MODEL 2. HYDRAULIC SERVO SYSTEMS

2.1. Contents

- ✓ Introduction to a hydraulic servo system
- ✓ Analog modules: FX2N-2AD, FX2N-4DA
- ✓ The PID controller of PLC FX3U

2.2. Introduction to the hydraulic servo model

2.2.1 A general introduction of the experimental model

A general introduction of the experimental model is shown in Figure 2.1

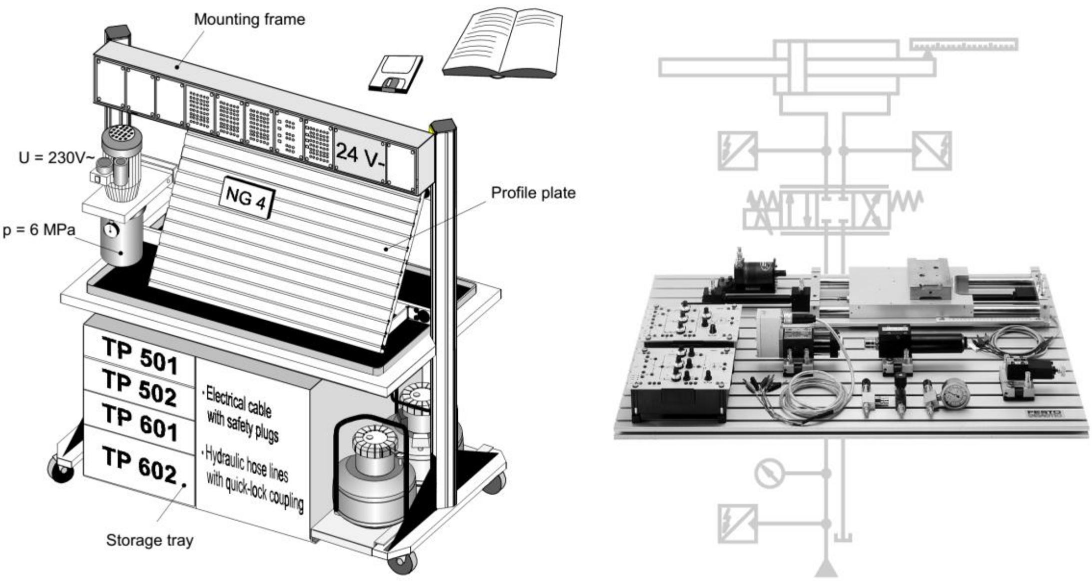


Fig 2.1: Mobile laboratory kit

2.2.2 Construction and Function of Linear Drive Module

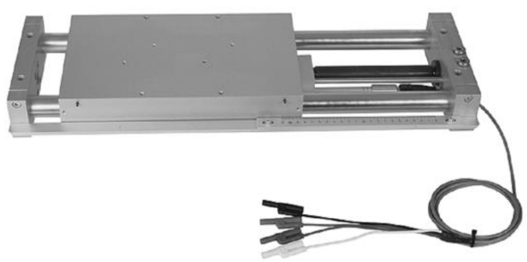


Fig 2.2: Linear hydraulic drive module

- ❖ **Construction of Linear Drive**

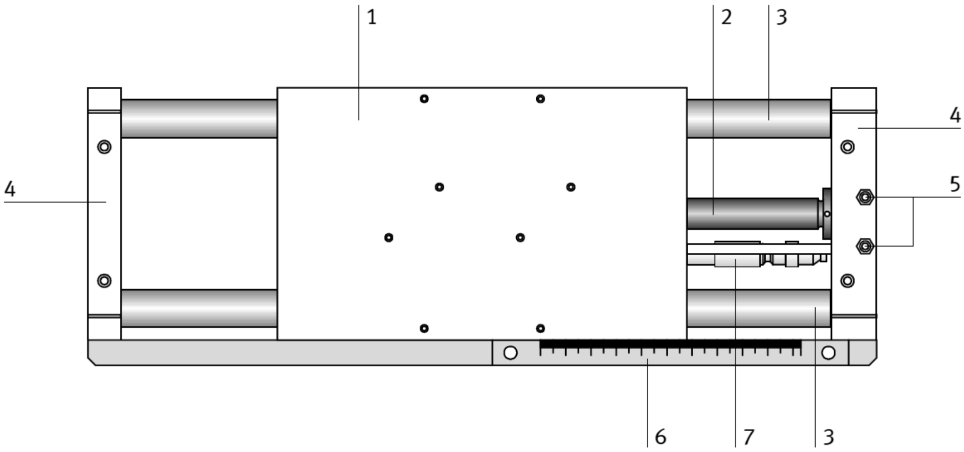


Fig 2.3: A diagram of linear hydraulic drive module

The linear drive (in Figure 2.3) consists of the following components:

(1) A slide

(2) A double-acting cylinder

(3) Two guiding rods

(4) Two yokes

(5) Two hydraulic quick connection couplings

(6) A scale

(7) Displacement encoder

❖ **Function of the Linear Drive:**

- ✓ The cylinder chambers are pressurized via the two hydraulic quick connection couplings.
- ✓ The chamber pressures and the effective piston surfaces produce a resulting force, which acts upon the slide.
- ✓ The traversing speed is determined by the prevailing oil flow rate, whereby the flow rates vary from the plain piston surface to the piston rod side.
- ✓ The slide is of low friction running on ball bearing guides.
- ✓ The displacement encoder has been fitted underneath the slide next to the hydraulic cylinder and is thus largely protected from damage.
- ✓ A scale has been attached to the mounting brackets for visual measurement of position.

- ✓ This can be adjusted slightly towards the mounting bracket.

❖ **Construction and connection of the displacement encoder**

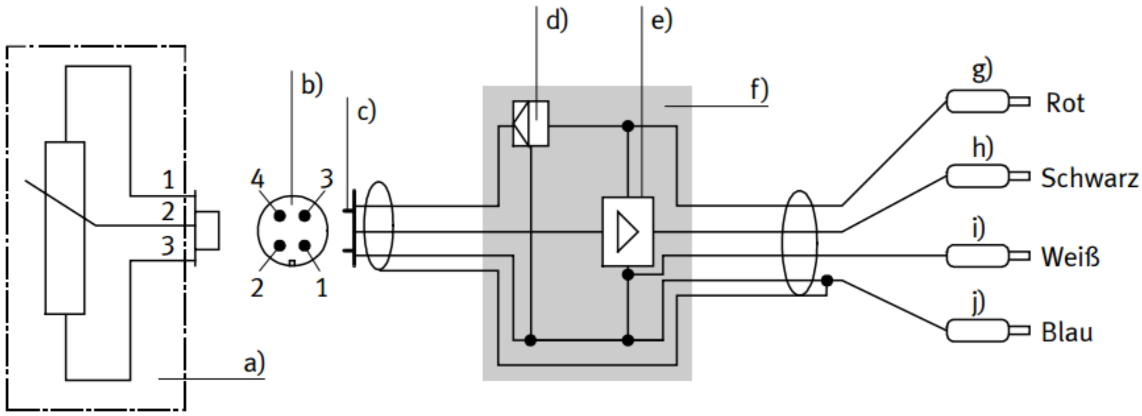


Fig 2.4: Construction and connection of the displacement encoder

a) Potentiometer	**f)** Housing
b) Pin assignment	**g)** Supply voltage
c) Plug	**h)** + Signal
d) Reference voltage source	**i)** – Signal
e) Impedance converter	**j)** Supply earth

Function of displacement encoder: The potentiometer is supplied with 10 V from a reference voltage source located in the supply line. The voltage tapped via the follower is proportional to the distance travelled by the connecting rod.

❖ **Technical data:**

Table 2.1: Technical data of hydraulic cylinder

Dimensions	
Length	625 mm
Width	200 mm
Stroke	200 mm
Slide size (Length x Width)	320 x 198 mm
Mounting holes in the yokes	M6

Useful load	
loads	maximum 50 kg

Displacement encoder, electrical	
Design	Potentiometer of 200 mm measured length, impedance converter and connecting cable
Supply voltage	+13 – +30 V
Output voltage	0 – 10 V
Linearity	±0,5 %
Mechanical stroke	204 mm
Maximum traversing speed	1.5 m/s
Operating temperature range	-40 – +150 °C
Protection class	IP 64

Drive unit	
Cylinder	16 x 10 x 200 mm
Area ratio	1 : 1.64
Medium	Mineral oil
Maximum operating pressure	12 MPa (120 bar)
Hydraulic connection	quick connection coupling
Drive force extending	2400 N
Drive force retracting	1450 N

2.2.3 Construction and Functions of Directional Control Valve

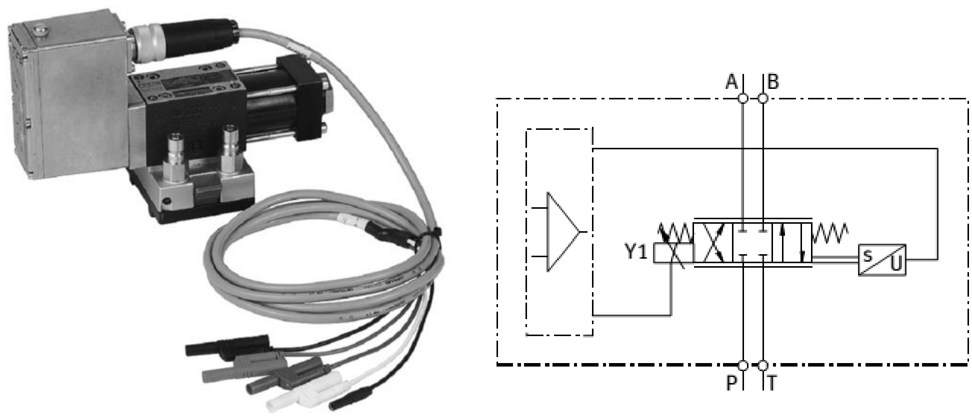
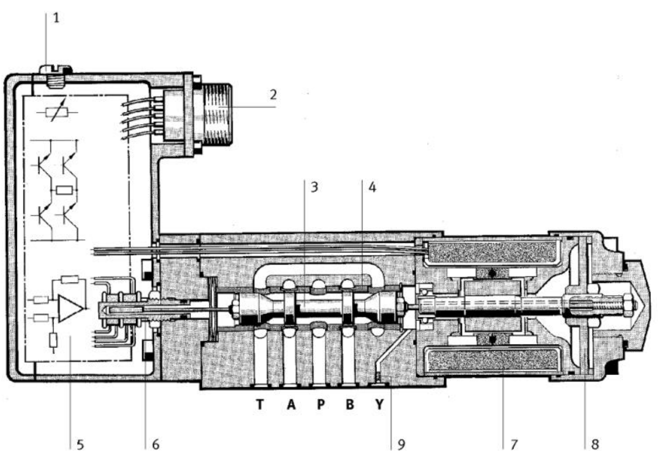


Fig 2.5: A 4 gate/3 position regulating valve

❖ **Construction of directional control valve**

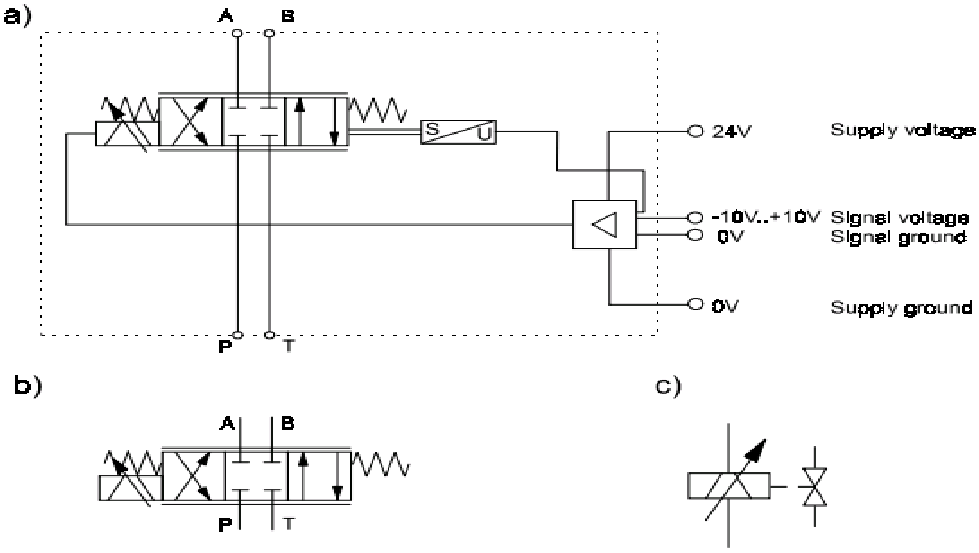
The directional control valve (shown in Figure 2.6) consists of the following components:



- Plug screw for zero setting (1)
- Extension plug (2)
- Control sleeve (3)
- Control socket (4)
- Integrated electronics (5)
- Position encoder (6)
- Linear motor (7)
- Reset spring (8)
- Plug (9)

Fig 2.6: Cross section of 4 gate /3 position regulating valve

❖ Function of Directional Control Valve



- An electrical control signal (in effect a control piston set-point position value, but subsequently referred to as a set-point volumetric flow rate value) is output to the integrated position controller, which drives the linear motor via the pulse-width modulated (PWM) driver electronics.
- The position encoder supplied via an oscillator measures the position of the control piston.
- This actual value signal is rectified via a demodulator, returned to the position controller and compared with the set-point value.
- The position controller now activates the linear motor until the set-point and actual value are the same, whereby the position of the control piston is proportional to the electrical input signal.
- The actual flow rate q is, however, not only dependent on this electrical input signal, but also critically depends on the pressure drop Δp at individual control edges.

