LHC Collimators for Phase 1

Direct and reverse torque required for different collimator configurations

LHC Collimator Review 04/11/2005

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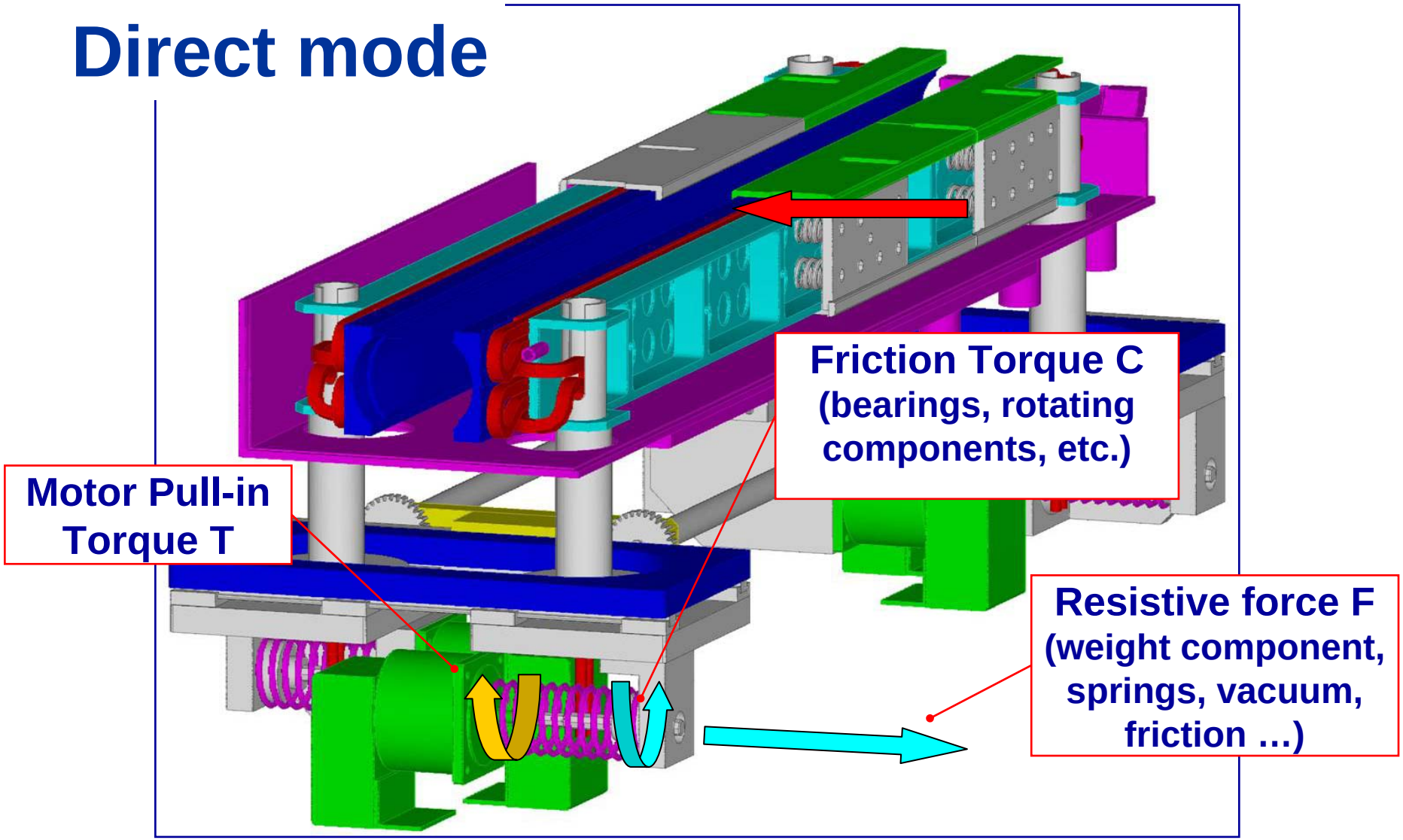
Torque calculations

Outline

- Actuation system layout
- Assumptions and hypotheses
- Some formulas
- Minimum motor torque required for direct motion (pull-in torque)
- Maximum admissible residual torque for back-drive motion (detent torque)
- Outlook and risks

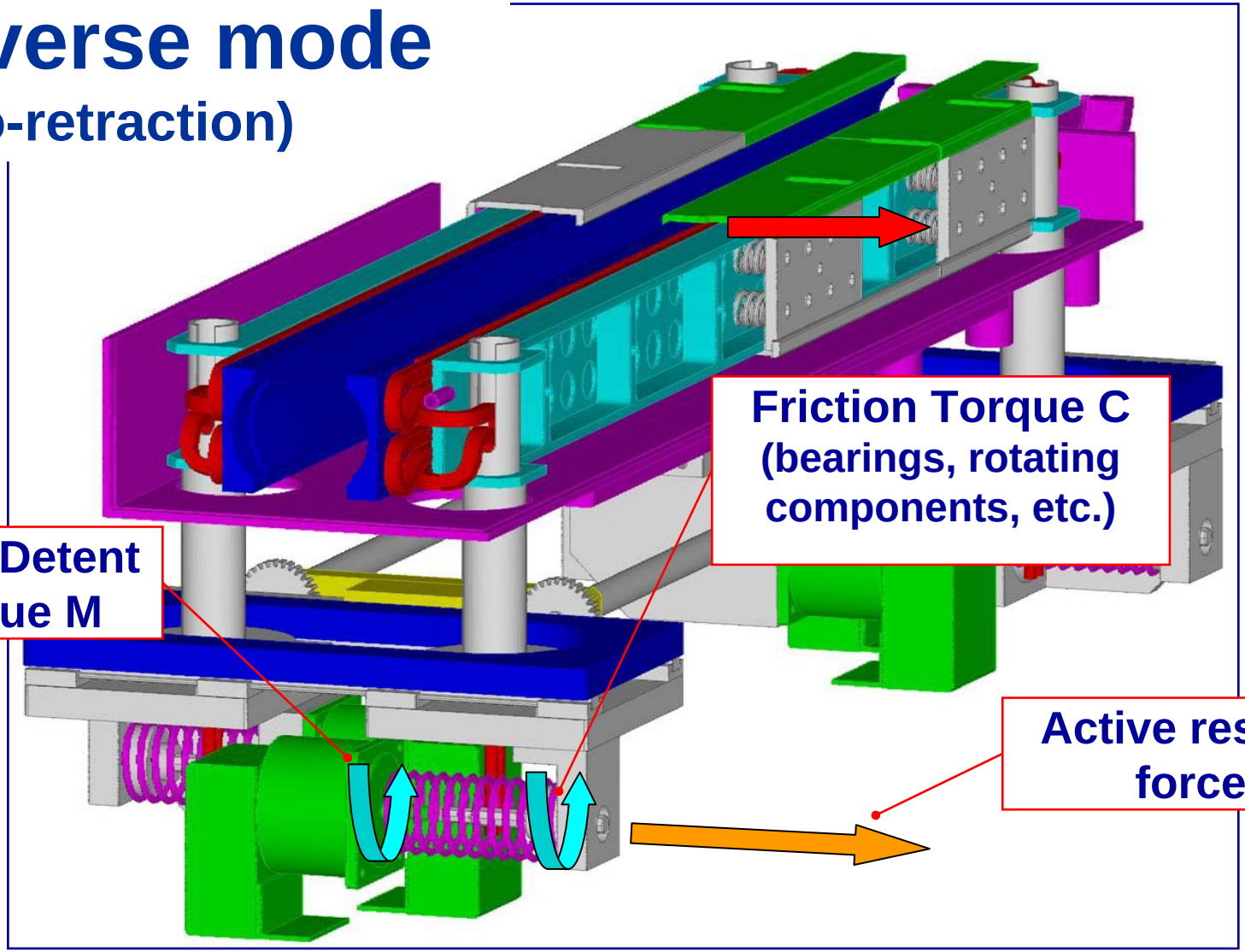
Actuation system layout

Direct mode



Actuation system layout

Reverse mode
(auto-retraction)



Design data and assumptions

- **Motor specifications:**
  - 400 steps/rev hybrid stepping motor
  - 3.5 Nm Nominal Torque - 80 mNm maximum Detent Torque
- **Re-circulating roller screw**
  - Diamter (d) 12mm –lead (p) 2mm – efficiency (η) 0.67
  - Strokes: maximum 35 mm – To beam axis 30 mm – Nominal position 25 mm
- **Springs (two versions)**
  - Wire Ø5 – K=5.15 N/mm – Preload=75mm
  - Wire Ø6.3 – K=12.98 N/mm – Preload=55mm
- **Effects taken into account:**
  - Spring loads
  - Weight of jaw and table assembly – moments of inertia of rotary parts
  - Effect of bellow (both elastic and vacuum)
  - Ball bearing friction
  - RF contacts friction
  - Table friction
  - No safety margins!!

Torque calculations

Some basic formulas

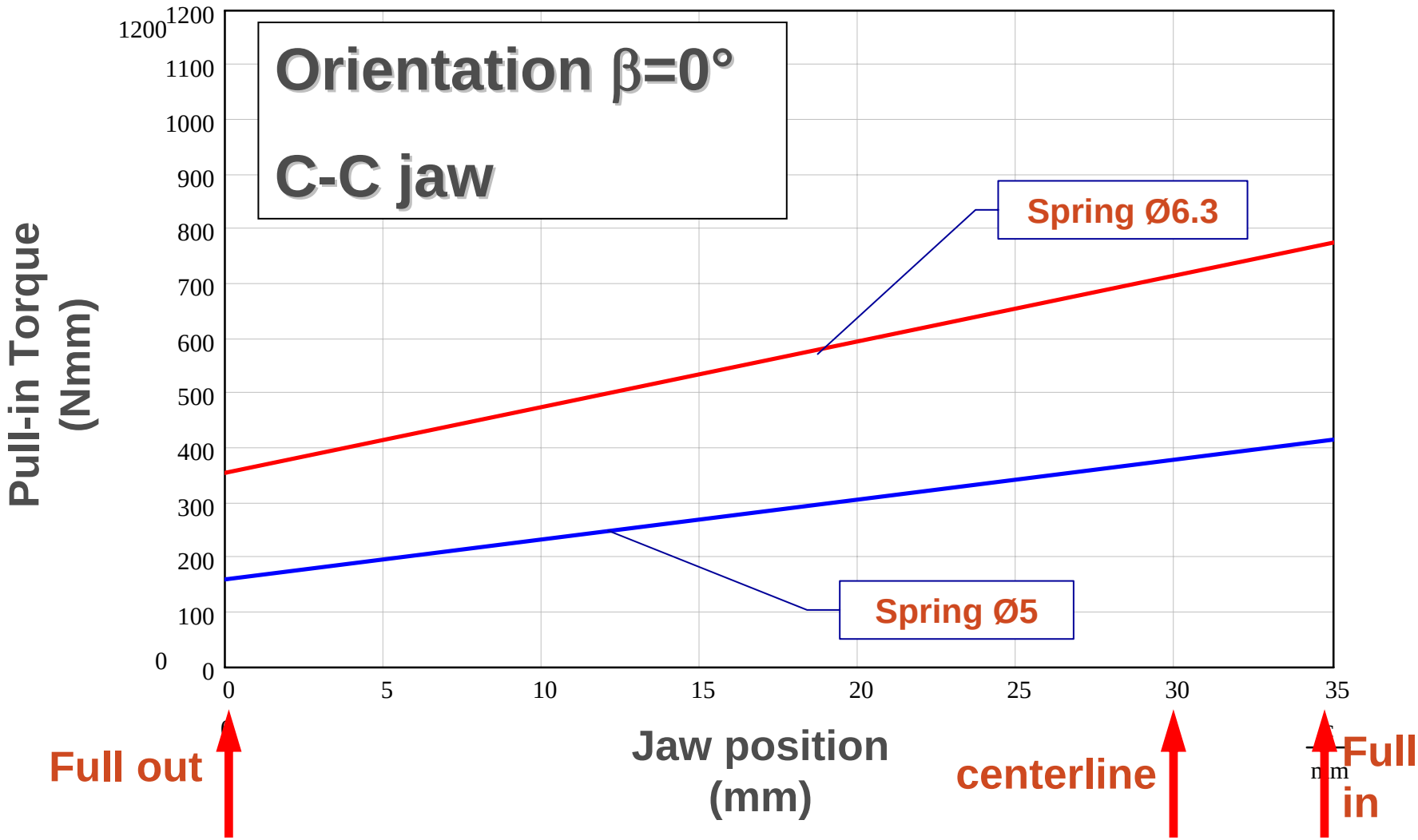
- **Practical direct efficiency:** $\eta_p = 0.9\eta = 0.6$
- **Reverse screw efficiency:** $\eta' = 2 - \frac{1}{\eta} = 0.5$
- **Required torque for direct drive:**

$$T = \frac{F(x)p}{2\pi\eta_p} + M$$

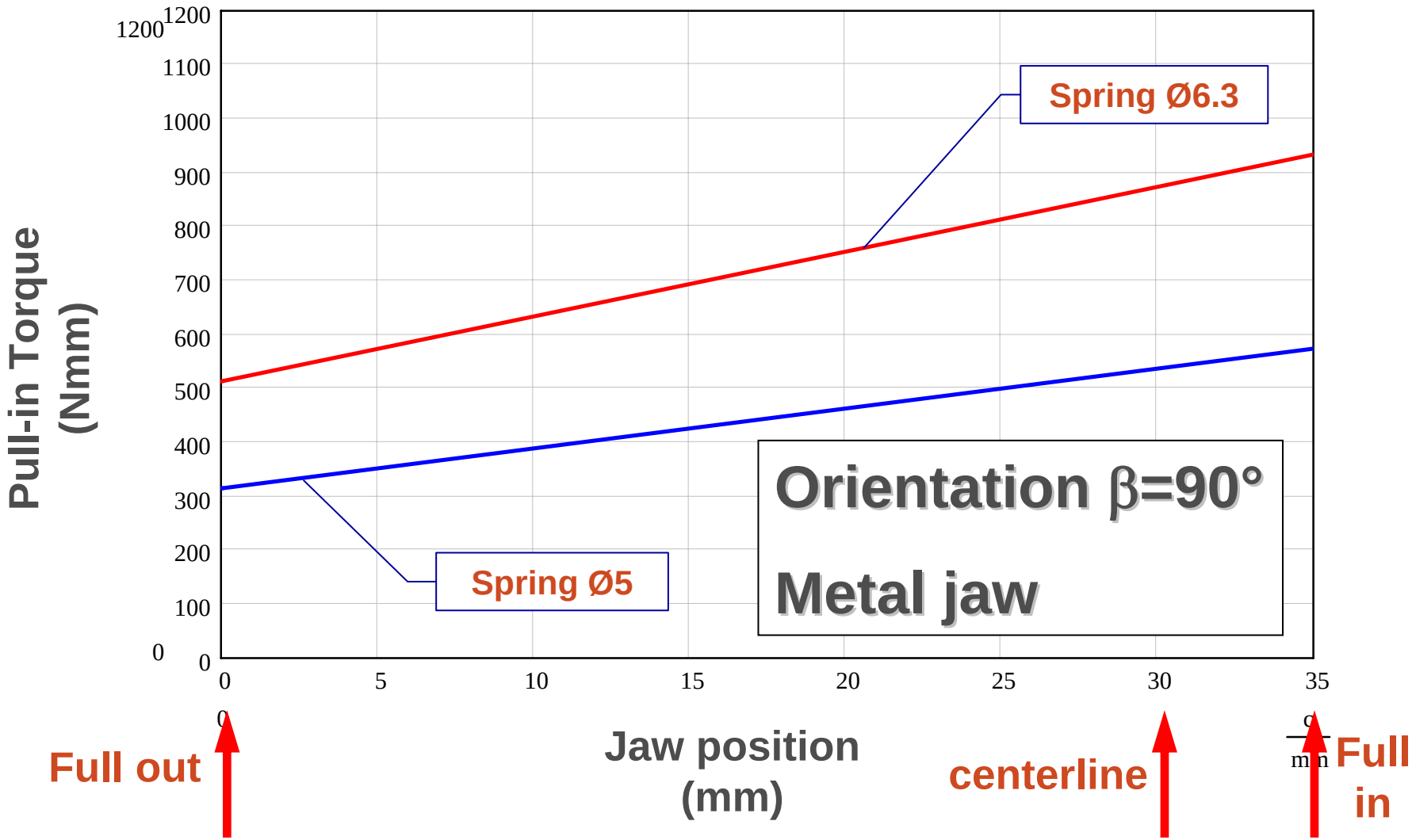
- **Back-driving torque available at motor shaft:**

$$T' = \frac{F(x)p\eta'}{2\pi} - M - C$$

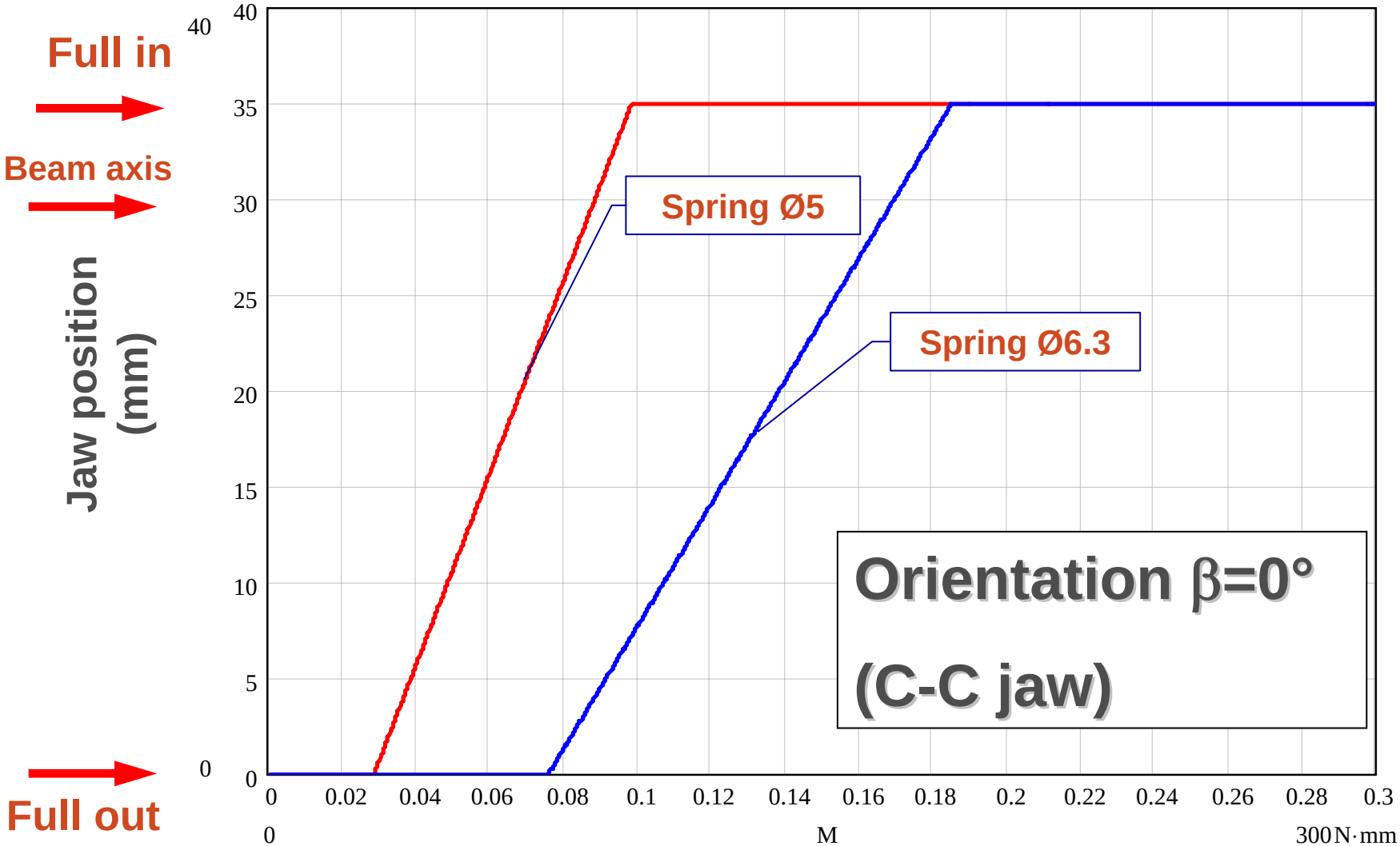
Minimum Motor Torque (Pull-in)



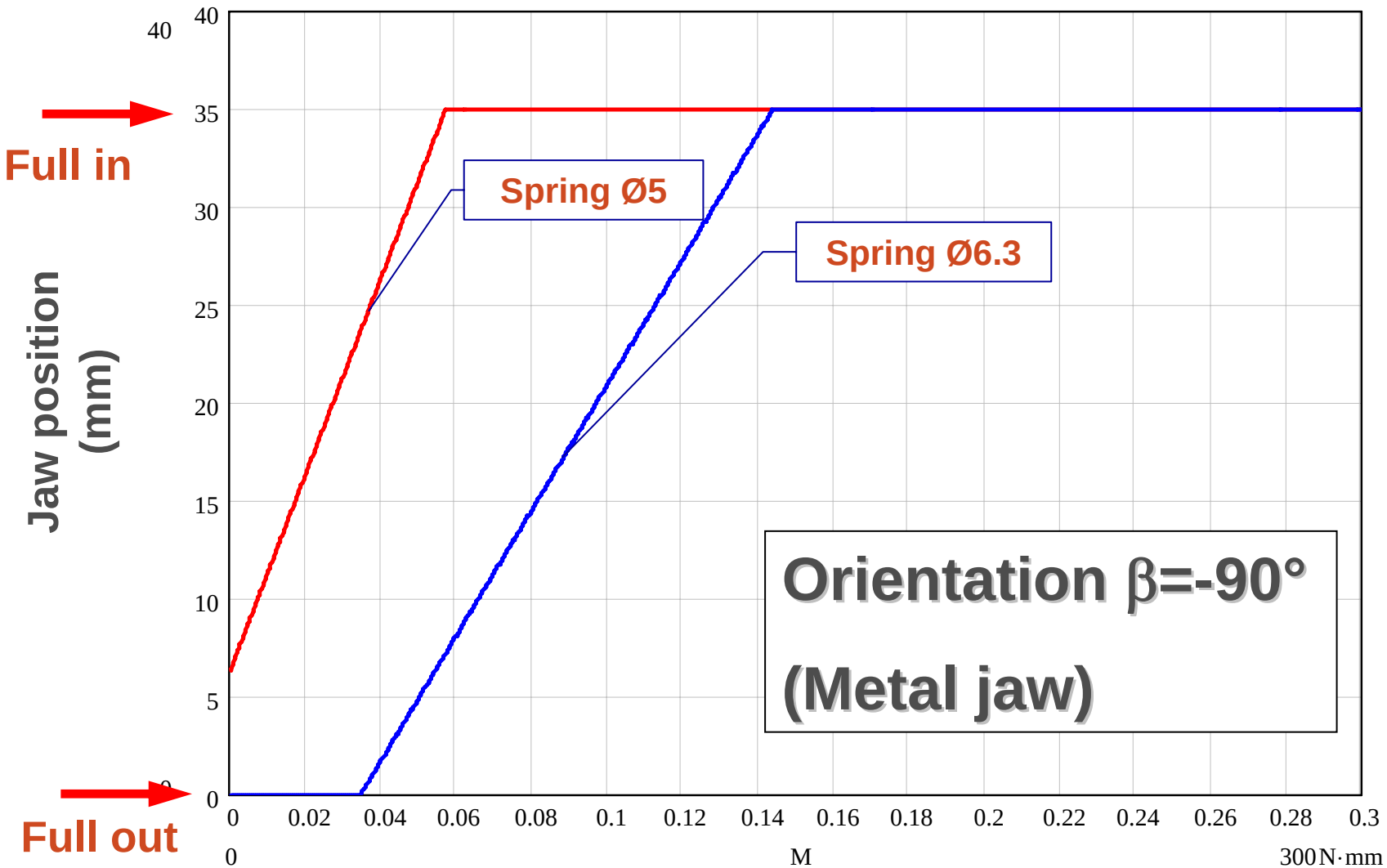
Minimum Motor Torque (Pull-in)



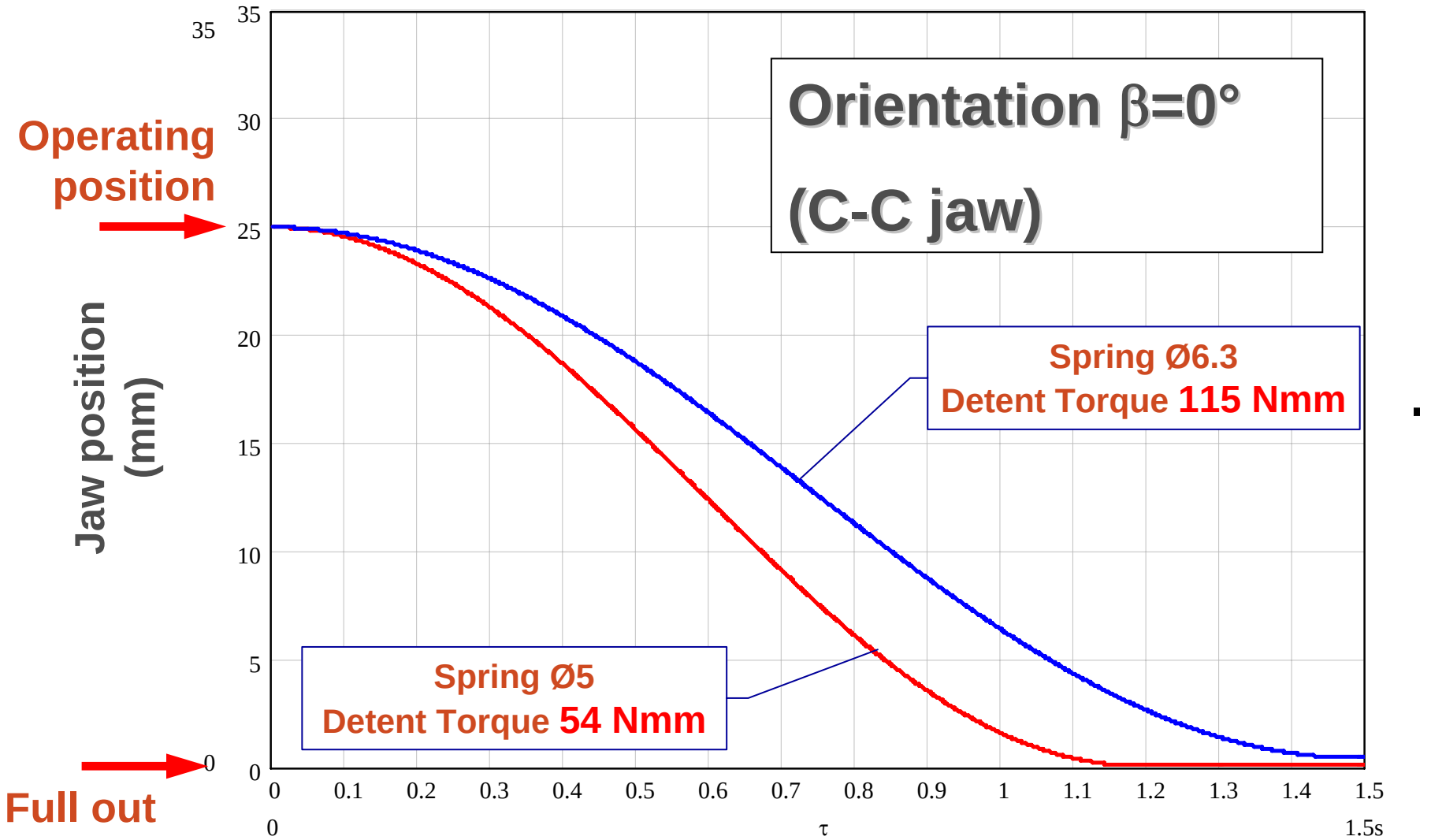
Return stroke (quasi-static) versus Motor Detent Torque



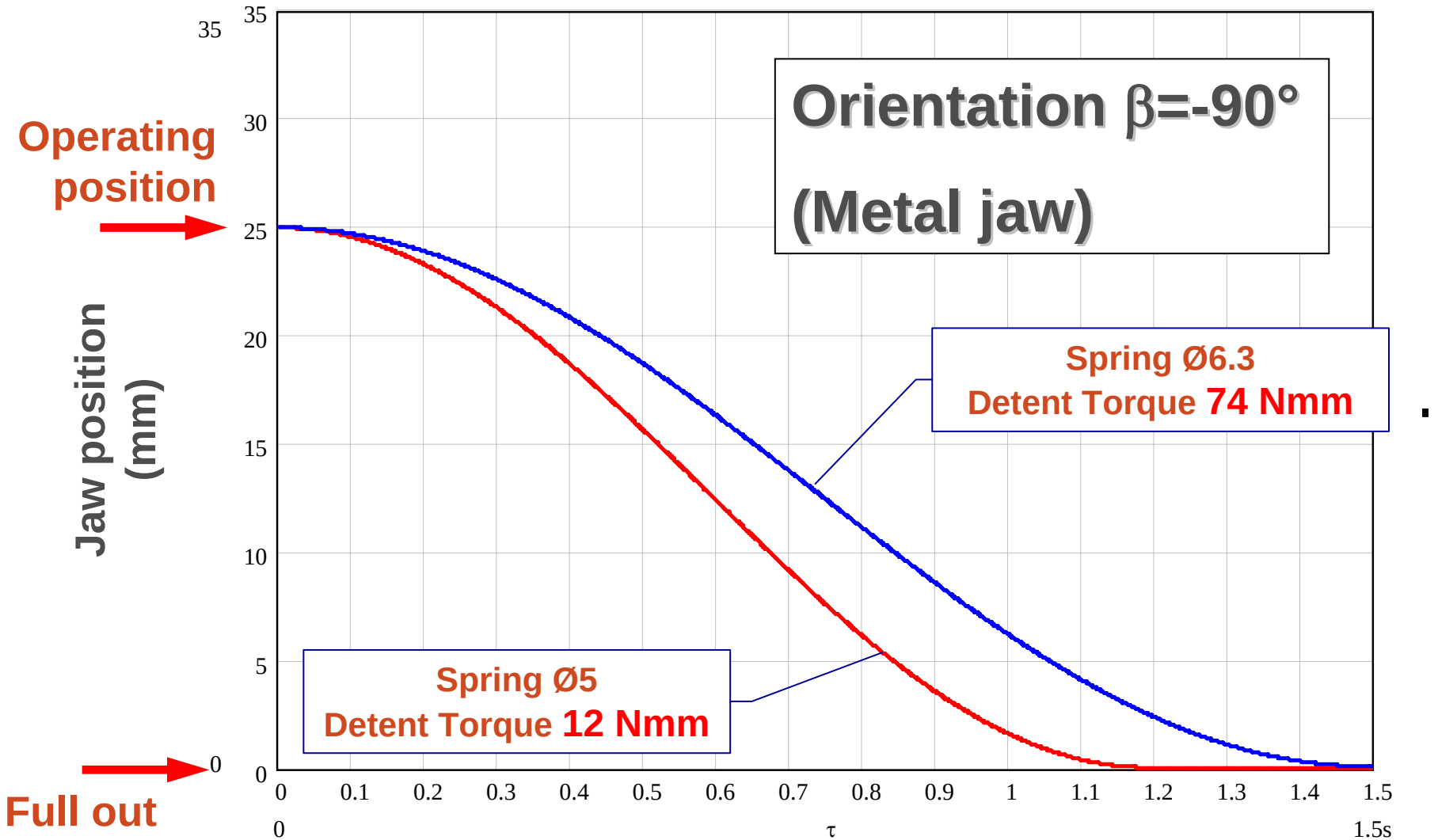
Return stroke (quasi-static) versus Motor Detent Torque



Maximum Return stroke (dynamic) versus time



Maximum Return stroke (dynamic) versus time



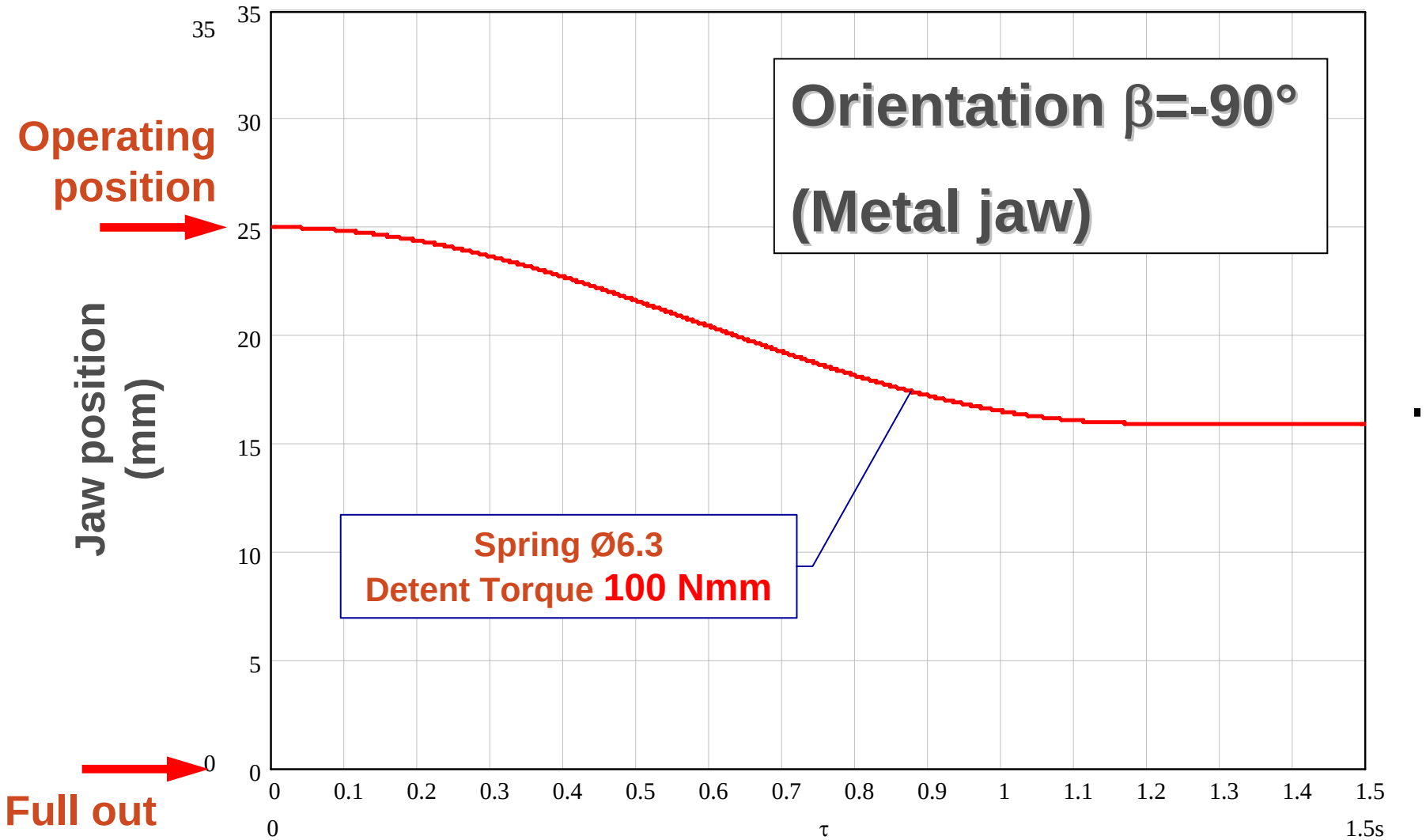
Outlook and Risks (1)

- Maximum required torque (Pull-in) is ~1 Nm for the worst configuration (metal jaw – vertical configuration – strong spring)
- In a quasi-static motion, full back-driving in the worst case is ensured for any jaw opening only if motor detent torque is smaller than 40 Nmm (or mNm)
- If a maximum detent torque of 80 Nmm is assumed, quasi-static self-retraction is not possible in the worst configuration for strokes smaller than 14mm
- In the horizontal configuration, a stiff spring is necessary to have always full retraction.
- If the jaw is assumed to be in the nominal position (25 mm stroke), full self-retraction is obtained up to ~74 Nmm detent torque.

Outlook and risks (2)

- No specific safety margins are used for these calculations!
- Friction prediction is very difficult and not necessarily conservative!
- Though big care has been paid in its qualification, the main concern is given by possible degradation of the roller screw efficiency (no auto-retraction is possible if the efficiency is smaller than 0.5)!
- An adequate safety margin should be taken for the minimum pull-in torque and the maximum detent torque (at least 1.5, plus an additional margin obtained from a Failure Mode Effect Analysis).

Maximum Return stroke (dynamic) versus time



Result table

Orientations		0º (Horizontal)		Vertical (±90º)	
		C/C jaw	Metal jaw	C/C jaw	Metal jaw
Ø6.3 mm (hard) spring	Pull-in Torque (@ 35mm stroke) - mNm	776	776	890	**931**
	Maximum Detent torque for full (q.s.) retraction (mNm)	77	77	47	36
	Quasi-static retraction (@ 80Nmm D.T.)	1	1	11	**14**
	Dynamic retraction from 25mm @ 80Nmm D.T. (mm)	0	0	0	**3**
Ø5 mm (soft) spring	Pull-in Torque	415	415	530	571
	Maximum Detent torque for full (q.s.) retraction	**30**	30	-	-
	Quasi-static retraction (@ 80Nmm D.T.)	**25**	25	-	-
	Dynamic retraction from 25mm @ 80Nmm D.T.	**25**	25	25	25