☐ Public
■ Non-public

Structure and Working Principle of PMSM(Permanent magnet synchronous motor)

Overseas Business Division

March 12, 2023

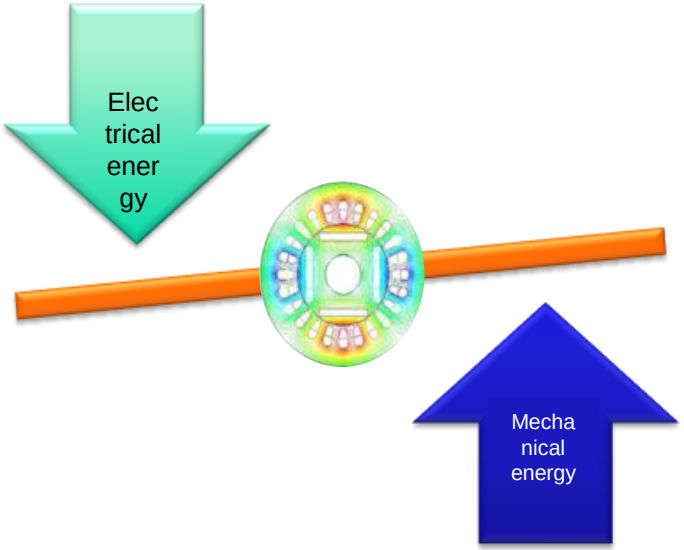
Contents

I. Overview of PMSM

Q: What is a motor?

The simplest motor

A motor is a device that realizes the conversion of electrical energy and mechanical energy based on the principle of electromagnetic induction.
The process of converting input electrical energy into mechanical energy for output is called motorization;
Conversely, the process of converting input mechanical energy into electrical energy for output is called power generation.



■ **The motor cannot work independently. It can output electrical or mechanical energy only when external energy is input.**

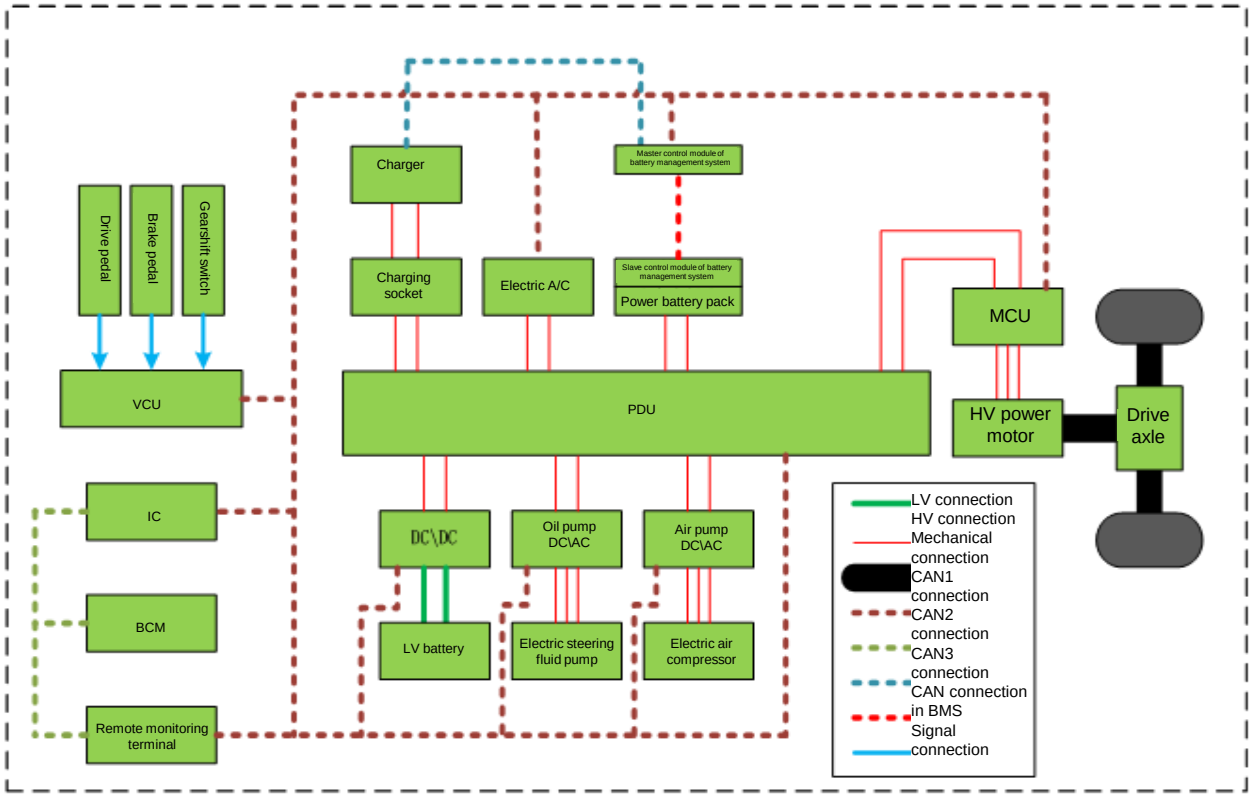
1. Development history of permanent-magnet synchronous motor

- In 1821, Faraday discovered that an energized conductor could rotate around a permanent magnet, successfully realizing the conversion of electrical energy into mechanical energy for the first time. After the discovery, he established an experimental model of motor which was considered the world's first permanent magnet motor.
- In 1822, Lussac (France) invented the electromagnet, a type of magnet in which the magnetic field is produced by means of a coil wound on an iron core. The electromagnet was an important invention, but was not given enough attention and applied at that time.
- In 1831, shortly after the discovery of electromagnetic induction, Faraday invented the world's first real motor - Faraday disk based on the principle of electromagnetic induction. In summer of the same year, Henry made a simple device (an oscillating motor) whose moving part was an electromagnet moving in a vertical direction. When the wire at the end was connected alternately with the two batteries, the polarity of the electromagnet changed automatically and the electromagnet and the permanent magnet attracted or repelled each other so that the electromagnet moved up and down at a speed of 75 rpm. Henry's motor demonstrated the continuous motion generated by the attraction or repulsion of the magnetic pole for the first time and witnessed the first application of the electromagnet in a motor.
- In 1832, Sturgeon invented the commutator and modified Henry's oscillating motor, thus producing the world's first rotating motor capable of generating continuous motion.
- In 1834, Jacobi (Germany) made a simple device: a six-arm wheel was installed between two horseshoe magnets, and each arm had two bar magnets. After energization, the bar magnet and the horseshoe magnet attracted or repelled each other, driving the wheel shaft to rotate. The boat with this device could reach a speed of 2.2 km/h. This device was the first practical motor. At the same time, Davenport (America) also successfully developed a motor for driving printing machines.
- In 1845, Wheatstone (Britain) replaced permanent magnets with electromagnets. In 1857, he also invented the self-excited excitation generator, creating a new era of excitation.
- In the middle of the 20th century, with the emergence of alnico and ferrite permanent magnets and the continuous improvement of their performance, various new permanent magnet motors were invented and widely used. Due to the improvement of high temperature resistance and the reduction of cost of NdFeB, NdFeB permanent magnet motors were more and more widely used in fire protection, industrial and agricultural production and daily life, and the varieties and application fields of permanent magnet motors were increasingly expanded.

1. Main functions of PMSM

As the core of EVs, the drive control system is designed to efficiently convert the energy of the power battery into the kinetic energy of the wheels under the control of the driver to drive the vehicle forward and backward. The drive control system is mainly composed of a motor and a motor control unit (MCU). **The energy flow between the motor and the battery is regulated by the MCU, and the motor and the wheels are connected through a mechanical drive.**

Functions of motor: Respond to the command given by the MCU. Provide power for the vehicle under normal driving conditions, and convert electrical energy into mechanical energy; regenerate the energy in case of braking, and convert mechanical energy into electrical energy to charge the on-board energy storage unit to extend the driving distance.

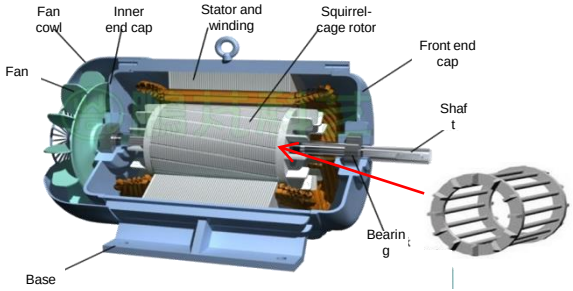


2. Main parameters of PMSM

Main parameters of PMSM (taking M4 light-duty truck as an example)	
Motor model	FTTB064
Peak power	115kW
Peak torque	300Nm/30s
Rated power	64kW
Rated torque	
Peak speed	12000rpm
Cooling mode	Water cooling, 12L/min, inlet temperature of 65℃
Battery voltage	540.96VDC
Maximum efficiency of motor	97%

3. Classification of PMSM

Common automotive power motors:
■**Permanent-magnet synchronous motor (PMSM)**
■ Brushless direct current motor (BLDC)
■ Asynchronous motor (ASM)
■ Electrically excited synchronous motor (ESM)



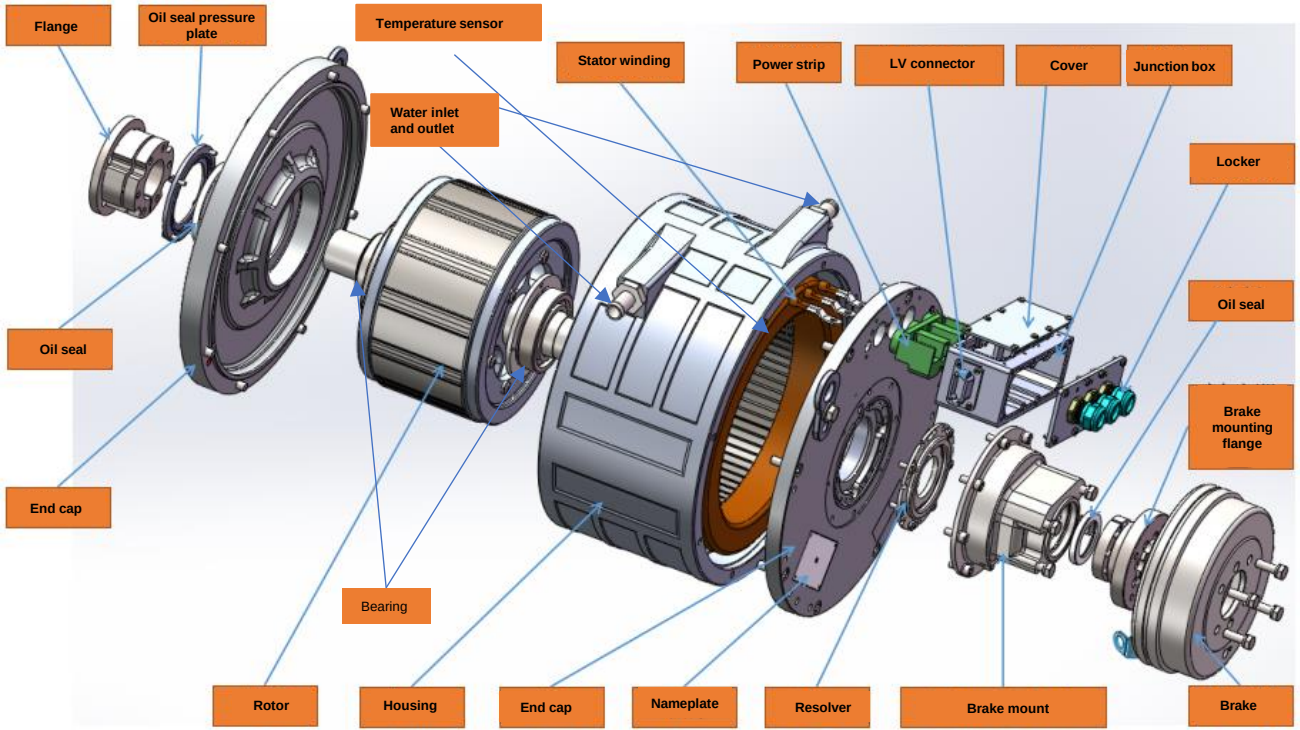
ASM (typically characterized by squirrel-cage rotor)