❖ Construction of Linear Motor

The linear motor (shown in Figure 2.7) is constructed by the following components

- Cable through hole (1)
- Permanent magnets (2)
- Reset springs (3)

- Bearing (4)
- Coil (5)
- Armature (6)
- Plug screw (7)

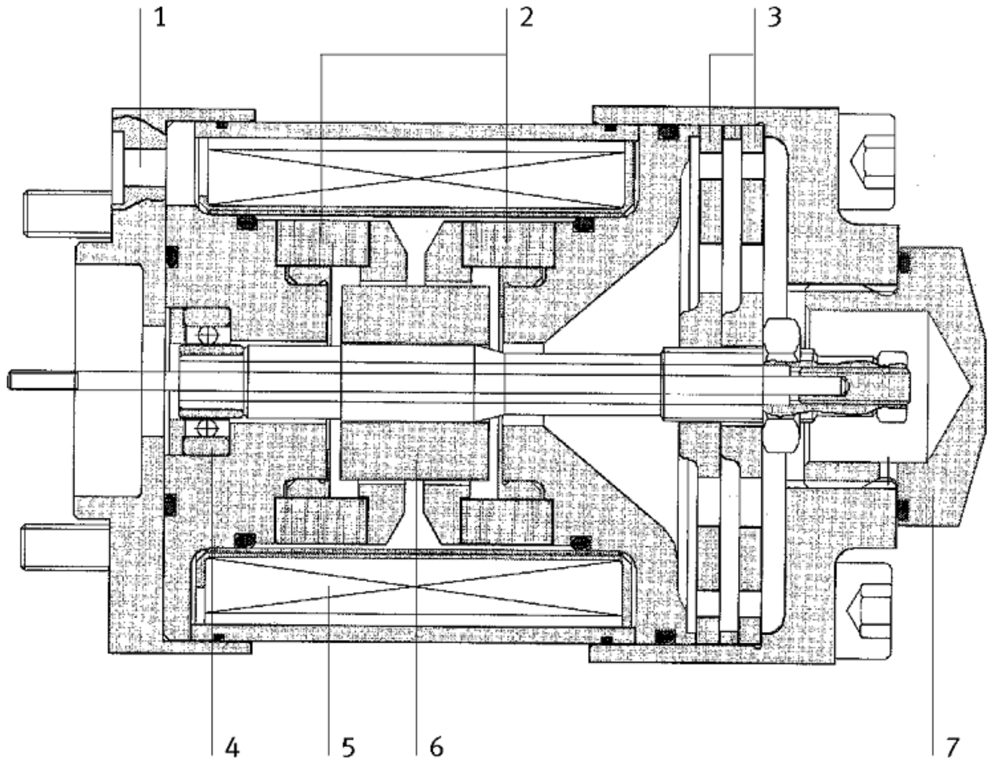


Fig 2.7: Linear motor

❖ Function of Linear Motor

- The linear motor is a differential motor energized via a permanent magnet.
- This means that part of the required magnetic force is already built-in.
- As a result of this, the current requirement of the linear motor is significantly less than that of comparable proportional magnets.
- The linear motor has a neutral mid-position and from this position is able to generate strokes and forces in both directions.
- These are proportional to the flow.
- Proportional solenoid systems, however require either two proportional solenoids with correspondingly complex wiring or operate unilaterally against a

spring, whereby a reliable spring setting can only be achieved by means of over-travelling a power port (A or B).

- This can lead to uncontrollable movements on the drive unit.
- The linear motor does not draw any current in the spring centered position (mid or out of trim position).
- The high spring rigidity and the resulting reset force is overcome when advancing from the mid-position as are external forces, in-creased frictional forces due to contamination of the piston spool).
- When returning in the direction of zero position, the spring force is combined with the motor force, i.e. maximum force is always available when the piston spool closes.

❖ **Static characteristics**

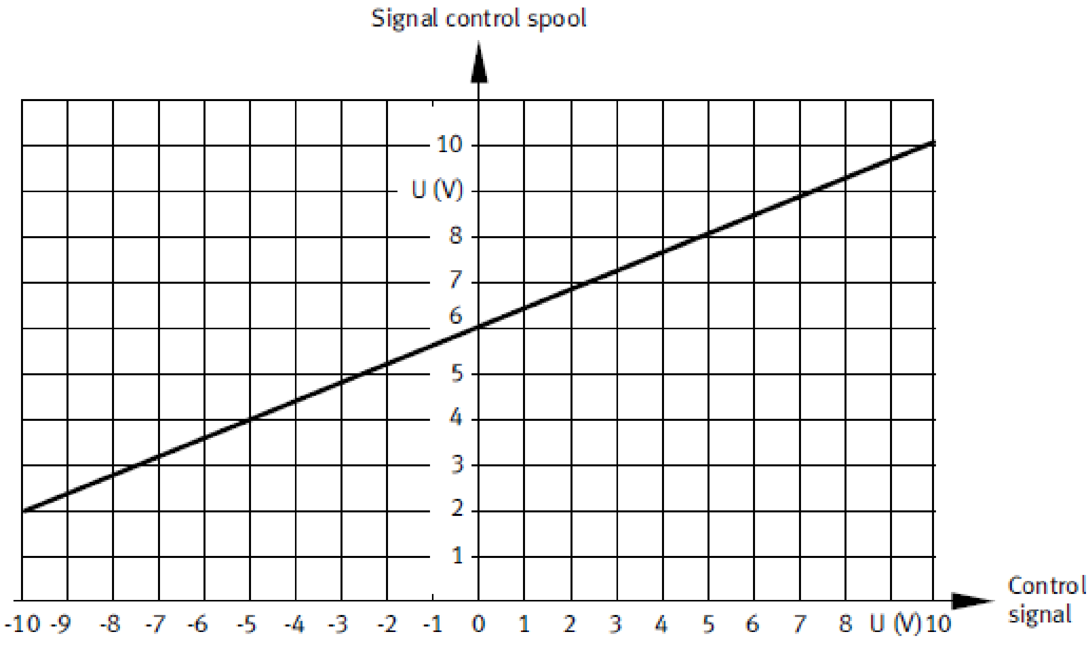


Fig 2.8: Control piston/signal characteristic curve

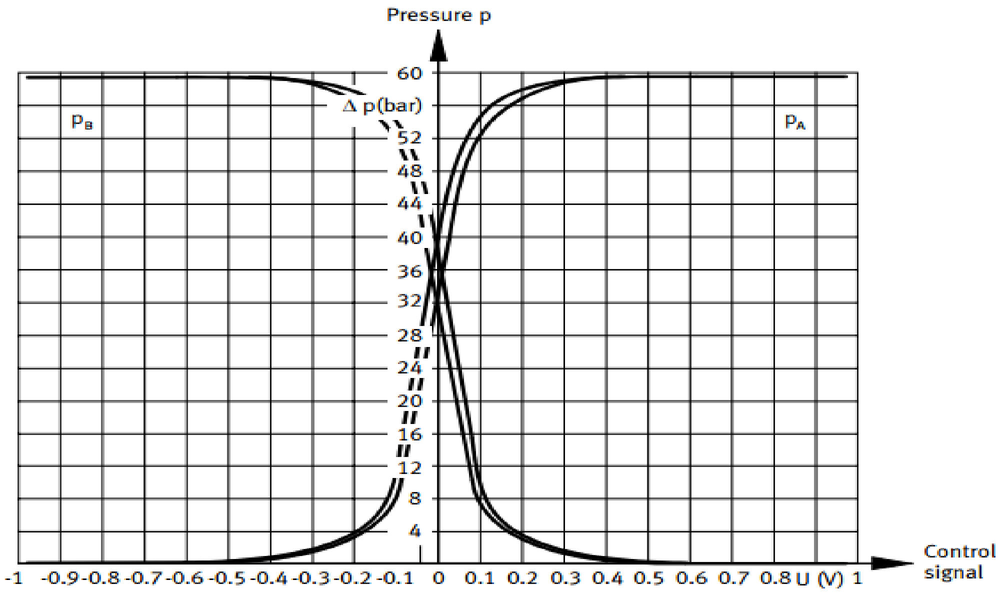


Fig 2.9: Pressure/signal characteristic curve

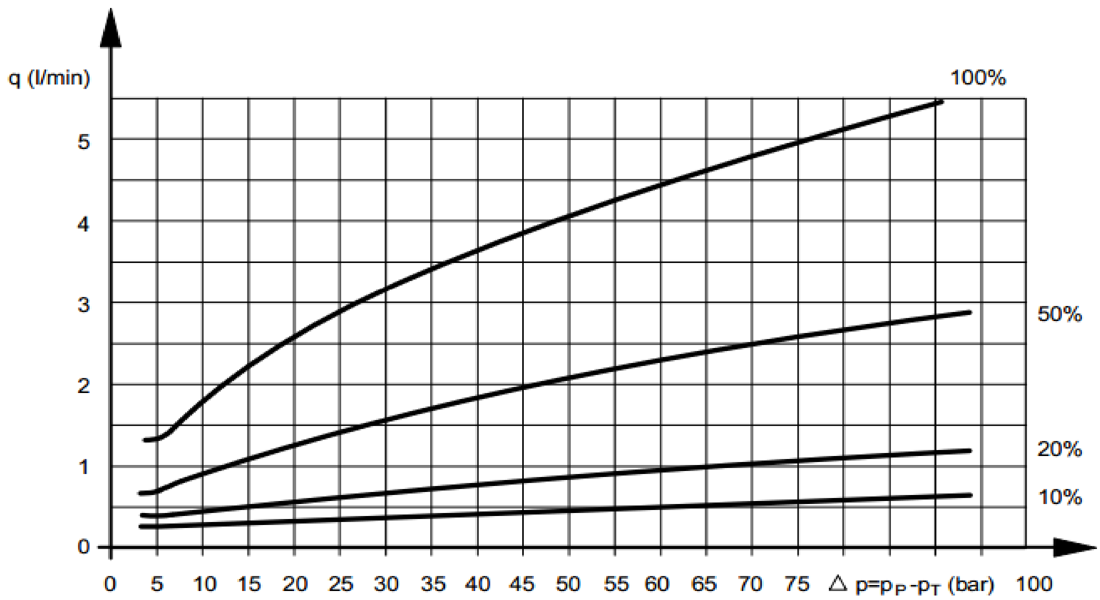


Fig 2.10: Flow rate/differential pressure characteristic curves

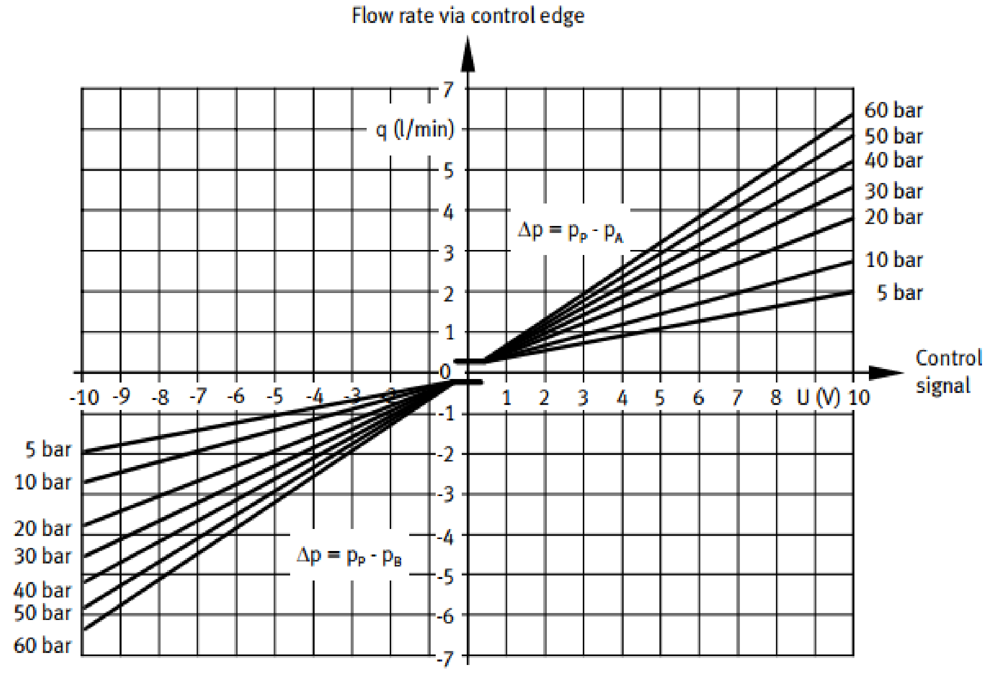


Fig 2.11: Flow rate/signal characteristic curves

❖ **Dynamic characteristics**

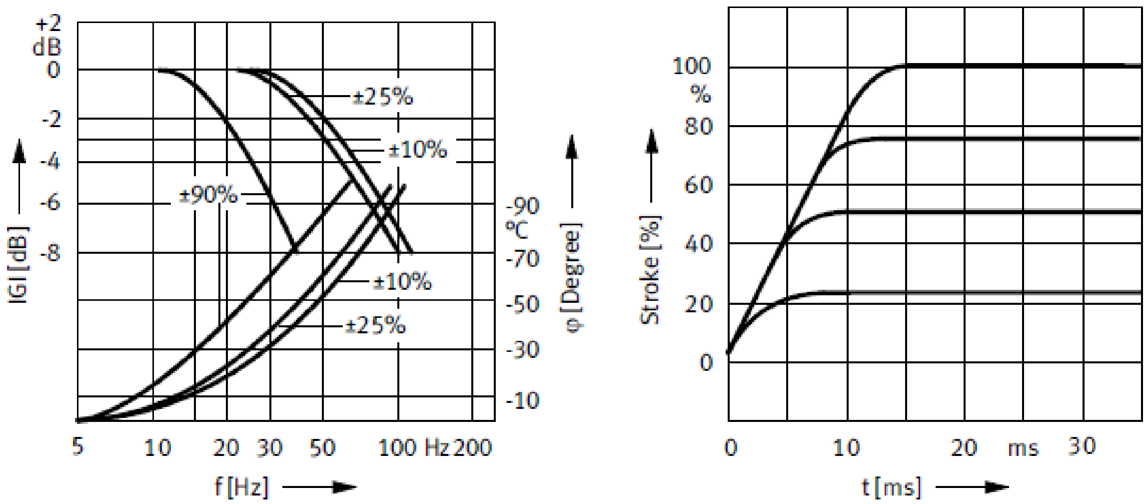


Fig 2.12: Dynamic characteristics of control valve

❖ Pin Assignments

Valve plug	Designation		Plug colour
A	Supply +	24 V	red
B	Supply –	0 V	blue
C			
D	Setpoint value +	0 – ±10 V	yellow
E	Setpoint value –	0 – ±10 V	green
F	Signal of control piston	4 – 20 mA	(coupling)

