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|---|---|---|---|---|---|
| **Product** | AMD | **Type/Series** | VFD-MS300 | **Appl. Note Nr.** | ….. |
| **Issued by** | MDSBU | **Author** | MDSBU | **Release Date** | 2019 |
| **Title** | MS300 PID Tension Control | | | | |

# Table of Contents

# Purpose and Function

The purpose of tension control is to keep the windings' tension constant throughout the work. The processed materials such as paper, film, wire, rope, etc. are rolled on the reel during processing, so winding and unwinding often occur during the process. Due to this reason, the tension needs to be kept constant during the process to avoid fluctuation, entanglement, sliding, lateral sliding, and so on.

To meet the tension control market demand, we optimize our tension control. Strengthening PID function and enhancing user-friendliness are our two main optimizations. For the first optimization, we add new functions of the main and auxiliary frequency, two sets of PID switching and smart start-up to increase the flexibility and performance of the PID function. For the second optimization, we improve the PID default value to make users easier to locate the appropriate PID parameter settings. The overall optimization should be able to fulfill 60% to 70% customer needs for tension control.

The table below shows the typical equipment by industry to be used:

| Industry | Typical Equipment |
|---|---|
| Electrical Engineering | drawing machine, strander, layer winding machine, pulling machine, stranding machine, gantry machine, shaker |
| Printing | winder machine, coating machine, woven bag printing machine |
| Fiber Optic | cable machine, sheath production line |
| Rubber & Plastic | blowing machine, extruder |

Note: For tension control application with pendulum mechanism, it is recommended that the range of the coil diameter should not exceed two times.

# 1. PID New Function and Optimization

## 1-1 New Parameter

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-31 | Proportional gain 2 | 0.00–500.00 | N/A | 1.00 |
| 08-32 | Integral time 2 | 0.00–100.00 | Sec. | 1.00 |
| 08-33 | Differential time 2 | 0.00–1.00 | Sec. | 0.00 |
| 08-65 | PID target value source | 0: Frequency command (Pr.00-20, Pr.00-30)<br>1: Pr.08-66 setting<br>2: RS-485 serial communication<br>3: External analog input (Refer to Pr. 03-00)<br>4: CANopen communication card<br>5: Reserved<br>6: Communication card (does not include CANopen card)<br>7: Digital keypad dial | N/A | 0 |
| 08-66 | PID target value setting | -100.00–100.00 | % | 50.00 |
| 08-67 | Master and auxiliary reverse running cutoff frequency | 0.0–100.0 | % | 10.0 |
| 08-68 | PID deviation limit | 0.00–100.00 | % | 0.00 |
| 08-69 | Integral separation level | 0.00–100.00 | % | 0.00 |
| 08-70 | Smart start-up level | 0.00–100.00 | % | 5.00 |
| 08-71 | Smart start-up frequency | 0.00–599.00 | Hz | 0.00 |
| 08-72 | Smart start-up acceleration time | 0.00–600.00 | S | 3.00 |
| 08-75 | PID2 paramter switch condition | 0: No switch<br>1: Auto-switch based on output frequency<br>2: Auto-swtich based on deviation | N/A | 0 |
| 08-76 | PID2 parameter switch deviation 1 | 0.00–Pr.08-77 | % | 10.00 |
| 08-77 | PID2 parameter switch deviation 2 | Pr.08-76–100.00 | % | 40.00 |
| 08-78 | Allowed reverse running time after start-up | 0.0–6553.5 | Sec. | 0.0 |

## 1-2 Parameter Changes

### 1) Change present value in the existing parameters

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-01 | Proportional gain (P) | 0.00–500.00 | N/A | 1.00 |

(The decimal point is changed to two digits)

### 2) New feature options in existing parameters

| Pr. | Explanation | Settings |
|---|---|---|
| 00-20 | Master frequency command source (AUTO) | 9: PID |

| Pr. | Explanation | Settings |
|---|---|---|
| 00-30 | Master frequency command source (HAND) | 9: PID |

### 3) New parameter description

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-65 | PID target value source | 0: Frequency command (Pr.00-20, Pr.00-30)<br>1: Pr.08-66 setting<br>2: RS-485 serial communication<br>3: External analog input (Refer to Pr.03-00)<br>4: CANopen communication card<br>5: Reserved<br>6: Communication card (does not include CANopen card)<br>7: Digital keypad dial | N/A | 0 |
| 08-66 | PID target value setting | -100.00–100.00 | % | 50.00 |

📖 Use Pr.08-65 to select the target source of the PID.

📖 When Pr.08-65=0, PID controller architecture shows as Figure 1. When Pr.08-65≠0, PID controller architecture shows as Figure 2.

📖 When Pr.08-65≠0, Pr.00-20 is automatically set to 9.

📖 When Pr.08-65=1, the PID command source is from Pr.08-66. When Pr.08-65≠1, Pr.08-66 displays the PID command.

📖 If Pr.08-65 = 2, 4 and 6, the corresponding communication address is C2003H.

📖 PID setting target (Pr.08-66) is a relative value, and the setting range is -100.00–100.00%.