Structural decomposition animation of motor

PMSM/BLDC (typically characterized by rotor or stator with permanent magnet)

- **Synchronous means that the motor speed is synchronous with the electromagnetic speed, and asynchronous means that the motor speed is lower than the electromagnetic speed.**
- **The speed of a synchronous motor will not change as long as the motor is not out of step regardless of load. The speed of an asynchronous motor will always change with the variation in the load.**

4. Structure and composition of AC PMSM



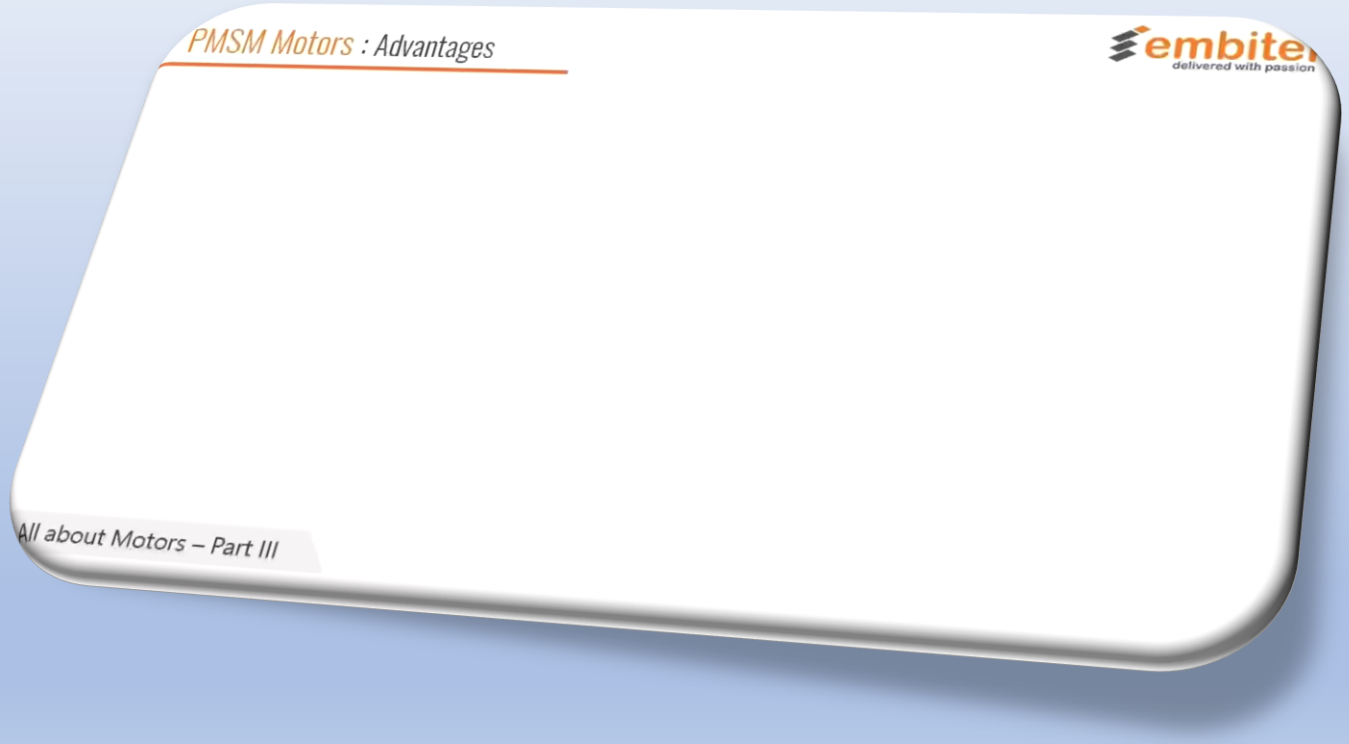
5. Advantages and disadvantages of AC PMSM

Advantages of PMSM:

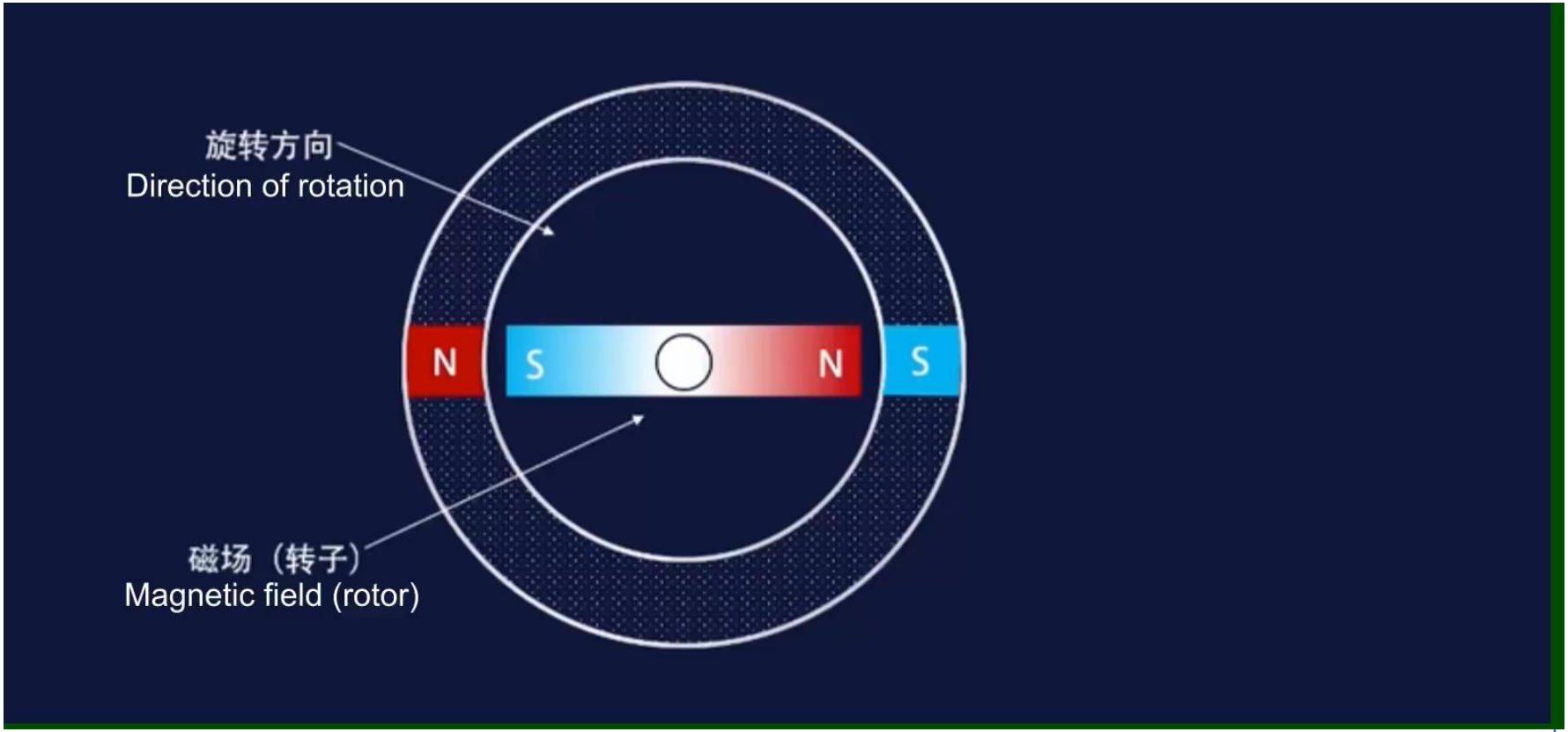
1. Simple structure and high reliability
2. High average efficiency
3. Minor temperature rise
4. Small size and light weight
5. High starting torque
6. High force and energy performance
7. High energy efficiency

Disadvantages of PMSM:

1. High cost of permanent magnet
2. Irreversible demagnetization of permanent magnet under high temperature, vibration and overcurrent conditions, which will affect the performance of the motor
3. High requirements for the control system
4. Inconvenient maintenance



6. Working principle of PMSM



Contents

II. Terms and definitions

II.

Terms and definitions

PMSM Permanent-magnet Synchronous Motor

DC Direct Current

AC Alternating Current

NTC Negative temperature coefficient

PTC Positive temperature coefficient

HV High voltage

LV Low voltage

PEU Power Electric Uint

Function description: A control plan in which some HV components are integrated in one module according to different combination plans (e.g. OBC+DC/DC+MCU)

MCU Motor Control Unit

Function description: It is mainly responsible for converting the DC HV power of the vehicle into the three-phase AC power according to the vehicle control command, controlling the operation of the motor, monitoring the speed, torque, voltage, and current of the motor in real time, and diagnosing the fault of the motor control system.

OBC On-borad Charger

Function description: It is designed to convert the mains AC voltage into the DC high voltage, charge the HV battery, and monitor the charging state.

DC/DC Direct Current/Direct Current Convertor

Function description: It is mainly designed to convert the DC high voltage into the DC low voltage, supply power to the on-board LV components during driving, and charge the LV battery.

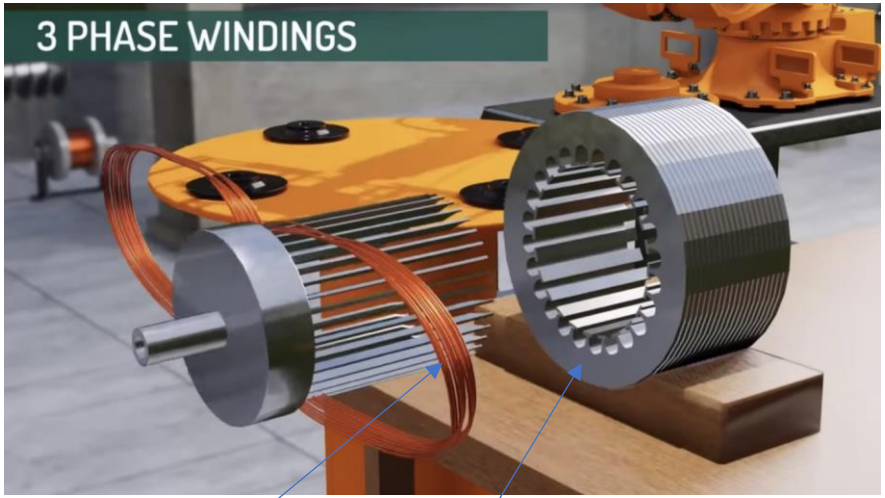
PDU Power Distribution Unit

Function description： It is designed to distribute the output path of the HV battery of the vehicle through the relay, and configure the high-current fuse for overcurrent protection.