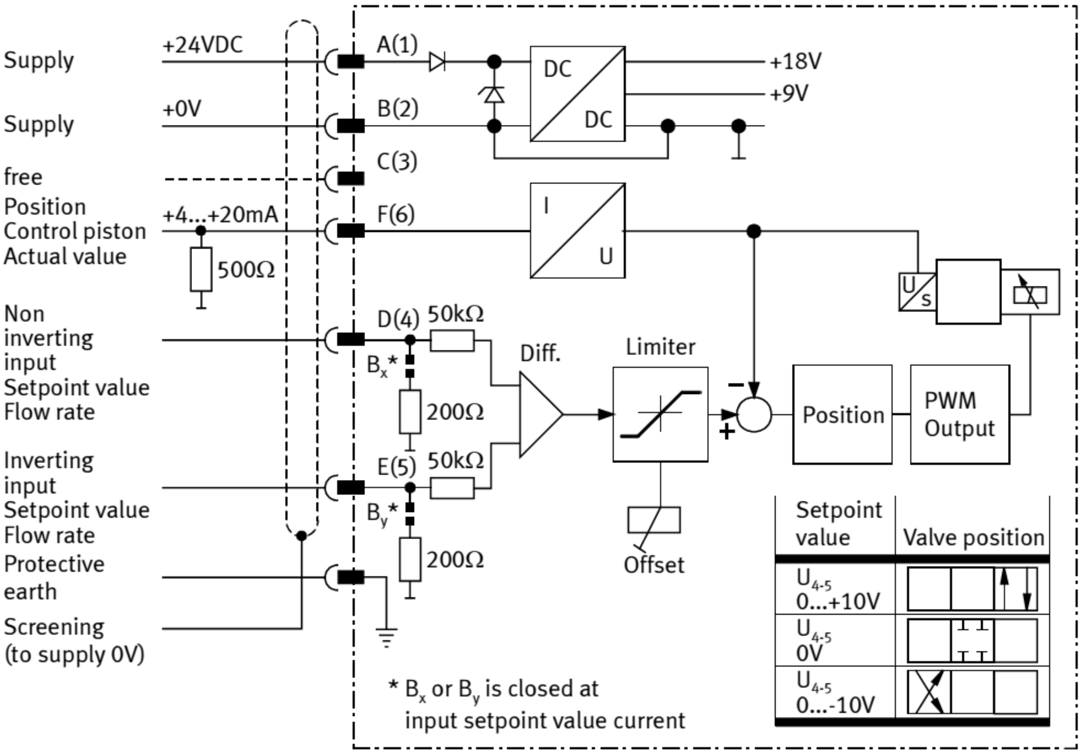


Fig 2.13: Pin assignments

3.2.4 Hydraulic power pack

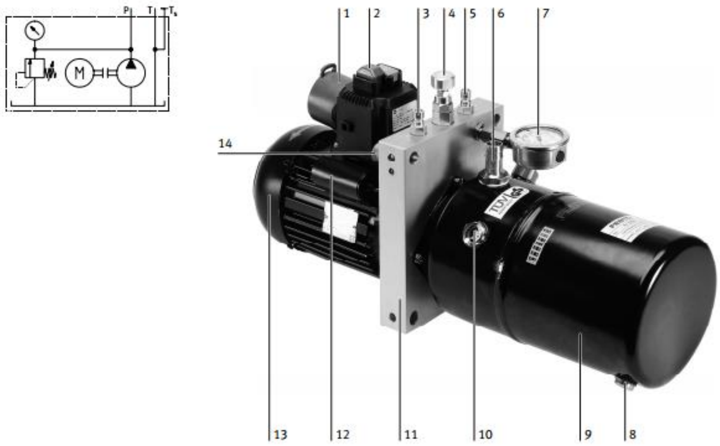


Fig 2.14: Hydraulic power pack

❖ **Design:**

(1) Power supply plug

(2) ON/OFF switch

(3) Tank connection T

(4) Pressure-relief valve

(5) Pressure port P

(6) Tank connection (blue) for reservoir

(7) Pressure gauge

(8) Drain screw

(9) Tank

(10) Sight glass for level indicator

(11) Flange

(12) Capacitor

(13) Electric motor

(14) Tank connection (blue) for discharge

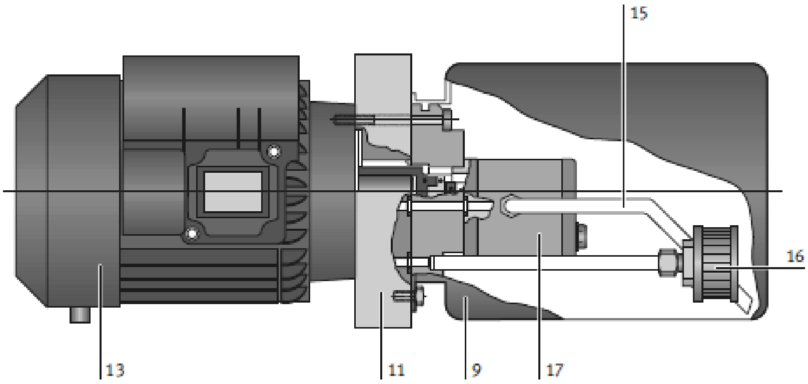


Fig 2.15: Construction and connection of the hydraulic power

- **Function**
  - The hydraulic power pack converts electrical energy into hydraulic drive power. The electric motor (13) drives a gear pump (17). The oil is fed from the tank (9) via the suction pipe (15) and applied at pressure port.
  - The pressure can be read from the pressure gauge (7). The pump delivers a virtually constant flow rate. The maximum pressure value is set by means of the pressure relief valve (4). This pressure can only be maintained up to the maximum delivery rate of the pump.
  - If the connected hydraulic circuit requires a higher flow rate, the pressure will fail. The pressure prevailing at this point adapts itself to the flow resistance of the connected circuit, whereby the flow rate e.g. on a pump by-pass circuit, return at low pressure.
  - The return flow is affected via the tank connection T (3) through the return filter (16) into the tank (9). A blue quick coupling socket (14) has been provided for the return flow from the pressure reservoir. The filling level can be read from the sight glass (10). The return flow from the discharge measurement tank is routed through connection (6).

❖ Technical data

Table 2.2: Technical data of the hydraulic power pack

Electrical	**152962**	**159328**	**539004**
Motor	AC current, single-phase, convection-cooled		
Nominal power rating	650 W	550 W	650 W
Nominal voltage	230 V	110 V	230 V
Nominal current	3.1 A	8.4 A	3.1 A
Frequency	50 Hz	60 Hz	60 Hz
Nominal speed	1320 rpm	1680 rpm	1650 rpm
Protection class	IP20		
Duty cycle	50%		
Actuation	Manual via ON/OFF switch		
Connection	Power supply plug to DIN 49441/CEE7 with additional earthing system.	Power supply plug to NEMA 5-15P	Power supply plug to NEMA 6-20P

Hydraulic	**152962**	**159328**	**539004**
Medium	Mineral oil, recommended viscosity 22 cSt (mm^2/s)		
Pump design	External gear pump		
Volumetric delivery rate	1.6 cm^3	1.6 cm^3	1.6 cm^3
Delivery rate at nominal speed	2.2 l/min	2.7 l/min	2.7 l/min
Operating pressure	0.5 – 6 MPa (5 – 60 bar)		
Setting	Manual		
Pressure gauge Indicating range	0 – 10 MPa (0 – 100 bar)		
Pressure gauge accuracy class	1.6		
Oil tank capacity	approx. 5 l		
Return filter, grade of filtration	90 µm		
Connections	One quick coupling socket for P and T, one coupling for tank line of reservoir (order no. 152859), one connection for discharge measurement tank (order no. 535816)		

2.3. FX2N-2AD

2.3.1 Introduction to FX2N-2AD

The FX2N-2AD is used to convert the analog input of two points (voltage and current input) into a digital value of 12 bits, and to forward the values to a PLC. FX2N-2AD can connected to the FX0N, FX1N, FX2N, FX3G, FX3GC, FX3U and the FX3UC series.

- The analog input is selected from the voltage or current input by the method of connecting wires.

- The analog to digital conversion characteristics can be adjusted

- The FX3U/FX3UC series PLC can use direct specification of buffer memory.

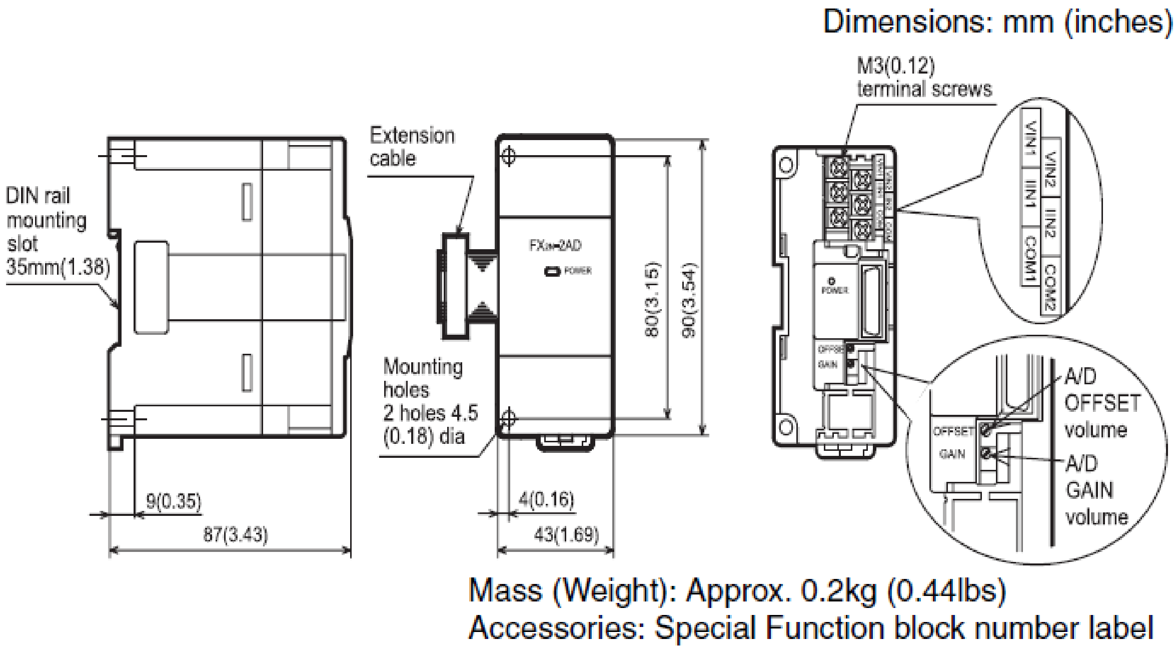


Fig 2.16: External dimensions and parts

2.3.2 Hardware connection

❖ **FX2N-2AD wiring**

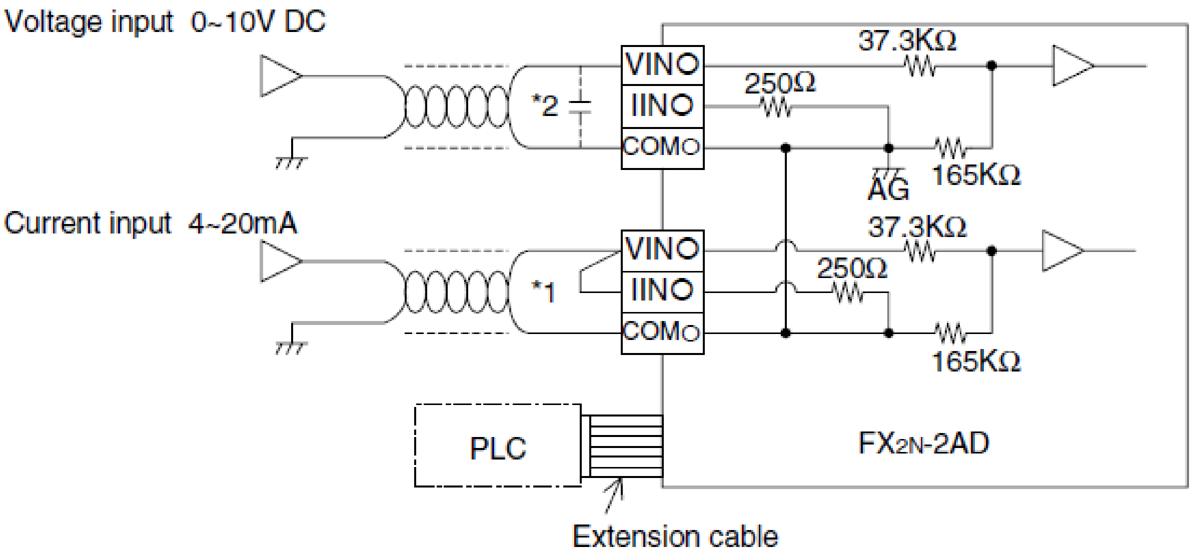


Fig 2.17: Wiring of FX2N-2AD

1:** The FX2N-2AD cannot have 1 channel as an analog voltage input and the other as current input because both channels use the same offset and gain values. ***For current input please short circuit VIN and IIN as shown in the diagram.

***2:** Connect a 0.1 to 0.47 µF 25V DC capacitor with the position of *2 when there is voltage ripple in the voltage input or there will be a lot of noise.

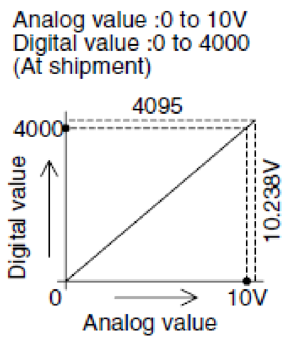
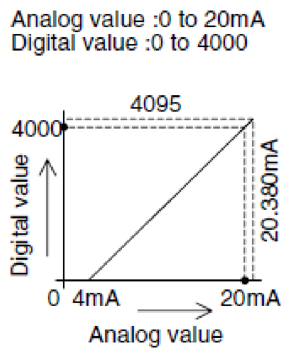
❖ **Connection with the PLC**

1) The FX2N-2AD and main unit (PLC) are connected by a cable on the right of the main unit.

2) Up to 4 FX2N-2AD units can connect to the FX0N series PLC, up to 5 for FX1N, up to 8 for FX2N/FX3G/FX3GC/FX3U/FX3UC or, up to 4 for the FX2NC series PLC, all with powered extension units.

However, the limitation exists for some special cases (refer the datasheet for more details)

2.3.3 Defining gain and offset

Item	Voltage input	Current input
Range of analog input	At shipping, the unit is adjusted to a digital range of 0 to 4000 for an analog voltage input of 0 to 10V DC. When using an FX2N-2AD for current or differing voltage inputs except 0 to 10V DC, it is necessary to adjust the offset and gain.	
	0 to 10V DC, 0 to 5V DC (input resistance 200KΩ) Warning-this unit may be damaged by an input voltage in excess of -0.5V, +15V DC	4 to 20mA (input resistance 250Ω) Warning-this unit may be damaged by an input current in excess of -2mA, +60mA
Digital output	12bit	
Resolution	2.5mV:10V/4000(At shipment) Change depending on the input characteristic.	4μA: (20-4)A/4000 Change depending on the input characteristic.
Integrated accuracy	±0.1V	±0.16mA
Processing time	2.5ms/1 channel (synchronized to the sequence program)	
Input characteristics		
	The input characteristic is the same for each channel.	

