RR-HA 系列伺服驱动器

用户手册

RR-HA Series Servo Driver

User Guide

V0.1.4

Author

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目录 Catalogue

0 版本记录 Version Log

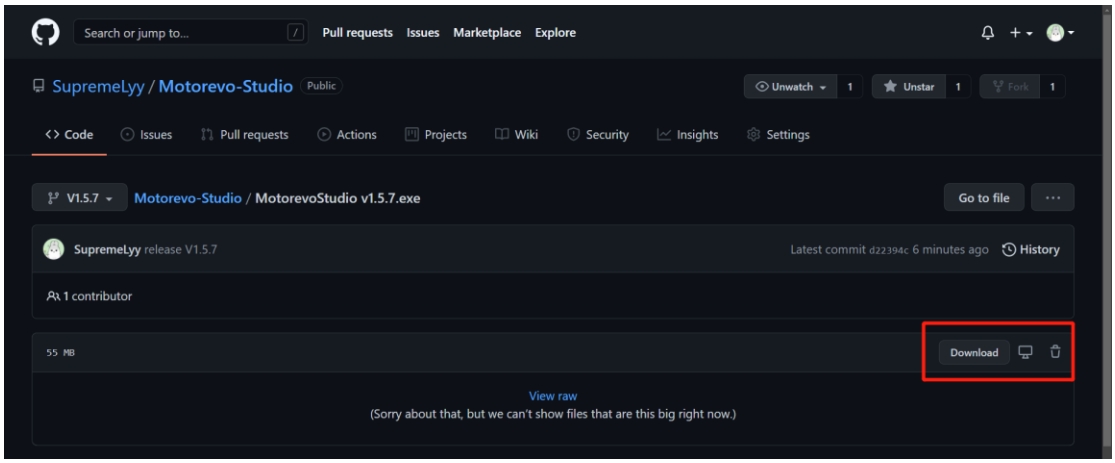
本产品版本更迭与适配情况如下，请确保您的固件版本号、Motorevo Studio 版本号以及说明书版本号对应一致，否则可能会带来严重的事故!

The version change and adaptation of this product are shown below. Please make sure that your firmware version code, Motorevo Studio version code and user Guide version code correspond to each other, otherwise serious accidents may occur!

驱动器版本号 Actuator Version	MotorevoStudio Version	User Guide Version	发布时间 Release Time	备注 Note
AF.22.00.12	V1.5.7	V0.1.4	2021.12.5	Remove position loop limit and velocity loop limit, use torque limit instead

您可以访问 https://github.com/SupremeLyy/Motorevo-Studio 获取最新的 Motorevo Studio 软件、使用手册以及驱动器固件 。

You can visit https://github.com/SupremeLyy/Motorevo-Studio to get the latest Motorevo Studio software, User Guide and actuator firmware.



1 产品简介 Introduce

RR-HA 系列伺服动力单元采用全新自主知识产权的机械结构和减速器设计方案，搭载同类产品中算力最高的驱动控制芯片，基于 Field-Oriented-Control 算法，搭配先进自抗扰控制技术和在线参数辨识技术对速度、角度、力矩进行控制。，该动力系统自重 950g，在 40Nm 负载情况下可以达到 0.001rad 以下的控制精度误差。并支持配合 Motorevo Studio 调参软件进行参数设置并升级固件。

The RR-HA series servo power unit adopts a new mechanical structure and reducer design scheme with independent intellectual property rights. It is equipped with the drive control chip with the highest computing power among similar products. It is based on the Field-Oriented-Control algorithm and is equipped with advanced automatic disturbance rejection control technology and online Parameter identification technology controls speed, angle and torque. , The power system has a dead weight of 950g, and can reach a control accuracy error of less than 0.001rad under a load of 40Nm. And support to cooperate with Motorevo Studio assistant software for parameter setting and firmware upgrade.

2 应用 Application

- 机械臂 Robotic Arms
- 无人机、机器人和遥控玩具 Drone, Robot, Remote toy
- 工业和物流机器人 Industrial and logistics robots
- 摄影云台 Camera PTZ

3 型号说明 Model Description

RR-HA-60-14-XXX-EC

EC：通讯方式，E:仅使用 EtherCAT, C:仅使用 CAN, EC:既可使用 EtherCAT 也可使用 CAN 通信
EC: communication method, E: EtherCAT only, C: CAN only, EC: both EtherCAT and CAN communication can be used

XXX：减速比 Gear ratio

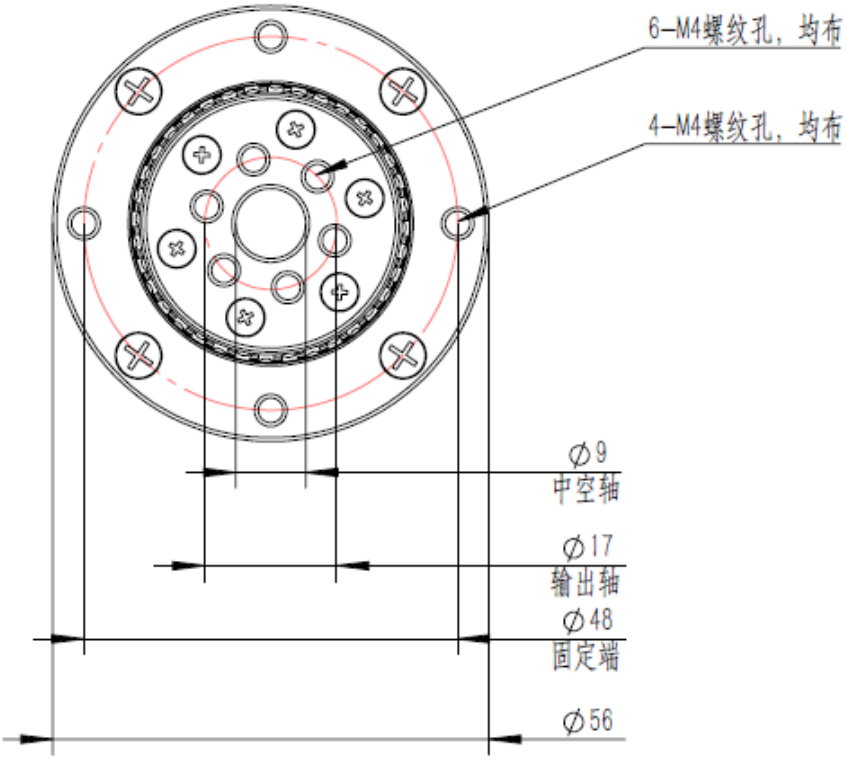
14：减速器型号 Reduction model

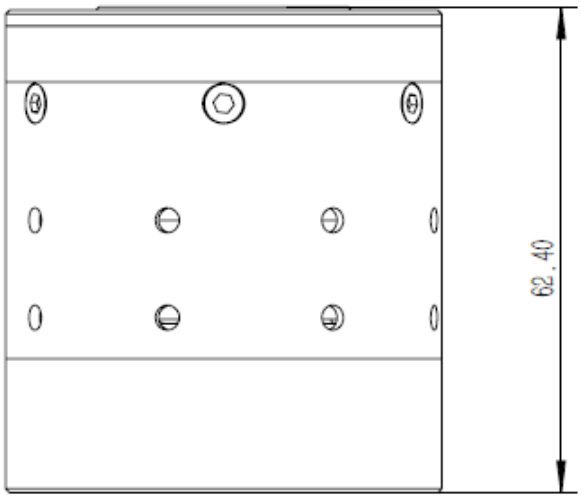
60：定子铁心直径(mm) Stator Diameter (mm)

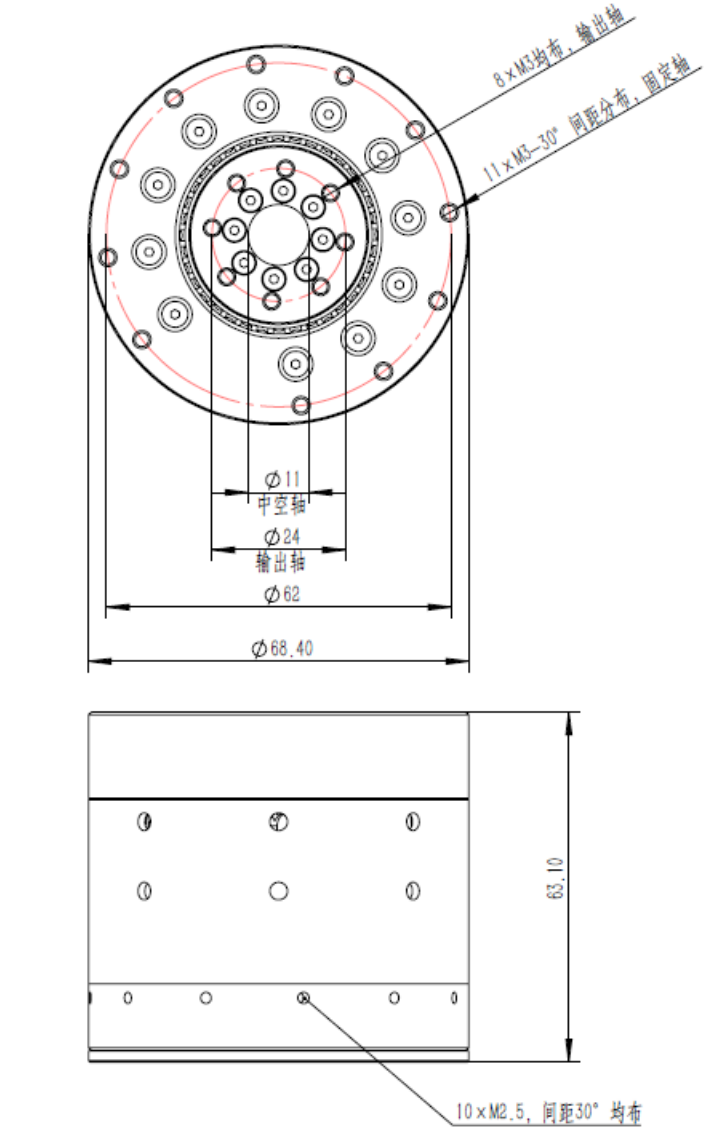
HA：减速器标识，HA:谐波减速器，PA:行星减速器
Reducer identification: HA: harmonic reducer, PA: planetary reducer

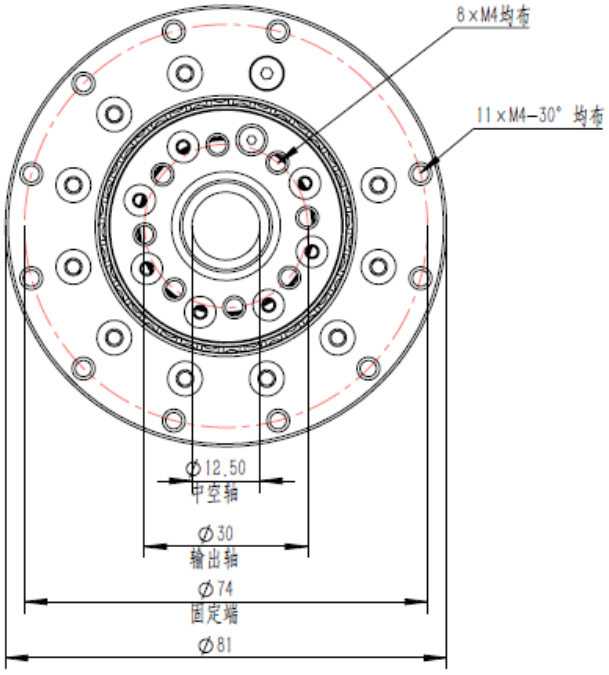
4 机械尺寸以及安装说明 Mechanical Size

RR-HA-40-EC






8×M3均布，输出轴
11×M3-30° 间距分布，固定轴
Ø11
中空轴
Ø24
输出轴
Ø62
Ø68.40
63.10
10×M2.5，间距30° 均布
7×M3，间距45° 均布
XT30电源
USB Micro
CAN线插口
Ø60
Ø60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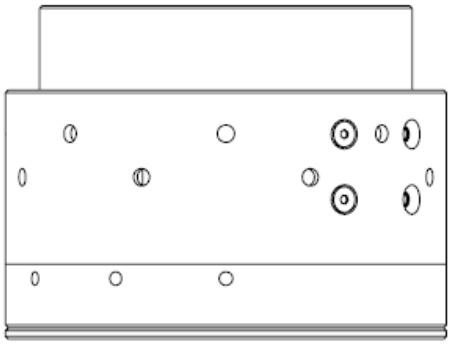
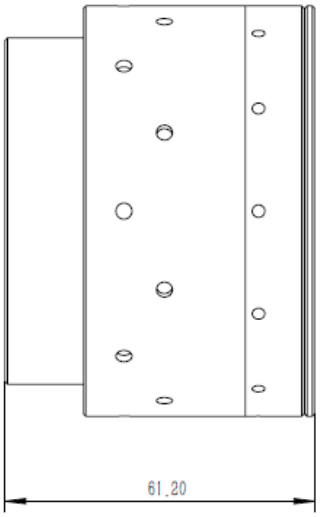
Ø12.50
中空轴
Ø30
输出轴
Ø74
固定端
Ø81

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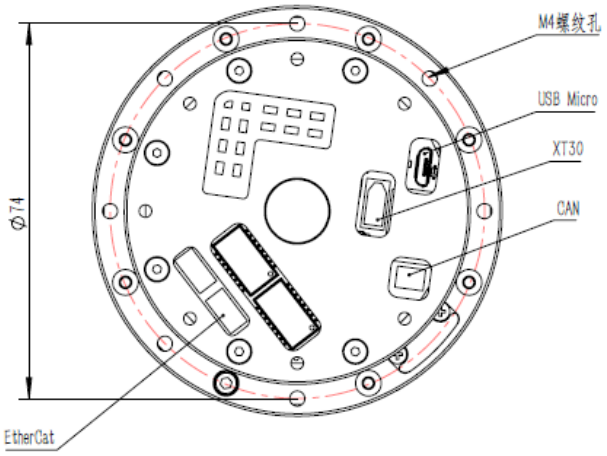
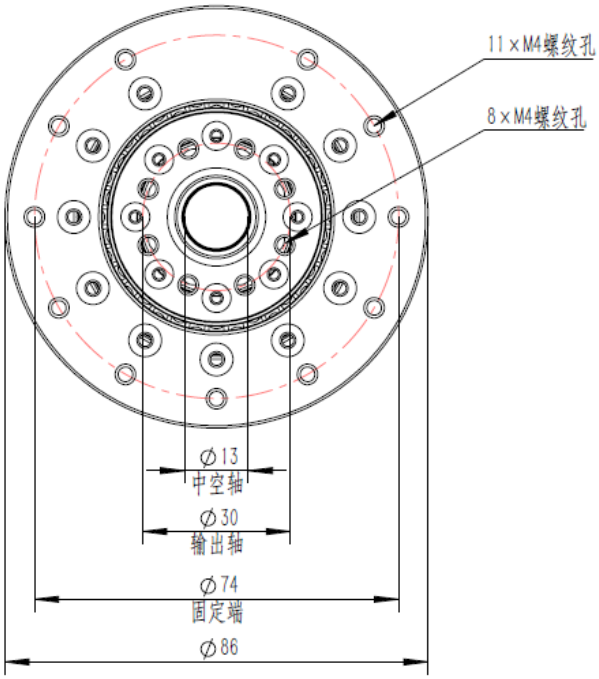
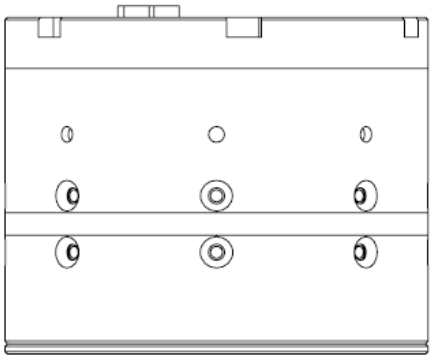
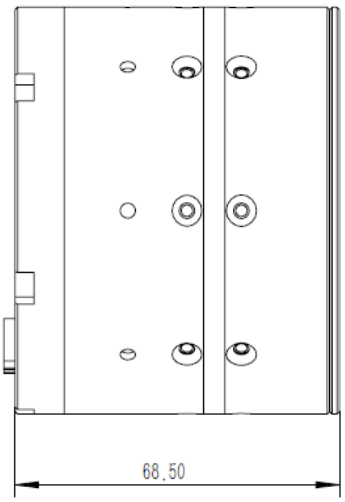

