OPEN DRIVE

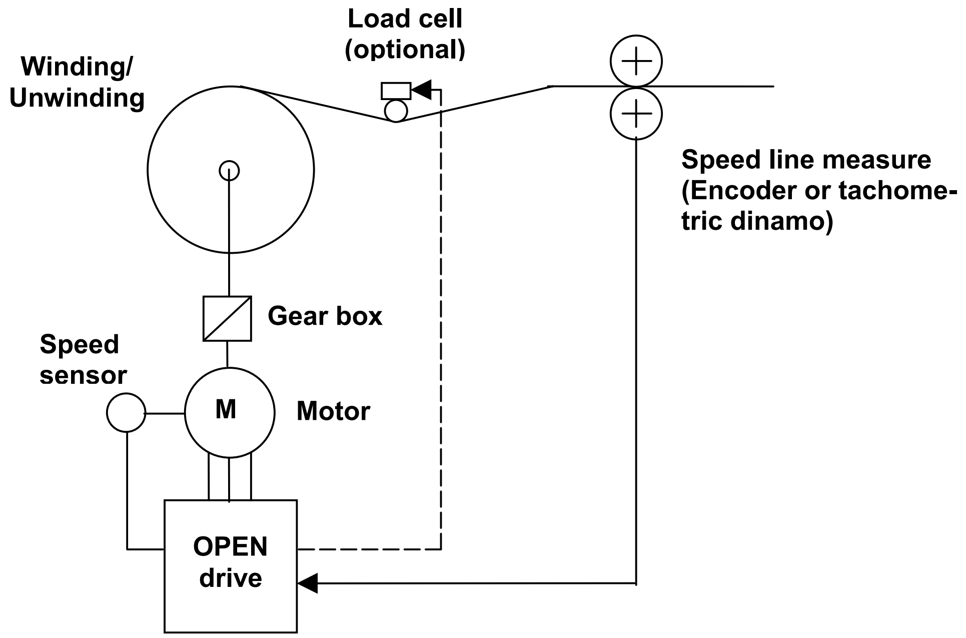
OPEN DRIVE

Application n°010
Tension control

INDEX

1. APPLICATION COFIGURATION 3
1.1 Application parameters 3
1.2 Application connections 4
1.3 Application logic inputs 4
1.4 Application analog inputs (unchangeables) 4
1.5 Application analog and monitor outputs 4
1.6 Application internal values 4
2. TENSION CONTROL 5
2.1 Adopted conventions 5
3. MEASURE OF THE SPEED LINE AND COMPUTING OF THE DIAMETER 6
3.1. Encoder (C91=0) 7
3.2. Tachometric dynamo (C91=1) 7
3.3 Diameter calculation 8
4 TENSION REGULATION 9
4.1 Tension reference 10
4.2 Direct tension control (with load cell) 10
4.3 Indirect tension control 10
4.3.1 Inertial load compensation 10
4.3.2 Frictions compensation 11
5 Working with speed Jog 11

The following application of the OPEN DRIVE is able to unwind or rewind a wire, keeping a constant tensile force on the material, in indirect or direct mode if it's available a load cell. The drive follows the line speed taken by a tensioney on which runs a wire (with no sliding between them); the signal can be taken by an encoder positioned on the tensioney shaft or by a tachometric dynamo. The unwinder/rewinder is completed with the calculation of the servo diameter in order to follow in a really fast way the line signal.