2.3.4 Allocation of Buffer Memory (BFM)

BFM number	b15 to b8	b7 to b4	b3	b2	b1	b0
#0	Reserved	Current value of input data (lower 8bit data)				
#1	Reserved		Current value of input data (higher 4bit data)			
#2 to 16	Reserved					
#17	Reserved				Analog to digital conversion beginning	Analog to digital conversion channel
#18 or more	Reserved					

BFM#0: The current value of the input data for the channel specified with BFM#17 (lower 8bit data) is stored.

BFM#1: The current value of the input data (higher 4bit data) is stored.

BFM#17: b0 to specify the Channel (CH1, CH2)

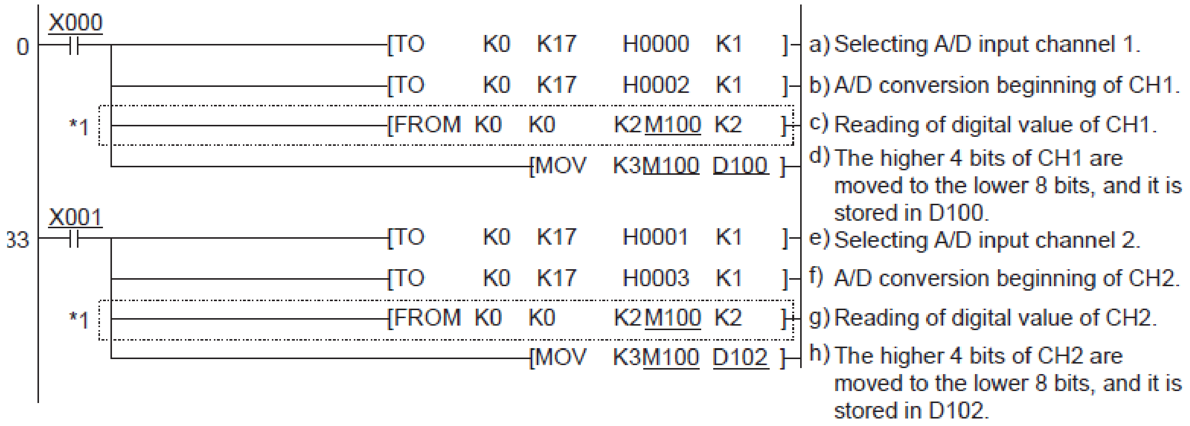
b0 = 0: CH1

b0 = 1: CH2

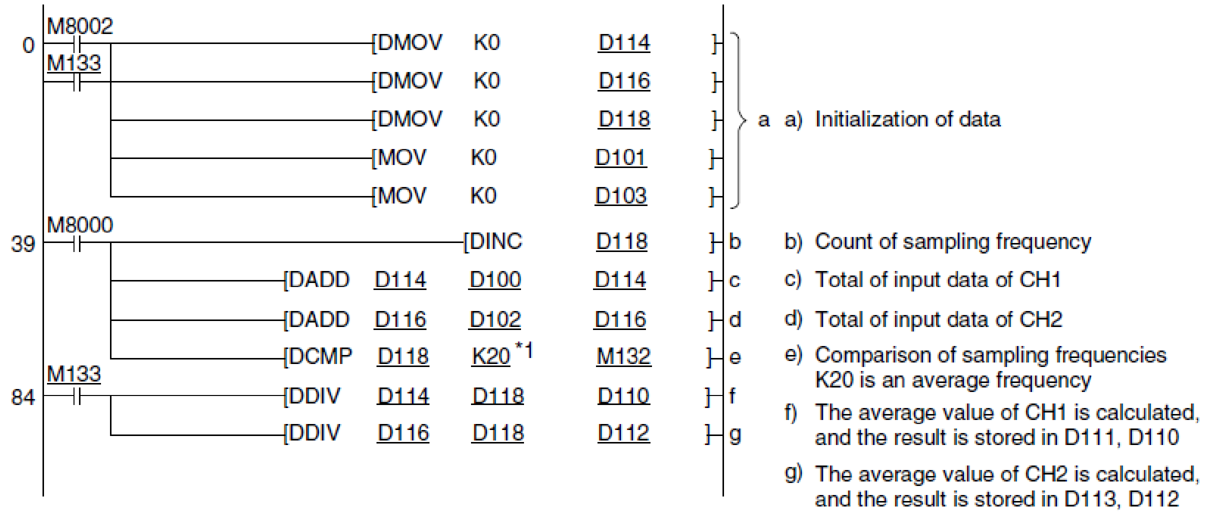
b1: 0→1 The A/D conversion process is started.

2.3.5 Example of programming analog input

Example 1: Reading analog values from 2 channels



Example 2: Normally, the values reading directly from analog input are unstable. Therefore, you should use the average value data instead.



2.4. FX2N-4DA

2.4.1 Introduction to FX2N-4DA

The FX2N-4DA analog special function block has 4 output channels. It has maximum resolution of 12 bits.

- ✓ The selection of voltage or current based input/output is by user wiring. Analog ranges of -10 to 10V DC (resolution: 5mV), and/or 0 to 20mA (resolution: 20mA) maybe selected independently for each channel.
- ✓ Data transfer between the FX2N-4DA and the main unit (PLC) is by buffer memory exchange. There are 32 buffer memories (each of 16 bits) in the FX2N-4DA.

- ✓ The FX2N-4DA occupies 8 points of I/O on the FX2N expansion bus. The 8 points can be allocated from either inputs or outputs. The FX2N-4DA draws 30mA from the 5V rail of the FX2N main unit or powered extension unit.

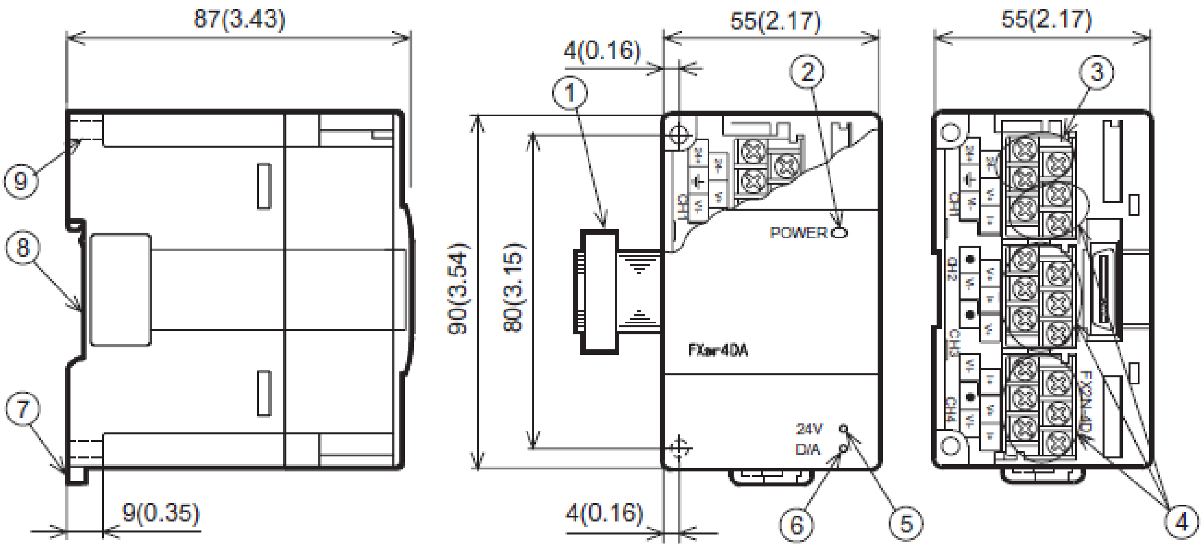


Fig 2.18: External dimensions and parts of FX2N-4DA

2.4.2 Hardware connection

❖ **FX2N-4DA wiring**

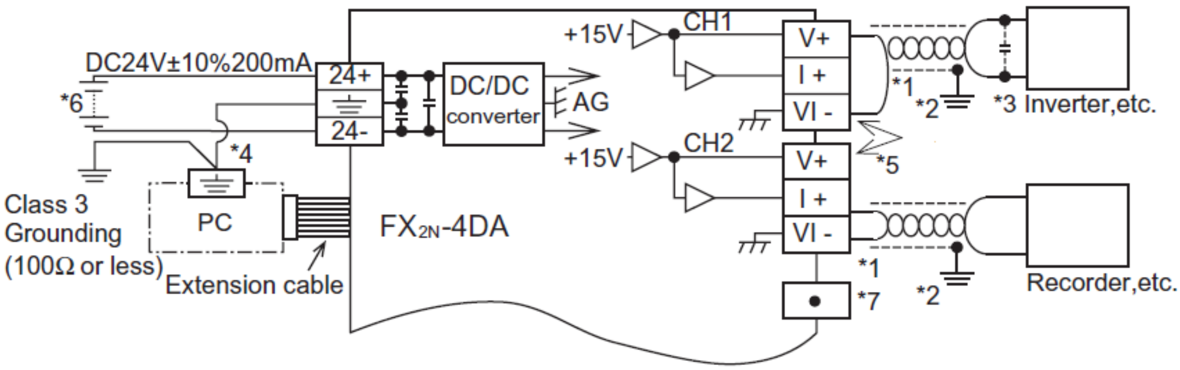


Fig 2.19: Wiring of FX2N-4DA

***1**: Use a twisted pair shielded cable for the analog output. This cable should be wired away from power lines or any other lines which could induce noise.

***2**: Apply 1-point grounding at the load side of the output cable.

***3**: If electrical noise or a voltage ripple exists at the output, connect a smoothing capacitor of 0.1 to 0.47mF, 25V.

***4**: Connect the terminal on the FX2N-4DA with the terminal on the PLC.

***5**: Shorting the voltage output terminal or connecting the current output load to the voltage output terminal may damage the FX2N-4DA.

***6**: The 24V DC service power of the programmable controller can also be used.

***7**: Do not connect any unit to the unused terminal

❖ **Connection with the PLC**

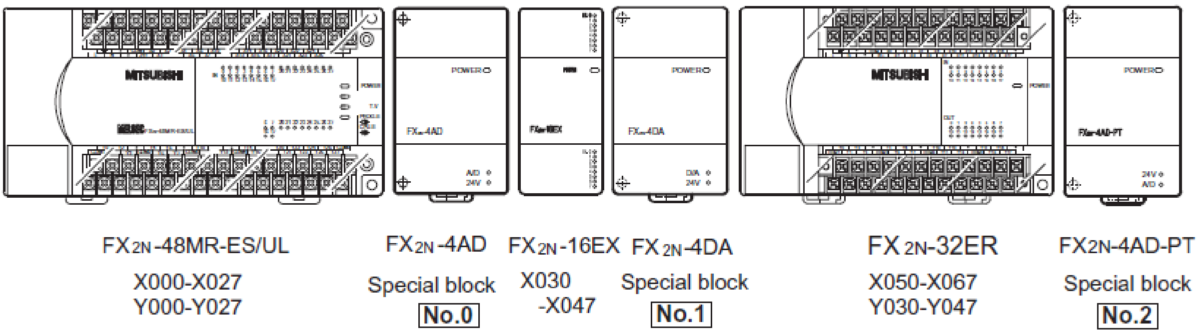
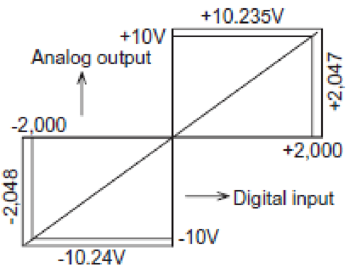
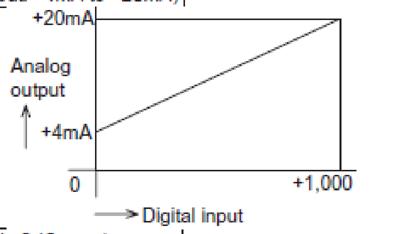
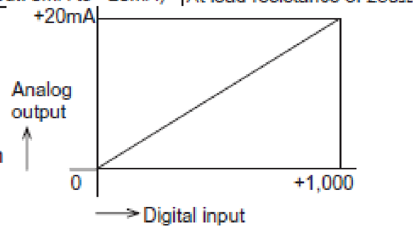


Fig 2.20: The layout of hardware connection

Various special blocks controlled by the FROM/TO commands, such as the analog input blocks high-speed counter blocks, etc. can be connected to the programmable controller (MPU), or connected to the right side of the other extension blocks or units. ***Up to eight special blocks*** can be connected to a single MPU in the numeric order of ***No. 0 to No. 7***.

2.4.3 Specifications

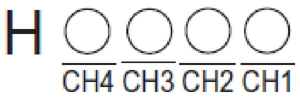
Item	Voltage output	Current output
Analog output range	-10V DC to +10V DC (External load resistance: 2kΩ to 1MΩ).	DC 0mA to +20mA (External load resistance: 500Ω).
Digital input	16 bits, binary, with sign (Effective bits for numeric value: 11 bits and sign bit (1 bit))	
Resolution	5mV (10V × 1/2000)	20µA (20mA × 1/1000)
Total accuracy	±1% (at full scale of +10V)	±1% (at full scale of +20mA)
Conversion speed	2.1ms for 4 channels (Change in the number of channels used will not change the conversion speed.)	
Isolation	Photo-coupler isolation between analog and digital circuits. DC/DC converter isolation of power from FX2N main unit. No isolation between analog channels.	
External power supply	24V DC ±10% 200mA	
Number of occupied I/O points	8 points taken from the FX2N expansion bus (can be either inputs or outputs)	
Power consumption	5V, 30mA (Internal power supply from MPU or powered extension unit)	
I/O characteristics (Default: mode 0) Follow the procedure described in section 8 to change	Mode 0 (Voltage output: -10V to +10V) At load resistance of 10kΩ  Command sent from the programmable controller can change the mode. The voltage/current output mode selected will determine the output terminals used.	Mode 1 (Current output: +4mA to +20mA) At load resistance of 250Ω  Mode 2 (Current output: 0mA to +20mA) At load resistance of 250Ω 

2.4.4 Allocation of Buffer Memory (BFM)

Data is transmitted between the FX2N-4DA and the MPU via buffer memories (16-bit 32-point RAM). Buffer memories marked "W" can be written to using the T0 instruction in the MPU. The status of BFM #0, #5, and #21, (marked E) will be written to EEPROM, therefore the set values will be retained even after turning off the power.