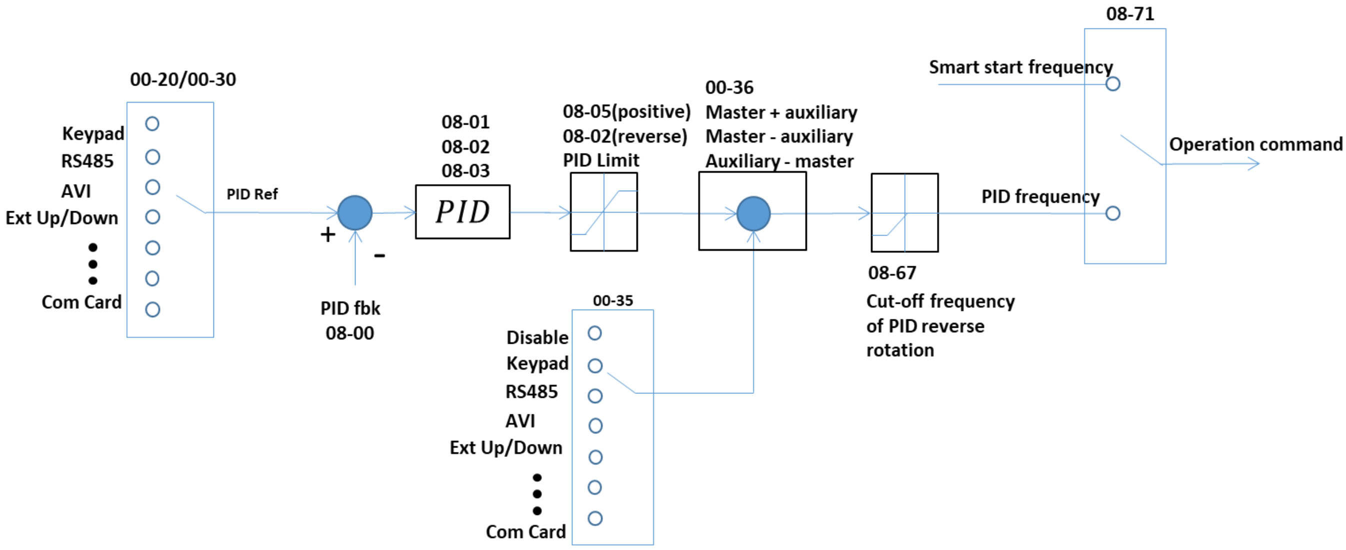



Figure 1 PID controller architecture when Pr.08-65=0

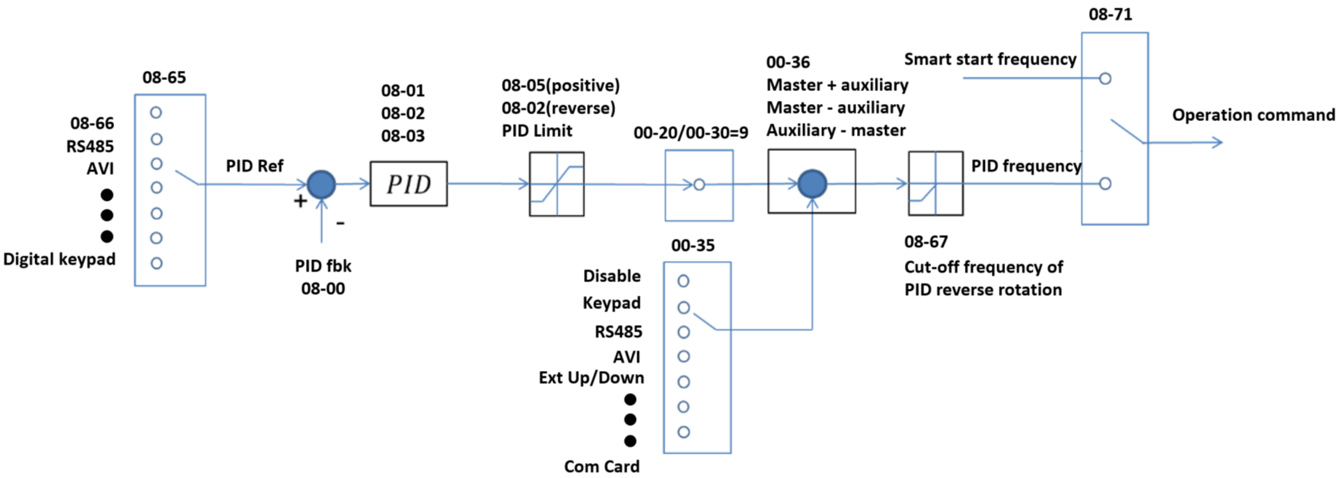



Figure 2 PID controller architecture when Pr.08-65≠0

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-67 | Master and auxiliary reverse running cutoff frequency | 0.0–100.0 | % | 10.0 |

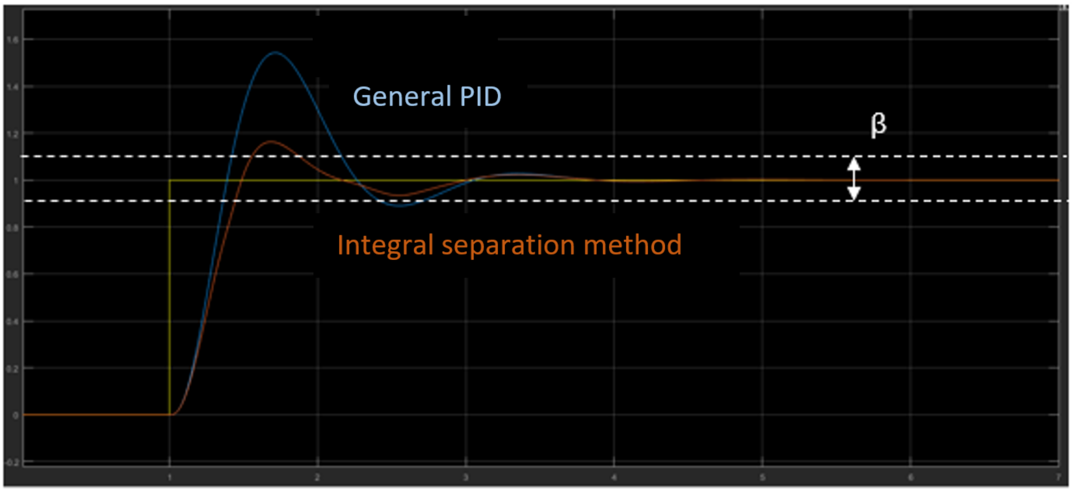
- 100% corresponds to Pr.01-00 maximum operation frequency.
- In some situations, only when the PID output frequency is negative (i.e. drive reverses), PID can control the given and the feedback to the same state. However, under certain circumstances, excessive reverse frequency is not allowed. Use Pr.08-67 to ensure the upper limit for master and auxiliary reverse frequency.

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-68 | PID deviation limit | 0.00–100.00 | % | 0.00 |

- When Pr.08-68≠0, the PID deviation limit function is enabled.
- If PID deviation ≤ Pr.08-68, PID stops adjustment, that is, PID output frequency maintains previous value. This function is very useful for some closed-loop control applications.

