MX-64AR, MX-64AT (Protocol 2.0)

1. Specifications

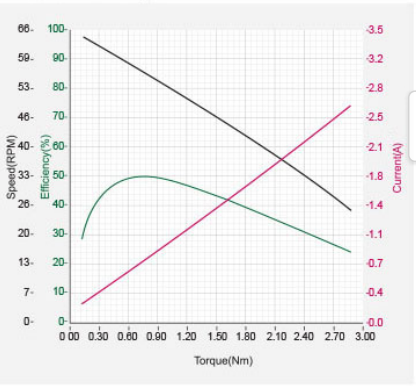
Item	Specifications
MCU	ST CORTEX-M3 (STM32F103C8 @ 72MHZ,32BIT)
Position Sensor	Contactless absolute encoder (12BIT,360 DEGREE) Maker : ams (www.ams.com), Part No : AS5045
Motor	Maxon
Baud Rate	8000 bps ~ 4.5 Mbps
Control Algorithm	PID Control
Resolution	0.088°
Operation Modes	Current Control Mode Velocity Control Mode Position Control Mode(0° ~ 360°) Extended Position Ctrl Mode(Multi-turn) Current-based Position Ctrl Mode PWM Control Mode
Weight	MX-64AR/AT : 135g, MX-64R/T : 126g
Dimensions (W x H x D)	40.2mm x 61.1mm x 41mm
Gear Ratio	200 : 1
Stall Torque	5.5Nm @ 11.1V, 3.9A 6.0Nm @ 12V, 4.1A 7.3Nm @ 14.8V, 5.2A
No Load Speed	58rpm @ 11.1V 63rpm @ 12V 78rpm @ 14.8V
Operating Temperature	-5°C ~ +80°C
Input Voltage	10 ~ 14.8V (Recommended : 12V)
Standby Current	100mA
Command Signal	Digital Packet
Protocol Type	MX-64T/MX-64AT: Half Duplex Asynchronous Serial Communication MX-64R/MX-64AR: RS485 Asynchronous Serial Communication (8bit,1stop, No Parity)
Physical Connection	MX-64T/MX-64AT: TTL Level Multidrop BUS MX-64R/MX-64AR: RS485 Multidrop BUS
ID	0 ~ 252
Feedback	Position, Velocity, Current, Realtime Tick, Trajectory, Input Voltage, etc
Material	Full Metal Gear MX-64AR/AT: Metal(Front), Engineering Plastic(Middle, Back) MX-64R/T: Engineering Plastic(Front, Middle, Back)

1. 1. Performance Graph

Data

	Unit	Data
Weight	g	135
Dimension	mm	40.2 x 61.1 x 41
Gear Ratio	type/material	200:1 (Spur/Metal)
Network	-	TTL / RS-485
Position Sensor (resolution)	-	Contactless Absolute Encoder (360˚/ 4096)
Motor	-	Maxon Motor
Operation Voltage	V	10~14.8
Stall Torque	N.m	6.0 at 12V
Stall Current	A	4.1 at 12V
No Load Speed	RPM	63 at 12V

Performance Graph



`Stall torque` Peak stall torque read from transient state

`Performance Graph(N-T Curve)` A graph shows torque measured in stable condition while increasing load. **Normally, stall torque is bigger than maximum torque on performance graph.**

`Caution` When connecting to power supply:

- For the stable power supply, we recommend using ROBOTIS controller or SMPS2Dynamixel.
- Connect your DYNAMIXEL to power supply while it's off and turn on/off with the power switch.

2. Control Table

The Control Table is a structure of data implemented in the DYNAMIXEL. Users can read a specific Data to get status of the DYNAMIXEL with Read Instruction Packets, and modify Data as well to control DYNAMIXEL with WRITE Instruction Packets.

2. 1. Control Table, Data, Address

The Control Table is a structure that consists of multiple Data fields to store status of the DYNAMIXEL or to control the DYNAMIXEL. Users can check current status of the DYNAMIXEL by reading a specific Data from the Control Table with Read Instruction Packets. WRITE Instruction Packets enable users to control the DYNAMIXEL by changing specific Data in the Control Table. The Address is a unique value when accessing a specific Data in the Control Table with Instruction Packets. In order to read or write data, users must designate a specific Address in the Instruction Packet. Please refer to Protocol 2.0 for more details about Instruction Packets.

`Note` Two's complement is applied for the negative value. For more information, please refer to Two's complement from Wikipedia.

2. 1. 1. Area (EEPROM, RAM)

The Control Table is divided into 2 Areas. Data in the RAM Area is reset to initial values when the power is reset(Volatile). On the other hand, data in the EEPROM Area is maintained even when the DYNAMIXEL is powered off(Non-Volatile). **Data in the EEPROM Area can only be written to if Torque Enable(64) is cleared to '0'(Off).**

2. 1. 2. Size

The Size of data varies from 1 to 4 bytes depend on their usage. Please check the size of data when updating the data with an Instruction Packet. For data larger than 2 bytes will be saved according to Little Endian.

2. 1. 3. Access

The Control Table has two different access properties. 'RW' property stands for read and write access permission while 'R' stands for read only access permission. Data

with the read only property cannot be changed by the WRITE Instruction. Read only property('R') is generally used for measuring and monitoring purpose, and read write property('RW') is used for controlling DYNAMIXEL.

2. 1. 4. Initial Value

Each data in the Control Table is restored to initial values when the DYNAMIXEL is turned on. Default values in the EEPROM area are initial values of the DYNAMIXEL (factory default settings). If any values in the EEPROM area are modified by a user, modified values will be restored as initial values when the DYNAMIXEL is turned on. Initial Values in the RAM area are restored when the DYNAMIXEL is turned on.

2. 2. Control Table of EEPROM Area

Address	Size (Byte)	Data Name	Description	Access	Initial Value
0	2	Model Number	Model Number	R	311
2	4	Model Information	Model Information	R	-
6	1	Firmware Version	Firmware Version	R	-
7	1	ID	DYNAMIXEL ID	RW	1
8	1	Baud Rate	Communication Baud Rate	RW	1
9	1	Return Delay Time	Response Delay Time	RW	250
10	1	Drive Mode	Drive Mode	RW	0
11	1	Operating Mode	Operating Mode	RW	3
12	1	Secondary(Shadow) ID	Secondary ID	RW	255
13	1	Protocol Version	Protocol Version	RW	2
20	4	Homing Offset	Home Position Offset	RW	0
24	4	Moving Threshold	Velocity Threshold for Movement Detection	RW	10
31	1	Temperature Limit	Maximum Internal Temperature Limit	RW	80
32	2	Max Voltage Limit	Maximum Input Voltage Limit	RW	160
34	2	Min Voltage Limit	Minimum Input Voltage Limit	RW	95
36	2	PWM Limit	Maximum PWM Limit	RW	885
38	2	Current Limit	Maximum Current Limit	RW	1941
40	4	Acceleration Limit	Maximum Acceleration Limit	RW	32767
44	4	Velocity Limit	Maximum Velocity Limit	RW	435
48	4	Max Position Limit	Maximum Position Limit	RW	4095
52	4	Min Position Limit	Minimum Position Limit	RW	0
63	1	Shutdown	Shutdown Error Information	RW	52

2. 3. Control Table of RAM Area

Address	Size (Byte)	Data Name	Description	Access	Initial Value
64	1	Torque Enable	Motor Torque On/Off	RW	0
65	1	LED	Status LED On/Off	RW	0
68	1	Status Return Level	Select Types of Status Return	RW	2
69	1	Registered Instruction	REG_WRITE Instruction Flag	R	0
70	1	Hardware Error Status	Hardware Error Status	R	0
76	2	Velocity I Gain	I Gain of Velocity	RW	1920
78	2	Velocity P Gain	P Gain of Velocity	RW	100
80	2	Position D Gain	D Gain of Position	RW	0
82	2	Position I Gain	I Gain of Position	RW	0