BFM		Description
W	#0 E	Output mode select. Factory setting H0000
	#1	Output data (Signed 16 bits binary: actual value 11 bits + sign) #1: CH1, #2: CH2, #3: CH3, #4: CH4
	#2	
	#3	
	#4	
	#5 E	Data holding mode. Factory setting H0000
#6, #7		Reserved

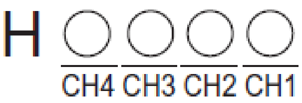
[BFM #0] Output mode select: The value of BFM #0 switches the analog output between voltage and current on each channel. It takes the form of a 4 digits hexadecimal number. The first digit will be the command for channel 1 (CH1), and the second digit for channel 2 (CH2) etc. The numeric values of these four digits respectively represent the following items:



O = 0:Sets the voltage output mode (-10 V to +10 V).
O = 1:Sets the current output mode (+4 mA to 20 mA).
O = 2:Sets the current output mode (0 mA to +20 mA).

[BFM #1, #2, #3 and #4] Output data channels CH1, CH2, CH3, and CH4 respectively. Initial values of all channels are 0.

[BFM #5] Data holding mode: While the programmable controller is in the STOP mode, the last output value in the RUN mode will be held. To reset the value to the offset value, write the hexadecimal value in BFM #5 as follows:



O = 0: Holds the output.
O = 1: Resets to the offset value.

Example: H0011 ······ CH1 and CH2 = Offset value CH3 and CH4 = Output holding

Please refer to the datasheet for the other BFMs [BFM #8…#31] in case you want to change the gain/offset of the module.

2.4.5 Operation and program examples

If the factory-set I/O characteristics are not changed and the status information is not used, you can operate the FX2N-4DA using the following simple program.

- ✓ CH1 and CH2: Voltage output mode (-10 V to +10 V)
- ✓ CH3: Current output mode (+4 mA to +20 mA)
- ✓ CH4: Current output mode (0 mA to +20 mA)

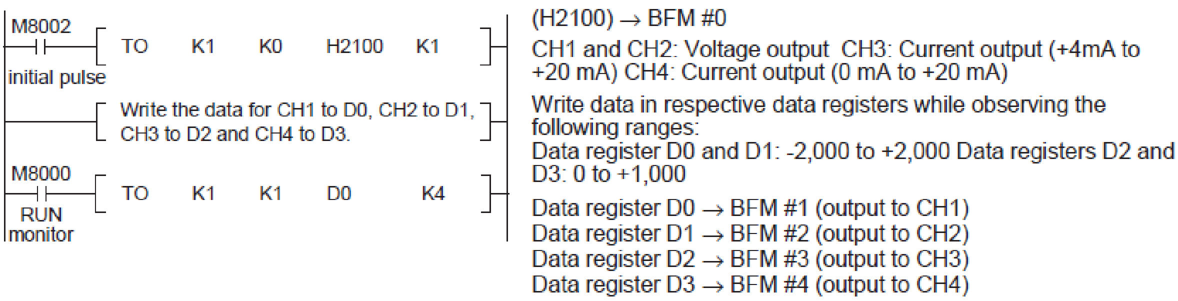


Fig 2.21: Code example using TO command

2.5. PID INSTRUCTION (FNC88)

2.5.1 Introduction

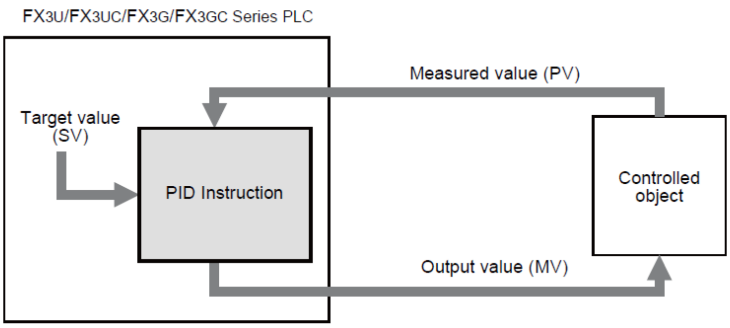
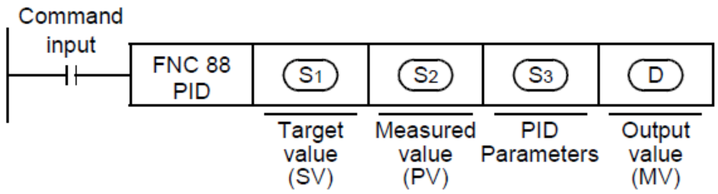


Fig 2.22: Operation diagram of PID instruction

16-bit PID operation

Once the target value S1, measured value S2 and PID parameters S3 to S3 + 6 are set and the program is executed, the operation result (MV) is transferred to the output value D at every sampling time. The sampling time is specified by S3



Set item		Description
S1	Target value (SV)	• Set the target value (SV). • PID instruction does not change the contents of setting. • Caution on using the auto tuning (limit cycle method) If the target value for auto tuning is different from the target value for PID control, it is necessary to set a value including the bias value first, and then store the actual target value when the auto tuning flag turns OFF.
S2	Measured value (PV)	This is the input value in PID control loop.
S3	Parameter*1	1) Auto tuning: In the case of limit cycle method Twenty-nine devices are occupied from the head device specified in S3. 2) Auto tuning: In the case of step response method a) Operation setting (ACT): When bits 1, 2 and 5 are not all "0" Twenty-five devices are occupied from the head device specified in S3. b) Operation setting (ACT): When bits 1, 2 and 5 are all "0" Twenty devices are occupied from the head device specified in S3.
D	Output value (MV)	1) In case of PID control (normal processing) Before driving PID instruction, the user should set the initial output value. After that, the operation result is stored. 2) Auto tuning: In the case of limit cycle method During auto tuning, the ULV or LLV value is output automatically. When auto tuning is finished, the specified MV value is set. 3) Auto tuning: In the case of step response method Before driving PID instruction, the user should set the initial output value. During auto tuning, PID instruction does not change the MV output.

2.5.2 Parameters

Set item			Setting	Remarks
S3	Sampling time (TS)		1 to 32767 (ms)	It cannot be shorter than operation cycle of the PLC.
S3 +1	Operation setting (ACT)	bit0	0: Forward operation 1: Backward operation	Operation direction
		bit1	0: Input variation alarm is invalid. 1: Input variation alarm is valid.	
		bit2	0: Output variation alarm is invalid. 1: Output variation alarm is valid.	Do not set to ON bit 2 and bit 5 at same time.
		bit3	Not available	
		bit4	0: Auto-tuning is not executed. 1: Auto-tuning is executed.	
		bit5	0: Upper and lower limits of output value are not valid. 1: Upper and lower limits of output value are valid.	Do not set to ON bit 2 and bit 5 at same time.
		bit6	0: Step response method 1: Limit cycle method	Select auto-tuning mode.
		bit7 to bit15	Not available	

S3 +2	Input filter constant (α)	0 to 99 (%)	When "0" is set, input filter is not provided.
S3 +3	Proportional gain (KP)	1 to 32767 (%)	
S3 +4	Integral time (TI)	0 to 32767 (× 100 ms)	When "0" is set, it is handled as "∞" (no integration).
S3 +5	Differential gain (KD)	0 to 100 (%)	When "0" is set, differential gain is not provided.
S3 +6	Differential time (TD)	0 to 32767 (× 10 ms)	When "0" is set, differential is not executed.
S3 +7 : S3 +19	These devices are occupied for internal processing of PID operation. Do not change data.		

Set item		Setting	Remarks
S3 +20*1	Input variation (incremental) alarm set value	0 to 32767	It is valid when operation direction (ACT) (bit 1 of S3 +1) is "1".
S3 +21*1	Input variation (decremental) alarm set value	0 to 32767	It is valid when operation direction (ACT) (bit 1 of S3 +1) is "1".
S3 +22*1	Output variation (incremental) alarm set value	0 to 32767	It is valid when operation direction (ACT) (bit 2 of S3 +1) is "1" or (ACT) (bit 5 of S3 +1) is "0".
	Output upper limit set value	–32768 to 32767	It is valid when operation direction (ACT) (bit 2 of S3 +1) is "0" or (ACT) (bit 5 of S3 +1) is "1"
S3 +23*1	Output variation (decremental) alarm set value	0 to 32767	It is valid when operation direction (ACT) (bit 2 of S3 +1) is "1" or (ACT) (bit 5 of S3 +1) is "0"
	Output lower limit set value	–32768 to 32767	It is valid when operation direction (ACT) (bit 2 of S3 +1) is "0" or (ACT) (bit 5 of S3 +1) is "1"

S3 +24 [*1]	Alarm output	bit0	0: Input variation (incremental) is not exceeded. 1: Input variation (incremental) is exceeded.	It is valid when operation direction (ACT) (bit 1 or bit 2 of S3 +1) is "1".
		bit1	0: Input variation (decremental) is not exceeded. 1: Input variation (decremental) is exceeded.	
		bit2	0: Output variation (incremental) is not exceeded. 1: Output variation (incremental) is exceeded.	
		bit3	0: Output variation (decremental) is not exceeded. 1: Output variation (decremental) is exceeded.	
The setting below is required when the limit cycle method is used (when the operation direction (ACT) b6 is set to ON).				
S3 +25	PV value threshold (hysteresis) width (SHPV)		Set it according to measured value (PV) fluctuation.	They are occupied when operation direction (ACT) (bit 6) is "ON (limit cycle method)."
S3 +26	Output value upper limit (ULV)		Set maximum value (ULV) of output value (MV).	
S3 +27	Output value lower limit (LLV)		Set minimum value (LLV) of output value (MV).	
S3 +28	Wait setting from end of tuning cycle to start of PID control (KW)		−50 to 32717%	

2.6. Experiment

2.6.1 The controller block diagram

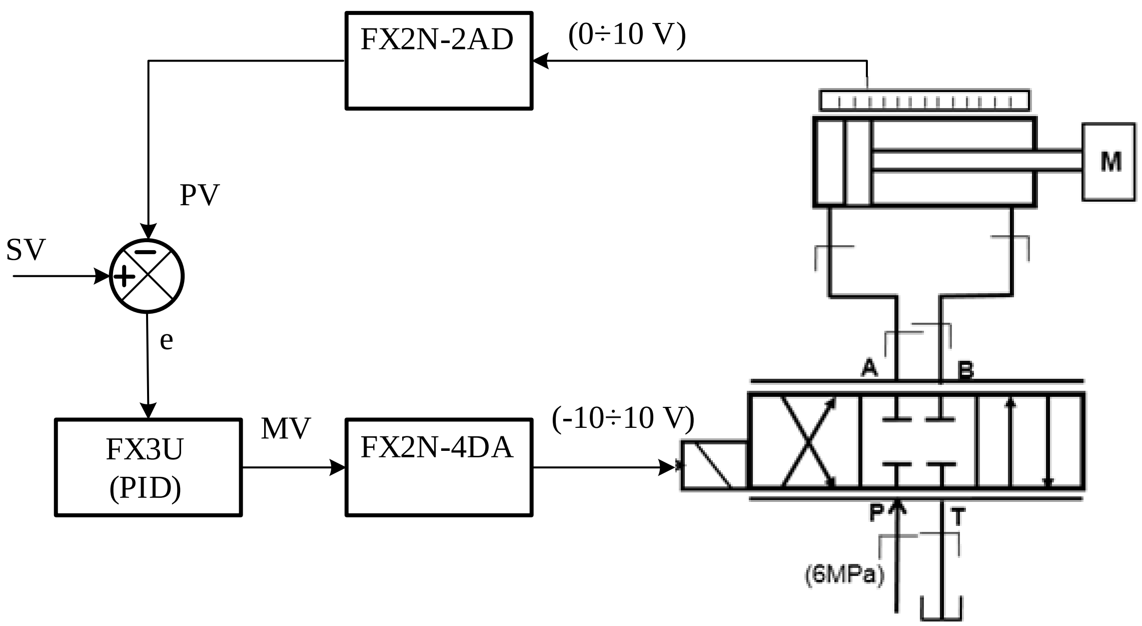
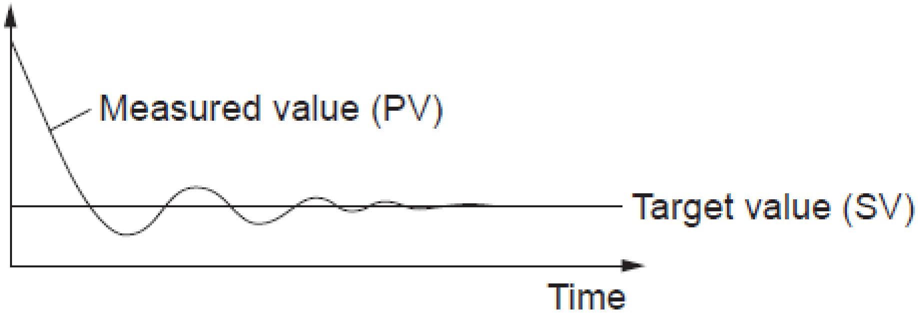


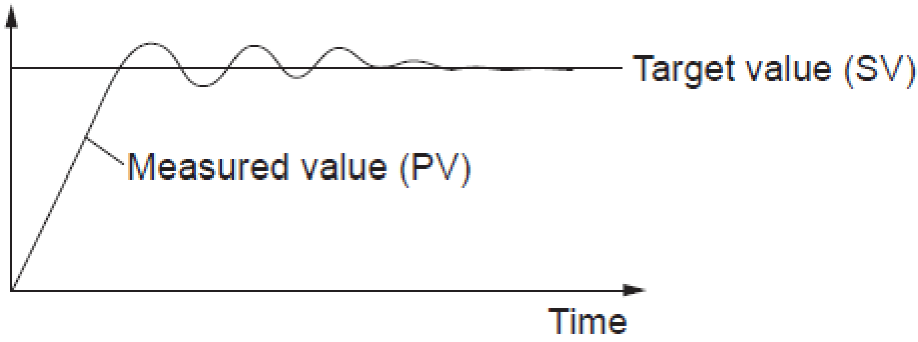
Fig 2.21: The block diagram of the control system