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-69 | Integral separation level | 0.00–100.00 | % | 0.00 |

- 🕮 Used to reduce overshoot when PID feedback has overshoot at start-up.
- 🕮 When Pr.08-69≠0, integral separation function is enabled.
- 🕮 The calculation of the integral separation level is based on PID error %.
- 🕮 Integral separation function is activated once only at start-up.
- 🕮 When PID deviation ≥ Pr.08-69, integral does not work in order to prevent overshoot from being too large. When PID deviation ≤ Pr.08-69, integral works to eliminate steady-state error.




| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-70 | Smart start-up level | 0.00–100.00 | % | 5.00 |
| 08-71 | Smart start-up frequency | 0.00–599.00 | Hz | 0.00 |
| 08-72 | Smart start-up acceleration time | 0.00–600.00 | Sec. | 3.00 |

- 🕮 When Pr.08-71≠0, smart start-up function is enabled.
- 🕮 The calculation of the smart start-up level is based on the percentage of PID deviation.
- 🕮 When PID feedback has overshoot at start-up, use smart start-up to reduce the overshoot of feedback.
- 🕮 The smart start-up function is activated once only at start-up.
- 🕮 When the smart start-up is enabled, it starts with Pr.08-71 frequency and Pr.08-72 acceleration time (the "acceleration time" in Pr.08-72 means the time that accelerates to Pr.08-71 frequency). When PID deviation is smaller than Pr.08-70, it switches back to normal PID control (switching to PID control makes the smart start-up frequency fill into PID's integral to keep the frequency continuous), as shown in Figure 3.

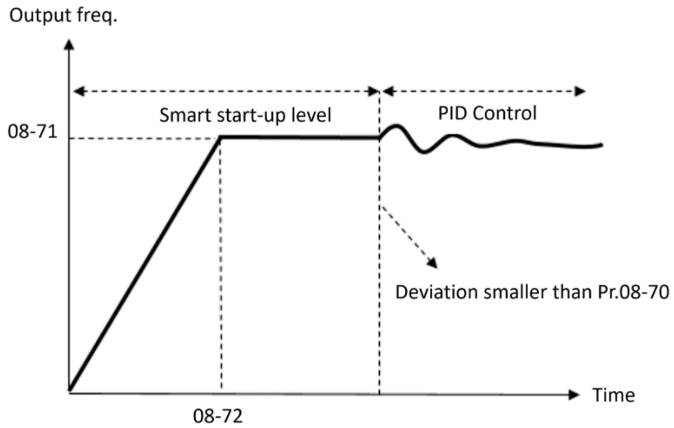



Figure 3 The process description for smart start-up and PID control

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-75 | PID2 parameter switch condition | 0: No switch<br>1: Auto-switch based on output frequency<br>2: Auto-switch based on deviation | N/A | 0 |
| 08-76 | PID2 parameter switch deviation 1 | 0.00–Pr.08-77 | % | 10.00 |
| 08-77 | PID2 parameter switch deviation 2 | Pr.08-76–100.00 | % | 40.00 |
| 08-31 | Proportional gain 2 | 0.00–500.00 | N/A | 1.00 |
| 08-32 | Integral time 2 | 0.00–100.00 | Sec. | 1.00 |
| 08-33 | Differential time 2 | 0.00–1.00 | Sec. | 0.00 |

- When Pr.08-65=0, the maximum output frequency Pr.01-00=60 Hz, the error is 100% and Pr.08-01=1.00, the output frequency is “1” times Pr.01-00 maximum output frequency, so the output frequency=60*100%*1=60 Hz. Calculation formula: Output frequency = Fmax (Pr.01-00) * Error % ((PID reference value (Pr.00-20/Pr.00-30) - PID feedback value (Pr.08-00)) * Pr.08-01.
- When Pr.08-65≠0, the internal calculation of P gain is reduced by 100 times, that is, when Pr.01-00=60Hz, error=100% and Pr.08-01=1.00, the output frequency is "0.01" times Pr.01-00 Fmax, so the output frequency=60*100%*0.01=0.6 Hz. Calculation formula: Output frequency = Fmax (Pr.01-00) * Error % ((PID reference value (Pr.08-66) - PID feedback value (Pr.08-00)) * Pr.08-01 * 0.01.
- For certain applications, one set of PID parameters cannot satisfy the needs of the entire running process. When this happens, use Pr.08-75 to enable the second set of PID parameter switch. The setting method for the second set of PID parameters (Pr.08-31–Pr.08-33) is the same as the first set of PID parameters (Pr.08-01–Pr.08-03).
- There are two ways to switch between the two sets of PID parameters, auto-switch based on frequency and auto-switch based on deviation. When you use auto-switch based on frequency and the output frequency is between Pr.01-07 and Pr.01-00, as shown in Figure 4, the PID parameter is the linear interpolation of these two sets of PID parameters. If you use auto-switch based deviation, as shown in Figure 5, and the deviation absolute value between the given and feedback is smaller than the PID2 parameter switch deviation 1 (Pr.08-76), the PID parameter uses the first set. If the deviation absolute value between the given and feedback is larger than the PID2 parameter switch deviation 2 (Pr.08-77), the PID parameter uses the second set. If the deviation absolute value between the given and feedback is between switch deviation 1 and switch deviation 2, the PID parameter is the linear interpolation of these two sets of PID parameters.

