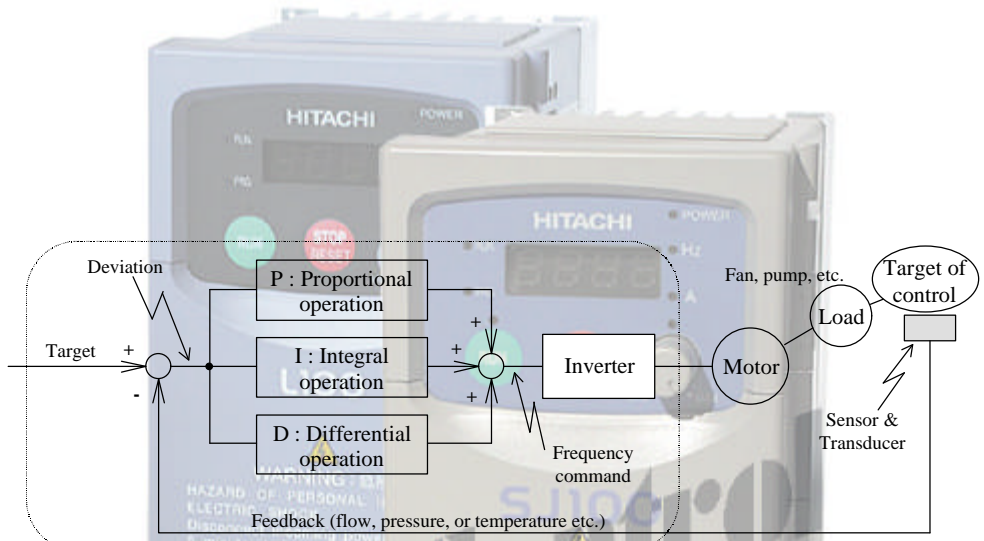


HITACHI

PID-CONTROL FUNCTION AND APPLICATION

Hitachi Inverters SJ100 and L100 Series



C O N T E N T S

CHAPTER 1 – OVERALL	1-1
CHAPTER 2 – L100/SJ100 PID CONTROL	
PID CONTROL	
<i>P: Proportional Control</i>	2-1
<i>I: Integral Control</i>	2-2
<i>D: Differential Control</i>	2-2
<i>PID Control</i>	2-2
ADJUSTMENT OF PID PARAMETERS	2-3
CHAPTER 3 – HOW TO USE	
STRUCTURE & PARAMETERS	
<i>Control Mode</i>	3-1
<i>Parameters</i>	3-1
<i>Deviation Calculation</i>	3-2
<i>Target Input</i>	3-2
<i>Feedback Input & Setting PID Performance Area</i>	3-2
<i>Scale Conversion</i>	3-3
SUMMARY OF PARAMETERS FOR PID CONTROL	3-3
EXAMPLES OF SETTING	
<i>Each Parameter Setting under Frequency Control Mode</i>	3-4
<i>Mode Setting (Target & Feedback)</i>	3-5
<i>Scale Conversion Ratio Setting</i>	3-5
<i>Target Input by Digital Input Signal</i>	3-5
<i>PID Mode Setting</i>	3-6
EXAMPLE OF EACH GAIN ADJUSTMENT (Kp & Ti)	
<i>Adjustment of Proportional Gain</i>	3-6
<i>Adjustment of Integration Time & Readjustment of Kp</i>	3-7
GENERAL CAUTIONS.....	3-7
CHAPTER 4 – EXAMPLES OF ACTUAL APPLICATIONS	
CONSTANT FLOW CONTROL.....	4-1
CONSTANT TEMPERATURE CONTROL	4-2

Chapter 1 – Overall

L100 and SJ100 series inverters have an integrated PID control function as standard. It can be used for controls, such as constant flow control for fan & pump applications, and it has 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.