Address	Size (Byte)	Data Name	Description	Access	Initial Value
84	2	Position P Gain	P Gain of Position	RW	850
88	2	Feedforward 2nd Gain	2nd Gain of Feed-Forward	RW	0
90	2	Feedforward 1st Gain	1st Gain of Feed-Forward	RW	0
98	1	BUS Watchdog	Dynamixel BUS Watchdog	RW	0
100	2	Goal PWM	Target PWM Value	RW	-
102	2	Goal Current	Target Current Value	RW	-
104	4	Goal Velocity	Target Velocity Value	RW	-
108	4	Profile Acceleration	Acceleration Value of Profile	RW	0
112	4	Profile Velocity	Velocity Value of Profile	RW	0
116	4	Goal Position	Target Position	RW	-
120	2	Realtime Tick	Count Time in Millisecond	R	-
122	1	Moving	Movement Flag	R	0
123	1	Moving Status	Detailed Information of Movement Status	R	0
124	2	Present PWM	Present PWM Value	R	-
126	2	Present Current	Present Current Value	R	-
128	4	Present Velocity	Present Velocity Value	R	-
132	4	Present Position	Present Position Value	R	-
136	4	Velocity Trajectory	Target Velocity Trajectory from Profile	R	-
140	4	Position Trajectory	Target Position Trajectory from Profile	R	-
144	2	Present Input Voltage	Present Input Voltage	R	-
146	1	Present Temperature	Present Internal Temperature	R	-
168	2	Indirect Address 1	Indirect Address 1	RW	224
170	2	Indirect Address 2	Indirect Address 2	RW	225
172	2	Indirect Address 3	Indirect Address 3	RW	226
...	...	...	...	...	...
218	2	Indirect Address 26	Indirect Address 26	RW	249
220	2	Indirect Address 27	Indirect Address 27	RW	250
222	2	Indirect Address 28	Indirect Address 28	RW	251
224	1	Indirect Data 1	Indirect Data 1	RW	0
225	1	Indirect Data 2	Indirect Data 2	RW	0
226	1	Indirect Data 3	Indirect Data 3	RW	0
...	...	...	...	...	...
249	1	Indirect Data 26	Indirect Data 26	RW	0
250	1	Indirect Data 27	Indirect Data 27	RW	0
251	1	Indirect Data 28	Indirect Data 28	RW	0
578	2	Indirect Address 29	Indirect Address 29	RW	634
580	2	Indirect Address 30	Indirect Address 30	RW	635
582	2	Indirect Address 31	Indirect Address 31	RW	636
...	...	...	...	...	...
628	2	Indirect Address 54	Indirect Address 54	RW	659
630	2	Indirect Address 55	Indirect Address 55	RW	660
632	2	Indirect Address 56	Indirect Address 56	RW	661
634	1	Indirect Data 29	Indirect Data 29	RW	0
635	1	Indirect Data 30	Indirect Data 30	RW	0

Address	Size (Byte)	Data Name	Description	Access	Initial Value
636	1	Indirect Data 31	Indirect Data 31	RW	0
...	...	...	...	...	...
659	1	Indirect Data 54	Indirect Data 54	RW	0
660	1	Indirect Data 55	Indirect Data 55	RW	0
661	1	Indirect Data 56	Indirect Data 56	RW	0

Caution Protocol 1.0 does not support addresses greater than 256. Therefore, Indirect Address 29 ~ 56 and Indirect Data 29 ~ 56 can only be accessed with Protocol 2.0.

2. 4. Control Table Description

Caution Data in the EEPROM Area can only be written when the value of Torque Enable(64) is cleared to '0'.

2. 4. 1. Model Number(0)

This address stores model number of the DYNAMIXEL.

2. 4. 2. Firmware Version(6)

This address stores firmware version of the DYNAMIXEL.

2. 4. 3. ID(7)

The ID is a unique value in the network to identify each DYNAMIXEL with an Instruction Packet. 0~252 (0xFC) values can be used as an ID, and 254(0xFE) is occupied as a broadcast ID. The Broadcast ID(254, 0xFE) can send an Instruction Packet to all connected DYNAMIXELs simultaneously.

Note Please avoid using an identical ID for multiple DYNAMIXELs. You may face communication failure or may not be able to detect Dynamixels with an identical ID.

2. 4. 4. Baud Rate(8)

Baud Rate determines serial communication speed between a controller and DYNAMIXELs.

Value	Baud Rate	Margin of Error
7	4.5M	0.000%
6	4M	0.000%
5	3M	0.000%
4	2M	0.000%
3	1M	0.000%
2	115,200	0.000%
1(Default)	57,600	0.000%
0	9,600	0.000%

Note Less than 3% of the baud rate error margin will not affect to UART communication.

2. 4. 5. Return Delay Time(9)

After the DYNAMIXEL receives an Instruction Packet, it delays transmitting the Status Packet for Return Delay Time (9). For instance, if the Return Delay Time(9) is set to '10', the Status Packet will be returned after 20[µsec] when the Instruction Packet is received.

Unit	Value Range	Description
2[µsec]	0 ~ 254	Default value '250'(500[µsec]), Maximum 508[µsec]

2. 4. 6. Drive Mode(10)

Drive Mode is availabe from the firmware version 38.

Bit	Item	Description
Bit 1(0x02) ~ 7(0x80)	N/A	Unused, always '0'
Bit 0(0x01)	Direction of Rotation	Normal Mode(0): CCW(Positive), CW(Negative) Reverse Mode(1): CCW(Negative), CW(Positive)

2. 4. 7. Operating Mode(11)

Value	Operating Mode	Description
0	Current Control Mode	DYNAMIXEL only controls current(torque) regardless of speed and position. This mode is ideal for a gripper or a system that only uses current(torque) control or a system that has additional velocity/position controllers.
1	Velocity Control Mode	This mode controls velocity. This mode is identical to the Wheel Mode(endless) from existing DYNAMIXELs. This mode is ideal for wheel-type robots.
3(Default)	Position Control Mode	This mode controls position. This mode is identical to the Joint Mode from existing DYNAMIXELs. Operating position range is limited by Max Position Limit(48) and Min Position Limit(52). This mode is ideal for articulated robots that each joint rotates less than 360 degrees.
4	Extended Position Control Mode(Multi-turn)	This mode controls position. This mode is identical to the Multi-Turn Mode from existing DYNAMIXELs. 512 turns are supported(-256[rev] ~ 256[rev]). This mode is ideal for multi-turn wrists or conveyer systems or a system that requires an additional reduction gear.
5	Current-based Position Control Mode	This mode controls both position and current(torque). Up to 512 turns are supported(-256[rev] ~ 256[rev]). This mode is ideal for a system that requires both position and current control such as articulated robots or grippers.
16	PWM Control Mode (Voltage Control Mode)	This mode directly controls PWM output. (Voltage Control Mode)

Note Switching Operating Mode will reset gains(PID, Feedfoward) properly to the selected Operating Mode. The profile generator and limits will also be reset.

1. Profile Velocity(112), Profile Acceleration(108) : Reset to '0'
2. Goal PWM(100), Goal Current(102) : Reset to PWM Limit(36), Current Limit(38) respectively
3. Current-based Position Control Mode : Reset to Position Gain(PID) and PWM Limit(36) values.

Changed Position Gain(PID) and PWM Limit(36) values can be read from the Control Table.

Note PWM is the abbreviation for Pulse Width Modulation that modulates PWM Duty to control motors. The PWM Control Mode changes pulse width to control average supply voltage to the motor and this technique is widely used in the motor control field. Therefore, PWM Control Mode uses Goal PWM(100) value to control supply voltage for DYNAMIXEL. PWM Control Mode is similar to the Wheel Mode of DYNAMIXEL AX and RX series.

2. 4. 8. Secondary(Shadow) ID(12)

Set the Dynamixel's Secondary ID. Secondary ID(12) is a value to identify each Dynamixel, just like the ID(7). However, unlike ID(7), Secondary ID(12) is not a unique value. Therefore, Dynamixels with the same Secondary ID value form a group. The differences between Secondary ID(12) and ID(7) are as follows :

1. Secondary ID(12) is not a unique value. i.e., a lot of Dynamixels may have the same Secondary ID value.

2. ID(7) has a higher priority than Secondary ID(12). i.e., if Secondary ID(12) and ID(7) are the same, ID(7) will be applied first.
3. The EEPROM area of the Control Table cannot be modified with Secondary ID(12). Only the RAM area can be modified.
4. If Instruction Packet ID is the same as Secondary ID(12), the Status Packet will not be returned.
5. If the value of Secondary ID(12) is 253 or higher, the Secondary ID function is deactivated.

Values	Description
0 ~ 252	Activate Secondary ID function
253 ~ 255	Deactivate Secondary ID function, Default value '255'

The following are examples of operation when there are five Dynamixels with ID (7) set from 1 to 5.

1. Set all five Dynamixels' Secondary ID(12) to '5'.
2. Send Write Instruction Packet(ID = 1, LED(65) = 1).
3. Turn on LED of Dynamixel with ID '1' and return the Status Packet.
4. Send Write Instruction Packet(ID = 5, LED(65) = 1).
5. Turn on LED on five Dynamixels. However, Status Packet of Dynamixel with ID '5' will be returned.
6. Set the Secondary ID(12) of all five Dynamixels to '100'.
7. Send Write Instruction Packet(ID = 100, LED(65) = 0).
8. Turn off LED on five Dynamixels. However, as there is no Dynamixel with ID '100', Status Packet is not returned.

2. 4. 9. Protocol Version(13)

Users can select Dynamixel protocol version (1.0 and 2.0). It is recommended to use an identical protocol version for multiple Dynamixels.

Value	Protocol Version	Compatible Dynamixels
1	1.0	AX Series, DX Series, RX Series, EX Series, MX Series with Firmware below v39
2(default)	2.0	MX-28/64/106 with Firmware v39 or above, X Series, Pro Series

Note The protocol 2.0 is greatly enhanced from the protocol 1.0. Accessing some of the Control Table area might be denied if protocol 1.0 is selected. This manual complies with protocol 2.0. Please refer to the Protocol section of e-Manual for more details about the protocol.

2. 4. 10. Homing Offset(20)

Users can adjust the Home position by setting Home Offset(20). The Homing Offset value is added to the Present Position(132). Present Position(132) = Actual Position + Homing Offset(20).

Unit	Value Range	Description
about 0.088°	-1,044,479 ~ 1,044,479 (-255 ~ 255[rev])	4,096 resolution

Note In case of the Position Control Mode(Joint Mode) that rotates less than 360 degrees, any invalid Homing Offset(20) values will be ignored(valid range : -1,024 ~ 1,024).

2. 4. 11. Moving Threshold(24)

This value helps to determine whether the Dynamixel is in motion or not.
When the absolute value of Present Velocity(128) is greater than the Moving Threshold(24), Moving(122) is set to '1', otherwise it is cleared to '0'.

	Values	Description
Unit	about 0.229 rpm	All velocity related Data uses the same unit

	Values	Description
Range	0 ~ 1,023	-

2. 4. 12. Temperature Limit(31)

This value limits operating temperature.
When the Present Temperature(146) that indicates internal temperature of Dynamixel is greater than the Temperature Limit(31), the Over Heating Error Bit(0x04) and Hardware Error Bit(0x80) in the Hardware Error Status(70) will be set.
If Overheating Error Bit(0x04) is configured in the Shutdown(63), Torque Enable(64) is cleared to '0' and Torque will be disabled.
For more details, please refer to the Shutdown(63) section.

Unit	Value Range	Description
About 1°	0 ~ 100	0 ~ 100°

`Caution` Do not set the temperature lower/higher than the default value. When the temperature alarm shutdown occurs, wait 20 minutes to cool the temperature before re-use. Keep using the product when the temperature is high can cause severe damage.

2. 4. 13. Min/Max Voltage Limit(32, 34)

These values are maximum and minimum operating voltages.
When current input voltage acquired from Present Input Voltage(144) exceeds the range of Max Voltage Limit(32) and Min Voltage Limit(34), Voltage Range Error Bit(0x01) and Hardware Error Bit(0x80) in the Hardware Error Status(70) are set.
If Input Voltage Error Bit(0x10) is configured in the Shutdown(63), Torque Enable(64) is cleared to '0' and Torque is disabled.
For more details, please refer to the Shutdown(63) section.

Unit	Value Range	Description
About 0.1V	95 ~ 160	9.5 ~ 16.0V

2. 4. 14. PWM Limit(36)

This value indicates maximum PWM output. Goal PWM(100) can't be configured with any values exceeding PWM Limit(36). PWM Limit(36) is commonly used in all operating mode as an output limit, therefore decreasing PWM output will result in decreasing torque and velocity. For more details, please refer to the Gain section of each operating modes.

Values	Description
0(0%) ~ 885(100%)	885 = 100[%] output

2. 4. 15. Current Limit(38)

This value indicates maximum current(torque) output limit. Goal Current(102) can't be configured with any values exceeding Current Limit(38). The Current Limit(38) is used in Torque Control Mode and Current-based Position Control Mode, therefore decreasing Current Limit(38) will result in decreasing torque of DYNAMIXEL. For more details, please refer to the Position PID Gain(80 ~ 84).

Unit	Value Range
about 3.36[mA]	0 ~ 1,941

`Note` Current Limit(38) could be differ by each DYNAMIXEL so please check the Control Table.

2. 4. 16. Acceleration Limit(40)

This value indicates maximum Profile Acceleration(108). Profile Acceleration(108) can't be configured with any values exceeding Acceleration Limit(40). Profile Acceleration(108) is used in all operating mode except PWM Control Mode in order to generate a target trajectory. For more details, please refer to the Profile Velocity(112).

Unit	Value Range
214.577 Rev/min^2	0 ~ 32,767

Note Bit information of the Error field in the Status Packet is different from protocol 1.0 and protocol 2.0. This manual complies with protocol 2.0. Please refer to the Protocol section of e-Manual for more details about the protocol.

2. 4. 17. Velocity Limit(44)

This value indicates maximum velocity of Goal Velocity(104) and Profile Velocity(112). For more details, please refer to the Profile Velocity(112).

Unit	Value Range
0.229rpm	0 ~ 1,023

2. 4. 18. Min/Max Position Limit(48, 52)

These values limit maximum and minimum target positions for Position Control Mode(Joint Mode) within the range of 1 rotation(0 ~ 4,095). Therefore, Goal Position(116) should be configured within the position limit range. These values are not used in Extended Position Control Mode and Current-based Position Control Mode.

Unit	Value Range
0.088°	0 ~ 4,095(1 rotation)

Note Max Position Limit(48) and Min Position Limit(52) are only used in Position Control Mode with a single turn.

2. 4. 19. Shutdown(63)

The Dynamixel can protect itself by detecting dangerous situations that could occur during the operation.
Each Bit is inclusively processed with the 'OR' logic, therefore, multiple options can be generated.
For instance, when '0x05' (binary : 00000101) is defined as Shutdown(63), Dynamixel can detect both Input Voltage Error(binary : 00000001) and Overheating Error(binary : 00000100).
If those errors are detected, Torque Enable(64) is cleared to '0' and the motor output becomes 0[%].
REBOOT is the only method to reset Torque Enable(64) to '1'(Torque ON) after the shutdown.
The followings are detectable situations.

Bit	Item	Description
Bit 7	-	Unused, Always '0'
Bit 6	-	Unused, Always '0'
Bit 5	Overload Error(default)	Detect persistent load that exceeds maximum output
Bit 4	Electrical Shock Error(default)	Detect electric shock on the circuit or insufficient power to operate the motor
Bit 3	Motor Encoder Error	Detect malfunction of the motor encoder
Bit 2	OverHeating Error(default)	Detect internal temperature exceeds the configured operating temperature
Bit 1	-	Unused, Always '0'
Bit 0	Input Voltage Error	Detect input voltage exceeds the configured operating voltage

Note If Shutdown occurs, use below method to reboot Dynamixels.