Contents

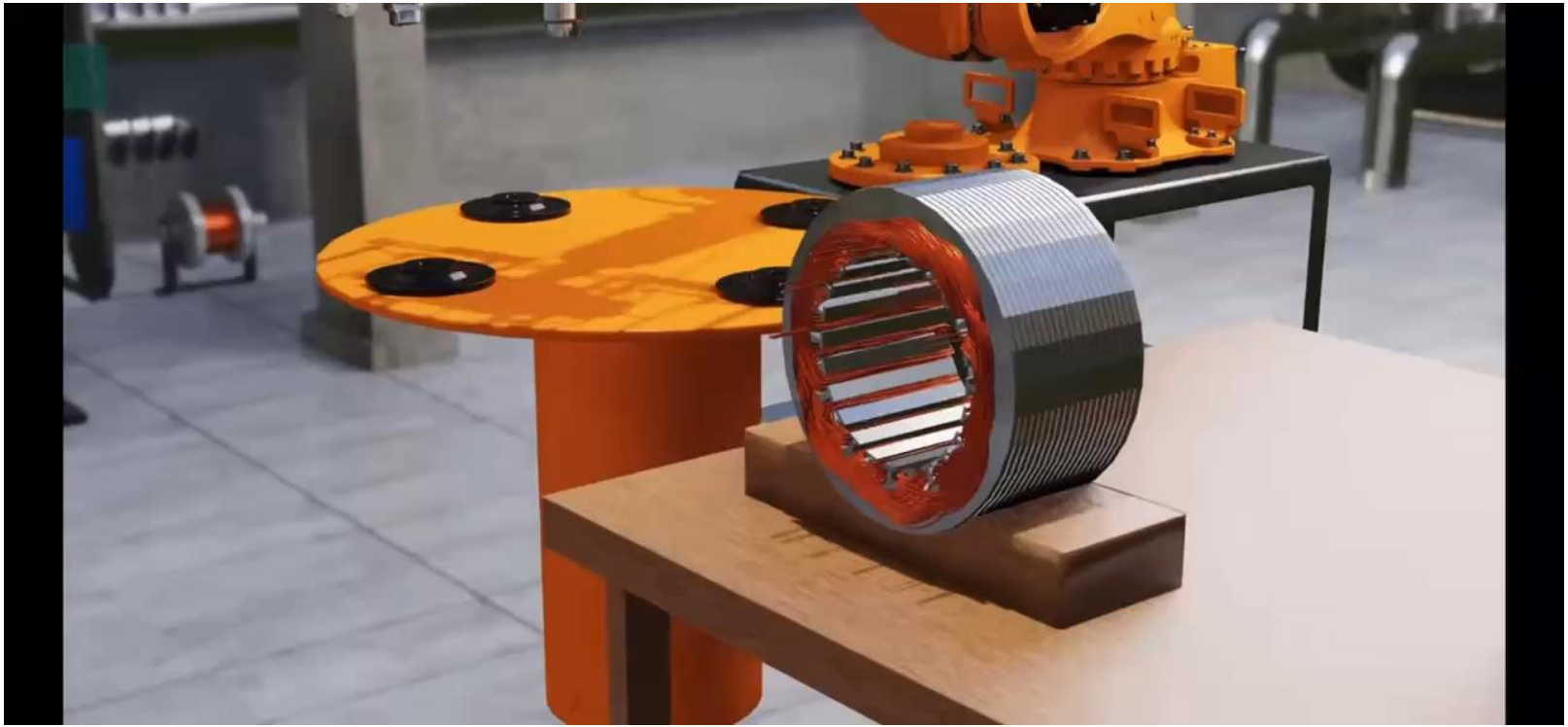
1. Structure of stator

As the stationary part of the motor, the stator is composed of stator core and stator winding.



2. Function of stator

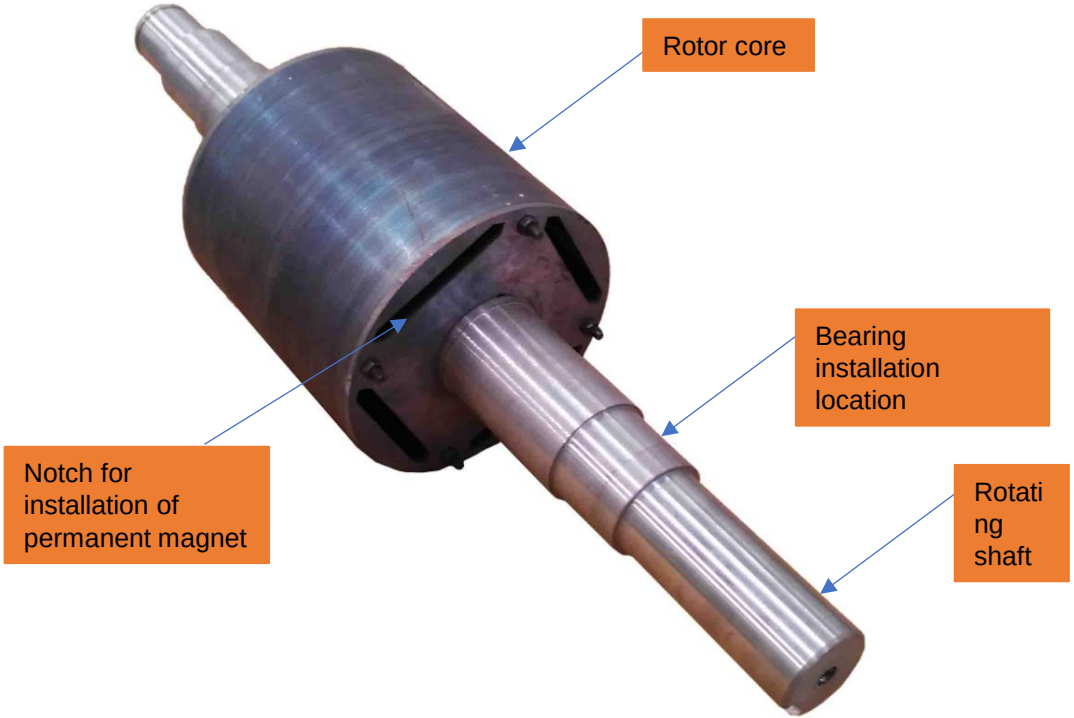
When the current is applied, a rotating magnetic field is formed in the stator winding of the motor



Contents

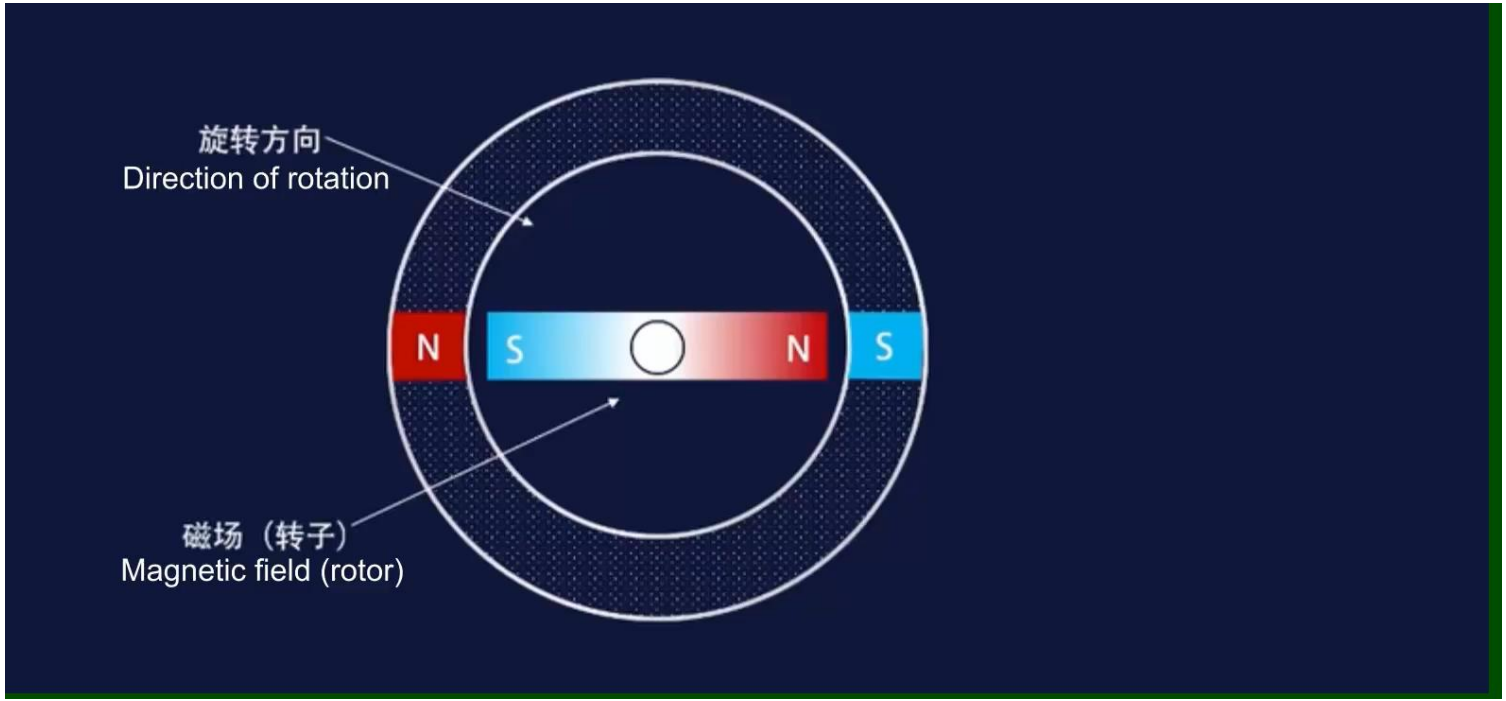
1. Structure of rotor

As a rotating body supported by the bearing, the rotor is mainly composed of rotor core, permanent magnet and rotating shaft.



3. Function of rotor

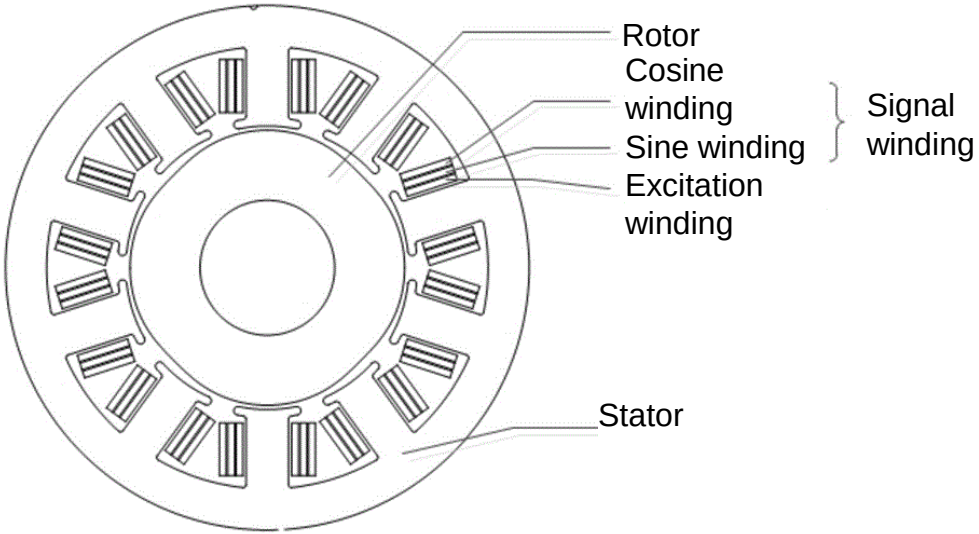
The rotor is provided with a permanent magnet whose magnetic poles are fixed. Therefore, according to the principle of “opposite poles attract each other, but similar poles repel”, the rotating magnetic field generated in the stator drives the rotor to rotate, and finally the rotation speed of the rotor is the same as that of the rotating magnetic poles generated in the stator so that the motor is driven to work.



Contents

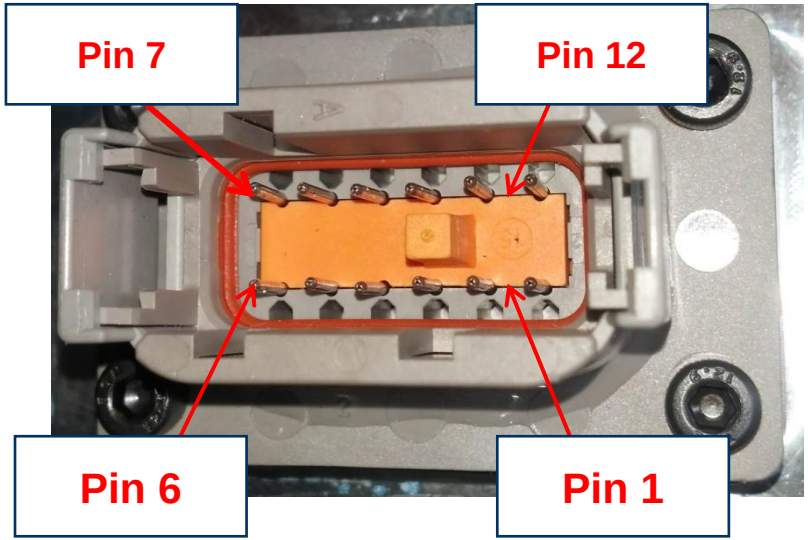
1. Composition of resolver

As an electromagnetic sensor, **the resolver/transformer is composed of a stator and a rotor** and used to measure the angular displacement and angular velocity of the rotating shaft of a rotating object.