1. APPLICATION COFIGURATION

1.1 Application parameters

PAR	DESCRIPTION	RANGE	DEFAULT	Normaliz. unit	Internal Rappr.
P180	Max motor speed ($n_{AVV\ MAX}$)	100 ÷ 30000	2037	rpm	1
P181	Measurement frequence for channel at max line speed	0.01 ÷ 199.99	18.11	KHz	100
P182	Voltage corresponding to the max line speed	2500 ÷ 10000	10000	mV	1
P183	Min. line speed for the diameter calculation	0.0 ÷ 100.0	5.0	% v_{MAX} linea	16383
P184	Tension reference	0.0 ÷ 200.0	50.0	% tension max	16383
P185	Min to Max roll diameter ratio	6.6 ÷ 100.0	50.0	% dmax	32767
P186	Maximum cell PI output	0.0 ÷ 200.0	100.0	% τ nom mot	4095
P187	Motor + roll with min diameter start-up time	0.1 ÷ 3000.0	1.0	seconds	10
P188	Motor + roll with max diameter strat-up time	0.1 ÷ 3000.0	20.0	seconds	10
P189	II° order filter time constant on speed line	0.0 ÷ 200.0	100.0	ms	10
P190	Stationary friction torque	0.0 ÷ 200.0	2.0	% τ nom mot	4095
P191	Friction torque to the maximum motor speed (P65)	0.0 ÷ 200.0	5.0	% τ nom mot	4095
P192	Min. number of pulses to calculate the diameter	0 ÷ 19999	19000		1
P193	Start diameter (dstart)	0.0÷200.0	50.0	% dstart/dmax	16383
P194	Filter on the correction term for diameter calculation	0.0 ÷ 1999.9	936.0	ms	10
P195	Voltage load cell corresponding to max tension	2500 ÷ 10000	10000	mV	1
P196	Kp load cell PI, proportional gain	0.5÷100.0	1.0		10
P197	Ta load cell PI, lead time constant	0.1÷1500.0	100.0	ms	10
P198	Torque boost	±200.0	0.0	% τ nom mot	4095
P199	Tf load cell PI, first order filter	0.0 ÷ 25.0	1.0	ms	10

1.2 Application connections

CON	DESCRIPTION	RANGE	DEFAULT	DEF. Meaning	Internal Rappr.
C90	Tension reference: digital (P184) or analog (A.I.2)	0,1	0	Digital Ref.	1
C91	Line Encoder or tachometric dinamo (A.I.1)	0,1	0	Encoder	1
C92	□iverse line speed measured	0,1	0	direct	1
C93	Enable load cell control	0,1	0	Not enable	1
C94	Enable inertia compensation	0,1	0	Not enable	1
C95	Enable friction compensation	0,1	0	Not enable	1
C96	Enable I30 logic input	0,1	0	Not enable	1
C97	Enable torque boost	0,1	0	Not enable	1

1.3 Application logic inputs

INPUT	Logic function assigned
I29	Preset initial diameter value (P184) on the high level (*"Preset speed ratio"*)
I30	Set positive motor direction (C76) only if C96=1
I31	Enable torque boost

1.4 Application analog inputs (unchangeables)

INPUT	Meaning
A.I.1	Tachometric dinamo on the line
A.I.2	Analog tension reference
A.I.3	Load cell Feedback

1.5 Application analog and monitor outputs

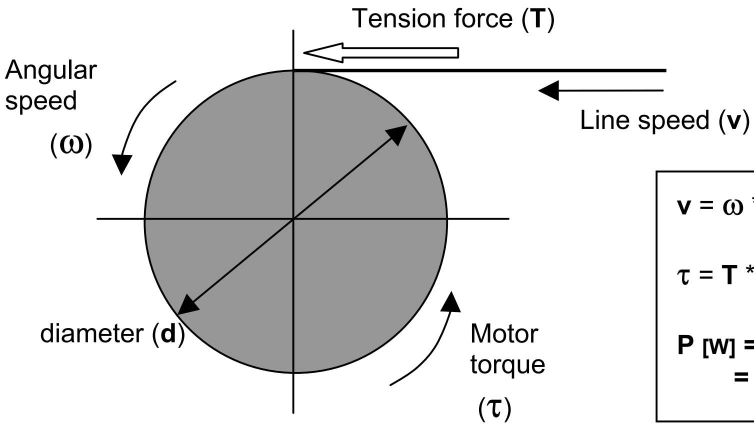
OUTPUT	INTERNAL VARIABLE ASSIGNED	Nor. unit	Internal rappr
O53	Calculated diameter	% d/dmax	16383
O54	Active diameter	% d/dmax	16383
O55	PID cell output	% tension max	16383
O56	Torque limit imposed by tension control	% τ nom mot	4095
O57	Filtered line speed	% n_{MAX} line	16383
O58	Motor speed pulses counter		1
O59	Line speed pulses counter		1
O60	Line speed	% n_{MAX} line	16383
O61	PID cell integral part memory	% tension max	16383
O62	Inertial load compensation	% tension max	16383
O63	Friction compensation	% τ nom mot	4095

