MGI Technologies Inc.

HITACHI INVERTER PID CONTROL
L100 / SJ100 Series

PID CONTROL

Instruction Manual and Operation Guide

L100/ SJ100-PID

www.mgitech.com

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CONTENTS

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1. OVERALL

L100 / SJ100 series inverters have an integrated PID control function as standard. They can be used for controls, such as constant flow control for fan & pump applications, and they have the following features.

- **Target signal** can be given not only by the digital operator but also by an external digital signal, which can be set to 16 different targets. Furthermore, it can also be given by an analog input signal (0 - 10V or 4 - 20mA).
- **Feedback signal** can be given to L100 / SJ100 by analog voltage input (10V max.) or by analog current input (20mA max.).
- For the **feedback signal**, the performance area can be defined individually. For example 0 - 5V, 4 - 20mA or others.
- Using a **scale conversion** function, you can get actual values of target value and/or feedback value for air flows, water flows or temperature on the display.

Please read this guide book to use the convenient PID function of the L100 / SJ100 series inverters correctly and without any trouble.

2. PID CONTROL ON L100 & SJ100

2-1 PID Control

"P" in PID stands for **P**roportional, "I" for **I**ntegration, and "D" for **D**ifferential. The combination of these controls is called PID control. PID control is widely used in various fields, such as the process control of air flow, water flow, pressure, temperature and others. It controls the output frequency of the inverter according to PID calculation, which is based on the **deviation** between target and feedback. The inverter adjusts its output frequency to correct the deviation. This control block diagram is shown in Fig. 2-1 below.

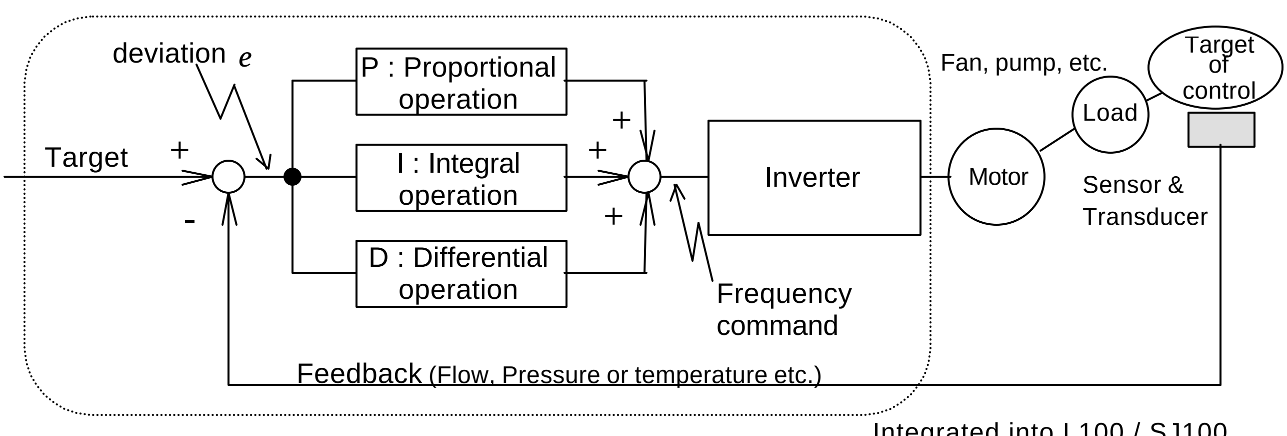


Fig. 2-1 Control block diagram of PID

L100 / SJ100 series inverter have an integrated PID control system, which is indicated by the dotted line in Fig. 2-1.

You can use PID control by setting a target value and feedback signal.

The example in Fig. 2-2 shows a connection diagram of ventilation flow control for a fan application.