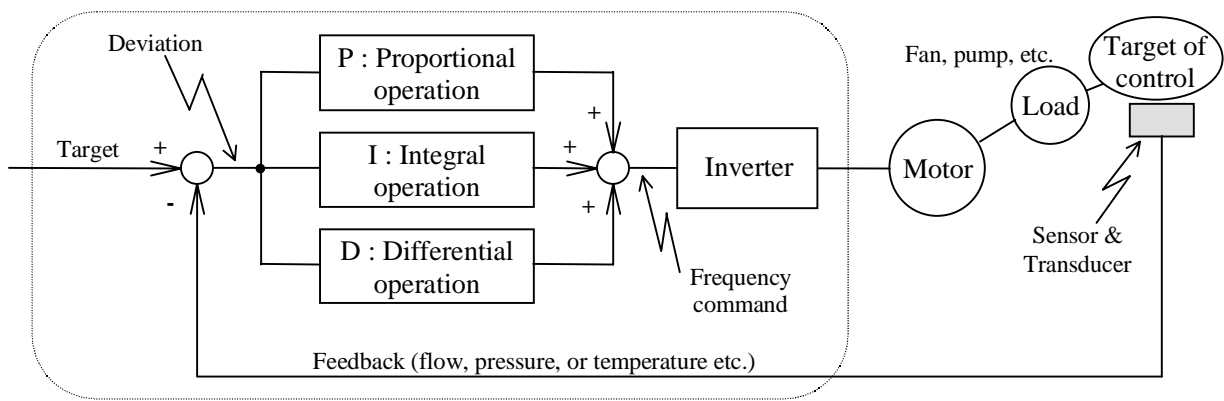
Using a **scale conversion** function, you can get actual values of target value and/or feedback value for air flow, water flow, or temperature on the display.

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

Chapter 2 – L100/SJ100 PID Control

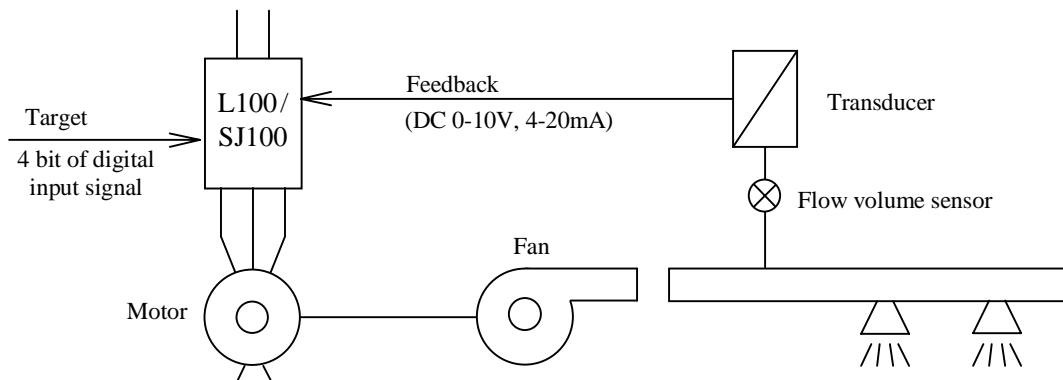
PID Control

„P“ in PID stands for **P**roportional, „I“ for **I**ntegral, 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 the figure below (the dotted line indicates the L100/SJ100 series inverters integrated PID control system):



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

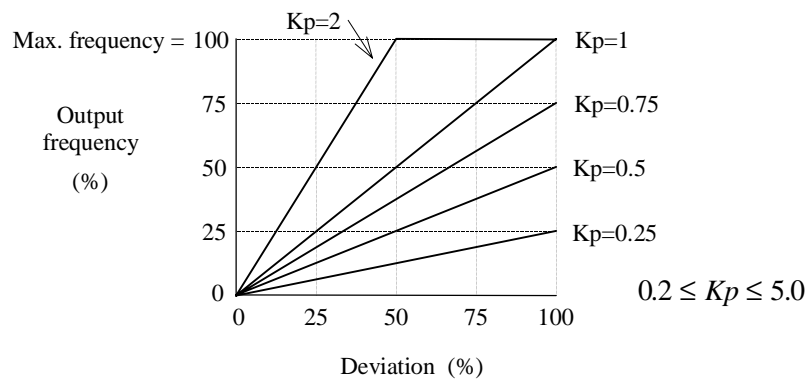
The example in the following figure shows a connection diagram of a ventilation flow control for a fan application:



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 (K_p)**. This parameter can be set under function *A 71*.

The next figure shows the relation between deviation and output frequency. If you set a high K_p, the response to a rapid change in deviation is fast, but if K_p is too high, the system can become unstable.



100% of output frequency in the above figure is equivalent to maximum output frequency. K_p can be chosen between 0.2 and 5.0 using function A 71.