1. H/W REBOOT : Turn off the power and turn on again
2. S/W REBOOT : Transmit REBOOT Instruction (For more details, please refer to the [Reboot] section of Protocol e-Manual.)

If Shutdown occurs, LED will flicker every second.(Firmware v41 or above)

2. 4. 20. Torque Enable(64)

Controls Torque ON/OFF. Writing '1' to this address will turn on the Torque and all Data in the EEPROM area will be protected.

Value	Description
0(Default)	Torque OFF(Free-run) and the motor does not generate torque
1	Torque ON and all Data in the EEPROM area will be locked

Note Present Position(132) can be reset when Operating Mode(11) and Torque Enable(64) are updated. For more details, please refer to the Homing Offset(20) and Present Position(132).

2. 4. 21. LED(65)

Turn on or turn off the LED on Dynamixel.

Bit	Description
0(Default)	Turn OFF the LED
1	Turn ON the LED

2. 4. 22. Status Return Level(68)

This value decides how to return Status Packet when Dynamixel receives an Instruction Packet.

Value	Responding Instructions	Description
0	PING Instruction	Status Packet will not be returned for all Instructions
1	PING Instruction READ Instruction	Status Packet will be returned only for READ Instruction
2	All Instructions	Status Packet will be returned for all Instructions

Note If the ID of Instruction Packet is set to Broad Cast ID(0xFE), Status Packet will not be returned for READ and WRITE Instructions regardless of Status Return Level. For more details, please refer to the Status Packet section for Protocol 1.0 or Protocol 2.0.

2. 4. 23. Registered Instruction(69)

Value	Description
0	REG_WRITE instruction is not received
1	REG_WRITE instruction is received

Note If ACTION instruction is executed, the value will be changed to 0.

2. 4. 24. Hardware Error Status(70)

This value indicates hardware error status. The Dynamixel can protect itself by detecting dangerous situations that could occur during the operation.
Each Bit is inclusively processed with the 'OR' logic, therefore, multiple options can be generated.
For instance, when '0x05' (binary : 00000101) is defined as Shutdown(63), Dynamixel can detect both Input Voltage Error(binary : 00000001) and Overheating Error(binary : 00000100).

If those errors are detected, Torque Enable(64) is cleared to '0' and the motor output becomes 0[%].
REBOOT is the only method to reset Torque Enable(64) to '1'(Torque ON) after the shutdown.
The followings are detectable situations.

Bit	Item	Description
Bit 7	-	Unused, Always '0'
Bit 6	-	Unused, Always '0'
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Bit 4	Electrical Shock Error(default)	Detect electric shock on the circuit or insufficient power to operate the motor
Bit 3	Motor Encoder Error	Detect malfunction of the motor encoder
Bit 2	OverHeating Error(default)	Detect internal temperature exceeds the configured operating temperature
Bit 1	-	Unused, Always '0'
Bit 0	Input Voltage Error	Detect input voltage exceeds the configured operating voltage

Note If Shutdown occurs, use below method to reboot Dynamixels.

1. H/W REBOOT : Turn off the power and turn on again
2. S/W REBOOT : Transmit REBOOT Instruction (For more details, please refer to the [Reboot] section of Protocol e-Manual.)

If Shutdown occurs, LED will flicker every second.(Firmware v41 or above)

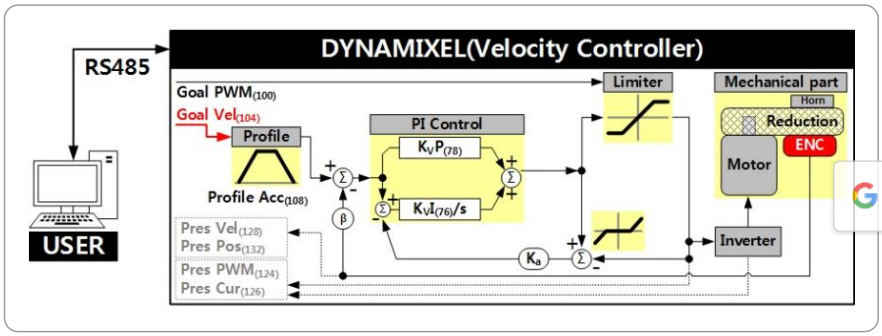
2. 4. 25. Velocity PI Gain(76, 78)

These values indicate Gains of Velocity Control Mode. Gains of DYNAMIXEL's internal controller can be calculated from Gains of the Control Table as shown below. The constant in each equations include sampling time. Velocity P Gain of DYNAMIXEL's internal controller is abbreviated to K_VP and that of the Control Table is abbreviated to $K_VP_{(TBL)}$.

	Controller Gain	Conversion Equations	Range	Description
Velocity I Gain(76)	K_VI	$K_VI = K_VI_{(TBL)} / 65,536$	0 ~ 16,383	I Gain
Velocity P Gain(78)	K_VP	$K_VP = K_VP_{(TBL)} / 128$	0 ~ 16,383	P Gain

Below figure is a block diagram describing the velocity controller in Velocity Control Mode. When the instruction transmitted from the user is received by DYNAMIXEL, it takes following steps until driving the horn.

1. An Instruction from the user is transmitted via DYNAMIXEL bus, then registered to Goal Velocity(104).
2. Goal Velocity(104) is converted to target velocity trajectory by Profile Acceleration(108).
3. The target velocity trajectory is stored at Velocity Trajectory(136).
4. PI controller calculates PWM output for the motor based on the target velocity trajectory.
5. Goal PWM(100) sets a limit on the calculated PWM output and decides the final PWM value.
6. The final PWM value is applied to the motor through an Inverter, and the horn of DYNAMIXEL is driven.
7. Results are stored at Present Position(132), Present Velocity(128), Present PWM(124) and Present Current(126).



Note K_a stands for Anti-windup Gain and 'β' is a conversion coefficient of position and velocity that cannot be modified by users. For more details about the PID controller, please refer to the PID Controller at wikipedia.

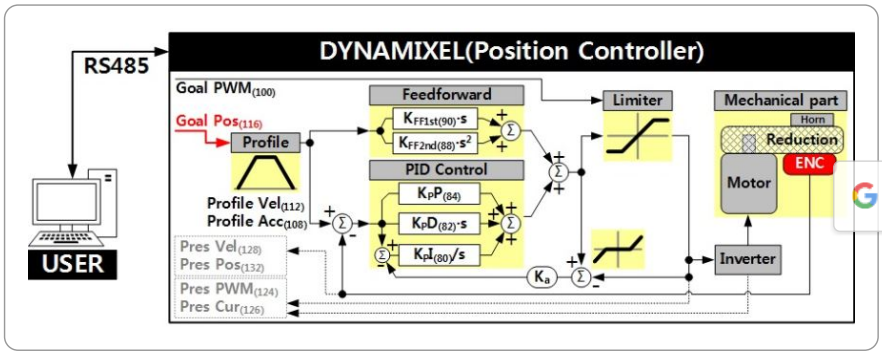
2. 4. 26. Position PID Gain(80, 82, 84), Feedforward 1st/2nd Gains(88, 90)

These Gains are used in Position Control Mode and Extended Position Control Mode. Gains of Dynamixel's internal controller can be calculated from Gains of the Control Table as shown below. The constant in each equations include sampling time. Position P Gain of Dynamixel's internal controller is abbreviated to K_PP and that of the Control Table is abbreviated to $K_PP_{(TBL)}$.