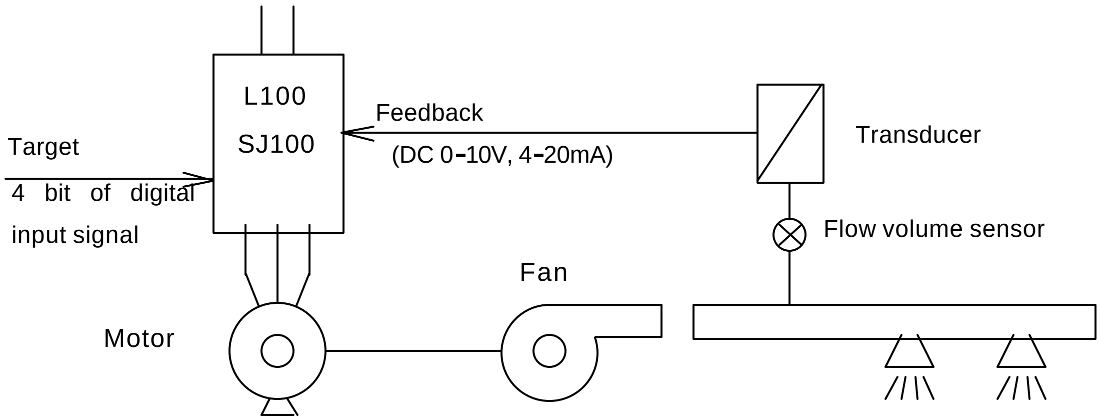


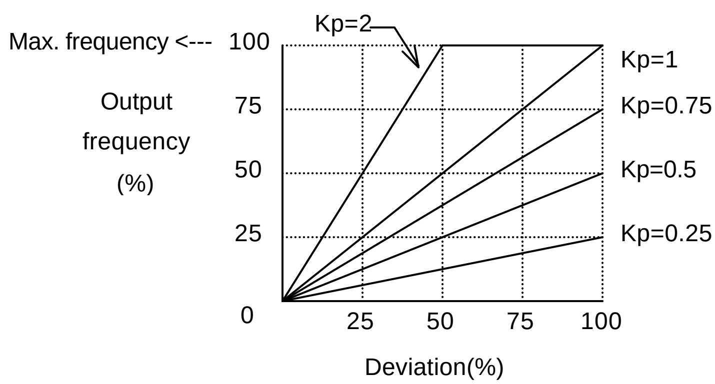
Fig. 2-2 Wiring example for flow control application

(1) P : Proportional Control

This controls the output frequency so that output frequency and deviation have a proportional relation. The coefficient of deviation and output frequency (expressed in %) is called **Proportional Gain (Kp)**. This parameter can be set under function [A71].

Fig. 2-3 shows the relation between deviation and output frequency.

If you set a high Kp, the response to a rapid change in deviation is fast, but if Kp is too high, the system can become unstable.



$0.2 \le Kp \le 5.0$

Fig. 2-3 Relation between deviation and output frequency of L100 / SJ100

100% of output frequency of above figure is equivalent to maximum output frequency.
Kp can be chosen between 0.2 and 5.0 in function [A71].

(2) I: Integral Control

This is a control to correct the output frequency by integrating the deviation. In case of proportional adjustment, a large deviation will result in a large output frequency adjustment, but if the deviation is small, then the resulting adjustment of output frequency will also be small. However, you cannot make the deviation zero. Integral performance compensates this problem.

Integral correction of output frequency is performed by accumulating the deviation according to the time passage, so that eventually, the deviation is zero. **Integration Gain (Ki)** is a coefficient that determines how many times of deviation to be integrated. The reciprocal of integration gain is **Integration Time (Ti : Ti=1/Ki)**.

> You set the integration time (Ti) on the L100 / SJ100 inverter. You can set the time between 0.5 second and 150 seconds. When "0.0" second is set, no integration control will be performed.

(3) D : Differential Control

This is a control to correct the output frequency by differentiating the deviation. Since P control is based on a current information of deviation and I control is based on a previous information of deviation, there will always be a delay of the control system. Differential control compensates this problem.

The correction of output frequency is performed according to the change ratio of deviation against time passage. Therefore, D control corrects the output frequency rapidly when there is a change in deviation. **Differentiation Gain (Kd)** is a coefficient to determine how many times of deviation to be differentiated.

> You can set Kd between 0 and 100. Gain is (Fmax / 10) * set value of [A74] against changed value of deviation per second.

(4) PID Control

PID control is a combined Proportional, Integral and Differential control. You can achieve the best control by adjusting each P-gain, I-gain and D-gain. You can get smooth control without any hunting by **P-control**; you can correct steady-state deviation by **I-control**; and by **D-control,** you can achieve a quick response to disturbances which can influence the feedback value. Large deviation can be suppressed by P-control. Small deviation can be corrected by I-control.

(Note) While D-control is performed based on a differentiation of deviation, it is a quite sensitive control. Therefore, it may also react to unnecessary signals such as noise and leads the system to an unstable control. D-control is not normally required for a control such as flow, pressure and temperature.

2-2 Each Gain of PID Adjustment & Control Characteristics

Each gain of PID varies from condition to condition, from system to system. That means it is necessary to set those parameters by taking into account the individual control characteristics of the system. Following are the aspects that are required for a good control of PID.

- Stable performance
- Quick response
- Small steady-state deviation

You adjust each parameter Kp, Ti and Kd inside the stable performance area. Generally, when you increase each gain (Kp, Ki, Kd) parameter (= decrease Integration time : Ti), you can get a quick response. But if you increase them too much, the control will be unstable, because the feedback value is continuously increasing and decreasing, which leads to an oscillation of the control. In the worst case the system is led to a divergence mode. (Refer to Fig. 2-4)

Following are the outlines to adjust each parameter.