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. The reciprocal of integration gain is **Integration Time (T_i : $T_i=1/K_i$)**.

On the L100/SJ100 inverter, you set the integration time (T_i). You can set the time between 0.5 seconds and 150 seconds. When „0.0“ seconds is set, no integration control will be performed.

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.

You can set K_d between 0 and 100. Gain is $(F_{max} / 10) * \text{set value of A 74}$ against changed value of deviation per second.

PID Control

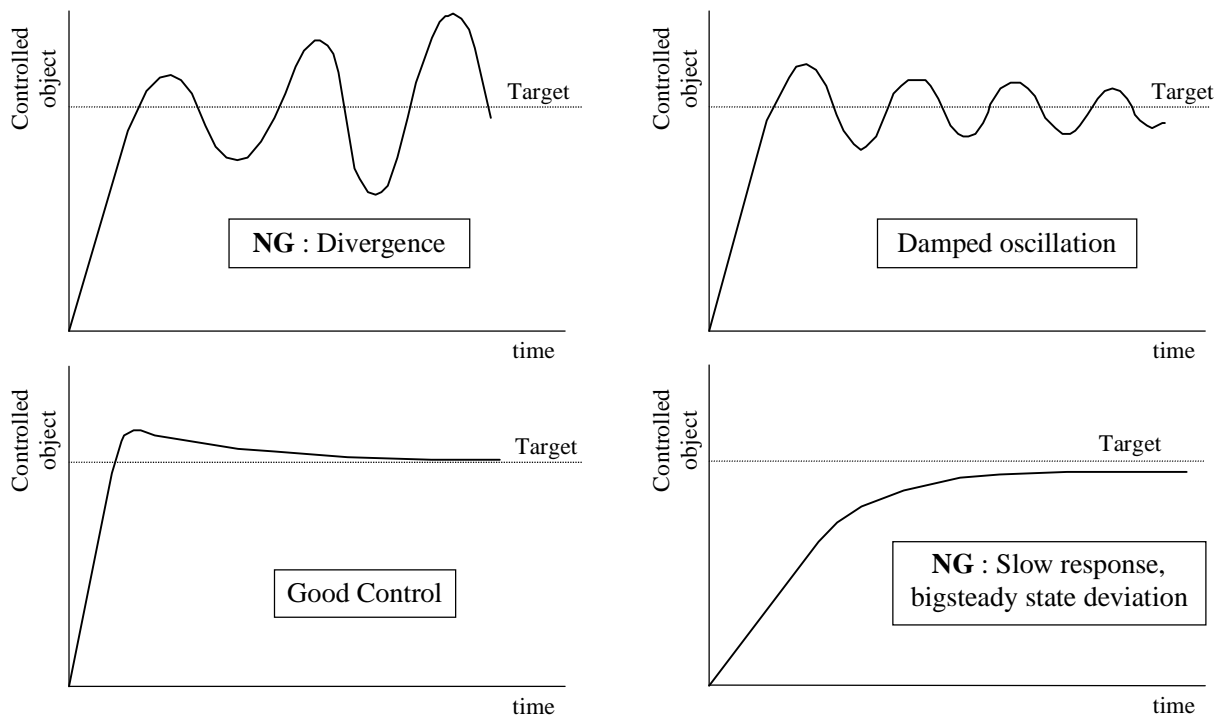
PID control is a combined proportional, integral and differential control. You can achieve the best control by adjusting each P-gain, I-gain and D-gain. You can get smooth control without any hunting by **P-control**; you can correct steady-state deviation by **I-control**; and by **D-control** you can 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.

Please keep in mind that since 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 outgoing noise and leads the system to an unstable control. D-control is not normally required for a control such as flow, pressure and temperature.

Adjustment of PID Parameters

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. The following aspects are required for a good control of PID: stable performance, quick response, and small steady-state deviation.