M4螺纹孔
USB Micro
XT30
CAN
EtherCat
Ø74


11×M4螺纹孔
8×M4螺纹孔
∅13
中空轴
∅30
输出轴
∅74
固定端
∅86

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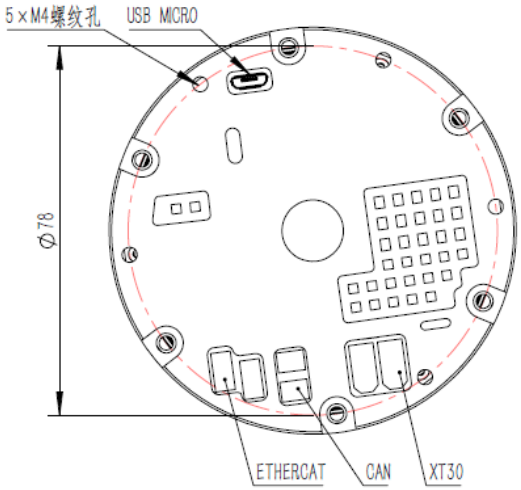
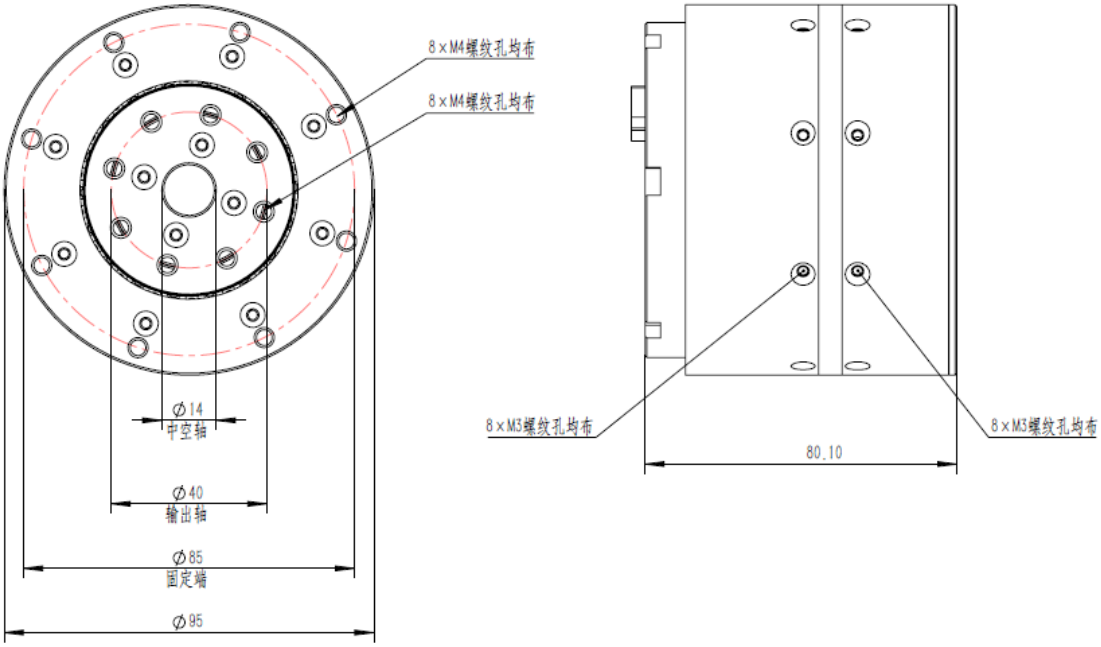
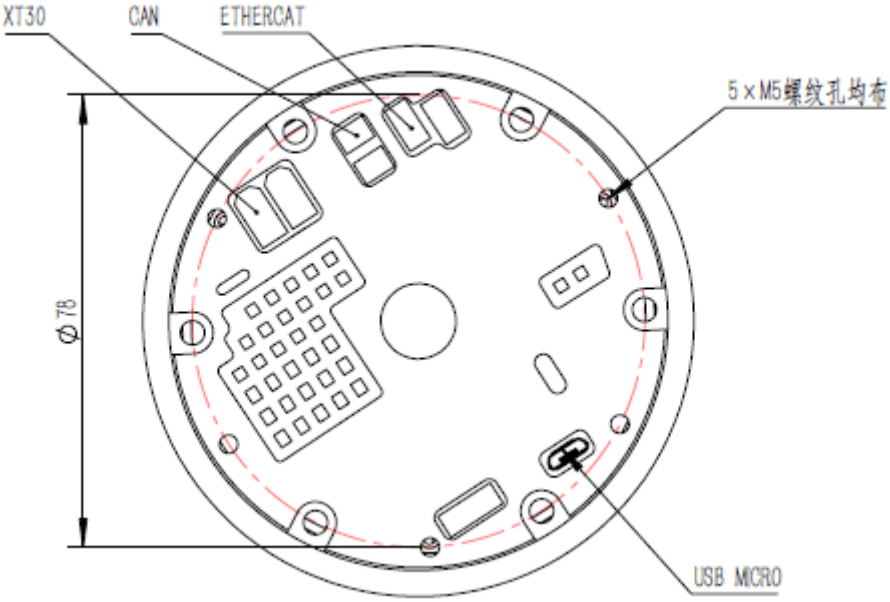