(1) After changing target,	response is slow	--- **Increase P-gain (Kp)**
	response is quick but unstable	--- **Decrease P-gain (Kp)**
(2) Target and feedback	do not become equal	--- **Decrease Integration time (Ti)**
	become equal after unstable vibration	--- **Increase Integration time (Ti)**
(3) Even after increasing Kp,	response is still slow	--- **Increase D-gain (Kd)**
	it is still unstable	--- **Decrease D-gain (Kd)**

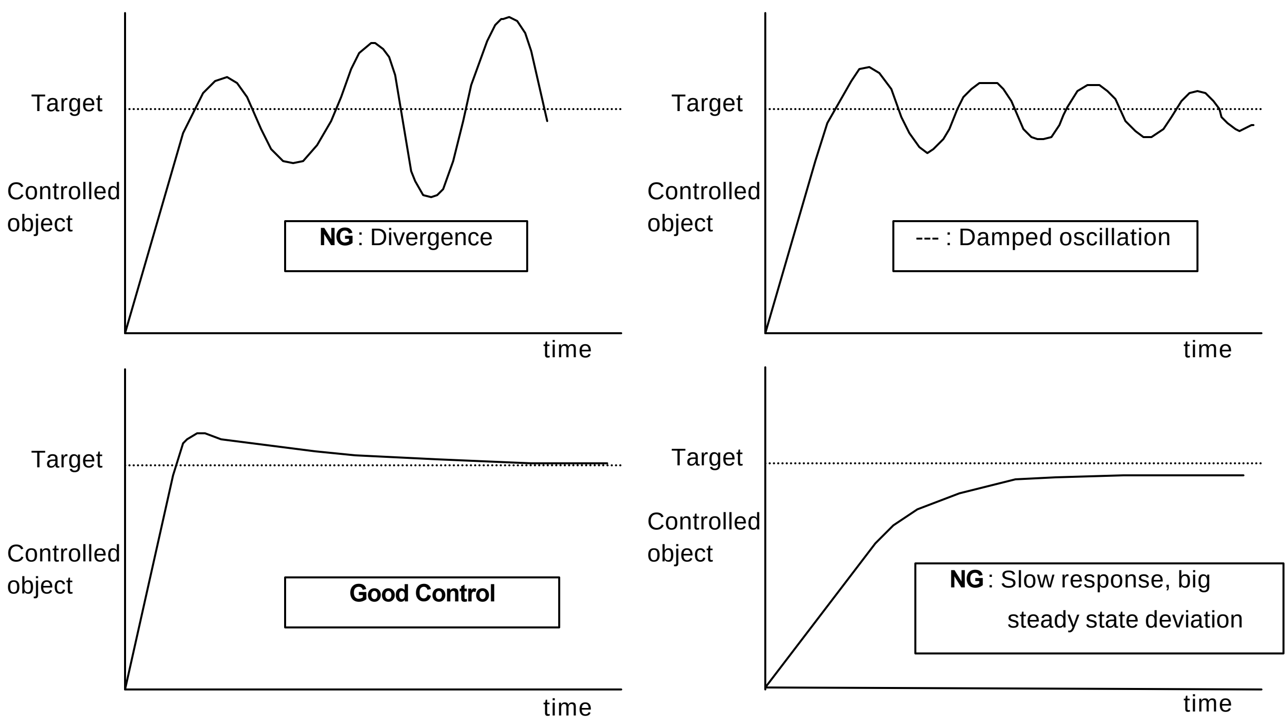


Fig. 2-4 Example of good control and bad control (in case of step response)

3-1 Structure & Parameters

(1) Control Mode

	Integrated operator	A71 : 00 / 01
	DOP, DRW	F43 : PID SW ON / OFF

L100 / SJ100 series inverters feature the following two control modes:

- **Frequency control mode (also sensorless vector for SJ100)**
- **PID control mode**

These can be switched over by "PID function selection (A71)".

Frequency control & sensorless vector mode is a general control mode of standard frequency inverters which enables you to give a frequency command to the inverter from each operator or by analog voltage or current, or by 4 bit digital command from the control terminal.

In the PID control mode, an output frequency is set automatically so that the deviation between target value and feedback value becomes zero.

(2) Parameters

Fig. 3-1 shows the relation between control block diagram of PID control and each parameter. Function numbers shown in the figure are based on the commands from the integrated operator of the inverter.