You adjust each parameter K_p , T_i and K_d inside the stable performance area. Generally, when you increase each gain (K_p , K_i , K_d) parameter (= decrease Integration time: T_i), 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 the following figure):



Following are the outlines to adjust each parameter:

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

Chapter 3 – How to use

Structure & Parameters

Control Mode

Integrated operator: *A 71* : 00 / 01
 DOP, DRW: *F 43* : PID SW ON / OFF

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

- **Frequency control mode**
- **PID control mode**

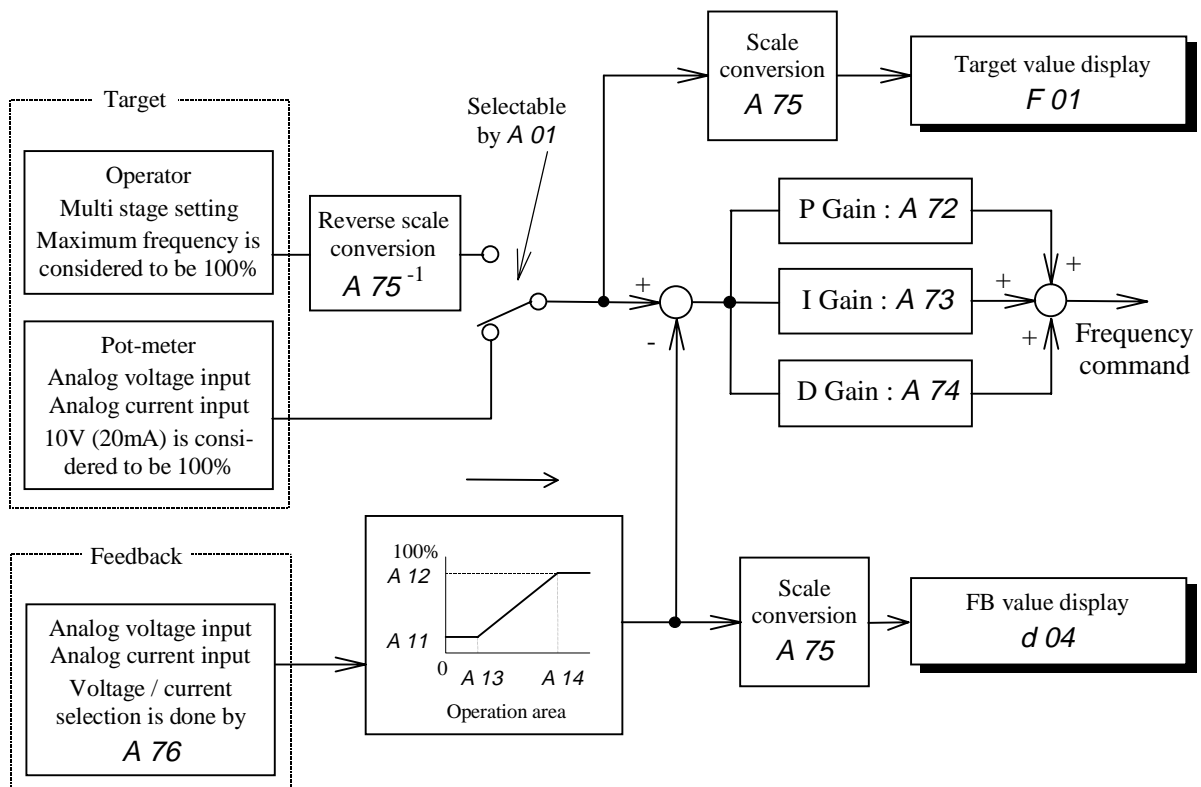
These can be switched over by „PID function selection” (*A 71*).

Frequency control 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.

Parameters

The following figure 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.



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 (N/m²), flow (m³/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 (A 75). 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 (A 11 - A 14), which allows you to define an area based on the feedback signal. Please refer to the following figures for better understanding.

Target Input

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

- Operator (Integrated operator 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 A 21 to A 35. 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.