1.6 Application internal values

INT	INTERNAL VARIABLE ASSIGNED	Nor. unit	Internal rappr
d50	Filtered line speed	% n_{MAX} linea	16383
d51	Calculated diameter	% d/dmax	16383
d52	Active diameter	% d/dmax	16383
d53	Tension reference	% tension max	16383
d54	Losad cell Feedback	% tension max	16383
d55	Cell PID output	% tension max	16383
d56	Torque limit imposed by tension control	% τ nom mot	4095
d57	Inertial load compensation	% tension max	16383
d58	Friction compensation	% τ nom mot	4095

2. TENSION CONTROL

The main target of this application is to control winder and unwinder drives, assuring a constant tension value on the material, relating to the diameter's variation and the line's speed one.



$$v = \omega * d/2$$

$$\tau = T * d/2$$

$$P_{[W]} = \omega_{[rad/s]} * \tau_{[Nm]} = v_{[m/s]} * T_{[N]}$$

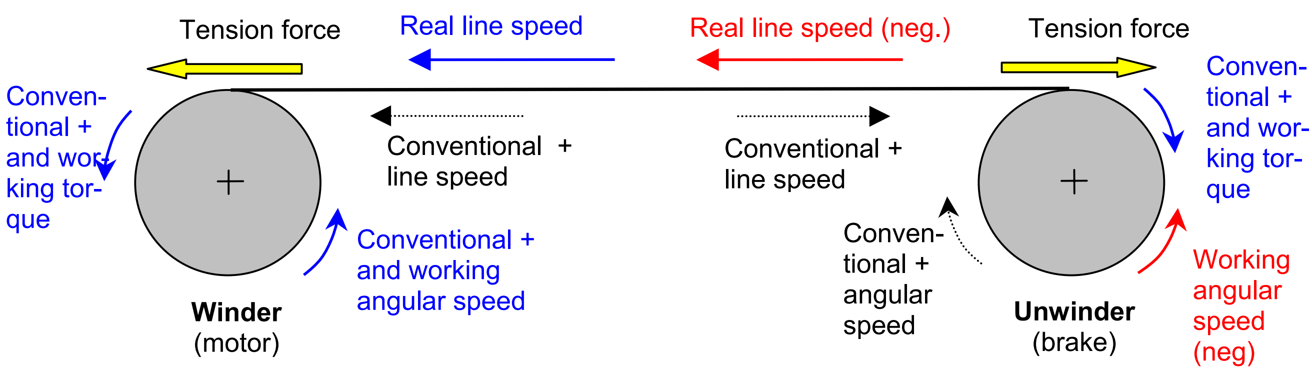
The line's speed is kept constant by the pilot drive of the machinery (the winder/unwinder is controlled in torque instead), so that when the roll diameter varies, it will be necessary that the angular speed of the winder/unwinder varies as well, to follow it. By reading the ratio between the line's speed and the angular speed it will be possible to estimate the diamter's value moment by moment. Once the diameter is known it will so be possible to calculate which torque the motor needs to supply in order to obtain the desired tensioning.

Tensioning's control is defined **direct** if there is a transducer of the tensioning's strength (load's cell) which will supply a feedback to the tensioning's regulator so that by a PI regulator it is possible to obtain the exact desired tensioning.

Tensioning's control is defined **undirect** if there is not a transducer of the tensioning's strength, so that the tensioning's regulator will work in open loop. Especially in this situation it is really important to balance correctly the components of the supplied torque which will not take part to the effective tensioning (frictions' torque and inertial ones).