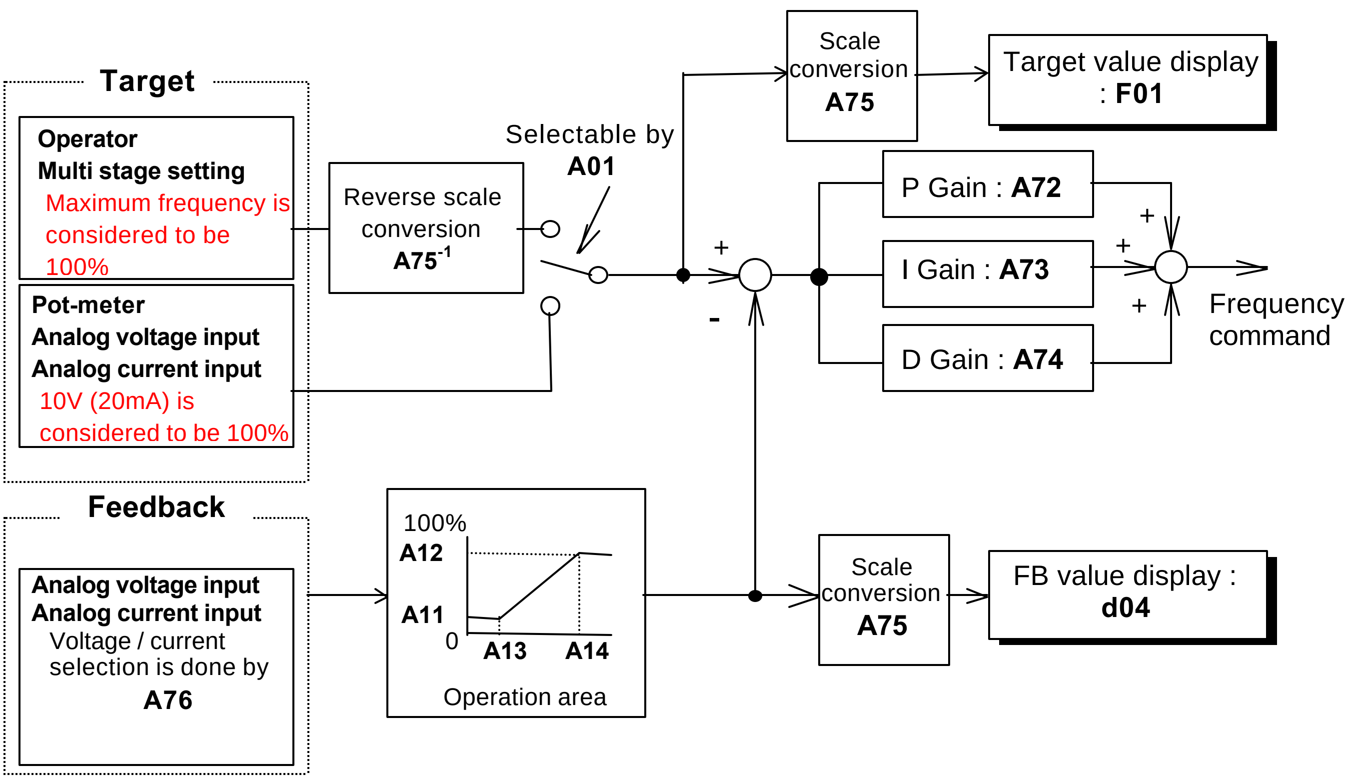


Fig. 3-1 control block diagram of PID control

(3) Deviation Calculation

Every calculation of PID control of L100 / SJ100 is based on "%" so that it can be used with various applications and units, such as pressure (psi, N/m^2), flow (gpm, cfm, m^3/min), temperature (degrees) and so on. For example, comparing target value and feedback value is based on % of target and % of feedback.

However, there is a useful function called scale conversion function (A75). If you use this function, you can set a target value and/or you can monitor target and feedback value in the actual units of the specific application. Additionally, there is a "performing area of PID setting" function (A11 - A14), which allows you to define an area based on the feedback signal. Please refer to Fig.3-2 and Fig.3-3 for better understanding.

(4) Target Input

Only one method of target input can be chosen from the following:

- Each operator (Integrated operator OPE, or DOP or DRW)
- 4 bits of digital input from control terminal
- Analog input terminal (O-L terminal or OI-L terminal)

In case of digital input of the target value from the terminal, it is necessary beforehand to set the required target value in functions A21 to A35. This allows you to define the target. Then you can get the one you required according to the combination of the 4 bits of digital input (condition). This is the same philosophy as multi stage speed control in the frequency control mode.

(5) Feedback Input & Setting PID Performance Area

Feedback signals from flow control should be given to one of the following units:

- Analog voltage input terminal (O terminal : 10V maximum)
- Analog current input terminal (OI terminal : 20mA maximum)

You should select one of them by "Feedback input method selection [A76]".

This feedback signal can be defined as shown in Fig.3-2 and Fig.3-3 below, so that you can select the suitable performance depending on the system. "100%" shown at vertical axis is a maximum value which is based on an internal calculation.