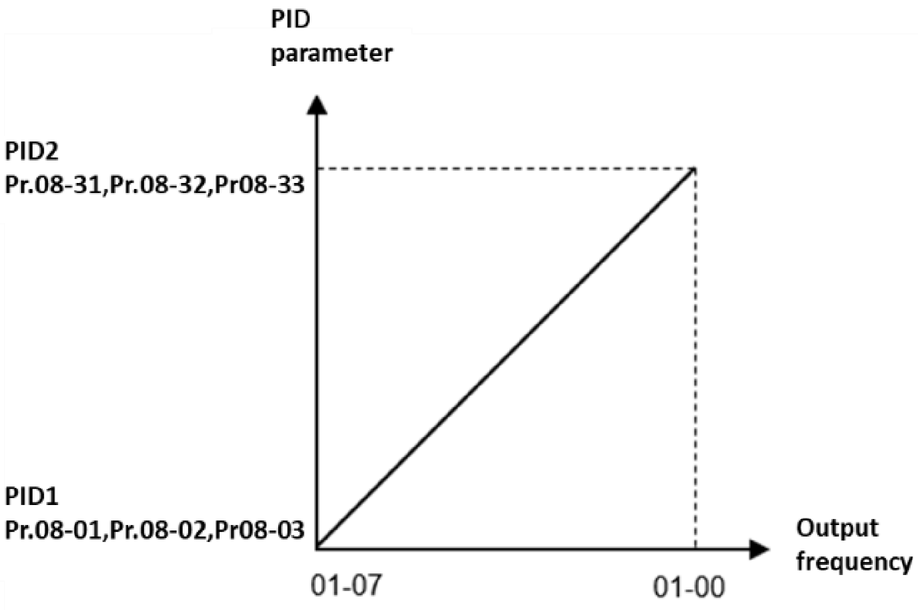


Figure 4 PID parameter auto-switches based on output frequency

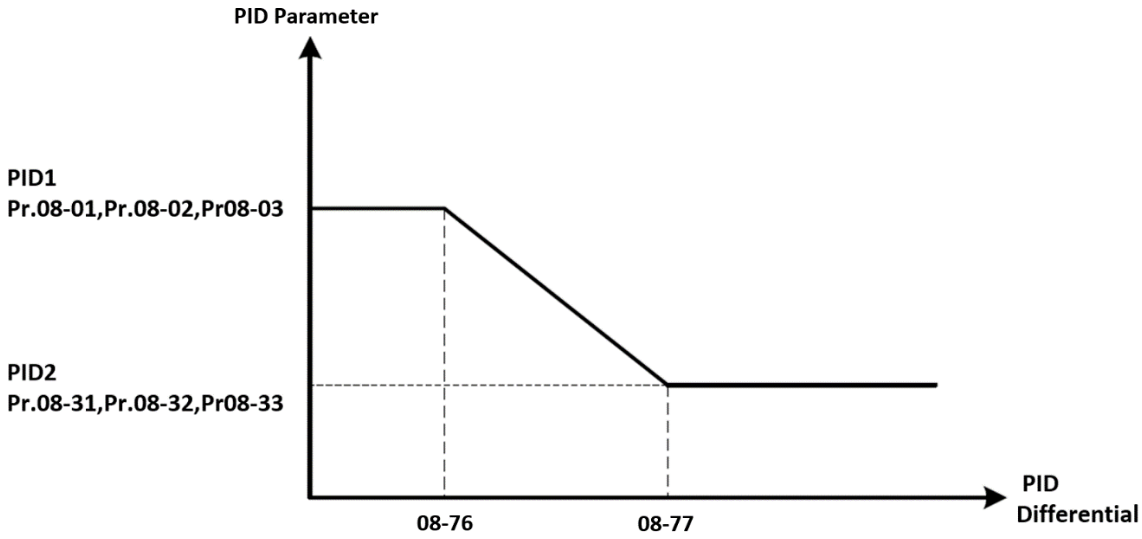


Figure 5 PID parameter auto-switches based on deviation

| Pr. | Explanation | Settings | Unit | Default |
|---|---|---|---|---|
| 08-78 | Allowed reverse running time after start-up | 0.0–6553.5 | Sec. | 0.0 |

- When Pr.08-78≠0, the allowed reverse running time after start-up function is enabled.
- If Pr.08-78 is set to 1 sec., PID control can change the running direction within 0–1 seconds of starting, and cannot change the running direction after 1 second of starting.

## 1-3 Macro and Procedure Setting

New function: 11: PID tension and 12: PID tension + Master and auxiliary in Macro / User-defined Macro

**13-00** Application Selection

Factory Setting : 00

Settings
- 00: Disabled
- 01: User-defined Parameter
- 02: Compressor
- 03: Fan
- 04: Pump
- 05: Conveyor
- 06: Machine tool
- 07: Packing
- 08: Textiles
- 09: PCB Machine
- 10: Logistics
- 11: PID tension
- 12: PID tension + Master and auxiliary frequency

Note: After you select the macro, some of the default values adjust automatically according to the application selection.