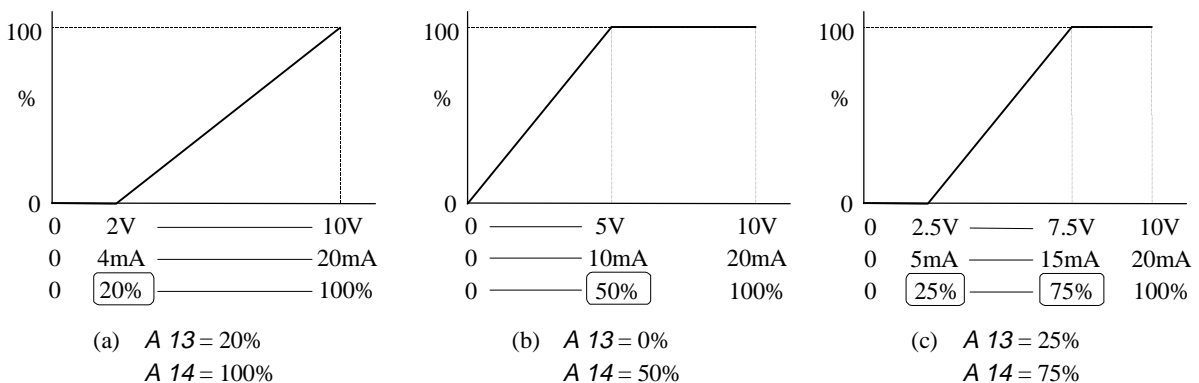
Feedback Input & Setting PID Performance Area

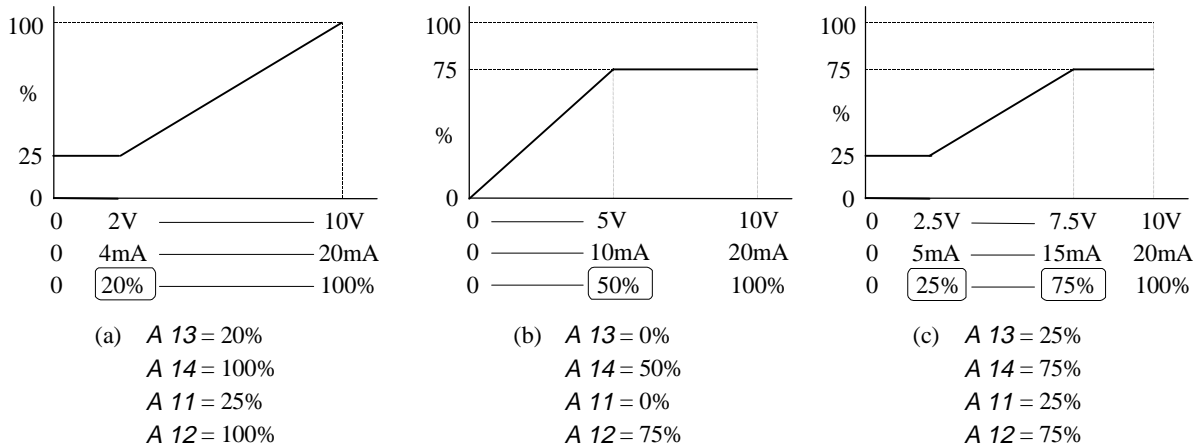
Feedback signals from flow control should be given using one of the following methods:

- 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“ A 76.

This feedback signal can be defined as shown in the figures 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.



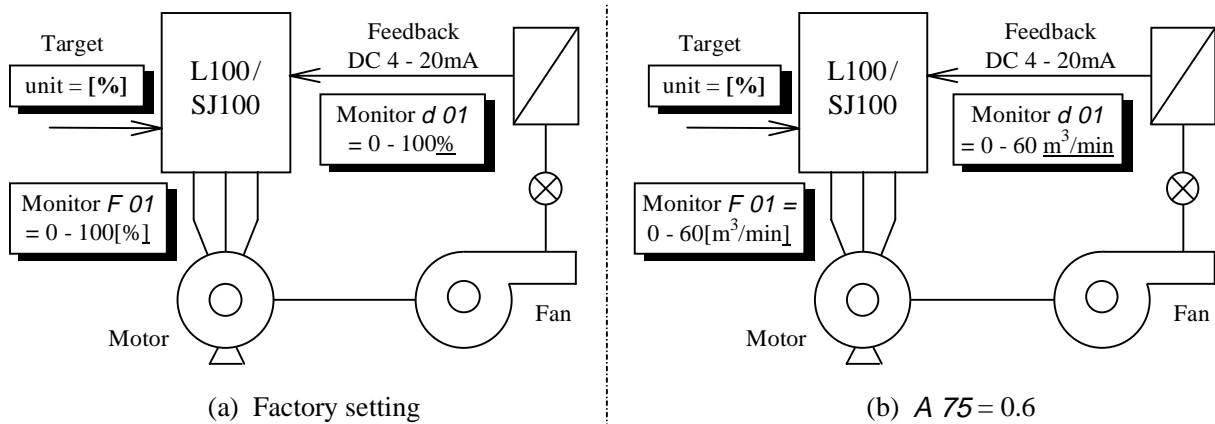


As you can see from the above figures, if you set parameters $A 11$ and $A 12$ other than „0“, you should set the target value inside the valid area of the vertical axis. Otherwise it is not possible to achieve stable performance because there is no feedback value. That means, the inverter will either output maximum frequency or stop or it will output lower limit frequency continuously if it is set.