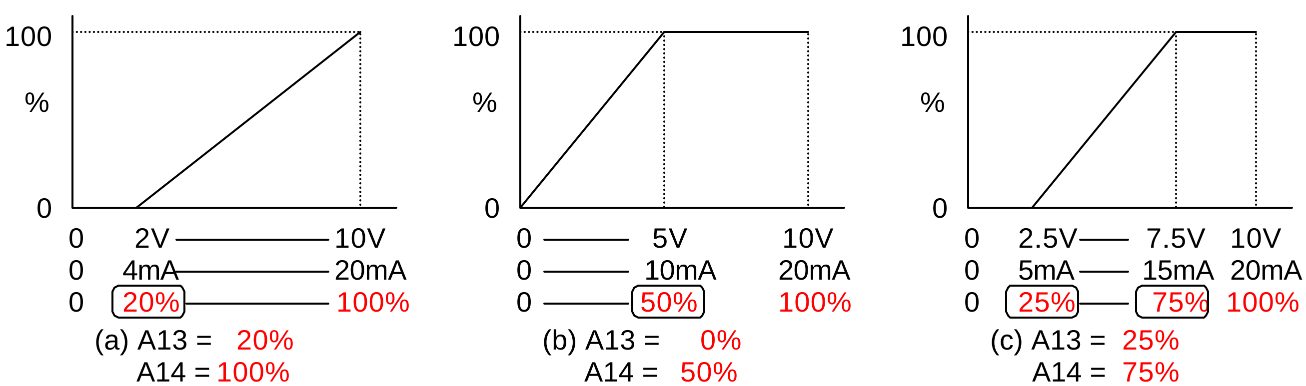


Fig. 3-2 Performance area setting (A11=0, A12=0 or 100) : Example 1

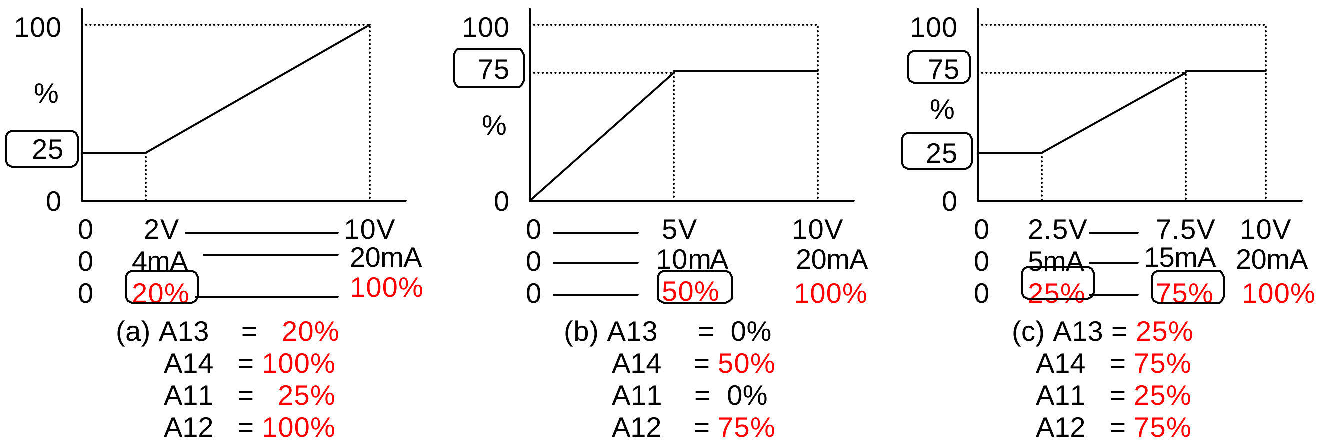


Fig. 3-3 Performance area setting : Example 2

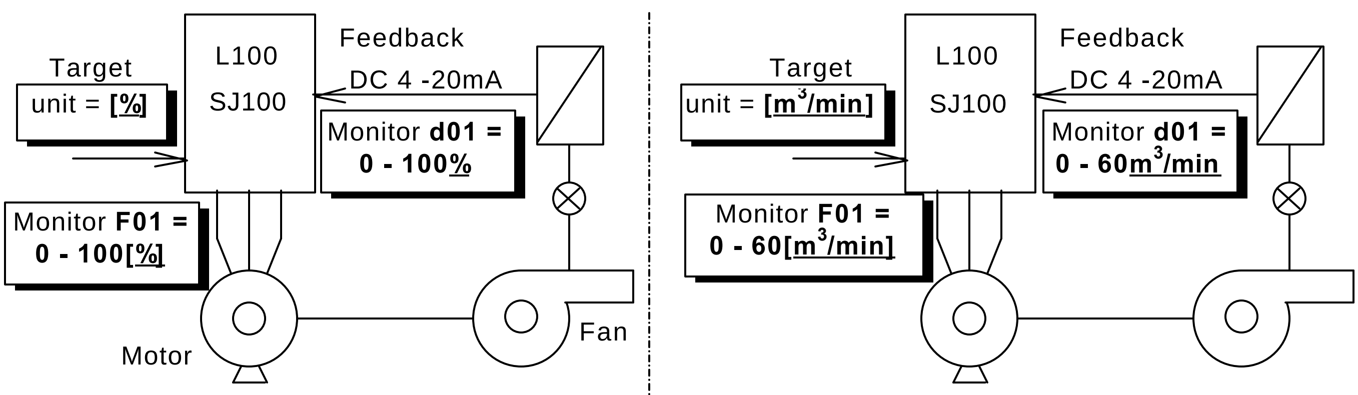
As you can see from Fig 3-3, if you set parameters A11 and A12 other than "0", you should set the target value inside the valid area of the vertical axis. Otherwise it is not possible to achieve stable performance because there is no feedback value. That means, the inverter will either output maximum frequency or stop or it will output lower limit frequency continuously if it is set.

(6) Scale Conversion

By using this function, you can set and display the target value and display the feedback value as an actual unit of the operating value. You can set the parameter individually against 100% of feedback value.

At factory setting, such input and display is based on 0 - 100%.

Example : In case of (a) in Fig.3-3, 20mA of feedback corresponds to **100%** of PID internal calculation. For instance, if actual flow at 20mA of feedback is 60 [m^3/ min], you set the parameter to 0.6 (=60 / 100) in function mode **A75**. Then you can get the actual feedback value on the monitor mode **d04**, and you can also set the target value by actual value of the control system.