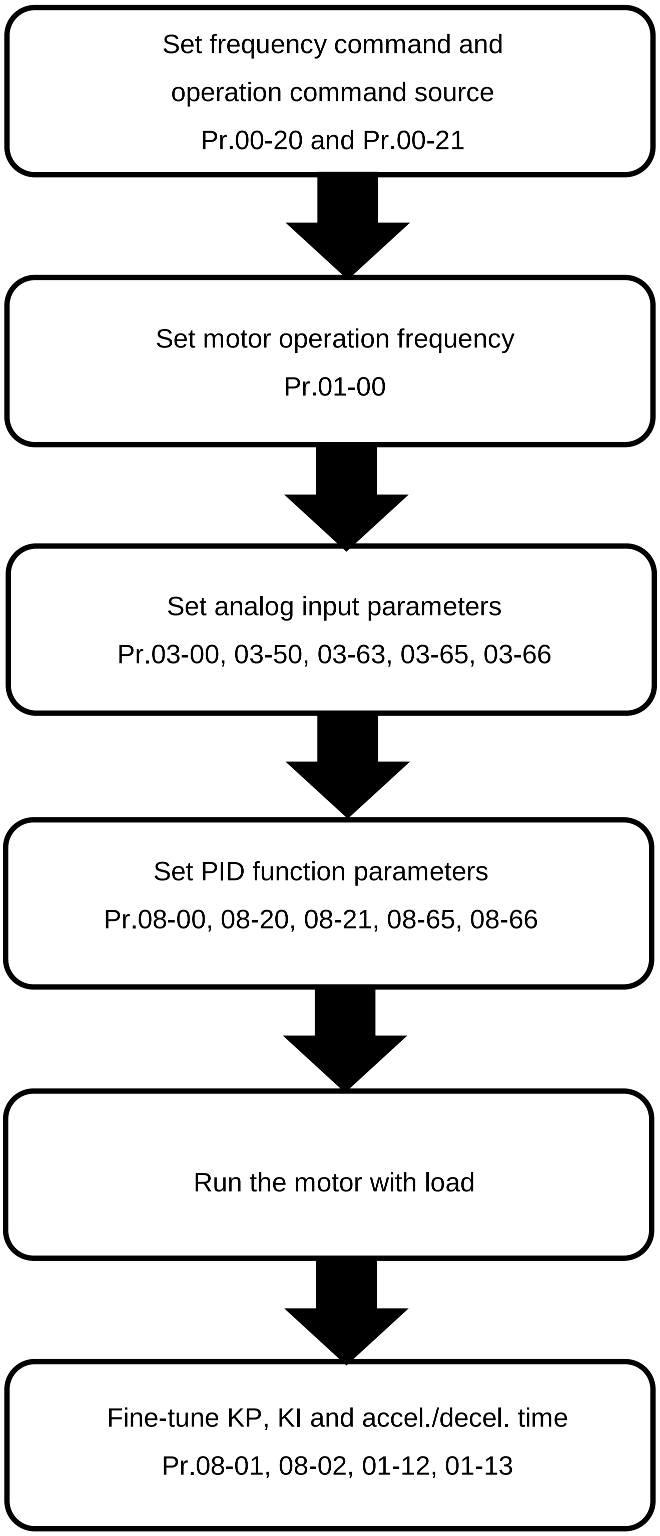
## PID Tension Control

Setting 11: PID tension

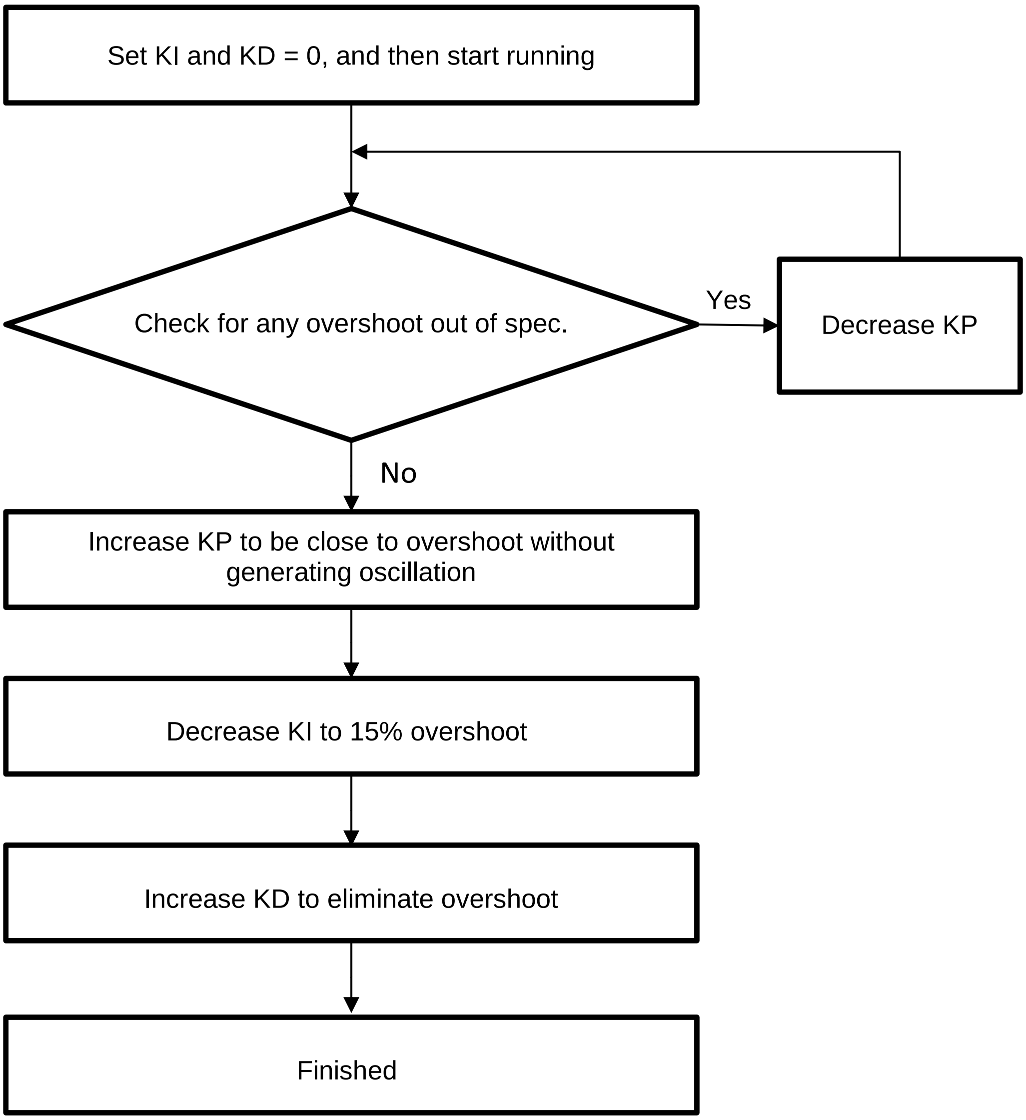
The table below shows the relevant PID tension application parameters.

| Pr. | Explanation | Settings |
|---|---|---|
| 00-20 | Master frequency command source (AUTO) | 9: PID |
| 00-21 | Operation command source (AUTO) | 1: External terminals |
| 01-00 | Maximum operation frequency of motor 1 | 60.00/50.00 Hz |
| 01-12 | Acceleration time 1 | 3 sec. |
| 01-13 | Deceleration time 1 | 3 sec. |
| 03-00 | Analog input selection (AVI) | 5: PID feedback signal |
| 03-50 | Analog input curve selection | 1: Three-point curve of AVI |
| 03-63 | AVI voltage lowest point | 0.00 V |
| 03-65 | AVI voltage mid-point | 9.99 V |
| 03-66 | AVI voltage proportional mid-point | 100.00% |
| 08-00 | Terminal selection of PID feedback | 1: Negative PID feedback: by analog input (Pr.03-00) |
| 08-01 | Proportional gain (P) | 10 |
| 08-02 | Integral time (I) | 1.00 sec. |
| 08-20 | PID mode selection | 1: Parallel connection |
| 08-21 | Enable PID to change the operation direction | 0: Operation direction can be changed |
| 08-65 | PID targe value source | 1: Pr.08-66 setting |
| 08-66 | PID target value setting | 50.00% |

Parameter setting process:



- Adjust AVI analog input three-point curve depending on the actual situation.
- Acceleration and deceleration time affects the adjustment result. If unstable situation still exists after adjusting PID, increase acceleration and deceleration time appropriately.
- If the error at start-up * KP gain (=output frequency) is not enough for the tension pendulum to restrain, it may cause wire breakage. In this case, increase the KP gain appropriately.
- Refer to the following flowchart for PID adjustment:



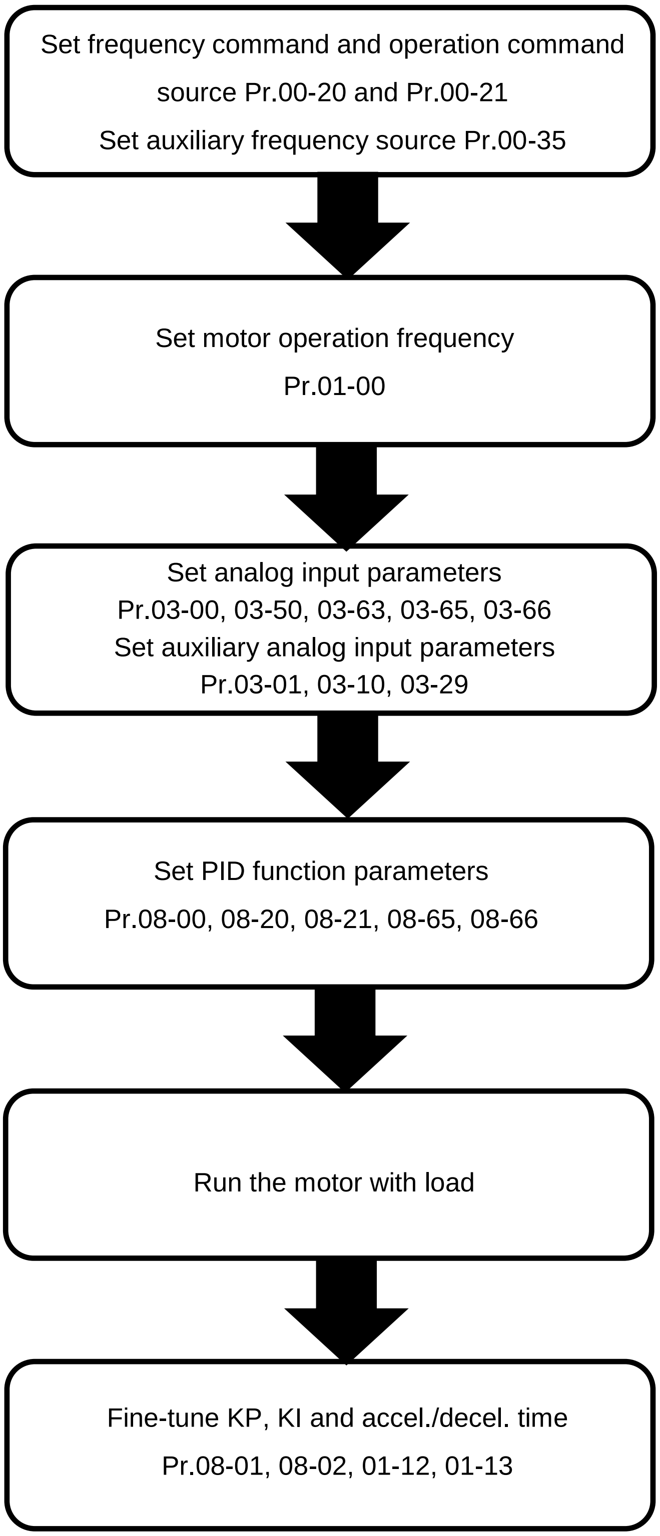
## PID Tension + Master and Auxiliary Frequency

Setting 12: PID tension + Master and auxiliary frequency

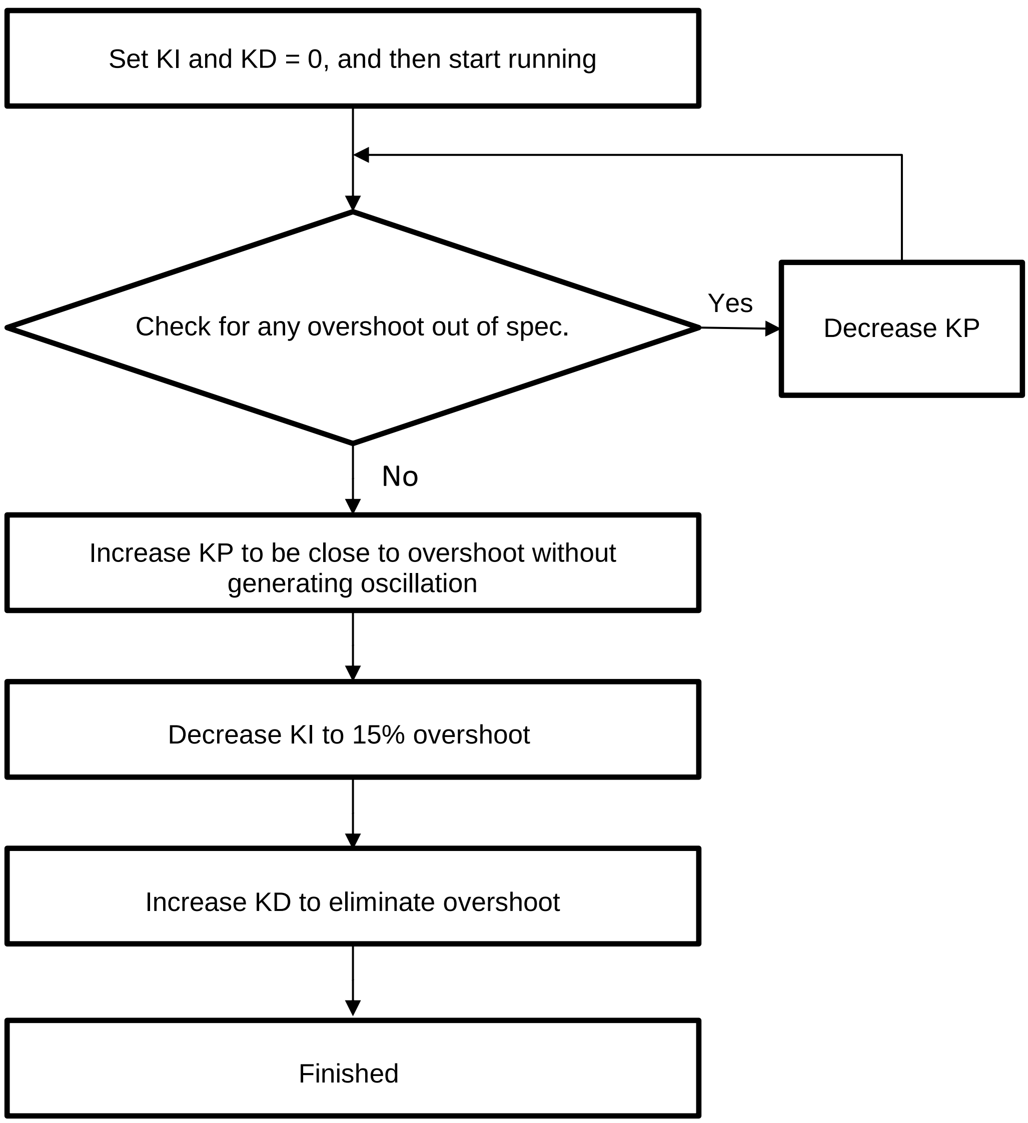
The table below shows the relevant PID tension and master and auxiliary frequency application parameters.

| Pr. | Explanation | Settings |
|---|---|---|
| 00-20 | Master frequency command source (AUTO) | 9: PID |
| 00-21 | Operation command source (AUTO) | 1: External terminals |
| 01-00 | Maximum operation frequency of motor 1 | 60.00/50.00 Hz |
| 01-12 | Acceleration time 1 | 3 sec. |
| 01-13 | Deceleration time 1 | 3 sec. |
| 00-35 | Auxiliary frequency source | 3: Analog input |
| 03-00 | Analog input selection (AVI) | 5: PID feedback signal |
| 03-01 | Analog input selection (ACI) | 12: Auxiliary frequency input |
| 03-10 | Reverse setting when analog signal input is negative frequency | 0: Negative frequency input is not allowed. The digital keypad or external terminal controls the forward and reverse direction. |
| 03-12 | Analog input gain (ACI) | 100.0% |
| 03-29 | ACI terminal input selection | 1: 0–10V |
| 03-50 | Analog input curve selection | 1: Three-point curve of AVI |
| 03-63 | AVI voltage lowest point | 0.00 V |
| 03-65 | AVI voltage mid-point | 9.99 V |
| 03-66 | AVI voltage proportional mid-point | 100.00% |
| 08-00 | Terminal selection of PID feedback | 1: Negative PID feedback: by analog input (Pr.03-00) |
| 08-01 | Proportional gain (P) | 10 |
| 08-02 | Integral time (I) | 1.00 sec. |
| 08-20 | PID mode selection | 1: Parallel connection |
| 08-21 | Enable PID to change the operation direction | 0: Operation direction can be changed |
| 08-65 | PID target value source | 1: Pr.08-66 setting |
| 08-66 | Setting for PID target value | 50.00% |
| 08-67 | Master and auxiliary reverse running cutoff frequency | 10.0% |

Parameter setting process:



Flowchart for PID adjustment:



# 2. Successful Application: Water-tank Wire Drawing Machine

## 2-1 Machine Working Theory

MS300 new function, tension control related parameter, optimizes low frequency torque performance, fast dynamic response and steady-state accuracy. Moreover, it provides two sets of PIDs to meet the needs for stable system operation in full speed range, making it easy to realize stable tension control in occasion for tension control with tension pendulum. Winding of the water-tank wire drawing machine is the core process in the control system for this equipment, and this process affects the quality of the steel wire directly.

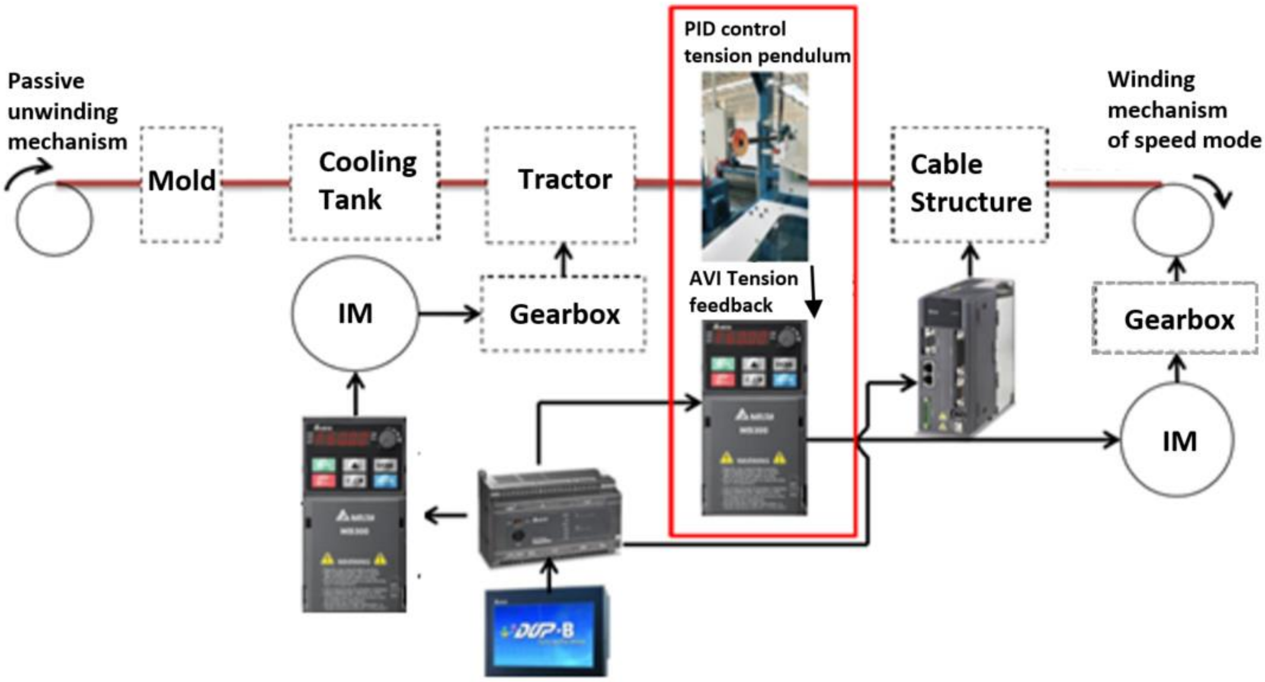
- Adopts tension pendulum adjustments. The tension during winding depends on the weight of the tension roller itself.
- Uses torque control. The tension during winding is determined by the torque given, and the wire tension may be imbalanced due to different winding diameters.

For highly crafted needed equipment like water-tank wire drawing machine, drive's PID correction is a commonly seen method for controlling tension pendulum adjustment. The basic requirements for water-tank wire drawing machine craft are as follows:

- Line speed 10 m/s at a minimum
- Stable tension control for both empty and full rolls
- Good low-frequency torque under full-volume large inertia for smooth starting and stable tension pendulum
- Stable tension pendulum during operation, starting and stopping (tension pendulum cannot be too high or too low)

## 2-2 Water-tank Wire Drawing Machine Structure

Water-tank wire drawing machine, consisting of many small production equipment in sequence, contains lots of drawing heads that can draw the steel wire to the required specification by gradually drawing and then putting the drawing head into water-tank. Because of this, the wire diameter changes after each drawing and the working line speed for each drawing head also changes accordingly. The winding uses a small-power motor to drag and the tension should be kept constant throughout the winding. If tension fluctuates, the winding on the winding wheel becomes uneven.