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 the above figure, 20mA of feedback corresponds to **100%** of PID internal calculation. For instance, if actual flow at 20mA of feedback is 60 [m³/min], you set the parameter to 0.6 (=60 / 100) in function mode A 75. Then you can get the actual feedback value on the monitor mode $d 04$, and you can also set the target value by actual value of the control system.



Summary of Parameters for PID Control

On the L100/SJ100 series inverters, the same function numbers for both frequency control mode and PID control mode are used. 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 the table below the explanation of function names for frequency control mode and 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
<i>d 04</i>	Monitor mode	-	PID Feedback monitor
<i>F 01</i>	Monitor mode	Output frequency monitor	Target value monitor
<i>A 01</i>	Monitor mode	Frequency command origin setting	Target value origin setting
<i>A 11</i>	<i>F 31</i>	External frequency setting START (unit: Hz)	Feedback value input <u>corresponding %</u> for lower acceptance level (unit: %)
<i>A 12</i>		External frequency setting END (unit: Hz)	Feedback value input <u>corresponding %</u> for upper acceptance level (unit: %)
<i>A 13</i>		External frequency setting START rate (unit: Hz)	Feedback value of lower acceptance level input (unit: %)
<i>A 14</i>		External frequency setting END rate (unit: Hz)	Feedback value of upper acceptance level input (unit: %)
<i>A 21 - A 35</i>	<i>F 11</i>	Multi-stage Speed 1 - 15 setting	Multi-stage Target 1 - 15 setting
<i>A 71</i>	<i>F 39</i>	-	PID mode selection
<i>A 72</i>		P-gain adjustment	
<i>A 73</i>		I-gain adjustment	
<i>A 74</i>		D-gain adjustment	
<i>A 75</i>		Scale conversion ratio setting	
<i>A 76</i>		Origin of feedback signal selection	

Examples of Setting

Each Parameter Setting under Frequency Control Mode

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

Acceleration ramp and Deceleration ramp

The output of PID calculation will not immediately be the 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 (*A 72*, *A 73*, *A 74*), you should set acceleration and deceleration ramp to the fastest value the system allows.

Take care to readjust the parameters after you have 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.

Mode Setting (Target & Feedback)

In PID control mode, combination of target origin and feedback origin can be set according to the following table:

		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)	<i>A 01</i> = 02 <i>A 76</i> = 01		<i>A 01</i> = 00 <i>A 76</i> = 01	-	<i>A 01</i> = 01 <i>A 76</i> = 01
	Current input (OI-L: 4-20mA)	<i>A 01</i> = 02 <i>A 76</i> = 00		<i>A 01</i> = 00 <i>A 76</i> = 00	<i>A 01</i> = 01 <i>A 76</i> = 00	-

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

Please note that the inverter decelerates according to a set deceleration ramp and stops when a stop command has been given during PID control.

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 “Scale Conversion” in chapter “Structure & Parameters”.

Target Input by Digital Input Signal

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

Input terminal assignment

L100/SJ100 series inverters have 5 intelligent input terminals. 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 *C 01* to *C 05*, which correspond to terminal 1 to 5 on the I/O card.

Setting each target value

Next, you set the required number of targets (up to 16 targets maximum) according to the following table. Please set them in function *A 21* to *A 35* which correspond to target 1 to 15. *A 20* and *F 01* 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.