(a) Factory setting **(b) A75 = 0.6**

Fig. 3-4 Example of Scale Conversion

3-2 Summary of Parameters for PID Control

On the L100 / SJ100 series inverters, we use the same function numbers for both frequency control mode and PID control mode. The function name for each function is based on frequency control mode, which is normally used for general application. Therefore, some functions have misleading explanations in the instruction manual.

To avoid confusion, please find in below Table 3-1 the explanation of function names for frequency control mode and PID control mode.

Table 3-1 Relation between Frequency Control Mode & PID Control Mode

Function No.		Function name	
Integrated Operator	DOP, DRW	Contents in case of Frequency control mode	Contents in case of PID control mode
d04	Monitor mode	-	PID Feedback monitor
F01	Monitor mode	Output frequency monitor	Target value monitor
A01	Monitor mode	Frequency command origin setting	Target value origin setting
A11	**F31**	External frequency setting START (Unit : Hz)	Feedback value input corresponding % for lower acceptance level (Unit : %)
A12		External frequency setting END (unit : Hz)	Feedback value input corresponding % for upper acceptance level (Unit : %)
A13		External frequency setting START rate (Unit : Hz)	Feedback value of lower acceptance level input (Unit : %)
A14		External frequency setting END rate (unit : Hz)	Feedback value of upper acceptance level input (Unit : %)
A21 - A35	**F11**	Multi-stage Speed 1 - 15 setting	Multi-stage Target 1 - 15 setting
A71	**F39**	-	PID mode selection
A72			P-gain adjustment
A73			I-gain adjustment
A74			D-gain adjustment
A75			Scale conversion ratio setting
A76			Origin of feedback signal selection

3-3 Example of Setting

(1) Each Parameter Setting under Frequency Control Mode

Before driving the system in PID mode, you select each required parameter under frequency control mode. Please **NOTE** the following items.

- **Acceleration ramp and Deceleration ramp**

The output of PID calculation (refer to Fig. 3-1) will not immediately be an output frequency of the inverter. Actual output frequency of the inverter is changed to the calculated output frequency **according to the set value of acceleration and deceleration ramp**. This means, even if you set high D-gain, change of the actual output frequency is restricted by the set acceleration and deceleration ramp, and this leads to an unstable control.

To achieve an overall stable performance range of PID control by changing each gain parameter (**A72**, **A73**, **A74**), you should set acceleration and deceleration ramp to the fastest value the system allows.

Take care to readjust the parameters after you changed acceleration and/or deceleration ramp.

- **Jump Frequency / Range**

The required condition for setting jump frequency is that there should be no change in feedback value when frequency is jumped. If there is a stable control point inside the jump frequency range, there will be a hunting between both ends of the range.

(2) Mode Setting (Target & Feedback)

In PID control mode, combination of target origin and feedback origin can be set according to the following table (Table 3-2).

Table 3-2 How to Set Origins for Target and Feedback

		Target Input Origin				
		Integrated Operator	Multi-stage target (Terminal)	Integrated Pot-meter	Analog Voltage input (O-L)	Analog Current input (OI-L)
Feedback Origin	Voltage input (O-L : 0-10V)	**A01** = 02 **A76** = 01		**A01** = 00 **A76** = 01	-	**A01** = 01 **A76** = 01
	Current input (OI-L : 4-20mA)	**A01** = 02 **A76** = 00		**A01** = 00 **A76** = 00	**A01** = 01 **A76** = 00	-

It is not possible to set both origin to the same analog input terminal.

(Note) Inverter decelerates according to a set deceleration ramp and stops when a stop command has been given during PID control.

(3) Scale Conversion Ratio Setting

Please set this ratio according to your application, e.g. flow, pressure, temperature and so on. For a detailed explanation, please refer to item (6) on page 9.

(4) Target Input by Digital Input Signal

Please refer to the following when changing the target by digital input signal (4 bit max.).

(a) Input terminal assignment

L100 series inverters have 5 intelligent input terminals (SJ100 have 6). First of all, please assign "**CF1**", "**CF2**", "**CF3**" and "**CF4**" to 4 of the intelligent input terminals. This assignment can be done by function number **C01** to **C05,** which correspond to terminal 1 to 5 on the I/O card.

(b) Setting each target value

Next, you set the required number of targets (up to 16 targets maximum) according to the following table (Table 3-3). Please set them in function **A21** to **A35** which correspond to target 1 to 15. **A20** and **F01** correspond to a target 0. Please note that in case a scale conversion ratio is set, you should set those targets as converted value according to this ratio.

Table 3-3 Multi-stage Target Input (1 : ON, 0 : OFF)

No.	CF4	CF3	CF2	CF1	Referred Target number (Function number to be inputted)
1	0	0	0	0	Target 0 (**A20** or **F01**)
2	0	0	0	1	Target 1 (**A21**)
3	0	0	1	0	Target 2 (**A22**)
4	0	0	1	1	Target 3 (**A23**)
5	0	1	0	0	Target 4 (**A24**)
6	0	1	0	1	Target 5 (**A25**)
7	0	1	1	0	Target 6 (**A26**)
8	0	1	1	1	Target 7 (**A27**)
9	1	0	0	0	Target 8 (**A28**)
10	1	0	0	1	Target 9 (**A29**)
11	1	0	1	0	Target 10 (**A30**)
12	1	0	1	1	Target 11 (**A31**)
13	1	1	0	0	Target 12 (**A32**)
14	1	1	0	1	Target 13 (**A33**)
15	1	1	1	0	Target 14 (**A34**)
16	1	1	1	1	Target 15 (**A35**)

e.g. if you need only 4 targets, you only use CF1 and CF2.