2.1 Adopted conventions

The adopted conventions ensure the correct operation both in winder and unwinder mode without any configuration:



Like it’s possible to see in the preceding figure, the follow convetion are adopted:

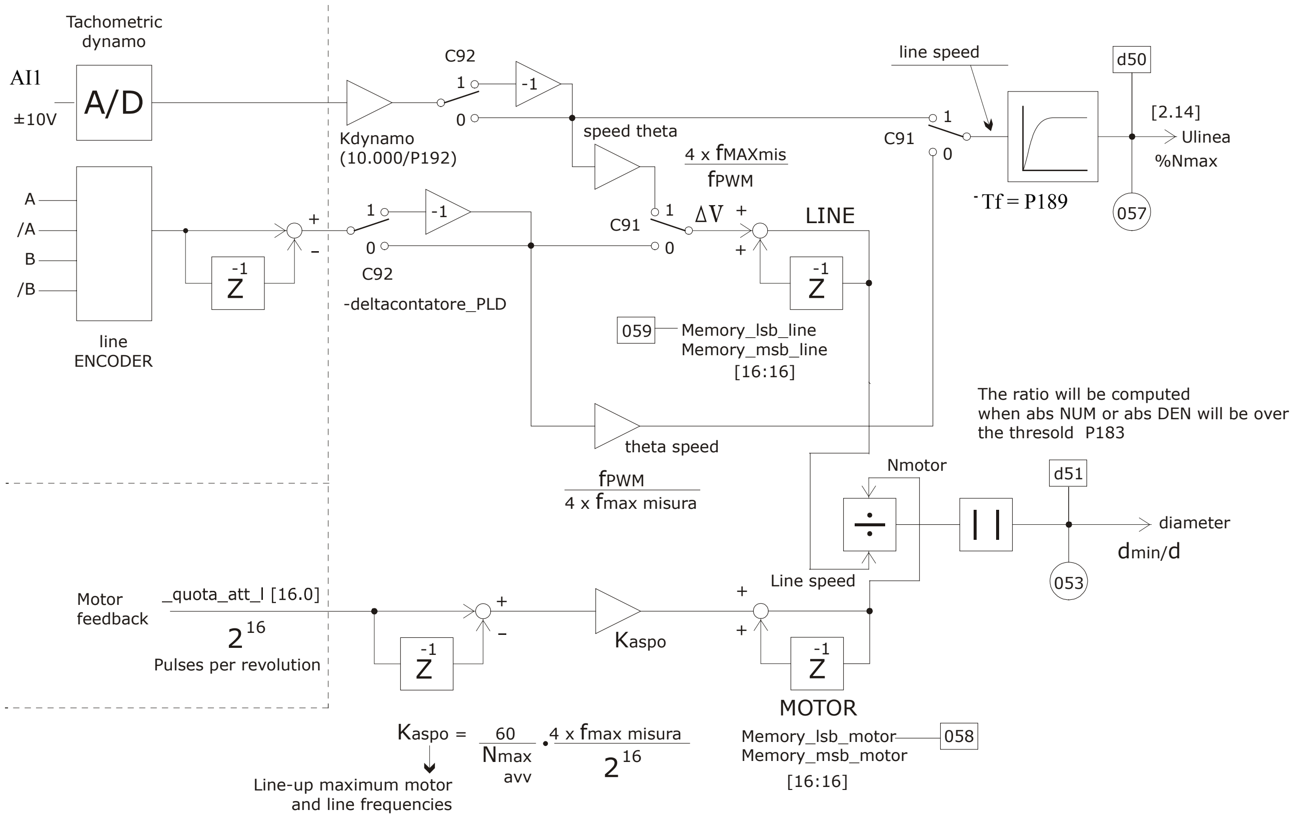
- The direction of the positive torque supplied by the motor is the one that produces the tensioning's strength in the expected direction.
- Line's speed is positive when the direction is going to the rool's:
  - For the winder line's speed of work is positive
  - For the unwinder line's speed of work is negative
- The angular speed of the rool's motor needs always to be concordant with the line's speed.