2.6.2 Operation settings

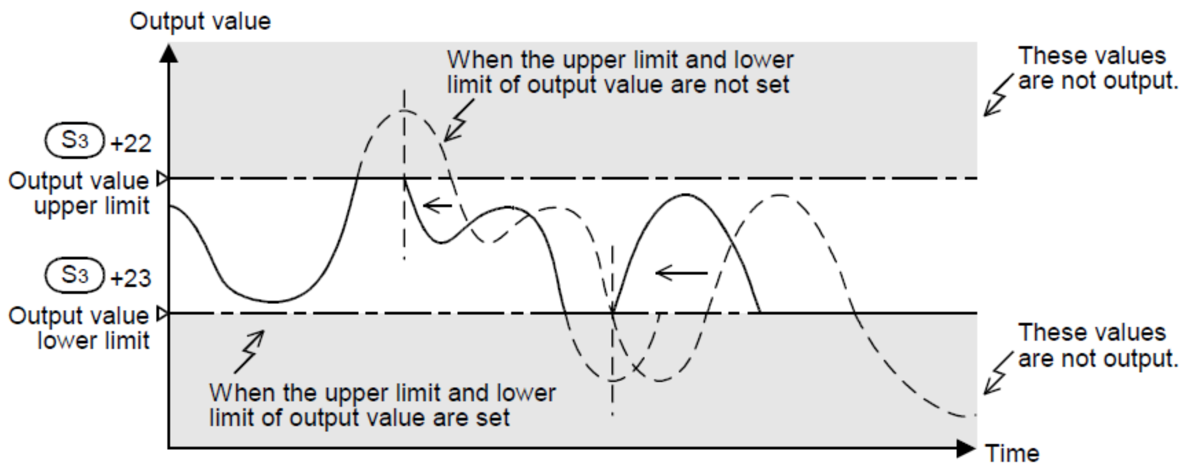
- **Forward operation: S3+1 bit 0 = 0**



- **Backward operation: S3+1 bit 0 = 1**



- **Upper and lower limit for output value: S3 +1 bit 5 = 1 (ON)**



- **Proportional gain (Kp): S3+3 (setting range: 1 – 32767)**
- **Integral time (Ti): S3+4 (0 – 32767) × 100 (ms) ("0" is considered as ∞, no integral)**
- **Differential time (Td): S3+6 (0 – 32767) × 10 (ms)**

2.6.3 Auto-tuning

This section describes the auto-tuning function of PID instruction. The auto-tuning function will automatically set the important constants, such as the proportional gain and the integral time, to ensure optimum PID control. There are two auto-tuning methods: ***limit cycle method and step response method.***

These following parameters will be set after auto-tuning mode:

Parameter	Setting position
Proportional gain (K_P)	(S3) +3
Integral time (T_I)	(S3) +4
Differential time (T_D)	(S3) +6

Step response method

In this method, by giving stepped output from 0 to 100% (0 to 75% or 0 to 50%) to the control system, three constants in the PID control are obtained from the operation characteristics (maximum ramp (R) and dead time (L)) and the input value variation.

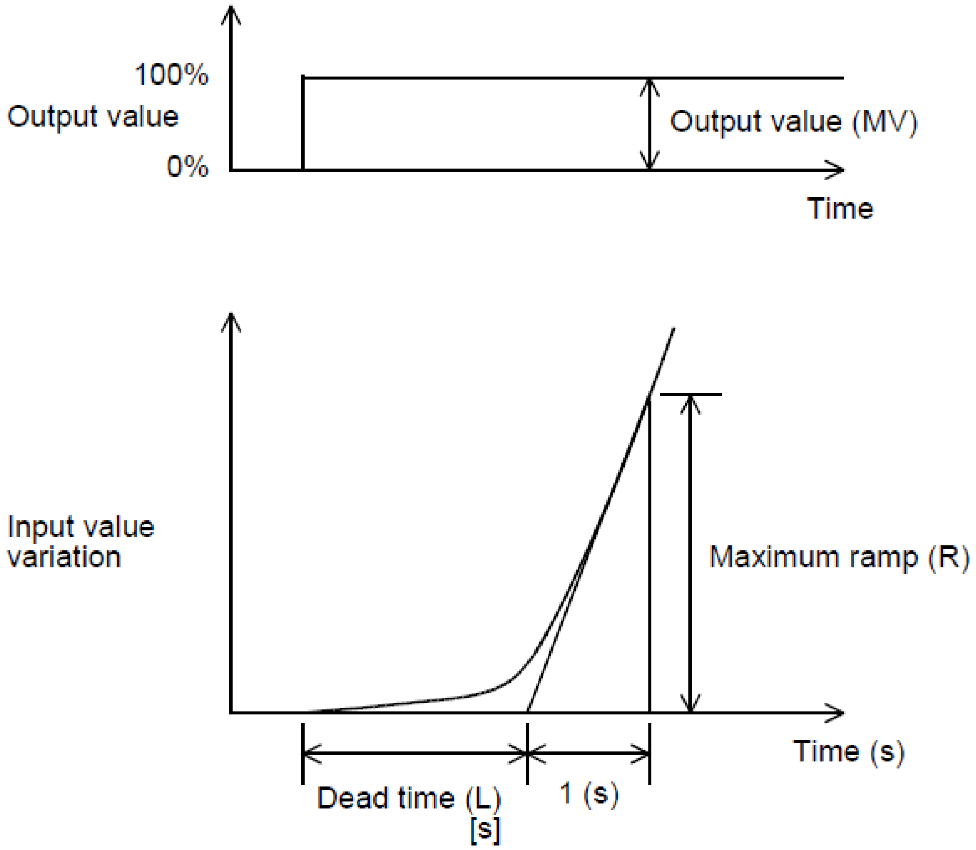


Fig 2.22: Step response method

Operation characteristics and three constants

Control type	Proportional gain (KP) [%]	Integral time (TI) [×100ms]	Differential time (TD) [×10ms]
Only proportional control (P operation)	$\frac{1}{RL} \times \frac{\text{Output value}}{\text{(MV)}} \times 100$	—	—
PI control (PI operation)	$\frac{0.9}{RL} \times \frac{\text{Output value}}{\text{(MV)}} \times 100$	33 L	—
PID control (PID operation)	$\frac{1.2}{RL} \times \frac{\text{Output value}}{\text{(MV)}} \times 100$	20 L	50 L

Auto tuning procedure:

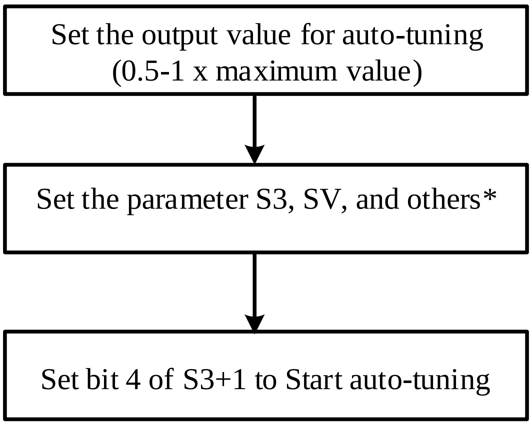
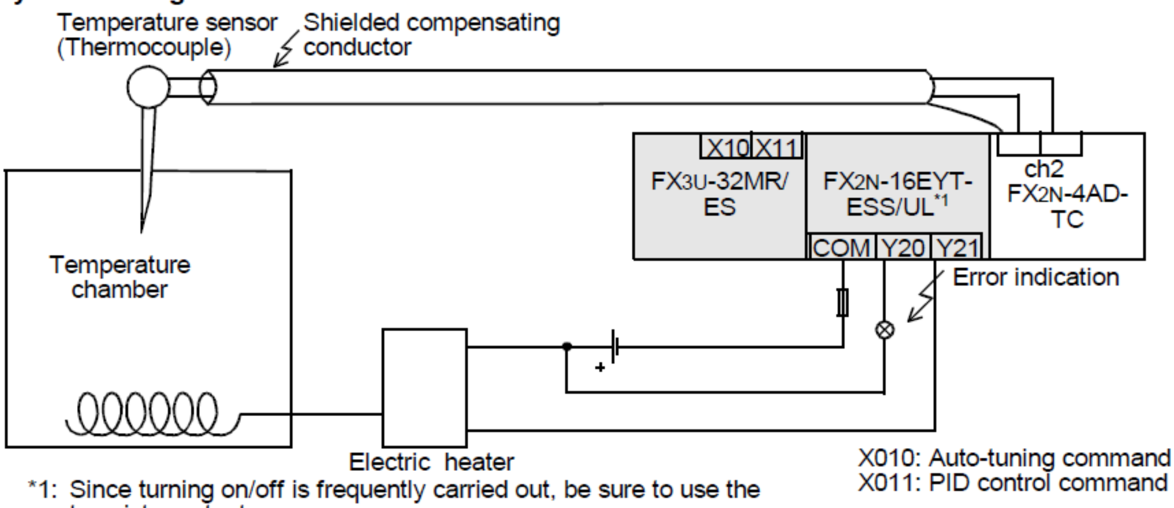


Fig 2.23: Auto tuning procedure of step response method

Set item and parameter		Remarks
Target value (SV)	S1	The difference from the measured value (PV) should be 150 or more. (For the details, refer to "2. Cautions on setting" below.)
Sampling time (TS)	S3	1,000 ms or more (For the details, refer to "2. Cautions on setting" below.)
Input filter (α)	S3 +2	
Differential gain (KD)	S3 +5	When setting the input filter, set the differential gain to "0" usually.
Others		Set other items, as necessary.

Example: A temperature control system

System configuration



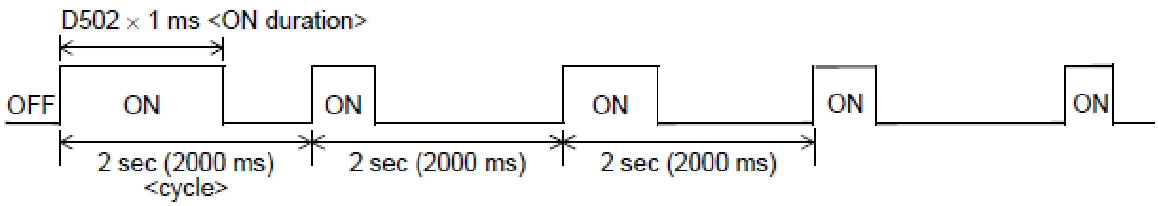
*1: Since turning on/off is frequently carried out, be sure to use the transistor outputs.

Setting contents

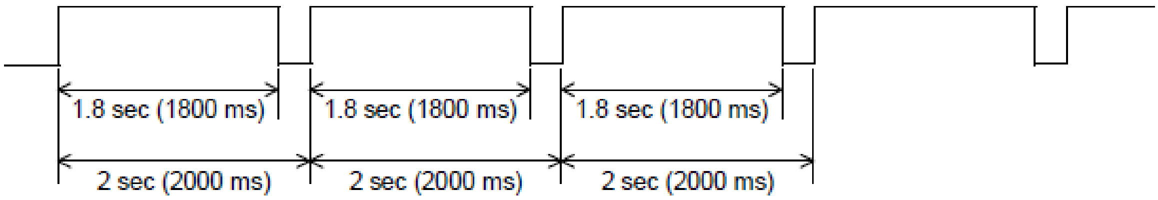
Item				During auto-tuning	During PID control
Target value			S1	500 (+50°C)	500 (+50°C)
Parameters	Sampling time (T_S)		S3	3000 ms	500 ms
	Input filter (α)		S3 +2	70%	70%
	Differential gain (K_D)		S3 +5	0%	0%
	Output value upper limit		S3 +22	2000 (2 seconds)	2000
	Output value lower limit		S3 +23	0	0
	Operation direction (ACT)	Input variation alarm	bit 1 of S3 +1	Not provided	Not provided
		Output variation alarm	bit 2 of S3 +1	Not provided	Not provided
		Output value upper/lower limit setting	bit 5 of S3 +1	Provided	Provided
Output value			D	1800	According to operation