	Controller Gain	Conversion Equations	Range	Description
Position D Gain(80)	K_PD	$K_PD = K_PD_{(TBL)} / 16$	0 ~ 16,383	D Gain
Position I Gain(82)	K_PI	$K_PI = K_PI_{(TBL)} / 65,536$	0 ~ 16,383	I Gain
Position P Gain(84)	K_PP	$K_PP = K_PP_{(TBL)} / 128$	0 ~ 16,383	P Gain
Feedforward 2nd Gain(88)	K_{FF2nd}	$K_{FF2nd(TBL)} / 4$	0 ~ 16,383	Feedforward Acceleration Gain
Feedforward 1st Gain(90)	K_{FF1st}	$K_{FF1st(TBL)} / 4$	0 ~ 16,383	Feedforward Velocity Gain

Below figure is a block diagram describing the position controller in Position Control Mode and Extended Position Control Mode. When the instruction from the user is received by Dynamixel, it takes following steps until driving the horn.

1. An Instruction from the user is transmitted via Dynamixel bus, then registered to Goal Position(116).
2. Goal Position(116) is converted to target position trajectory and target velocity trajectory by Profile Velocity(112) and Profile Acceleration(108).
3. The target position trajectory and target velocity trajectory is stored at Position Trajectory(140) and Velocity Trajectory(136) respectively.
4. Feedforward and PID controller calculate PWM output for the motor based on target trajectories.
5. Goal PWM(100) sets a limit on the calculated PWM output and decides the final PWM value.
6. The final PWM value is applied to the motor through an Inverter, and the horn of Dynamixel is driven.
7. Results are stored at Present Position(132), Present Velocity(128), Present PWM(124) and Present Current(126).

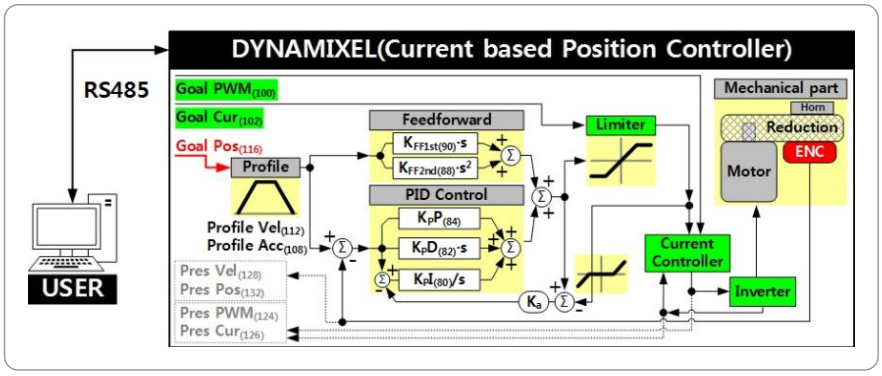


Note In case of PWM Control Mode, both PID controller and Feedforward controller are deactivated while Goal PWM(100) value is directly controlling the motor through an Inverter. In this manner, users can directly control the supplying voltage to the motor.

Note K_a is an Anti-windup Gain that cannot be modified by users.

Below figure is a block diagram describing the current-based position controller in Current-based Position Control Mode. As Current-based Position Control Mode is quite similar to Position Control Mode, differences will be focused in the following steps. The differences are highlighted with a green marker in the block diagram as well.

1. Feedforward and PID controller calculates target current based on target trajectory.
2. Goal Current(102) decides the final target current by setting a limit on the calculated target current.
3. Current controller calculates PWM output for the motor based on the final target current.
4. Goal PWM(100) sets a limit on the calculated PWM output and decides the final PWM value.
5. The final PWM value is applied to the motor through an Inverter, and the horn of DYNAMIXEL is driven.
6. Results are stored at Present Position(132), Present Velocity(128), Present PWM(124) and Present Current(126).



Note K_a is an Anti-windup Gain that cannot be modified by users. For more details about the PID controller and Feedforward controller, please refer to the PID Controller and Feed Forward.

2. 4. 27. BUS Watchdog(98)

Bus Watchdog (98) is available from firmware v38. It is a safety device (Fail-safe) that stops the DYNAMIXEL if the communication between the controller and DYNAMIXEL communication (RS485, TTL) is disconnected due to an unspecified error. Communication is defined as all the Instruction Packet in the DYNAMIXEL Protocol.

	Values	Description
Unit	20[ms]	-

	Values	Description
Range	0	Deactivate Bus Watchdog Function, Clear Bus Watchdog Error
Range	1 ~ 127	Activate Bus Watchdog
Range	-1	Bus Watchdog Error Status

The Bus Watchdog function monitors the communication interval (time) between the controller and DYNAMIXEL when Torque Enable (64) is '1'. If the measured communication interval (time) is larger than Bus Watchdog (98), the DYNAMIXEL will stop. Bus Watchdog (98) will be changed to '-1' (Bus Watchdog Error). If the Bus Watchdog Error screen appears, the Goal Value (Goal PWM(100), Goal Current(102), Goal Velocity(104), Goal Position(116)) will be changed to read-only-access. Therefore, when a new value is written to the Goal Value, a Range Error will be returned via the Status packet. If the value of Bus Watchdog (98) is changed to '0', Bus Watchdog Error will be cleared.

Note For details of Range Error, please refer to the protocol of the e-Manual.

The following are examples of the operation of the Bus Watchdog function.

1. After setting the operating mode (11) to speed control mode, change the Torque Enable (64) to '1'.
2. If '50' is written in the Goal Velocity (104), the DYNAMIXEL will rotate in CCW direction.
3. Change the value of Bus Watchdog (98) to '100' (2,000 [ms]). (Activate Bus Watchdog Function)
4. If no instruction packet is received for 2,000 [ms], the DYNAMIXEL will stop. When it stops, the Profile Acceleration (108) and Profile Velocity (112) are applied as '0'.
5. The value of Bus Watchdog (98) changes to '-1' (Bus Watchdog Error). At this time, the access to the Goal Value will be changed to read-only.
6. If '150' is written to the Goal Velocity (104), Range Error will be returned via Status Packet.
7. If the value of Bus Watchdog (98) is changed to '0', Bus Watchdog Error will be cleared.
8. If "150" is written in the Goal Velocity (104), the DYNAMIXEL will rotate in CCW direction.

2. 4. 28. Goal PWM(100)

In case of PWM Control Mode, both PID controller and Feedforward controller are deactivated while Goal PWM(100) value is directly controlling the motor through an Inverter. In other control modes, this value is used to limit PWM value. This value cannot exceed PWM Limit(36). Please refer to the Gain section in order to see how Goal PWM(100) affects to different control modes.

Range	Description
-PWM Limit(36) ~ PWM Limit(36)	Initial Value of PWM Limit(36) : '885'

2. 4. 29. Goal Current(102)

In case of Torque Control Mode, Goal Current(102) can be used to set a target current. This value sets a limit to current in Current-based Position Control mode. This value cannot exceed Current Limit(38).

Unit	Value Range
about 3.36[mA]	-Current Limit(38) ~ Current Limit(38)

Note Applying high current to the motor for long period of time might damage the motor.

2. 4. 30. Goal Velocity(104)

In case of Velocity Control Mode, Goal Velocity(104) can be used to set a target velocity. This value cannot exceed Velocity Limit(44). For now, Goal Velocity(104) is used for target velocity, but this value is not used to limit the velocity.

Unit	Value Range
0.229 rpm	-Velocity Limit(44) ~ Velocity Limit(44)

Note The maximum velocity and maximum torque of DYNAMIXEL is affected by supplying voltage. Therefore, if supplying voltage changes, so does the maximum velocity. This manual complies with recommended supply voltage(12[V]).

Note If Profile Acceleration(108) and Goal Velocity(104) are modified simultaneously, modified Profile Acceleration(108) will be used to process Goal Velocity(104).

2. 4. 31. Profile Acceleration(108)

The acceleration of Profile can be set with this value. Profile Acceleration(108) can be used in all control modes except Torque Control Mode. Profile Acceleration(108) cannot exceed Acceleration Limit(40). For more details, please refer to the Profile Velocity(112).

