoddy or used up connectors are the most common reason for destructions of the drive, the controller and possible components around it.

!NOTE: The electric connectors and cables must be connected professionally and have to be isolated with a shrink hose.

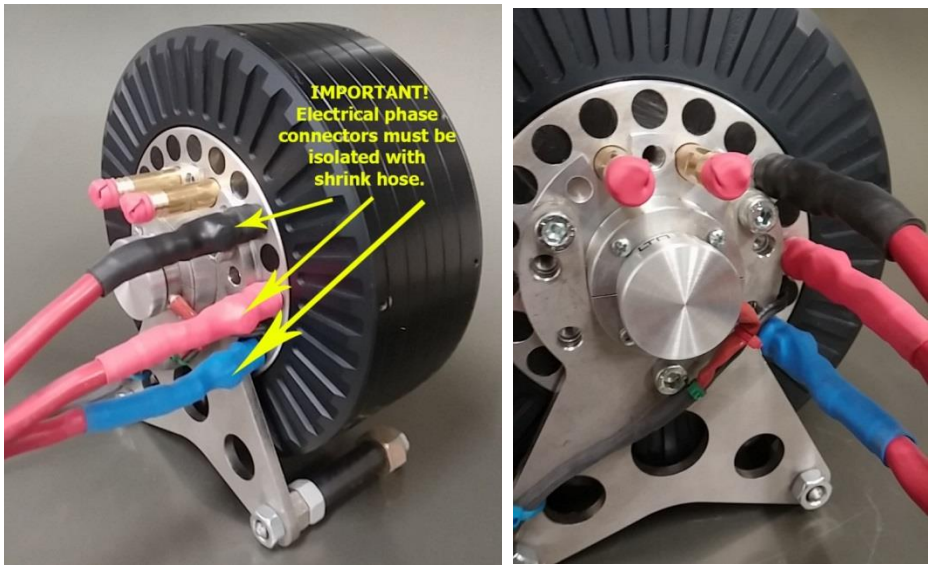


Figure 45: Isolation of electrical phase connectors with shrink hose

!NOTE: 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!

!NOTE: 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. Distance between communication and power cables must be big enough in order to achieve undisturbed communication between sensor and controller.

4. Setting the controller software:

a) Basic controller software settings must be set in the controller software. Controller settings should be discussed with controller producer.
b) 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.
c) 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.

18. How to choose the correct EMRAX motor type for your application:

1. First you need to know what **RPM and torque you will need** for your application.

   To find the suitable EMRAX motor you should check the maximal motor RPM listed in Technical data table for each EMRAX motor. Make sure, to consider the Torque/RPM graph and that the controller gives 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) for each EMRAX motor. With this data **you can calculate what battery voltage (Vdc) you need** to achieve desired RPM at load application.
   It is possible to achieve higher RPM with magnetic field weakening (MFW). You can use magnetic field weakening mode 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 (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 5 to 10 % 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:

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

   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 increasing 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 RPM/1Vdc at load to 14 RPM/1Vdc at no load application.

   In this case the motor the speed is: $365\ [Vdc] * 11 = 4015\ [RPM]$.

   Specific torque for 228MV motor is 0,75Nm/1Arms.

   Therefore at 180 Arms of the current from Bamocar D3, the motor power is:

   $4015\ [RPM] * 135\ Nm \div 9550 = 56{,}7[kW]$ 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 higher motor current. You need app 340 Arms peak (which gives app 230 to 240 Nm of torque with EMRAX 228 MV 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. In this case you can use EMRAX 228 HV.

19. 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.

EMRAX is in process of obtaining **ISO 9001:2015** certificate.

EMRAX is in process of obtaining **European Union Aviation Safety Agency (EASA)** certificate for EMRAX 268 motor.

20. Service

In case of fault or damage go to our web site and follow the steps. Do not ship the motor back to us without informing us in any case!

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