## 2-3 Site Condition and Results

### Optimization for pendulum starts at high point

× If you start the original PID control at high point, the pendulum falls dramatically to 25.4% at the lowest, and oscillation occurs when starting the pendulum, as shown in Figure 6.

✓ Considering the need for small gain at high speed, we optimize the characteristics of high speed and low speed by using two new parameters to realize two sets of PIDs. After new parameter adjustment, start with the same load. Then, the pendulum becomes stable and drops to 32.5% at lowest, as shown in Figure 7.

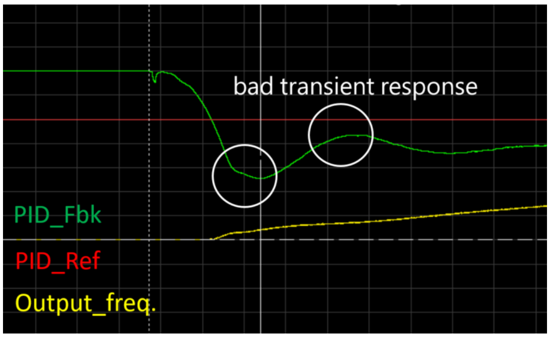



Figure 6


Figure 7

### Optimization for pendulum starts at low point

× If you start the original PID control at low point, the pendulum falls dramatically and overshot occurs when starting the pendulum, as shown in Figure 8.

✓ Using our new parameter, integral separation, and setting the integral intervention interval to 30% can significantly improve the overshoot and undershoot, as shown in Figure 9.


Figure 8

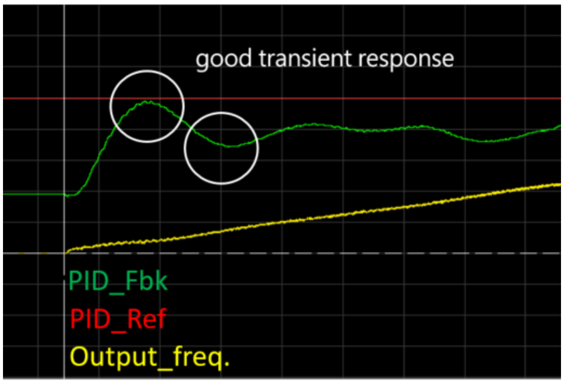



Figure 9

### Optimization for pendulum position (stopping optimization)

- ✗ If the output frequency decreases to 0, and at this time, the PID error is still negative, the pendulum is not in a good position, as shown in Figure 10.

- ✓ Using our new parameter, allowed reverse running time after start-up, (the reverse running function is enabled once start-up) can reduce the pendulum position to 53.2% at stopping, as shown in Figure 11.

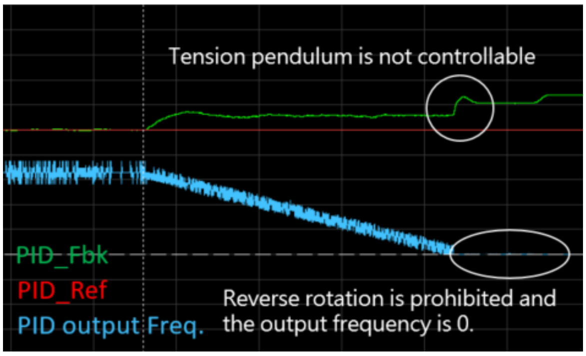



Figure 10

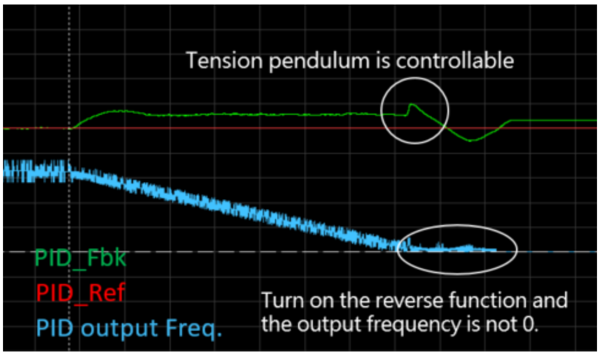



Figure 11

In consideration of the above adjustments and improvements, the MS300 is able to meet the craft requirement and achieve the best results. It is stable regardless of the coil size and diameter, and runs steadily even under critical condition like full roll or 5 m/s and 10 m/s line speed, as shown in Figure 12 and Figure 13.

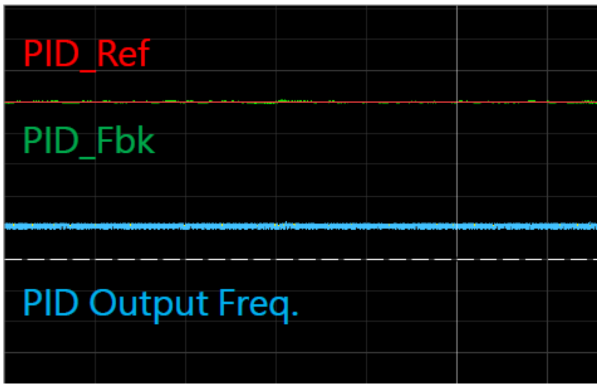



Figure 12

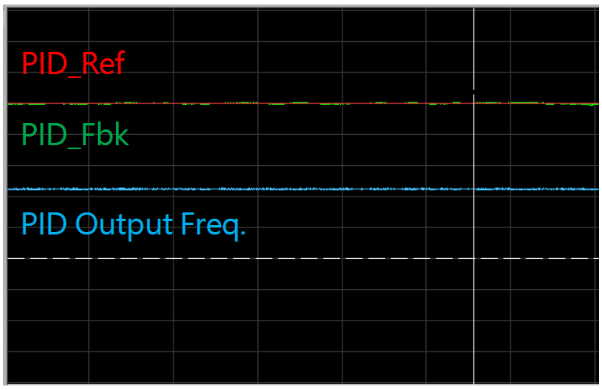



Figure 13