No.	CF4	CF3	CF2	CF1	Referred target number (function number to be input)
	(1 : ON. 0 : OFF)				
1	0	0	0	0	Target 0 (A 20 or F 01)
2	0	0	0	1	Target 1 (A 21)
3	0	0	1	0	Target 2 (A 22)
4	0	0	1	1	Target 3 (A 23)
5	0	1	0	0	Target 4 (A 24)
6	0	1	0	1	Target 5 (A 25)
7	0	1	1	0	Target 6 (A 26)
8	0	1	1	1	Target 7 (A 27)
9	1	0	0	0	Target 8 (A 28)
10	1	0	0	1	Target 9 (A 29)
11	1	0	1	0	Target 10 (A 30)
12	1	0	1	1	Target 11 (A 31)
13	1	1	0	0	Target 12 (A 32)
14	1	1	0	1	Target 13 (A 33)
15	1	1	1	0	Target 14 (A 34)
16	1	1	1	1	Target 15 (A 35)

So for example, if you need only 4 targets, you only use CF1 and CF2. If you need 8 targets, you use CF1, CF2, and CF3.

PID Mode Setting

Please set PID mode selection A 71 to 01. You can also set this function at first.

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 the figures under “Adjustment of PID Parameters” in chapter “L100/SJ100 PID Control”).

Please use oscilloscope or other 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, so that you can change targets using a step change.

At the output, the control system must be stable.

Adjustment of Proportional Gain (Kp: Function No. A 72)

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 can 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.

Adjustment of Integration Time (Ti: Function No. A 73) & 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.

Please note, that in the instruction manual, description of A 73 function is „**Integration Gain (Ki)**“. But actually this is an „**Integration Time (Ti)**“. Please pay attention when you set this parameter.

General Cautions

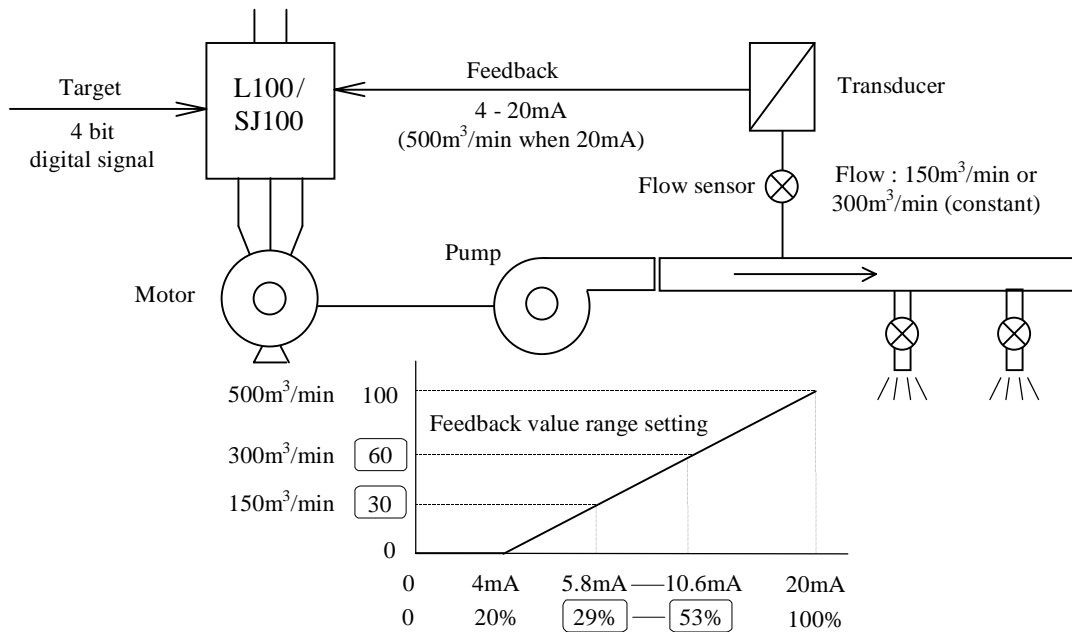
When you set AVR function (A 81) to „**DOFF**“ which makes AVR function invalid only during deceleration using PID control, there is a possibility of hunting of the motor in some applications. This is because the motor repeatedly accelerates and decelerates each time an AVR function is switched over, which may lead to an unstable rotation of the motor. Set AVR function OFF in this case.

Chapter 4 – Examples of actual Applications

In this chapter you will find some exemplary settings for actual application.