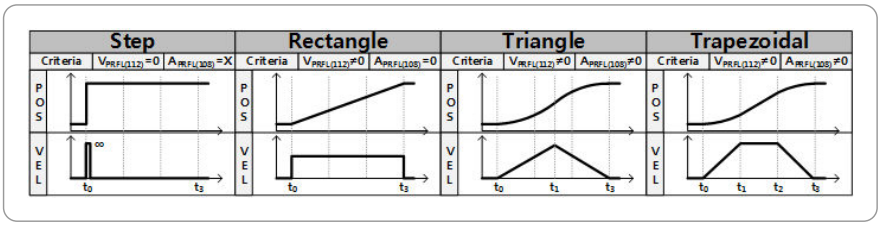
Unit	Value Range	Description
214.577 Rev/min^2	0 ~ Acceleration Limit(40)	'0' stands for an infinite acceleration

2. 4. 32. Profile Velocity(112)

The Maximum velocity of Profile can be set with this value.
Profile Velocity(112) can be used in all control modes except Torque Control Mode and Velocity Control Mode.
Profile Velocity(112) cannot exceed Velocity Limit(44).
Velocity Control Mode only uses Profile Acceleration(108) instead of Profile Velocity(112).

Unit	Value Range	Description
0.229 rpm	0 ~ Velocity Limit(44)	'0' stands for an infinite velocity

The Profile is an acceleration/deceleration control method to reduce vibration, noise and load of the motor by controlling dramatically changing velocity and acceleration. It is also called Velocity Profile as it controls acceleration and deceleration based on velocity.
DYNAMIXEL provides 4 different types of Profile.
The following explains 4 Profiles and how to select them.
Profiles are usually selected by a combination of Profile Velocity(112) and Profile Acceleration(108).
Triangular and Trapezoidal Profiles exceptionally consider total travel distance(ΔPos, the distance difference between target position and current position) as an additional factor.
For convenience, Profile Velocity(112) is abbreviated to V_{PRFL} and Profile Acceleration(108) is abbreviated to A_{PRFL}.
'X' stands for "Don't Care" case.

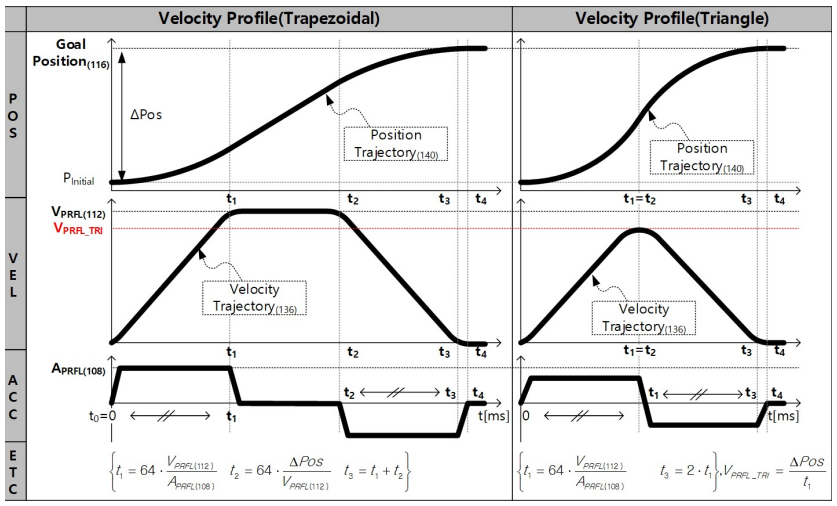


When given Goal Position(116), Dynamixel's profile creates target velocity trajectory based on current velocity(initial velocity of the Profile).
When Dynamixel receives updated target position from a new Goal Position(116) while it is moving toward the previous Goal Position(116), velocity smoothly varies for the new target velocity trajectory.
Maintaining velocity continuity while updating target velocity trajectory is called Velocity Override.
For a simple calculation, let's assume that the initial velocity of the Profile is '0'.

The following explains how Profile processes Goal Position(116) instruction in Position Control mode, Extended Position Control Mode, Current-based Position Control Mode.

1. An Instruction from the user is transmitted via Dynamixel bus, then registered to Goal Position(116).
2. Acceleration time(t1) is calculated from Profile Velocity(112) and Profile Acceleration(108).
3. Types of Profile is decided based on Profile Velocity(112), Profile Acceleration(108) and total travel distance(ΔPos, the distance difference between target position and current position).
4. Selected Profile type is stored at Moving Status(123).(Refer to the Moving Status(123))
5. Dynamixel is driven by the calculated target trajectory from Profile.
6. Target velocity trajectory and target position trajectory from Profile are stored at Velocity Trajectory(136) and Position Trajectory(140) respectively.
7. V_{PRFL_TRI} of ③ and Travel time(t3) to reach Goal Position(116) is calculated as below.

Condition	Types of Profile
$V_{PRFL}(112) = 0$	Profile not used (Step Instruction)
$(V_{PRFL}(112) \neq 0)$ & $(A_{PRF}(108) = 0)$	Rectangular Profile
$(V_{PRFL}(112) \neq 0)$ & $(A_{PRF}(108) \neq 0)$ & $(V_{PRFL\_TRI} \leq V_{PRFL}(112))$	Triangular Profile
$(V_{PRFL}(112) \neq 0)$ & $(A_{PRF}(108) \neq 0)$ & $(V_{PRFL\_TRI} > V_{PRFL}(112))$	Trapezoidal Profile

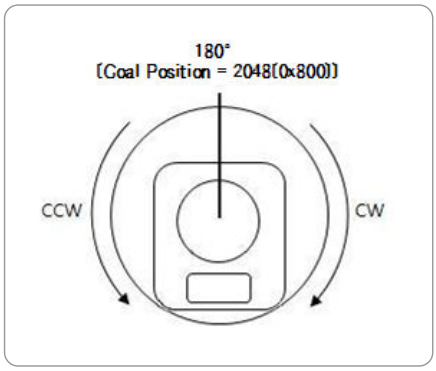


Note Dynamixel supports Jerk control in order to minimize dramatic change of acceleration. Therefore, actual travel time by the target trajectory of Profile could be longer than t3(t4 of above figure).

Note Velocity Control Mode only uses Profile Acceleration(108). Step and Trapezoidal Profiles are supported. Velocity Override and Jerk control are supported as well.
Acceleration time(t1) can be calculated as below equation.
t_1 = 64 * {Goal Velocity(104) / Profile Acceleration(108)}

2. 4. 33. Goal Position(116)

Target position can be set with Goal Position(116). From the front view of Dynamixels, CCW is an increasing direction whereas CW is a decreasing direction. The way to reaching Goal Position(116) is differ by 4 Profiles provided by Dynamixels. Please refer to the Profile Velocity(112) for more details.



Mode	Values	Description
Position Control Mode	Min Position Limit(52) ~ Max Position Limit(48)	Initial Value : 0 ~ 4,095
Extended Position Control Mode	-1,048,575 ~ 1,048,575	-256[rev] ~ 256[rev]
Current-based Position Control Mode	-1,048,575 ~ 1,048,575	-256[rev] ~ 256[rev]

Degree Conversion Constant	Description
0.088°/Value	1[rev] : 0 ~ 4,095

Note If Profile Acceleration(108), Profile Velocity(112) and Goal Position(116) are modified simultaneously, Goal Position(116) is processed based on updated Profile Acceleration(108) and Profile Velocity(112).

2. 4. 34. Realtime Tick(120)

This value indicates Dynamixel's time.

Unit	Value Range	Description
1 ms	0 ~ 32,767	The value resets to '0' when it exceeds 32,767

2. 4. 35. Moving(122)

This value indicates whether Dynamixel is in motion or not. If absolute value of Present Velocity(128) is greater than Moving Threshold(24), Moving(122) is set to '1'. Otherwise, it will be cleared to '0'. However, this value will always be set to '1' regardless of Present Velocity(128) while Profile is in progress with Goal Position(116) instruction.

Value	Description
0	Movement is not detected
1	Movement is detected, or Profile is in progress(Goal Position(116) instruction is being processed)

2. 4. 36. Moving Status(123)

This value provides additional information about the movement. Following Error Bit(0x08) and In-Position Bit(0x01) only work with Position Control Mode, Extended Position Control Mode, Current-based Position Control Mode.

		Details	Description
Bit 7	0x80	-	Unused
Bit 6	0x40	-	Unused
Bit 5 ~ Bit 4	0x30	Profile Type(0x30) Profile Type(0x20) Profile Type(0x10) Profile Type(0x00)	Trapezoidal Velocity Profile Triangular Velocity Profile Rectangular Velocity Profile Profile is not used
Bit 3	0x08	Following Error	Dynamixel fails to reach target position trajectory
Bit 2	0x04	-	Unused

		Details	Description
Bit 1	0x02	Profile Ongoing	Profile is in progress with Goal Position(116) instruction
Bit 0	0x01	In-Position	Dynamixel is reached to target position

2. 4. 37. Present PWM(124)

This value indicates present PWM. For more details, please refer to the Goal PWM(100).

2. 4. 38. Present Current(126)

This value indicates current Current. For more details, please refer to the Goal Current(102).

2. 4. 39. Present Velocity(128)

This value indicates present Velocity. For more details, please refer to the Goal Velocity(104).

2. 4. 40. Present Position(132)

This value indicates present Position. For more details, please refer to the Goal Position(116).

> Note Present Position(132) represents 4 byte continuous range(-2,147,483,648 ~ 2,147,483,647) when Torque is turned off regardless of Operating Mode(11). However, Present Position(132) will be reset in those cases:
>
> 1. Present Position(132) is reset with the value within 1 rev (0 ~ 4,095) when Operating Mode(11) is changed to Position Control Mode.
> 2. Present Position(132) is reset with the value within 1 rev (0 ~ 4,095) when Torque is turned on in Position Control Mode.
>
> Reset Present Position(132) value can be affected by Homing Offset(20).

2. 4. 41. Velocity Trajectory(136)

This is a target velocity trajectory created by Profile. Operating method can be changed based on control mode. For more details, please refer to the Profile Velocity(112).

1. **Velocity Control Mode** : When Profile reaches to the endpoint, Velocity Trajectory(136) becomes equal to Goal Velocity(104).
2. **Position Control Mode, Extended Position Control Mode, Current-based Position Control Mode** : Velocity Trajectory is used to create Position Trajectory(140). When Profile reaches to an endpoint, Velocity Trajectory(136) is cleared to '0'.

2. 4. 42. Position Trajectory(140)

This is a target position trajectory created by Profile. This value is only used in Position Control Mode, Extended Position Control Mode and Current-based Position Control Mode. For more details, please refer to the Profile Velocity(112).

2. 4. 43. Present Input Voltage(144)

This value indicates present voltage that is being supplied. For more details, please refer to the Max/Min Voltage Limit(32, 34).

2. 4. 44. Present Temperature(146)

This value indicates internal temperature of Dynamixel. For more details, please refer to the Temperature Limit(31).

2. 4. 45. Indirect Address, Indirect Data

Indirect Address and Indirect Data are useful when accessing two remote addresses in the Control Table as sequential addresses. Sequential addresses increase Instruction Packet efficiency. Addresses that can be defined as Indirect Address is limited to RAM area(Address 64 ~ 661). If specific address is allocated to Indirect

Address, Indirect Address inherits features and properties of the Data from the specific Address. Property includes Size(Byte length), value range, and Access property(Read Only, Read/Write). For instance, allocating 65(Address of LED) to Indirect Address 1(168), Indirect Data 1(224) can perform exactly same as LED(65).

`Example 1` Allocating Size 1 byte LED(65) to Indirect Data 1(224).

1. Indirect Address 1(168) : change the value to '65' which is the address of LED.
2. Set Indirect Data 1(224) to '1' : LED(65) also becomes '1' and LED is turned on.
3. Set Indirect Data 1(224) to '0' : LED(65) also becomes '0' and LED is turned off.

`Example 2` Allocating Size 4 byte Goal Position(116) to Indirect Data 2(225), 4 sequential bytes have to be allocated.

1. Indirect Address 2(170) : change the value to '116' which is the first address of Goal Position.
2. Indirect Address 3(172) : change the value to '117' which is the second address of Goal Position.
3. Indirect Address 4(174) : change the value to '118' which is the third address of Goal Position.
4. Indirect Address 5(176) : change the value to '119' which is the fourth address of Goal Position.
5. Set 4 byte value '1,024' to Indirect Data 2 : Goal Position(116) also becomes '1024' and Dynamixel moves.

Indirect Address Range	Description
64 ~ 661	EEPROM address can't be assigned to Indirect Address

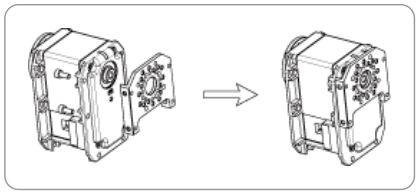
`Note` In order to allocate Data in the Control Table longer than 2[byte] to Indirect Address, all address must be allocated to Indirect Address like the above Example 2.

`Note` Indirect Address 29 ~ 56 and Indirect Data 29 ~ 56 can only be accessed with Protocol 2.0.