Thanks to these conventions the rool's motor will always work with a supplied positive torque, it will not be necessary to set the winder/unwinder working mode, because it will be enough to check the direction of the line's speed (positive for winding and negative for unwinding) and will be correct the inertial and friction compensation terms

During drive starting-up the user has to impose:

1. The line speed measured has to be positive when the material is going on the roll. Eventually works on **C92** connection for invert the sign.
2. The angular speed of the rool's motor needs always to be concordant with the line's speed. Eventually works on **C76** for invert the positive direction.

3. MEASURE OF THE SPEED LINE AND COMPUTING OF THE DIAMETER



The line speed can be measured by using a tachometric dynamo or by having a digital signal coming from an Encoder; the selection is made setting rightly the connection **C91** : if 0 the control manages a signal from Encoder, if 1 it manages an analog signal (connected to the A.I.1) coming from a tachometric dynamo.
In both cases thanks to the connection **C92=1** the speed sign of measured line can be reversed.
About parameterisation it is necessary to correctly set the parameters from **P180** to **P182**, due to the fact that the work will be based on the percent of this values.
The data that has to be written in **P180** it is the maximum speed of the motor of the unwinder/rewinder in rpm.

Note : the maximum line speed in m/min (Vel_linea $_{MAX}$), the minimum diameter of the winder in m (dmin) and the reduction ration (R), the revolution speed of the motor in rpm (n avv $_{MAX}$)
It will be:

$$n_{avv\ MAX\ [rpm]} = \frac{Vel\_linea_{MAX[m/min]} \cdot R}{\pi \cdot d\min[m]}$$

E. g. :

Vel_linea $_{MAX}$ = 400m/min
d min = 0,3m
R = 4,8

} n avv $_{MAX}$ = 2037 rpm → P180

The other two parameters depend on the feedback type connected to the line :

3.1. Encoder (C91=0)

In this case it is necessary to set the parameter **P181** in KHz the frequence for channel related to the maximum line speed.
Note : the maximum line speed in m/min (Vel_linea $_{MAX}$), the diameter of the pulley measured in m (dpul) and the number pulses per revolution of the Encoder N_{ENC} , the maximum measure frequence for channel, will be :

$$f_{mis\ MAX\ [Hz]} = \frac{Vel\_linea_{MAX[m/min]}}{60} \cdot \frac{N_{ENC}}{\pi \cdot d_{pul}[m]}$$

E. g. :

Vel_linea $_{MAX}$ = 400m/min
dpul = 0,12m
N_{ENC} = 1024 ppr

} f mis $_{MAX}$ = 18,11 KHz → P181

Due to the fact that all the rising edges of the Encoder signal are computed, the maximum frequency managed in the internal part of the converter is 4 times the one reported in P181. The pulses counter will be refreshed with this frequency and the diameter will be computed when the pulses accumulated will be over the threshold reported in P192.

3.2. Tachometric dynamo (C91=1)

In this case it is necessary to set in the parameter **P182** in mV the voltage produced by the tachometric dynamo related to the maximum line speed.

Not having any limit about the internal representation of the line frequency related to the maximum speed, the parameter **P181** has been chosen to set it. So the maximum line speed reported by the tachometric dynamo will correspond *internal* line frequency equal to 4 x P191 KHz. (this obviously values only for the diameter computation, that will be done every time the pulses accumulated will be over the threshold reported in P183).

3.3 Diameter calculation

The diameter's calculation is made by the ratio between the rotation's speed of the motor and the line's speed.
Both speeds re managed in frequency and there is an internal coefficient (Kaspo) used to align the two frequencies when the line speed is at maximum value with minimum roll diameter: in that case the motor runs to its maximum speed (P180). So in this way it will be possible to measure the roll diameter respect to its minimum value.
In order to improve the precision the work will be done in space and it is possible to set in parameter **P192** the minimum pulses' number to refresh the calculation.
P192's choice is made as a trade-off between:

refresh's time of the measurem (P192 low) ←→ measurement resolution (P192 high)

For having a good resolution the threshold has to be greater than 1000 pulses but the diameter upgrade cannot be to slow especially for thick rolled materials: the right choise depends on the application.
The following considerations are important if the diameter changes quickly, on the contrary it is possible to leave P192=19000 (default) that means to work with the maximum resolution.