Constant Flow Control

In the example shown in the figure below, targets are 150m³/min and 300m³/min:

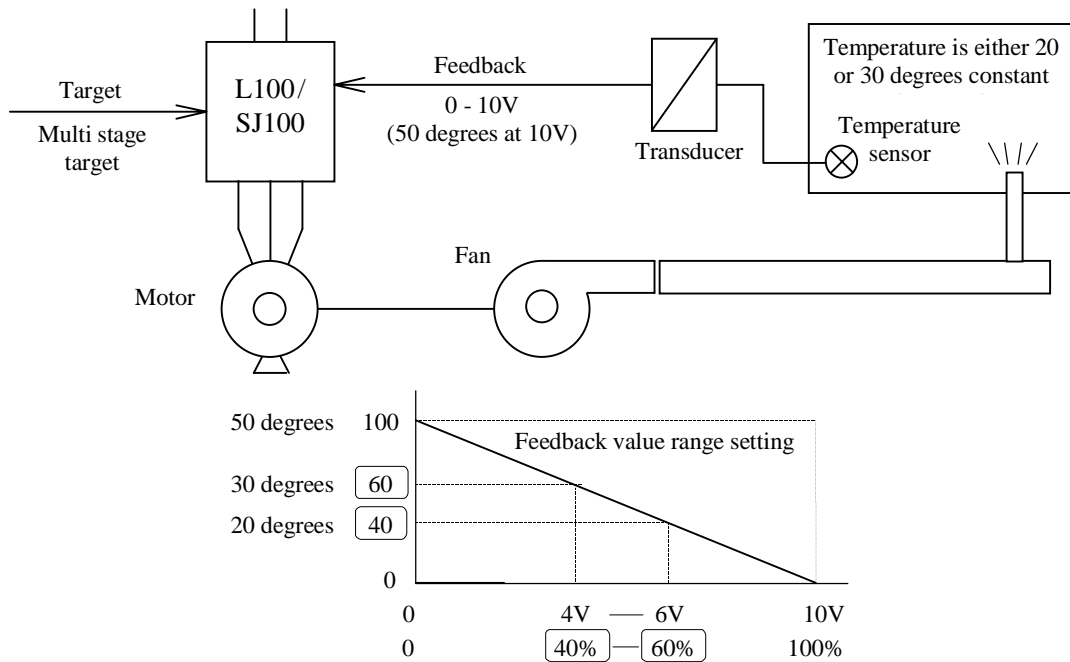


Function Number		Function Name Under PID Control Mode	Input Data	Remarks
Integrated Operator	DOP, DRW			
F 01	Monitor mode	Target 0	150	Directly input „150 [m ³ /min]“ because scale conversion ratio is given
A 01		Target input origin setting	02	Operator
A 11	F 31	Feedback value input corresponding % for lower acceptance level	0	0%
A 12		Feedback value input corresponding % for upper acceptance level	100	100%
A 13		Feedback value input for lower acceptance level setting	20	20%
A 14		Feedback value input for upper acceptance level setting	100	100%
A 21	F 11	Target 1	300	300 [m ³ /min]
A 71	F 39	PID mode selection	01	PID mode ON
A 72		P-gain adjustment	-	Depends on each application
A 73		I-gain adjustment	-	
A 74		D-gain adjustment	-	
A 75		PID scale conversion ratio setting	5.0	100% when 500 [m ³ /min]
A 76		Origin of feedback signal selection	00	Feedback from OI-L terminal

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 (targets are 20 and 30 degrees):



Function Number		Function Name	Input Data	Remarks
Integrated Operator	DOP, DRW	Under PID Control Mode		
<i>F 01</i>	Monitor mode	Target 0	20	Directly input „20 [degrees]“ because scale conversion ratio is given
<i>A 01</i>		Target input origin setting	02	Operator
<i>A 11</i>	<i>F 31</i>	Feedback value input corresponding % for lower acceptance level	100	100%
<i>A 12</i>		Feedback value input corresponding % for upper acceptance level	0	0%
<i>A 13</i>		Feedback value input for lower acceptance level setting	0	0%
<i>A 14</i>		Feedback value input for upper acceptance level setting	100	100%
<i>A 21</i>	<i>F 11</i>	Target 1	30	30 [degrees]
<i>A 71</i>	<i>F 39</i>	PID mode selection	01	PID mode ON
<i>A 72</i>		P-gain adjustment	-	Depends on each application
<i>A 73</i>		I-gain adjustment	-	
<i>A 74</i>		D-gain adjustment	-	
<i>A 75</i>		PID scale conversion ratio setting	5.0	100% when 50 [degrees]
<i>A 76</i>		Origin of feedback signal selection	00	Feedback from OI-L terminal