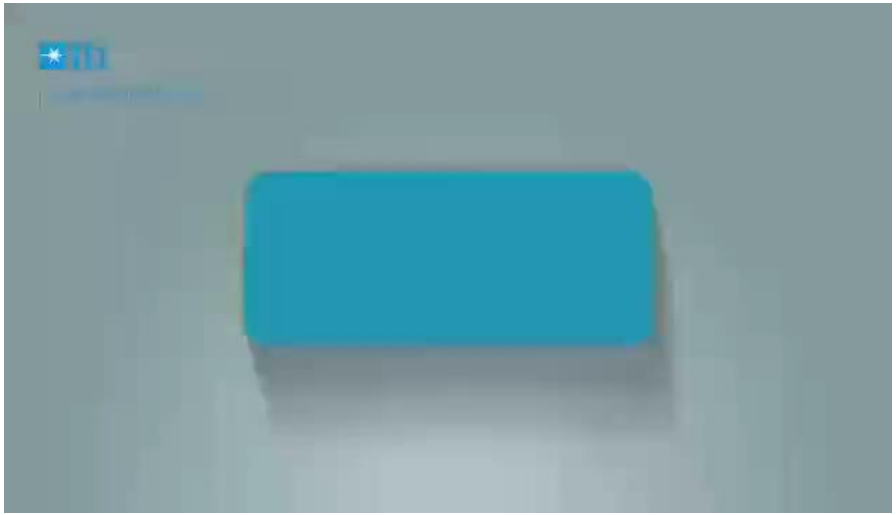
Resolver

2. Definitions of external interfaces of resolver (taking JJE motor as an example)



Pin definition of LV connector (taking M4 motor end as an example)				
Pin No.	Wire color	Signal name	Resistance	Remarks
1	Gray	R1+	111.2~87.74KΩ@25℃	NTC temperature sensor 1
2	Gray	R1-		
3	Gray	R2+	111.2~87.74KΩ@25℃	NTC temperature sensor 2
4	Gray	R2-		
5		GND	To the harness shielding layer	Resolver shielding
6		GND	To the harness shielding layer	
7	Black	COS-	45-66Ω@25℃	Resolver cosine
8	Red	COS+		
9	Blue	SIN-	57-71Ω@25℃	Resolver sine
10	Yellow	SIN+		
11	Green	REF-	24-30Ω@25℃	Resolver excitation
12	White	REF+		

3. Function and working principle of resolver

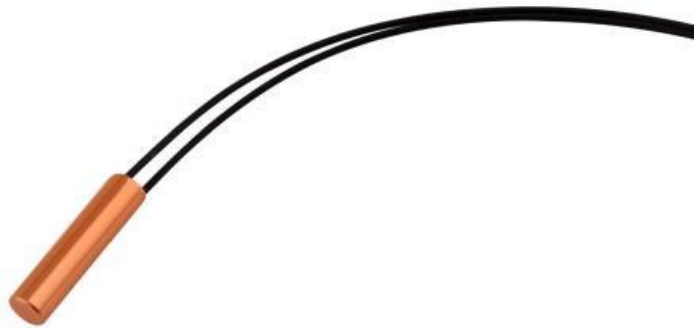


Contents

1. Working principle of temperature sensor

NTC temperature sensor: It is a kind of thermistor and probe.

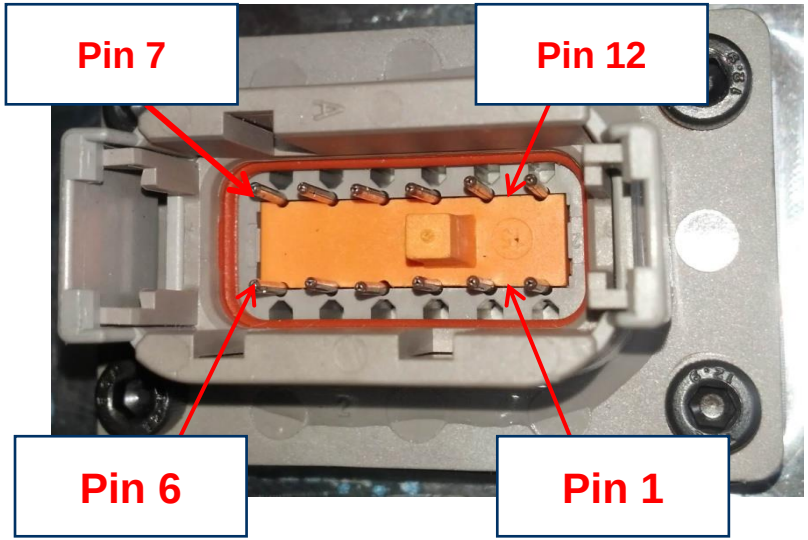
NTC temperature sensor



The working principle is as follows:

The resistance drops rapidly as the temperature rises. Usually, 2 or 3 metal oxides are used, mixed in fluid-like clay and calcined in a high-temperature furnace to form a dense sintered ceramic.

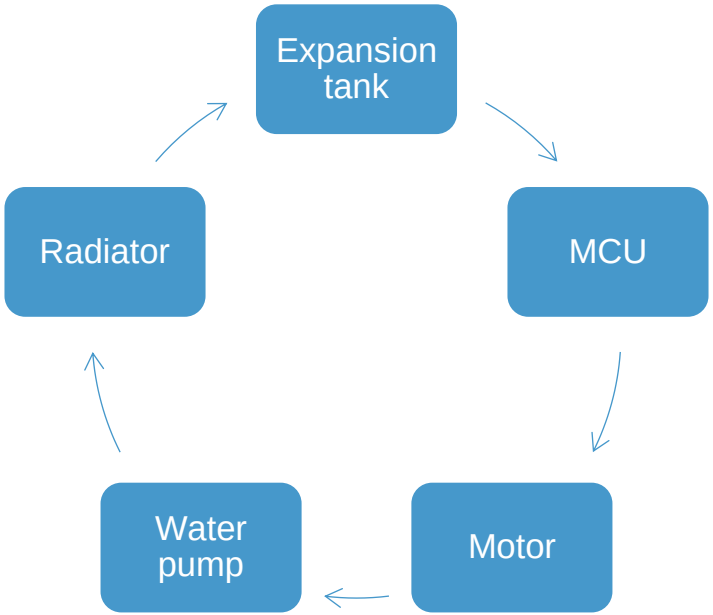
2. Parameters of temperature sensor



Pin definition of LV connector (taking M4 motor end as an example)				
Pin No.	Wire color	Signal name	Resistance	Remarks
1	Gray	R1+	111.2~87.74KΩ@25℃	NTC temperature sensor 1
2	Gray	R1-		
3	Gray	R2+	111.2~87.74KΩ@25℃	NTC temperature sensor 2
4	Gray	R2-		
5		GND	To the harness shielding layer	Resolver shielding
6		GND	To the harness shielding layer	
7	Black	COS-	45-66Ω@25℃	Resolver cosine
8	Red	COS+		
9	Blue	SIN-	57-71Ω@25℃	Resolver sine
10	Yellow	SIN+		
11	Green	REF-	24-30Ω@25℃	Resolver excitation
12	White	REF+		

Contents

Cooling system



The cooling system percentage is sent according to the temperature of the HV power motor and MCU. When the required cooling percentage of the drive system is up to 50%, the speed percentage of the cooling fan reaches 50%; when the required cooling percentage of the drive system is up to 100%, the speed percentage of the cooling fan reaches 100% speed. The change must be linear; the water pump works after power-on.

Required cooling temperature threshold and overtemperature threshold

The PEU and motor share a cooling circuit. The coolant pump will start to operate after it is connected to HV (HV power-on, charging); the fan will operate at high or low speed or stop under the control of VCU according to the temperature of MCU, motor and OBC:

Name	Low-speed fan OFF (° C)	Low-speed fan ON (℃)	High-speed fan OFF (℃)	High-speed fan ON (℃)
MCU	＜55	≥60	＜60	≥65
Motor	＜80	≥85	＜90	≥95

In case of poor working conditions or poor cooling due to cooling system failure, the electric drive system will run at reduced power due to overtemperature to actively protect the system; serious overtemperature may also lead to breakdowns. The temperature thresholds for an overtemperature fault are as follows:

Name	Temperature threshold	Fault description
MCU	＞90℃	Level 1 fault is reported, power is limited, and turtle light and motor overtemperature light are on
	＞100℃	Level 3 fault is reported, MCU turns off the IGBT, and motor overtemperature light and motor fault light are turned on
Motor	＞140℃	Level 1 fault is reported, power is limited, and turtle light and motor overtemperature light are on
	＞160℃	Level 3 fault is reported, MCU turns off the IGBT, and motor overtemperature light and motor fault light are turned on

Contents

1. Safety precautions

1. The motor must be removed and installed by **qualified and authorized personnel**. In principle, the electric drive system shall not be operated in the power-on state. Even if the motor **isn't connected to the HV power supply**, **insulation protection shall be carried out** before operation.

(Be sure to use a multimeter to check whether there is still residual voltage at the HV terminal before operation)

2. Before installing or removing the motor in any case, please make sure:
   a. the auxiliary battery (12 V/24 V battery) is turned off or not connected.
   b. the power battery (HV battery) is turned off or not connected.
(Note: Do not remove the electric drive system in severe weather such as rain, heavy fog and sandstorm.)

3. Do not touch the surface of the motor during operation or just after shutdown:
   a. The motor may be in a high temperature state during operation, which may cause severe burns or other personal injuries.
   b. The motor and MCU will generate HV power, which may result in a risk of electric shock.

4. During welding of the vehicle, protective measures must be taken for the HV and LV harness connectors of the motor to avoid burns of the surrounding harness.

2. Inspection before driving

1. ●Check whether the parking brake lever is pulled up.
.
2. ●Turn off unnecessary lamps and electronic equipment.
.
3. ●Move the shift lever to “N” position.
.
4. ●Turn the ignition switch to "ON" position and stay for (1~3) s, during which it is necessary to power on the controller for self-test and check whether the indication of the IC is normal.
5. ●If the IC shows no fault, step on the brake pedal, turn the ignition switch to "START" and stay for at least (0.5~1) s.
6. ●Release the ignition switch, and the “READY” indicator lamp on the IC lights up, indicating the HV system of the vehicle works normally.

1. Turn the ignition switch to "ON" position and stay for (1~3) s.

2. Step on the brake pedal, turn the ignition switch to "START" position, and stay for (0.5~1) s.

3. The “READY” indicator lamp on the IC lights up, indicating that the system works normally.

Note: Do not turn the ignition switch to "START" position without a short stay, otherwise the HV system of the vehicle may fail to work.

3. Requirements for use of the vehicle not used for a long time

- The optimal SOC range for the stored battery shall be 40%~60%.
- The lithium-ion battery shall be stored at an ambient temperature of -35℃--55℃

  in a flat, dry and ventilated indoor place protected against exposure to direct sunlight and rain and kept away from heat sources.
- The positive and negative poles of the battery pack shall be free of ingress of any conductive dirt such as metal materials and shall be protected by insulating materials.
- The battery pack should be protected against shock and stress from mechanical equipment.
- The battery maintenance of the vehicle stored for a long time must be carried out every three months to prevent battery damage.
- Before vehicle use for the first time after storage for a long time, "battery maintenance" shall be done at least once to activate the

  battery system to restore its performance to the best state.

4.1 Maintenance requirements

- Personnel requirements: Before performing maintenance on the motor system, the maintenance personnel shall be trained such that they are aware of safety precautions, and familiar with the measuring equipment and tools to be used, and the operation requirements.
- Maintenance site and environment requirements: When performing maintenance, avoid open-air operation under the weather conditions such as sand, dust, rain and snow. If maintenance needs to be carried out under these weather conditions, appropriate protection shall be provided to avoid entry of sand, dust, water or other foreign matters to the motor system.
- Definition of maintenance scope: The scope of maintenance is limited to the external interface parts only. It is forbidden to open the motor end cap or housing for internal maintenance. Improper opening may result in permanent damage on the motor and other serious personal injuries or substantial property damage. The consequences will not borne by our company. If there is a fault involving the inside of the motor system, please contact the after-sales service personnel of our company.
- In case of a fault alarm, the driver may carry out the preliminary inspection as indicated by the alarm message according to this manual. If there is no obvious insulation damage and wiring fault, the power supply may be switched on for test again. If no fault alarm is given, the motor can continue to run. In this case, the driver shall record the fault information properly to facilitate subsequent overhaul. If the fault alarm is still given, notify the maintenance personnel for overhaul. The driver shall not open the housing or the box without permission to avoid unnecessary losses.