5×M4螺纹孔
USB MICRO
∅78
ETHERCAT
CAN
XT30

RR-HA-80-EC

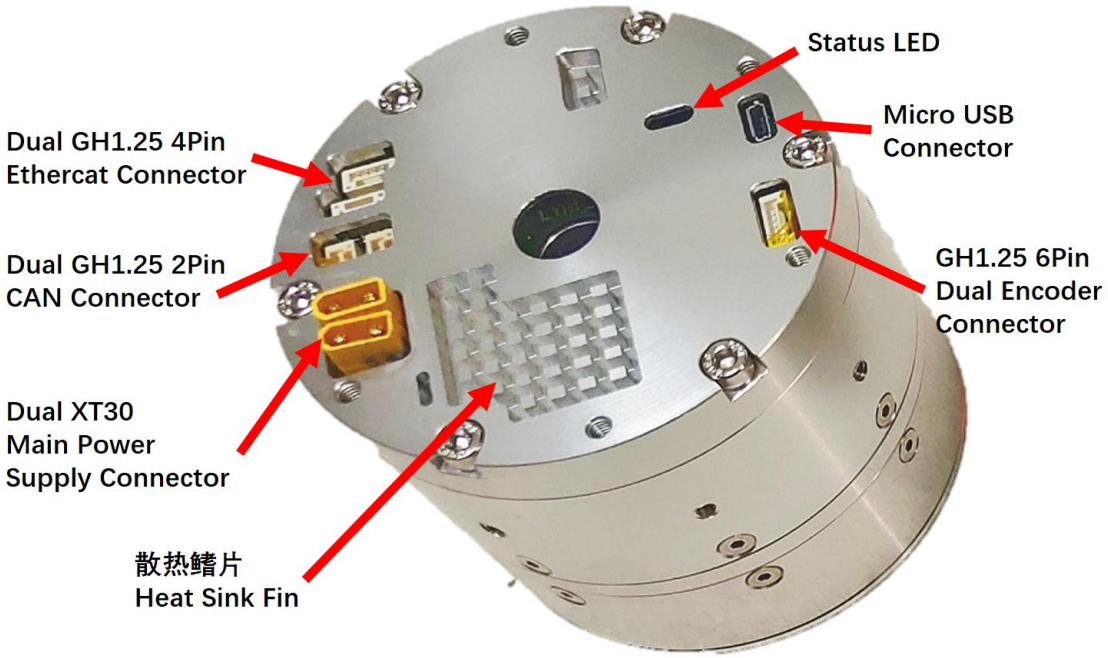

8×M4螺纹孔均布
8×M4螺纹孔均布
Ø14
中空轴
Ø40
输出轴
Ø85
固定端
Ø95
8×M3螺纹孔均布
8×M3螺纹孔均布
80.10

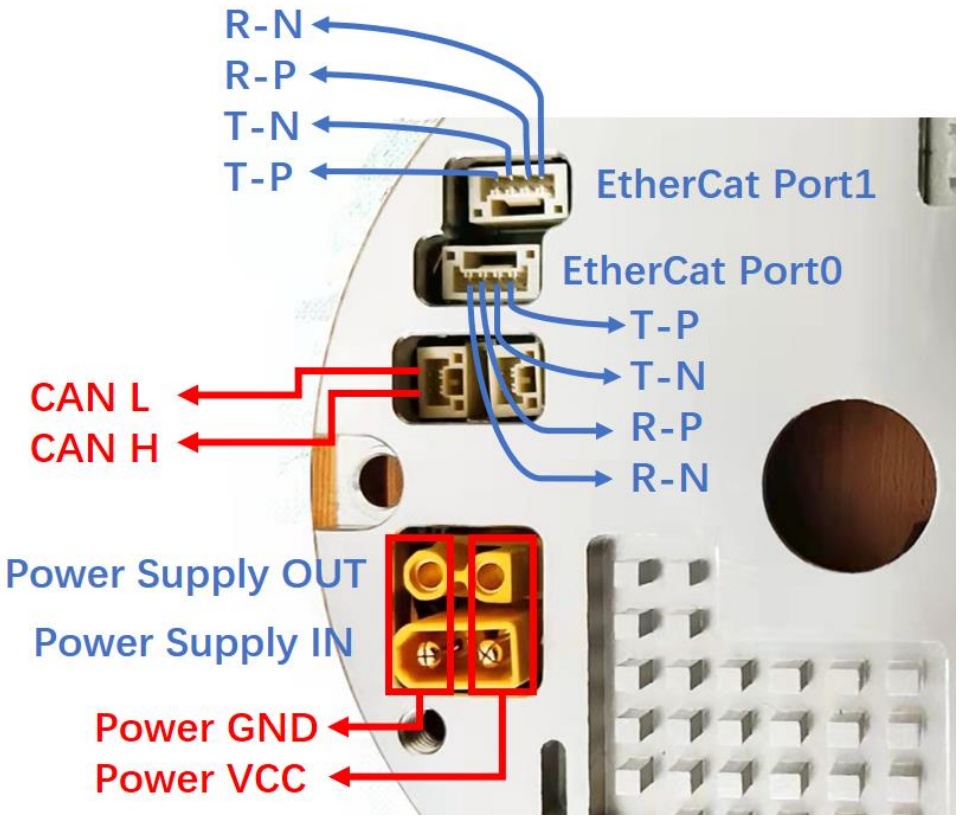

XT30
CAN
ETHERCAT
5×M5螺纹孔均布
Ø78
USB MICRO

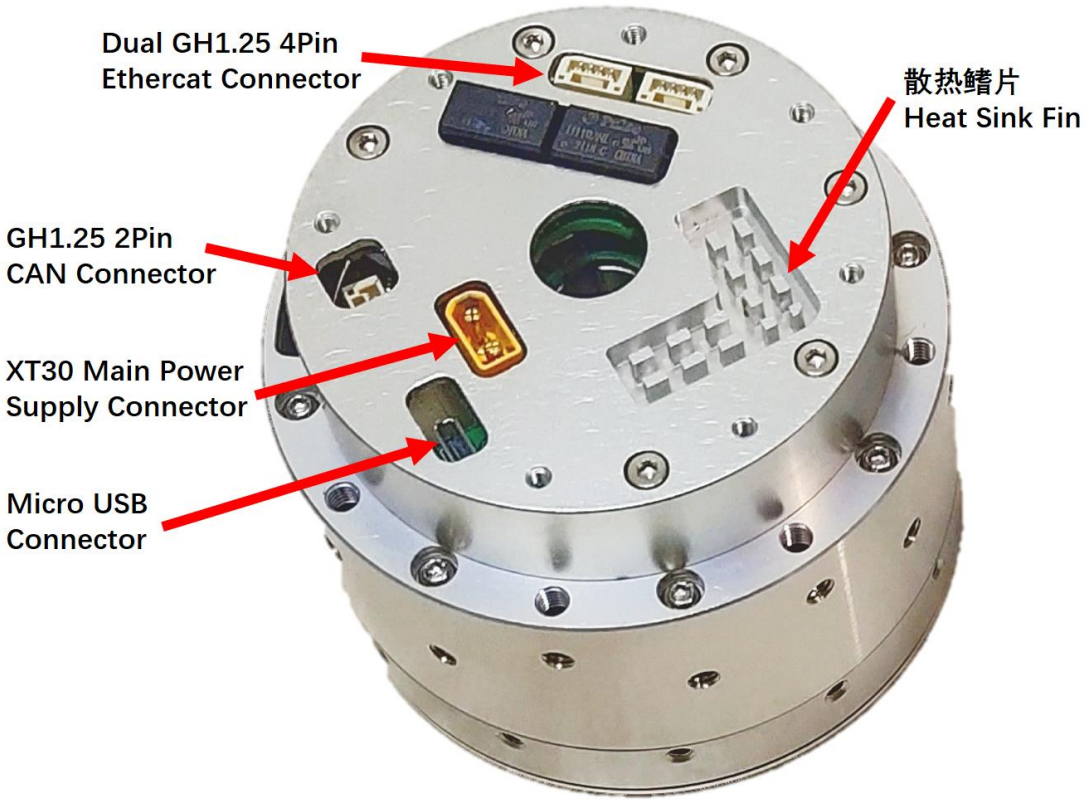
5 伺服驱动器驱动器 Electric Driver

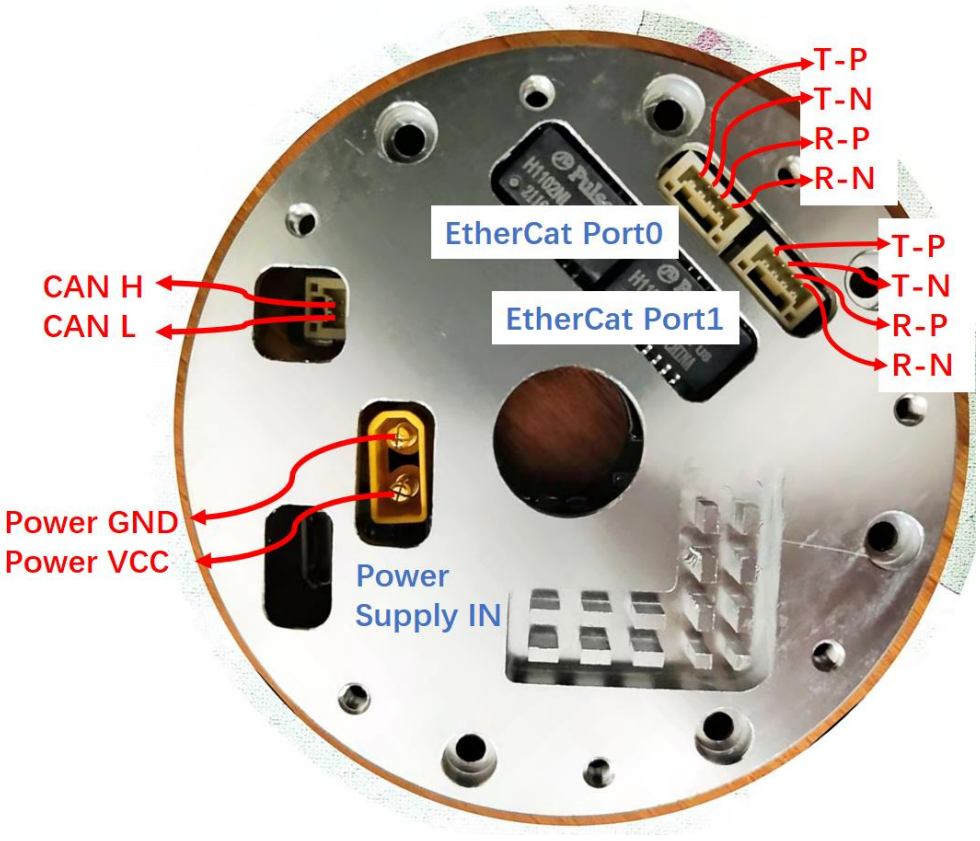
5.1 驱动器接口定义 Actuator Connector Defination

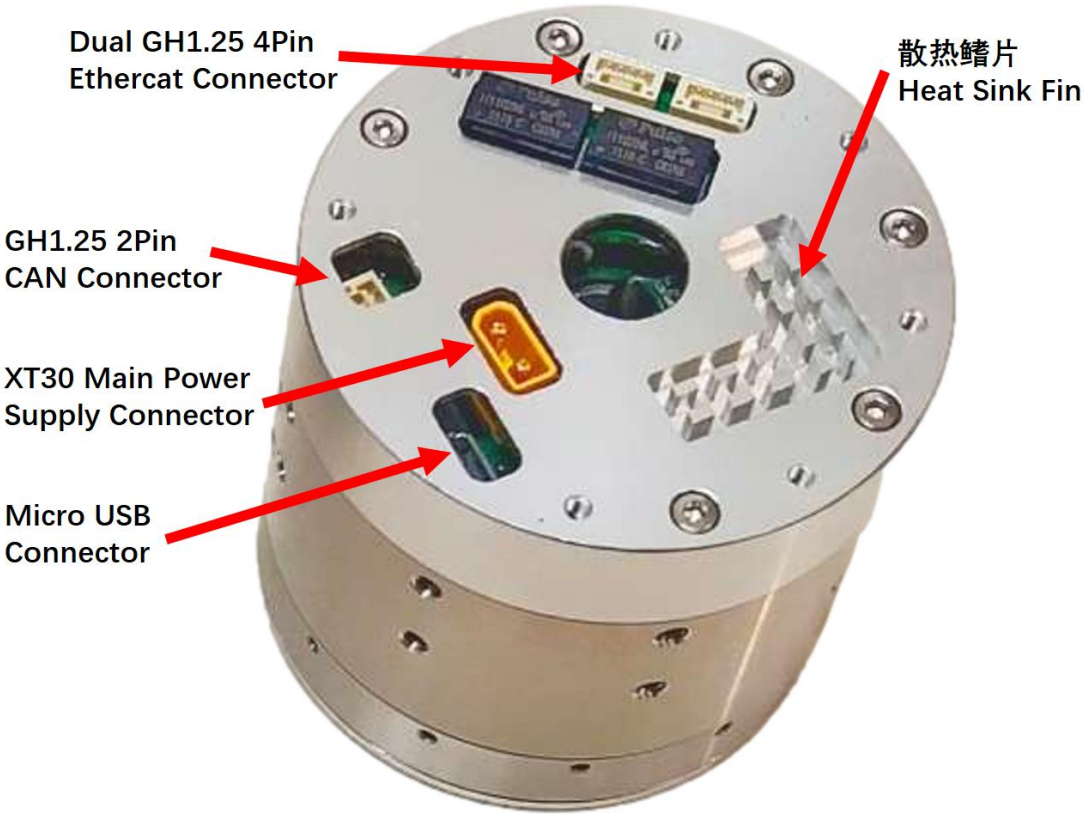
----------RR-HA-70-EC----------

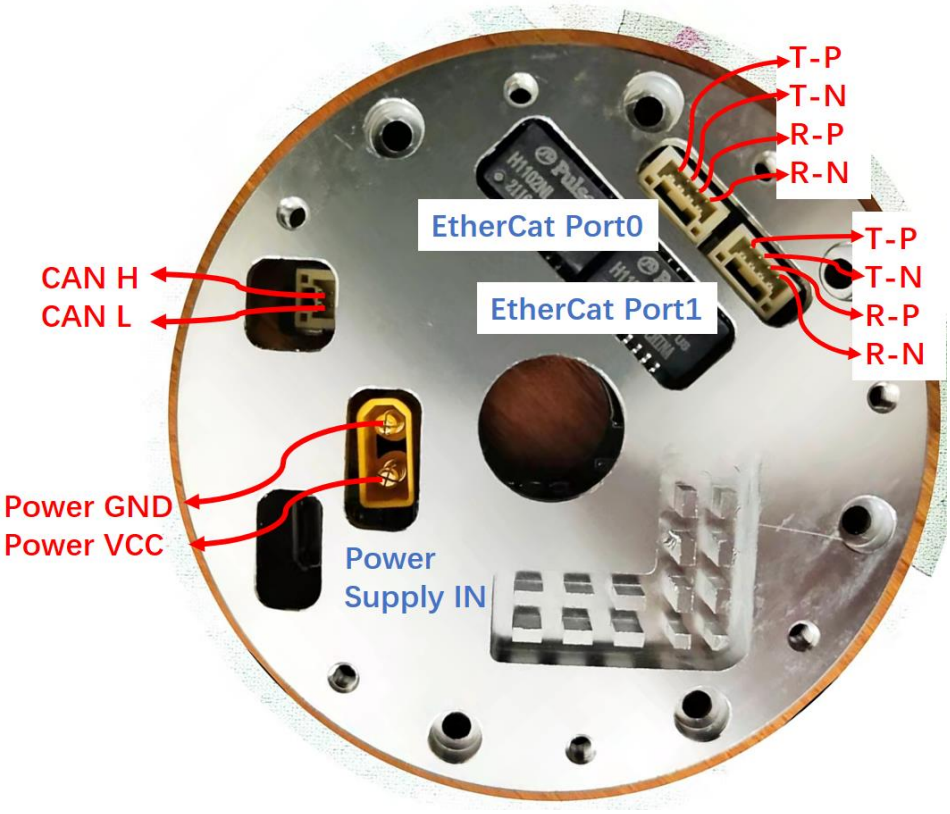


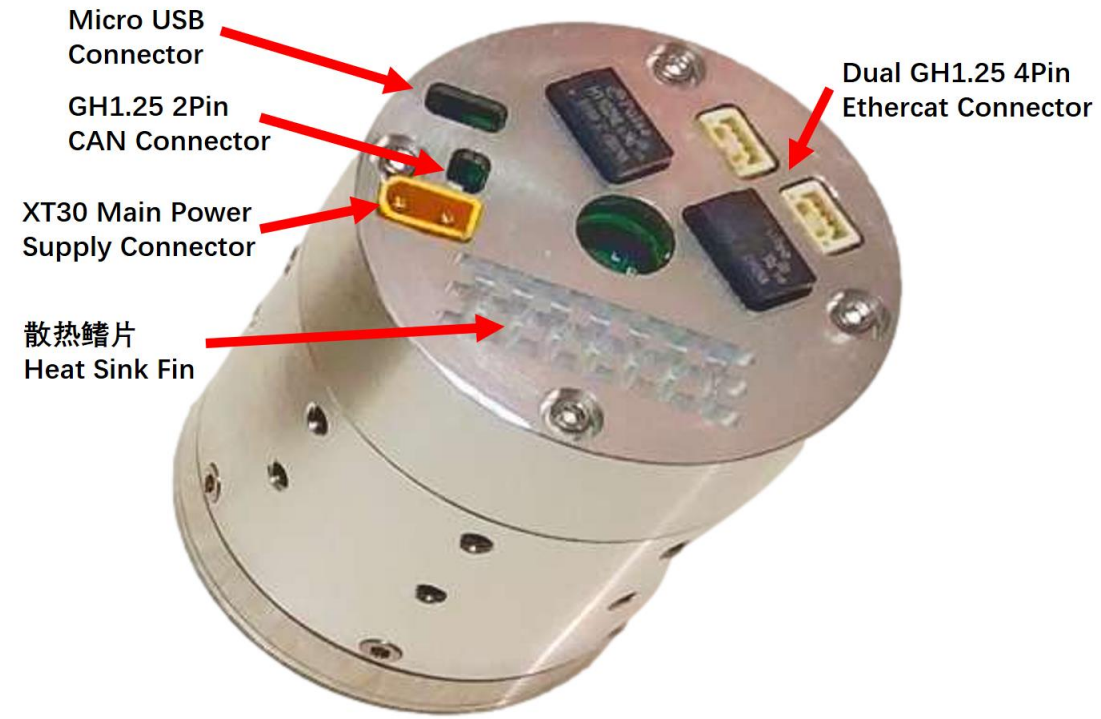


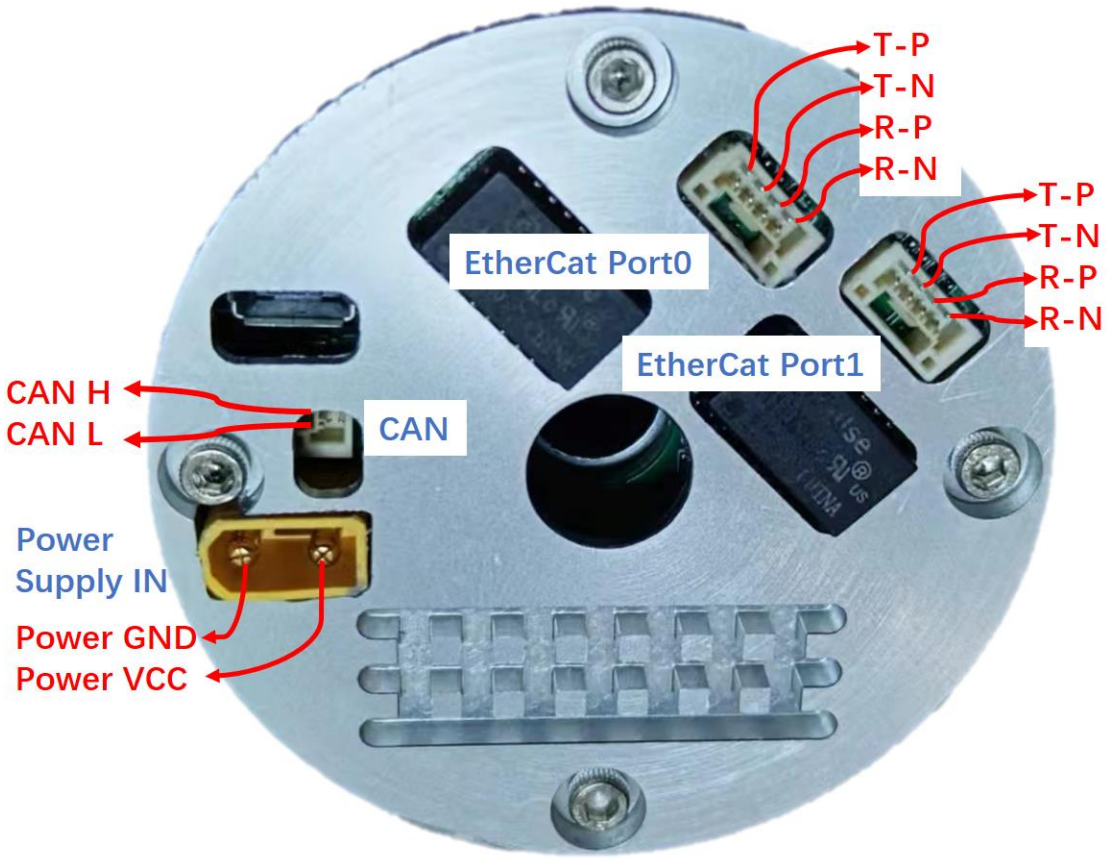

Dual GH1.25 4Pin
Ethercat Connector
散热鳍片
Heat Sink Fin
GH1.25 2Pin
CAN Connector
XT30 Main Power
Supply Connector
Micro USB
Connector


T-P
T-N
R-P
R-N
EtherCat Port0
T-P
T-N
R-P
R-N
EtherCat Port1
CAN H
CAN L
Power GND
Power VCC
Power
Supply IN


Dual GH1.25 4Pin
Ethercat Connector
散热鳍片
Heat Sink Fin
GH1.25 2Pin
CAN Connector
XT30 Main Power
Supply Connector
Micro USB
Connector


T-P
T-N
R-P
R-N
EtherCat Port0
T-P
T-N
R-P
R-N
EtherCat Port1
CAN H
CAN L
Power GND
Power VCC
Power
Supply IN


Micro USB
Connector
GH1.25 2Pin
CAN Connector
XT30 Main Power
Supply Connector
散热鳍片
Heat Sink Fin
Dual GH1.25 4Pin
Ethercat Connector


T-P
T-N
R-P
R-N
T-P
T-N
R-P
R-N
EtherCat Port0
EtherCat Port1
CAN H
CAN L
CAN
Power
Supply IN
Power GND
Power VCC