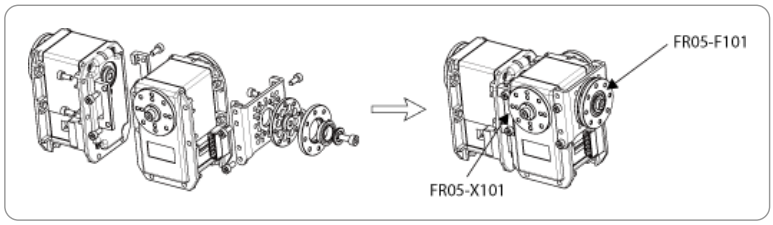
3. How to Assemble

3. 1. Optional Frames

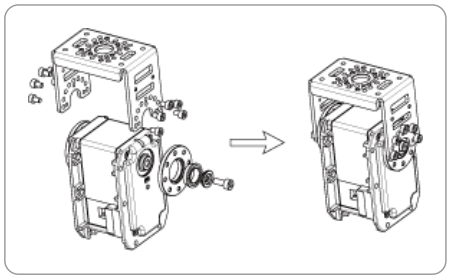
- FR05-B101



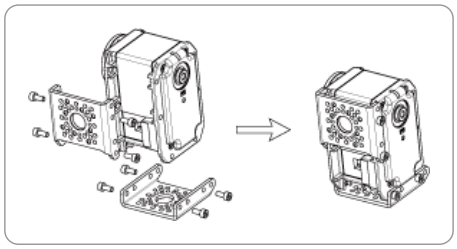
- FR05-F101 and FR05-X101



- FR05-H101



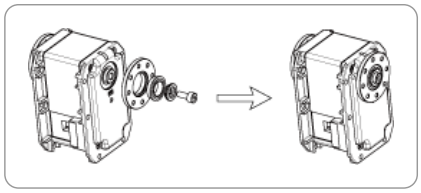
- FR05-S101



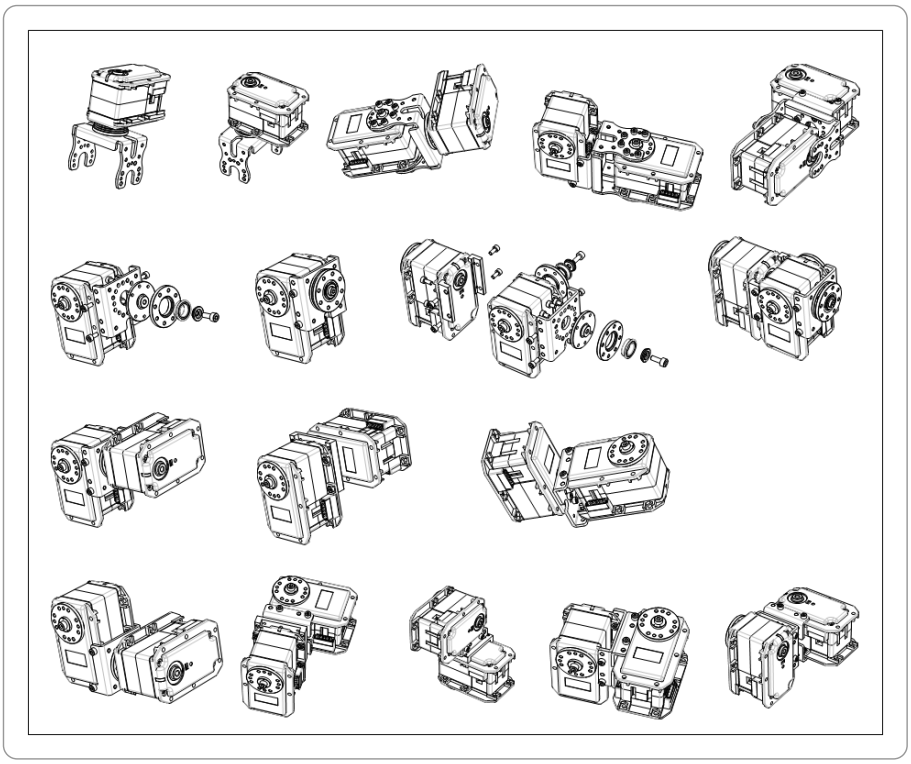
3. 2. Horns

- HN05-I102

- HN05-N101



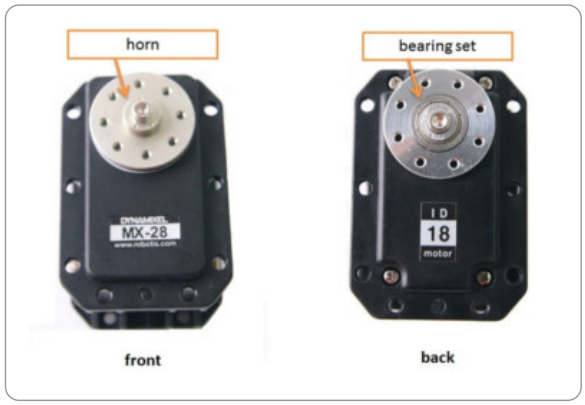
3. 3. Combination Structures



4. Maintenance

4. 1. Horn and Bearing Replacement

The horn is installed on the front wheel gear serration of the DYNAMIXEL whereas the bearing set is installed on the back.



4. 1. 1. Installing the Horn

Place the thrust horn washer into the actuator before inserting the horn. You must carefully align the horn to the wheel gear serration by aligning dots.

Once alignment is properly done, gently push the center of the horn toward the actuator. Make sure that the horn washer is in place as you tighten the bolt.

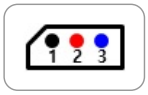
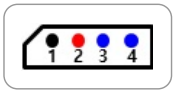
4. 1. 2. Installing the Bearing Set

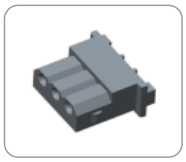
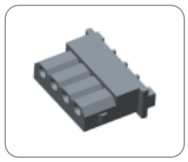
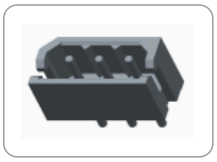
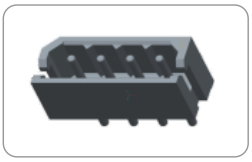
You may need to remove the bearing set from the previous actuator and reinstall it into the new actuator. The bearing set can also be purchased separately. As bearing set is rotating freely, therefore alignment is not required when assembling to DYNAMIXEL.

5. Reference

Note Compatibility Guide

5. 1. Connector Information

Item	TTL	RS-485
Pinout	1 GND 2 VDD 3 DATA	1 GND 2 VDD 3 DATA+ 4 DATA-
Diagram		

Item	TTL	RS-485
Housing	 MOLEX 50-37-5033	 MOLEX 50-37-5043
PCB Header	 MOLEX 22-03-5035	 MOLEX 22-03-5045
Crimp Terminal	MOLEX 80-70-1039	MOLEX 80-70-1039
Wire Gauge	21 AWG	21 AWG

5. 2. Videos

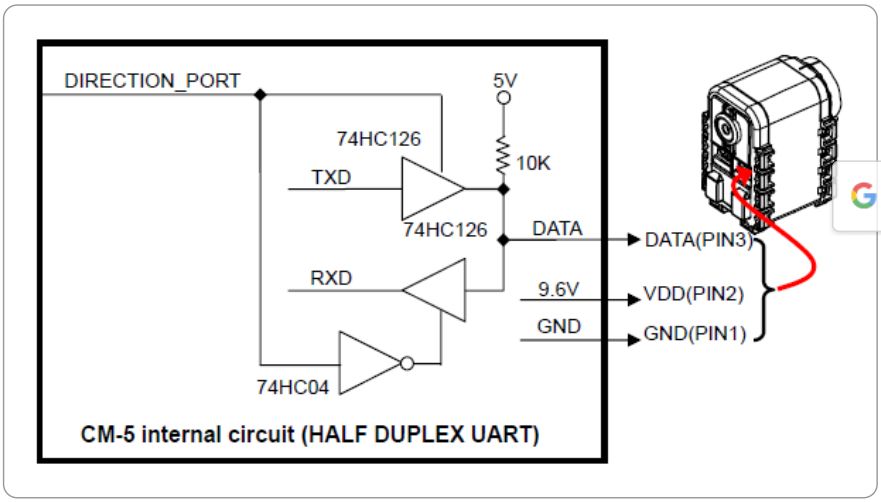
5. 3. Drawings

- Download MX-64AT_AR DWG
- Download MX-64AT_AR PDF
- Download MX-64AT_AR STEP
- Download MX-64T DWG
- Download MX-64T PDF
- Download MX-64T STEP
- Download MX-64T IGES
- Download MX-64R DWG
- Download MX-64R PDF
- Download MX-64R STEP
- Download MX-64R IGES

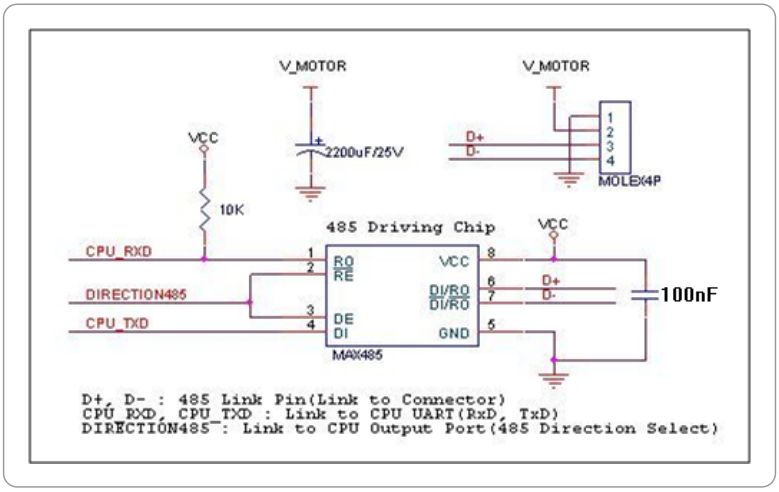
5. 4. Communication Circuit

To control the Dynamixel actuators, the main controller needs to convert its UART signals to the half duplex type. The recommended circuit diagram for this is shown below.

5. 4. 1. TTL Communication



5. 4. 2. RS-485 Communication



The power of Dynamixel is supplied via Pin1(-), Pin2(+).
(The above circuit is built into Dynamixel-only controller.)
In the above circuit diagram, the direction of data signal of TxD and RxD in the TTL Level is determined according to the level of DIRECTION 485 as follows:
In case of DIRECTION485 Level = High: The signal of TxD is output to D+ and D-
In case of DIRECTION485 Level = Low: The signal of D+ and D- is output to RxD