4.2 Maintenance period and content

Generally, the first maintenance is carried out after use for 6 months or 5,000 km. Please refer to the table below for details.

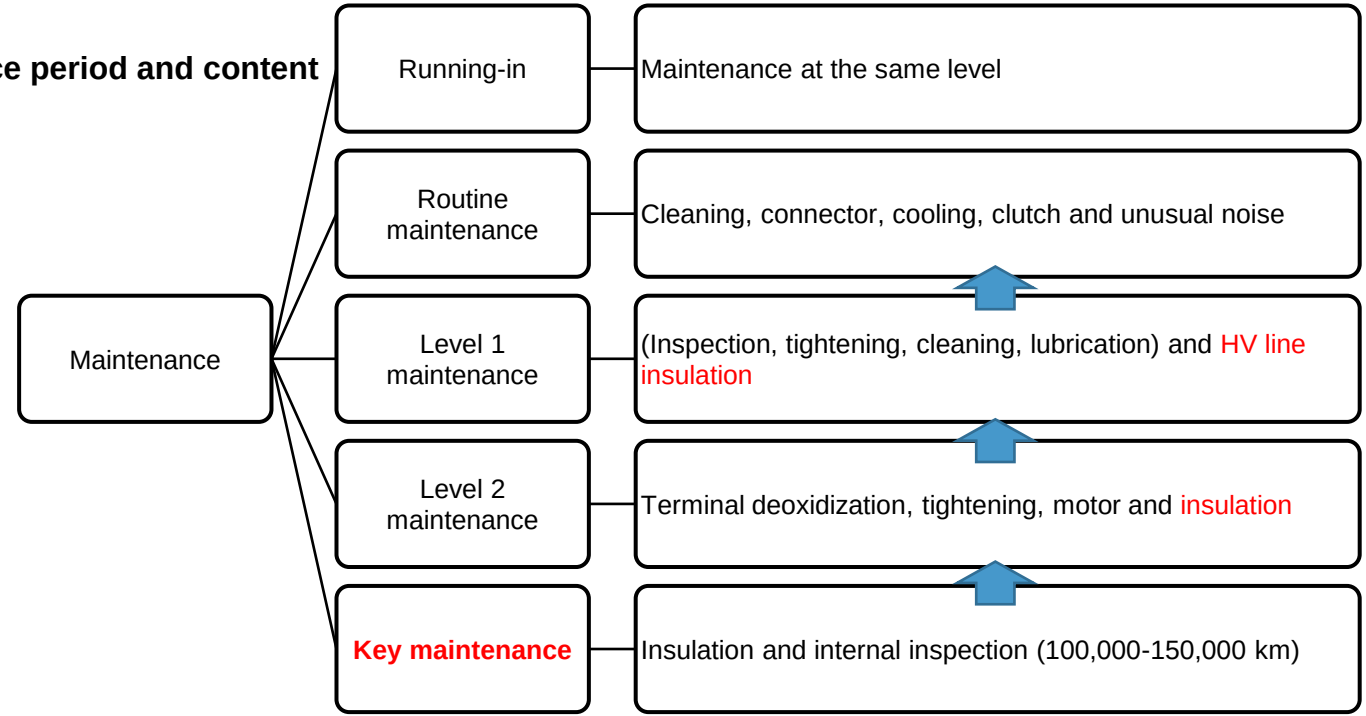
4.3 Maintenance period and content

I: Inspection, cleaning and correction or replacement as necessary. A: Adjustment. R: Replacement. T: Tightening to specified torque. L: Lubrication.

Maintenance interval / Maintenance item		Mileage or months									
	×1,000 km (kilometers)	5	55	155	205	255	305	355	405	455	505
	Months	6.5	12.5	18.5	24.5	30.5	36.5	42.5	48.5	54.5	60.5
Gearbox oil		R	R	R	R	R	R	R	R	R	R
Brake drum		I	Check whether the vehicle is parked completely after braking each time								
Coupling flange				I		I		I		I	
Motor mounting fastener				I		I		I		I	
HV BDU		I		I		I		I		I	
Three-phase line connection firmness				I		I		I		I	
Ground insulation of motor winding				I		I		I		I	
LV signal harness		I		I		I		I		I	
Ground		I		I		I		I		I	
Coolant		I	I	I	I	I	I	I	I	I	I
Oil seal				I		I		I		I	

According to the odometer or month count, whichever comes first

4.3 Maintenance period and content



The items of the maintenance at the upper level include those of the maintenance at the lower level except running-in!

4.4 Routine maintenance

Routine maintenance

No.	Maintenance item	Operation content	Technical requirement
1	Motor	Clean the motor	The surface of the motor shall be free of dust, water stains and obvious rust.
		Check the cooling system	1. Check whether the radiator is full of antifreeze. Add antifreeze if it is sufficient. 2. Check the pipeline for aging, deformation and leakage. 3. To ensure the cooling of the motor, it is necessary to remove dust, fiber and other foreign matters on the surface of the radiator of the motor cooling system and the air inlet and outlet of the electronic fan. 4. Check the cooling system fixing screws for looseness.
		Turn the ignition switch to ON position for inspection	1. The motor system and weak current control power supply displayed on the IC shall be normal; the motor temperature shall be normal; the motor feedback voltage, current and speed shall be zero;
		Check the driving state monitoring	1. Check whether any mechanical noise is made during running of the motor. 2. Record the fault information of the motor system during driving (as indicated on the IC).

4.5 Regular maintenance

Level 1 maintenance

No.	Maintenance item	Operation content	Technical requirement
2	Motor	All routine maintenance items	In accordance with the maintenance requirements
		1. Check the wiring of the U-, V- and W-phase terminals at the motor end and the grounding of the motor. 2. Check the motor three-phase input line and junction box. 3. Check whether dust is accumulated on the surface of the motor. 4. Check whether the LV connector is fixed properly. 5. Check the motor operation. 6. Test the resistance between phases A and B, phases A and C or phases B and C of the motor. 7. Measure the resistance of the three-phase line of the motor with an insulation meter. 8. Check the tightness of the motor output shaft end flange, and check whether the output shaft oil seal is in good condition without foreign matters. 9. Check whether the supporting steel plate of the motor is fixed properly. 10. Check the cooling water pipe joint for leakage.	1. The wiring at U-, V- and W-phase terminals shall be firm without looseness; the ground resistance of the motor housing shall be lower than 0.01 Ω. 2. The insulation layer of the input cable shall be undamaged, and the three-phase junction box cover shall be tightened and sealed properly. 3. The surface of the motor shall be dry and clean, without dust, and the groove of the reinforcement shall be free of foreign matters. 4. The LV connector interface shall be undamaged, and the harness shall be fixed reliably and effectively. 5. No unusual noise shall be made during test run and motor operation. 6. The three resistance values shall be approximately balanced and equal, which is normal. In case of any abnormality, maintenance is required. 7. The measured resistance between the pole and the harness shielding layer shall be higher than 100 MΩ. 8. The flange at the output end of the motor shall be free of looseness and the oil seal shall be in good condition. 9. The supporting steel plate of the motor shall be firm and reliable. 10. The cooling water pipe joint shall be free of leakage and looseness.

4.5 Regular maintenance

Level 2 maintenance

No.	Maintenance item	Operation content	Technical requirement
3	Motor	All Level 1 maintenance items	In accordance with the maintenance requirements
		1. Check and re-tighten the fixing screws at U-, V- and W-phase terminals. 2. Remove the dust from the junction box and the oxide layer from the terminals. 3. Check the insulation performance of the motor.	1. The wiring at U-, V- and W-phase terminals shall be firm without looseness. 2. The terminal surfaces shall be subject to dust removal and cleaned. **3. The insulation resistance of the motor shall be higher than 100 MΩ.**

4.5 Regular maintenance

- The gearbox oil defined in Dexron-VI specification or Castrol BOT 351 lv (Castrol BOT 351FE Plus) shall be selected.
- Currently, oil shall be added for the motors of FOTON M4 and G7 vehicles:

Model	Filling volume (L)	First maintenance period
M4	0.6±0.03	6 months/5,000 km
G7	1.2±0.05	6 months/5,000 km

- Bolts commonly used for maintenance and their torque requirements are given in the table below; for other parts, see the removal and installation steps of the brake drum.

Model	Torque (N.m)		
	Drain bolt	Filler bolt	Vent valve
M4	45±5 Nm	45±5 Nm	0.55±0.05 N.m (applied with thread lock adhesive
G7	45±5 Nm	45±5 Nm	0.55±0.05 N.m (applied with thread lock adhesive

Emergency measures

The principle of "people-oriented" shall be followed, and the losses shall be minimized on the premise of ensuring personal safety.

a. Traffic accident

Step 1: Stop the vehicle stably, apply the parking brake, open the door, evacuate the passengers, turn off the ignition switch, turn on the hazard warning lamp, place a warning triangle 50 m-100 m away in the direction of the oncoming vehicle, turn off the HV and LV main power switch if possible, and disconnect the MSD.

Step 2: Handle the traffic accident according to local traffic regulations and procedures.

Step 3: Notify the vehicle dealer and relevant units as soon as possible, and drag the faulty vehicle to the designated safe area for further inspection, repair or scrapping according to the dealer's instructions. **Do not use the vehicle before the relevant parties give the judgment result.**

b. Fire: If the HV and LV harnesses catch fire, cut off all power supplies as soon as possible, and use the on-board fire extinguisher to spray extinguishant until the fire is extinguished.

c. Wading: In case of wading, drive the vehicle through the waterlogged road at a constant speed. If the water depth exceeds 30 cm, it is recommended to make a detour. After wading, the vehicle shall be ventilated and dried.

Immersion:

If the vehicle gets into the water or is submerged in stagnant water due to accidents, please pay attention to the following:

Step 1
Turn off the ignition switch, disconnect the 24 V power supply and cut off the high voltage.

Step 2
Drag the vehicle out of the water and drain water.

Step 3
If handling of HV harnesses or HV components is necessary in this case, please wear high-voltage insulating gloves.

Principles for handling the vehicle immersed in water:

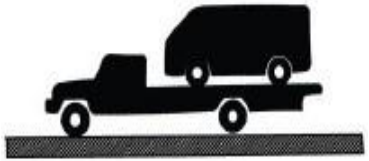
✓New energy vehicles submerged in stagnant water are prohibited from being started and should be handled by professionals. Professionals shall wear special PPE to disconnect the MSD and all HV/LV harnesses of the battery pack, and tow the vehicle to the repair shop
✓After the motor is immersed in water, professionals shall be assigned to check and analyze the motor completely. The motor can be used again after its function is confirmed to be normal.

Precautions for towing:

When the vehicle needs to be towed due to an accidental fault, **it is recommended to use a flatbed semi-trailer**. If the above condition isn't met, **the following suggestions are provided**:

1. Towing with the axle shaft removed (recommended)

Remove the axle shaft and the three-phase line at the motor end. **At this time, the vehicle can be towed directly**, without damaging the AMT and MCU.



Towing the vehicle with a faltbed semi-trailer

2. Towing with the axle shaft not removed (optional)

First, **power off the vehicle** (cut off the main power supply), turn the key off, and engage the **neutral (N) gear**. Then, if **the vehicle is matched with a transmission**, tow the vehicle at the specified towing speed. Finally, if **the vehicle is matched with a transmission**, determine whether **a transmission fault is displayed** on the IC;

① If the IC **does not display a fault related to the transmission**, **the vehicle can be towed at the specified towing speed**.

② If the IC displays a fault related to the transmission, the vehicle cannot be towed until **the axle shaft is removed**.

Towing with the drive shaft removed

Towing speed requirements

	Direct drive	Single-reduction	With transmission
Speed	<15 km/h	<15 km/h	<8km/h
Remarks	If the towing speed exceeds the specified value, the axle shaft must be removed.		

3. For the **axle-driven motor**, the plan of towing with a **flatbed semi-trailer** shall be adopted.

➢ In case of major faults such as smoking and electric leakage of the motor, cut off the power supply immediately, and report to the professionals for maintenance. If components are damaged, report to the manufacturer for maintenance.

Contents

List of typical faults

- **The main faults of this product include:**
- DC bus overvoltage
- DC bus undervoltage
- Motor phase overcurrent
- Motor overspeed
- Motor winding overtemperature
- CAN communication failure
- Stalling alarm
- Motor insulation fault
- Motor resolver fault
- Unusual noise of motor
- Single-reduction motor oil seal fault

Diagnosis methods and solutions of typical faults

No.	Fault mode	Cause analysis	Solution
1	DC bus overvoltage	1. The DC bus voltage exceeds the fault threshold. If the motor is still in the power generation state when the battery voltage is close to the threshold, overvoltage may occur.	1. Limit the regenerative braking of the motor in the VCU when the voltage is close to the overvoltage limit.
		2. The battery contact is open suddenly. If the motor is in the regenerative braking state, the capacitor inside the MCU will be filled with energy quickly, resulting in overvoltage (which is so dangerous that the MCU is prone to damage).	1. It is strongly recommended not to disconnect the DC relay during operation in any motor fault mode, and ensure that the DC relay will not be disconnected suddenly.
		3. During operation at high speed, if the MCU suddenly enters the protection state to disconnect the pulse and enter the uncontrollable power generation state, overvoltage may occur.	1. Find the cause of fault protection.
2	Motor phase overcurrent	1. Overcurrent during high-speed operation may be caused by the angle error of the resolver signal.	1. Check the resolver angle on the surface of the motor, and use the diagnostic scan tool to read the angle stored in the MCU to ensure that the resolver angle of the motor is correct.
		2. The looseness and water or mud ingress result in a resolver signal error.	1. Check the resolver harness on one side of the motor to ensure that it is free of pollution and water ingress. 2. Measure whether the resistance of the motor resolver is within the normal range on the connector side of the MCU. Generally, the resistance is 10-30 Ω and varies according to the resolver model.

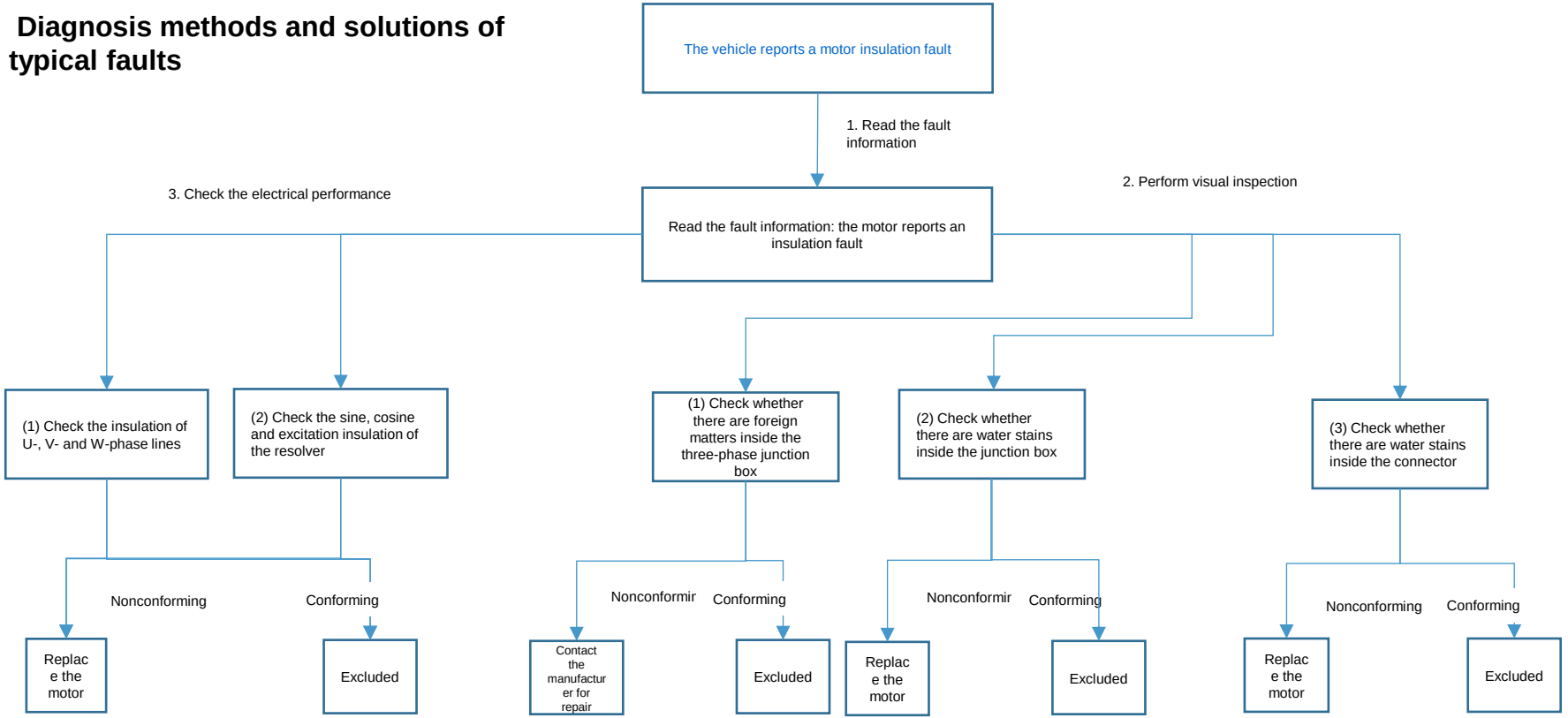
Diagnosis methods and solutions of typical faults

No.	Fault mode	Cause analysis	Solution
2	Motor phase overcurrent	3. In case of abnormal ground insulation of the HV power supply system, jitter and loss of control of the motor are likely to occur, resulting in overcurrent.	1. Check the ground insulation of the DC terminal. Normally, the value shall be about 6 MΩ. If it is lower than 6 MΩ, the insulation may be abnormal.
		4. In case of overcurrent at a very low speed or torque, the three-phase line of the motor may be shorted to ground.	1. Measure the ground insulation of the motor on the DC side of the motor. The insulation value shall be about 6 MΩ. Disconnect the three-phase line of the motor and check the ground insulation of the motor. The insulation value shall be greater than 100 MΩ. If the ground insulation value of the three-phase terminals of the motor is smaller than 100 MΩ, contact the JJE after-sales department for treatment.
3	Motor overspeed	1. The actual speed of the motor exceeds the set threshold.	1. In case of overspeed during driving under normal road conditions, use the VCU to limit the motor speed. 2. In case of overspeed during downhill driving rather than during driving under normal road conditions, use the VCU to configure the coasting feedback torque to limit the speed before overspeed occurs.
4	Motor winding overtemperature	1. The motor cooling water circuit and radiator are blocked or lack of coolant, the cooling water pump and cooling fan are damaged, etc.	1. Check the engine cooling system. 2. Read the temperature change curve of the motor through the BMU. If the temperature of the motor changes suddenly during operation, the cooling water circuit may be faulty.
		2. The motor is overloaded for too long time, resulting in motor overtemperature.	1. Make an analysis according to the monitoring data.
		3. The motor temperature sensor (NTC) has such faults as short circuit and water ingress.	1. If the motor overtemperature is detected when the actual temperature of the motor is not high, check the resistance of the motor temperature sensor with a multimeter. (Taking Foton P3 as an example) Under normal circumstances, the resistance of the temperature sensor shall be 111.2 KΩ~87.74 KΩ at 25° C. The higher the temperature, the lower the resistance value. If the resistance is lower than 87 KΩ at 25° C, the temperature sensor may be faulty.

Diagnosis methods and solutions of typical faults

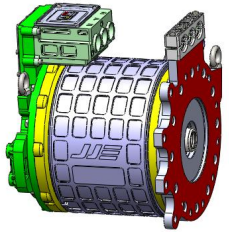
No.	Fault mode	Cause analysis	Solution
5	CAN communicatio n failure	The MCU doesn’t receive the signal from the VCU within the specified time period.	1. Check the vehicle harness, and read the CAN bus fault frame ratio through the bus recorder. 2. Check the connection for looseness, and check whether the three-phase line between the motor and the MCU is shielded properly.
6	DC bus undervoltage	1. When the voltage on the DC side of the motor is lower than the threshold, the VCU gives an enable command. 2. The contactor on the DC side of the motor is open. 3. The fuse on the DC side of the motor is faulty.	1. Connect the BMU software to collect and record the data. 2. Check the voltage on the DC side. In case of a sudden change, the contactor must be open. 3. Measure the resistance and continuity of the fuse with a multimeter.
7	Motor stalling	The motor speed doesn’t match with the torque and current output by the motor. At this time, the motor overtemperature alarm may be issued due to stalling.	1. Check whether the motor is stuck. If so, please find out the cause or replace the motor with a new one of the same model. 2. Check whether the fault is caused by an operation error. If the parking brake is not released, step on the accelerator pedal for correction, and the fault can be eliminated.

Diagnosis methods and solutions of typical faults

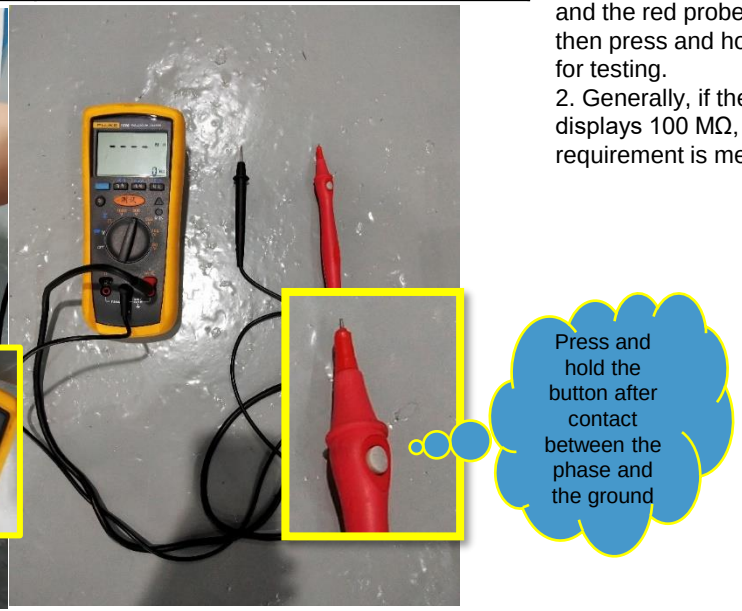


Diagnosis methods and solutions of typical faults

Test item	No.	Requirement	Criterion	Equipment
Electrical performance	1	Insulation resistance between phase and ground at a voltage of 500 VDC	>100 MΩ	Insulation meter



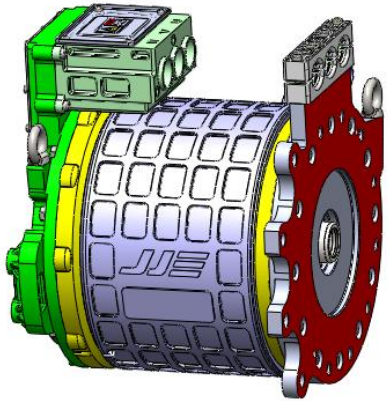
1. Select a special insulation meter, connect the black probe to the ground and the red probe to the phase, and then press and hold the TEST button for testing.
2. Generally, if the insulation meter displays 100 MΩ, the insulation requirement is met.



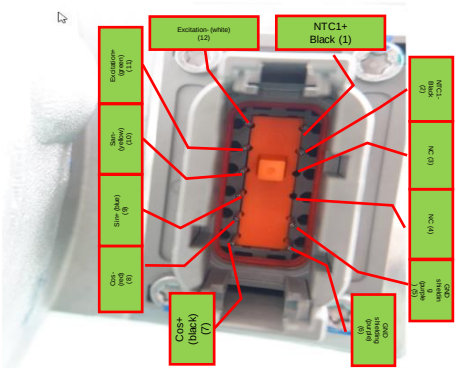
Foton (P3, M4 and G7) PMSM insulation fault confirmation methods

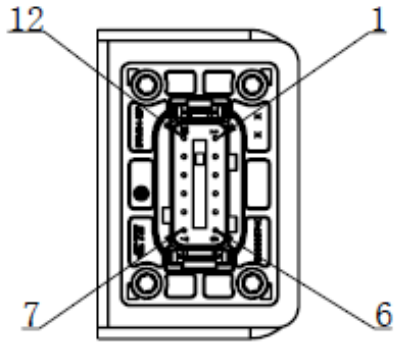
- Confirm the model: Foton (P3), corresponding to JJE TZ220XS612D motor
- Use a special insulation meter, connect the black probe to the ground and the red probe to the resolver pin, press and hold the TEST button to test the three-phase (U, V and W), sine, cosine, excitation, NTC1 and NTC2 insulation respectively. The criterion is as follows: ≥100 MΩ@500 VDC.

Note: Pin definitions are shown in the figure below：



Electrical performance test of motor — standard			
No.	Test location	Criterion	Equipment
1	NTC 1/NTC 2 ground insulation	≥100 MΩ@500 VDC	Insulation meter
2	Resolver: Sine/cosine/excitation ground insulation	≥100 MΩ@500 VDC	Insulation meter
3	U/V/W-phase ground insulation	≥100 MΩ@500 VDC	Insulation meter

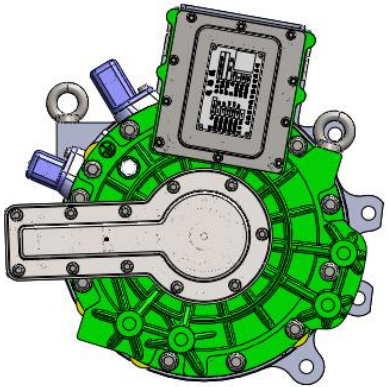




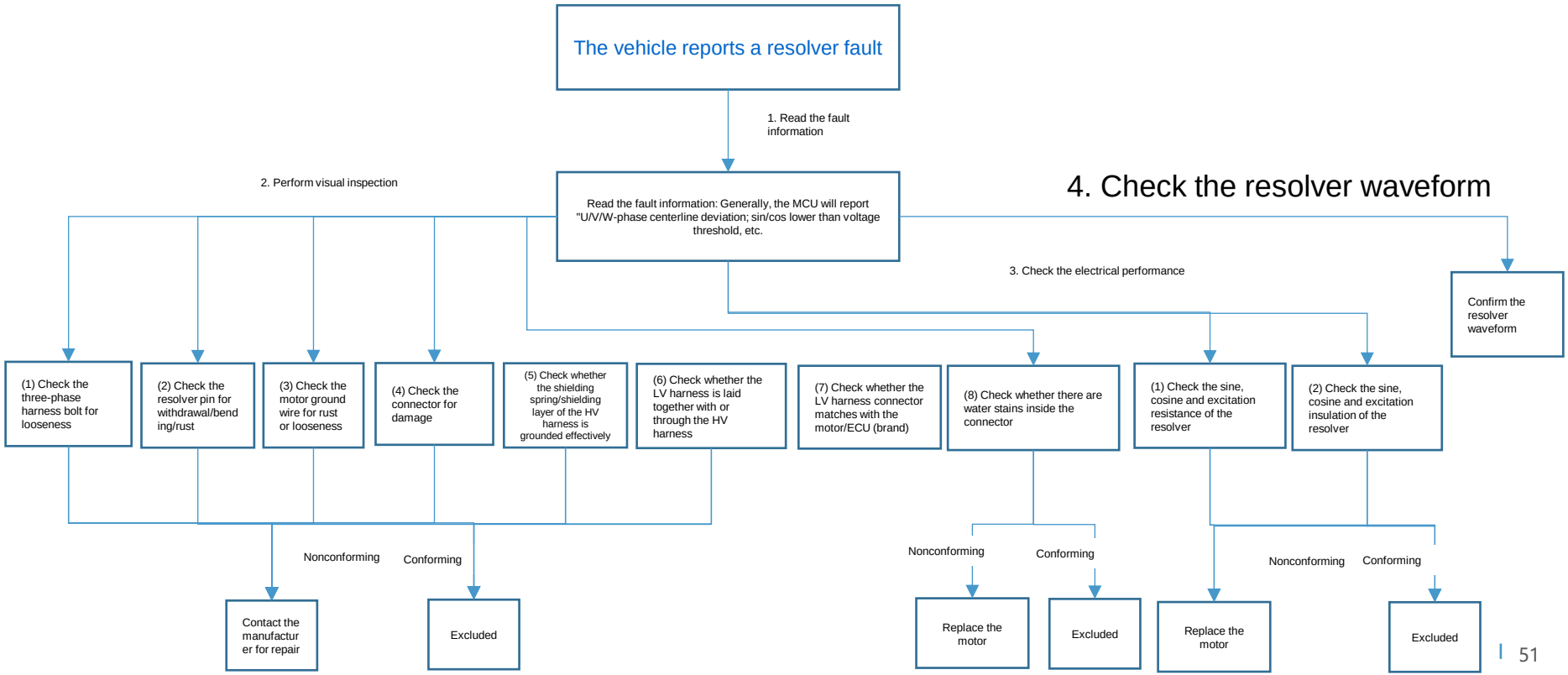
Pin definitions of LV connector (Table 1)

(1-2303064-1)

Pin No.	Color	Definition	Remarks
1	Black	R1+	NTC temperature sensor
2	Black	R1−	
3			
4			
5	Purple	GND	Shielding
6	Purple		
7	Black	COSLo	Resolver cosine
8	Red	COS	
9	Blue	SINLo	Resolver sine
10	Yellow	SIN	
11	Green	REFLo	Resolver excitation
12	White	REF	

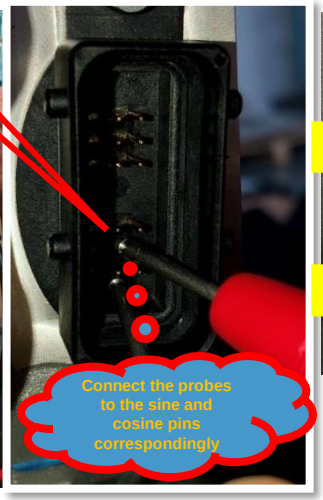


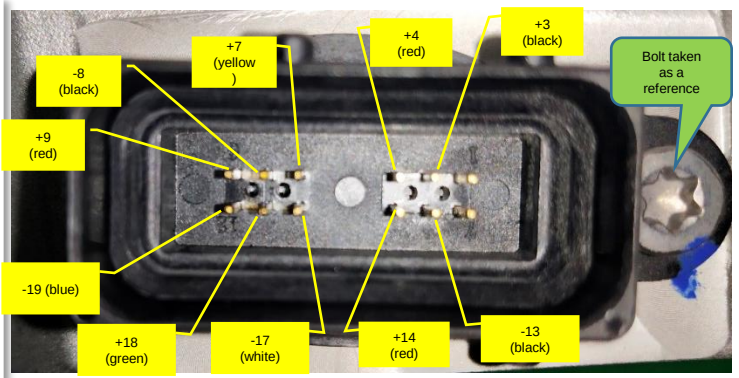
Diagnosis methods and solutions of typical faults



Diagnosis methods and solutions of typical faults

- Measurement method of resistance；
- Set the multimeter to the resistance position;
- Check the unit in the upper right corner of the screen: MΩ, Ω, KΩ, diode; select Ω for the resistance of the CMA motor resolver.
- Select a special multimeter, connect the black and red probes to the sine (+ and -), cosine (+ and -) and excitation (+ and -) poles in sequence, and measure the sine, cosine and excitation resistance values respectively.



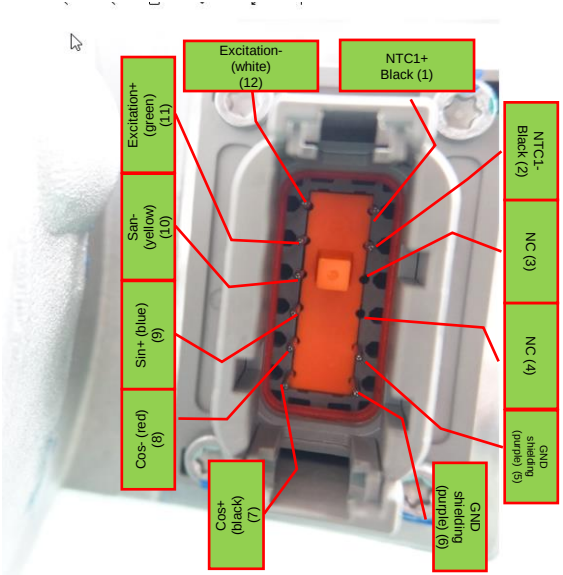


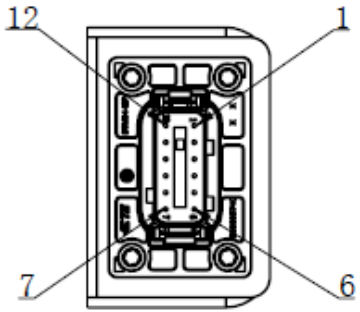
IX. Common faults and troubleshooting methods

IX. Foton (P3, M4 and G7) motor resolver fault confirmation methods:

If no problem is found in the following test, the motor fault can be preliminarily excluded:

- Before the test, check the motor ground wire and three-phase harness bolt for looseness, the resolver pin for withdrawal/bending/rust, and the connector for water ingress and surface damage;
- Confirm the model: Foton (P3), corresponding to JJE TZ220XS612D motor;
- Set the multimeter to the resistance position;
  - Check the unit in the upper right corner of the screen: MΩ, Ω, KΩ, diode; select Ω for the resistance of the CMA motor resolver.
  - Select a special multimeter, connect the black and red probes to the sine (+ and -), cosine (+ and -) and excitation (+ and -) poles in sequence, and measure the sine, cosine and excitation resistance values respectively.



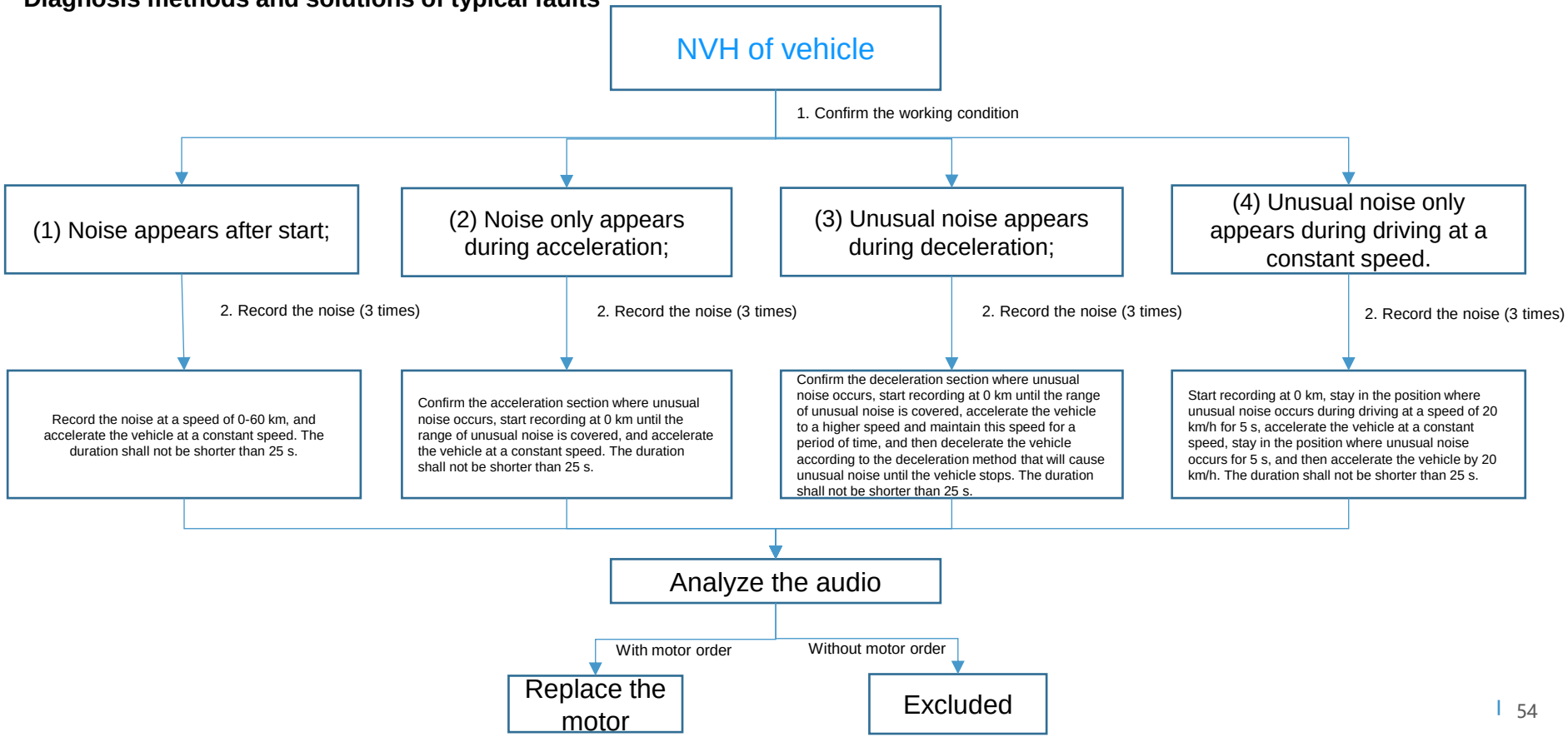


Electrical performance test of Foton (P3) motor — standard		
No.	Test location	Criterion
1	LV connector pin — resolver resistance, excitation (11, 12)	24.3-29.7Ω@25℃
2	LV connector pin — resolver resistance, SIN (9, 10)	54-56@25℃
3	LV connector pin — resolver resistance, COS (7, 8)	57.6-70.4Ω@25℃

Electrical performance test of Foton (M4) motor — standard		
No.	Test location	Criterion
1	LV connector pin — resolver resistance, excitation (11, 12)	24-30Ω@25℃
2	LV connector pin — resolver resistance, SIN (9, 10)	57-71Ω@25℃
3	LV connector pin — resolver resistance, COS (7, 8)	45-66Ω@25℃

Electrical performance test of Foton (G7) motor — standard		
No.	Test location	Criterion
1	LV connector pin — resolver resistance, excitation (11, 12)	20.6±2Ω@25℃
2	LV connector pin — resolver resistance, SIN (9, 10)	49.8±5Ω@25℃
3	LV connector pin — resolver resistance, COS (7, 8)	55.3±5Ω@25℃

Diagnosis methods and solutions of typical faults



Preliminary judgment methods for NVH of the motor

If you feel that NVH of the vehicle is made by the motor, a professional audio analysis will be required in order to accurately determine whether the motor is faulty. If no noise in the motor-related order is found in the audio analysis, it can be judged that the motor is normal. The service station shall send back the audio in the following way.

Specific steps:

1. Determine the working condition of NVH; (e.g. unusual noise appears during acceleration, deceleration or driving at a constant speed)
2. Record the noise:

(1) Recording tool: Mobile phone/recording pen (Note: As for a mobile phone, the original recording equipment shall be used;)

(2)

If unusual noise appears during acceleration: Before recording, keep the vehicle stationary. After recording is initiated, gradually accelerate the vehicle (don't accelerate the vehicle too fast, unless unusual noise only occurs in case of fast acceleration) to a higher speed through driving under the working conditions where unusual noise appears. (If unusual noise appears at a speed of 60 mph, the maximum speed shall not be lower than 70 mph). After accelerating the vehicle to the maximum speed, accurately record the maximum speed or its corresponding engine speed, maintain it for a second or two, and then gradually decelerate the vehicle until it stops.

If unusual noise appears during deceleration: After recording is initiated, accelerate the vehicle to a higher speed and maintain this speed for a period of time, and then decelerate the vehicle according to the deceleration method that will cause unusual noise until the vehicle stops.

If unusual noise only occurs when the vehicle runs at a constant speed such as 50 mph: accelerate the vehicle gradually from 0 mph to 30 mph and maintain this speed for more than 5 s; gradually accelerate the vehicle to 50 mph and maintain this speed for more than 5 s; accelerate the vehicle to 70 mph and maintain this speed for more than 5 s; and brake the vehicle until it stops.

Note:

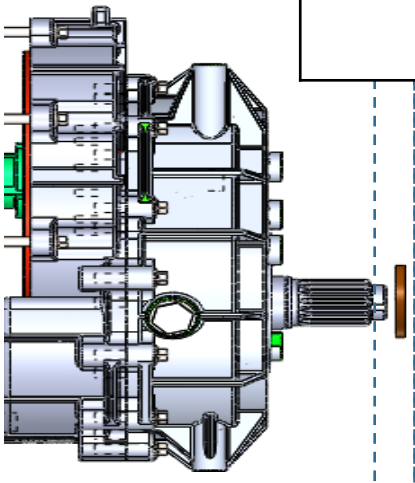
The recording shall be started before the vehicle starts and finished after the vehicle stops. In case of failure to keep the vehicle stationary due to limited conditions (such as driving on an expressway), drive the vehicle at a low speed for a period of time, start recording, and accelerate the vehicle after 5 s

Repeat the operation twice or three times to select the clearest recording.

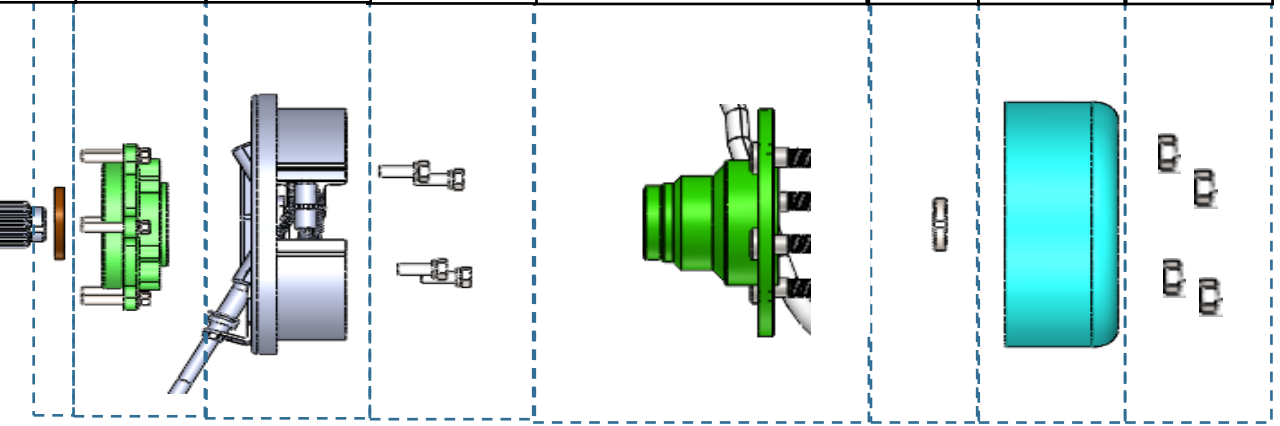
Passengers in the vehicle shall keep quiet, and the recording staff shall keep the arm on the side of the hand holding the recorder as stable as possible and ensure that the recorder doesn't shake violently.

3. Analyze the audio: The audio will be sent to the motor manufacturer for confirmation. Generally, the result will be published on the day after recording.

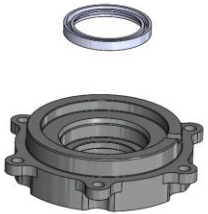
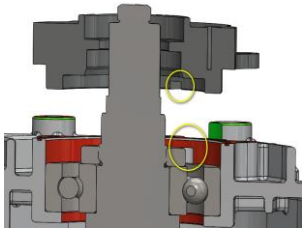
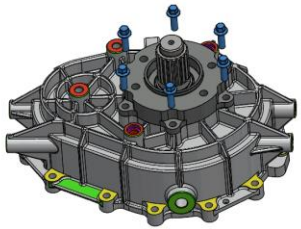
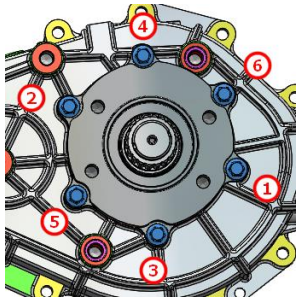
Instructions for replacement of oil seal for 220 single-reduction motor

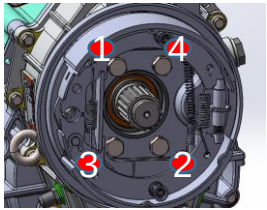
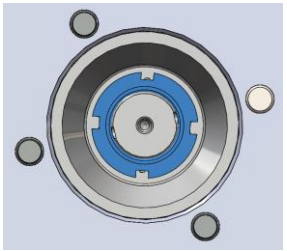


8: Remove the oil seal and replace it	7: Remove the fixing plate	6: Remove the brake base plate	5: Remove the 4 bolts under the brake base plate	4: Remove the flange	3: Remove the lock nut on the shaft	2: Remove the 4 bolts connecting the propeller shaft and the brake	1: Remove the 4 bolts connecting the propeller shaft and the brake



Oil seal | Fixing plate | Brake base plate | Base plate bolt | Flange | Lock nut | Outer drum | Lock nut

Step	Placement of oil seal and positioning plate	Press-fitting of oil seal	Installation of fixing plate assembly	Placement of bolts	Tightening of bolts
List of materials	1. Oil seal 2. Fixing plate			Hexagon flange bolt Small series 6-M8X25 (32090780)	
Operation demonstration					
Tooling, tools, inspection tools					
Major Step (What)	Put the mounting side of the fixing plate upwards on the positioning plate of the press, and install the oil seal on the press head	Use a hand press to press the oil seal into the fixing plate evenly; apply high temperature resistant grease to the inner and outer rings of the oil seal	Place the fixing plate on reducer cover assembly in the correct direction	Coat the bolt head with thread lock adhesive and install it in the bolt hole of the fixing plate	1. Start the torque gun, and pre-tighten the 6 bolts diagonally to the torque of 14 Nm as shown in the figure 2. Start the torque gun for the second time, and tighten the bolts to the torque of 27 Nm in sequence
Key Point (How)	The direction of the oil seal shall be correct, and the lip shall be undamaged.	The direction of the oil seal shall be correct, and the lip shall be undamaged.	In case of installation, the fixing plate shall be placed horizontally, and the notches of the oil guide groove shall be on the opposite side.	The bolt specification and quantity shall be correct.	1. The bolt quantity shall be correct; 2. The bolts shall be pre-tightened to the torque of 14 Nm and finally tightened to the torque of 27 Nm.

Step	Installation of brake front housing	Heating of flange	Installation of flange	Installation of lock nut	Installation of outer drum
List of materials	4*hex head bolt M12×30 4*standard spring washer		Small round nut		
Operation demonstration					
Tooling, tools, inspection tools					
Major Step (What)	1. Take the brake drum front housing, and install it on the reducer cover in the correct direction 2. Take the M12 hex head bolt and washer, apply thread lock adhesive to the head, and fix the brake drum front housing	Take the flange, put it into the intermediate frequency heater, and heat it	Take the heated flange, align it with the spline, and install it into the shaft end	1. Take the pneumatic tool and socket, and align the four jaws of the socket with the nut; 2. Start the pneumatic tool, and lock the nut 3. Perform punching and riveting after locking	
Key Point (How)	Torque: 114±10	Heating at 180℃ for 120-180 s	Wear thick heat-resistant cotton gloves during operation	Torque of lock nut: 170~230 Nm	

THANKS