(5) PID Mode Setting

Please set PID mode selection **A71** to "**01**". You can also set this function first.

3-4 Example of Each Gain Adjustment (Kp & Ti)

- Check the response of feedback signal or output frequency of the inverter when step changing the target. (Please refer to Fig. 2-4)
- Please use oscilloscope or others measuring equipment to observe the waveform of feedback value or output frequency of the inverter (frequency monitor).
- Prepare two targets which can be changed by digital input signal in advance, so that you can change targets with a step change.
- At the outset, the control system must be stable.

(1) Adjustment of Proportional Gain (Kp : Function No. A72)

Start driving only with P-control, without I-control and D-control.

First, set minimum value of P-gain and see how it works. According to the result, increase P-gain gradually. Repeat this procedure until you get a good performance. (Alternatively, you set maximum P-gain and observe the performance. If the system is not stable, you set the medium value and see how it works. Repeat this procedure...)

In case there is an unstable performance, decrease P-gain.

If the steady state deviation is in the acceptable range, you have completed tuning the P-gain.

(2) Adjustment of Integration Time (Ti : Function No. A73) & Readjustment of Kp

Start adjustment by setting minimum integration time. Even though it is difficult to adjust, decrease P-gain.

In case the deviation does not converge, decrease integration time. If the control becomes unstable at that time, decrease P-gain.

Repeat this procedure to find the suitable parameters.

(Note) In the instruction manual, description of **A73** function is "**Integration Gain (Ki)**". But actually this is an "**Integration Time (Ti)**". Please note this when you set this parameter.

3-5 General Cautions

(1) When you set AVR function (**A81**) to "**DOFF**" which makes AVR function invalid only while deceleration with PID control, there is a possibility of hunting of the motor in some applications. This is because the motor repeatedly accelerates and decelerates and each time an AVR function is switched over, which may lead to an unstable rotation of the motor. Set AVR function **OFF** in this case.

4. EXAMPLE OF ACTUAL APPLICATION

This chapter presents some settings for typical applications.

4-1 Constant Flow Control

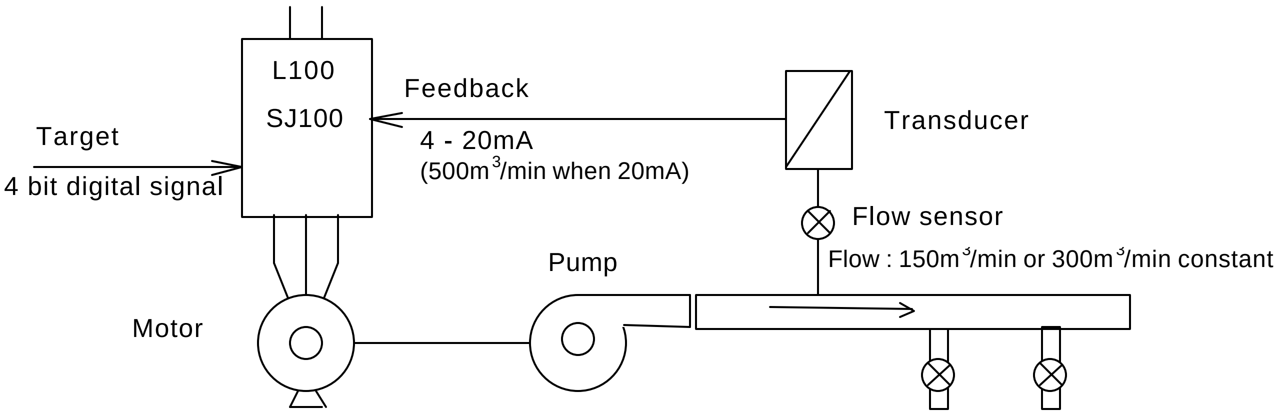
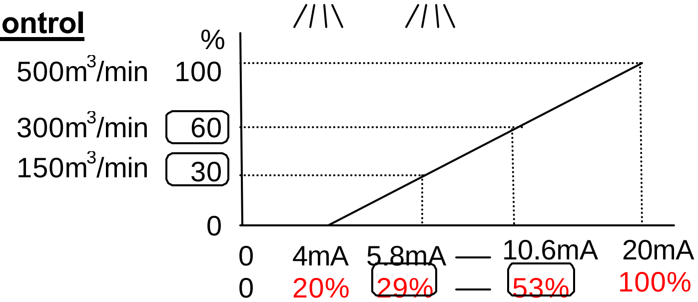


Fig. 4-1 Example of Constant Flow Control

In this case (targets are 150m³/min & 300m³/min), each setting can be as follows.