Operation of the electric heater

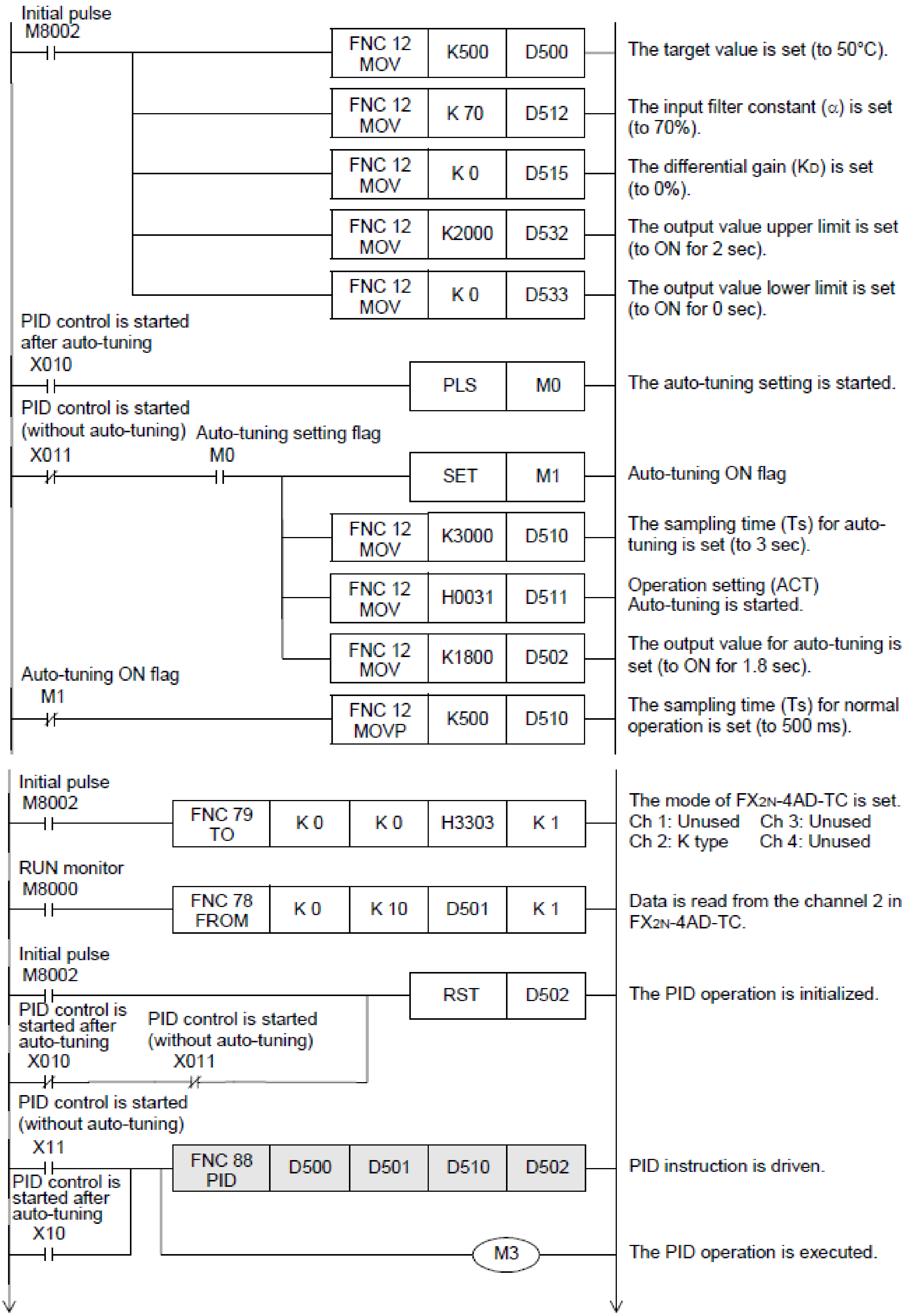
1) During PID control

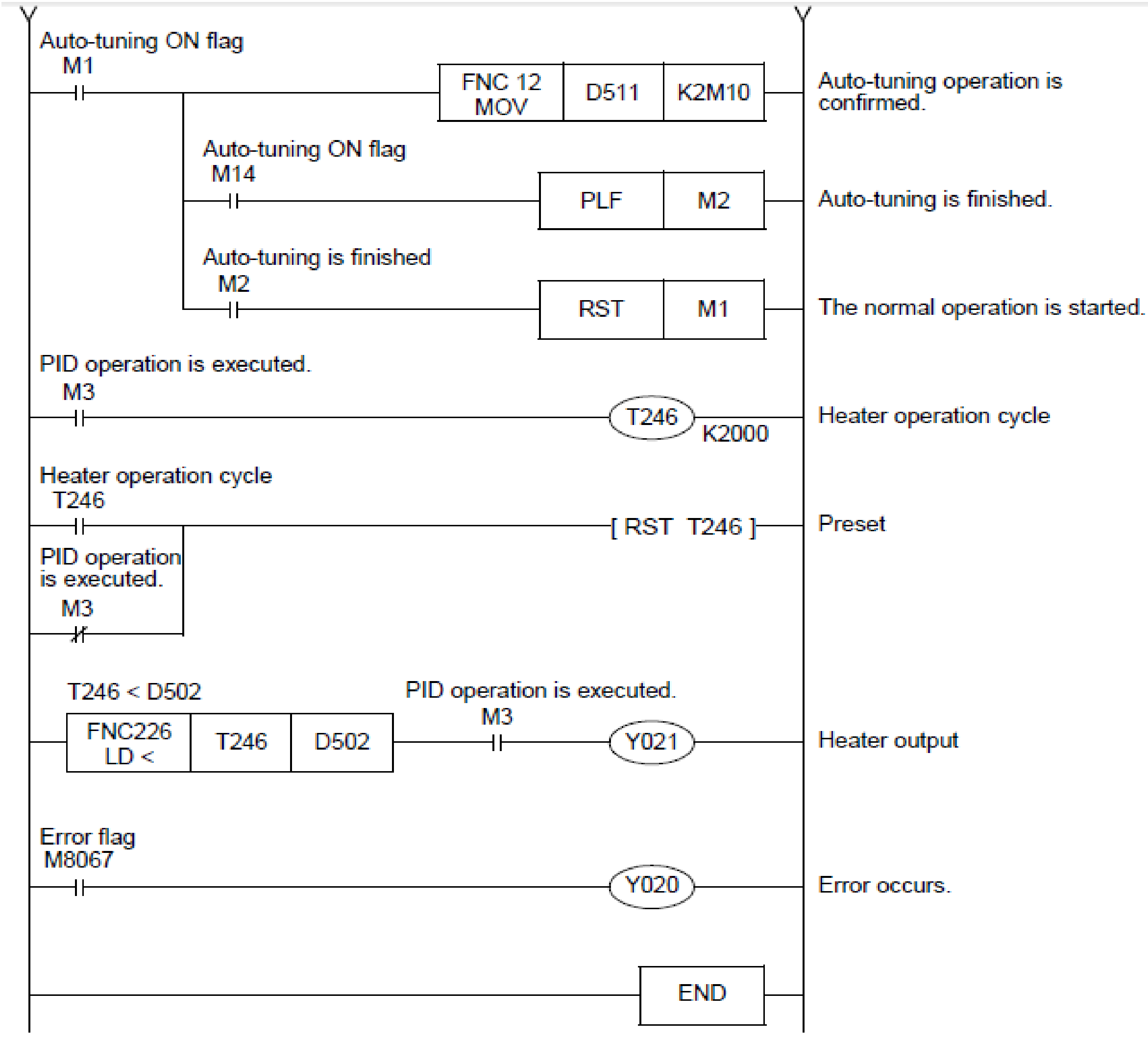


2) During auto-tuning: When the output is 90% of the maximum output



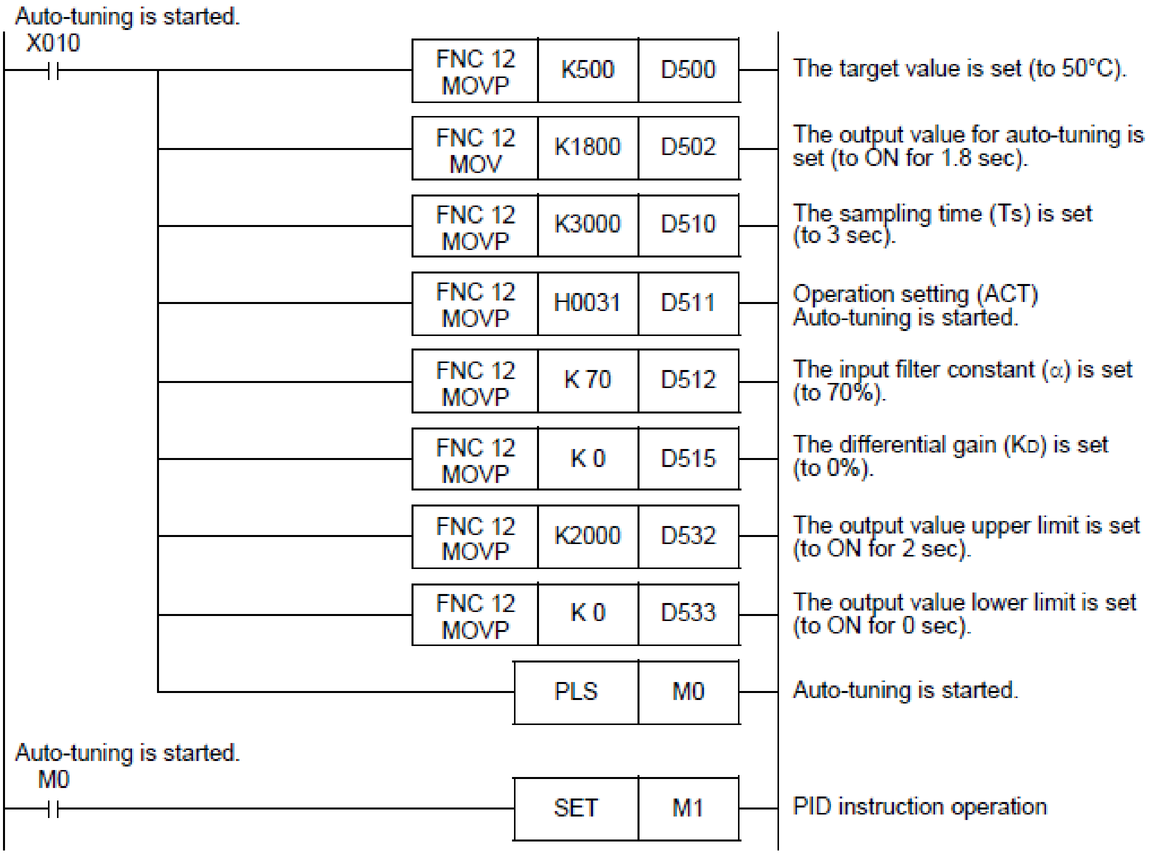
Program example of auto-tuning (step response method) and PID control

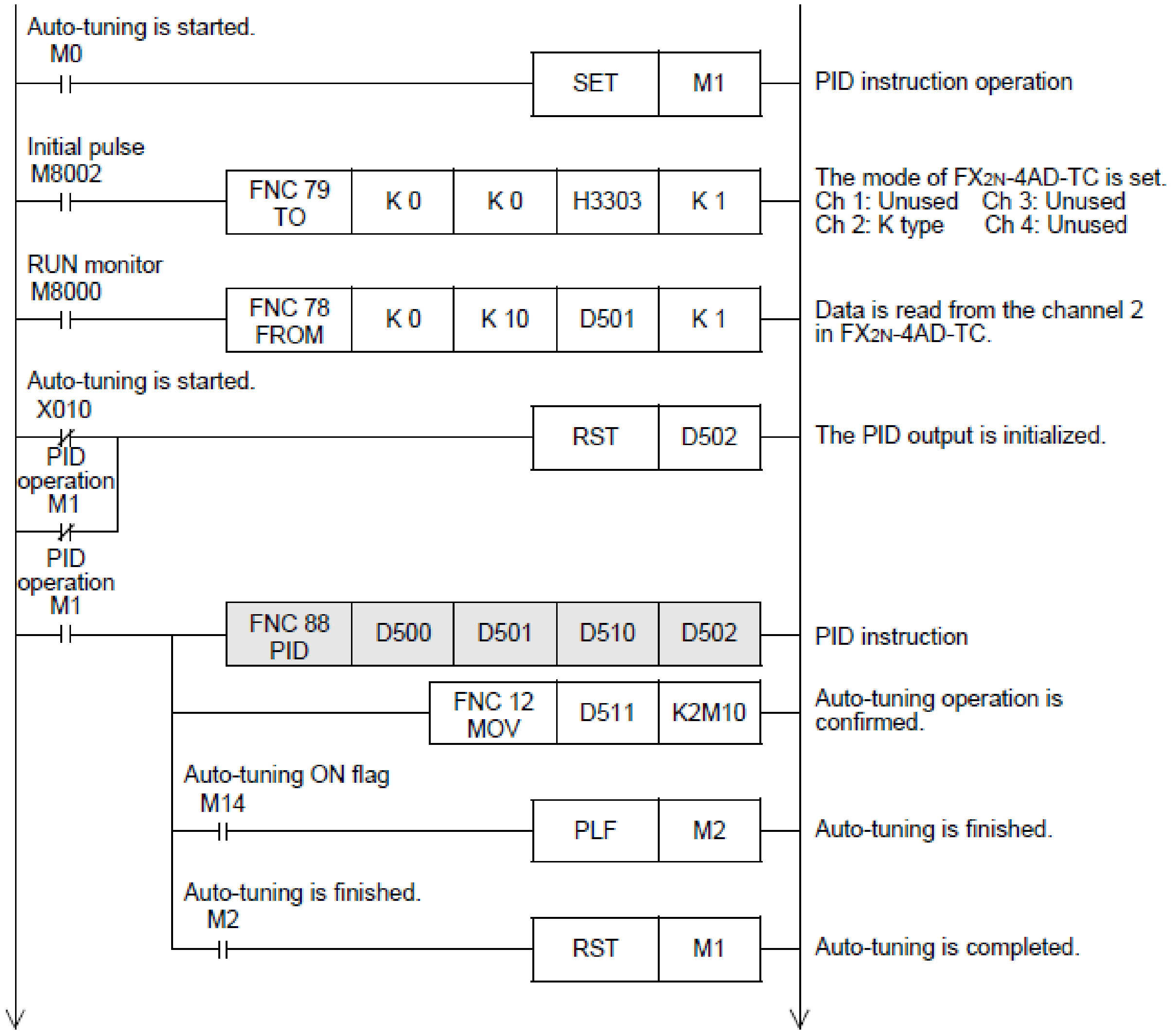


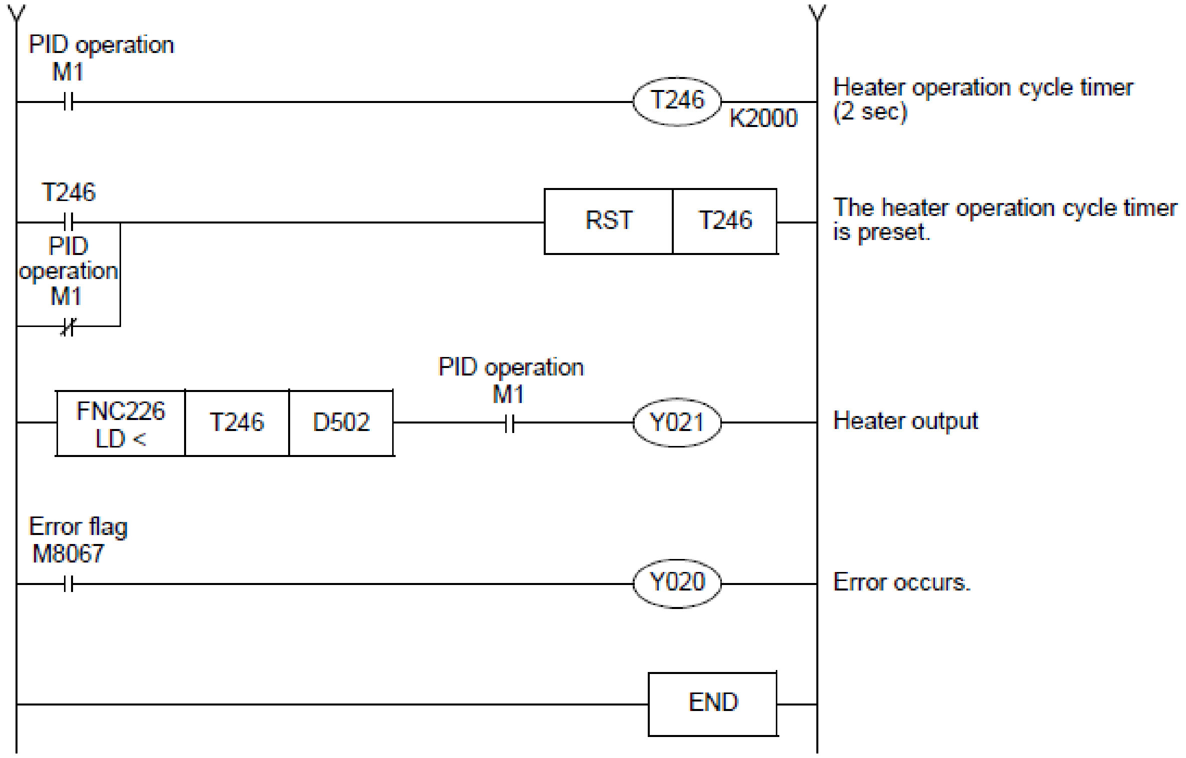


Auto-tuning ON flag
M1
FNC 12
MOV
D511
K2M10
Auto-tuning operation is confirmed.
Auto-tuning ON flag
M14
PLF
M2
Auto-tuning is finished.
Auto-tuning is finished
M2
RST
M1
The normal operation is started.
PID operation is executed.
M3
T246
K2000
Heater operation cycle
Heater operation cycle
T246
[RST T246]
Preset
PID operation is executed.
M3
T246 < D502
FNC226
LD <
T246
D502
PID operation is executed.
M3
Y021
Heater output
Error flag
M8067
Y020
Error occurs.
END