On diameter calculation, the line pulses are the first to reach the P192 threshold because the line and motor frequency are equal only with minimum diameter, in the other case the line frequency is the greatest.

Material pulses per meter **Im** = $\frac{\text{fline} \times 4}{\text{v line max}/60}$ with f line = line frequency measured in Hz

v line max = max line speed in m/min

Material lenght to refresh the diameter **Lm** = $\frac{\text{Threshold}}{\text{Pulses per meter}} = \frac{\text{P192}}{\text{Im}}$ meter

The worst case is with minimum roll diameter, because with high motor speed there will be more turns and therefore the diameter changes more quickly:

Maximum roll revolutions **n giri** $_{\textbf{MAX}}$ = $\frac{\text{Material lenght to refresh}}{\text{Minimum circumference}} = \frac{\text{Lm}}{\pi \times \text{dmin}} = \frac{\text{P192}}{\text{Im} \times \pi \times \text{dmin}}$

The bond raises from how many rool's revolutions can be tolerated before the diameter calculation is refreshed and this set the upper threshold limit, while the lower limit (1000) is imposed by resolution:

$$1000 \leq \text{P192} \leq \text{Pulses per meter} \times \text{Maximum roll revolutions} \times \text{Minimum circumference} = \text{Im} \times \text{n giri}_{\text{MAX}} \times \pi \times \text{dmin}$$

The minimum diameter is a process data, the maximum roll revolutions are imposed like bond on diameter refresh time and the Pulses per meter depends on the line speed measure.
If the condition isn't respected it will be necessary to increase the material pulses per meter or increasing the line Encoder resolution or decreasing the measuring pulley diameter.

The diameter periodically computed is shown in the internal value **d51** in percent of maximum diameter.
Every new data will be used in the servodiamter correction only if the line speed (**d50**) is over a threshold set in the parameter **P183** (in % of the maximum line speed).
The real diameter used in tension control is shown the internal value **d52** in percent of maximum diameter.

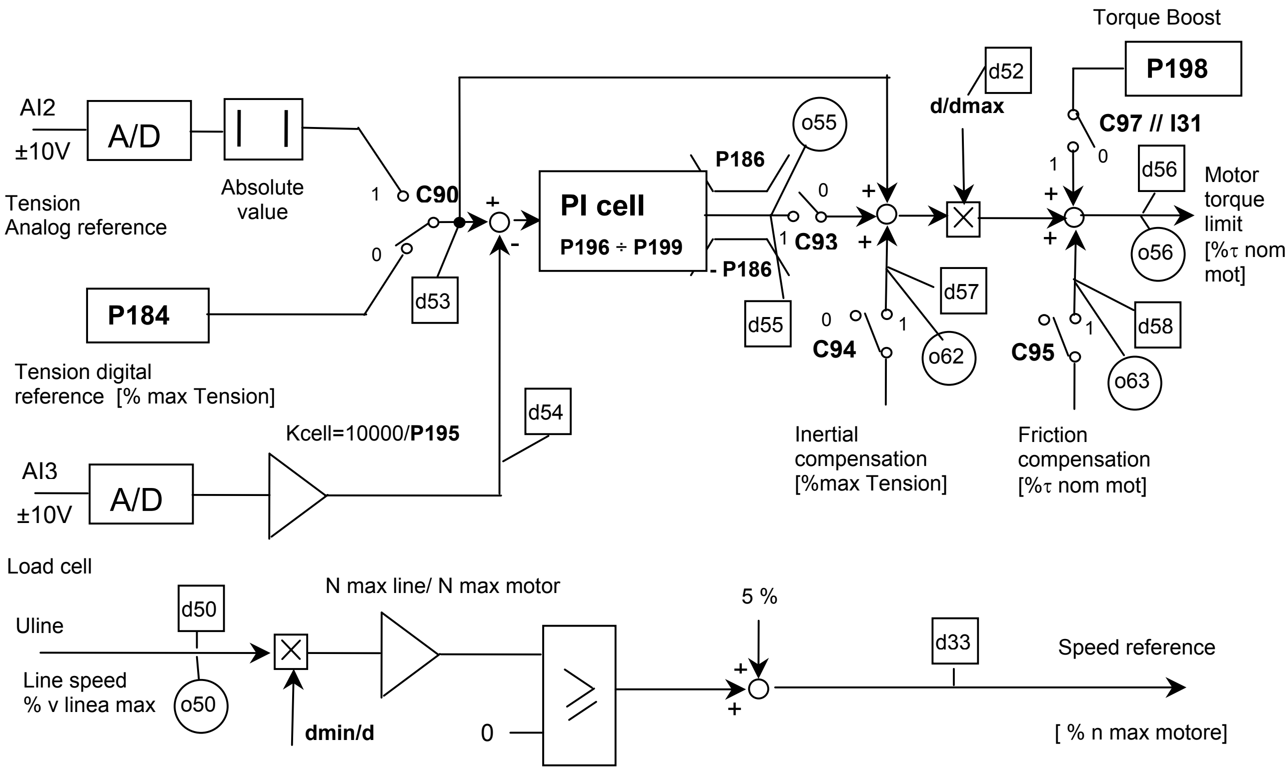
It is possible to force the initial value of the diameter by using the logic input **I29** (“Preset speed ratio”): on the high level the value set in the parameter **P193** is set in the actual diameter.

