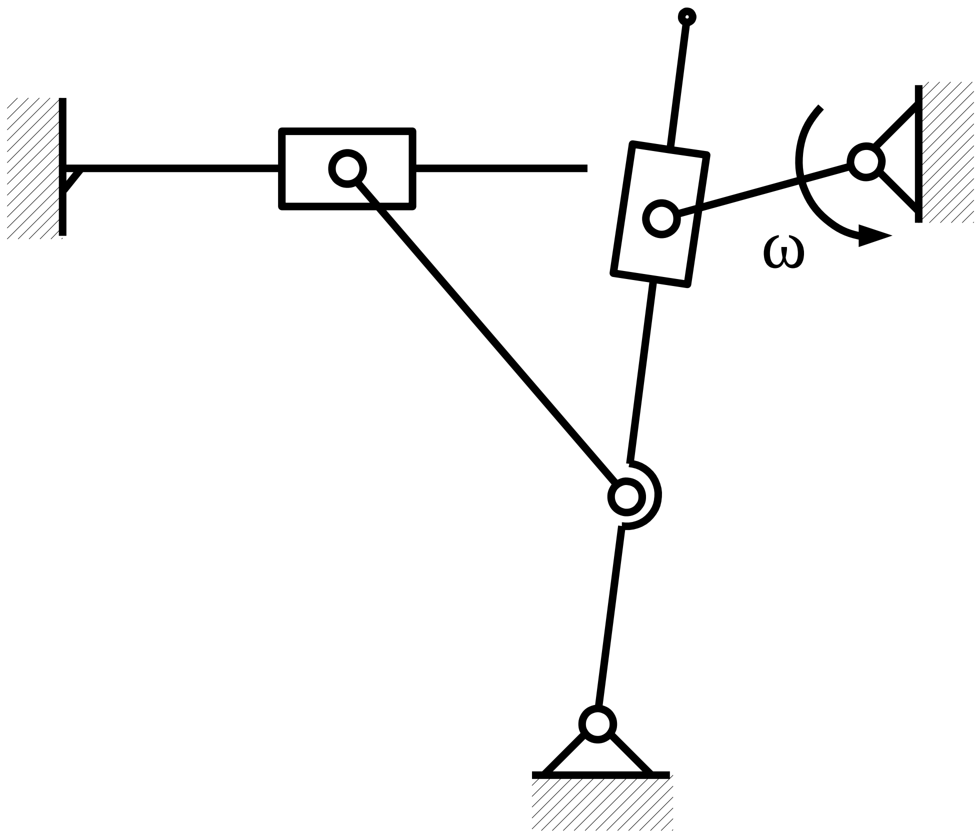
TM&AC - Winter 2017/2018

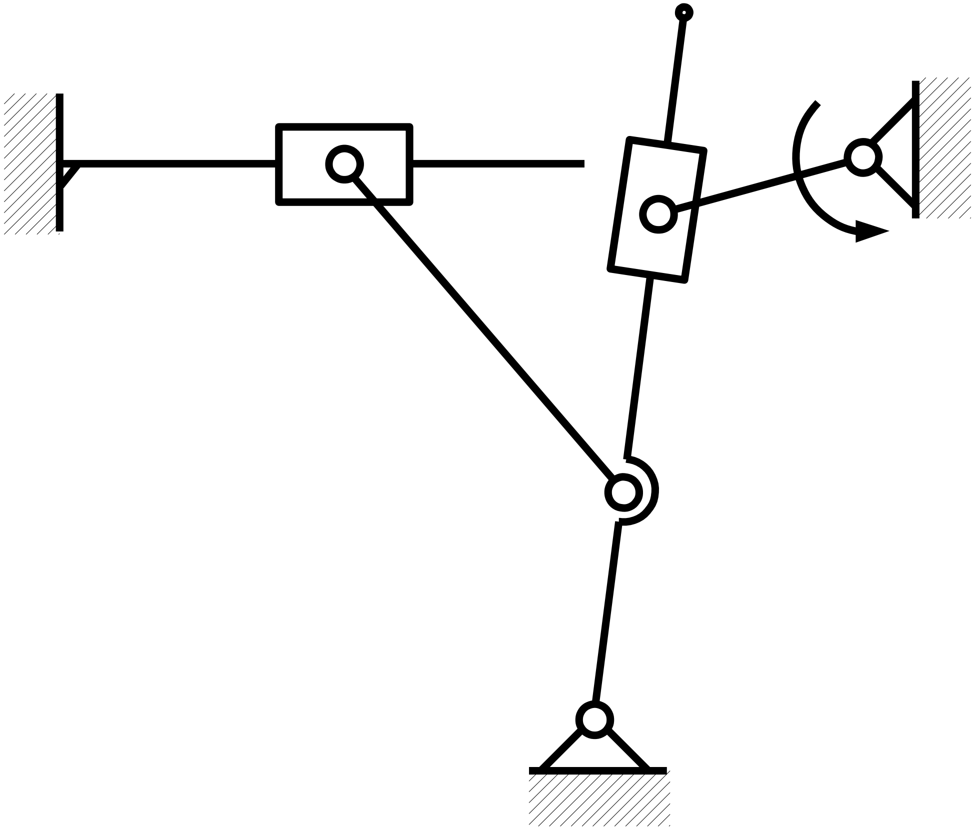
velocities and accelerations in planar mechanisms
EXAMPLE

Given: mechanism geometry and constant angular velocity ω of driven element.

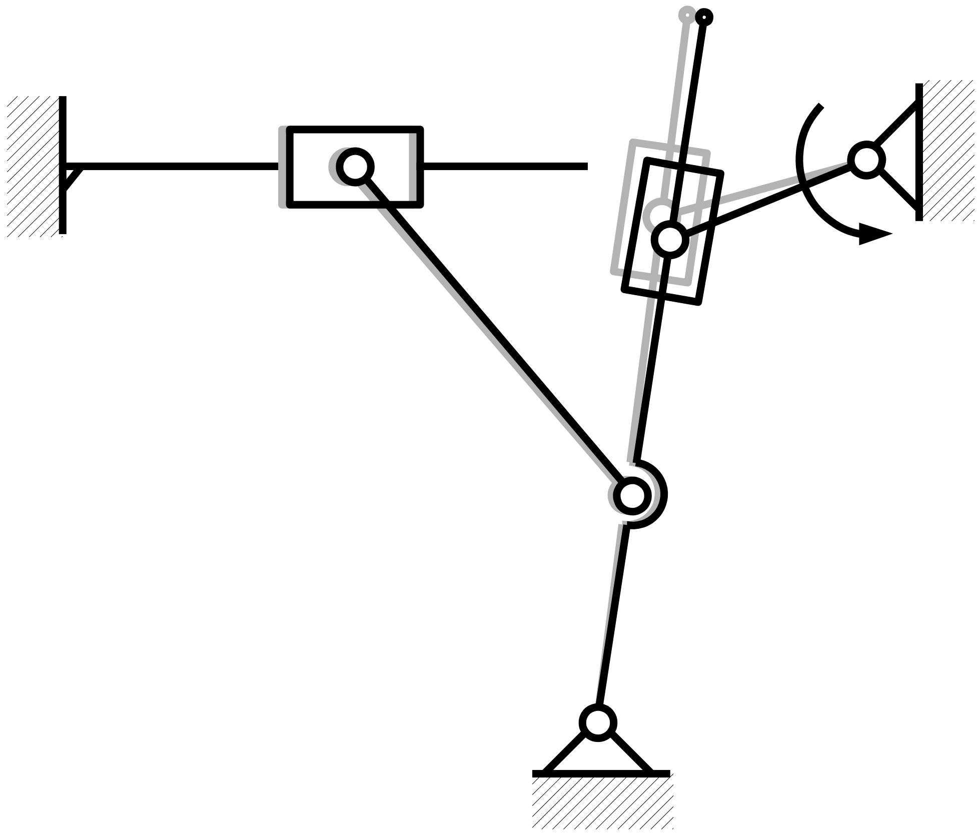


Warsaw University of Technology, The Faculty of Automotive and Construction Machinery Engineering
Institute of Machine Design Fundamentals, Department of Mechanics, http://www.ipbm.simr.pw.edu.pl/,
Sebastian Korczak, PhD, Eng.

How it works?

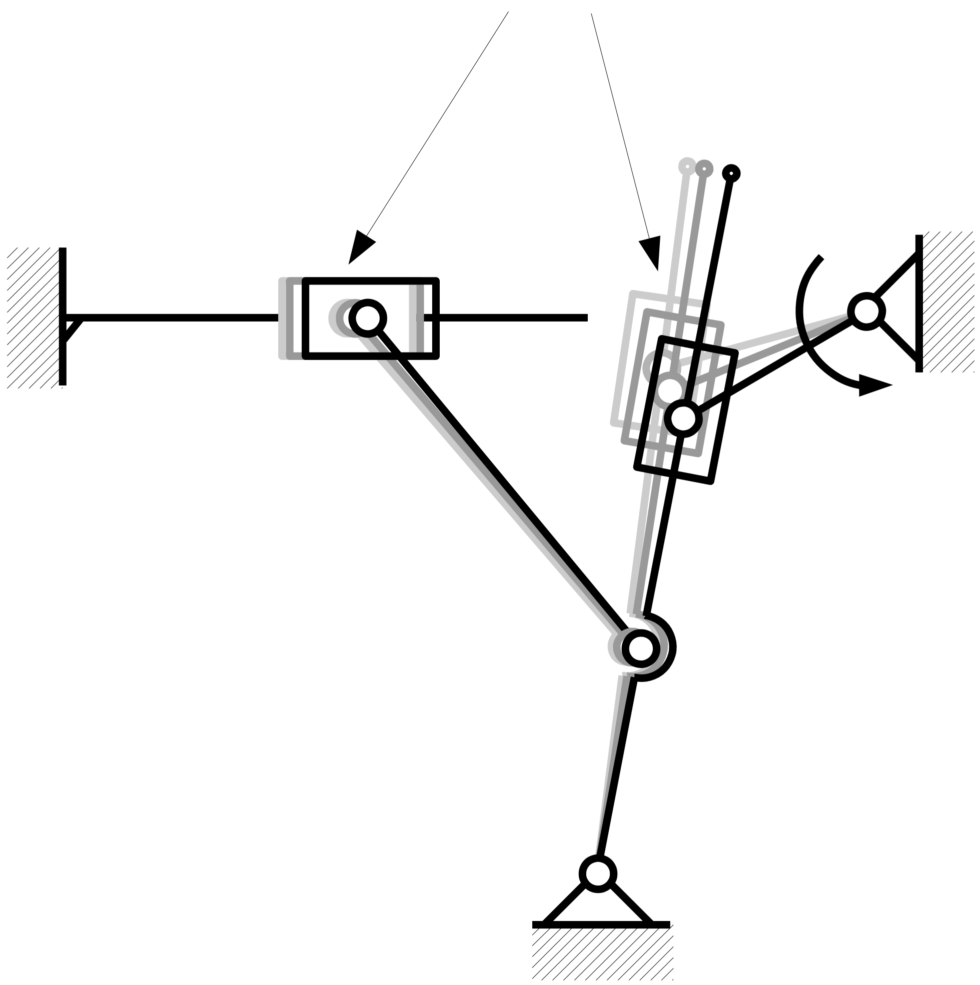


How it works?

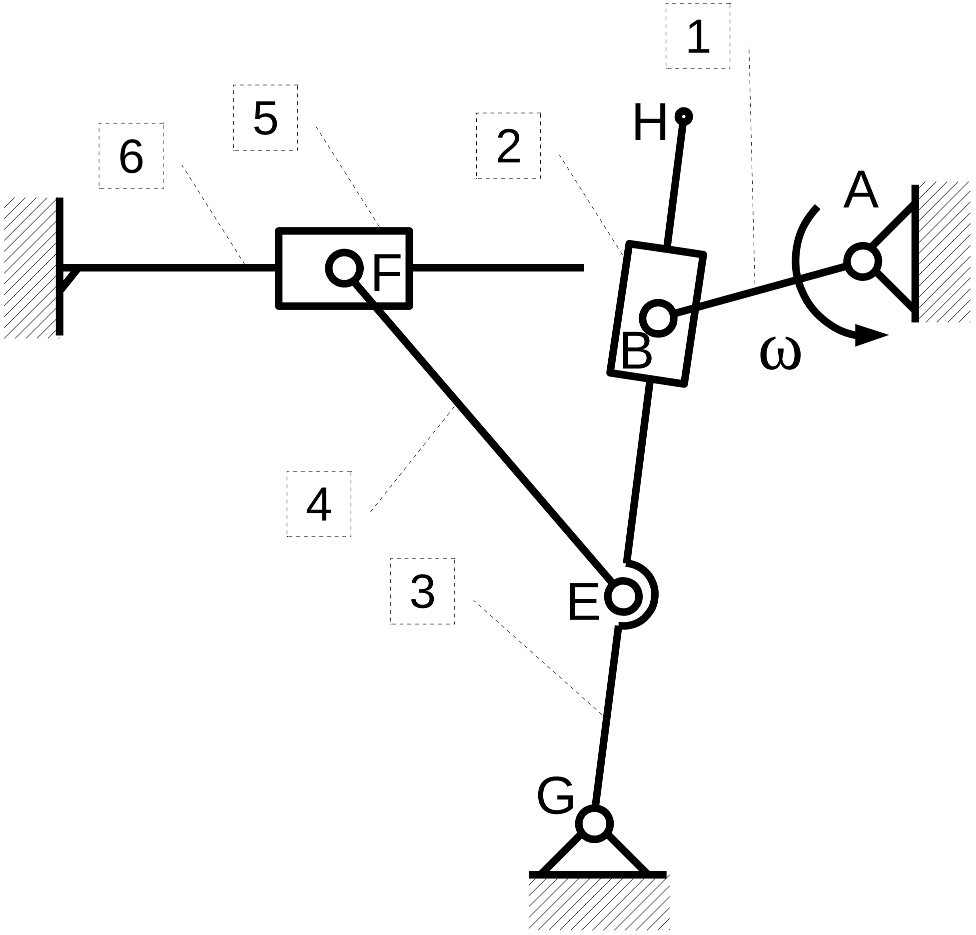


How it works?

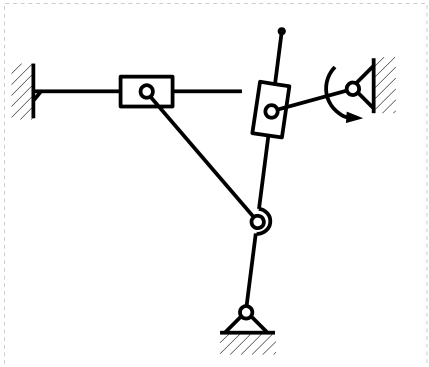
notice relative motion

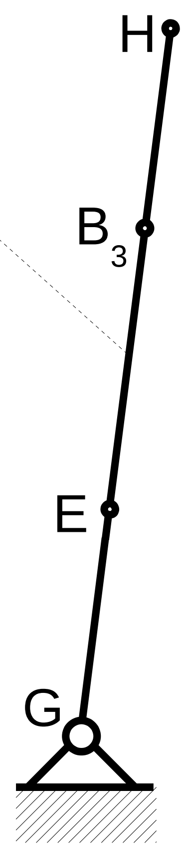


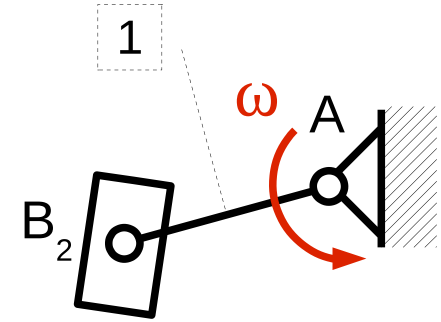
For given mechanism's orientation denote elements and characteristic points

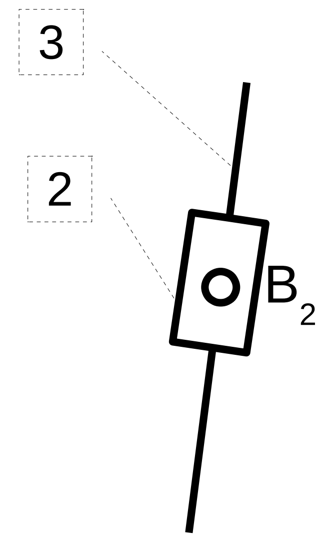


Because of relative motion of the slider 2 along the rod 3 denote point B_2 fixed with slider and B_3 fixed with rod

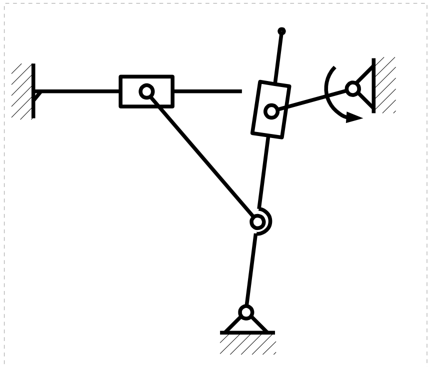


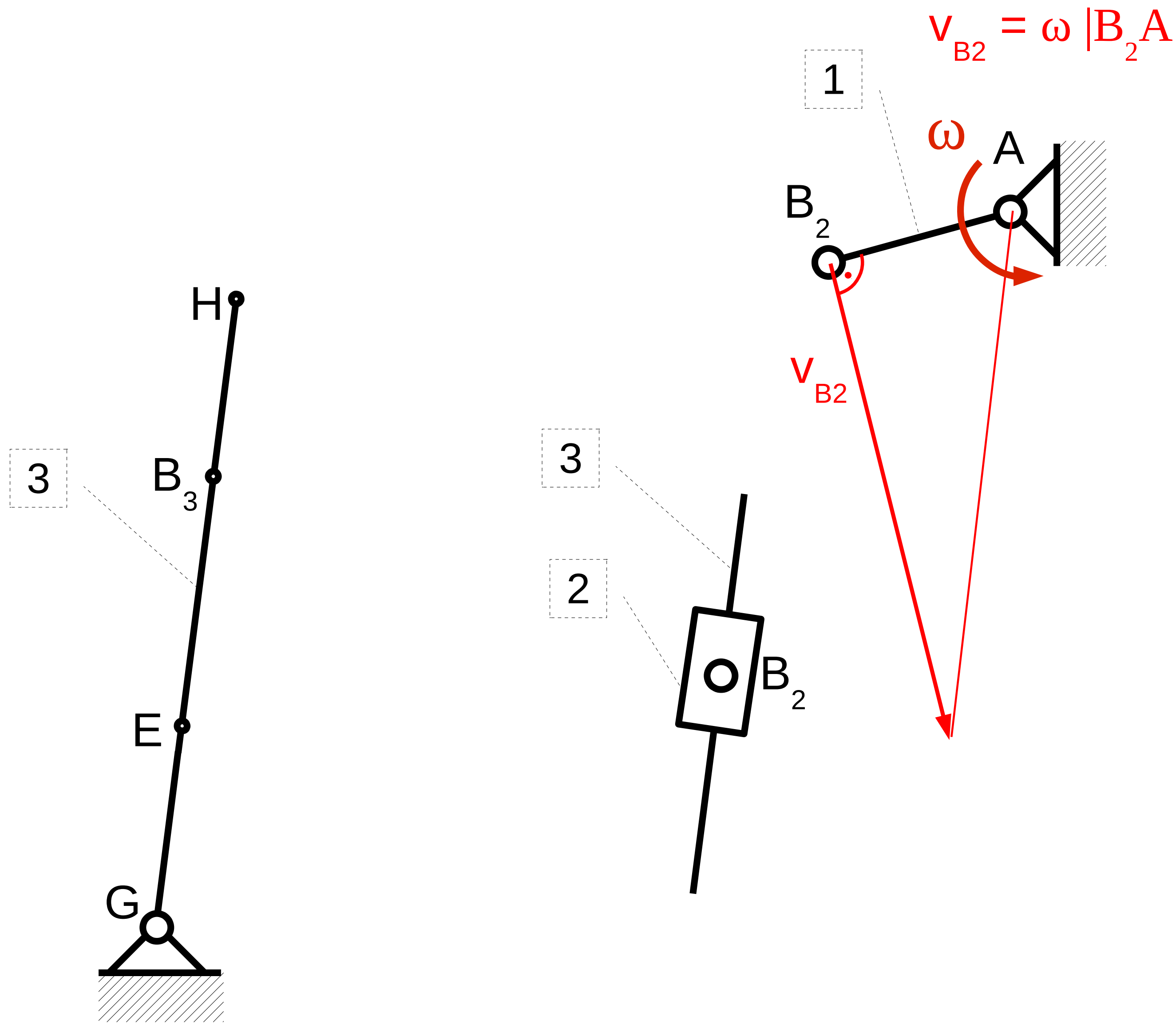






Determine the velocity of the 1st element





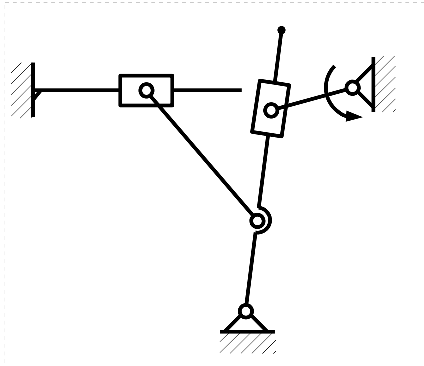
Let us assume:

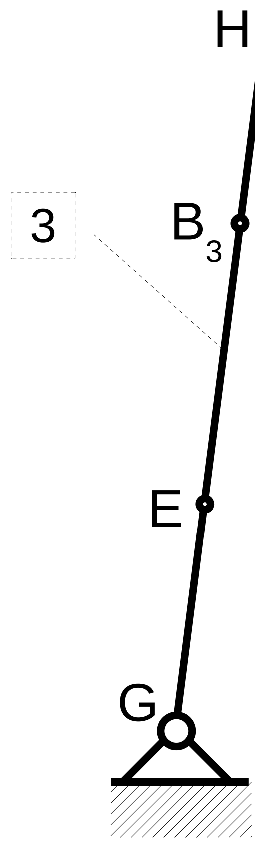
relative motion - movement of the slider 2 along the rod 3

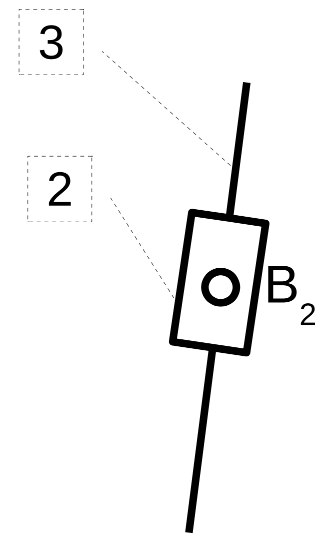
reference frame motion (transportation) – movement of the rod 3

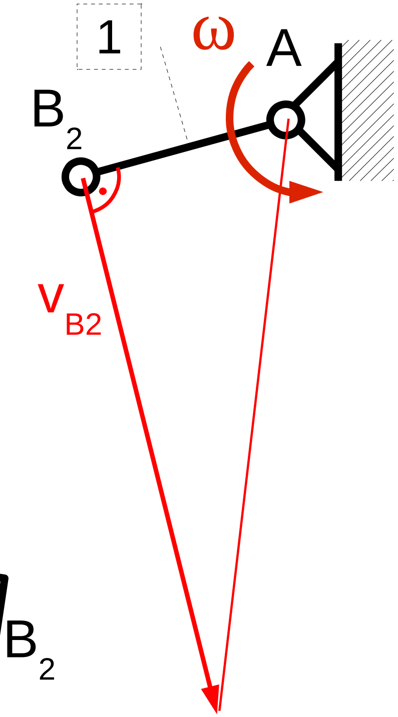
Global velocity of the B2:

$$v_{B2} = v_{B3} + v_{B2B3}$$

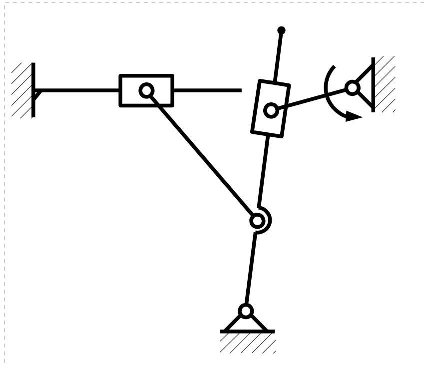




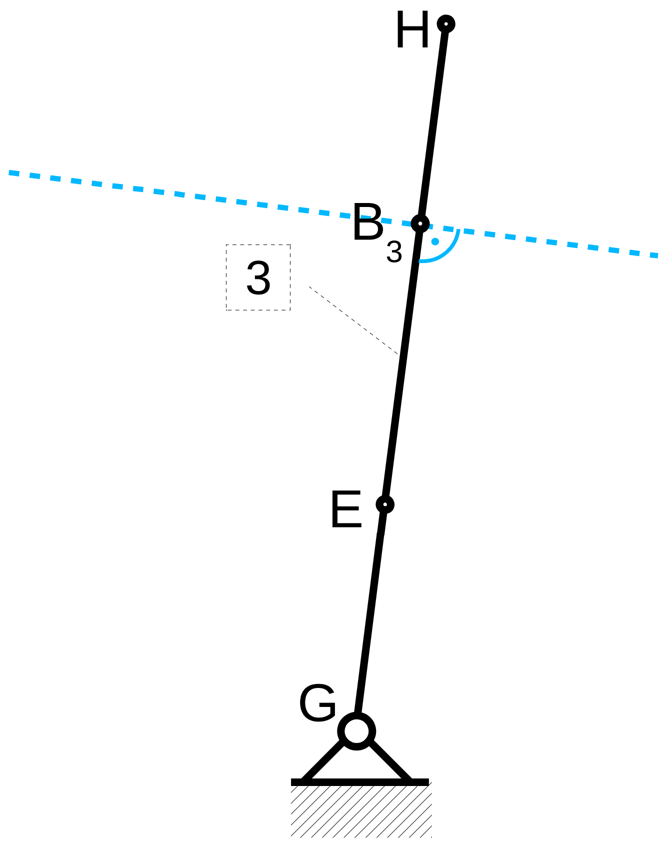


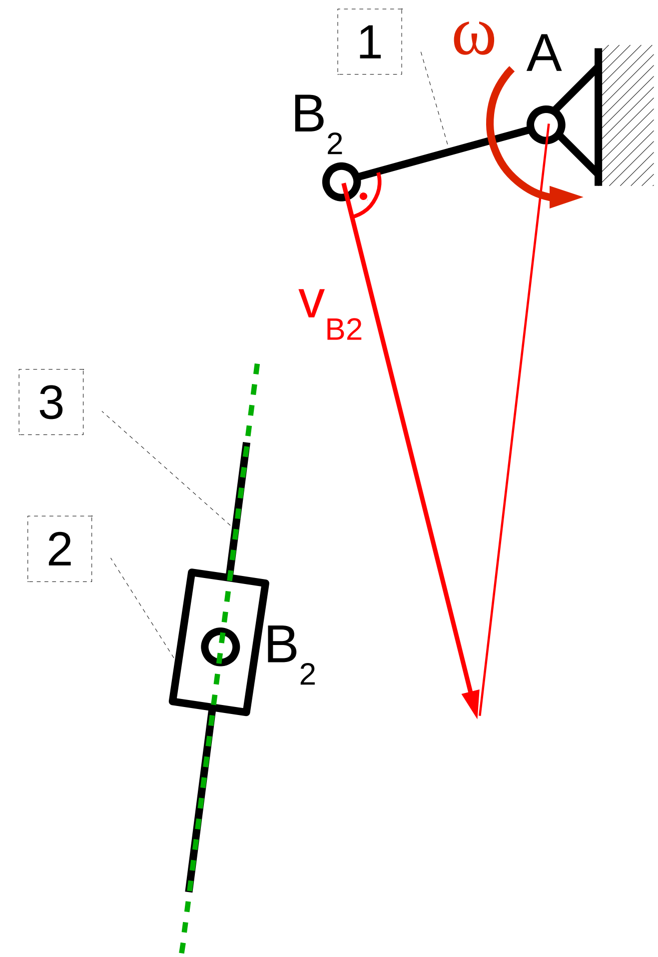


velocities' directions...



$$\underset{\perp 1}{\underline{\underline{v_{B2}}}} = \underset{\perp 3}{\underline{v_{B3}}} + \underset{\parallel 3}{\underline{v_{B2B3}}}$$





Velocity scheme

$$\underset{\perp 1}{\underline{\underline{v_{B2}}}} = \underset{\perp 3}{\underline{v_{B3}}} + \underset{\parallel 3}{\underline{v_{B2B3}}}$$

Velocity scheme

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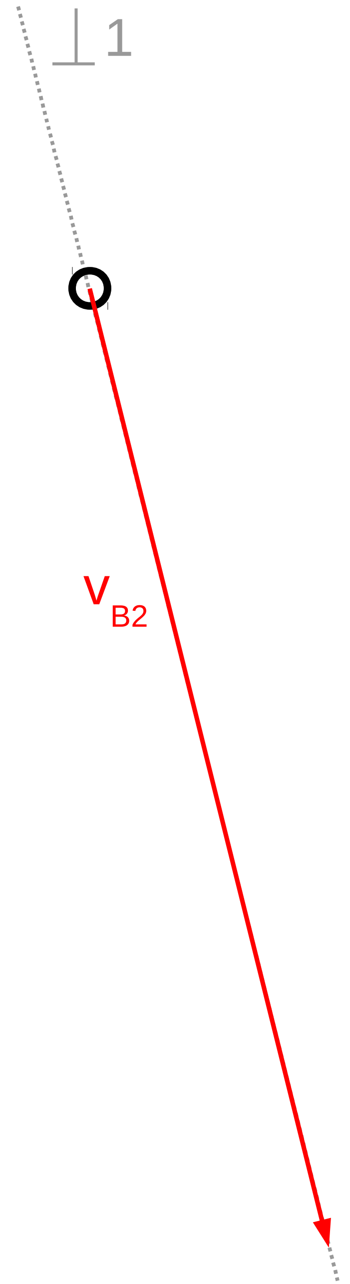
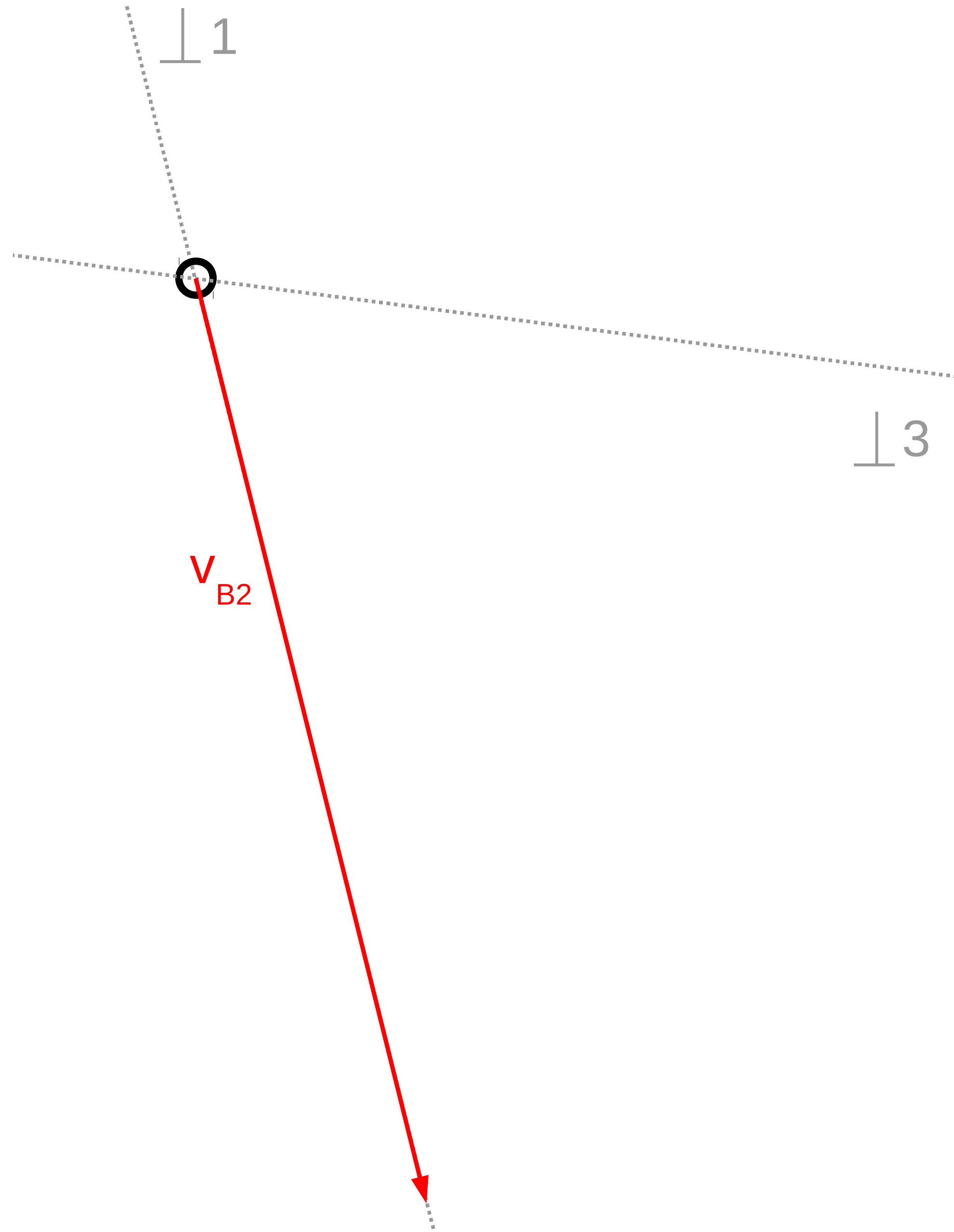


Velocity scheme

$$\underset{\perp 1}{\underline{\underline{v_{B2}}}} = \underset{\perp 3}{\underline{v_{B3}}} + \underset{\parallel 3}{\underline{v_{B2B3}}}$$



Velocity scheme

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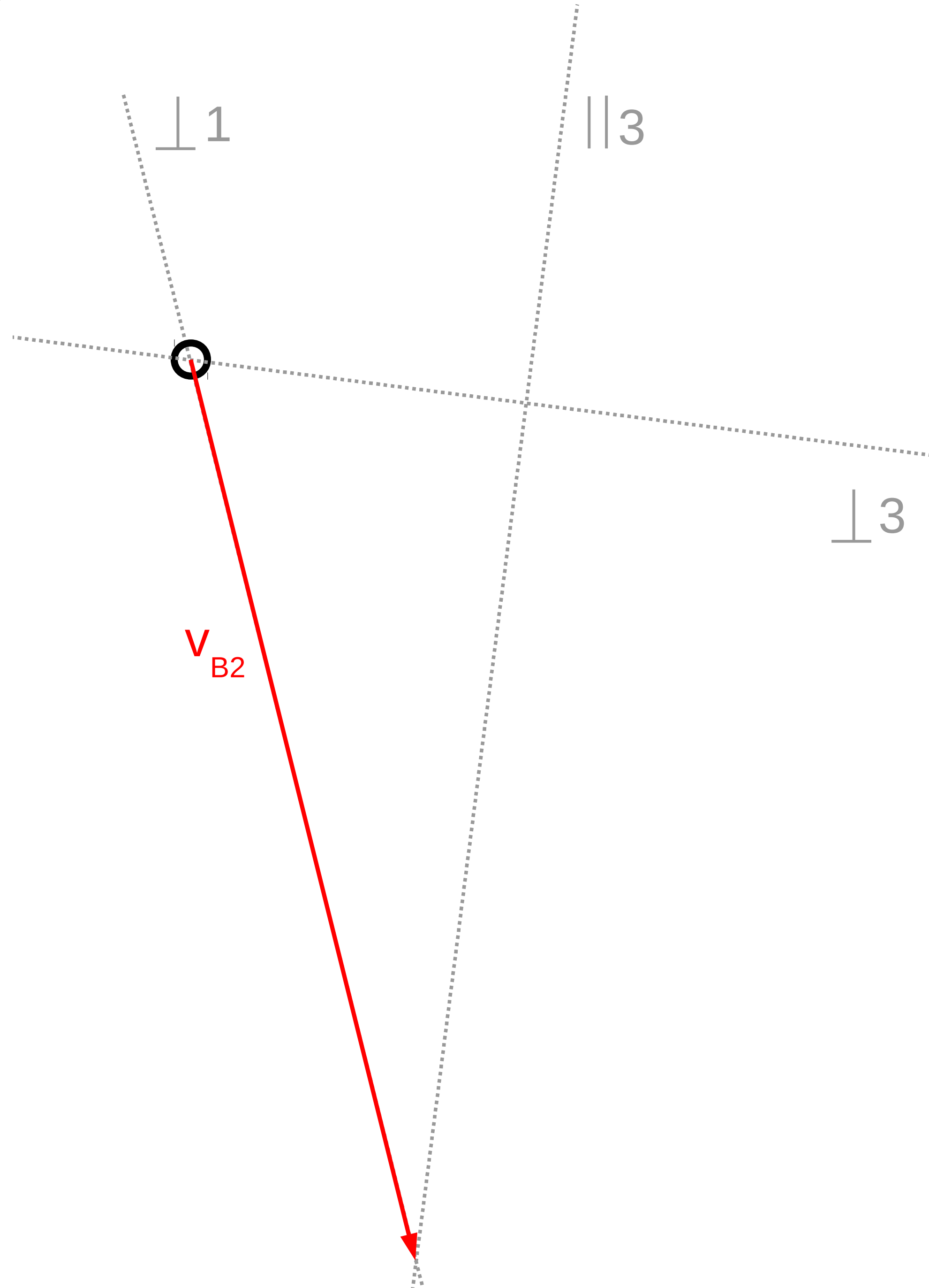
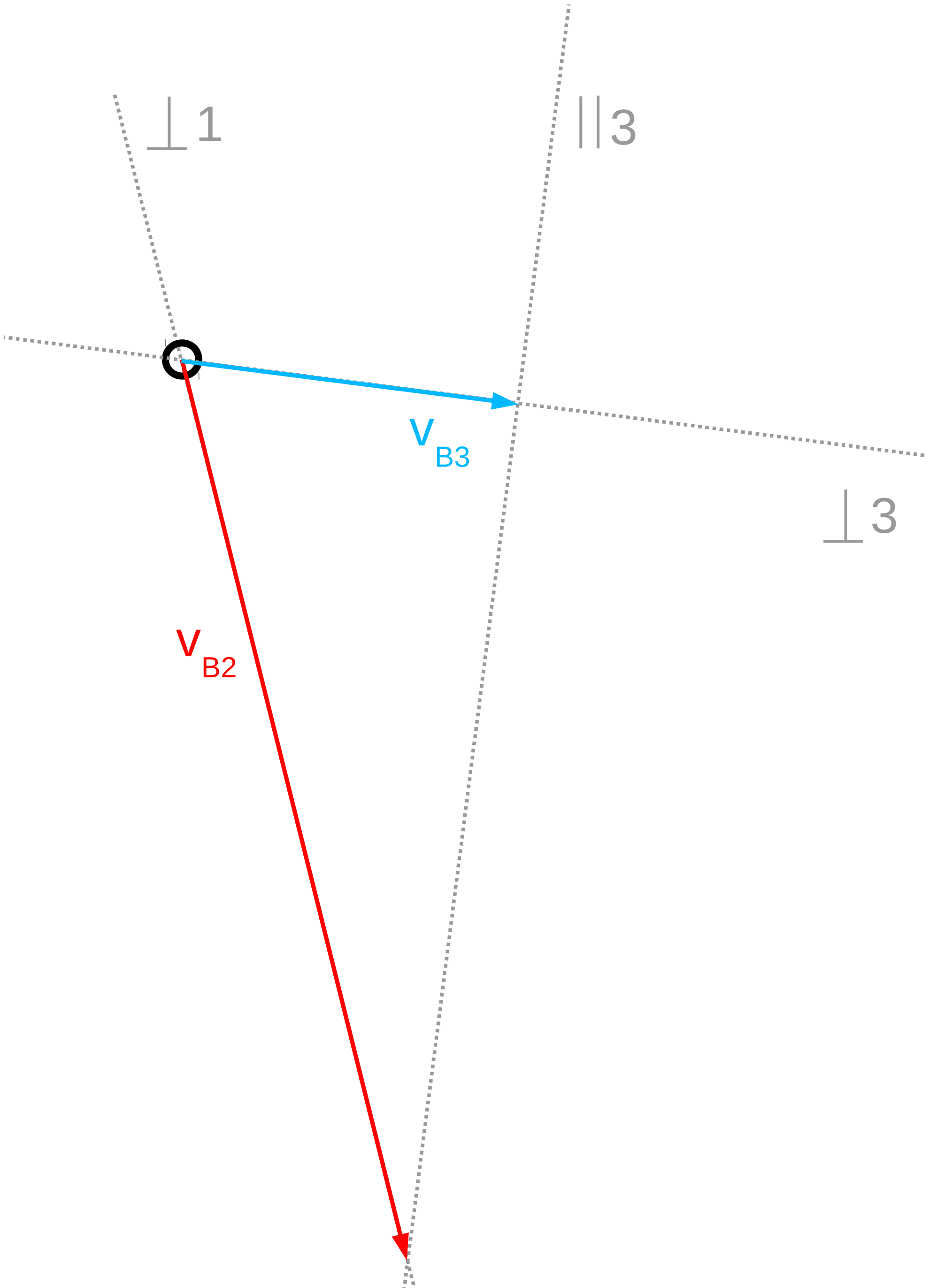
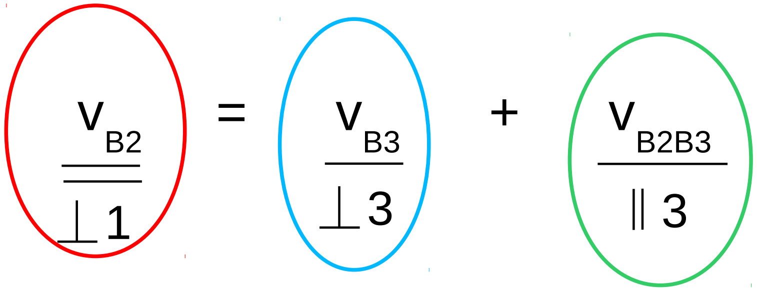


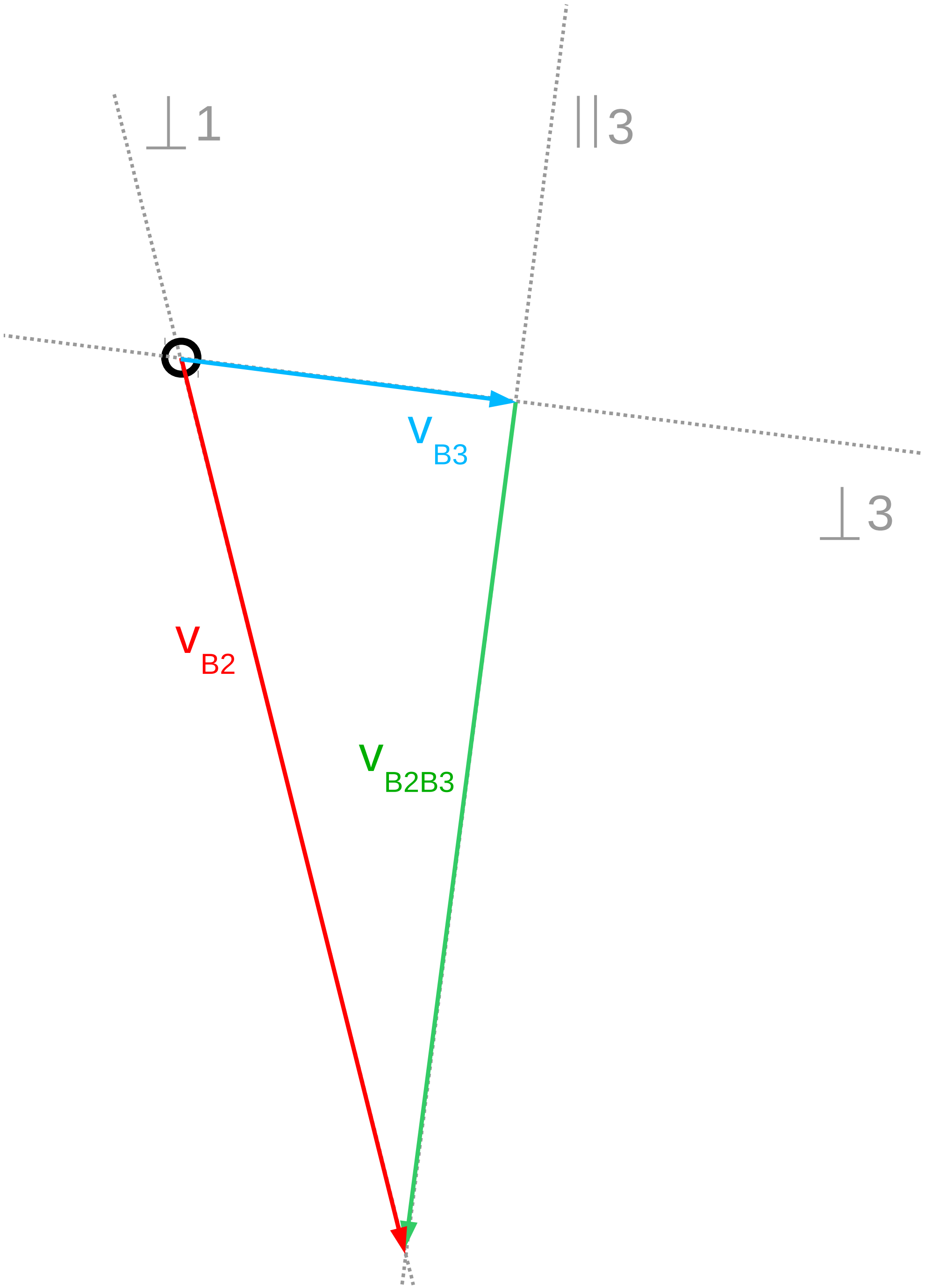
Velocity scheme

$$\underset{\perp 1}{\underline{\underline{v_{B2}}}} = \underset{\perp 3}{\underline{v_{B3}}} + \underset{\parallel 3}{\underline{v_{B2B3}}}$$

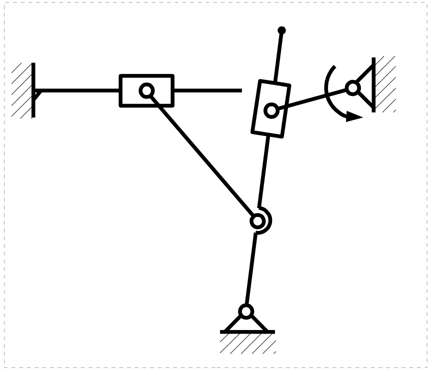


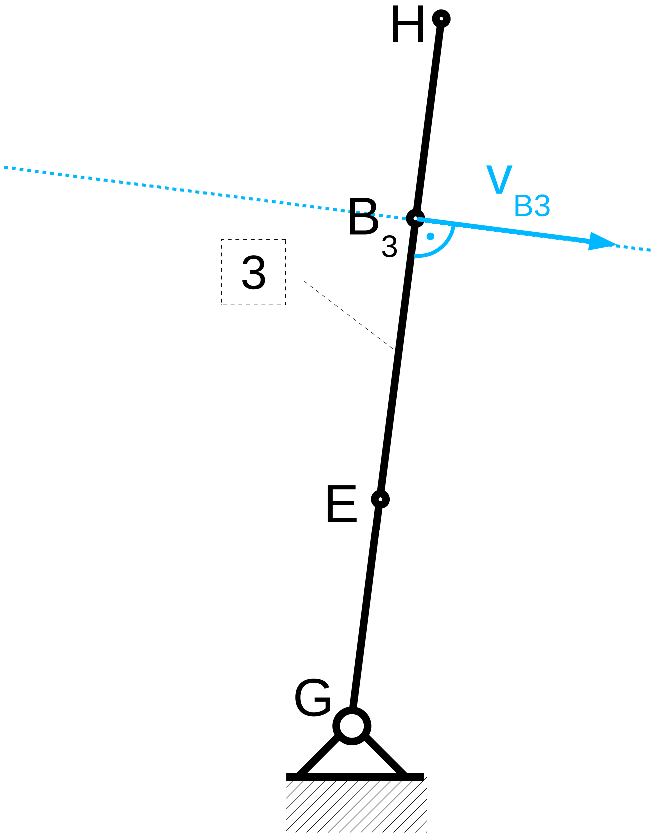
Velocity scheme

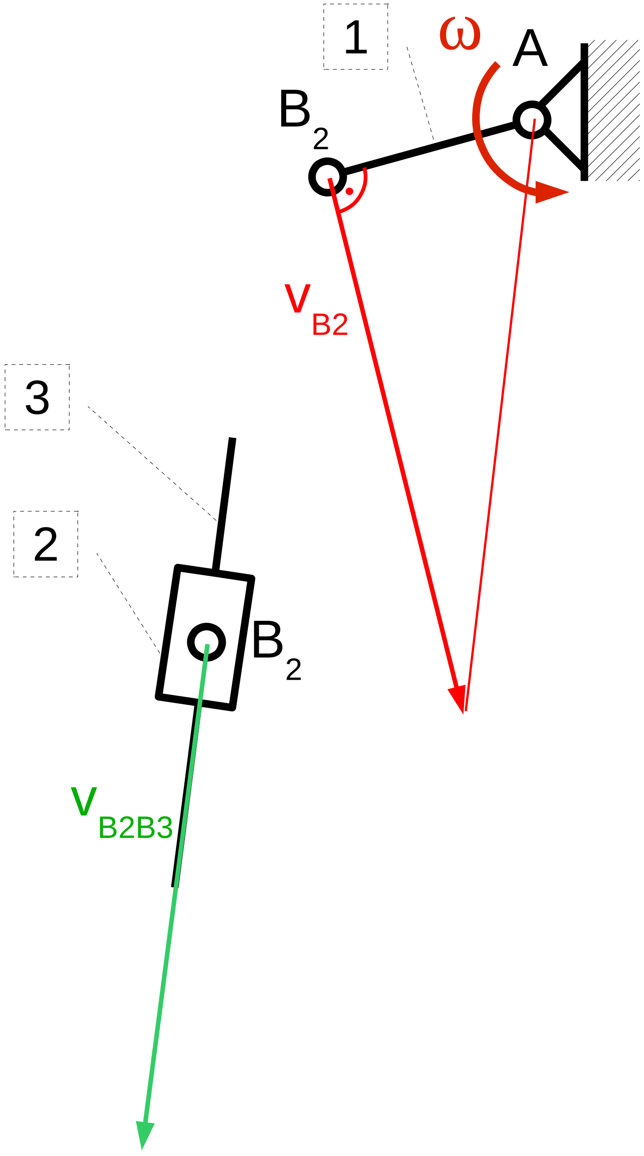




We just found velocities in relative motion.

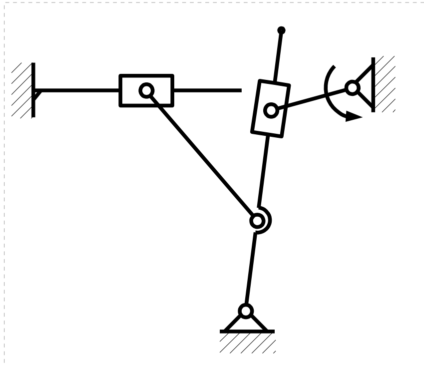


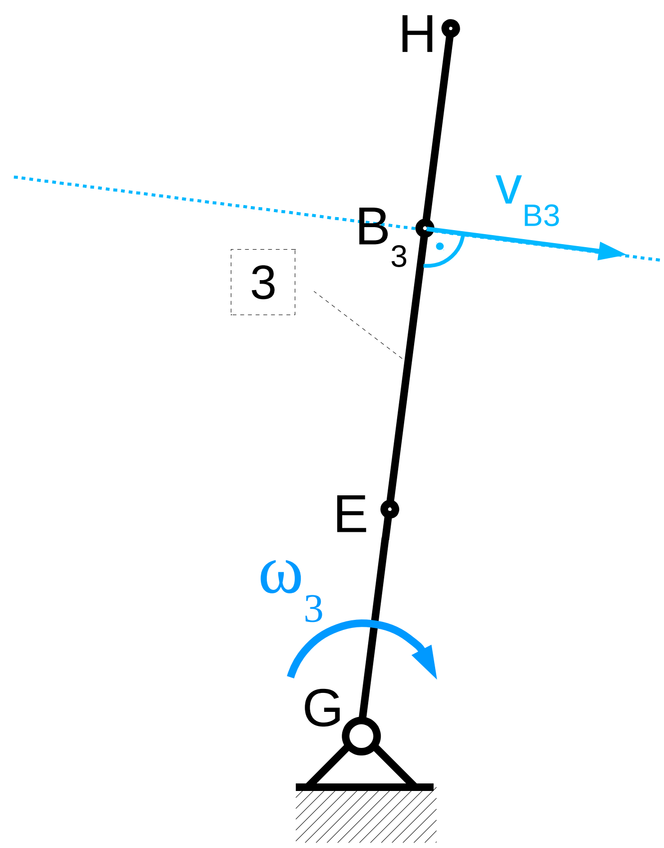


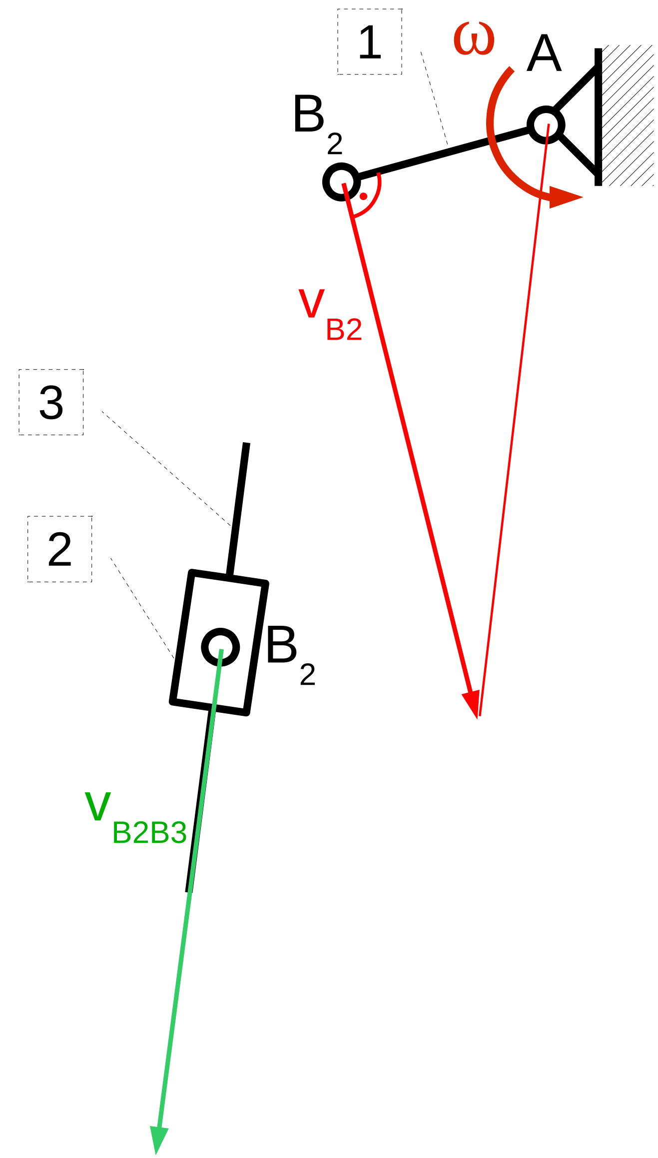


From the B_3 velocity we obtain angular velocity of the rod 3

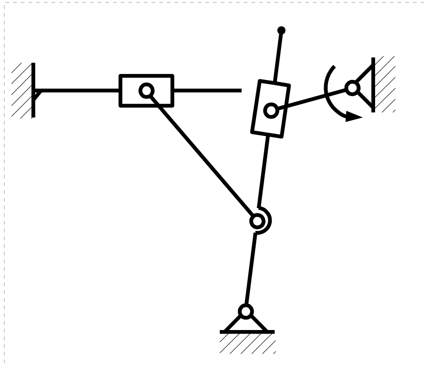
$$\omega_3 = \frac{|v_{B3}|}{|B_3G|}$$



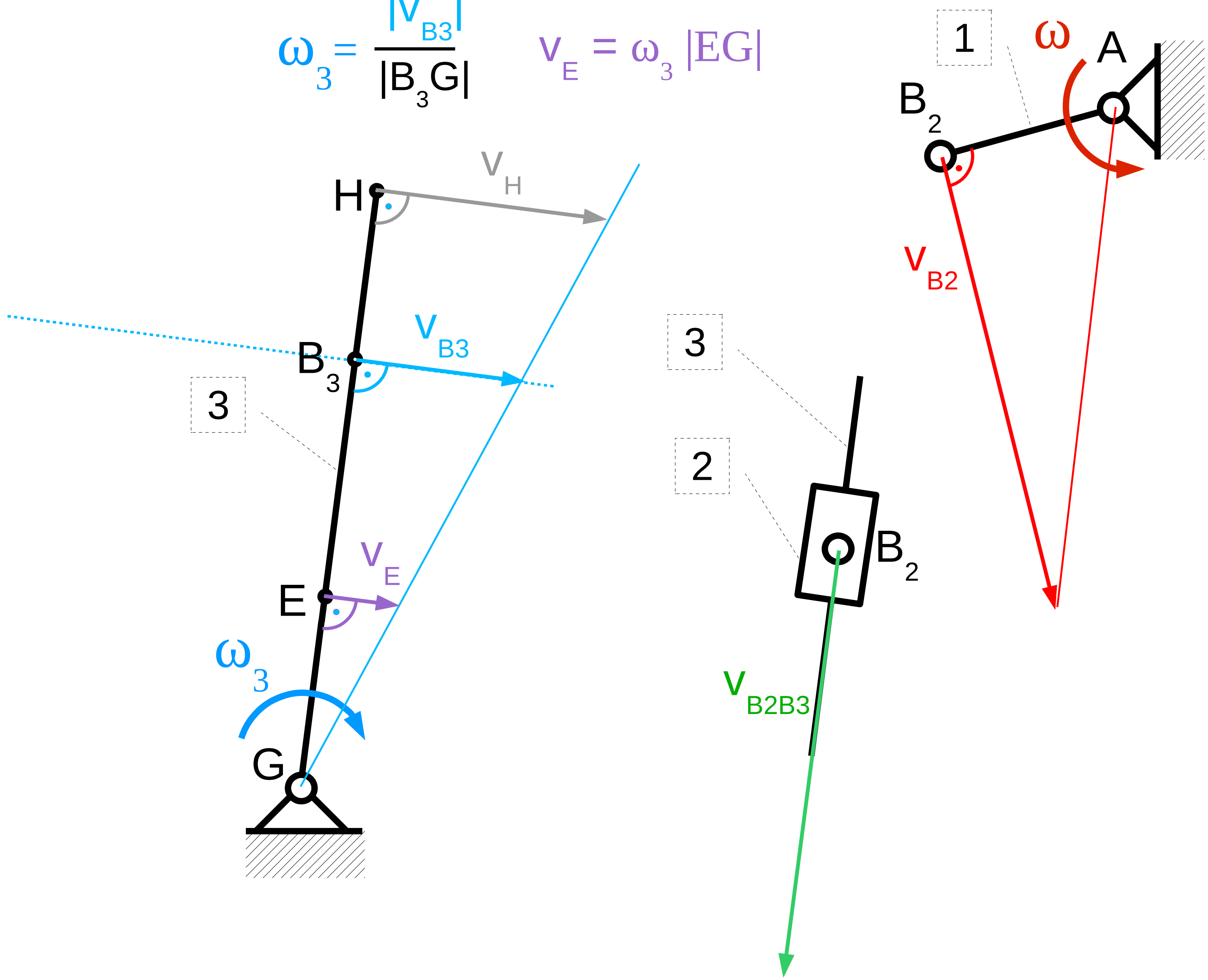




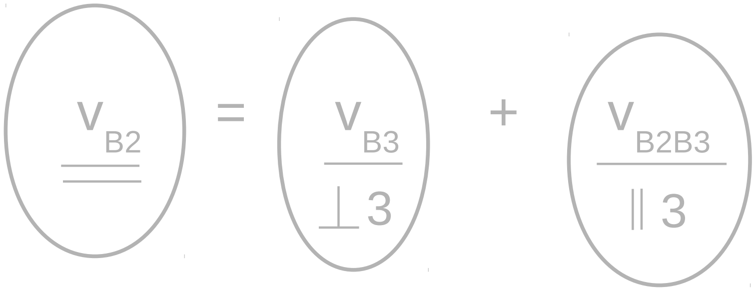
With ω we can find now velocities of point E or H.

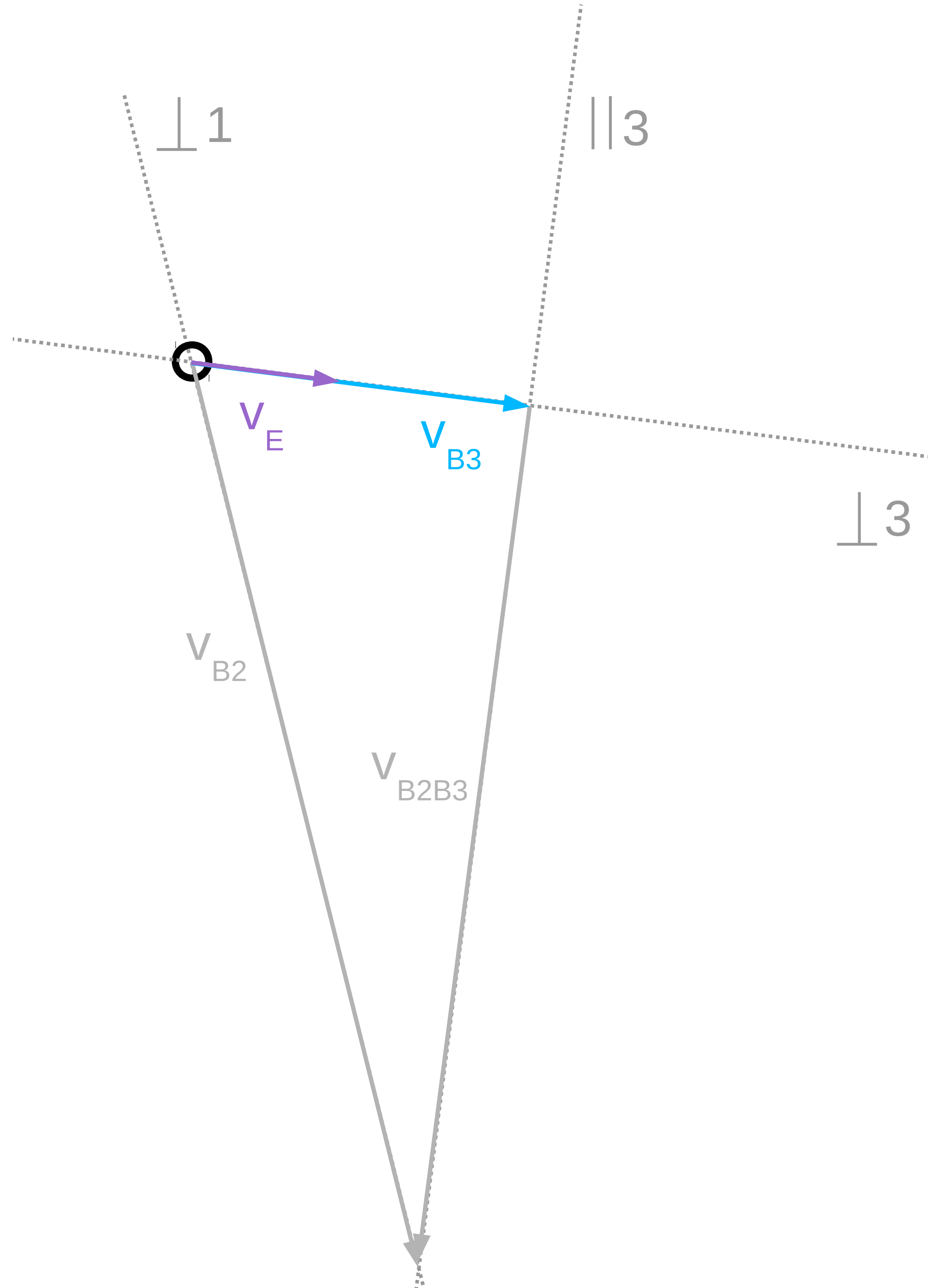


$$\omega_3 = \frac{|v_{B3}|}{|B_3G|} \qquad v_E = \omega_3 \, |EG|$$



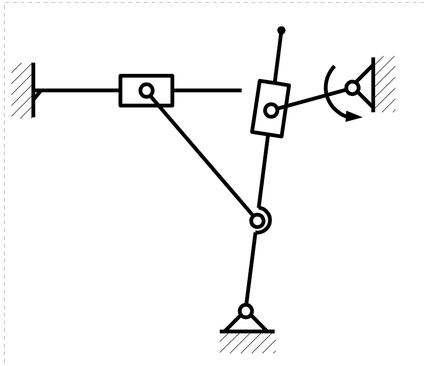
Velocity scheme cont.

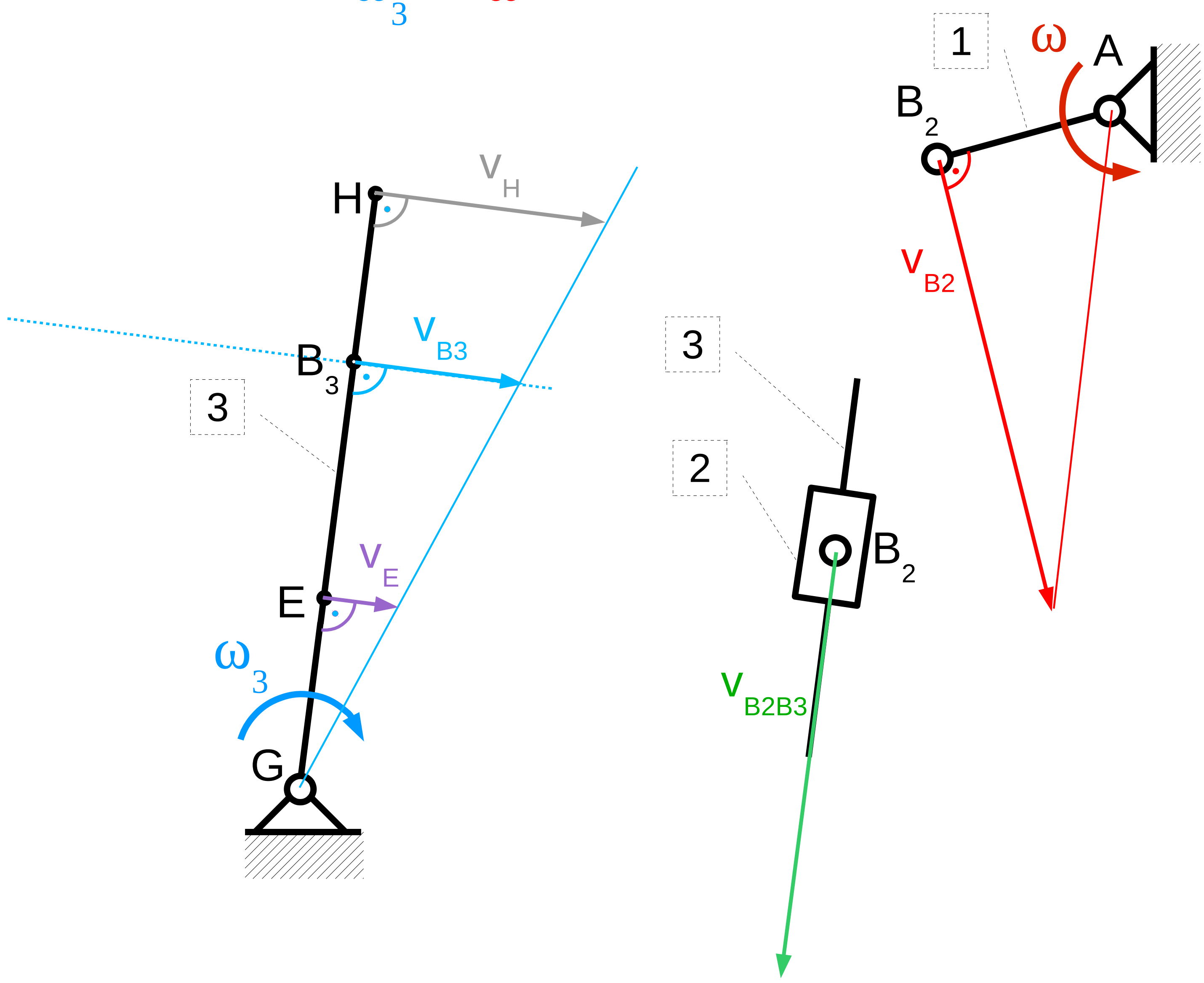




From relation between |BG| and |BA| and relation between V_{B3} i V_{B2}:

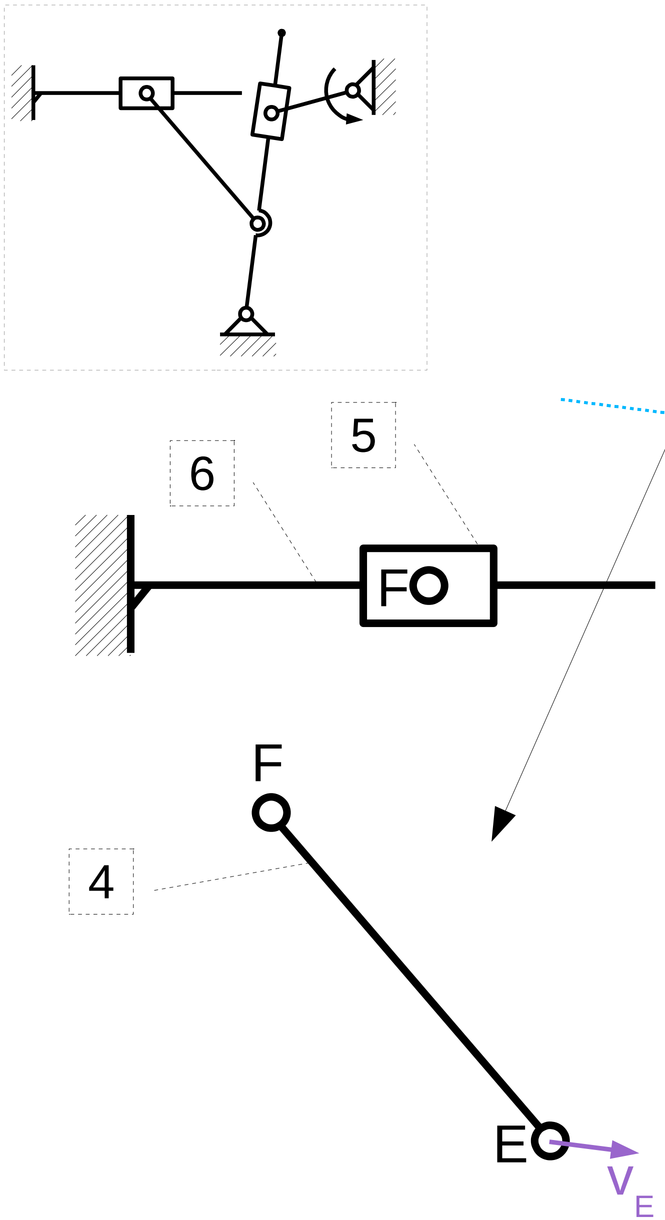
$\omega_3 < \omega$

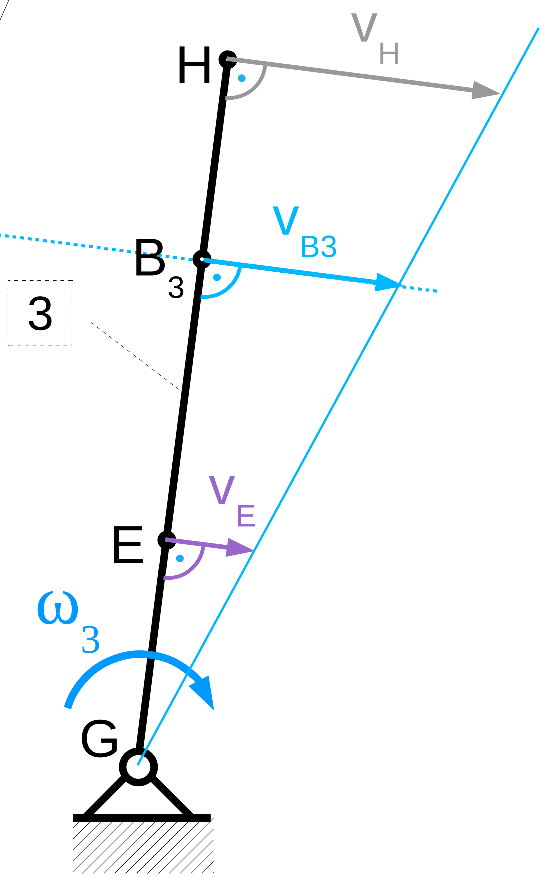


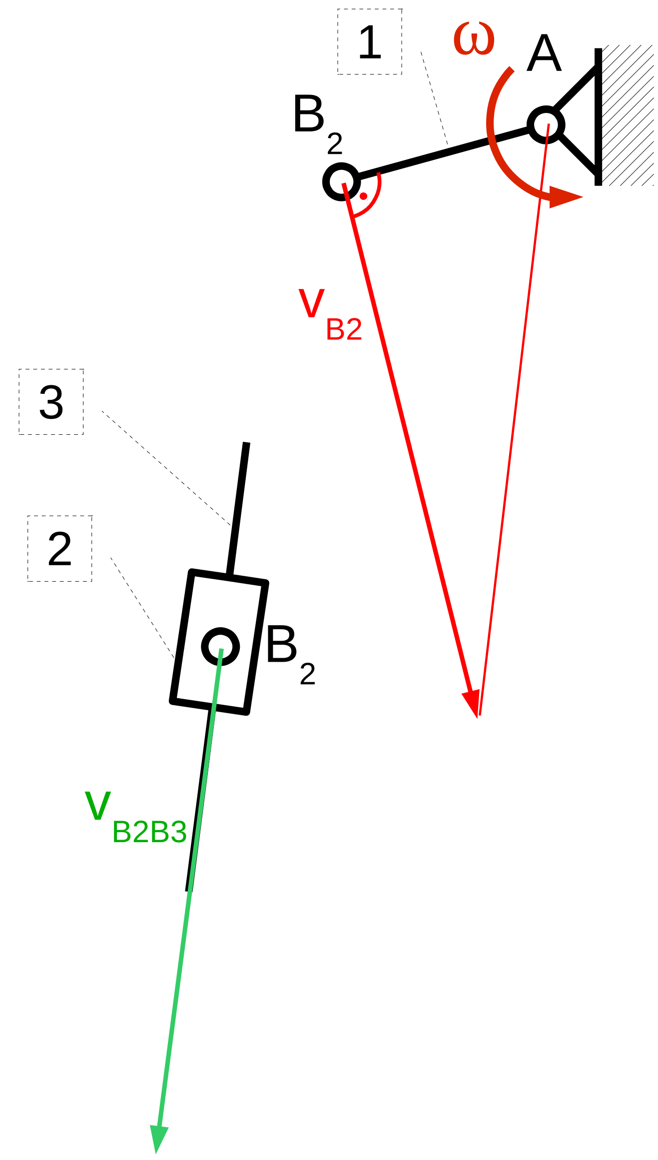


Let's go to the 4th element.
Calculate velocity of the F point using velocity of the E.

$$\underset{\parallel 6}{\underline{v_F}} = \underset{\perp 3}{\underline{\underline{v_E}}} + \underset{\perp 4}{\underline{v_{FE}}}$$



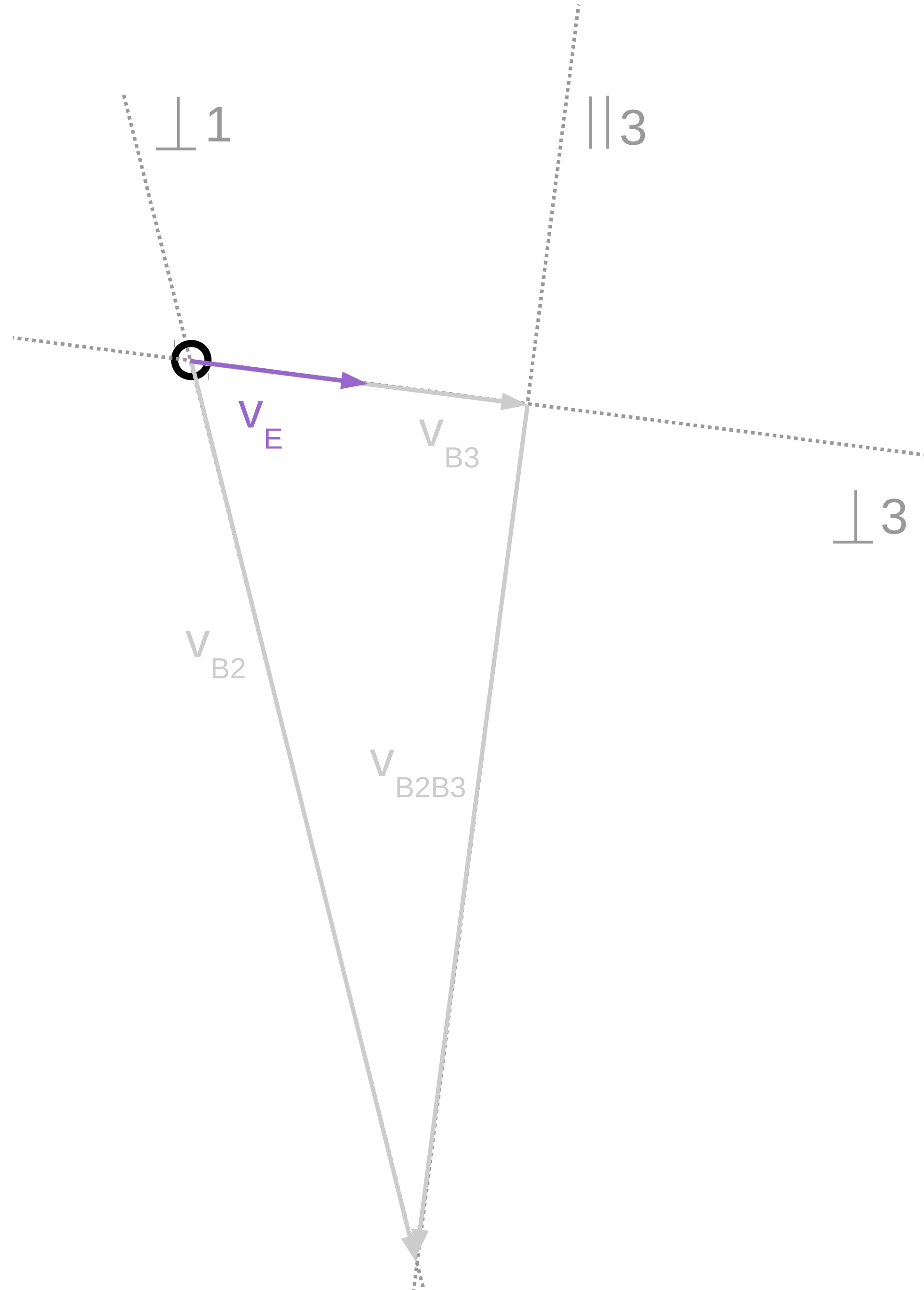




Velocity scheme

$$\underset{}{\underline{\underline{v_{B2}}}} = \underset{\perp 3}{\underline{v_{B3}}} + \underset{\parallel 3}{\underline{v_{B2B3}}}$$

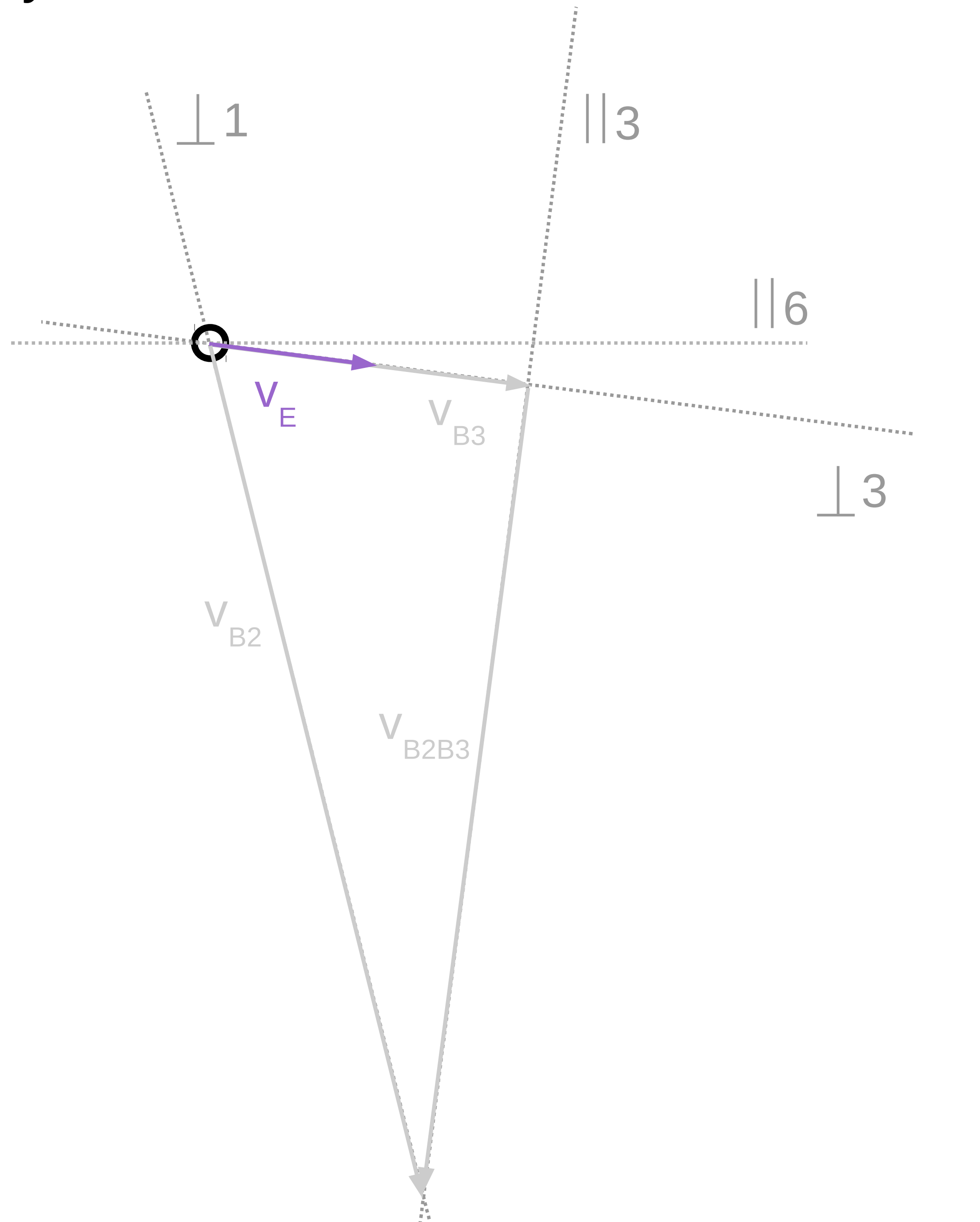
$$\underset{\parallel 6}{\underline{v_F}} = \underset{\perp 3}{\underline{\underline{v_E}}} + \underset{\perp 4}{\underline{v_{FE}}}$$



Velocity scheme

v_{B2}	=	v_{B3}	+	v_{B2B3}
$=$		$\perp 3$		$\parallel 3$

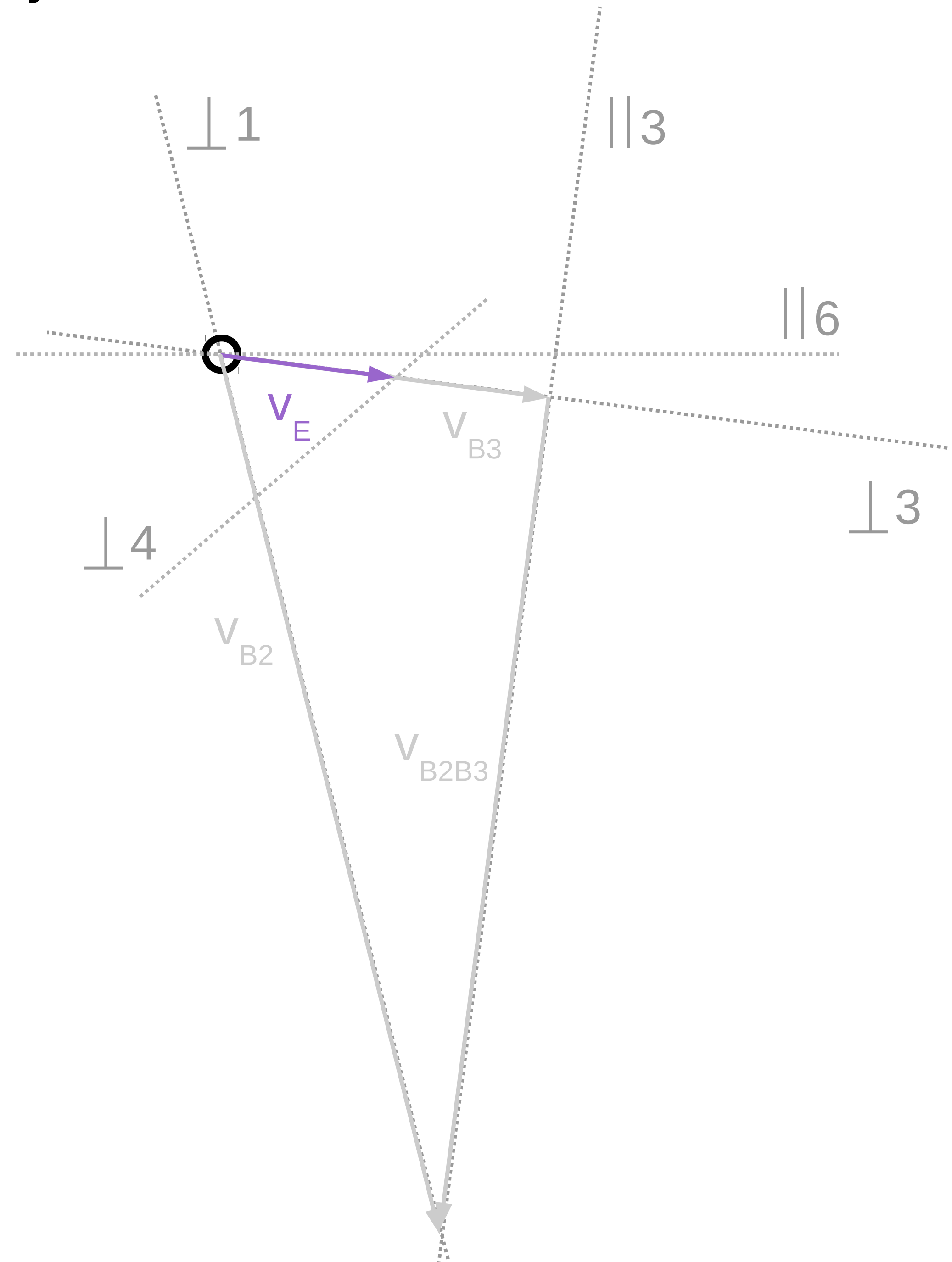
v_F	=	v_E	+	v_{FE}
$\parallel 6$		$\perp 3$		$\perp 4$



Velocity scheme

$$\underset{=}{v_{B2}} = \underset{\perp 3}{v_{B3}} + \underset{\parallel 3}{v_{B2B3}}$$

$$\underset{\parallel 6}{v_{F}} = \underset{\perp 3}{\underline{v_{E}}} + \underset{\perp 4}{v_{FE}}$$



Velocity scheme

$$\underset{=}{v_{B2}} = \underset{\perp 3}{v_{B3}} + \underset{\parallel 3}{v_{B2B3}}$$

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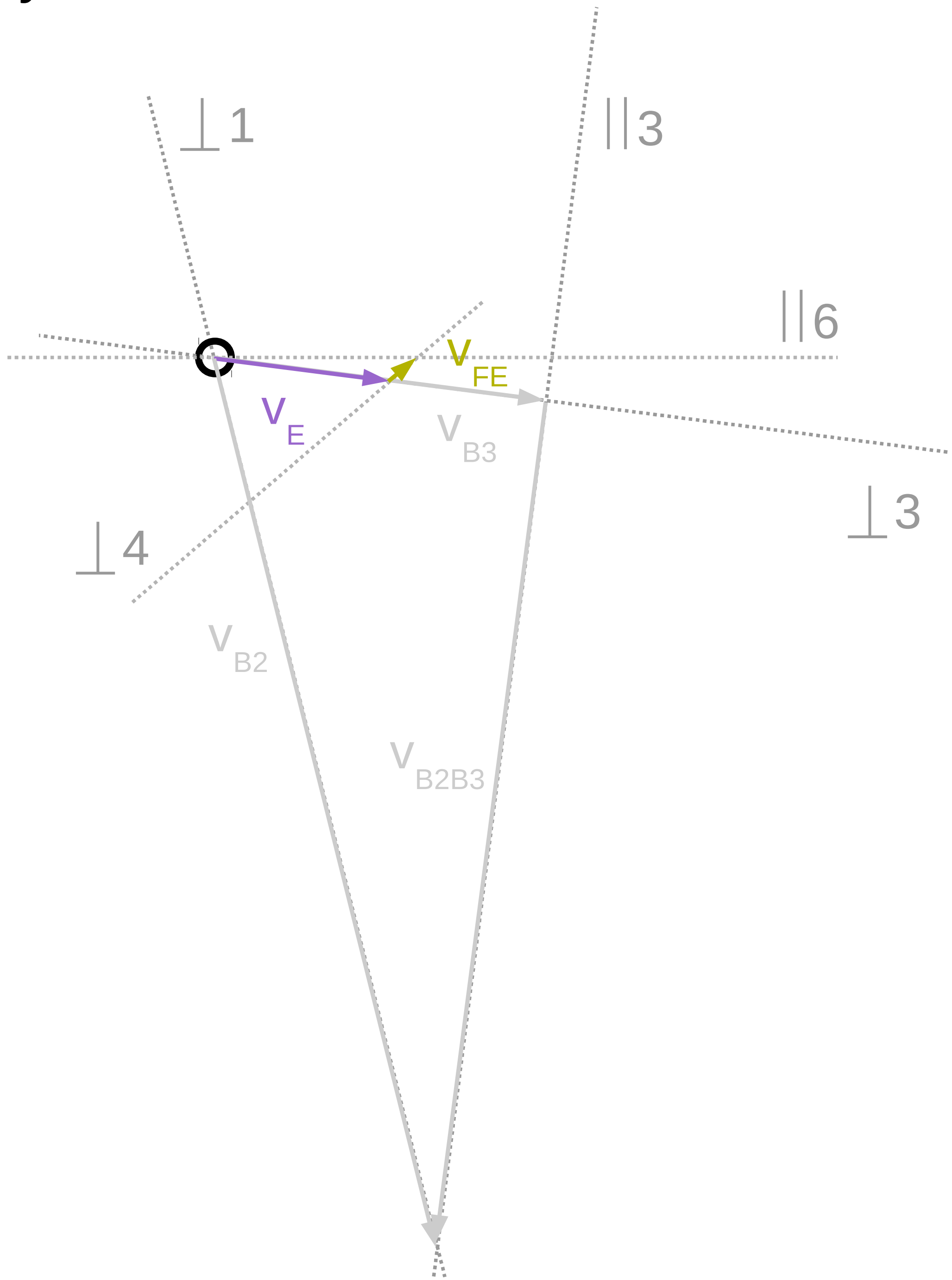

Velocity scheme

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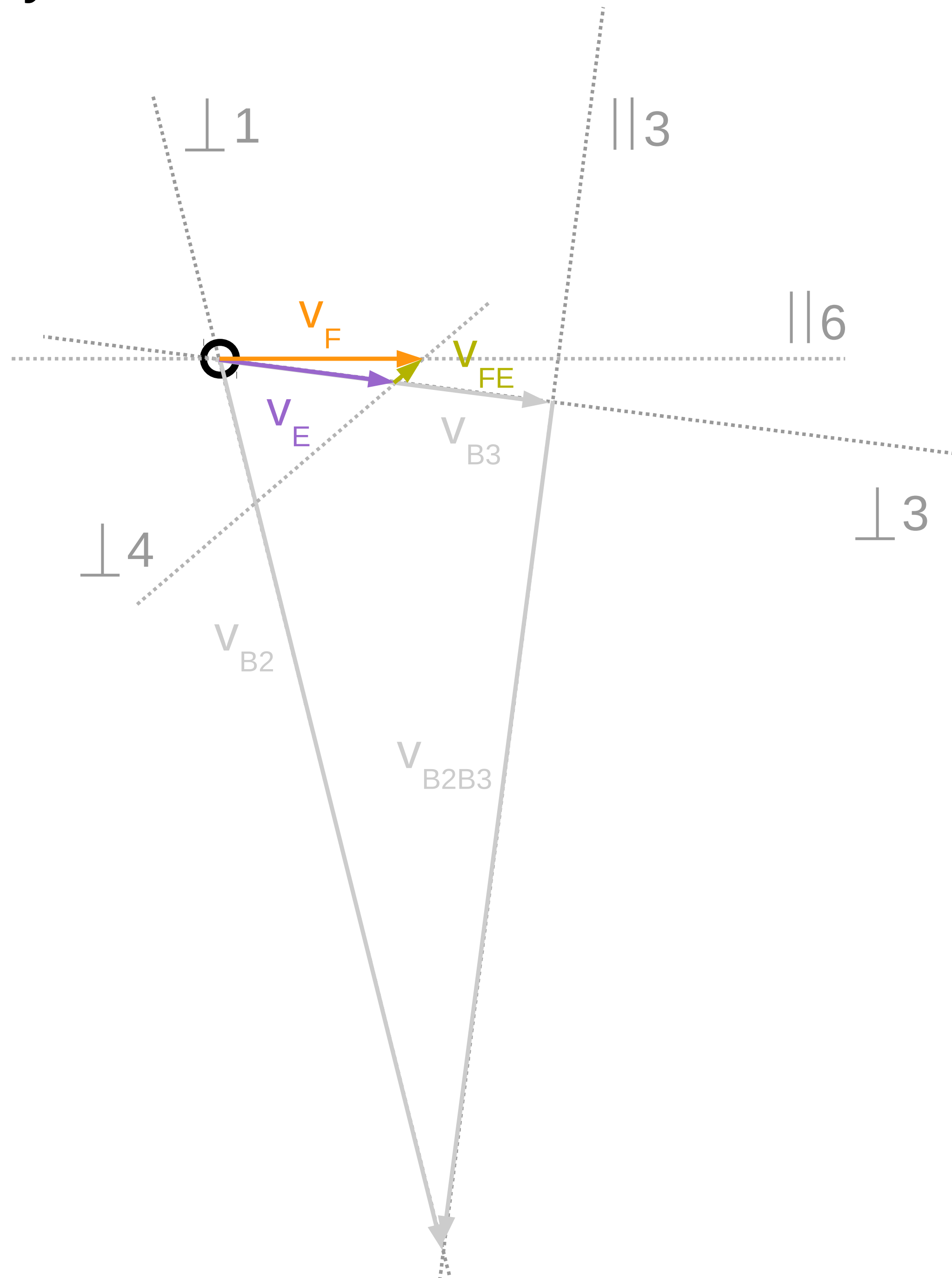
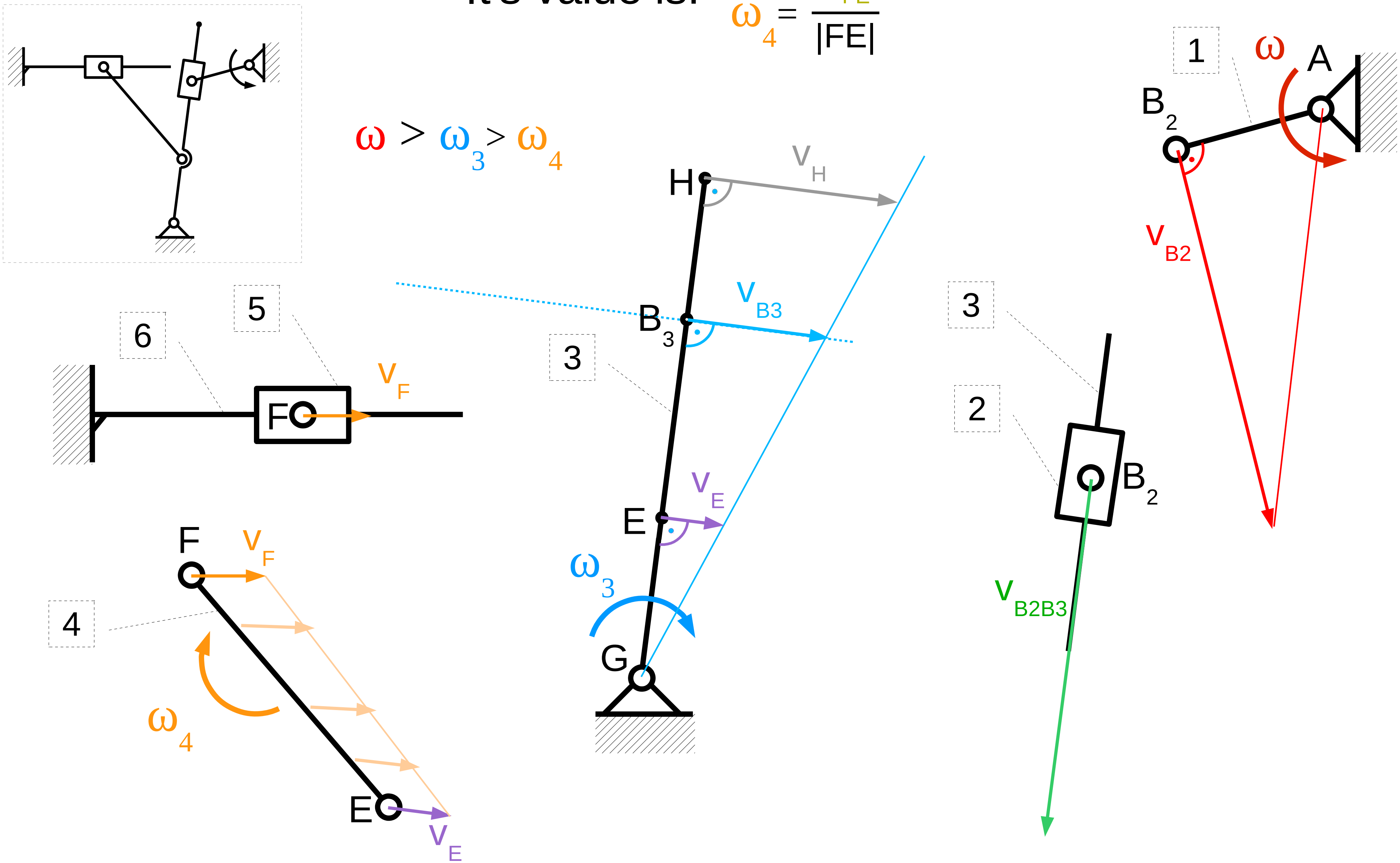
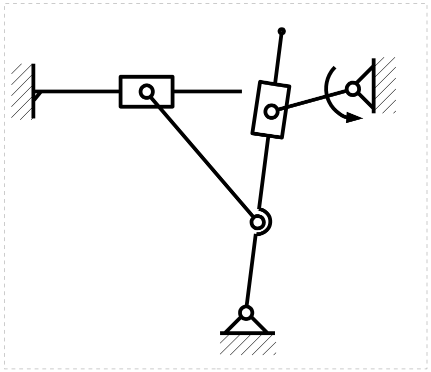


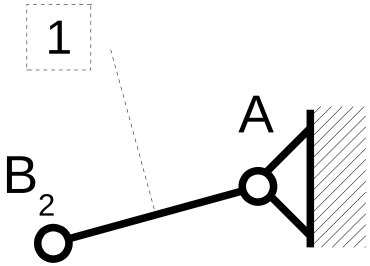
Let us find angular velocity of the 4th element.
It's direction is determined by direction of V_{FE}.

It's value is: $\omega_4 = \dfrac{V_{FE}}{|FE|}$

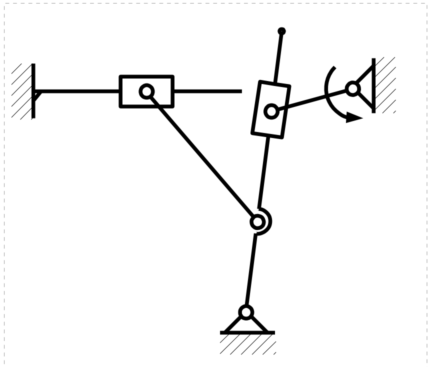


Now we can start acceleration analysis from the 1st element.

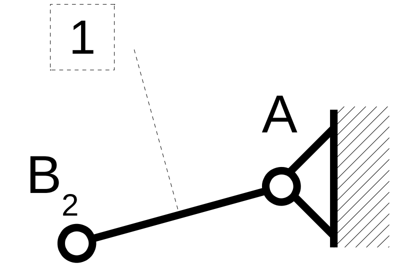




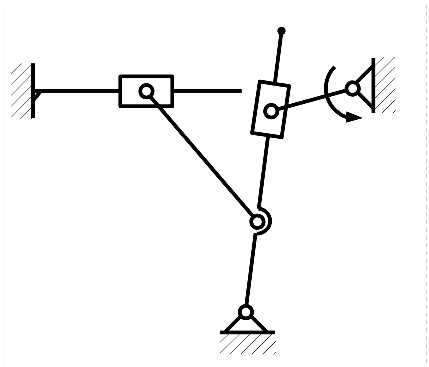
Acceleration analysis for the 1st element.



$$p_{B2} = p_A + p^n_{B2A} + p^t_{B2A}$$



Acceleration analysis for the 1st element.

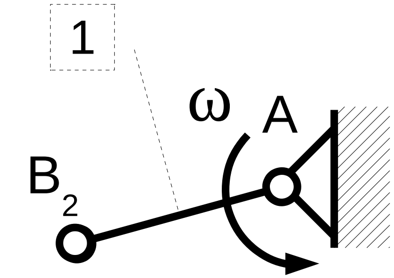


$$p_{B2} = p_A + p^n_{B2A} + p^t_{B2A}$$

p_A: $=0$; p^n_{B2A}: $||1$

$$|p^n_{B2A}| = \omega^2 \, |B_2A| \qquad |p^t_{B2A}| = \varepsilon \, |B_2A| = 0$$

$$\varepsilon = \frac{d\omega}{dt} = 0$$



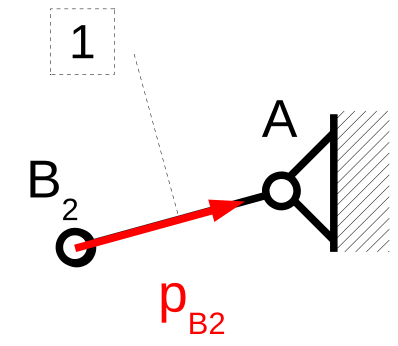
ω assumed constant

Acceleration analysis for the 1st element.

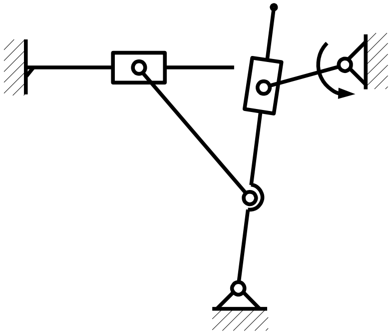
$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$$\| 1$$

$$|p^n_{B2A}| = \omega^2 \, |B_2A|$$



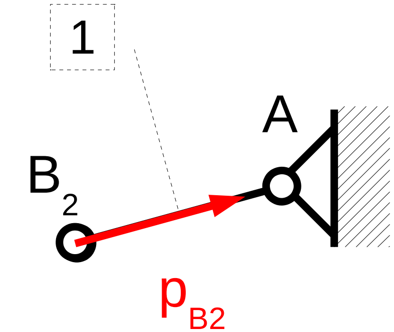
Now is time for the 3rd element



$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$\|1$

$$|p^n_{B2A}| = \omega_2^2\,|B_2A|$$

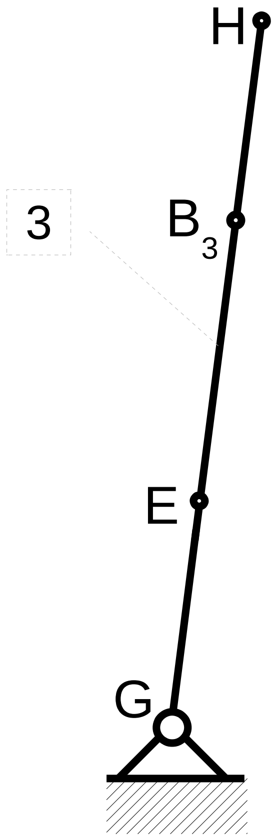


$$p_{B3} = \underline{\underline{p_G}} + \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

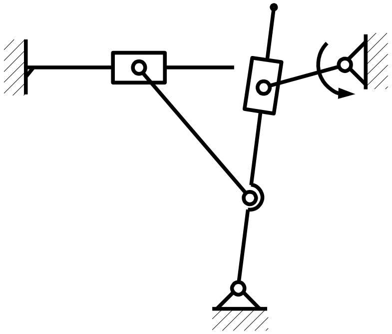
$=0 \quad \|3 \quad \perp 3$

$$|p^n_{B3G}| = \omega_3^{\,2}\,|B_3G|$$

from velocity scheme



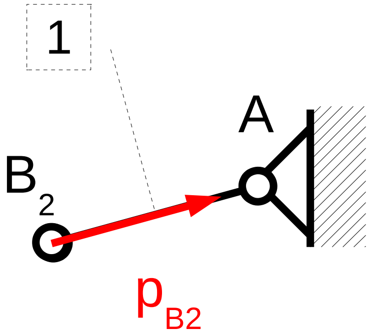
Now is time for the 3rd element



$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$\| 1$

$$|p^n_{B2A}| = \omega^2 \, |B_2A|$$

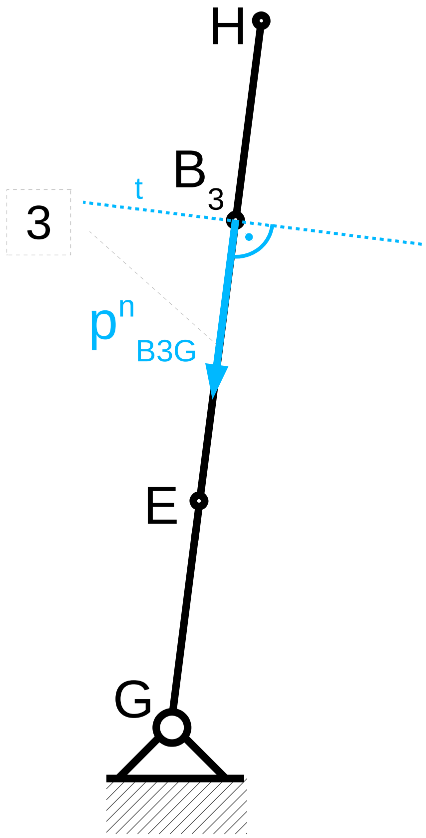


$$p_{B3} = \underline{\underline{p_G}} + \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$=0$ $\quad \| 3 \quad \perp 3$

$$|p^n_{B3G}| = \omega_3^{\;2} \, |B_3G|$$

from velocity scheme



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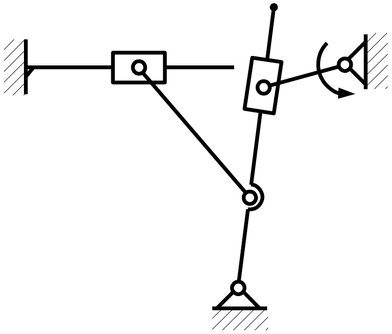
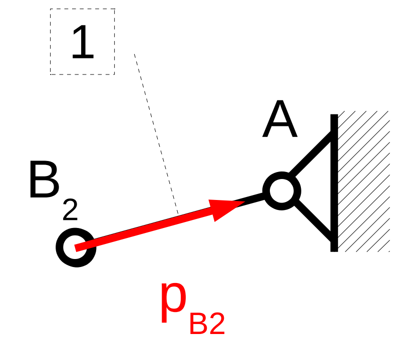


$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$\parallel 1$

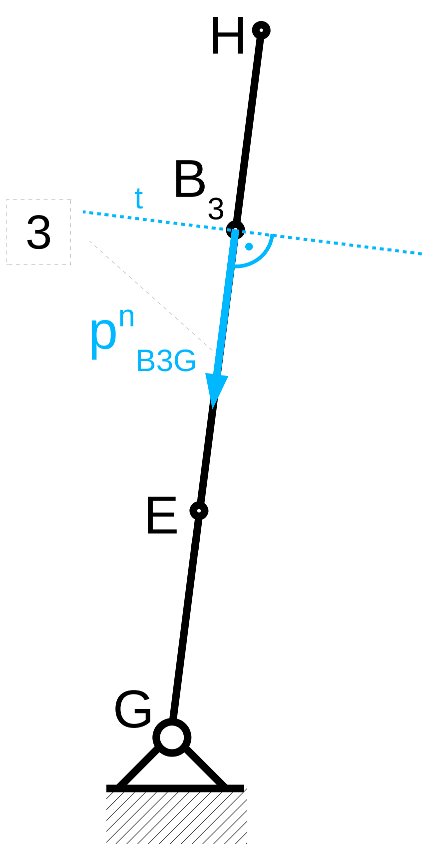
$$|p^n_{B2A}| = \omega^2 \, |B_2A|$$



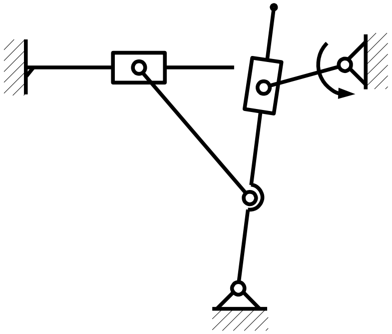
$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$\parallel 3$ $\perp 3$

$$|p^n_{B3G}| = \omega_3^{\,2} \, |B_3G|$$



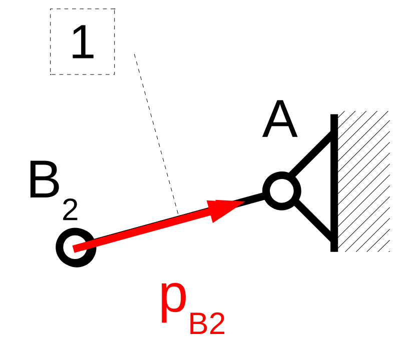
Let us think about relative motion of 2 and 3.



$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$\| 1$

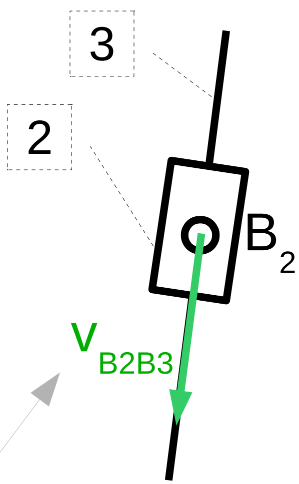
$$|p^n_{B2A}| = \omega^2 \, |B_2A|$$

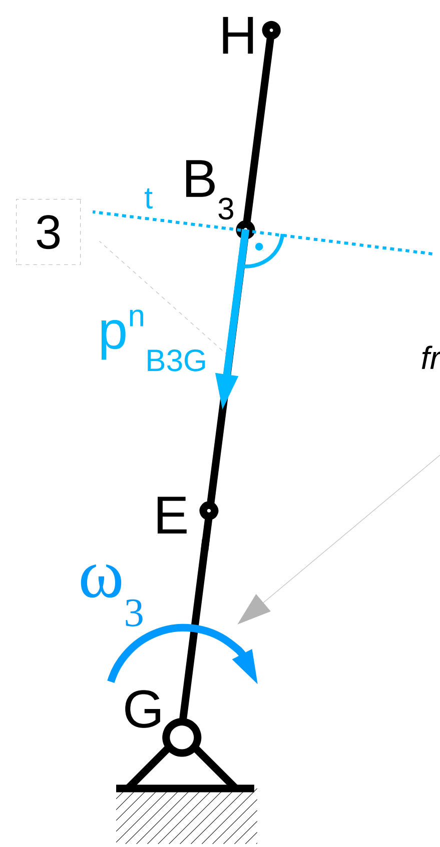


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$\| 3$ $\perp 3$

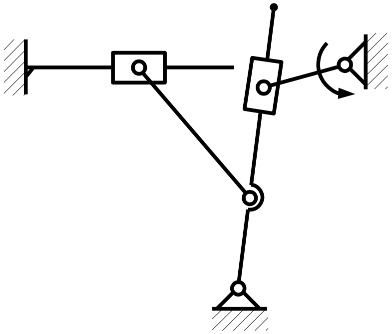
$$|p^n_{B3G}| = \omega_3^{\,2} \, |B_3G|$$





from velocity scheme

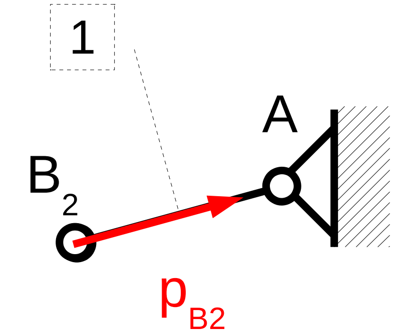
Let us think about relative motion of 2 and 3.



$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$\|1$

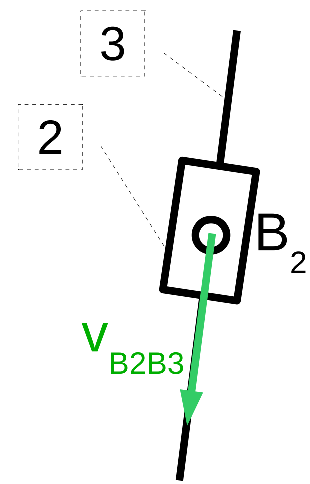
$$|p^n_{B2A}| = \omega^2\,|B_2A|$$

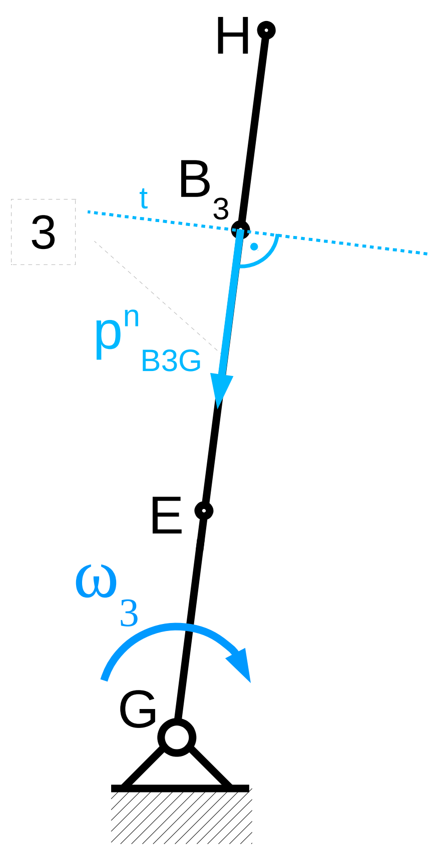


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$\|3$ $\perp 3$

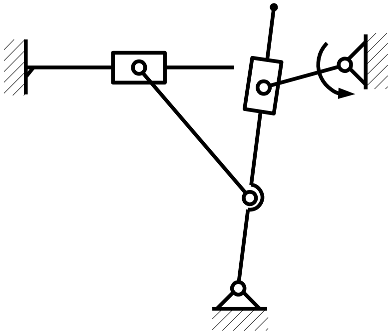
$$|p^n_{B3G}| = \omega_3^{\,2}\,|B_3G|$$





REFERENCE FRAME: rod 3
RELATIVE MOTION: slider 2 movement along rod 3

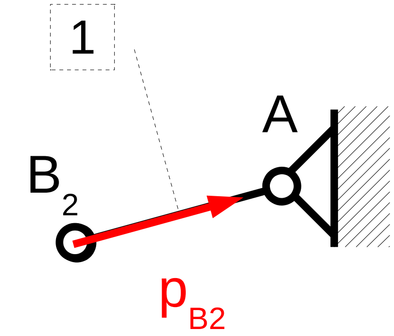
Let us think about relative motion of 2 and 3.



$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$||1$

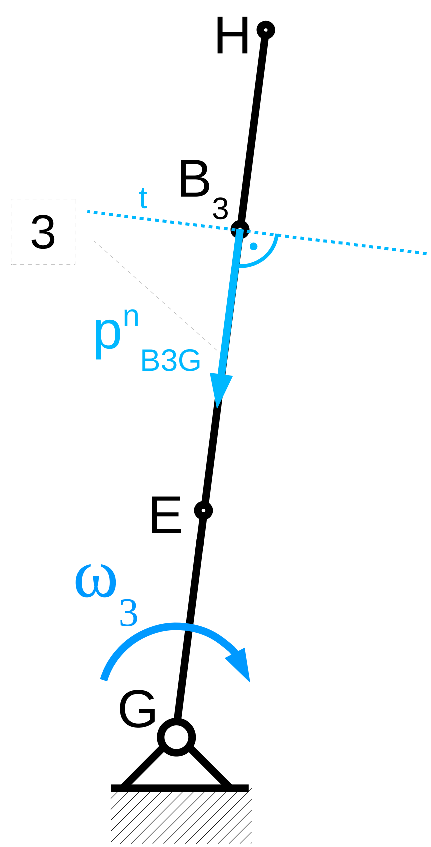
$$|p^n_{B2A}| = \omega^2\,|B_2A|$$

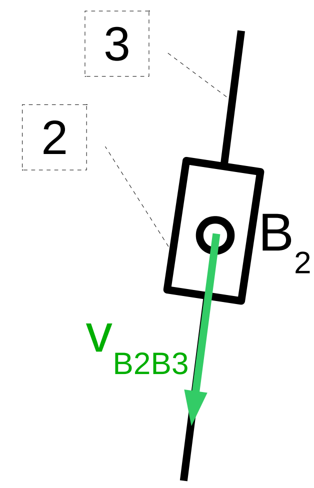


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$||3$ $\perp 3$

$$|p^n_{B3G}| = \omega_3^{\ 2}\,|B_3G|$$



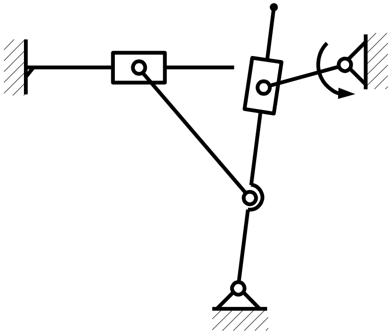


REFERENCE FRAME: rod 3
RELATIVE MOTION: slider 2 movement along rod 3

EQUATION FOR RELATIVE MOTION:

$$p_{B2} = p^u_{B3} + p^w + p^c$$

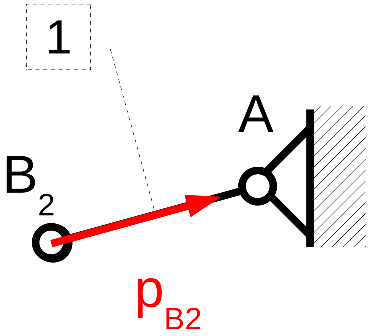
Let us think about relative motion of 2 and 3.



$$p_{B2} = p^n_{B2A}$$

$\|1$

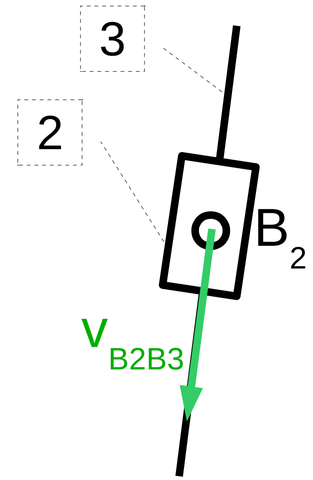
$$|p^n_{B2A}| = \omega^2 \, |B_2A|$$

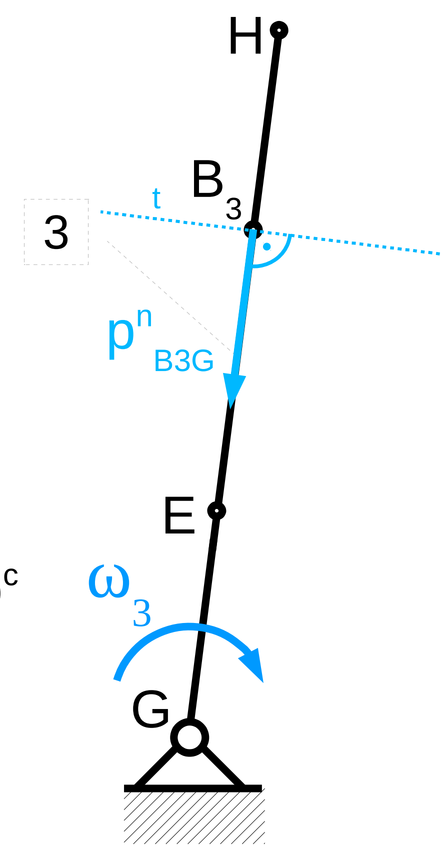


$$p_{B3} = p^n_{B3G} + p^t_{B3G}$$

$\|3$ $\perp 3$

$$|p^n_{B3G}| = \omega_3^{\,2} \, |B_3G|$$





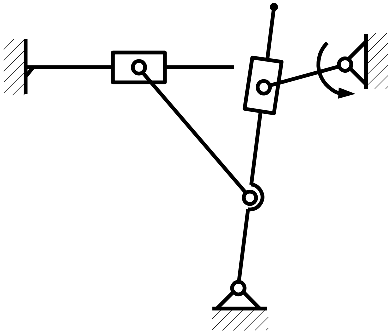
REFERENCE FRAME: rod 3
RELATIVE MOTION: slider 2 movement along rod 3

EQUATION FOR RELATIVE MOTION:

$$p_{B2} = p^u_{B3} + p^w + p^c$$

$$p^n_{B2A} = p^n_{B3G} + p^t_{B3G} + p^w_{B2B3} + p^c$$

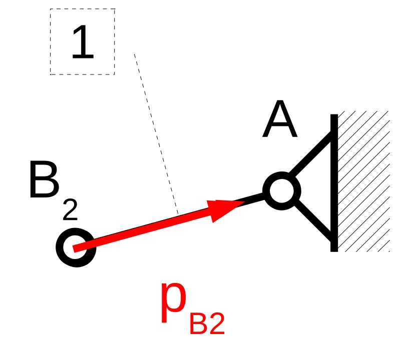
Let us think about relative motion of 2 and 3.



$$p_{B2} = \underline{\underline{p^n_{B2A}}}$$

$\parallel 1$

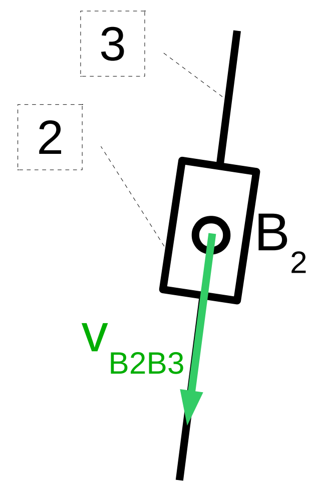
$$|p^n_{B2A}| = \omega^2 \, |B_2A|$$

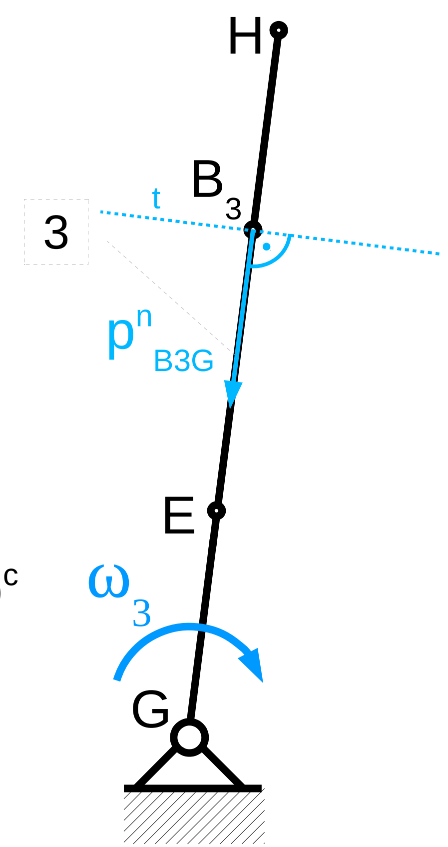


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$\parallel 3$ $\quad \perp 3$

$$|p^n_{B3G}| = \omega_3^2 \, |B_3G|$$





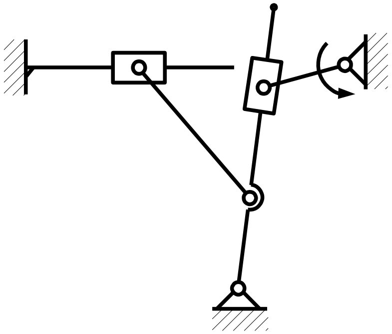
REFERENCE FRAME: rod 3
RELATIVE MOTION: slider 2 movement along rod 3

EQUATION FOR RELATIVE MOTION:

$$p_{B2} = p^u_{B3} + p^w + p^c$$

$$\underline{\underline{p^n_{B2A}}} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}} + \underline{p^w_{B2B3}} + p^c$$

$\parallel 1 \qquad \parallel 3 \qquad \perp 3 \qquad \parallel 3$

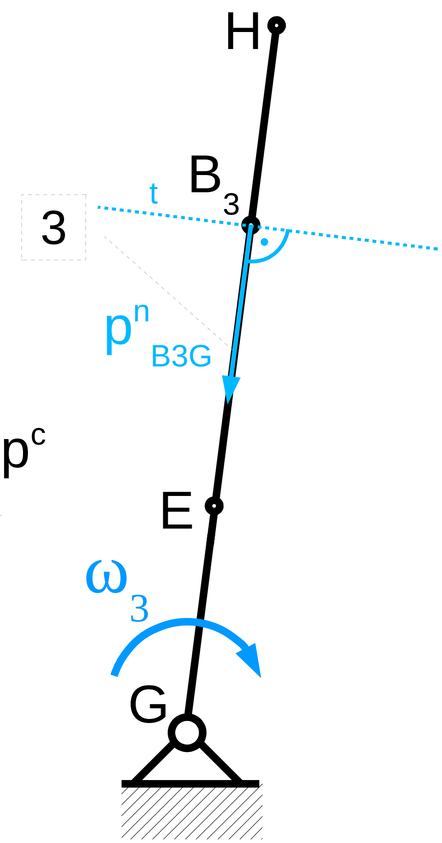


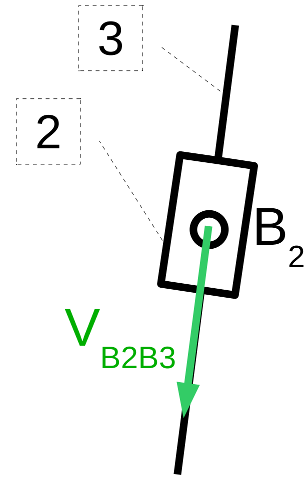
$$p_{B2} = p^{u}_{B3} + p^{w} + p^{c}$$

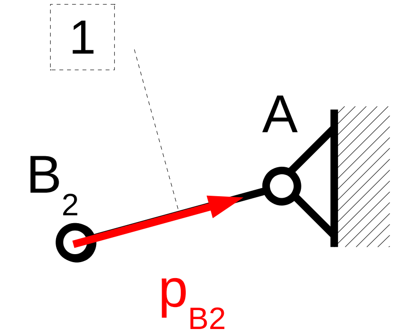
$$\underline{\underline{p^{n}_{B2A}}} = \underline{\underline{p^{n}_{B3G}}} + \underline{p^{t}_{B3G}} + \underline{p^{w}_{B2B3}} + p^{c}$$

$\parallel 1$	$\parallel 3$	$\perp 3$	$\parallel 3$

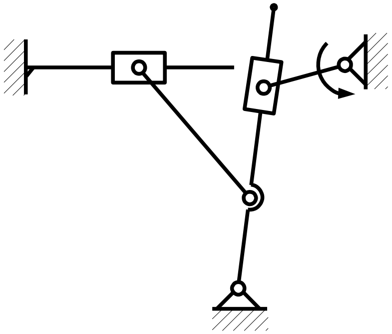
$$p^{c} = 2\omega_3 \times V_{B2B3}$$

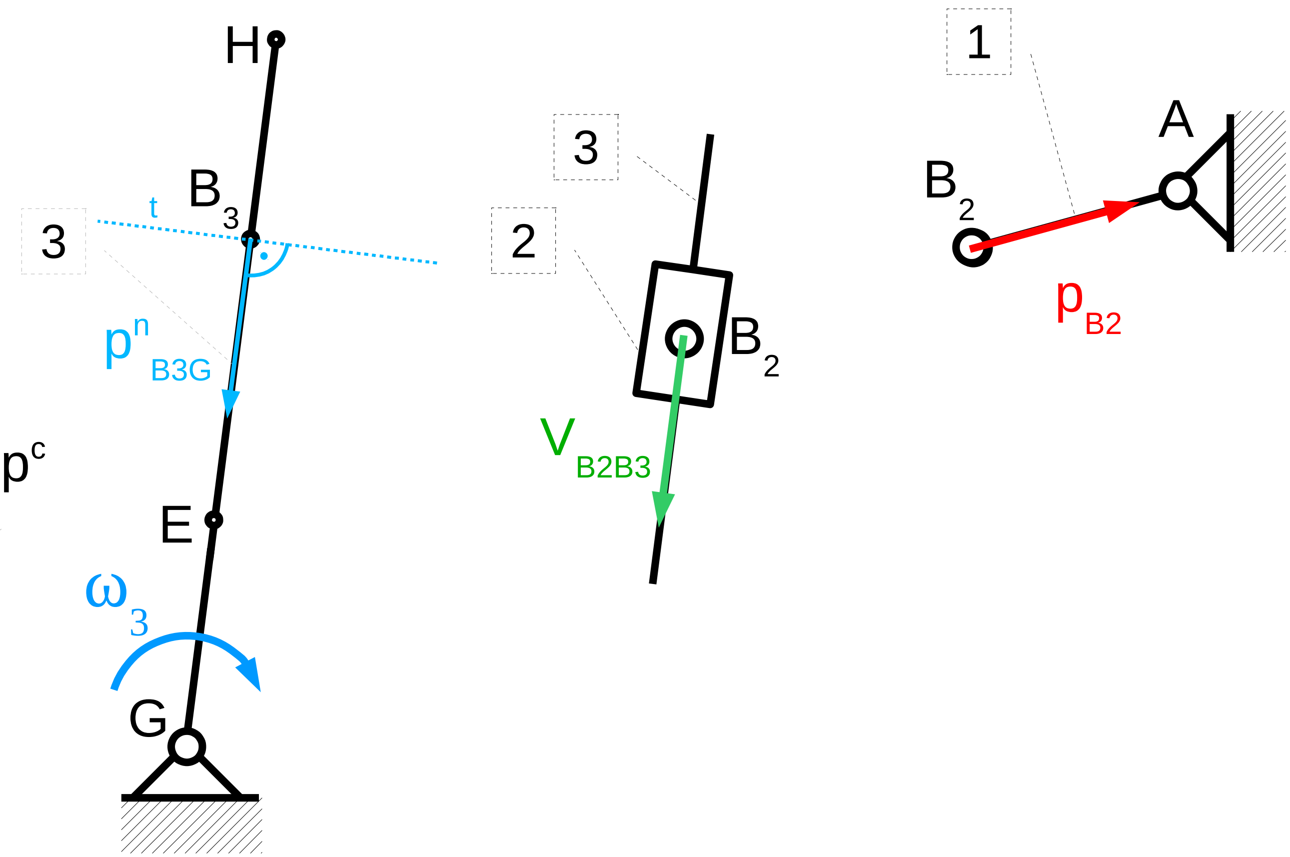






Coriolis acceleration





$$p_{B2} = p^u_{B3} + p^w + p^c$$

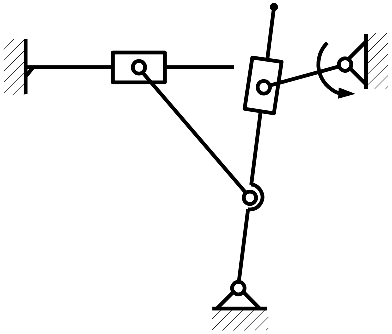
$$p^n_{B2A} = p^n_{B3G} + p^t_{B3G} + p^w_{B2B3} + p^c$$

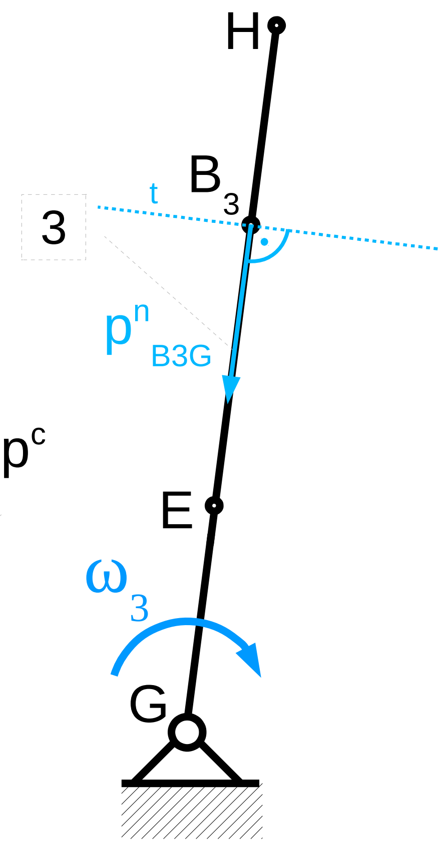
|| 1 || 3   ⊥ 3 || 3

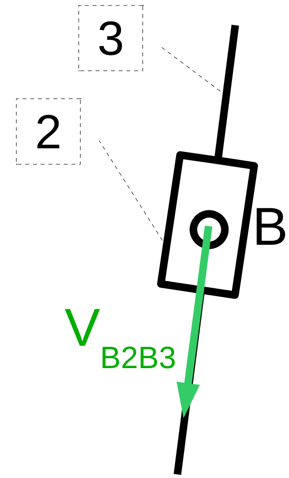
$$p^c = 2\omega_3 \times V_{B2B3}$$

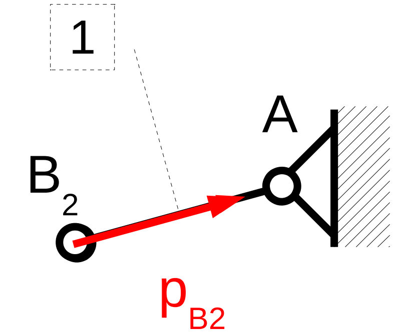
$$|p^c| = 2|\omega_3|\,|V_{B2B3}|\,\sin(\measuredangle(\omega_3, V_{B2B3}))$$

Coriolis acceleration









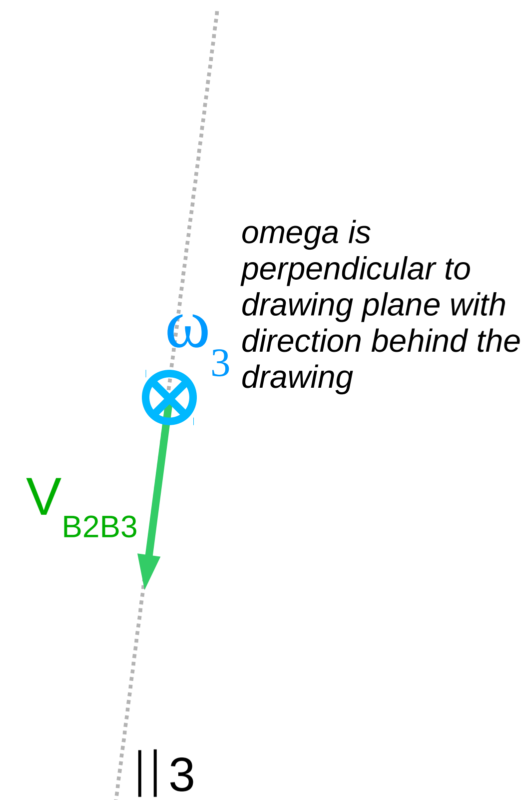
$$p_{B2} = p^{u}_{B3} + p^{w} + p^{c}$$

$$\underline{\underline{p^{n}_{B2A}}} = \underline{\underline{p^{n}_{B3G}}} + \underline{p^{t}_{B3G}} + \underline{p^{w}_{B2B3}} + p^{c}$$

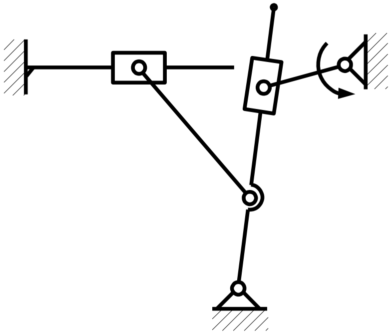
||1 ||3 ⊥3 ||3

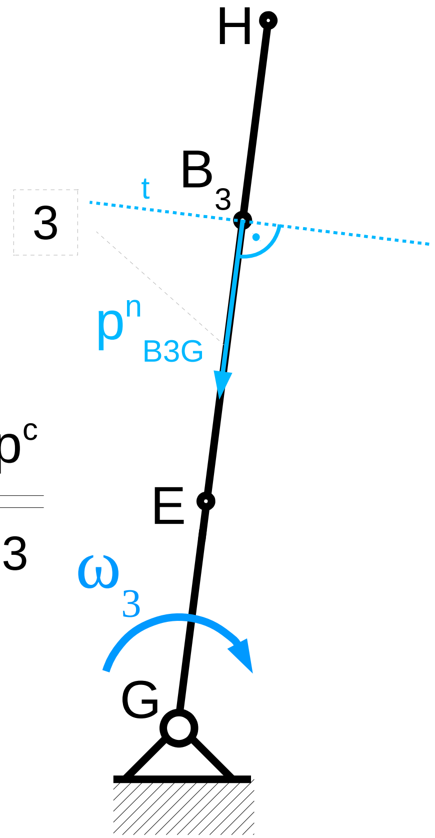
$$p^{c} = 2\omega_3 \times V_{B2B3}$$

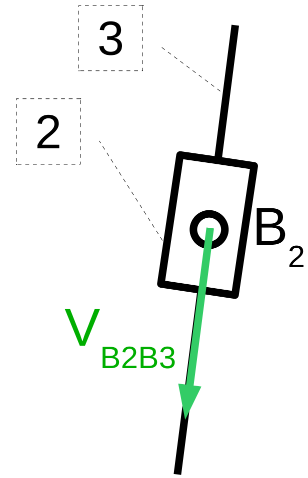
$$|p^{c}| = 2|\omega_3|\,|V_{B2B3}|\,\sin(\sphericalangle(\omega_3, V_{B2B3}))$$

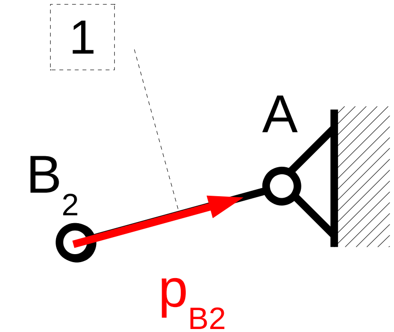


Coriolis acceleration







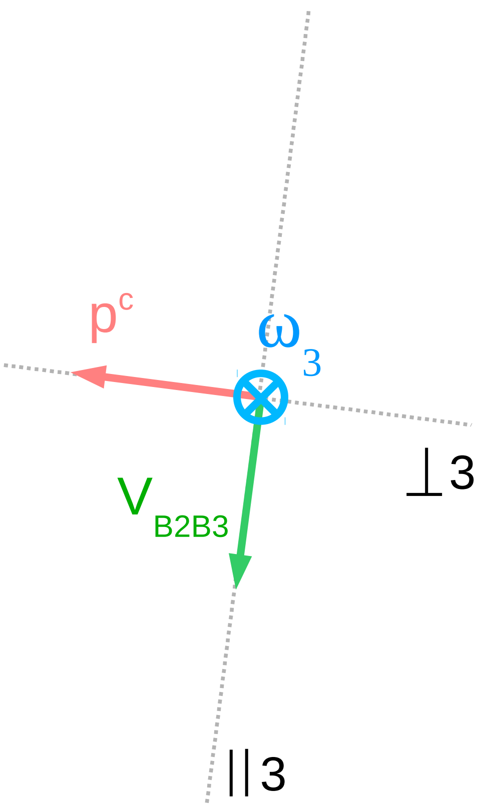


$$p_{B2} = p^u_{B3} + p^w + p^c$$

$$\underset{||1}{\underline{\underline{p^n_{B2A}}}} = \underset{||3}{\underline{\underline{p^n_{B3G}}}} + \underset{\perp 3}{\underline{p^t_{B3G}}} + \underset{||3}{\underline{p^w_{B2B3}}} + \underset{\perp 3}{\underline{\underline{p^c}}}$$

$$p^c = 2\omega_3 \times V_{B2B3}$$

$$|p^c| = 2|\omega_3|\,|V_{B2B3}|\,\sin(\underbrace{\sphericalangle(\omega_3, V_{B2B3})}_{\text{right angle}}) = 2|\omega_3|\,|V_{B2B3}|$$



Acceleration scheme

$$\underline{\underline{p^{n}_{B2A}}} = \underline{\underline{p^{n}_{B3G}}} + \underline{p^{t}_{B3G}} + \underline{p^{w}_{B2B3}} + \underline{\underline{p^{c}}}$$

$$\parallel 1 \qquad \parallel 3 \qquad \perp 3 \qquad \parallel 3 \qquad \perp 3$$

Acceleration scheme

$$\underset{\|1}{\underline{\underline{p^{n}_{B2A}}}} = \underset{\|3}{\underline{\underline{p^{n}_{B3G}}}} + \underset{\perp 3}{\underline{p^{t}_{B3G}}} + \underset{\|3}{\underline{p^{w}_{B2B3}}} + \underset{\perp 3}{\underline{\underline{p^{c}}}}$$

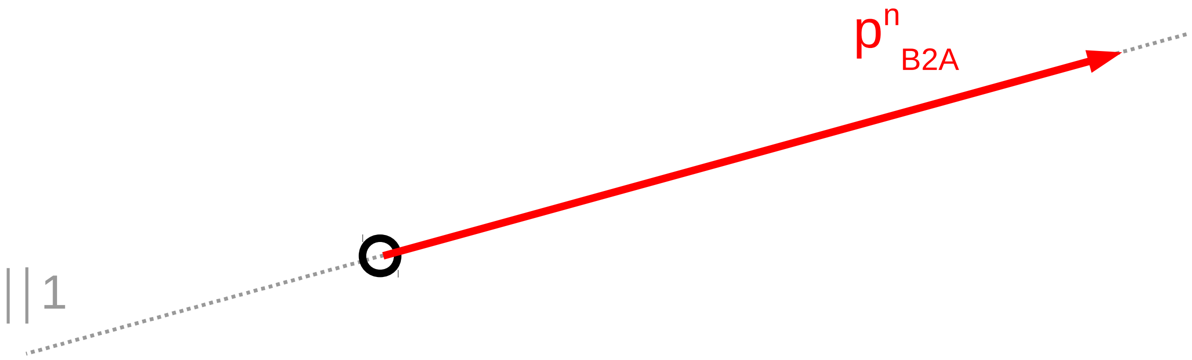
$$\underset{\|1}{\underline{\underline{p^{n}_{B2A}}}} - \underset{\perp 3}{\underline{\underline{p^{c}}}} - \underset{\|3}{\underline{p^{w}_{B2B3}}} = \underset{\|3}{\underline{\underline{p^{n}_{B3G}}}} + \underset{\perp 3}{\underline{p^{t}_{B3G}}}$$

Acceleration scheme

$$\underset{\parallel 1}{\underline{\underline{p^n_{B2A}}}} - \underset{\perp 3}{\underline{\underline{p^c}}} - \underset{\parallel 3}{\underline{p^w_{B2B3}}} = \underset{\parallel 3}{\underline{\underline{p^n_{B3G}}}} + \underset{\perp 3}{\underline{p^t_{B3G}}}$$

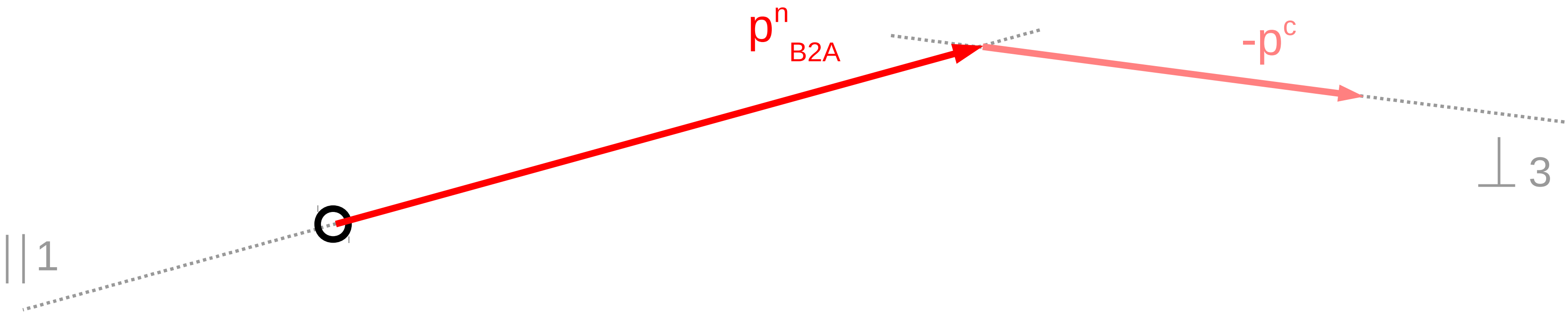
Acceleration scheme

$$\underset{\parallel 1}{\underline{\underline{p^{n}_{B2A}}}} - \underset{\perp 3}{\underline{\underline{p^{c}}}} - \underset{\parallel 3}{\underline{p^{w}_{B2B3}}} = \underset{\parallel 3}{\underline{\underline{p^{n}_{B3G}}}} + \underset{\perp 3}{\underline{p^{t}_{B3G}}}$$



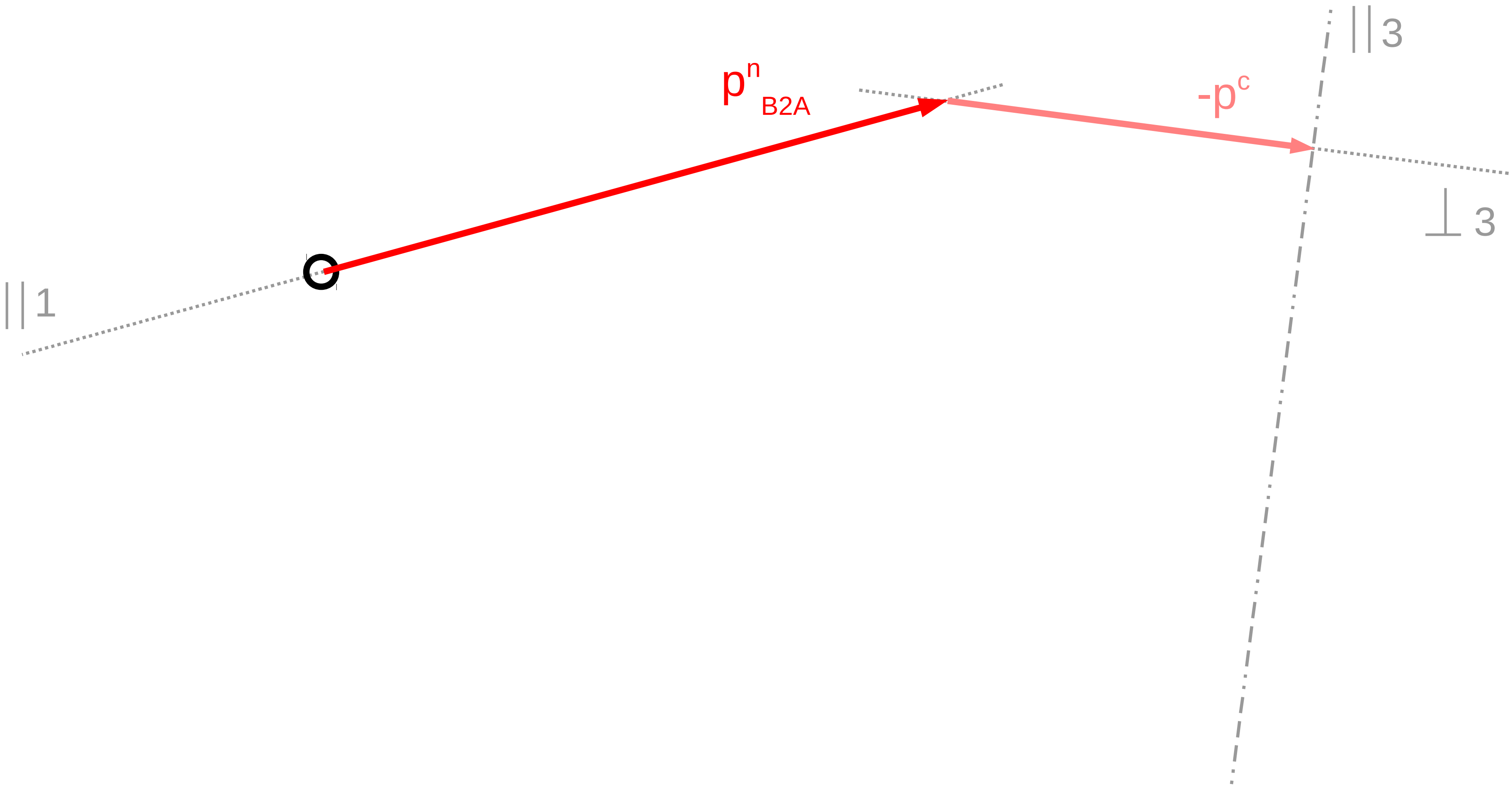
Acceleration scheme

$$\underset{\parallel 1}{\underline{\underline{p^n_{B2A}}}} - \underset{\perp 3}{\underline{\underline{p^c}}} - \underset{\parallel 3}{\underline{p^w_{B2B3}}} = \underset{\parallel 3}{\underline{\underline{p^n_{B3G}}}} + \underset{\perp 3}{\underline{p^t_{B3G}}}$$



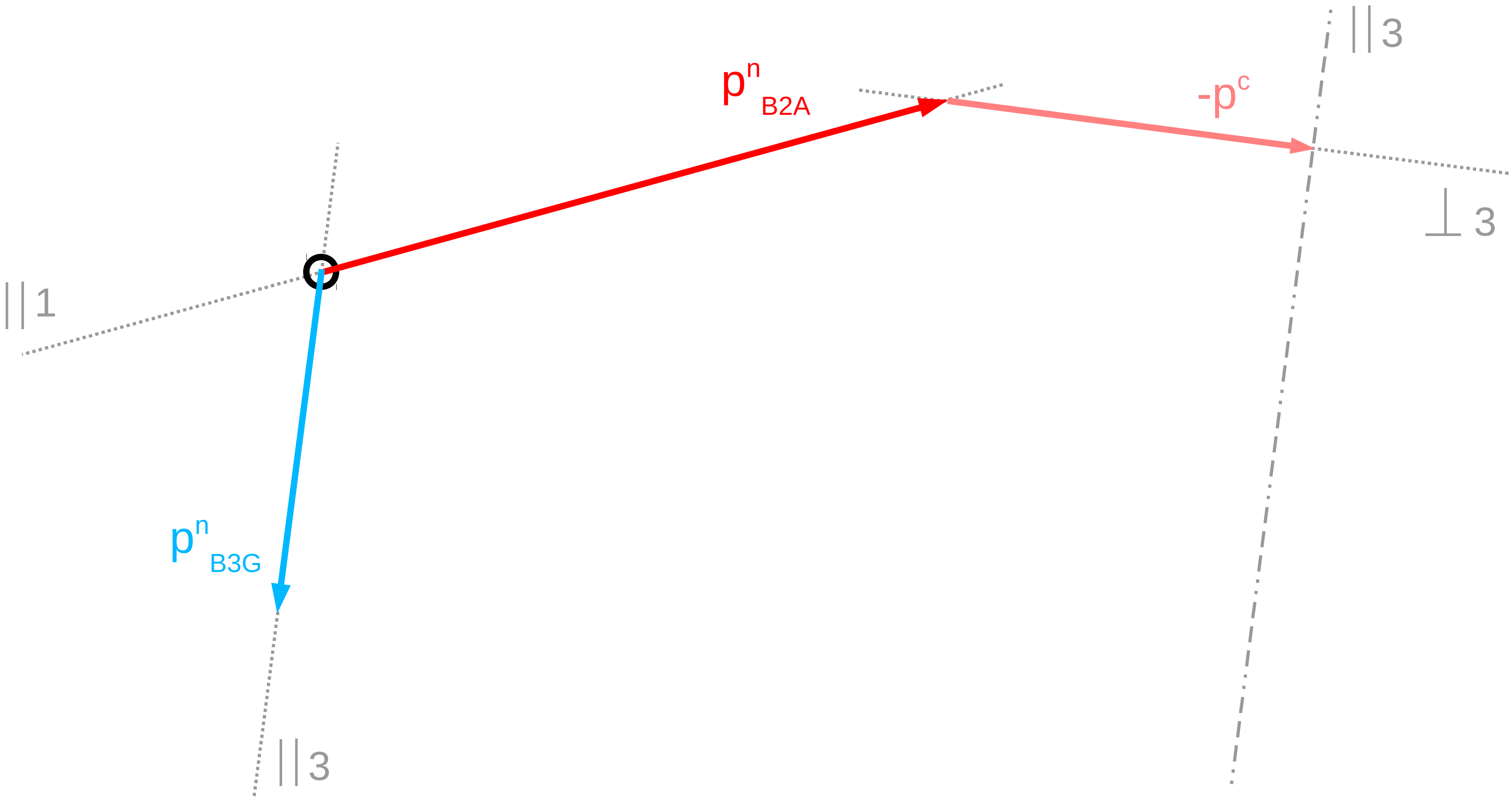
Acceleration scheme

$$\underset{||1}{\underline{\underline{p^n_{B2A}}}} - \underset{\perp 3}{\underline{\underline{p^c}}} - \underset{||3}{\underline{p^w_{B2B3}}} = \underset{||3}{\underline{\underline{p^n_{B3G}}}} + \underset{\perp 3}{\underline{p^t_{B3G}}}$$



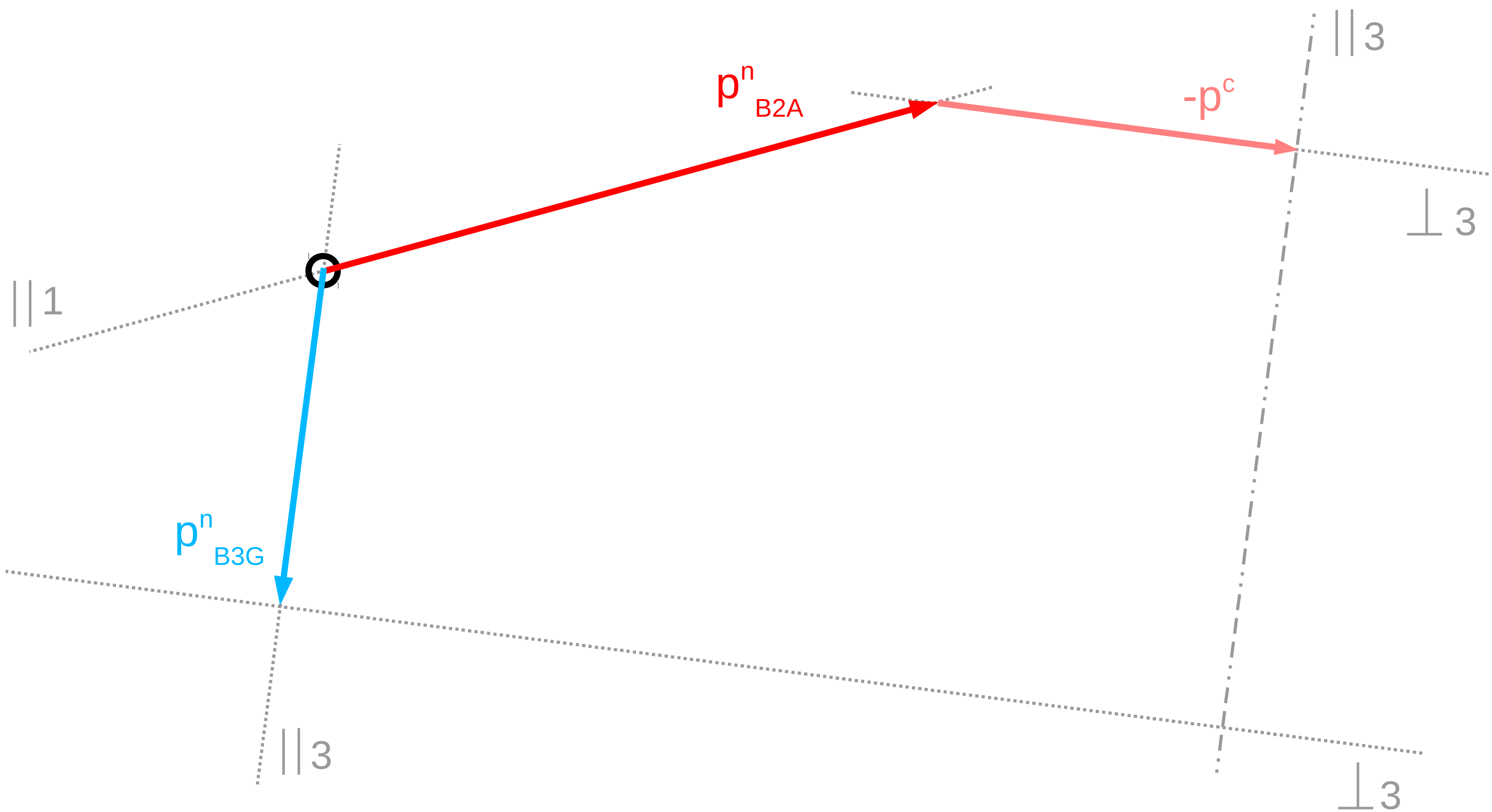
Acceleration scheme

$$\underset{\parallel 1}{\underline{\underline{p^n_{B2A}}}} - \underset{\perp 3}{\underline{\underline{p^c}}} - \underset{\parallel 3}{\underline{p^w_{B2B3}}} = \underset{\parallel 3}{\underline{\underline{p^n_{B3G}}}} + \underset{\perp 3}{\underline{p^t_{B3G}}}$$



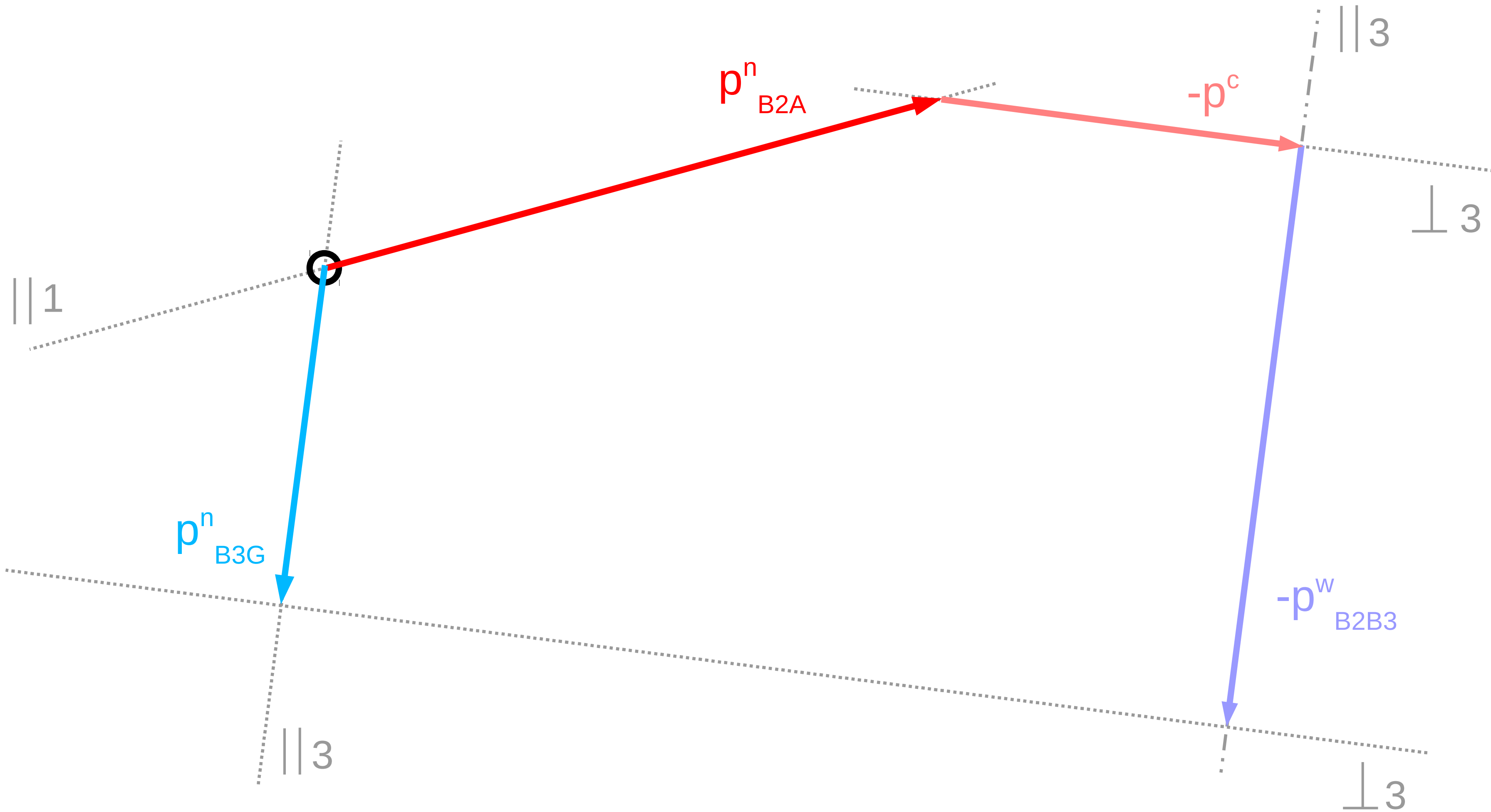
Acceleration scheme

$$\underbrace{p^n_{B2A}}_{||1} \underbrace{- p^c}_{\perp 3} \underbrace{- p^w_{B2B3}}_{||3} = \underbrace{p^n_{B3G}}_{||3} \underbrace{+ p^t_{B3G}}_{\perp 3}$$



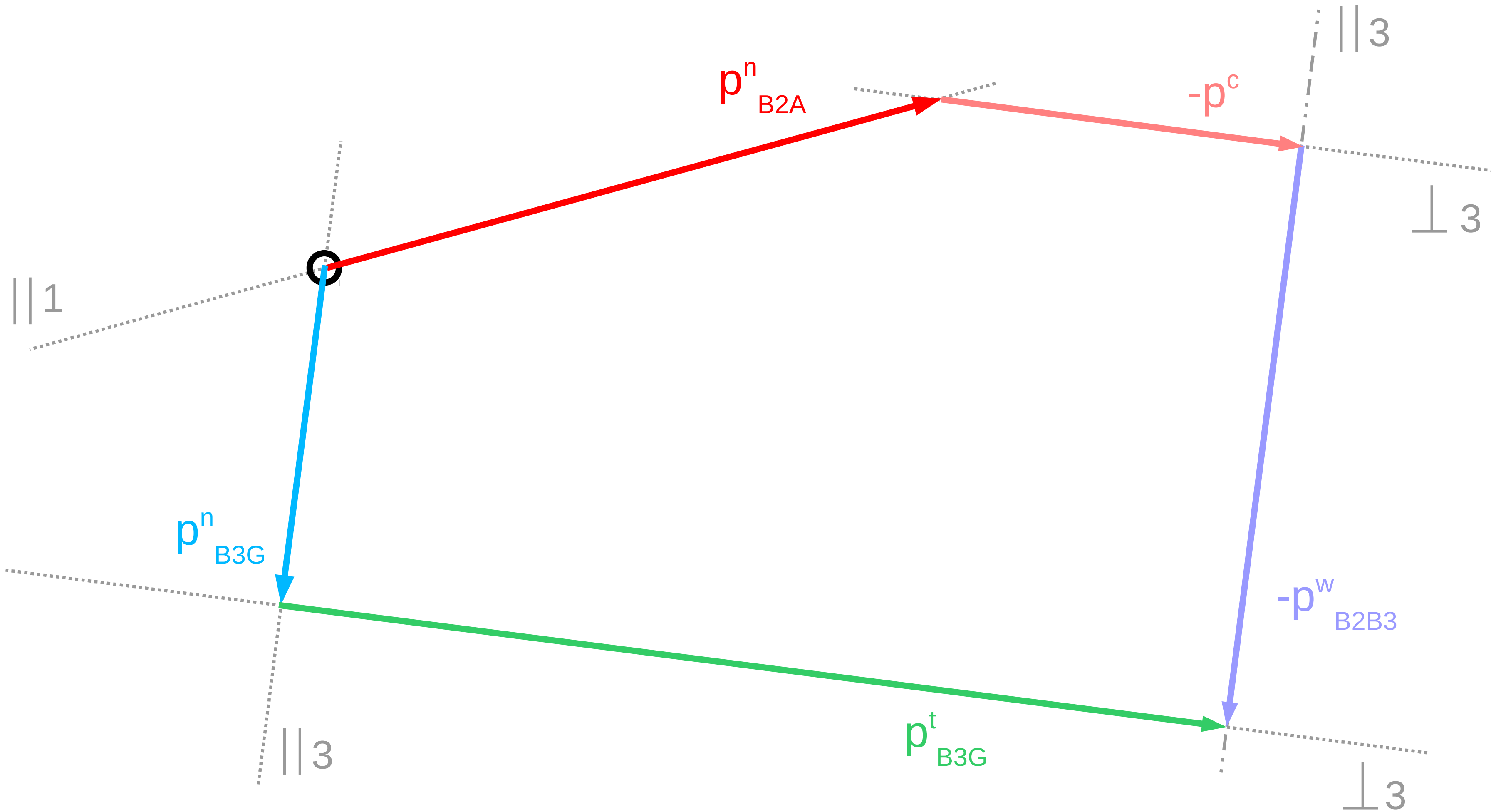
Acceleration scheme

$$\underbrace{\underline{\underline{p^{n}_{B2A}}}}_{\parallel 1} - \underbrace{\underline{\underline{p^{c}}}}_{\perp 3} - \underbrace{\underline{p^{w}_{B2B3}}}_{\parallel 3} = \underbrace{\underline{\underline{p^{n}_{B3G}}}}_{\parallel 3} + \underbrace{\underline{p^{t}_{B3G}}}_{\perp 3}$$



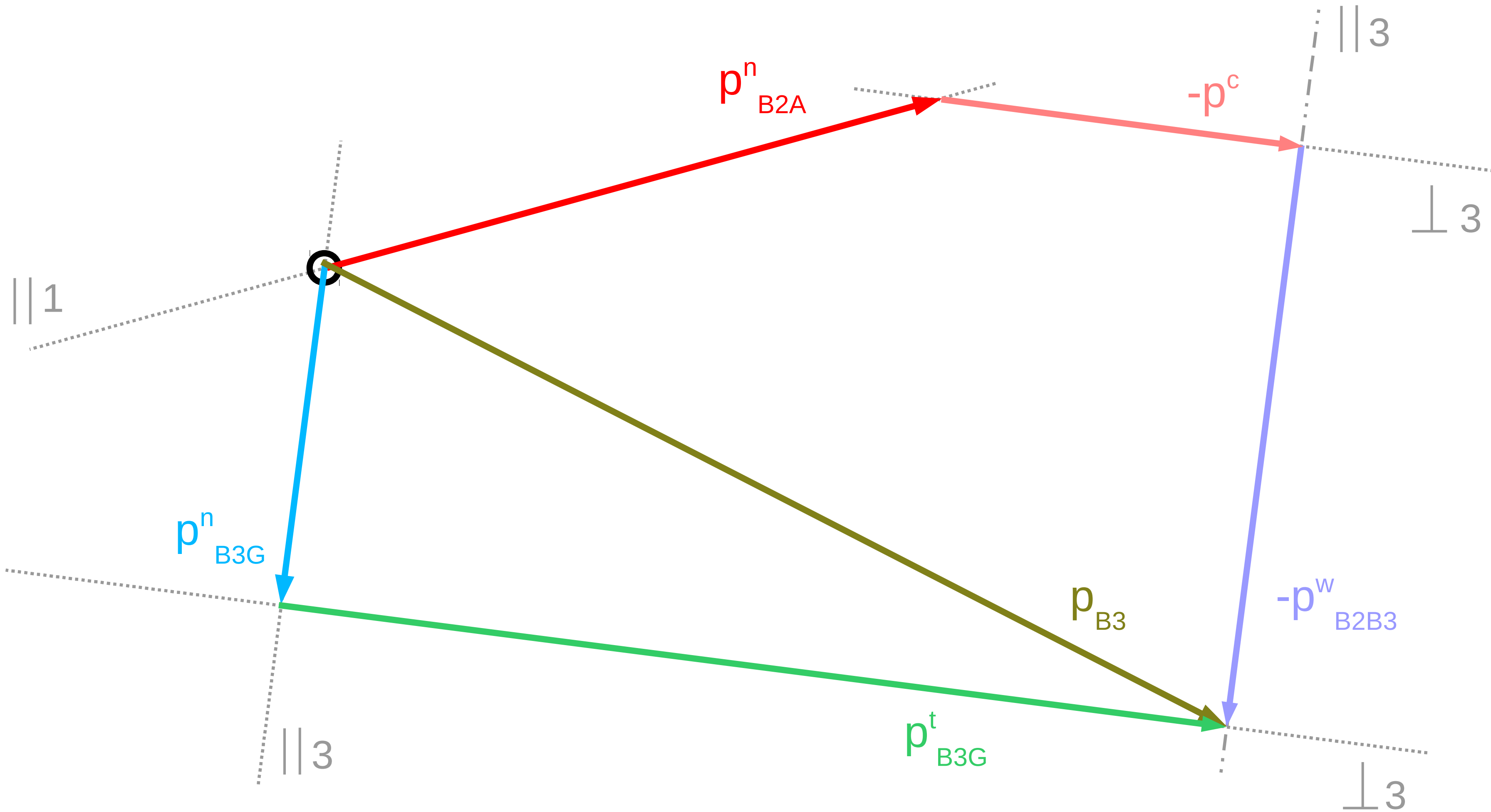
Acceleration scheme

$$\underset{\parallel 1}{p^{n}_{B2A}} - \underset{\perp 3}{p^{c}} - \underset{\parallel 3}{p^{w}_{B2B3}} = \underset{\parallel 3}{p^{n}_{B3G}} + \underset{\perp 3}{p^{t}_{B3G}}$$

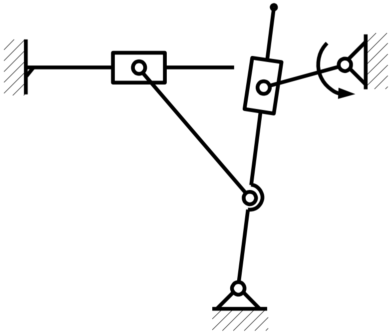


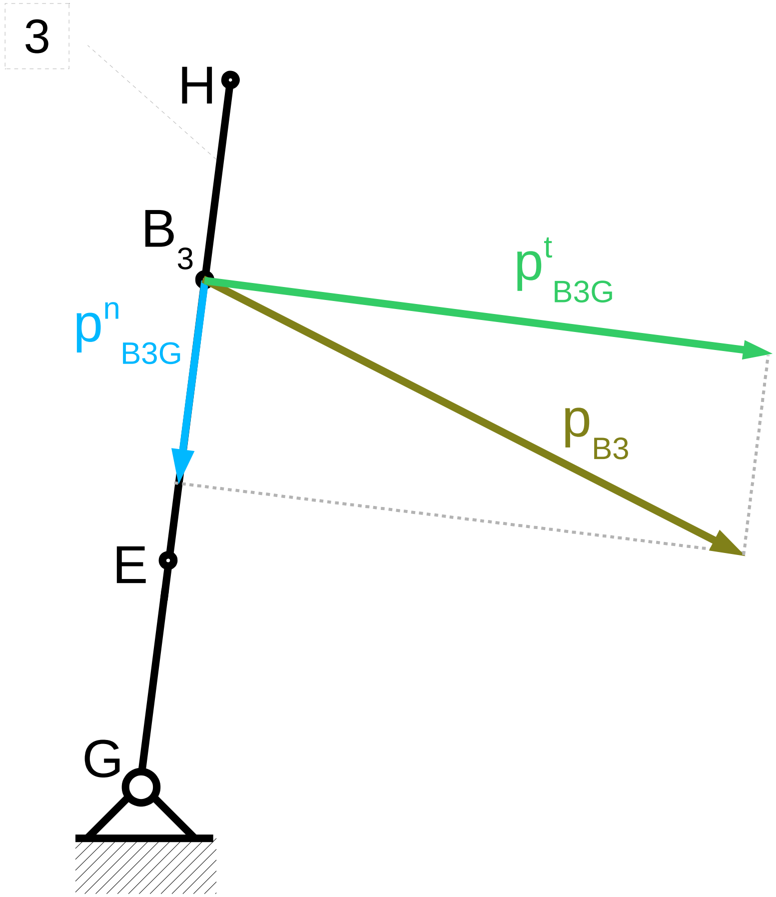
Acceleration scheme

$$\underset{\parallel 1}{\underline{\underline{p^n_{B2A}}}} - \underset{\perp 3}{\underline{\underline{p^c}}} - \underset{\parallel 3}{\underline{p^w_{B2B3}}} = \underset{\parallel 3}{\underline{\underline{p^n_{B3G}}}} + \underset{\perp 3}{\underline{p^t_{B3G}}}$$

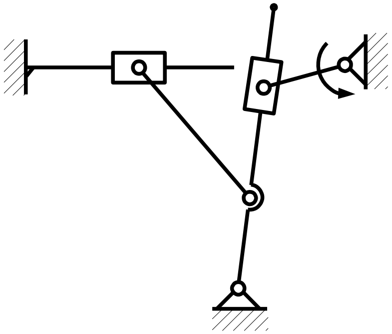


3rd element's accelerations

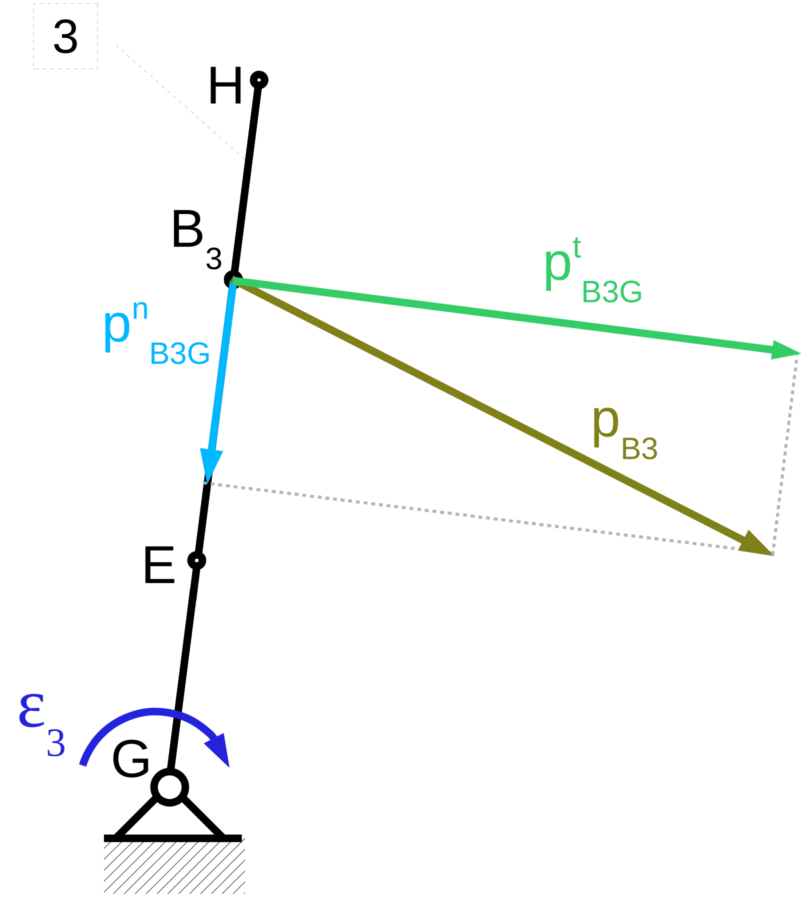




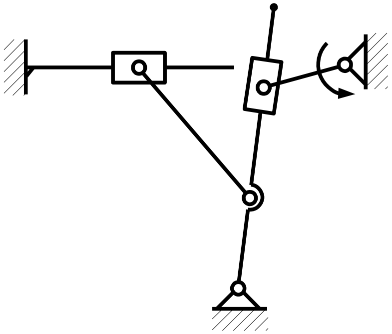
3rd element's accelerations



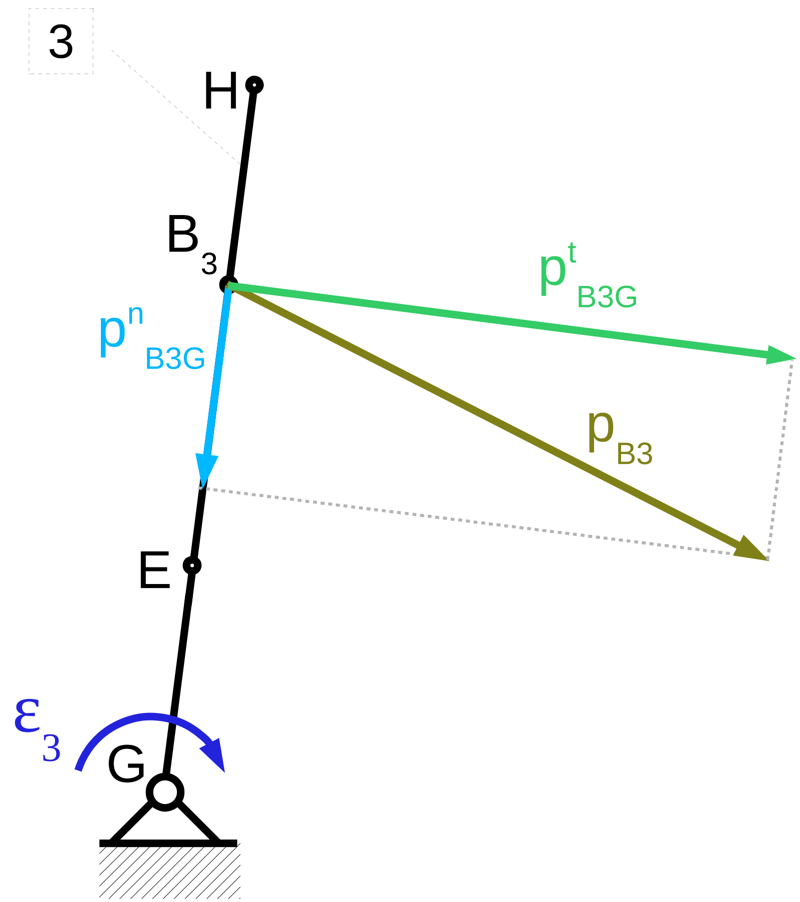
$$\varepsilon_3 = \frac{|p^t_{B3G}|}{|B_3G|}$$



Acceleration of the E point



$$\varepsilon_3 = \frac{|p^t_{B3G}|}{|B_3G|}$$

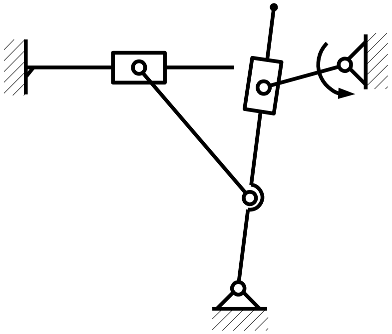


$$p_E = p_G + p^n_{EG} + p^t_{EG}$$

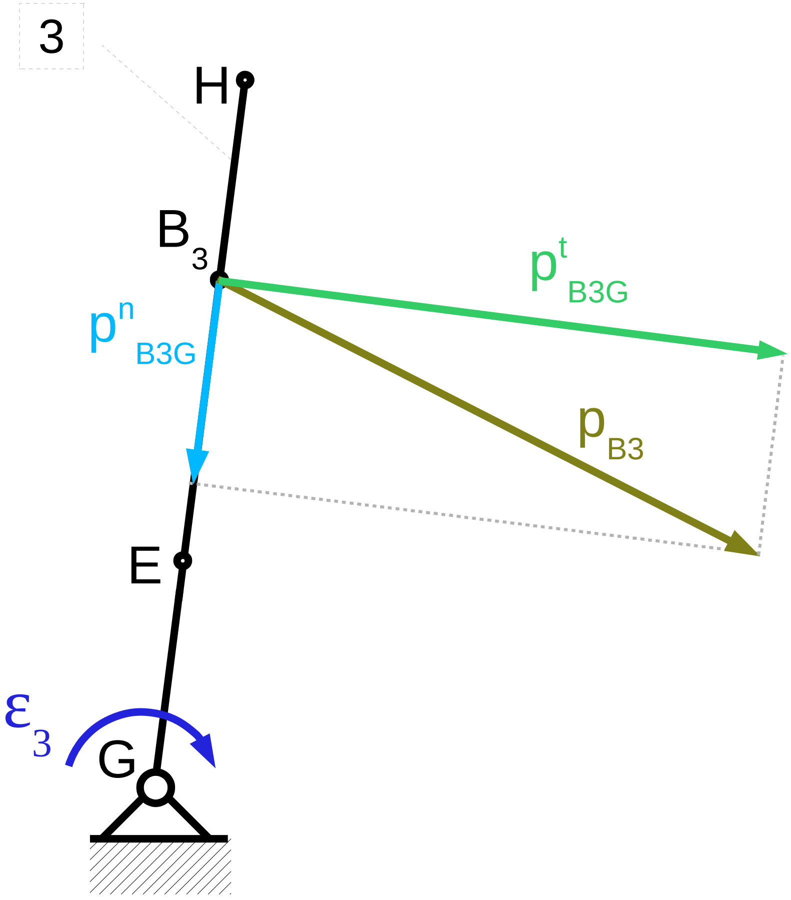
$$|p^n_{EG}| = \omega_3^2\, |EG|$$

$$|p^t_{EG}| = \varepsilon_3\, |EG|$$

Acceleration of the E point



$$\varepsilon_3 = \frac{|p^t_{B3G}|}{|B_3G|}$$



$$p_E = p_G + p^n_{EG} + p^t_{EG}$$

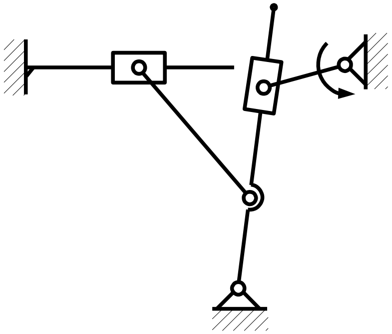
$$|p^n_{EG}| = \omega_3^{\,2}\,|EG|$$

$$|p^t_{EG}| = \varepsilon_3\,|EG|$$

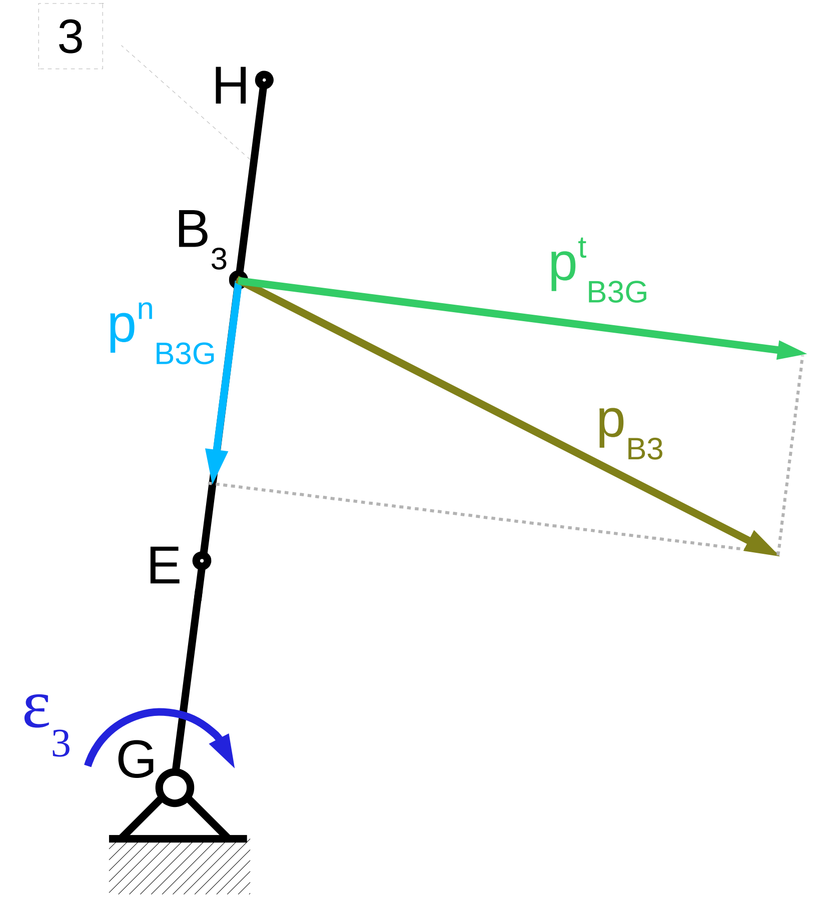
$$|p^n_{B3G}| = \omega_3^{\,2}\,|B_3G|$$

$$|p^t_{B3G}| = \varepsilon_3\,|B_3G|$$

Acceleration of the E point



$$\varepsilon_3 = \frac{|p^t_{B3G}|}{|B_3G|}$$



$$p_E = p_G + p^n_{EG} + p^t_{EG}$$

$$|p^n_{EG}| = \omega_3^2\,|EG| = |p^n_{B3G}|\,\frac{|EG|}{|B_3G|}$$

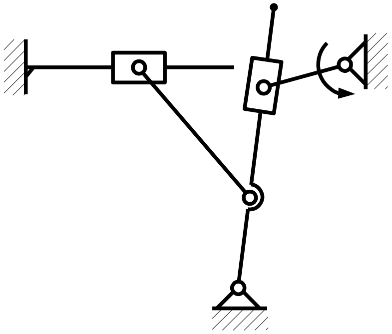
$$|p^t_{EG}| = \varepsilon_3\,|EG| = |p^t_{B3G}|\,\frac{|EG|}{|B_3G|}$$

after substitution

$$|p^n_{B3G}| = \omega_3^2\,|B_3G|$$

$$|p^t_{B3G}| = \varepsilon_3\,|B_3G|$$

Acceleration of the E point



$$\varepsilon_3 = \frac{|p^t_{B3G}|}{|B_3G|}$$

$$p_E = p_G + p^n_{EG} + p^t_{EG}$$

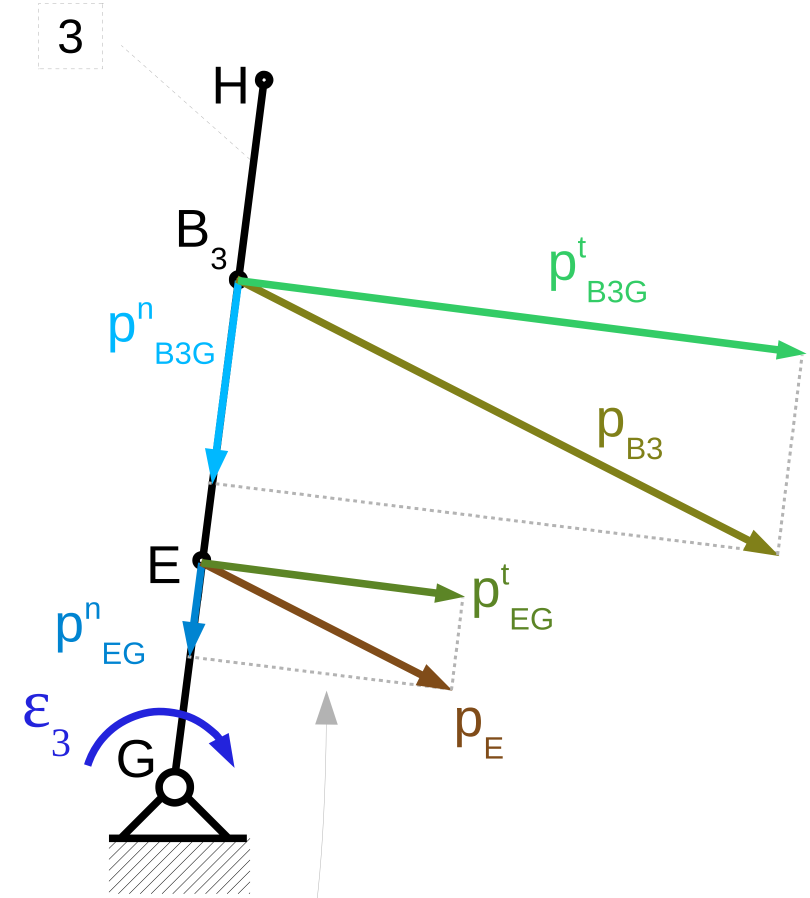
$$|p^n_{EG}| = \omega_3^{\,2}\,|EG| = |p^n_{B3G}|\,\frac{|EG|}{|B_3G|}$$

$$|p^t_{EG}| = \varepsilon_3\,|EG| = |p^t_{B3G}|\,\frac{|EG|}{|B_3G|}$$

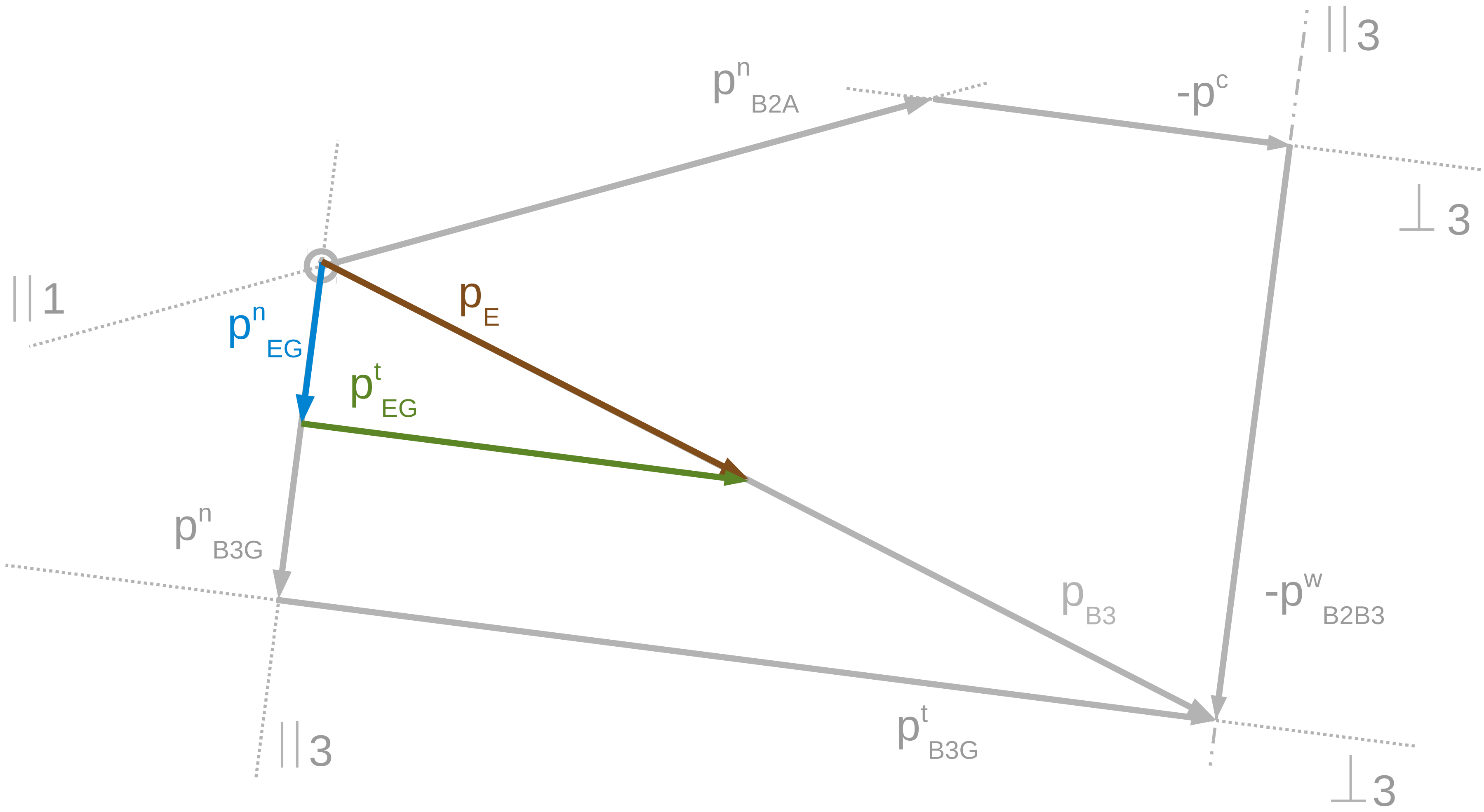
$$|p^n_{B3G}| = \omega_3^{\,2}\,|B_3G|$$

$$|p^t_{B3G}| = \varepsilon_3\,|B_3G|$$

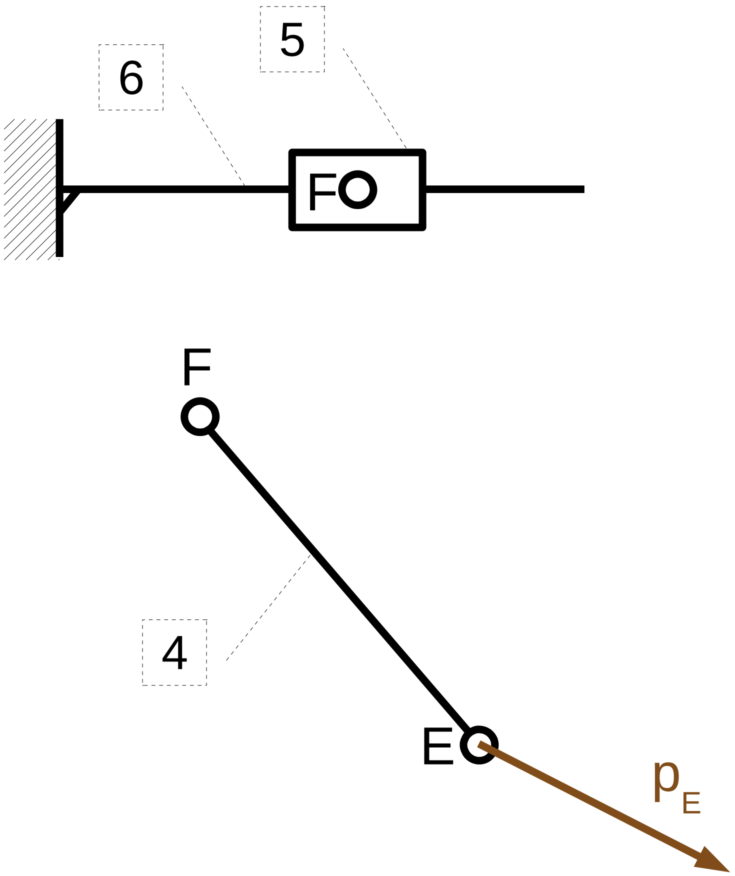
and we obtain proportionally accelerations



Acceleration scheme

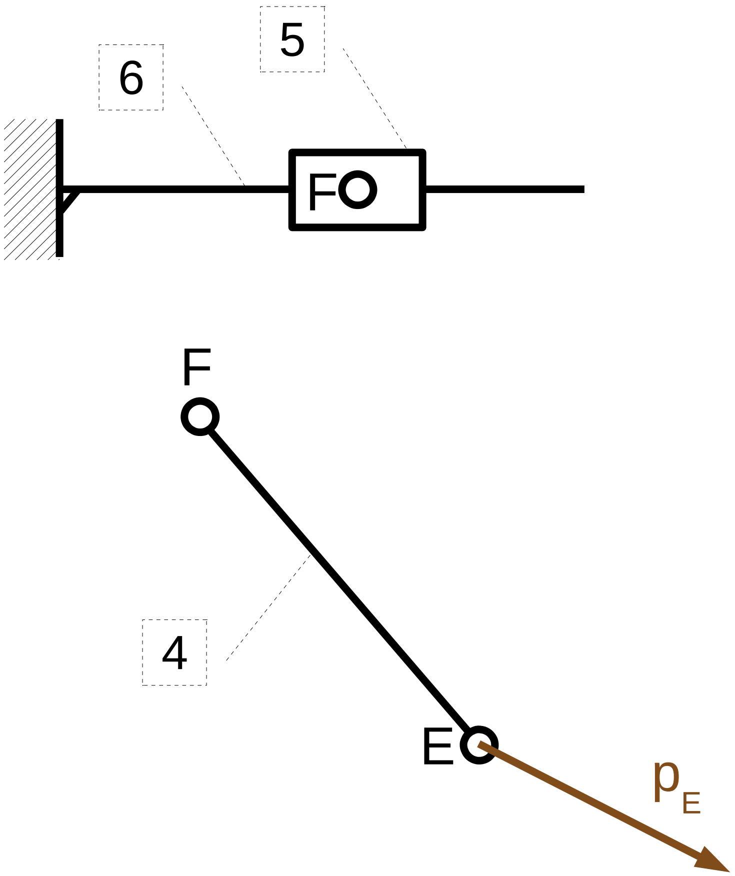


Accelerations of the 4th element

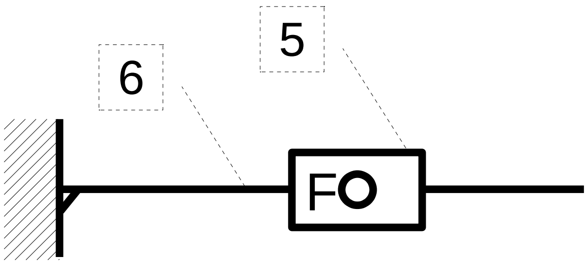


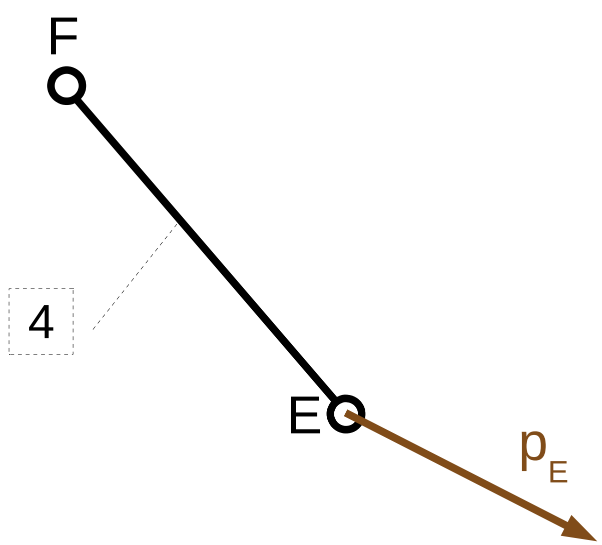
Accelerations of the 4th element

$$p_F = p_E + p^n_{FE} + p^t_{FE}$$



Accelerations of the 4th element





$$p_F = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} + \underline{p^t_{FE}}$$

p^n_{FE}: || 4 $\qquad$ p^t_{FE}: ⊥4

$$|p^n_{FE}| = \omega_4^2 \, |FE|$$

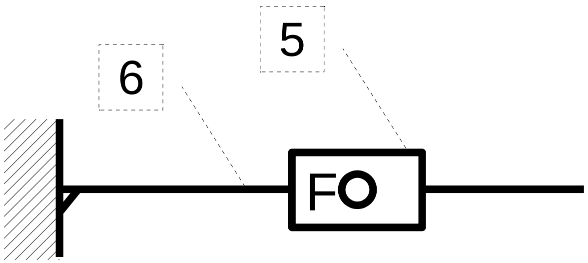
from velocity scheme

Accelerations of the 4th element

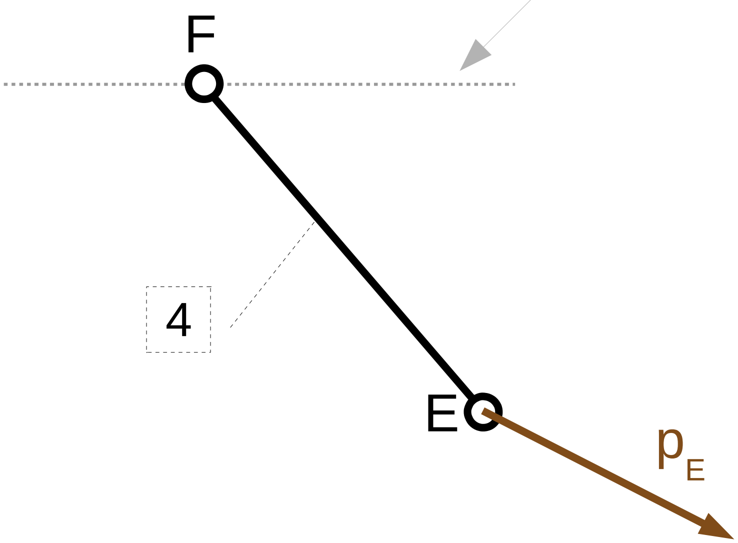
$$\underset{\parallel 6}{\underline{p_F}} = \underline{\underline{p_E}} + \underset{\parallel 4}{\underline{\underline{p^n_{FE}}}} + \underset{\perp 4}{\underline{p^t_{FE}}}$$

$$|p^n_{FE}| = \omega_4^{\ 2}\, |FE|$$

from velocity scheme

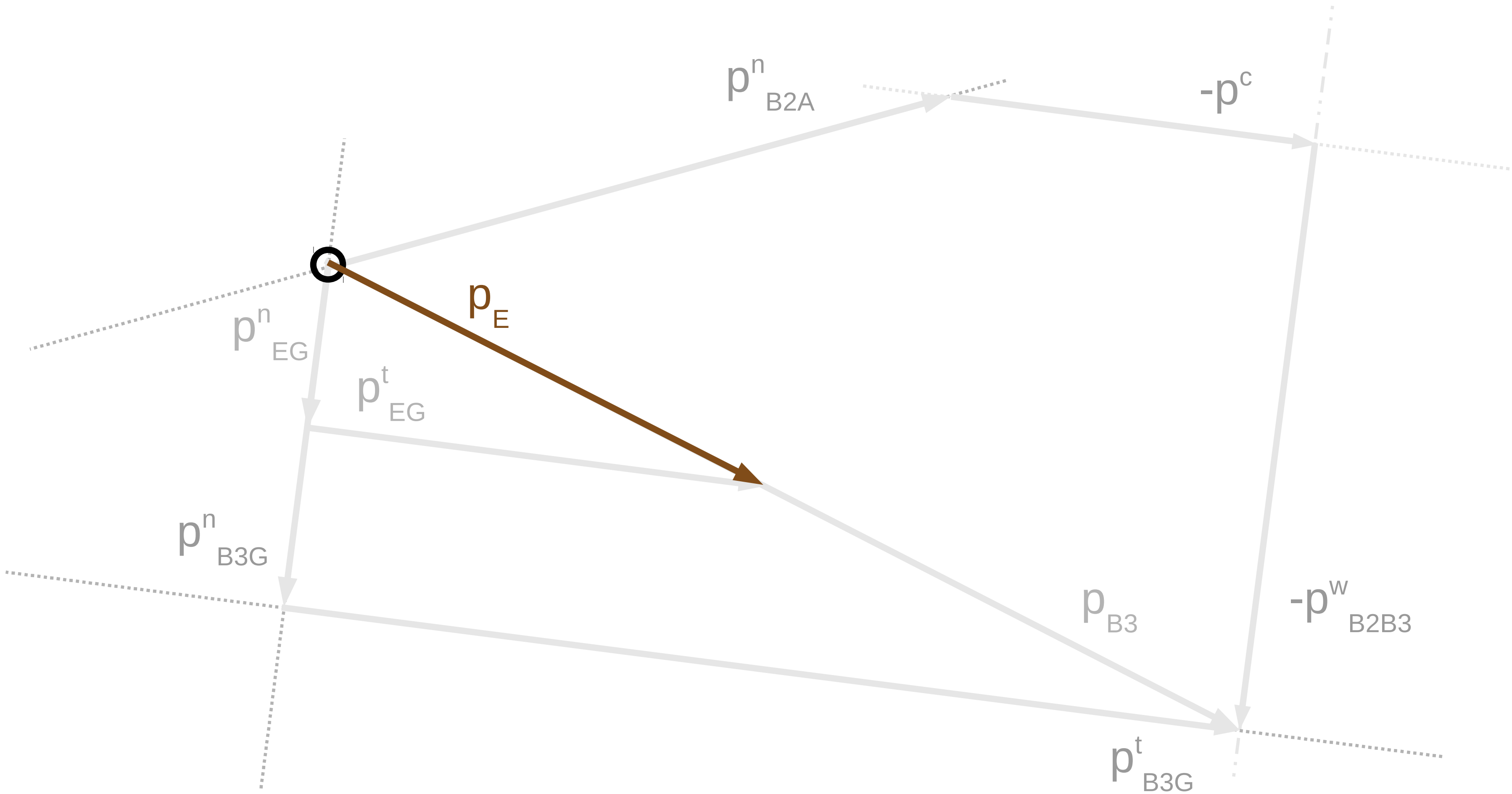


point F is moving along fixed element number 6. So it's acceleration is parallel to 6.



Acceleration scheme

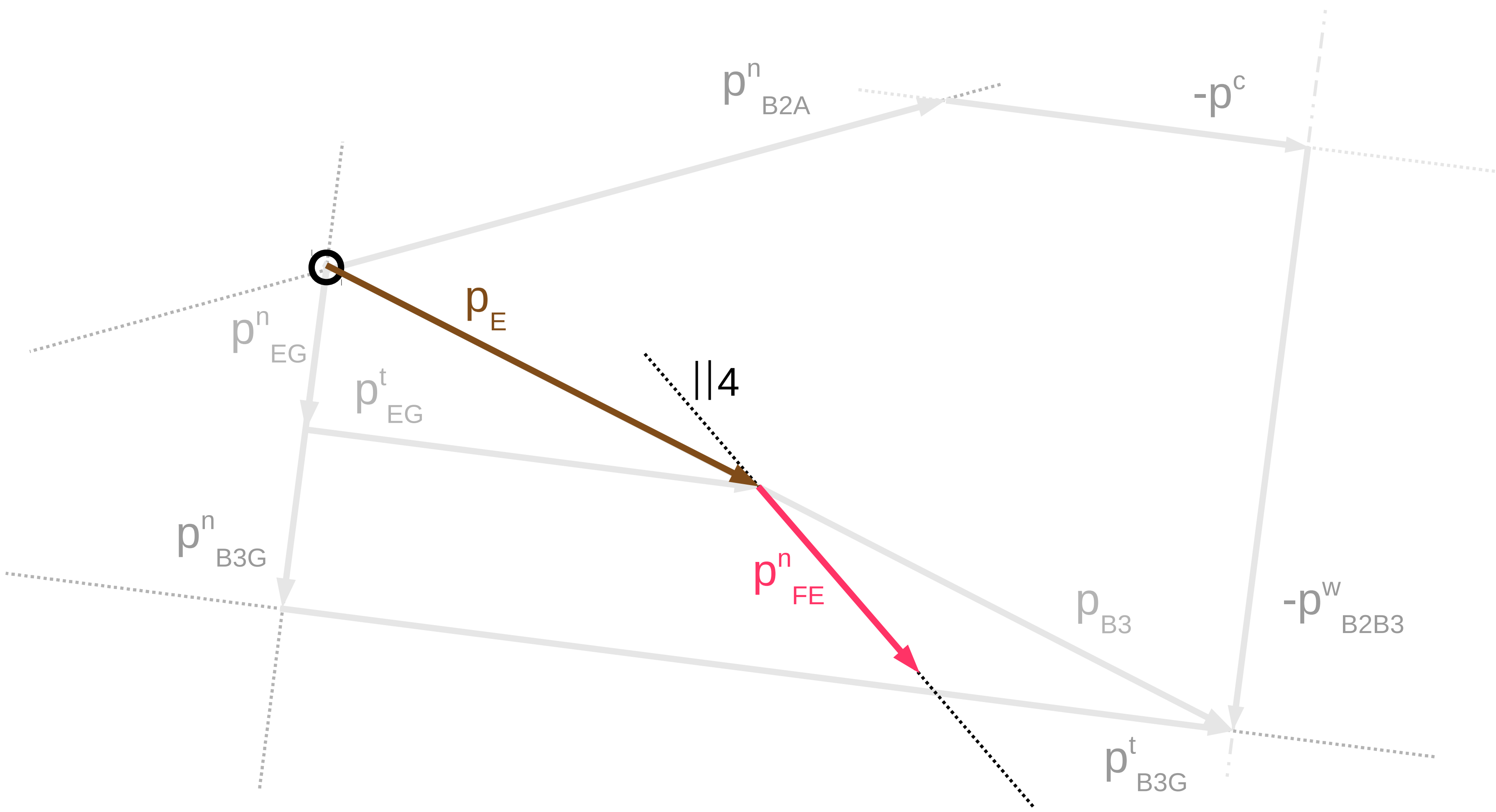
$$\underset{\parallel 6}{\underline{p_F}} = \underline{\underline{p_E}} + \underset{\parallel 4}{\underline{\underline{p^n_{FE}}}} + \underset{\perp 4}{\underline{p^t_{FE}}}$$



Acceleration scheme

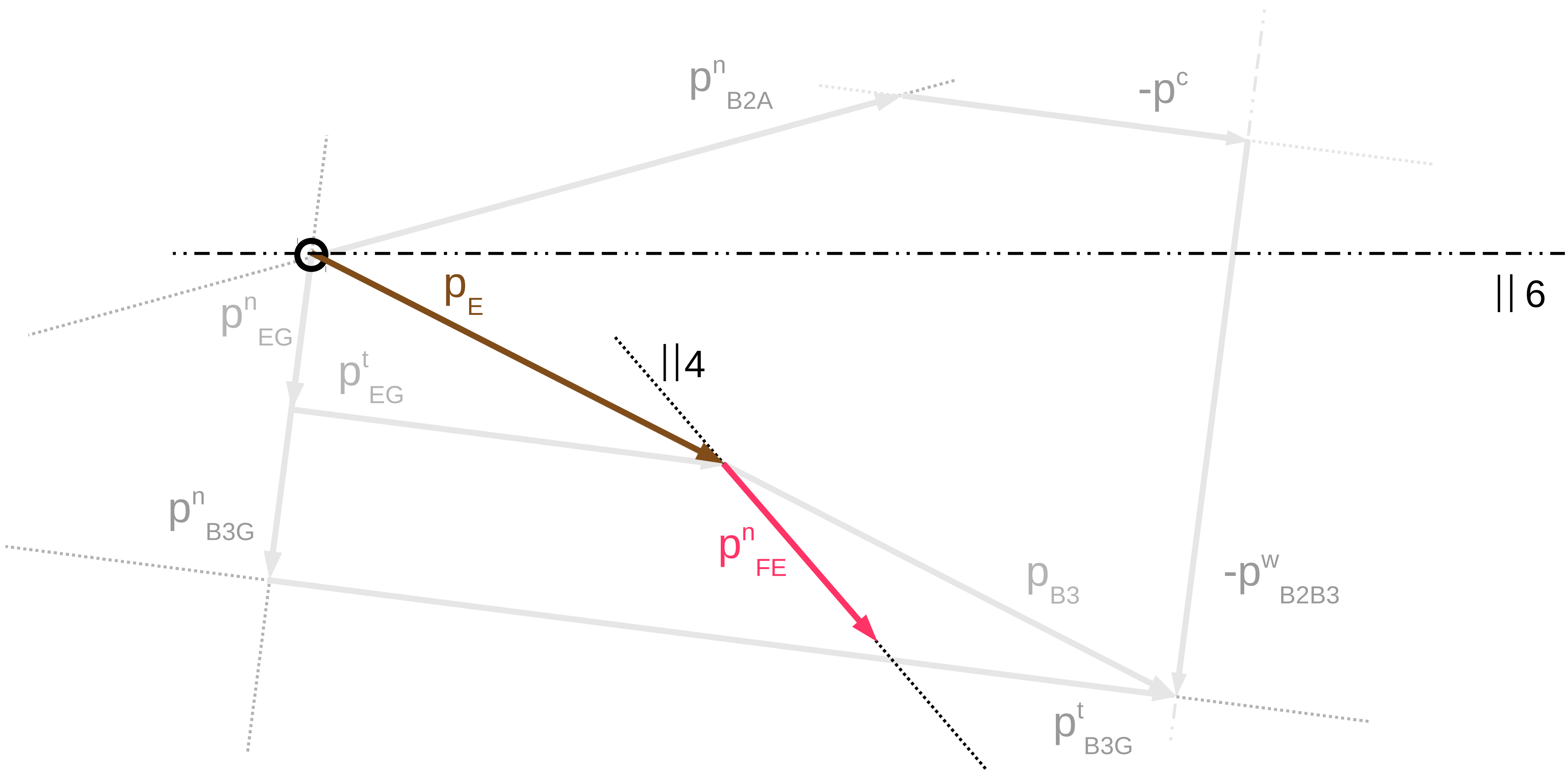
$$\underline{p_F} = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} + \underline{p^t_{FE}}$$

$\|6 \qquad \qquad \|4 \qquad \perp 4$



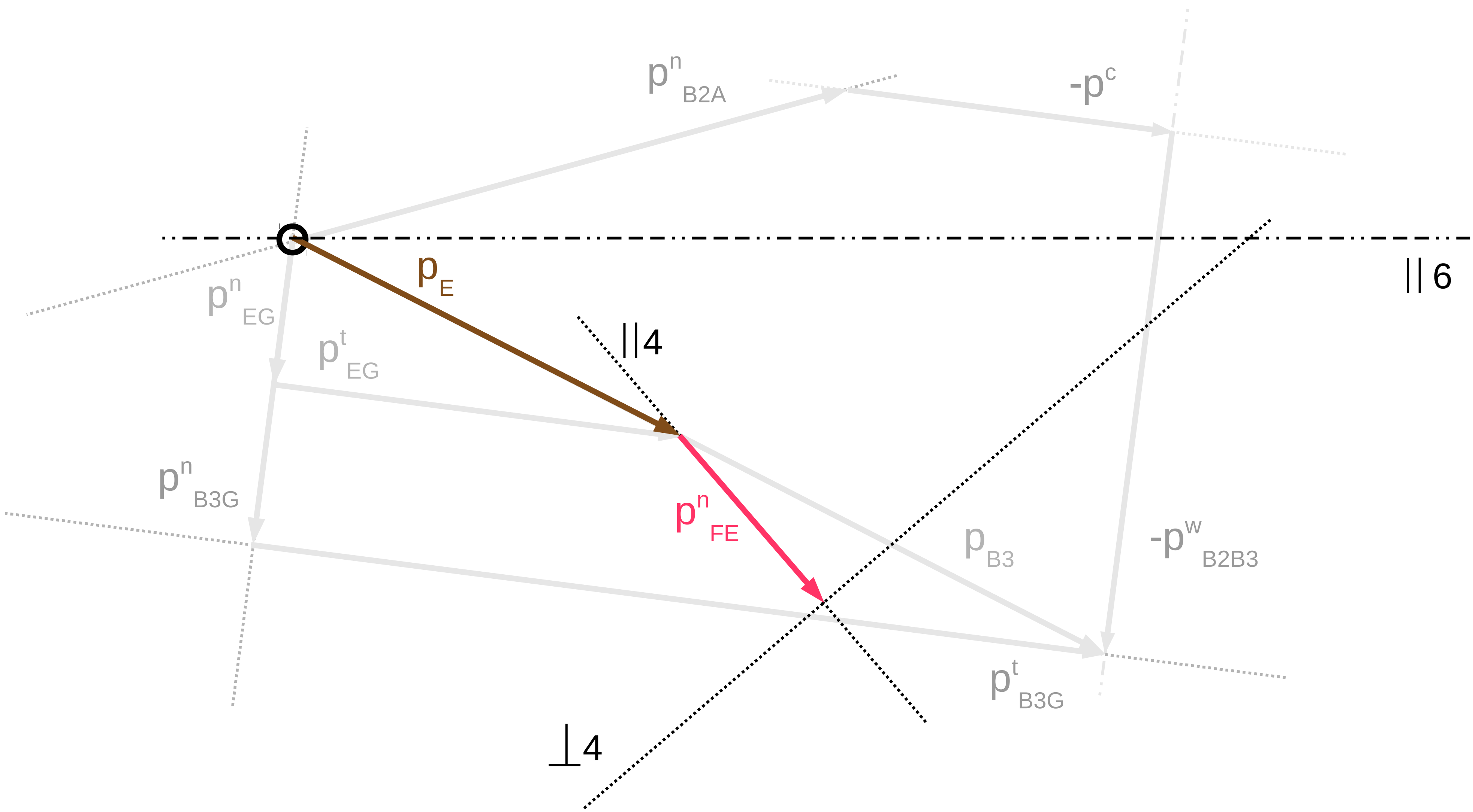
Acceleration scheme

$$\underset{\parallel 6}{\underline{p}_{F}} = \underline{\underline{p}}_{E} + \underset{\parallel 4}{\underline{\underline{p}}^{n}_{FE}} + \underset{\perp 4}{\underline{p}^{t}_{FE}}$$



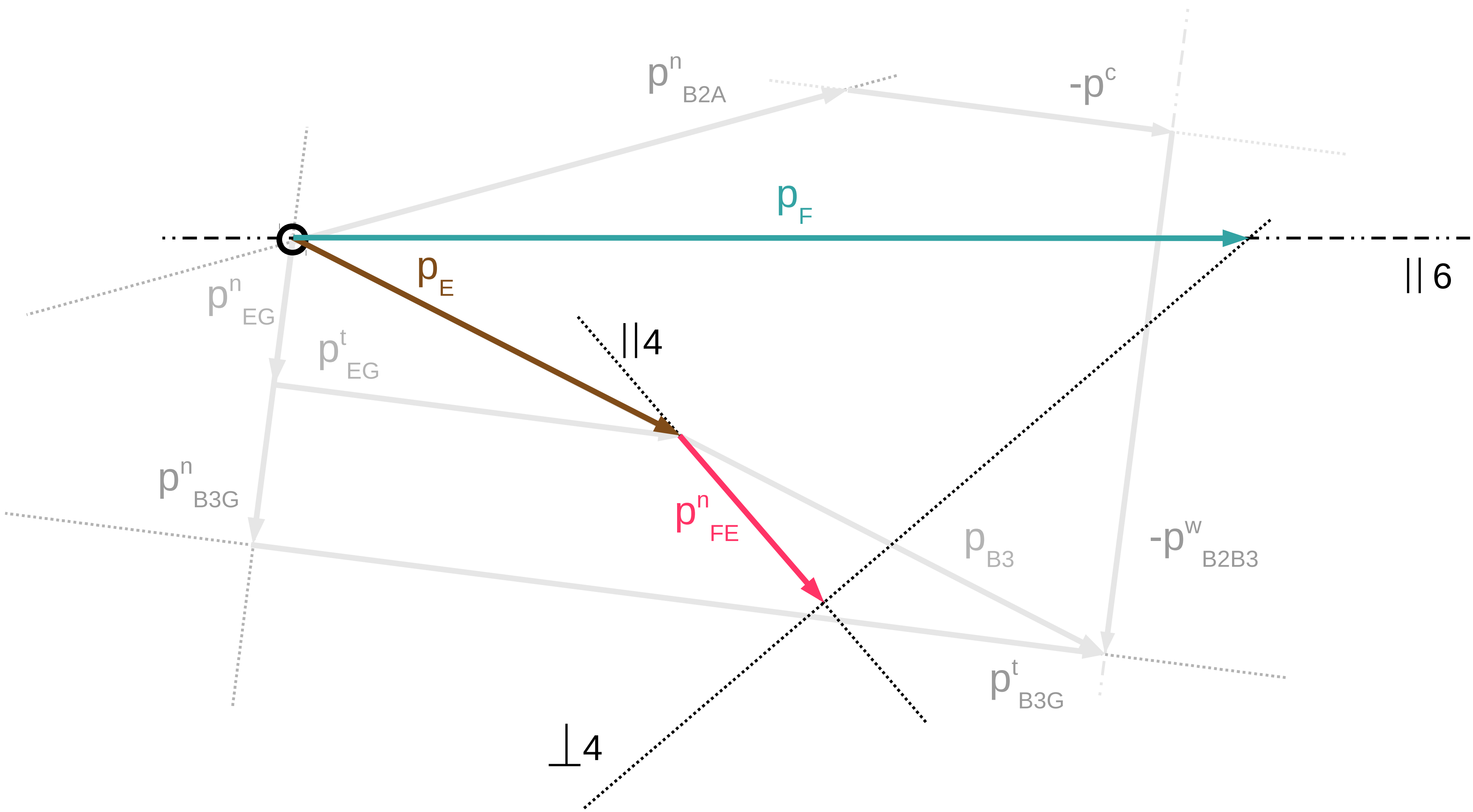
Acceleration scheme

$$\underset{\parallel 6}{\underline{p_F}} = \underline{\underline{p_E}} + \underset{\parallel 4}{\underline{\underline{p^n_{FE}}}} + \underset{\perp 4}{\underline{p^t_{FE}}}$$



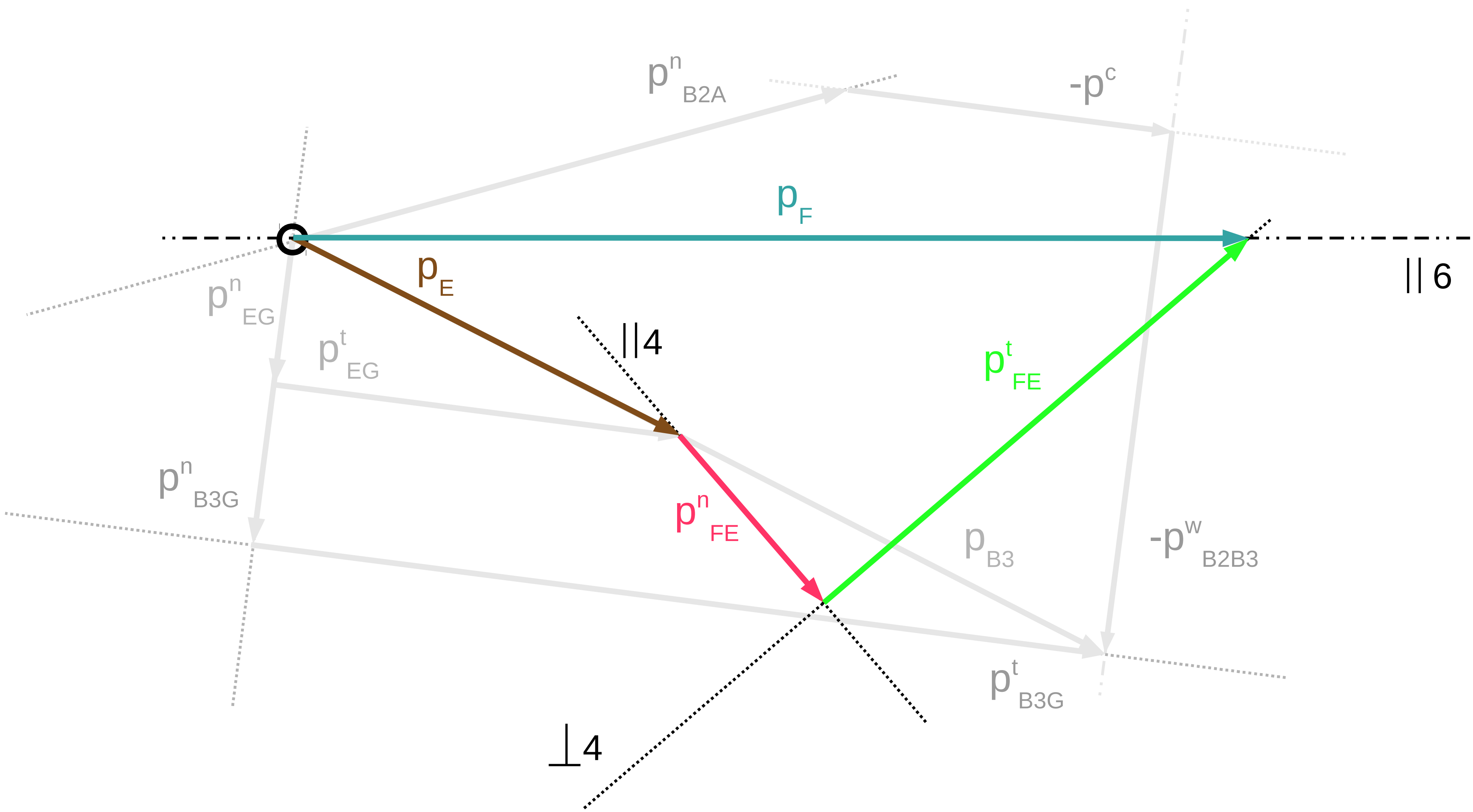
Acceleration scheme

$$\underset{\parallel 6}{\underline{p_F}} = \underline{\underline{p_E}} + \underset{\parallel 4}{\underline{\underline{p^n_{FE}}}} + \underset{\perp 4}{\underline{p^t_{FE}}}$$

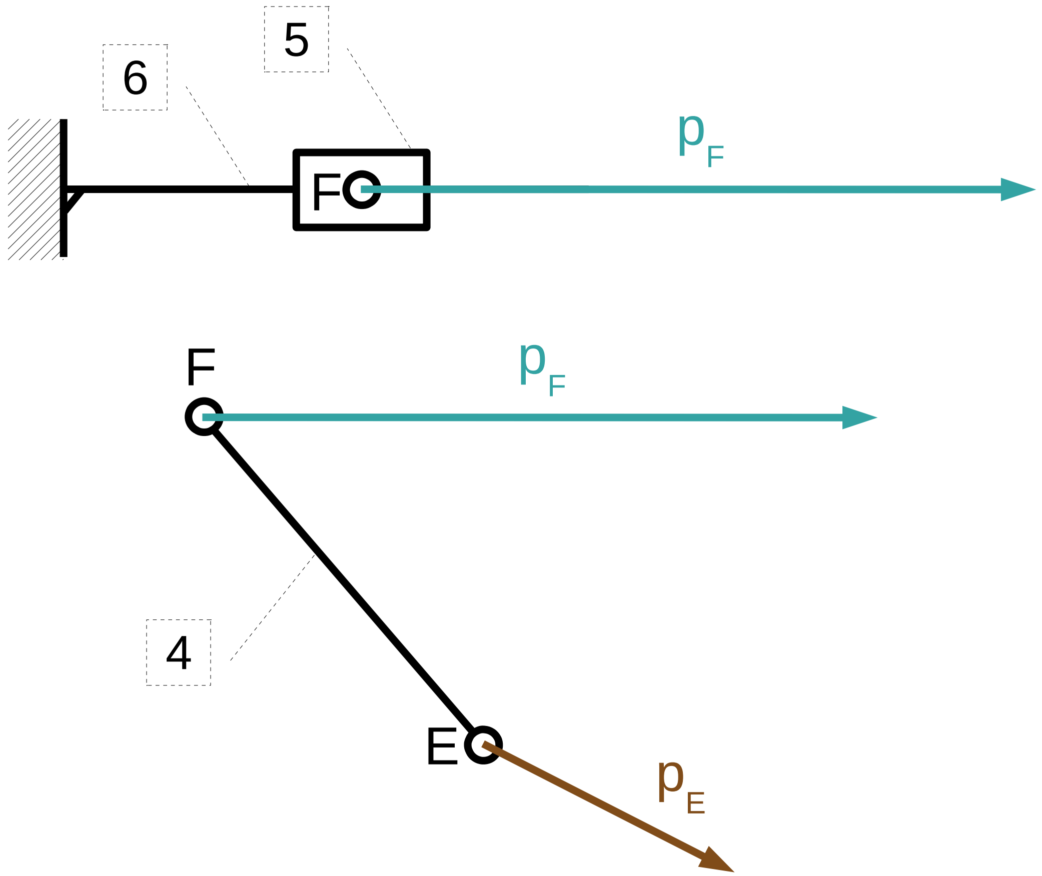


Acceleration scheme

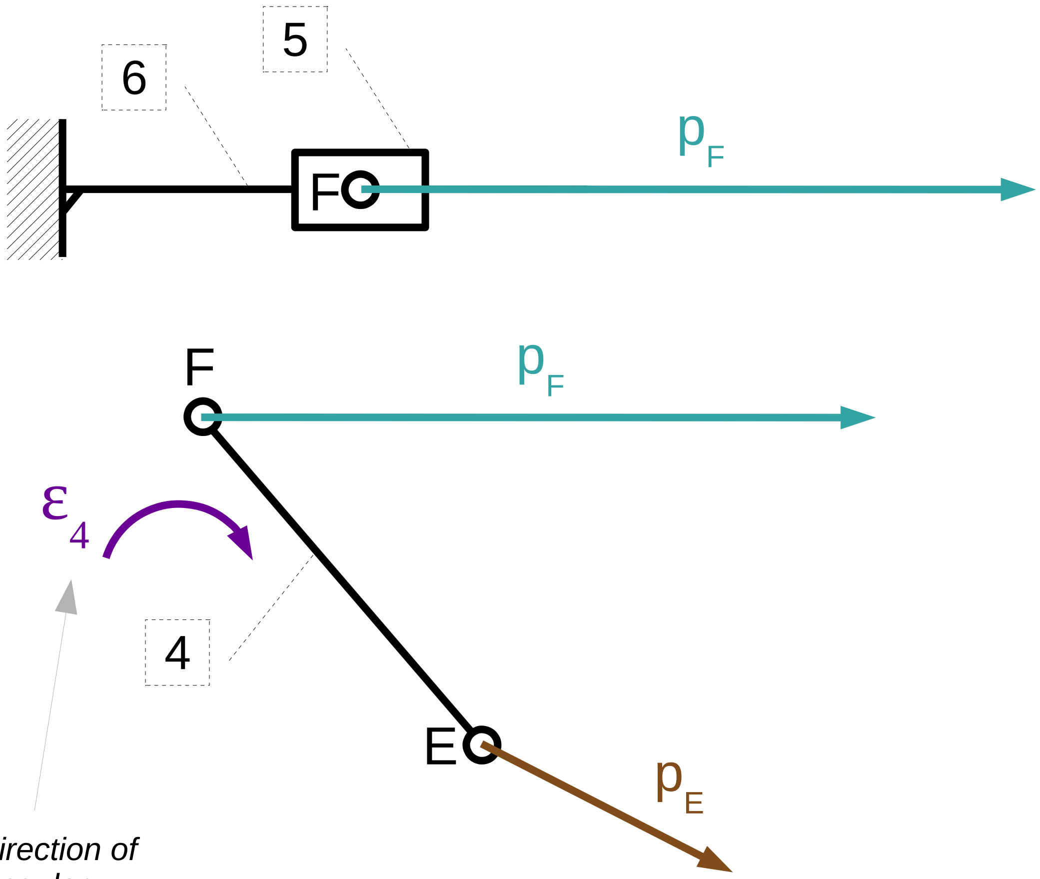
$$\underset{\parallel 6}{\underline{p_F}} = \underline{\underline{p_E}} + \underset{\parallel 4}{\underline{\underline{p^n_{FE}}}} + \underset{\perp 4}{\underline{p^t_{FE}}}$$



Accelerations of the the 4th element

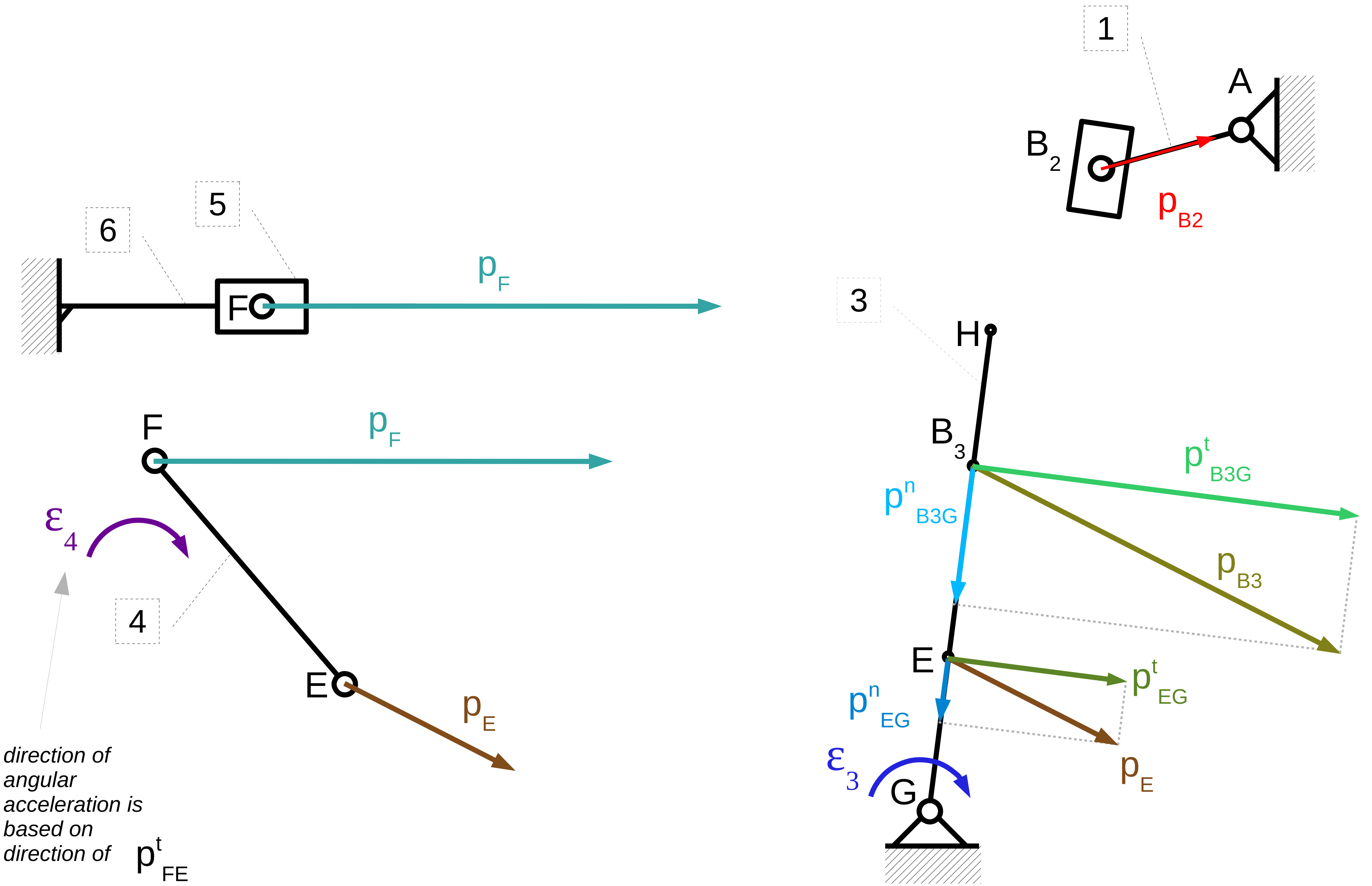


Accelerations of the the 4th element



direction of angular acceleration is based on direction of p^t_{FE}

Whole mechanism's accelerations



Whole mechanism's accelerations