5.2 驱动器工作参数 Electrical Characteristic

电气特性 Electrical Characteristics				
参数 Parameter	**MIN**	**TYP**	**MAX**	**UNIT**
工作电压 Operating Voltage	8	24	36	V
连续工作电流 Continuous Operating Current	0.015		20	A
瞬时工作电流 Peak Current			80	A
CAN 总线比特率 CAN Bus bit rate		1		MHz
待机电流 Rest Mode Current	10	20	18	mA
工作环境温度 Operating Temperature	0	25	90	℃
储存温度 Storage Temperature	-10	25	115	℃
编码器分辨率 Encoder Resolution		14		Bits
ESD Rating *Human-body model*		±1000		V
开关频率 Switch Frequency	19.8	20	20.2	KHz

5.3 驱动器配置表 Configuration of Drivers

驱动器配置表 Configuration of Drivers											
型号 Model	保护 Protection			支持控制模式 Support Control Model			通信方式 Communication		最大转矩 Max Torque (N·m)	双编码器 Dual Encoder	泄放电阻 Shunt Resistor
	过流 OC	**过温 OT**	**力限 TL**	**伺服 Servo**	**速度 Velocity**	**力位混合 T-P Mix**	**CAN**	**Ether CAT**			
HA-40-14-XXX-C	√	√	√	√	√	√	√	×		√	×
HA-50-17-XXX-C	√	√	√	√	√	√	√	×		√	√
HA-60-20-XXX-C	√	√	√	√	√	√	√	×		√	√
HA-70-20S-XXX-C	√	√	√	√	√	√	√	×		√	√
HA-80-25-XXX-C	√	√	√	√	√	√	√	×		√	√
HA-40-14-XXX-EC	√	√	√	√	√	√	√	√		√	×
HA-50-17-XXX-EC	√	√	√	√	√	√	√	√		√	√
HA-60-20-XXX-EC	√	√	√	√	√	√	√	√		√	√
HA-70-20S-XXX-EC	√	√	√	√	√	√	√	√		√	√
HA-80-25-XXX-EC	√	√	√	√	√	√	√	√		√	√

5.4 开机自检 Self-check

每当驱动板上电时，驱动板都会执行一次硬件健康开机自检，如检测到硬件损伤，则驱动板不会驱动电机运行，也不会接收/返回 CAN 消息，同时状态指示灯(蓝灯)按一定规律闪烁，蜂鸣器也将随蓝灯一起发声指示故障，此时移除电源，请按照以下流程检查:
Whenever the driver board is powered on, the driver board will perform a hardware health power-on self-check. If hardware damage is detected, the driver board will not drive the motor, nor will it receive/return CAN messages. At the same time, the status indicator (blue LED) Flashing according to a certain pattern, the buzzer will also sound along with the blue light to indicate failure. At this time, remove the power supply and check according to the following process:

状态指示灯/蜂鸣器闪烁情况 Indicator/buzzer flash	故障类型 Fault type	处理方法 Method
长-短-短-短 Long-short-short-short	CAN 收发器硬件故障 CAN transceiver hardware failure	请联系客服 Please contact after-sales.
长-长-短-短 Long-long-short-short	检测到非法固件 Illegal firmware detected	请联系客服 Please contact after-sales.
短-长-短-短 Short-long-short-short	角度传感器硬件故障 Angle sensor hardware failure	确保驱动板牢固地固定在电机上，三颗安装螺丝以及垫片都完好且旋紧，电机磁环无破损，若无法解决，请联系客服 Make sure that the drive board is firmly fixed to the motor, the three mounting screws and washers are intact and tightened, and the motor magnetic ring is not damaged. If you cannot solve it, please contact after-sales.
短-短-长-短 Short-short-long-short	驱动器硬件故障 Drive hardware failure	请检查驱动功率管表面是否完好，驱动板表面是否干净无异物，移除主供电，再接入，若无法解决，请联系客服 Please check whether the surface of the drive power tube is intact and whether the surface of the drive board is clean and free of foreign objects. Remove the main power supply and reconnect it. If it cannot be resolved, please contact after-sales.

状态指示灯/蜂鸣器 闪烁情况 Indicator/buzzer flash	故障类型 Fault type	处理方法 Method
短-短-短-长 Short-short-short-long	功率管硬件故障 Power MOSFET hardware failure	请检查驱动功率管表面是否完好，驱动板表面是否干净无异物，以及三相动力线是否与驱动板焊接牢固，若无法解决，请联系客服 Please check whether the surface of the MOSFET is intact, whether the surface of the drive board is clean, and whether the three-phase power line is firmly soldered to the drive board. If you cannot solve it, please contact after-sales.
长-长-长-短 Short-short-long -long	EtherCAT 通信故障 EtherCAT communication failure	RR-HA-40 及 RR-HA-60 用户请检查 EtherCAT 通信小板与底层主板连接是否牢固，若无法解决，请联系客服 For RR-HA-40 and RR-HA-60 users, please check whether the connection between the EtherCAT communication board and the bottom main board is secure, if you can't solve it, please contact after-sales.

5.5 校准 Calibration

每且仅当您将驱动板安装到新的电机上，或更换过电机三相线的顺序，或对驱动板进行过拆装后，都必须执行校准。校准后，您便可正常使用电机。

校准流程如下：

You must perform calibration every time you install the drive board to a new motor, or change the order of the three-phase wires of the motor, or disassemble and assemble the drive board. After calibration, you can use the motor normally.

The calibration process is as follows:

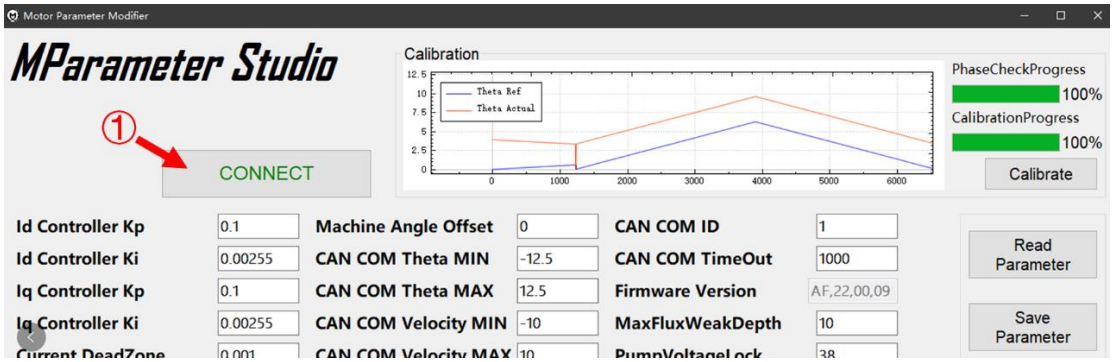


Fig 5.4.1 建立 PC-Motor 连接 Establish a PC-Motor connection

请确保电机处于 Rest 模式下，电机输出端无任何外加负载，插入 USB 数据线，确保 24V 主供电稳定，进入 Motor Parameter Studio 界面，点击 UNCONNECT 按键，若显示绿色 CONNECT 字样，则说明 USB 连接成功。若点击 UNCONNECT 显示 Motor Not Found，请检查 USB 线缆是否连接正常，电机是否在 Reset 模式下。

Please make sure that the motor is in the Rest mode and there is no external load on the motor output. Insert the USB data cable to ensure that the 24V main power supply is stable. Enter the Motor Parameter Studio interface and click the UNCONNECT button. If the green CONNECT is displayed, the USB connection is successful. If you click UNCONNECT to display Motor Not Found, please check whether the USB cable is connected properly and whether the motor is in Reset mode.

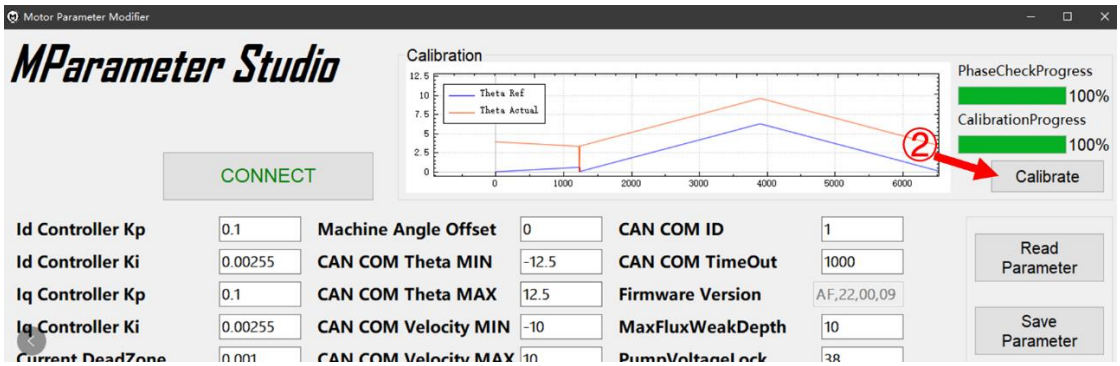


Fig 5.4.2 开始校准 Start calibration

在 USB 设备连接成功后，点击下方 Calibrate，等待两个进度条均如下图所示显示 100%时，即校准完毕，校准时电流约为 0.2~0.4A，校准结束后，电流恢复至 0.03A 左右，移除 USB 数据线，断开 24V 供电再接入，即完成一次校准。

After the USB is successfully connected, click Calibrate below, and wait for the two progress

bars to display 100% as shown in the figure below, that is, the calibration is completed, and the current is about 0.2~0.4A during calibration. After the calibration, the current returns to about 0.03A. , Remove the USB data cable, disconnect the 24V power supply and reconnect it to complete a calibration.

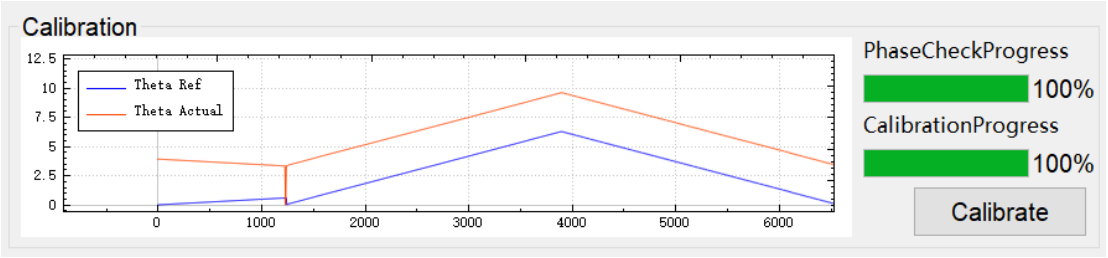


Fig 5.4.3 校准完成曲线 Calibration completion curve

6 控制与通信 Control and Communication

6.1 状态定义 Definition of State

动力单元共有两种运行状态：The power unit has two operating states:

- **Rest State:**

休眠模式，在 Reset 状态下，工作电流约为 0.02A（24V），状态指示灯不常亮，功率管不开关，驱动板 ABC 三相均输出 24V，此时电机处于低功耗待机状态，对所有收到的 CAN 报文、EtherCAT 报文进行回应，角度编码器正常工作。

In the Reset state, the current is about 0.02A (24V), the status indicator is not always on, the power tube does not switch, and the three phases of the drive board ABC output 24V DC. At this time, the motor is in a low-power standby state. All received CAN messages and EtherCAT messages respond, and the angle encoder works normally.

- **Motor State:**

运行模式，在 Motor 状态下，状态指示灯（蓝灯）常亮，功率管将会开始工作，此时电机进入正常工作状态，此时电机的工况由 CAN 发送命令直接控制，在此状态下，板子上 ABC 三相输出矢量调制 PWM 波，对所有收到的 CAN 报文、EtherCAT 报文进行回应，角度编码器正常工作。

状态机切换如下图：

In the Motor state, the status indicator (blue light) is always on, and the power tube will start to work. At this time, the motor enters the normal working state. At this time, the working condition of the motor is directly controlled by the CAN command. In this state , The ABC three-phase output vector modulated PWM wave on the board responds to all received CAN messages and EtherCAT messages, and the angle encoder works normally.

The state machine switch is as follows:

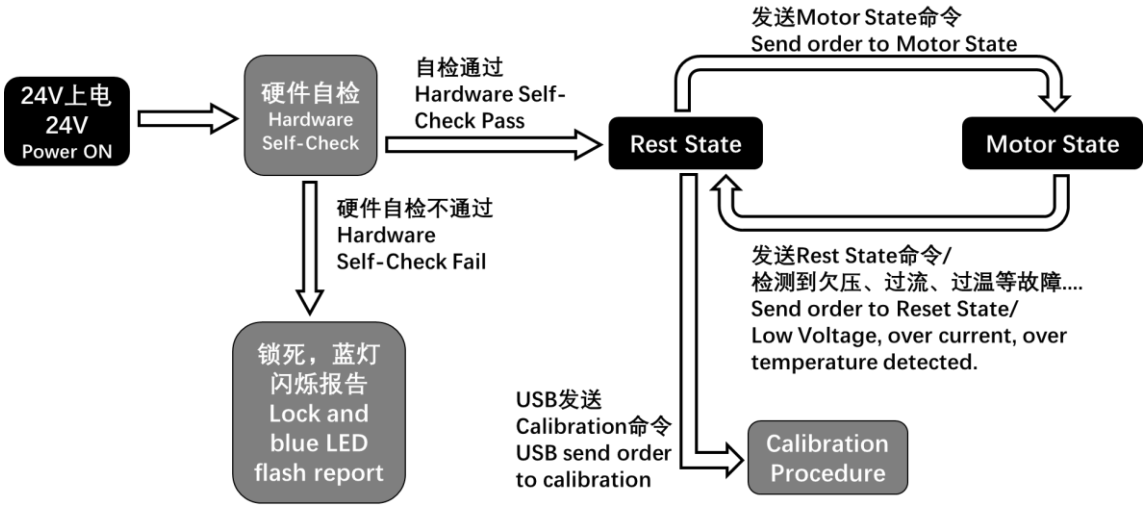


Fig 6.1.1 状态机切换示意图 State machine switching diagram

6.1.2 使用 CAN 切换状态 Switch State through CAN

命令执行器进入 **Motor State**，请发送:
Command the actuator to enter **MOTOR STATE,** please send:

Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFC

命令执行器进入 **Rest State**，请发送:
Command the actuator to enter **REST STATE**, please send:

Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFD

命令执行器设置当前角度为零位，请发送:
Command the actuator to set the current angle to **Zero Position**, please send:

Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFE

6.1.3 使用 EtherCAT 切换状 Switch State via EtherCAT

本产品以使用倍福的 EtherCAT 上位机 TWINCAT3 为例。通讯帧协议采用 CIA402 协议，EtherCAT 发送和反馈的数据如下图所示。
This product takes twincat3 from BECKHOFF as an example. The communication frame protocol adopts cia402 protocol.
The data sent and feedback by EtherCAT is shown in the figure below.

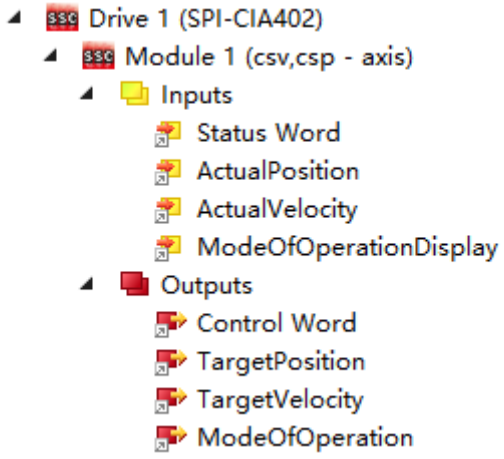


Fig 6.1.3. 1 EtherCAT 发送和反馈数据 The data sent and feedback by EtherCAT

通过改变 Control Word 的参数，对电机的状态进行修改。
Modify the state of the motor by changing the parameters called Control Word.