Feedback value range setting

Function Number		Function Name	Input	Remarks
Integrated Operator	DOP, DRW	Under PID Control Mode	Data	
F01	Monitor mode	Target 0	150	Directly input "150 [m³/min]" because scale conversion ratio is given
A01		Target input origin setting	02	Operator
A11	**F31**	Feedback value input corresponding % for lower acceptance level	0	0%
A12		Feedback value input corresponding % for upper acceptance level	100	100%
A13		Feedback value input for lower acceptance level setting	20	20%
A14		Feedback value input for upper acceptance level setting	100	100%
A21	**F11**	Target 1	300	300 [m³/min]
A71	**F39**	PID mode selection	01	PID mode ON
A72		P-gain adjustment	-	Depends on each application
A73		I -gain adjustment	-	
A74		D-gain adjustment	-	
A75		PID scale conversion ratio setting	5.0	100% when 500 [m³/min]
A76		Origin of feedback signal selection	00	Feedback from OI-L terminal

4-2 Constant Temperature Control

In case of constant flow control mentioned in the previous section, output frequency of the inverter increases in case feedback value is smaller than target value, and output frequency of the inverter decreases in case the feedback value is bigger than the target value. However, in case of constant temperature control, this is the opposite. The inverter increases its output frequency to drive a cooling fan much faster in case the feedback signal of temperature is higher than target temperature, for example. Below you can find an example of how to drive such an application.

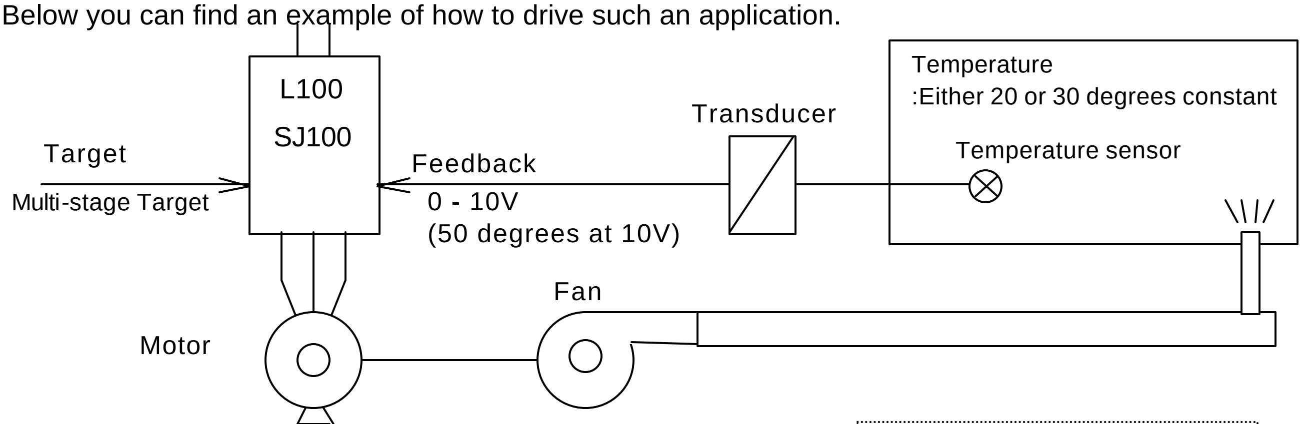
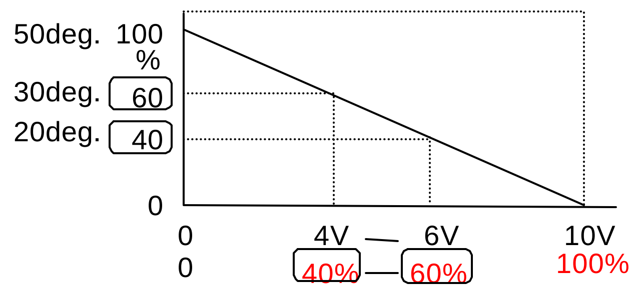


Fig. 4-2 Example of Constant Temperature Control



Feedback value range setting

In this case (targets are 20 & 30 degrees), each setting can be as follows.

Function Number		Function Name Under PID Control Mode	Input Data	Remarks
Integrated Operator	DOP, DRW			
F01	Monitor mode	Target 0	20	Directly input “20 [deg]” because scale conversion ratio is given
A01		Target input origin setting	02	Operator
A11	**F31**	Feedback value input corresponding % for lower acceptance level	100	100%
A12		Feedback value input corresponding % for upper acceptance level	0	0%
A13		Feedback value input for lower acceptance level setting	0	0%
A14		Feedback value input for upper acceptance level setting	100	100%
A21	**F11**	Target 1	30	30 deg
A71	**F39**	PID mode selection	01	PID Mode ON
A72		P-gain adjustment	-	Depends on each application
A73		I -gain adjustment	-	
A74		D-gain adjustment	-	
A75		PID scale conversion ratio setting	0.5	100% when 50 [deg]
A76		Origin of feedback signal selection	01	Feedback from O-L terminal

5. INDEX

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