In order to have a slowly correction of the servodiameter , specially if the initial data is different from the real one, there is a filter of the 1st order with time constant settable in ms in **P194.**

NB: In the tension control is important to know also the ratio between the actual diameter and its maximum value. With diameter calculation it’s possible to measure the actual diameter referred to its minimum value, so it’s very important to set correctly the parameter **P185** that define the ratio between minimum and maximum diameter value.

4 TENSION REGULATION

The tension regulation is a roll motor torque control that uses the diameter to calculate the torque necessarry to obtain the force desidered. In our implementation the motor is controlled in speed, working on torque limit to regulate the tension.



This solution gives the following advantages:

- It’s possibile to have a speed soft start with low speed regulator gains
- When the torque limit is reached, automatically the speed regulator proportional gain is increased 10 times for follow quickly the torque reference variation
- If the material is broken the motor runs only at 5% of maximum speed

4.1 Tension reference

The tension reference is in percent of maximum tension and can be shown in the internal value d53.

The maximum tension is : $T_{MAX}[N] = \frac{\tau_{nom}[Nm] \times R}{d_{MAX}[m]/2}$ and $T_{MAX}[Kg] = \frac{T_{MAX}[N]}{9,81}$

For example:

τ nom = 35Nm ; R = 15 ; d_{MAX} = 800mm → T_{MAX} = 1312,5N = 133,8 Kg

The tension reference can be digital setting the parameter **P184** or analog using AI2 input (absolut value).
The **C90** connection is used to choose the active reference : 0 for digital, 1 for analog.

4.2 Direct tension control (with load cell)

To enable the direct tension control set **C93=1**. In this case it's used a load cell, its voltage feedback must be conected to analog input A.I.3. With parameter **P195** is possible to set the input voltage corresponding to the maximum tension desidered. In the internal valur **d54** is shown the load cell feedback in percent of maximum tension.

NB: keep attention to the load cell feedback sign. The positive sign must correspond to a force in the correct working direction for unwinder/winder.

In the PI input there is a first order filter with time constant set in ms in **P199**.
The proportional gain is set in **P196**, the lead time in ms in **P197**. The PI output is limited by parameter **P186**.
The PI has an anti wind-up function to avoid to store the error in the memory when the output is limited.

In the direct tension control are not so important to compensate friction and intertial loads, this compensations however can be used like feedforward compensations.

4.3 Indirect tension control

To enable the indirect tension control set **C93=0.** In this case the tension control is in open loop so that it is highly important to estimate correctly the diameter's value and to compensate the effective real loads.

4.3.1 Inertial load compensation

In the speed transients a part of motor torque is used by the inertial loads , therefore this terms is function of total inertia and roll inertia changes with the diameter.
To compensate correctly the inertial loads it's necessary to set the following parameters:

- **P187** = Fixed part start-up time
  This is the time in seconds necessary to the fixed load (motor+ gear box+roll with minimum diameter) to reach the maximu speed (P180) with the nominal motor torque.

- **P188** = Maximum load start-up time
  This is the time in seconds necessary to the maximum load (motor+ gear box+roll with maximum diameter) to reach the maximu speed (P180) with the nominal motor torque.

- **P189** = II° order filter time constant on speed line
  The inertial load compensation is proportional to the speed derivate so it's very important to filter the speed line to avoid a big noise on the compensation term.

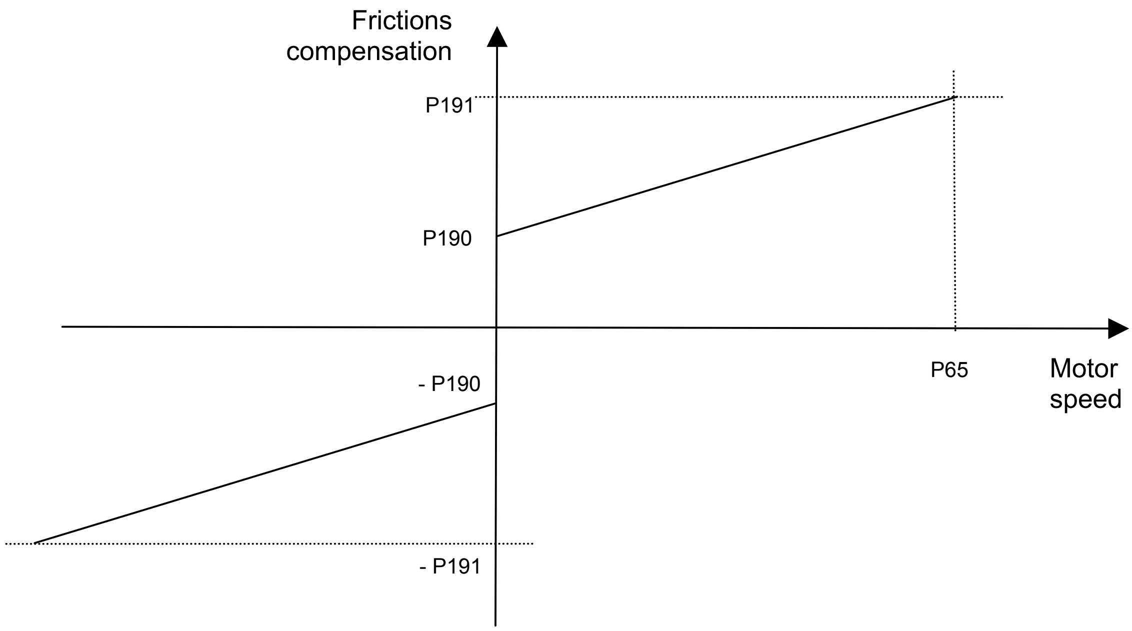
The inertial load compensation has to be enable with **C94=1**. It's possible to shown the compensation term in percent of maximum tension in the internal value **d57** and in the analog output **o62**.

4.3.2 Frictions compensation

A part of motor torque is used to win the frictions.
To compensate correctly the friction loads it's necessary to set the following parameters:

- **P190** = Stationary friction torque in percent of nominal motor torque
- **P191** = Friction torque to maximum motor speed (P65)

This is the compensation characteristic:



The frictions compensation has to be enable with **C95=1**. It's possible to shown the compensation term in percent of nominal motor torque in the internal value **d58** and in the analog output **o63**.

5 Working with speed Jog

Setting **C24=1** or **I05=H** it's possible to bypass the tension regulation and give to the motor a digital speed reference imposed in parameter **P07** in percent of maximum motor speed (P65).