参数 Parameter	电机状态 State
0X07	Rest State
0X15	Motor State

6.2 控制模式 Control Mode

本伺服动力单元集成了多种控制模式，您可以选择您需要的模式进行使用，您可以在6.7.3 章中查看如何修改控制模式。

This actuator integrates a variety of control modes, you can choose the mode you need to use, you can see how to modify the control mode in Chapter 6.7.3.

6.2.1 伺服模式 Servo Mode

本驱动板的伺服控制模式基于电流环、速度环、位置环三闭环控制器，在此基础上使用非线性滑膜观测器(ULSMO)对扰动进行观测和建模，并施加前馈转矩以抵消扰动，并采用了在线参数辨识技术，实时检测电机运行状态，动态调整控制器。

总而言之，该模式下具有过渡速度可控、抗扰性强、极小静差以及高带宽等特色，伺服控制模式的简略控制框图如下：

The servo control mode is based on three closed-loop controllers of current loop, speed loop, and position loop. On this basis, the Nonlinear Sliding Mode Observer (ULSMO) is used to observe and model the disturbance, and apply the feedforward torque to counteract disturbances, and adopt online parameter identification technology, real-time detection of motor running status, and dynamically adjust the controller.

All in all, this mode has the characteristics of controllable transition speed, high Robustness and bandwidth, minimal static error. The simple control block diagram of the servo control mode is as follows:

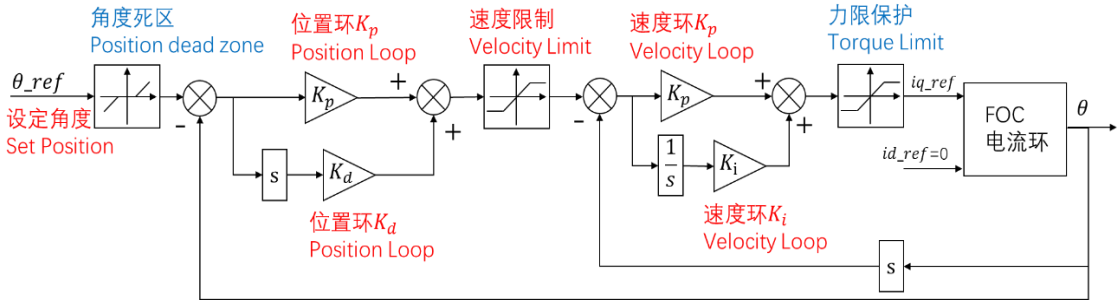


Fig 6.2.1.1 伺服模式控制框图示意图 Diagram of servo mode control

*其中红色的参数均需要通过 CAN 通信的方式设定，蓝色的参数需要通过 USB 连接 PC，在 Motorevo Studio 中修改,参见第 6.7 章。

*The red parameters need to be set via CAN communication, and the blue parameters need to be connected to a PC via USB and modified in Motorevo Studio. please refer to Chapter 6.7

在此模式下，若使用 CAN 协议对执行器进行控制，请参考 6.3.1 节使用 CAN 控制电机在伺服模式运行。

In this mode, if the CAN protocol is used to control the actuator, please refer to section 6.3.1 Using CAN to control the motor to run in the servo mode.

6.2.2 力位混合模式 Torque-Position-Mix Control Mode

本驱动板的力位混合控制模式基于电流环、位置环双闭环控制器，力位混合控制模式的简略控制框图如下：

The Torque-Position Mixed control mode is based on the current loop and position loop double closed-loop controller. The simplified control block diagram of the force-position hybrid control mode is as follows:

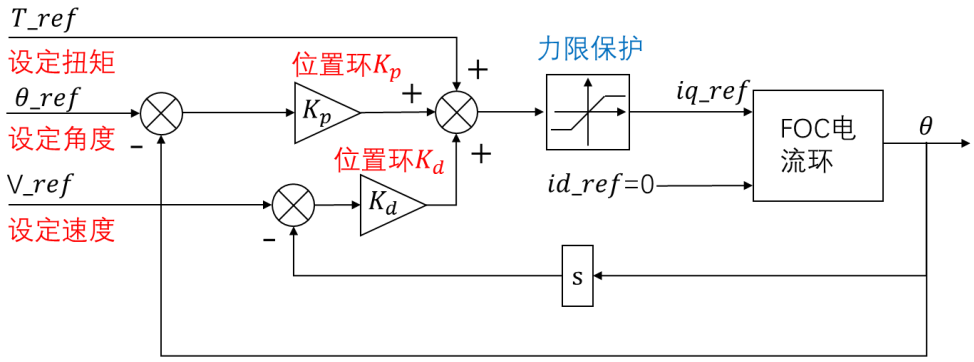


Fig 6.2.1.1 力位混合模式控制框图示意图 Diagram of Torque-Position-Mix Control Mode

*其中红色的参数均需要通过 CAN 通信的方式设定，蓝色的参数需要通过 USB 连接 PC，在 Motorevo Studio 中修改,参见第 6.7 章。

*The red parameters need to be set via CAN communication, and the blue parameters need to be connected to a PC via USB and modified in Motorevo Studio. please refer to Chapter 6.7

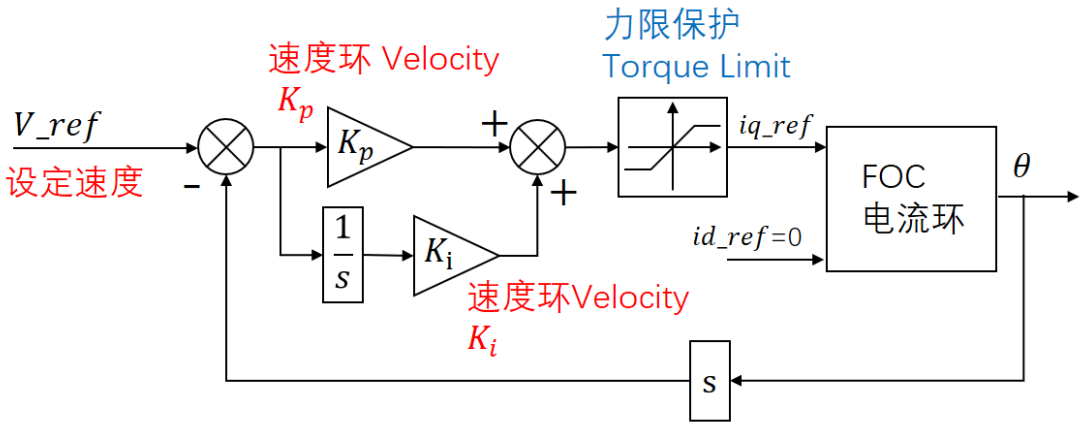
在此模式下，若使用 CAN 协议对执行器进行控制，请参考 6.3.2 节使用 CAN 控制电机在力位混合模式运行。

In this mode, if the CAN protocol is used to control the actuator, please refer to section 6.3.2 Using CAN to control the motor to run in the force position mixed mode.

6.2.3 速度模式 Velocity Mode

本驱动板的速度控制模式基于电流环、速度环双闭环控制器，在此基础上也使用非线性滑膜观测器(ULSMO)对扰动进行观测和建模，在突然施加负载的情况下较传统的控制器降速更低，能提供一个持续地、稳定地转速。

The speed control mode is based on the current loop and speed loop double closed-loop controller. On this basis, the nonlinear Sliding Mode Observer (ULSMO) is also used to observe and model the disturbance. The controller has a lower speed reduction and can provide a continuous and stable speed.



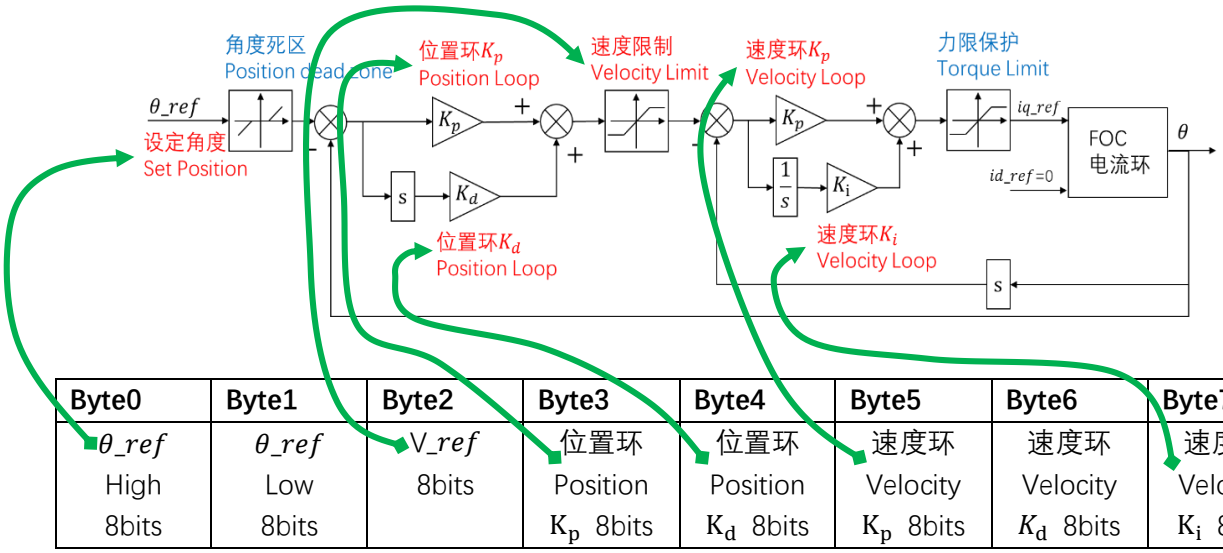
*其中红色的参数均需要通过 CAN 通信的方式设定，蓝色的参数需要通过 USB 连接 PC，在 Motorevo Studio 中修改,参见第 6.7 章。

*The red parameters need to be set via CAN communication, and the blue parameters need to be connected to a PC via USB and modified in Motorevo Studio. please refer to Chapter 6.7

6.3 使用 CAN 控制电机运行 Operation with CAN

6.3.1 使用 CAN 控制电机在伺服模式运行 Operation in Servo Mode with CAN

控制帧结构如下 The control frame structure is as follows:



Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
θ_ref High 8bits	θ_ref Low 8bits	V$_ref$ 8bits	位置环 Position K_p 8bits	位置环 Position K_d 8bits	速度环 Velocity K_p 8bits	速度环 Velocity K_d 8bits	速度环 Velocity K_i 8bits

其中，每个参数的映射范围如下 The mapping range of each parameter is as follows:

参数 Parameter	比特数 Bits	映射范围 Mapping range	单位 Units
θ_ref Set Position	16bits	[0x0000~0xFFFF] map to: **[CAN COM Theta MIN ~ CAN COM Theta MAX]** Default: -12.5 ~ +12.5	rad
V$_ref$ Transition Velocity	8bits	[0x00~0xFF] map to: **[CAN COM Velocity MIN ~ CAN COM Velocity MAX]** Default: -10.0 ~ +10	rad/s
位置环 Position Loop K_p	8bits	[0x00~0xFF] map to: **[CAN COM Kp MIN ~ CAN COM Kp MAX]** Default: 0.0 ~ 250.0	/
位置环 Position Loop K_d	8bits	[0x00~0xFF] map to: **[CAN COM Kd MIN ~ CAN COM Kd MAX]** Default: 0.0 ~ 50.0	/
速度环 Velocity Loop K_p	8bits	[0x00~0xFF] map to: **CAN COM Kp MIN ~ CAN COM Kp MAX** Default: 0.0 ~ 250.0	/

速度环 Velocity Loop K_{d}	8bits	[0x00~0xFF] map to: **[CAN COM Kd MIN ~ CAN COM Kd MAX]** Default：0.0 ~ 50.0	/
速度环 Velocity Loop K_{i}	8bits	[0x00~0xFF] map to: **[CAN COM Ki MIN ~ CAN COM Ki MAX]** Default：0.0 ~ 0.05	/

实例 Example: $\theta_{ref} = 3.14(rad)$, $V_{ref} = 2.0\left(\frac{rad}{s}\right)$,

位置环 Position Loop: $K_p = 15.0$

位置环 Position Loop: $K_d = 4.5$

速度环 Velocity Loop: $K_p = 50.0$

速度环 Velocity Loop: $K_{\mathrm{d}} = 0$

速度环 Velocity Loop: $K_{\mathrm{i}} = 0.001$

(使用默认参数范围 Using default mapping range)

转化为控制帧为 Converted into a control frame as:

Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0xA0	0x26	0x99	0x0F	0x16	0x33	0x00	0x05

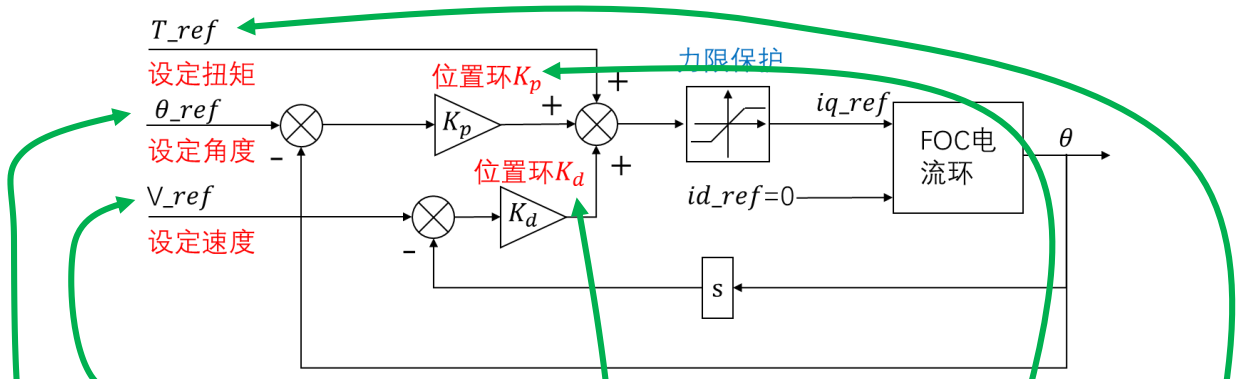
伺服模式下上位机 CAN 指令封包例程

Host CAN command packet routine in servo mode.

```
/* @brief:发送函数 Package Function
   @param:
    f_posi: 电机的目标角度，单位为弧度
    The target angle of the motor, in radians
    f_velo: 电机到达目标角度的最大转速，单位为 rad/s
    The maximum speed of the motor reaching the target angle, the
    unit is rad/s
    f_kp:   电机位置环 Kp Position Loop Kp
    f_kd:   电机位置环 kd Position Loop Kd
    f_kp_i: 电机速度环 Kp Velocity Loop Kp
    f_ki_i: 电机速度环 Ki Velocity Loop Ki
    f_kd_i: 电机速度环 Kd Velocity Loop Kd
    id:     电机 id  CAN ID */
void Protocsend(float f_posi,float f_velo,float f_kp,float f_kd,
float f_kp_i,float f_kd_i,float f_ki_i,uint8_t id)
{
    int p = float_to_uint(f_posi, P_MIN, P_MAX, 16);
    int v = float_to_uint(f_velo, V_MIN, V_MAX, 8);
    int kp = float_to_uint(f_kp, KP_MIN, KP_MAX, 8);
    int kd = float_to_uint(f_kd, KD_MIN, KD_MAX, 8);
    int kp_i = float_to_uint(f_kp_i,KP_MIN,KP_MAX,8);
    int kd_i = float_to_uint(f_kd_i,KD_MIN,KD_MAX,8);
    int ki_i = float_to_uint(f_ki_i,KI_MIN,KI_MAX,8);

    uint8_t data[8];
    data[0] = p >> 8;
    data[1] = p & 0xFF;
    data[2] = v;
    data[3] = kp;
    data[4] = kd;
    data[5] = kp_i;
    data[6] = kd_i;
    data[7] = ki_i;
    transmitFromCanInterface(data,id);
}
```

6.3.2 使用 CAN 控制电机在力位混合模式运行 Operation in Torque-Position-Mixed Mode with CAN

控制帧结构如下 The control frame structure is as follows:



Byte0	Byte1	Byte2	Byte3	
θ_ref High 8bits	θ_ref Low 8bits	V_ref High 8bits	V_ref Low 4 bits (High 4 bits of Byte3)	K_p High 4 bits (Low 4 bits of Byte3)

Byte4	Byte5	Byte6		Byte7
K_p Low 8bits	K_d High 8bits	K_d Low 4 bits (High 4 bits of Byte6)	T_ref High 4 bits (Low 4 bits of Byte6)	T_ref Low 8 bits

其中，每个参数的映射范围如下：

The mapping range of each parameter is as follows:

参数 Parameter	比特数 Bits	映射范围 Mapping range	单位 Units
θ_ref Set Position	16bits	[0x0000~0xFFFF] map to: **[CAN COM Theta MIN ~ CAN COM Theta MAX]** Default: -12.5 ~ +12.5	rad
V_ref Transition Velocity	12bits	[0x000~0xFFF] map to: **[CAN COM Velocity MIN ~ CAN COM Velocity MAX]** Default: -10.0 ~ +10	rad/s
K_p	12bits	[0x000~0xFFF] map to: **[CAN COM Kp MIN ~ CAN COM Kp MAX]** Default: 0.0 ~ 250.0	/
K_d	12bits	[0x000~0xFFF] map to: **[CAN COM Kd MIN ~ CAN COM Kd MAX]** Default: 0.0 ~ 50.0	/

T_ref	12bits	[0x000~0xFFF] map to: **[CAN COM Torque MIN ~ CAN COM Torque MAX]** Default: -50.0 ~ 50.0	Nm

实例 1 **位置 PD 控制** ***Example1*** **Position PD Controller：**

$\theta_{ref} = 3.14(rad)$

$V_{ref} = 0.0\left(\frac{rad}{s}\right)$,

$K_p = 15.0$

$K_d = 4.5$

$T\_ref = 0$

(使用默认参数范围 Using default mapping range)

转化为控制帧为 Converted into a control frame as:

Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0xA0	0x26	0x7F	0xF0	0xF5	0x17	0x07	0xFF

实例 2 力位混合控制 Example2 **Position-Torque Mix Controller：**

$\theta_{ref} = 3.14(rad)$

$V_{ref} = 0.0\left(\frac{rad}{s}\right)$,

$K_p = 15.0$

$K_d = 4.5$

$T\_ref = 5$

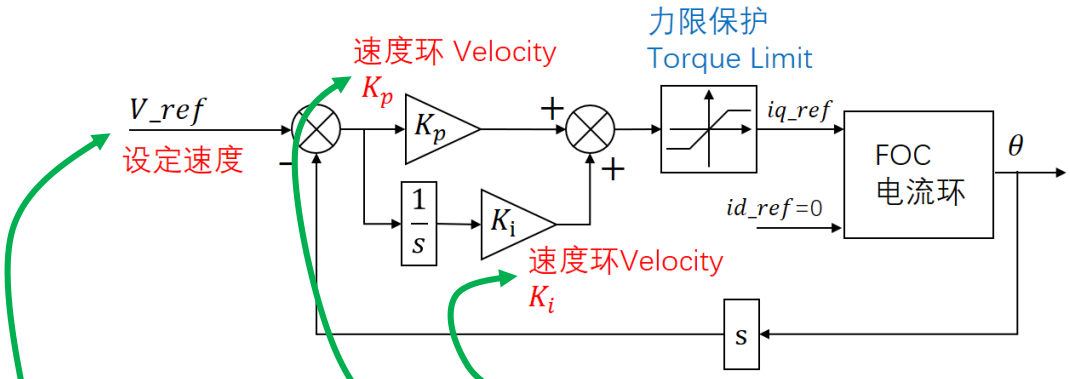
(使用默认参数范围 Using default mapping range)

转化为控制帧为 Converted into a control frame as:

Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0xA0	0x26	0x7F	0xF0	0xF5	0x17	0x08	0xCC

6.3.3 使用 CAN 控制电机在速度模式运行 Operation in Velocity Mode with CAN

控制帧结构如下 The control frame structure is as follows:



Byte0	Byte1	Byte2	Byte3	
V_ref High 8bits	V_ref Low 8bits	K_p High 8bits	K_p Low 4 bits (High 4 bits of Byte3)	K_d High 4 bits (Low 4 bits of Byte3)

Byte4	Byte5	Byte6		Byte7
K_d Low 8bits	K_i High 8bits	K_i Low 4 bits (High 4 bits of Byte6)	Meaningless	0xAC Identification

其中，每个参数的映射范围如下：

The mapping range of each parameter is as follows:

参数 Parameter	比特数 Bits	映射范围 Mapping range	单位 Units
V_ref Set Velocity	16bits	[0x0000~0xFFFF] map to: **[CAN COM Velocity MIN ~ CAN COM Velocity MAX]** Default: -10.0 ~ +10.0	rad/s
K_p	12bits	[0x000~0xFFF] map to: **[CAN COM Kp MIN ~ CAN COM Kp MAX]** Default: 0.0 ~ 250.0	/
K_d	12bits	[0x000~0xFFF] map to: **[CAN COM Kd MIN ~ CAN COM Kd MAX]** Default: 0.0 ~ 50.0	/
K_i	12bits	[0x000~0xFFF] map to: **[CAN COM Ki MIN ~ CAN COM Ki MAX]** Default: 0.0 ~ 0.05	/

6.4 使用 EtherCAT 控制电机运行 Operation with EtherCAT

通过改变 ModeOfOperation 的参数，对电机的控制模式进行修改。
Modify the control mode of the motor by changing the parameters called ModeOfOperation.

参数 Parameter	控制模式 Control Mode
0X04	伺服模式 Servo Mode
0X05	速度模式 Velocity Mode
0X07 (暂无 Not yet)	力位混合模式 Torque-Position-Mix Control Mode

6.4.1 使用 EtherCAT 控制电机在伺服模式运行 Operation in Servo Mode with EtherCAT

将 ModeOfOperation 的值设置为 0x04,让电机处于伺服运动模式。
Set the value of ModeOfOperationto 0x04 to put the motor in Servo Mode
再将 Control Word 的值设置为 0x15，让电机处于运行模式。
Then set the value of Control Word to 0x15 to put the motor in Motor State
再将 TargetVelocity 的值设置为目标速度，速度的单位是 rad/s.
Then set the value of TargetVelocity the target speed, and the unit of speed is rad / s

再将 TargetPosition 的值设置为目标位置，位置的单位是 rad.
Then set the value of TargetPositionas the target location, and the unit of location is rad

电机的实时位置和速度信息会显示在 ActualPosition 和 ActualVelocity 中。
The real-time position and speed information of the motor is displayed in actualposition and actualvelocity.
使用结束后，建议将 Control Word 的值设置为 0x07，让电机处于待机模式。
After use, it is recommended to set the value of control word to 0x07 to put the motor in Rest State
后续通过 PLC 或者是别的编程方式可以实现更加复杂的运动控制。
Later, more complex motion control can be realized through PLC or other programming methods.

6.4.2 使用 EtherCAT 控制电机在力位混合模式运行 Operation in Torque-Position-Mix Mode with EtherCAT

暂未发布
Not release yet.

6.4.3 使用 EtherCAT 控制电机在速度模式运行 Operation in Velocity Mode with EtherCAT

将 ModeOfOperation 的值设置为 0x05 让电机处于速度模式。
Set the value of ModeOfOperationto 0x04 to put the motor in Velocity Mode.
再将 Control Word 的值设置为 0x15，让电机处于运行模式。
Then set the value of Control Word to 0x15 to put the motor in Motor State

再将 TargetVelocity 的值设置为目标速度，速度的单位是 rad/s.
Then set the value of TargetVelocityas the target speed, and the unit of speed is rad / s

电机的实时位置和速度信息会显示在 ActualPosition 和 ActualVelocity 中。
The real-time position and speed information of the motor is displayed in actualposition and actualvelocity.

使用结束后，建议将 Control Word 的值设置为 0x07，让电机处于待机模式。
After use, it is recommended to set the value of control word to 0x07 to put the motor in Rest State

后续通过 PLC 或者是别的编程方式可以实现更加复杂的运动控制。
Later, more complex motion control can be realized through PLC or other programming methods.

6.5 CAN 通信反馈 CAN communication feedback

6.5.1 反馈帧格式 Feedback frame format

无论在什么状态和模式下，驱动板在收到报文标识符为 **CAN COM ID** 的报文时都会进行一次应答，反馈当前电机的位置(rad)，速度(rad/s)，扭矩(N·m)。应答的报文标识符恒定为 **0x200**，波特率为 1Mbps，DLC 为 8 字节。您可以在 6.7 章查看如何修改 **CAN COM ID。**

Regardless of the state and mode, the drive board will respond once when it receives a message whose message identifier is **CAN COM ID**, and feedback the current motor position (rad), speed (rad/s), and torque (N· m). The message identifier of the response is always 0x200, the baud rate is 1Mbps, and the DLC is 8 bytes. You can see how to modify CAN COM ID in Chapter 6.7.

Byte0	Byte1	Byte2	Byte3	Byte4		Byte5	Byte6	Byte7
驱动器 **CAN COM ID** Actuator **CAN COM ID**	位置高 8bits Position High 8 bits	位置低 8bits Position Low 8 bits	速度高 8bits Velocity High 8 bits	速度低 4bits（Byte4 高 4 字节） Velocity Low 4 bits (Byte4 high 4 bytes)	输出力矩高 4bits（Byte4 低 4 字节） Torque High 4 bits (Byte4 low 4 bytes)	输出力矩低 8bits Torque Low 8 bits	故障码高 8bits Fault code High 8bits	故障码低 8bits error code Low 8bits

6.5.2 反馈帧状态解包 Feedback frame state unpacking

位置 Position:

0x0000~0xFFFF 对应 **CAN COM Theta MIN ~ CAN COM Theta MAX**

默认值 Default: -12.5 rad ~ +12.5 rad

0x0000~0xFFFF maps to **CAN COM Theta MIN ~ CAN COM Theta MAX**

Default: -12.5 rad ~ +12.5 rad

速度 Velocity:

0x000~0xFFF 对应 **CAN COM Velocity MIN ~ CAN COM Velocity MAX**

默认值 Default: -12.5 rad ~ +12.5 rad

0x000~0xFFF maps to **CAN COM Velocity MIN ~ CAN COM Velocity MAX**

Default: -10.0 rad/s ~ +10 rad/s

力矩 Torque:

0x000~0xFFF 对应 **CAN COM Torque MIN ~ CAN COM Torque MAX**

默认值 Default: -12.5 rad ~ +12.5 rad

0x000~0xFFF maps to **CAN COM Torque MIN ~ CAN COM Torque MAX**

Default: -50.0 N·m ~ +50.0 N·m

故障码 16Bits Fault Code have 16 bits

Bit 15	**Bit 14**	**Bit 13**	**Bit 12**	**Bit 11**	**Bit 10**	**Bit 9**	**Bit 8**
NM	NM	NM	NM	NM	NM	OC	VGSF
Bit 7	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0**
VDSF	OTSD	UVLO	GDF	VDS_OCP	NM	B_OTP	LVBUS

具体释义如下 The specific definition is as follows::

故障码 Fault Code	解决方法 Solution
NM	无意义，可忽略 Meaningless, can be ignored
LVBUS	供电电压低于 8V 时报此错误。检查供电电压是否大于 8V。 This error is reported when the supply voltage is lower than 8V. Check whether the power supply voltage is greater than 8V.
B_OTP	驱动板温度高于温度保护阈值时报此错误。请检查电机是否存在过载、散热情况是否良好、工作环境温度是否过高、电机有无长时间堵转。 This error is reported when the temperature of the driver board is higher than the temperature protection threshold. Please check whether the motor is overloaded, whether the heat dissipation is good, whether the working environment temperature is too high, and whether the motor is locked for a long time.
VDS_OCP	重新上电，若问题依旧存在，请联系客服人员 Power on again, if the problem persists, please contact customer service
GDF	检擦驱动板正反面是否有异物，重新上电，若问题依旧存在，请联系客服人员 Check whether there is any foreign matter on the front and back of the driver board, and power on again. If the problem persists, please contact customer service.
UVLO	重新上电，若问题依旧存在，请联系客服人员 Power on again, if the problem persists, please contact customer service
OTSD	驱动器温度过高时报此错误。请检查电机是否存在过载、散热情况是否良好、工作环境温度是否过高、电机有无长时间堵转。 This error is reported when the drive temperature is too high. Please check whether the motor is overloaded, whether the heat dissipation is good, whether the working environment temperature is too high, and whether the motor is locked for a long time.
VDSF	重新上电，若问题依旧存在，请联系客服人员 Power on again, if the problem persists, please contact customer service
VGSF	

OC	请检查电机是否存在过载、控制板是否存在短路、工作环境温度是否过高、电机有无长时间堵转。 Please check whether the motor is overloaded, whether the control board is short-circuited, whether the working environment temperature is too high, and whether the motor is locked for a long time.

6.5.3 CAN 解包例程 CAN unpacking routine

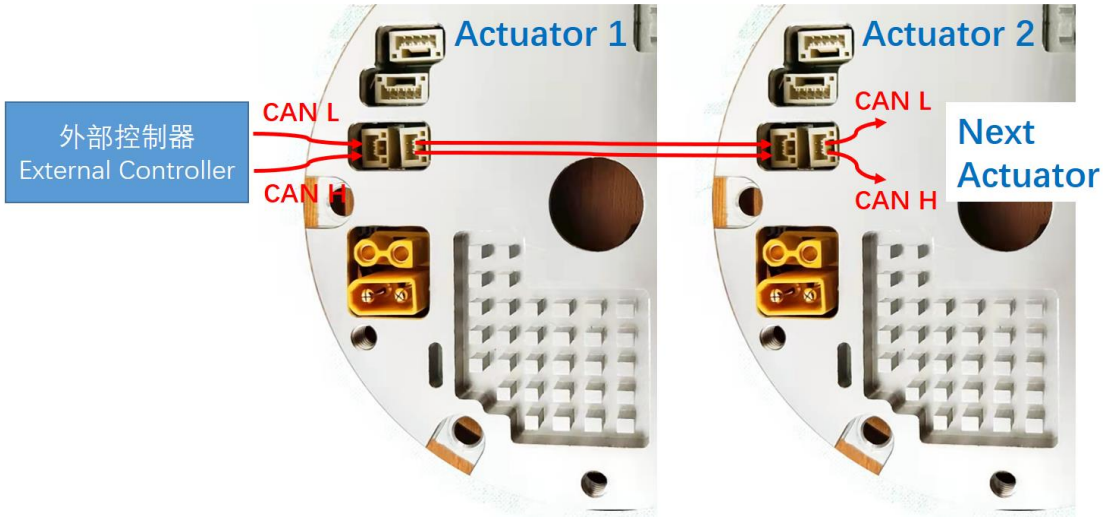
```
typedef struct
{
    uint8_t id;
    float position;
    float velocity;
    float torque;
    uint16_t fault;

} motorInfoDef;
motorInfoDef motorInfo;
// 以下参数必须和驱动板中一致
//The following parameters must be consistent with the drive board!
#define P_MIN (-12.5f)
#define P_MAX (12.5f)
#define V_MIN (-10.0f)
#define V_MAX (10.0f)
#define T_MIN (-50.0f)
#define T_MAX (50.0f)


float uint_to_float(int x_int, float x_min, float x_max, int bits)
{
    /// converts unsigned int to float, given range and number of bit
s ///
    float span = x_max - x_min;
    float offset = x_min;
    return ((float)x_int)*span/((float)((1<<bits)-1)) + offset;
}
```

```c
/* @brief:解包电机回传数据
    Unpack the motor return data
    @param:
    buff:CAN 返回的 8 字节原属数据 The returned 8-byte original data
    motor:存储转换结果的结构体 Structure for storing conversion results
    @ret: void
    */
void unpackCanInfoFromMotor(uint8_t* buff,motorInfoDef* motor)
{
    int id, p_int=0x00, v_int=0x00, t_int=0x00;
    id = data[0];

    p_int = (data[1] << 8)| (0x00ff&data[2]);
    v_int = (data[3] << 4) | ((0x00ff&data[4]) >> 4);
    t_int = ((data[4] & 0xF) << 8) | (0x00ff&data[5]);
    p_int &= 0x0000ffff;        //16bit
    v_int &= 0x00000fff;        //12bit
    t_int &= 0x00000fff;        //12bit

    motor->id = id;
    motor->position = uint_to_float(p_int,P_MIN,P_MAX,16);
    motor->velocity = uint_to_float(v_int,V_MIN,V_MAX,12);
    motor->torque = uint_to_float(t_int,T_MIN,T_MAX,12);
    motor->fault = (data[6] << 8) | data[7]);
     // 添加您自己的故障处理代码
     // Add your fault handle code here
}
```

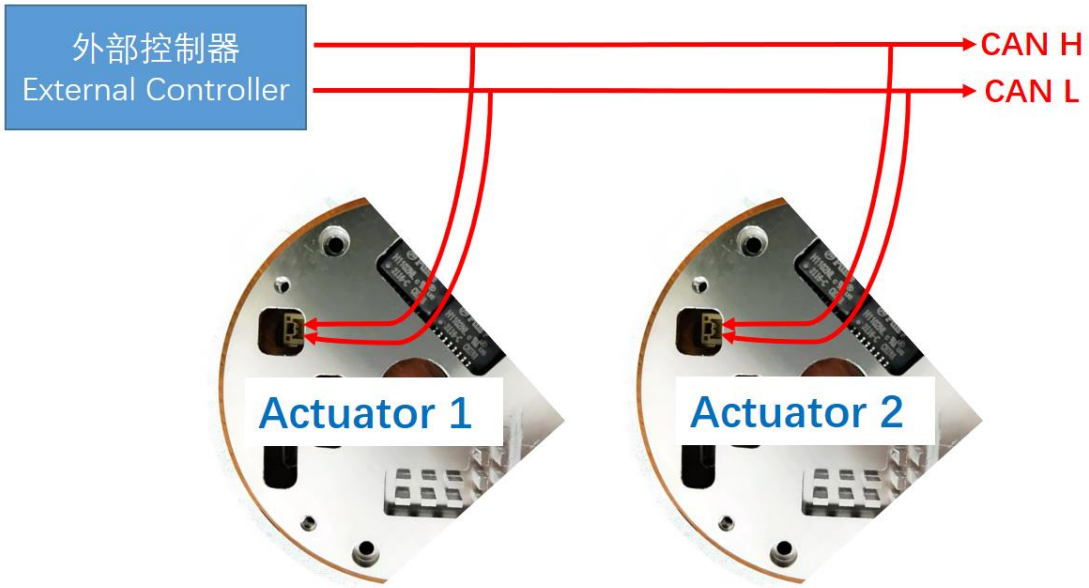
6.6 多执行器级联运行 Multiple actuator cascade operation

6.6.1 CAN 实现多执行器级联运行 Multiple actuator cascade operation via CAN

如图所示，可以将多台执行器串联在一条 CAN 总线上。
As shown in the figure, multiple actuators can be connected in series on a CAN bus.

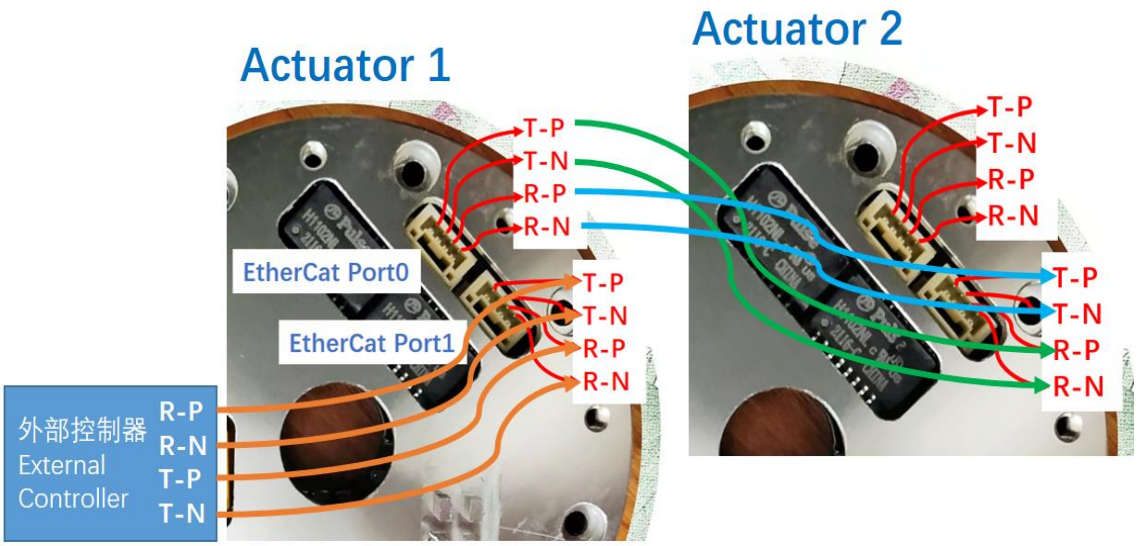


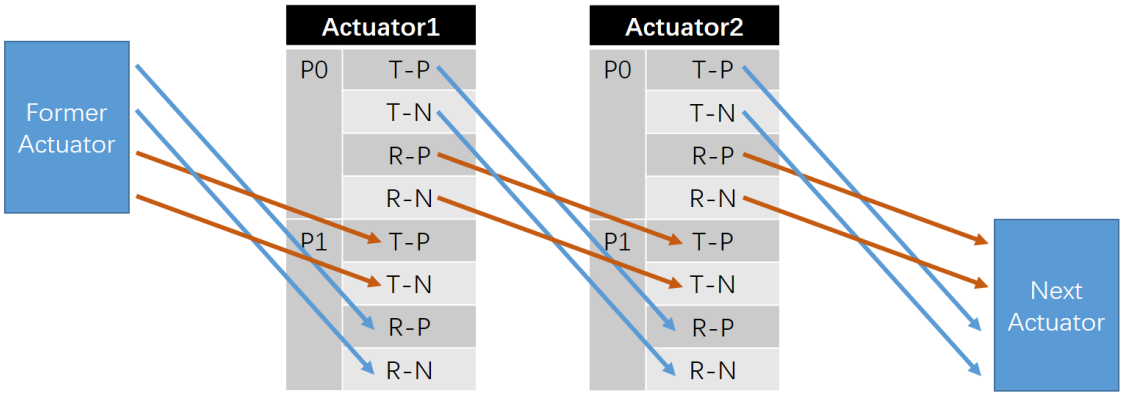
也可以如下图所示，并联运行。
It can also operate in parallel as shown in the figure below.



6.6.2 EtherCAT 实现多执行器级联运行 Multiple actuator cascade operation via EtherCAT

若使用 EtherCAT 控制多台执行器，请严格按照以下连接方式连接。
If you use EtherCAT to control multiple actuators, please connect them in strict accordance with the following connection methods.
请注意，TP 与 TN，RP 与 RN 间尽量使用双绞线连接，如无法实现，请确保 P 信号线与 N 信号线的长度尽量一致!
Please note that twisted pair connection shall be used between TP and TN, RP and RN as much as possible. If it cannot be achieved, please ensure that the length of P signal line and N signal line is the same as possible!





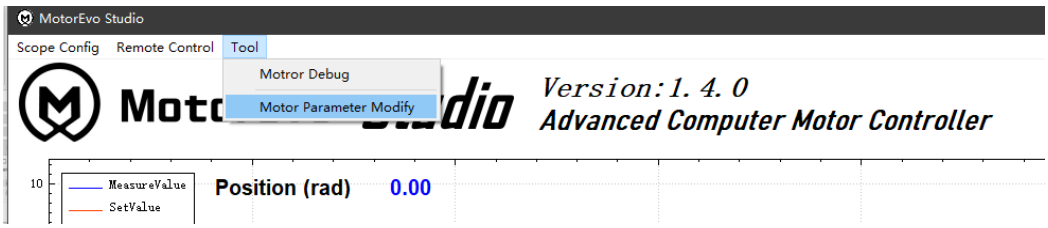
6.7 使用 MParameter Studio 修改电机参数 Use MParameter Studio to modify motor parameters

6.7.1 建立连接与保存 Establish connection and save

Step1.

按下图所示，从 Motorevo Studio 软件中进入 MParameter Studio 界面，在确保没有 24V 供电的情况下，插入 USB 线。

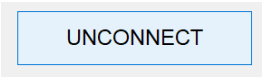
As shown in the figure below, enter the MParameter Studio interface from the Motorevo Studio software, and plug in the USB cable while ensuring that there is no 24V power supply.



Step2.

插入 USB 线后点击 UNCONNECT 等待软件自动识别并连接，变成绿色 **CONNECT** 字样则说明驱动板连接成功。

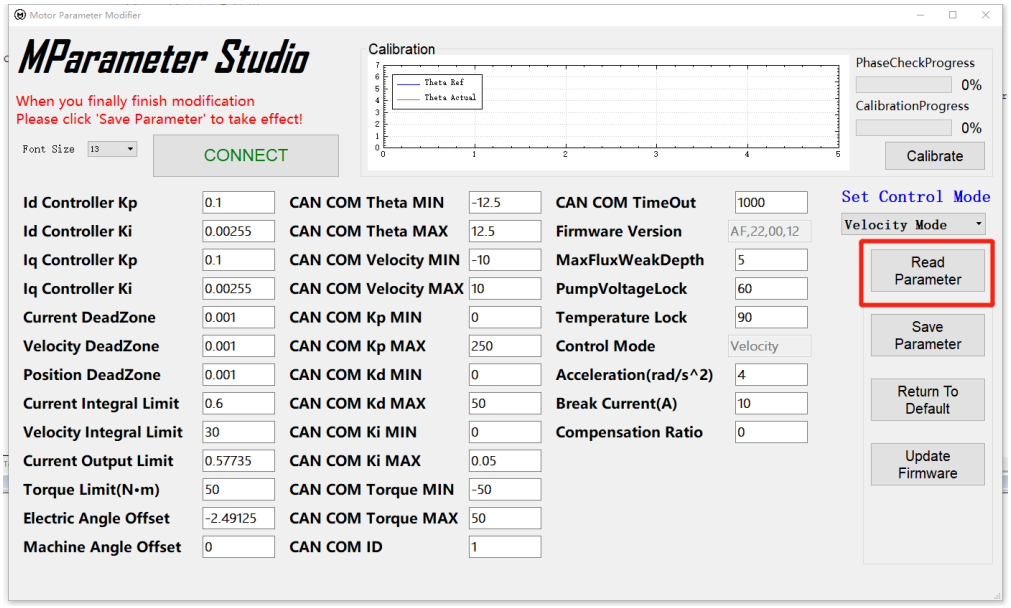
After plugging in the USB cable, click UNCONNECT and wait for the software to automatically recognize and connect. If it turns into green CONNECT, it means that the driver board is successfully connected.



Step3.

点击 Read Parameter 按键，从驱动板中读取当前参数。

Click the Read Parameter button to read the current parameters from the driver board.



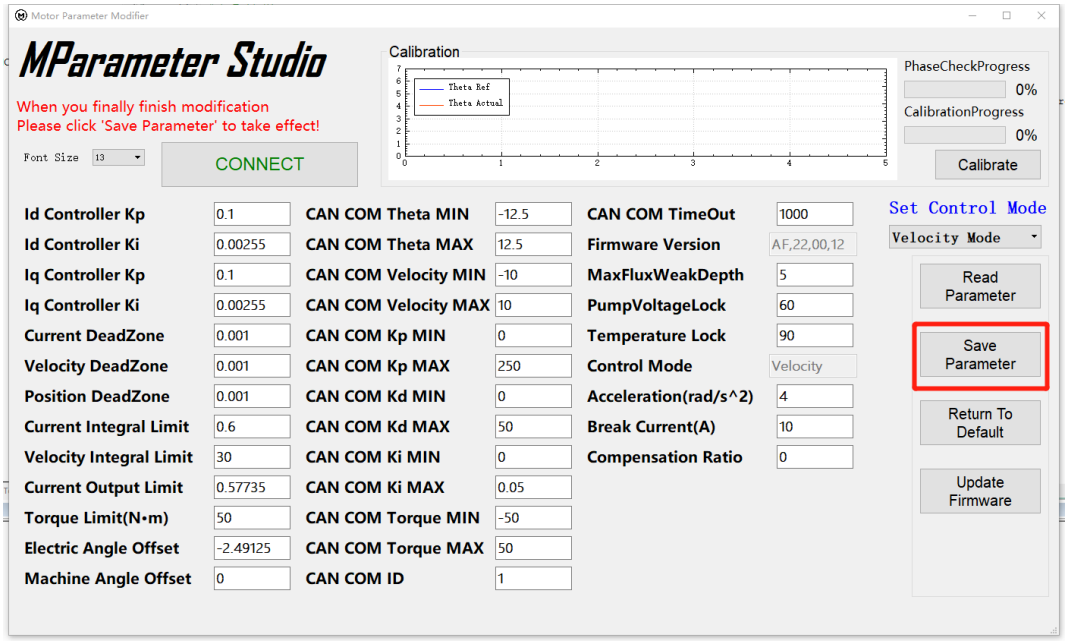
Step4.

您便可以修改参数，**每次修改完后请务必按下键盘上的回车按键**，全部修改完后，请点击 Save Flash 命令，电机会将您设置的这组参数永久地储存在内部。

提示：点击 Save Flash 后请等待 1~2s，让驱动板完成 Flash 擦写，期间请尽量保持连接和驱动板的稳定，保存完成后您可以再按 Read Parameter 读取一次，以检查驱动板是否正确保存了您的参数。

You can modify the parameters. **After each modification, be sure to press Enter in keyboard.** After all modifications are completed, please click the Save Flash command. The motor will permanently store the set of parameters you set internally.

Tip: After clicking Save Flash, please wait 1~2s for the driver board to complete the Flash erasing. During this period, please try to keep the connection and driver board stable. After saving, you can press Read Parameter to read again to check whether the driver board is correct. Your parameters are saved.



6.7.2 参数解释 Parameter explanation

参数名 Parameter Name	解释 Explanation
Id Controller Kp **Id Controller Ki** **Iq Controller Kp** **Iq Controller Ki**	电流控制器参数，不建议用户自行更改 Current controller parameters, users are not recommended to change by themselves.
Current DeadZone	电流环死区参数，不建议用户自行更改 Current loop dead zone parameters, users are not recommended to change by themselves
Velocity DeadZone	速度环死区参数，不建议用户自行更改 Veolcity loop dead zone parameters, users are not recommended to change by themselves
Position DeadZone	位置环死区参数，通常不建议自行更改。若电机在稳发生小范围抖动，可以适当调大，若电机稳态误差过大，则需适当调小。 The position loop dead zone parameter is usually not recommended to be changed by yourself. If the motor jitter occurs in a small range in a stable state, it can be increased appropriately, and if the steady-state error of the motor is too large, it needs to be adjusted appropriately.
Current Integral Limit	电流环积分限，通常不建议自行更改，若电机输出力矩不足，可以适当调大。 The current loop integral limit is usually not recommended to be changed by yourself. If the output torque of the motor is insufficient, it can be increased appropriately.
Velocity Integral Limit	速度环积分限，通常不建议自行更改，若电机输出力矩不足，可以适当调大。 The speed loop integral limit is usually not recommended to be changed by yourself. If the output torque of the motor is insufficient, it can be increased appropriately.
Current Output Limit	电流环输出限幅，不建议用户自行更改 Current loop output limit, users are not recommended to change by themselves
Torque Limit	力限保护，单位 Nm，若在力位混合模式或串级模式下最大输出转矩不足，可以适当调大 Torque limit protection(Nm), if the maximum output torque is insufficient in Torque-Position mixed mode or Servo Mode, it can be increased appropriately
Electric Angle Offset	用户严禁修改此参数，擅自修改可能导致驱动板烧毁。 The user is strictly prohibited to modify this parameter. Unauthorized modification may cause the driver board to burn out.

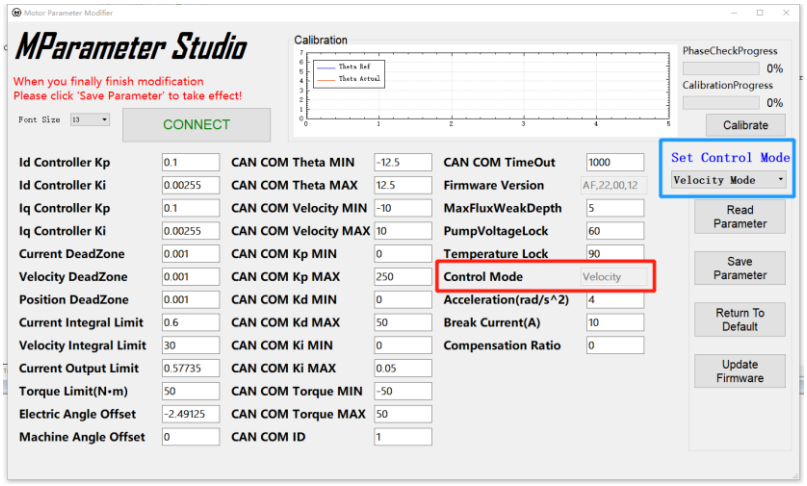
Machine Angle Offset	不建议用户自行更改 Users are not recommended to change by themselves
CAN COM Theta MIN	CAN 通讯数据范围，详情请参照前文 6.3 章。 CAN communication data mapping range, please refer to Chapter 6.3 for details.
CAN COM Theta MAX	
CAN COM Velocity MIN	
CAN COM Velocity MAX	
CAN COM Kp MIN	
CAN COM Kp MAX	
CAN COM Kd MIN	
CAN COM Kd MAX	
CAN COM Ki MIN	
CAN COM Ki MAX	
CAN COM Torque MIN	
CAN COM Torque MAX	
CAN COM ID	**设置本机 CAN ID 号，范围为 0~1024** Set the CAN ID number of the machine, the range is 0~1024
CAN COM TimeOut	设置 CAN 中断超时报警时间，单位 ms，详情请参照前文。 Set the CAN interrupt timeout alarm time(ms), please refer to the previous article for details
Firmware Version	固件版本号 Firmware version number
Max Flux Weak Depth	弱磁扩速深度，该值越大，最高转速越高，注意该值过高可能会导致电机失控。 The depth of field weakening expansion. The larger the value, the higher the maximum speed. Note that if the value is too high, it may cause the motor to lose control.
Pump Voltage Lock	电机倒拉反转时会产生一个较高的泵生电压，严重时该电压会将直流侧电压泵生至 50v 以上，设置该值可以修改驱动板泵生电压抑制门限，即母线电压高于该值时开始抑制。 When the motor is pulled back and reversed, a higher pumping voltage will be generated. In severe cases, the voltage will pump the DC side voltage above 50v. Setting this value can modify the pumping voltage suppression threshold of the drive board, that is, the bus voltage is higher than this. The value starts to suppress.
Temperature Lock	驱动板过温保护阈值（摄氏度），当板载的温度传感器检测到驱动板温度高于该值时，启动保护程序，防止驱动板过热烧毁。 The driver board over-temperature protection threshold (degrees Celsius). When the on-board temperature sensor detects that the driver board temperature is higher than this value, the protection program is started to prevent the driver board from overheating and burning.

Acceleration	加速度（单位：m/s^2），执行器在伺服模式下的加速度值。 Acceleration (unit: m/s^2), the acceleration value of the actuator in servo mode.
Break Current	刹车电流（单位：A）,执行器在倒拉反转下最大的刹车电流值。 Braking current (unit: A), the maximum braking current value when the actuator is pulled backwards and reversed.
Compensate Ratio	范围：0~1，非线性滑膜观测器(ULSMO)对扰动的抑制能力，该值越大，抗扰性越强。 Range from 0~1, the ability of nonlinear slide mode observer (ULSMO) to suppress disturbances, the larger the value, the stronger the immunity.

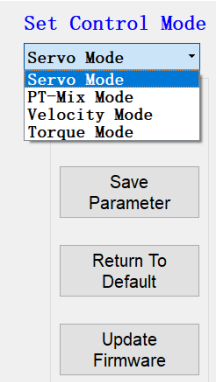
6.7.3 修改控制模式 Modify Control Mode

您可以在 MParameter Studio 中修改控制模式，方法如下：
You can modify the control mode in MParameter Studio as follows:

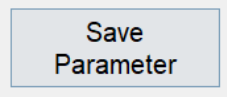
- Step 1
  按照 6.7.1 章节所示的方法建立成功建立连接
  Follow the method shown in section 6.7.1 to successfully establish a connection
- Step 2
  查看当前控制模式，您可以在如图所示的红色框中看到当前的控制模式，并在蓝色框中选择期望的控制模式。
  Check the current control mode, you can see the current control mode in the red box as shown in the figure below, and select the desired control mode in the blue box.



- Step 3
  选择您期望的控制模式
  Choose your desired control mode



- Step 4
  单击'Save Parameter'按键，确保您的更改生效，修改控制模式随即完成。
  Click the 'Save Parameter' button to ensure that your changes take effect, and then the modification of the control mode is completed.

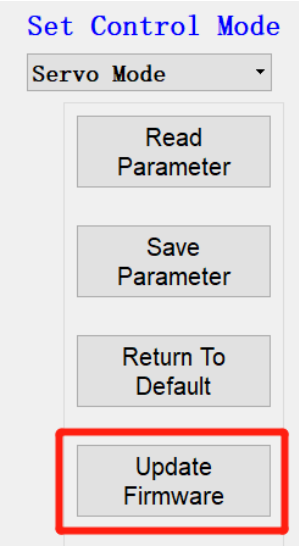


6.7.4 固件升级 Firmware upgrade

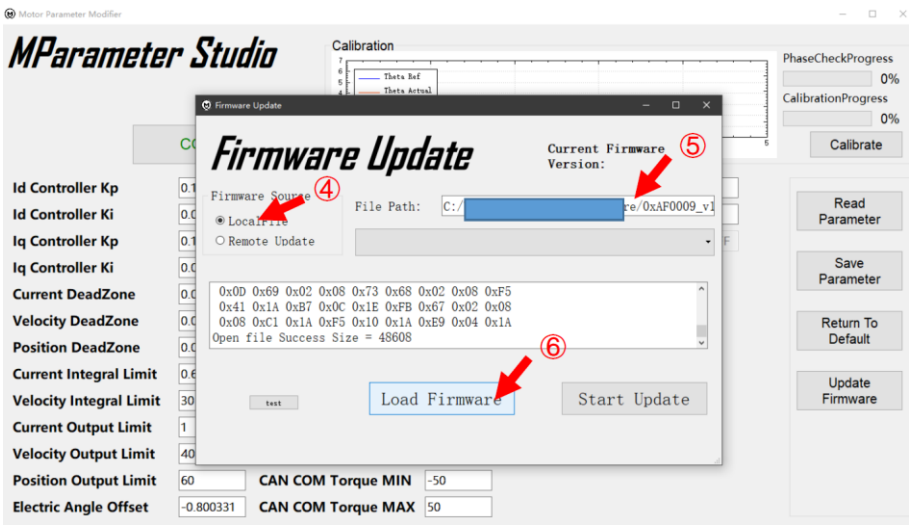
您可以使用 Motorevo Studio 对驱动板进行固件上的升级，以获取更好的控制品质、更高的精度以及更低的功耗，请随时关注我们的官网发布的新固件包，并按照以下流程升级固件。

You can use Motorevo Studio to upgrade the firmware of the driver board to obtain better control quality, higher accuracy and lower power consumption. Please feel free to pay attention to the new firmware package released on our official website and follow the process below to upgrade firmware.

- Step 1
  按照 6.7.1 章节所示的方法建立成功建立连接
  Follow the method shown in section 6.7.1 to successfully establish a connection
- Step 2
  确保 USB 连接稳固，中途意外中断连接可能会导致升级失败，升级失败可能导致执行器无法正常工作，需要返厂维修。
  Make sure that the USB connection is stable. Unexpected interruption of the connection in the middle may cause the upgrade to fail. If the upgrade fails, the actuator may not work normally and needs to be returned to the factory for repair.
- Step 3
  点击 Update Firmware 按键，进入固件升级界面。
  Click the Update Firmware button to enter the firmware upgrade interface.



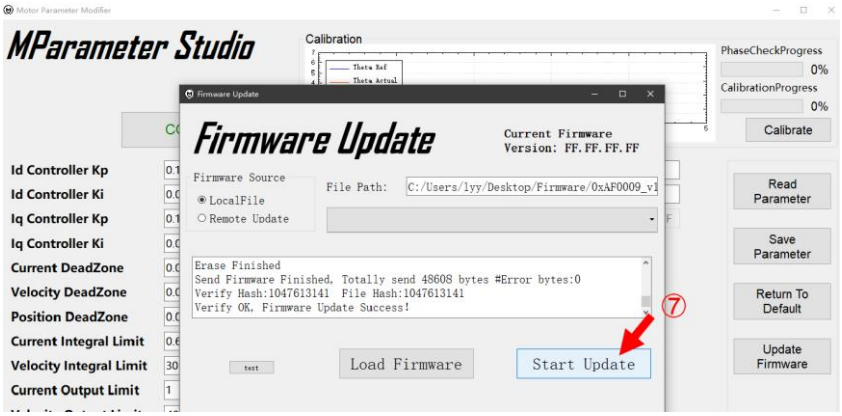
- Step 4,5,6
  勾选 Local File 选项，单机路径框，选择要升级的固件文件，点击 Load Firmware 按键，读入升级固件文件，等待控制台输出 Open file Success
  Check the Local File option, click the path box, select the firmware file to be upgraded, click the Load Firmware button, read in the upgraded firmware file, and wait for the console to output Open file Success.



- Step 7

  点击 Start Update 按键，等待控制台输出如右图消息，若显示"Verify OK"则升级成功，驱动板蓝灯开始不停闪烁。随后断开 USB 重启驱动板，以及 Motorevo Studio 上位机（关闭全部窗口），即升级完成。

  Click the Start Update button and wait for the console to output the message as shown on the right. If it displays "Verify OK", the upgrade is successful and the blue light on the driver board starts to flash continuously. Then disconnect the USB and restart the driver board and the upper computer of Motorevo Studio (close all windows), and the upgrade is complete.



- 注意 Caution!

  1、 请在升级过程中严格按以上流程操作，确保 USB 连接稳固，并不要中途断开升级，否则容易造成驱动板永久性损伤!

  Please strictly follow the above procedures during the upgrade process to ensure that the USB connection is stable, and do not disconnect the upgrade midway, otherwise it will easily cause permanent damage to the driver board!

  2、 固件升级**可能**会对用户参数和校准结果进行擦写，请在升级完毕固件后执行一遍“校准”操作，并检查驱动板内的参数是否符合当前用户需求。

  The firmware upgrade may erase and write user parameters and calibration results. Please perform the "calibration" operation after the firmware upgrade is completed, and check whether the parameters in the driver board meet the current user requirements.

7 通过 CAN 总线使用 Motorevo Studio 控制电机运行实例

Motor operation demo controlled by Motorevo Studio via CAN bus

8 通过 EtherCAT 使用 TWINCAT3 和控制电机运行实例

Motor operation demo controlled by TWINCAT3 via EtherCAT bus