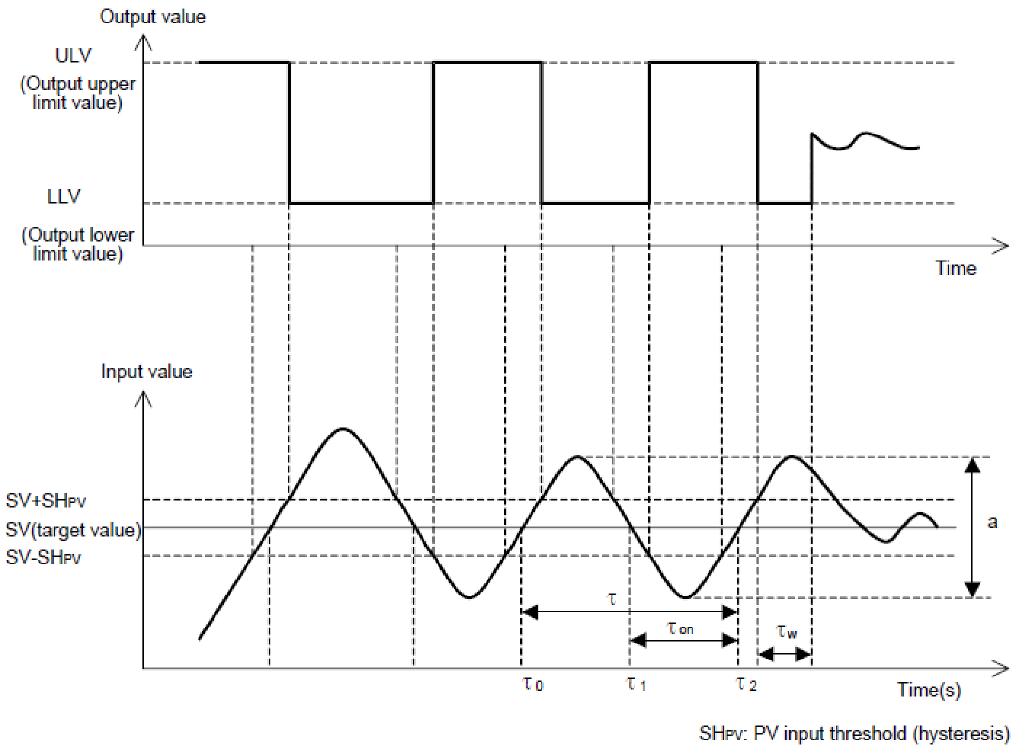
Program example of auto-tuning (step response method)




Auto-tuning is started.
M0
SET
M1
PID instruction operation
Initial pulse
M8002
FNC 79
TO
K 0
K 0
H3303
K 1
The mode of FX2N-4AD-TC is set.
Ch 1: Unused Ch 3: Unused
Ch 2: K type Ch 4: Unused
RUN monitor
M8000
FNC 78
FROM
K 0
K 10
D501
K 1
Data is read from the channel 2
in FX2N-4AD-TC.
Auto-tuning is started.
X010
RST
D502
The PID output is initialized.
PID
operation
M1
PID
operation
M1
FNC 88
PID
D500
D501
D510
D502
PID instruction
FNC 12
MOV
D511
K2M10
Auto-tuning operation is
confirmed.
Auto-tuning ON flag
M14
PLF
M2
Auto-tuning is finished.
Auto-tuning is finished.
M2
RST
M1
Auto-tuning is completed.


PID operation
M1
T246
K2000
Heater operation cycle timer
(2 sec)
T246
RST
T246
The heater operation cycle timer
is preset.
PID
operation
M1
FNC226
LD <
T246
D502
PID operation
M1
Y021
Heater output
Error flag
M8067
Y020
Error occurs.
END

Limit cycle method



Operation characteristics and three constants

Control type	Proportional gain (KP) [%]	Integral time (TI) [×100ms]	Differential time (TD) [×10ms]
Only proportional control (P operation)	$\frac{1}{a}(ULV - LLV) \times 100$	—	—
PI control (PI operation)	$\frac{0.9}{a}(ULV - LLV) \times 100$	$33 \times \tau_{on}\left(1 - \frac{\tau_{on}}{\tau}\right)$	—
PID control (PID operation)	$\frac{1.2}{a}(ULV - LLV) \times 100$	$20 \times \tau_{on}\left(1 - \frac{\tau_{on}}{\tau}\right)$	$50 \times \tau_{on}\left(1 - \frac{\tau_{on}}{\tau}\right)$

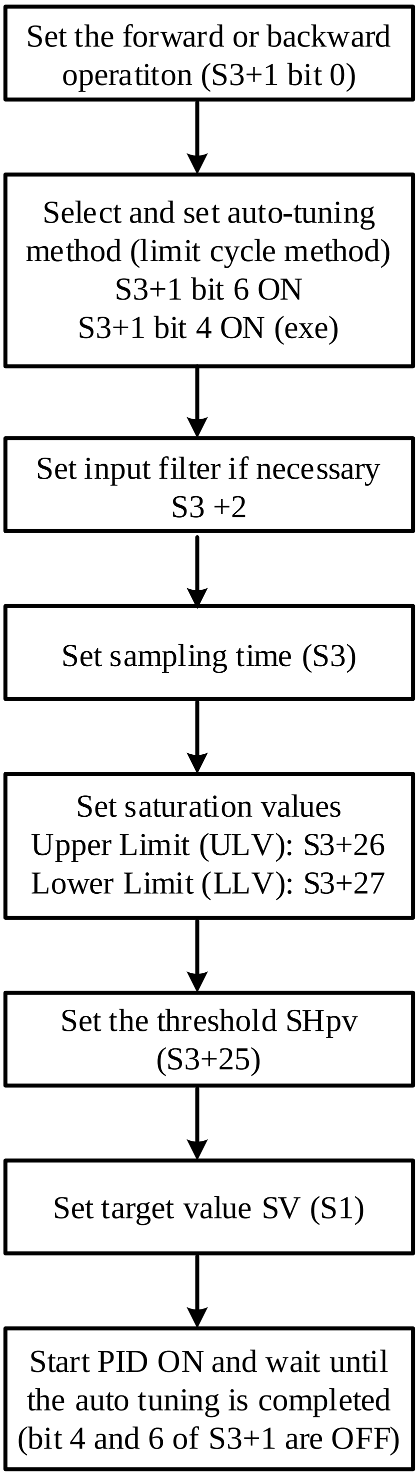


Fig 2.22: Procedure of limit cycle method

Write a PLC program to control the position of the slide table of the linear drive using the mentioned Mitsubishi modules. The report of this experiment should include the PLC program and some obtained results.

References

1. Mitsubishi Electric, FX2N-2AD Special Function Block – User's Guide.

2. Mitsubishi Electric, FX2N-4DA Special Function Block – User's Guide.

3. Mitsubishi Electric, FX3G/FX3U/FX3GC/FX3UC Series Programmable Controller – User's Manual: Analog Control Edition.

4. Mitsubishi Electric, FX3x Series Programmable Controller – Programming Manual: Basic and Applied Instruction Manual.

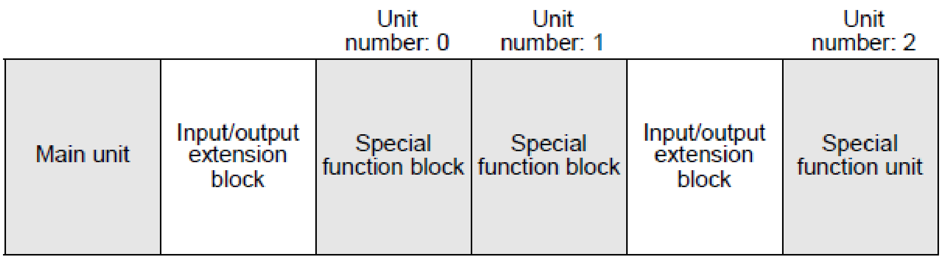
APPENDIX.

1. Buffer Memory (BFM)

➢ Assignment of unit numbers

Unit numbers from 0 to 7 will be assigned to the special function units/blocks starting from the left.

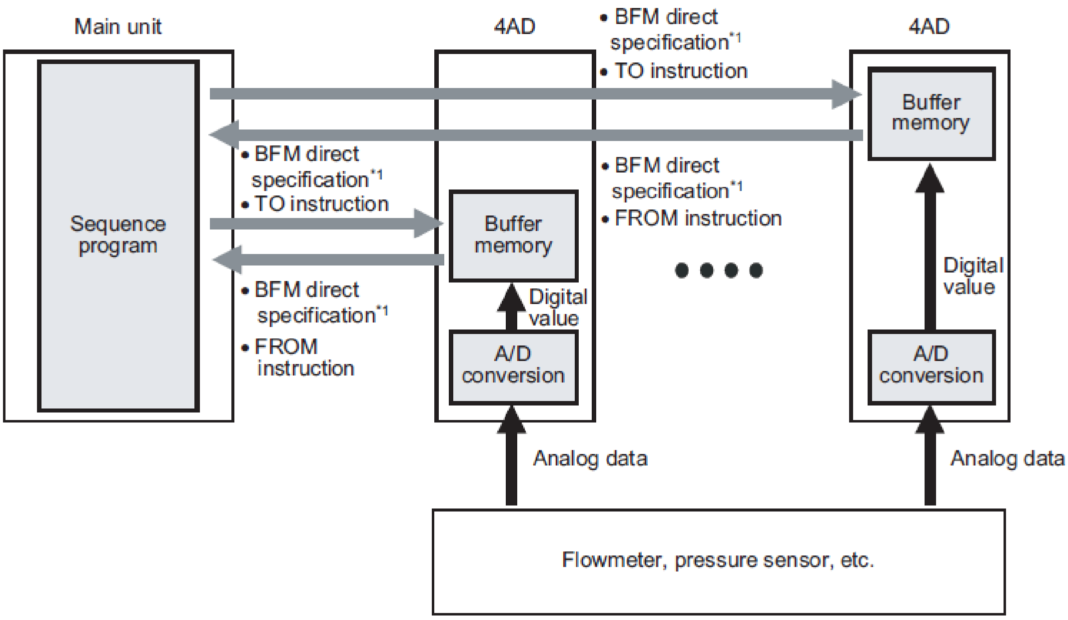
When connected to the FX3G/FX3U/FX3GC/FX3UC (D, DS, DSS) Series PLC (main unit)



➢ Outline of buffer memory

The analog signals input into the 4AD will be converted into digital values (12 bit) and then stored in the 4AD buffer memory.

To read/write data from/to the 4AD buffer memory, the buffer memory can be directly specified using the FROM/TO instruction or an applied instruction. Using this function, sequence programs can be easily created

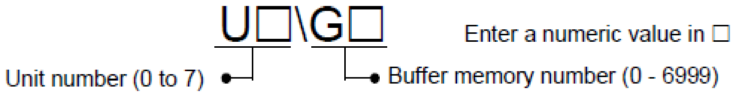


***1**. Since buffer memory direct specification (U[]\G[]) can directly specify the buffer memory in the source or destination area of an applied instruction (only in FX3U/FX3UC PLCs)

➢ Buffer memory reading/writing method

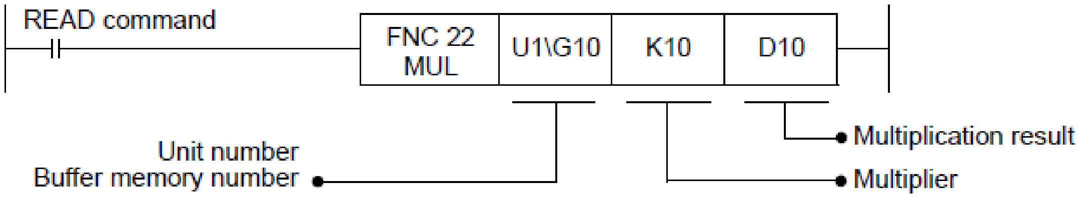
✓ Buffer memory direct specification (FX3U/FX3UC)

When directly specifying the buffer memory, specify the following device in the source or destination area of the applied instruction as follows:



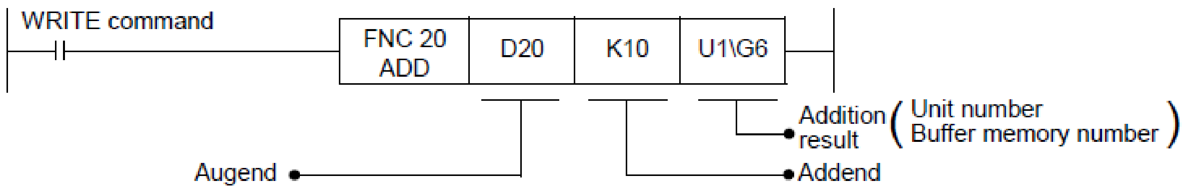
Example 1:

If the following program is created, data in buffer memory (BFM #10) of unit 1 will be multiplied by the data (K10), and then the multiplication result will be output to data registers (D10, D11).



Example 2:

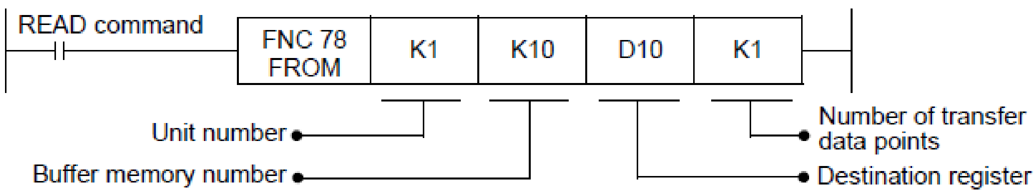
If the following program is created, the value in data register (D20) is added to K10 and written to buffer memory (BFM #6) of unit 1.



✓ FROM/TO instruction (FX3G, FX3U, FX3GC, FX3UC PLC)

1. FROM instruction (Reading out BFM data to PLC)

Use the FROM instruction to read the data from the buffer memory. In a sequence program, use this instruction as follows:



2. TO instruction (Writing PLC data into BFM)

Use the TO instruction to write data to a buffer memory. In a sequence program, use this instruction as follows: