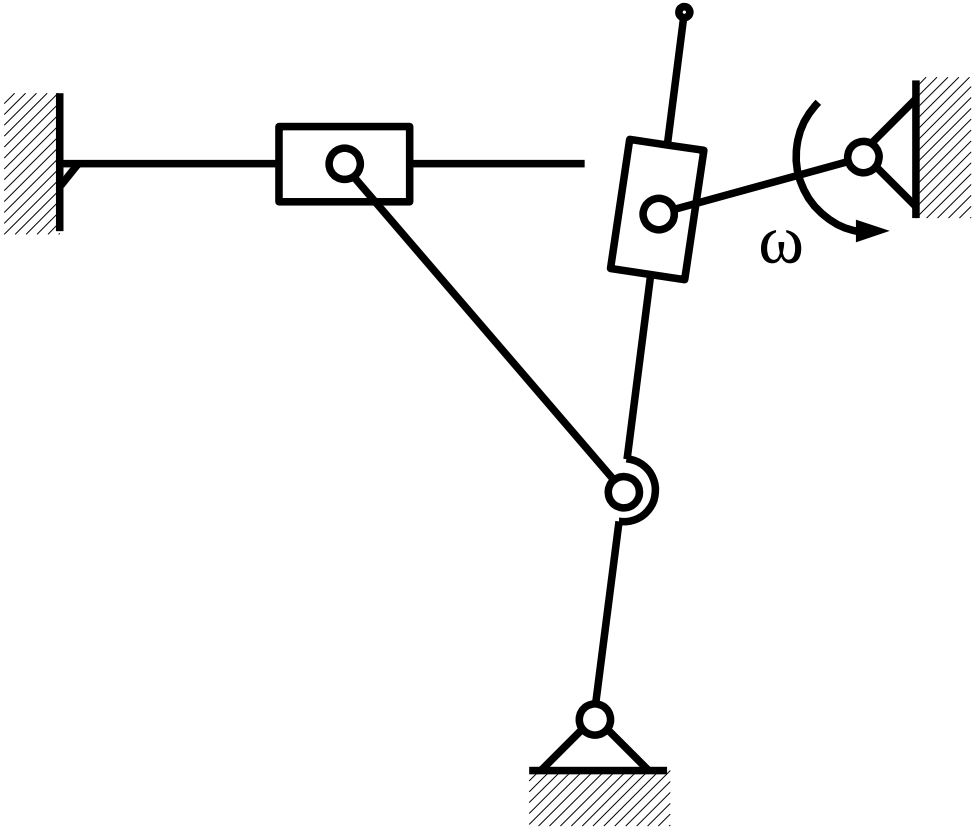
Podstawy automatyki i teorii maszyn

zima 2019/2020

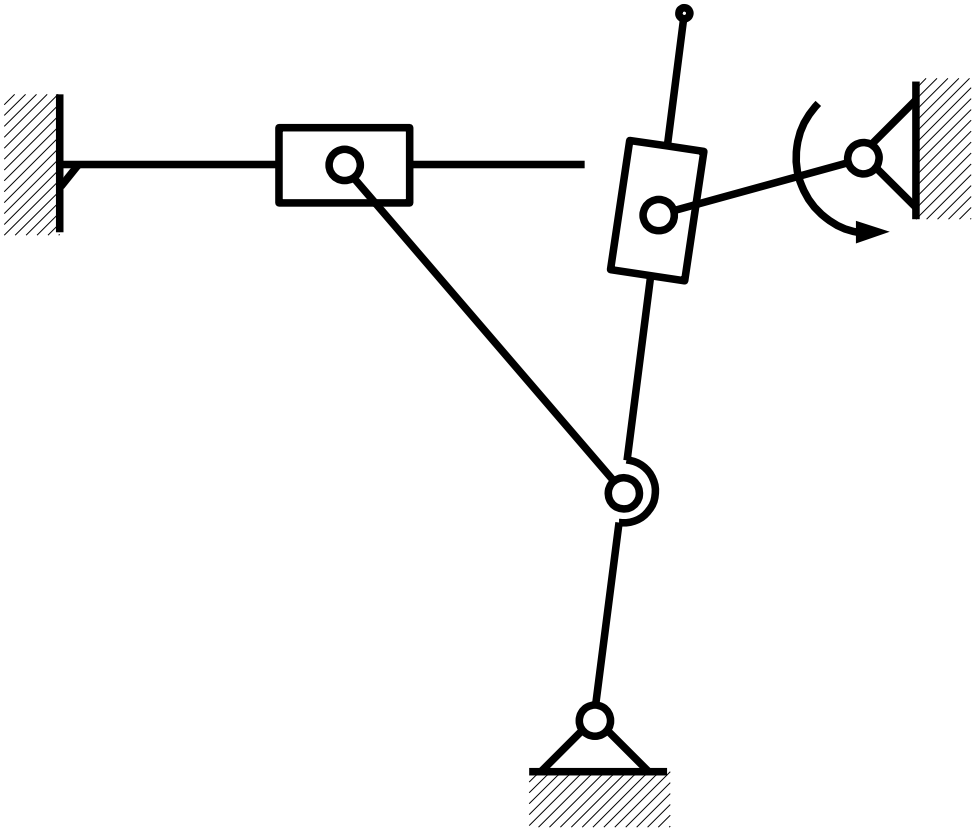
Przykład wyznaczania prędkości i przyspieszeń mechanizmu płaskiego metodą wykreślną

Dane: geometria mechanizmu (wymiary elementów, ich położenie i orientacja) oraz stała prędkość kątowa ω elementu napędowego



Wydział Samochodów i Maszyn Roboczych, Politechnika Warszawska,
Instytut Podstaw Budowy Maszyn, Zakład Mechaniki, dr inż. Sebastian Korczak

Jak pracuje ten mechanizm?



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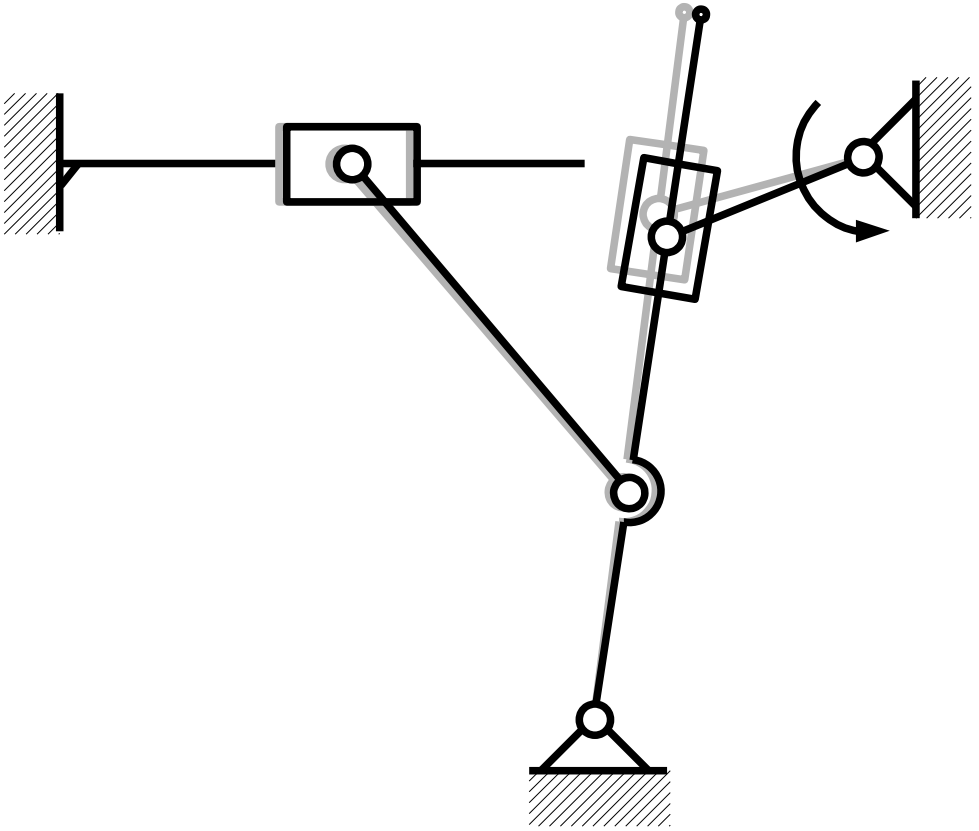
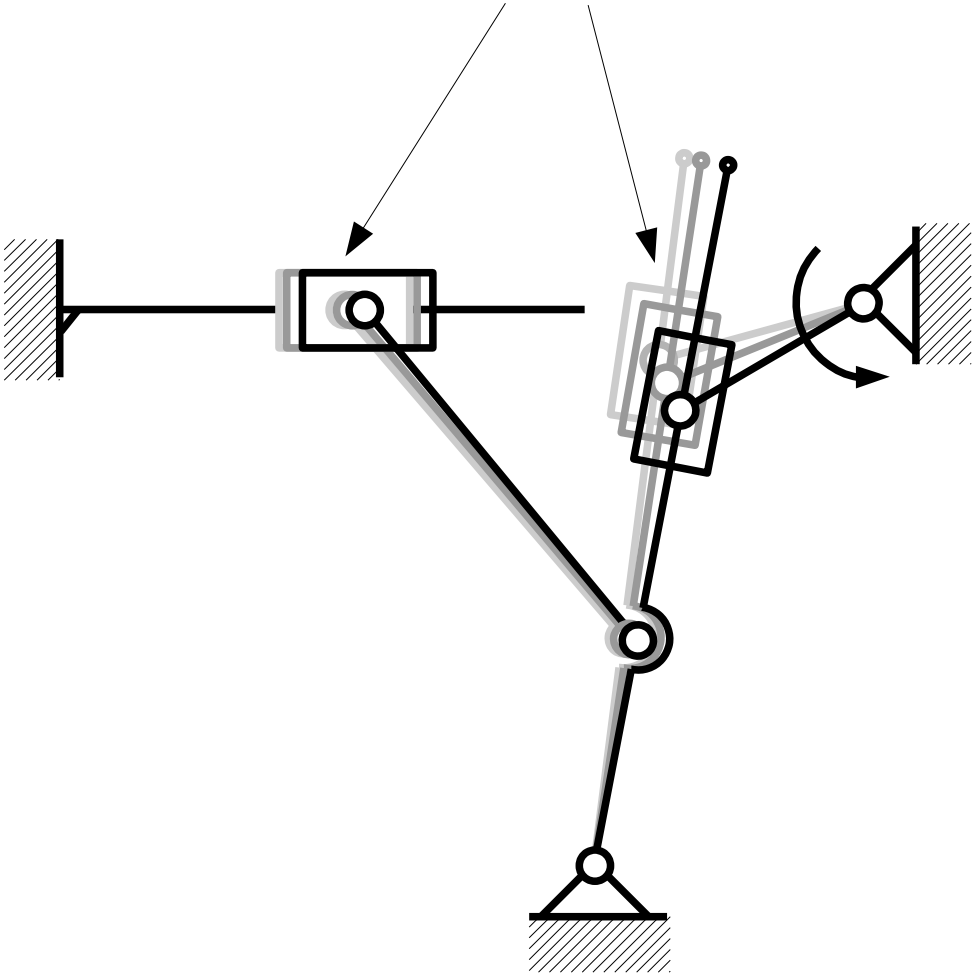
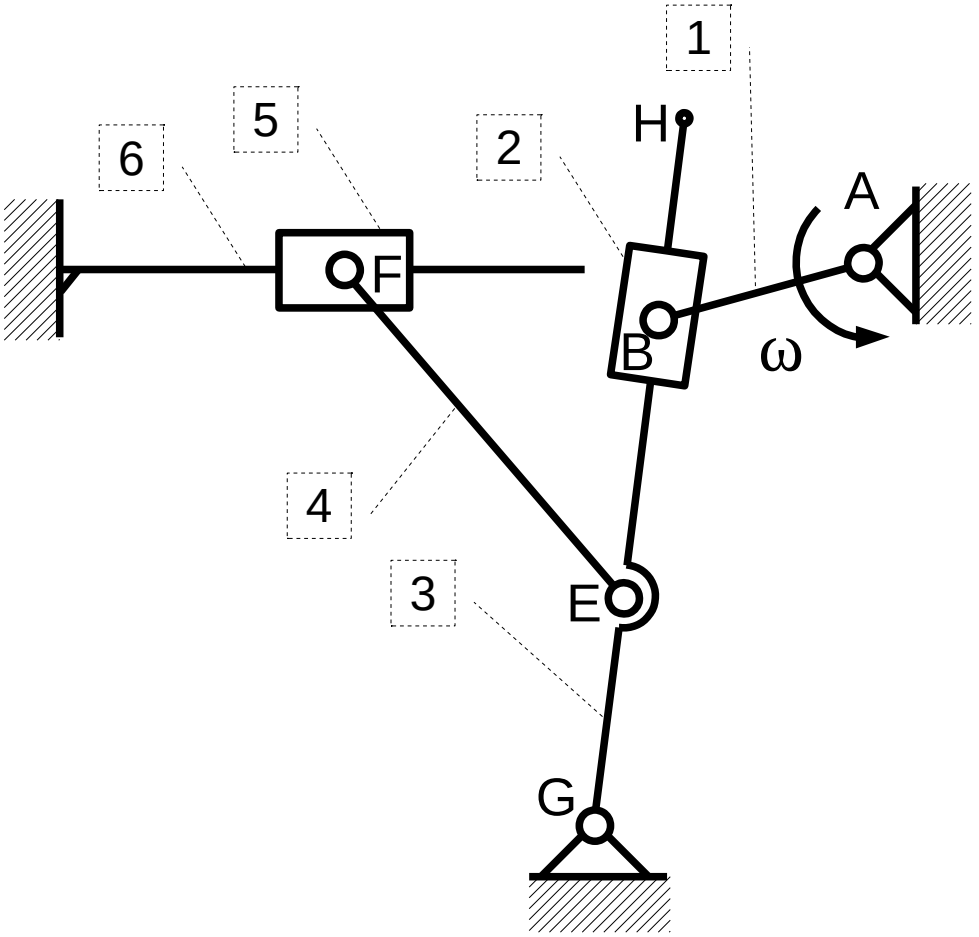


Jak pracuje ten mechanizm?

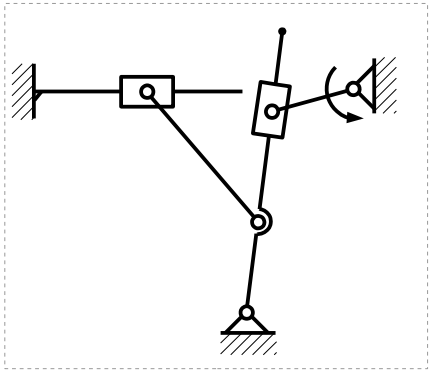
zauważamy ruch względny

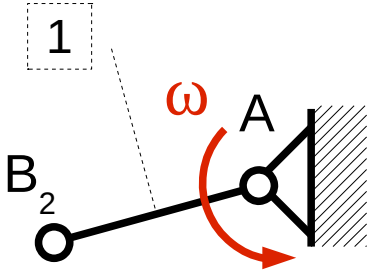


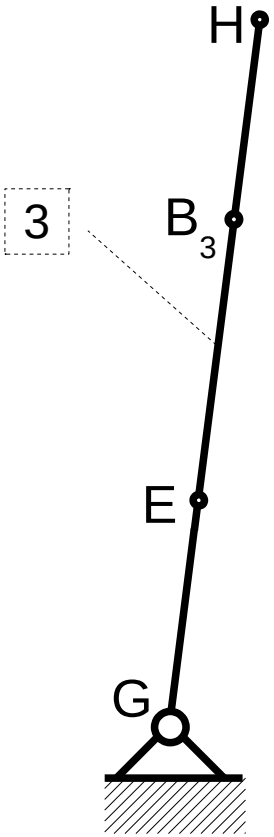
Wracamy do rozważanego położenia mechanizmu, numerujemy człony i nazywamy punkty

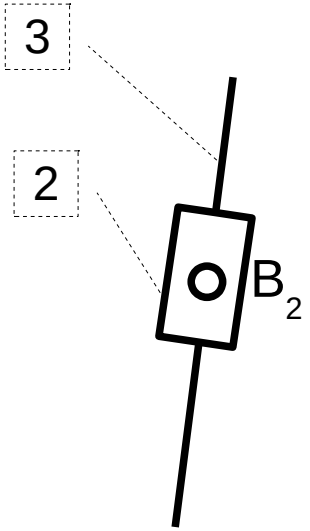


Ze względu na ruch względny suwaka 2 po pręcie 3 wprowadzamy oznaczenia punktów B_2 i B_3

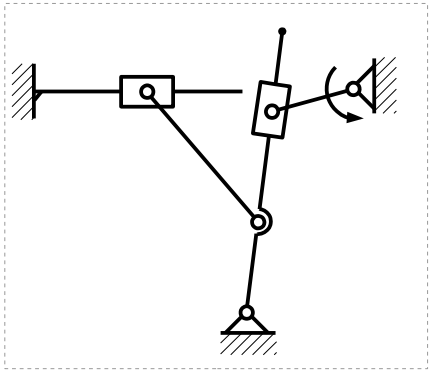


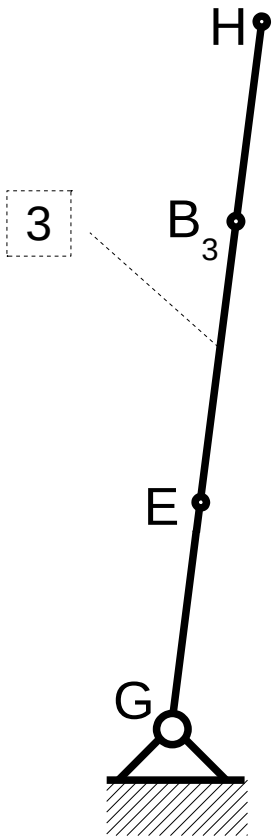


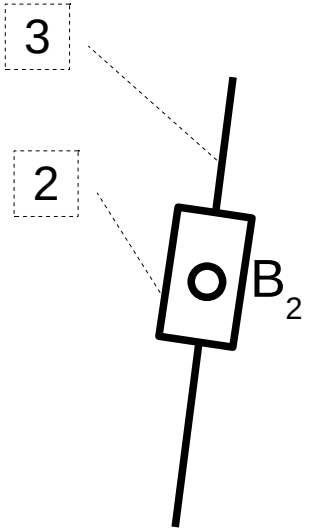


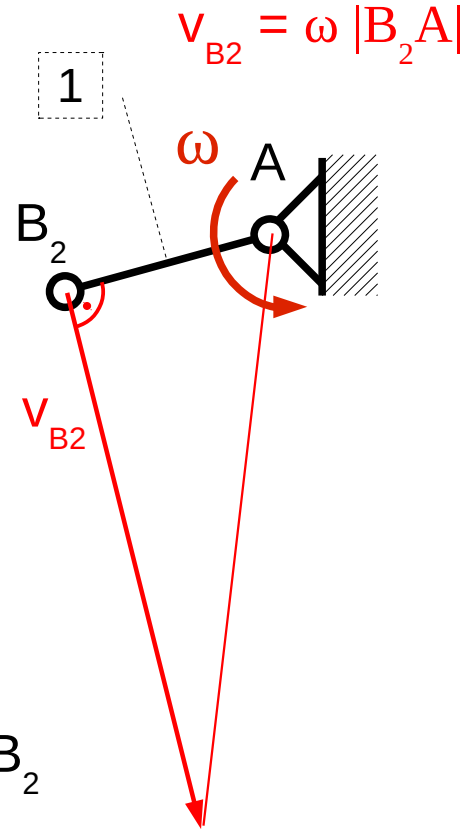


Wyznaczamy prędkość końca członu 1

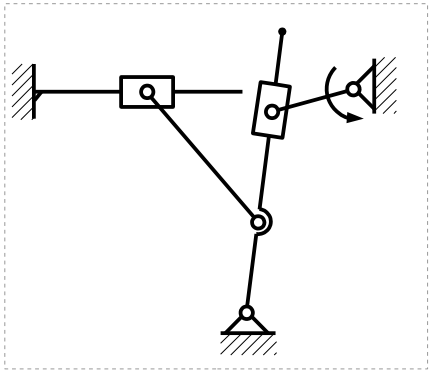




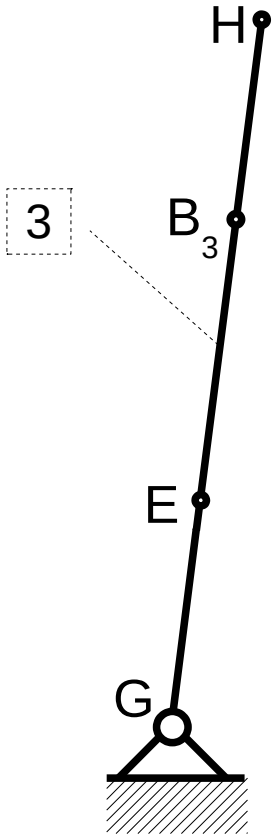


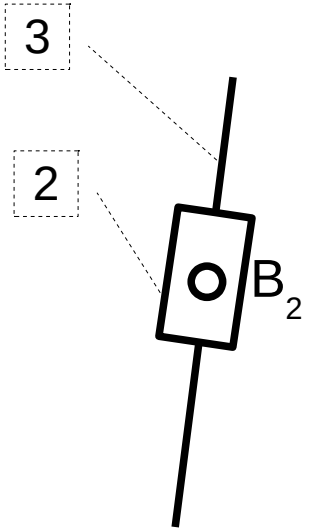


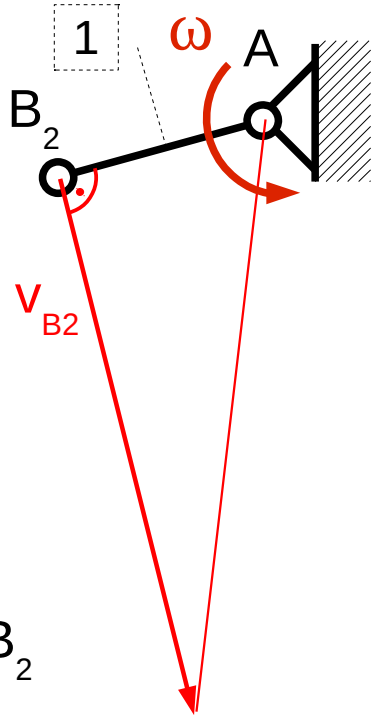
Przyjmujemy, że ruchem złożonym porusza się suwak 2, ruchem unoszenia jest zatem ruch pręta 3, a ruchem względnym - ruch suwaka wzdłuż pręta



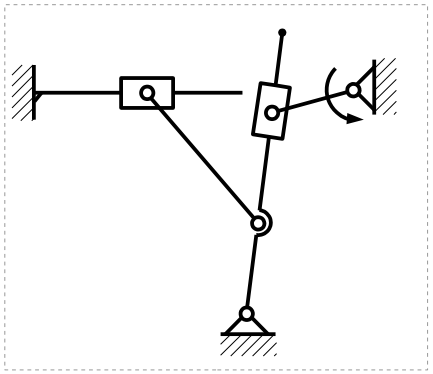
$$v_{B2} = v_{B3} + v_{B2B3}$$



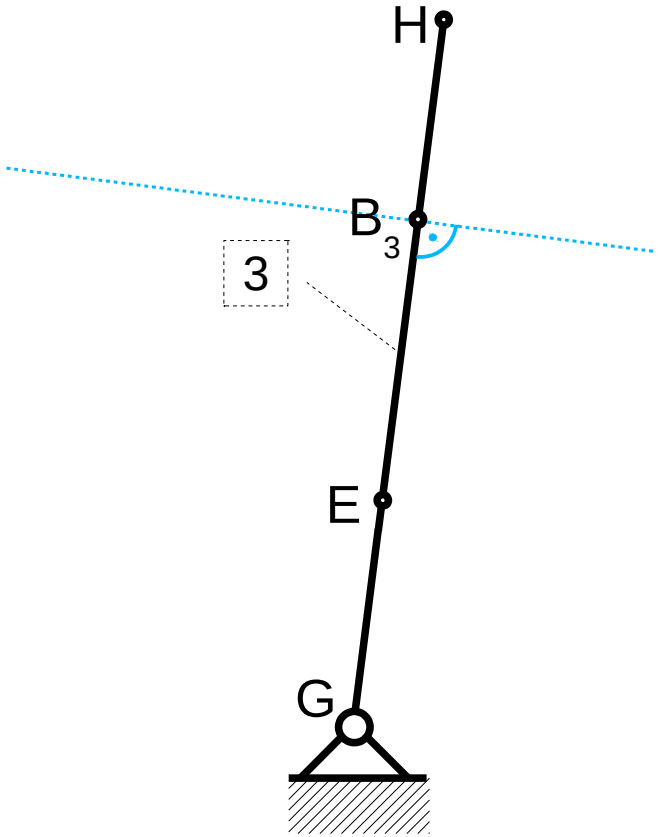


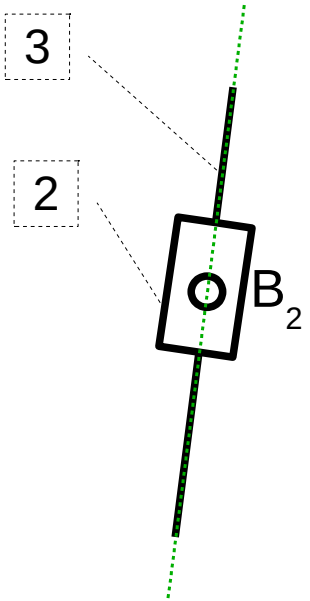


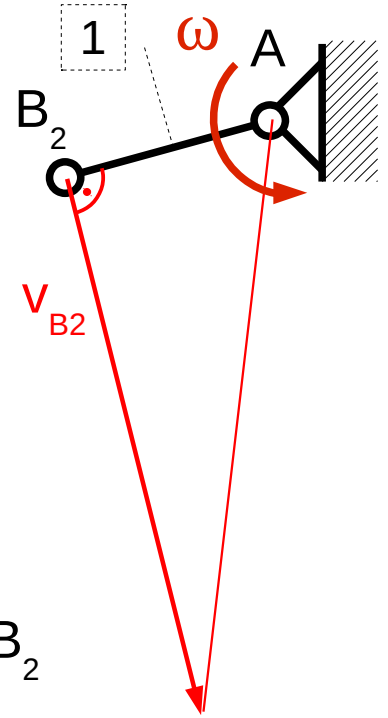
Określamy kierunki prędkości w równaniu ruchu względnego



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







Plan prędkości

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

$$\underline{v_{B3}} \perp 3 \qquad \underline{v_{B2B3}} \parallel 3$$

Plan prędkości

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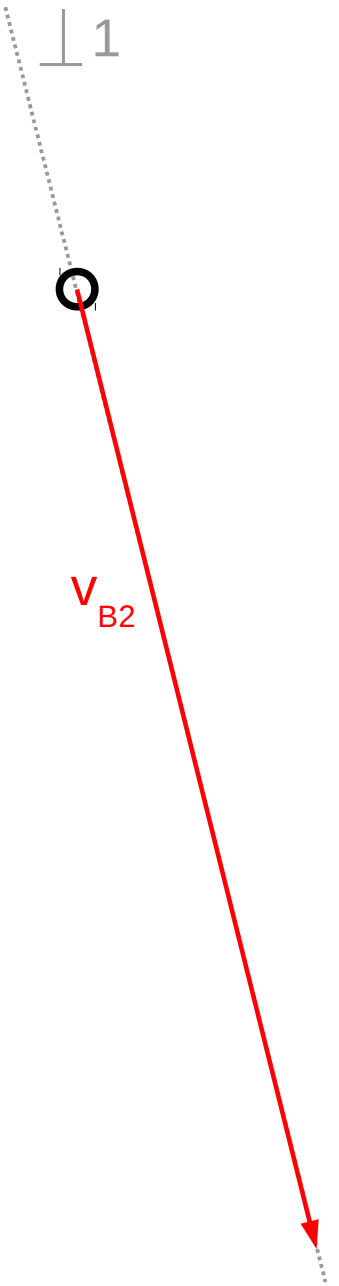

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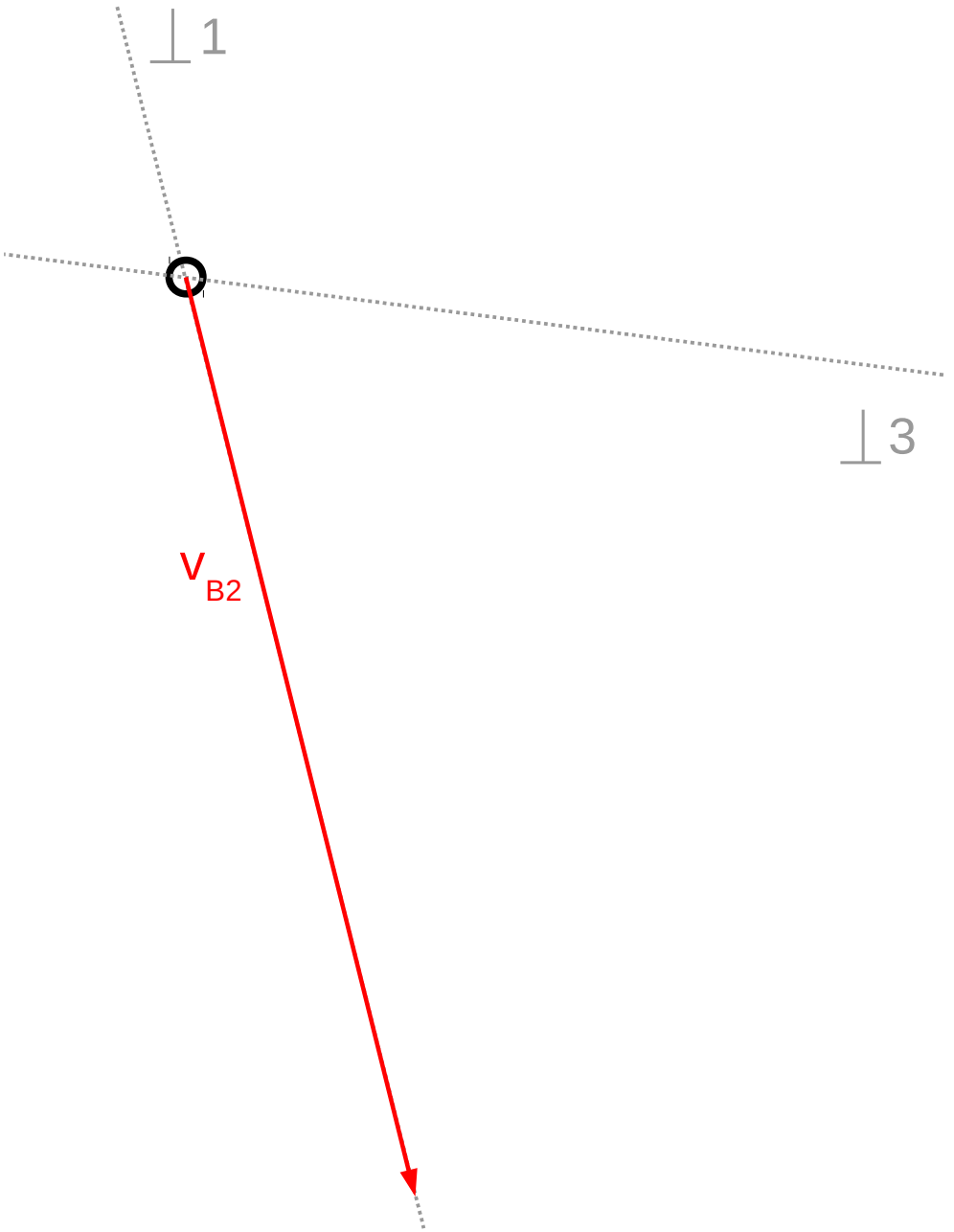

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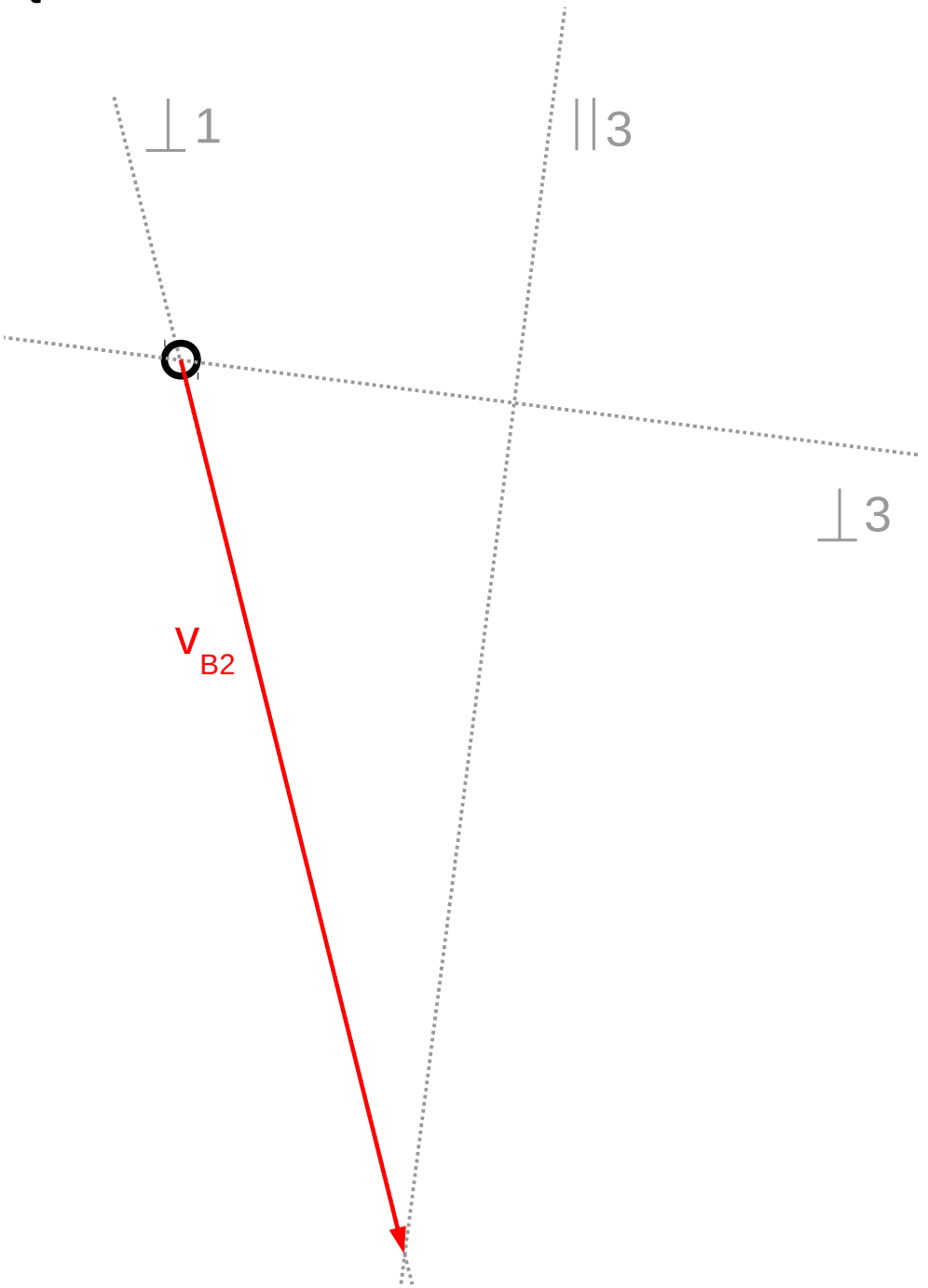

Plan prędkości

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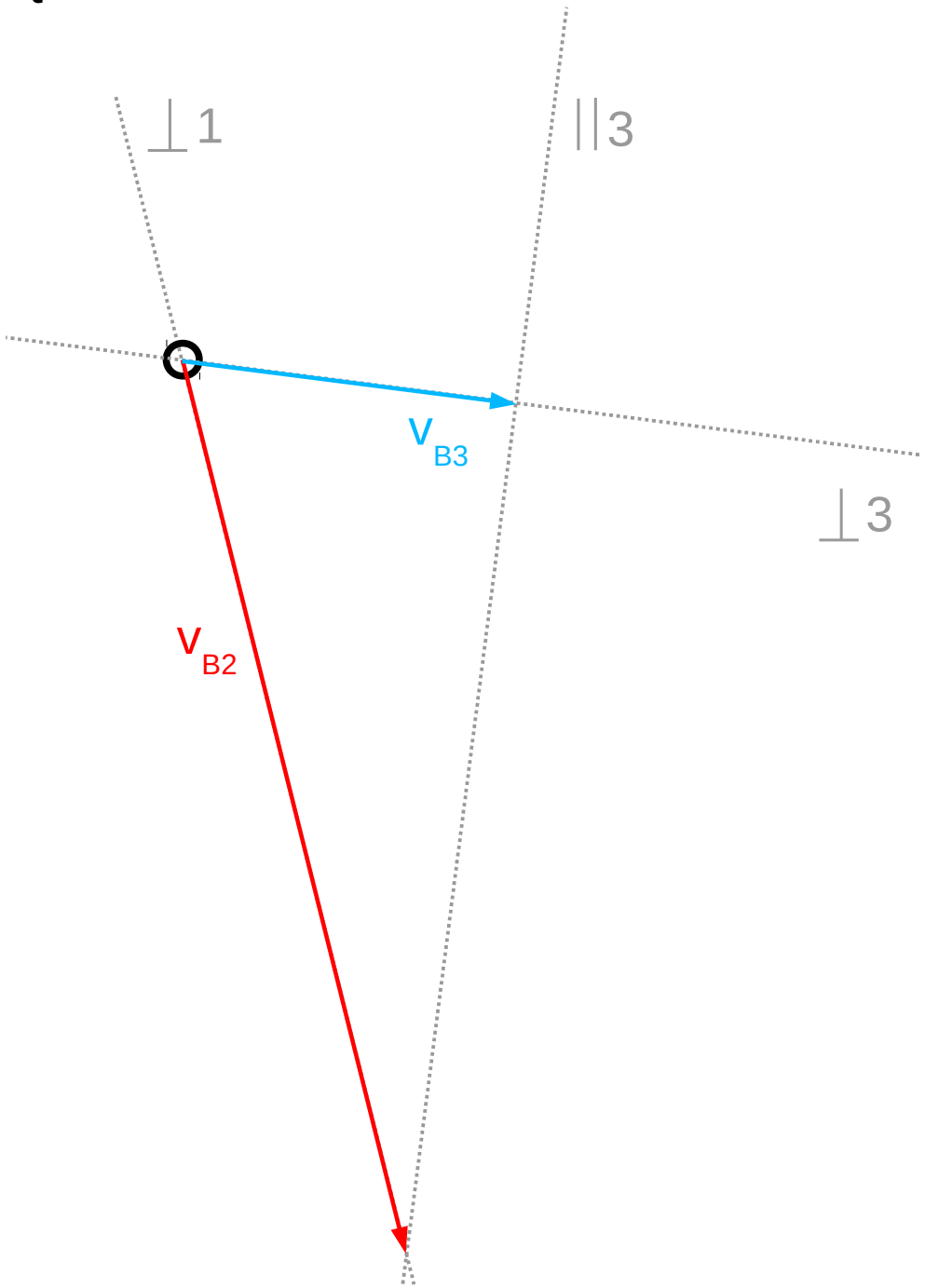

Plan prędkości

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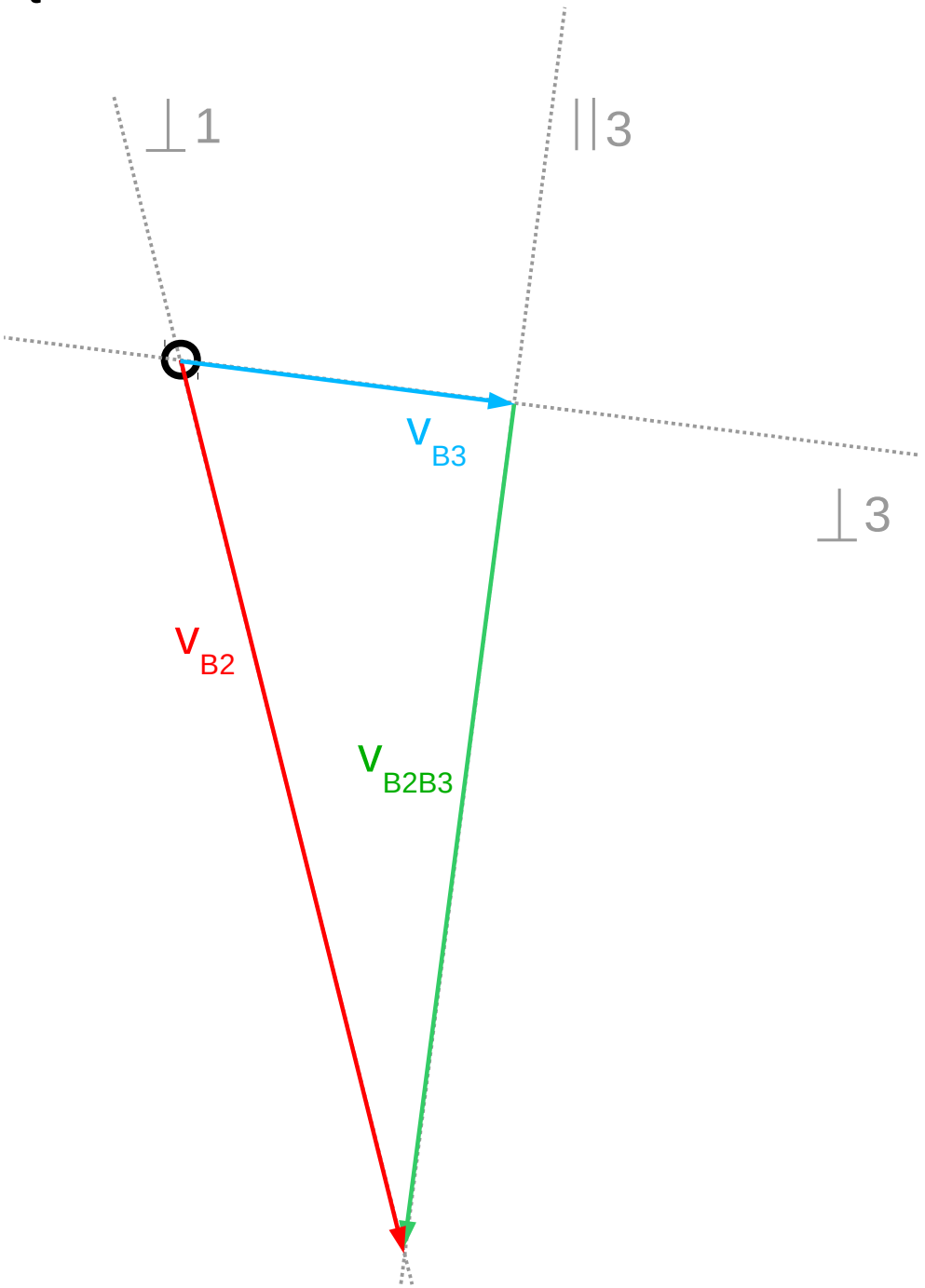
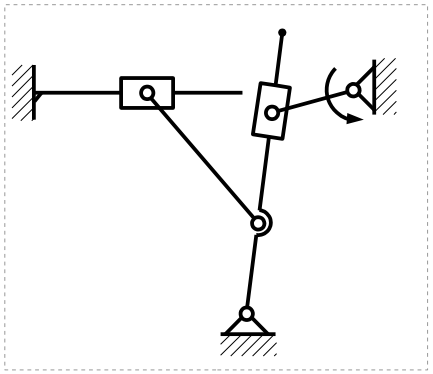
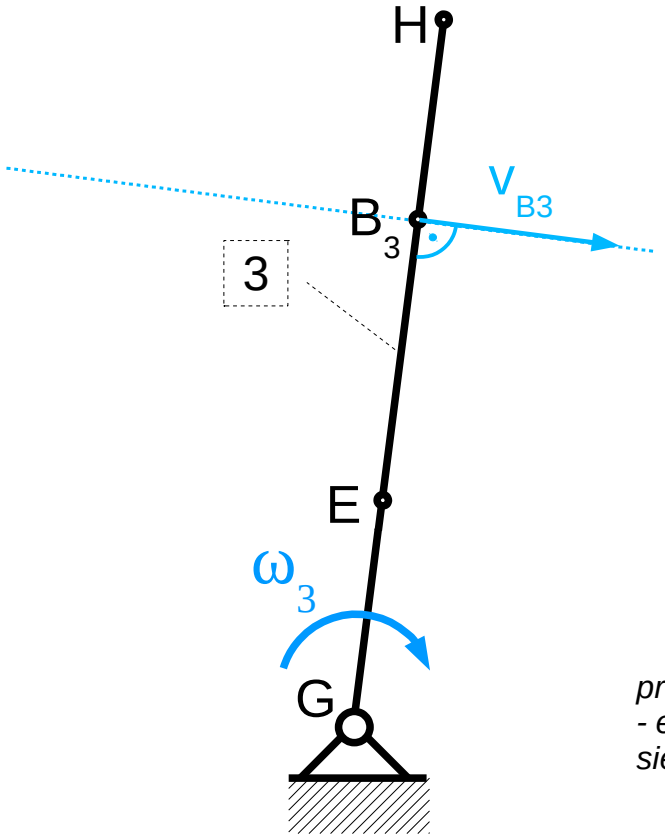
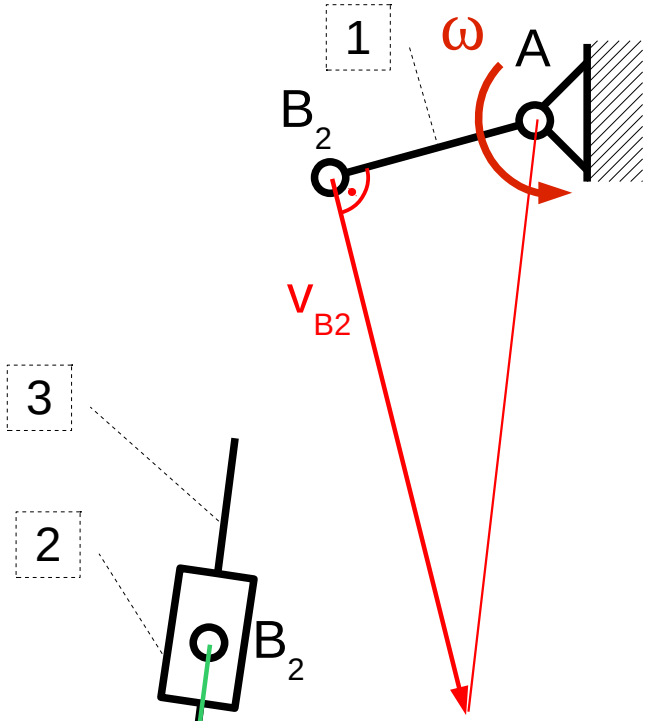
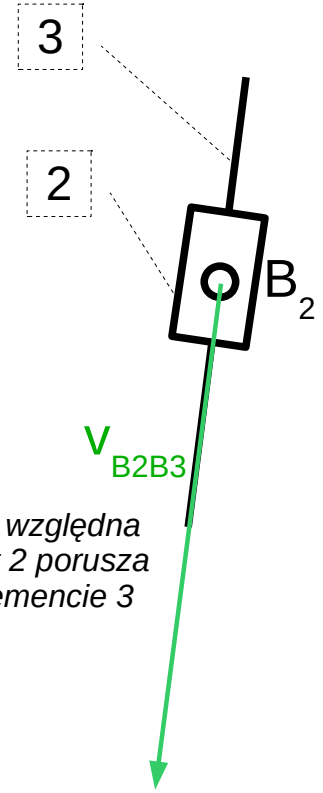


Wyznaczona prędkość punktu B_3 i prędkość względną



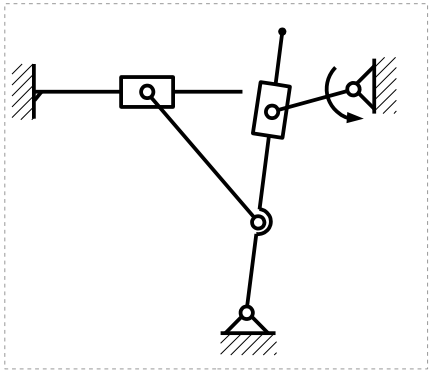




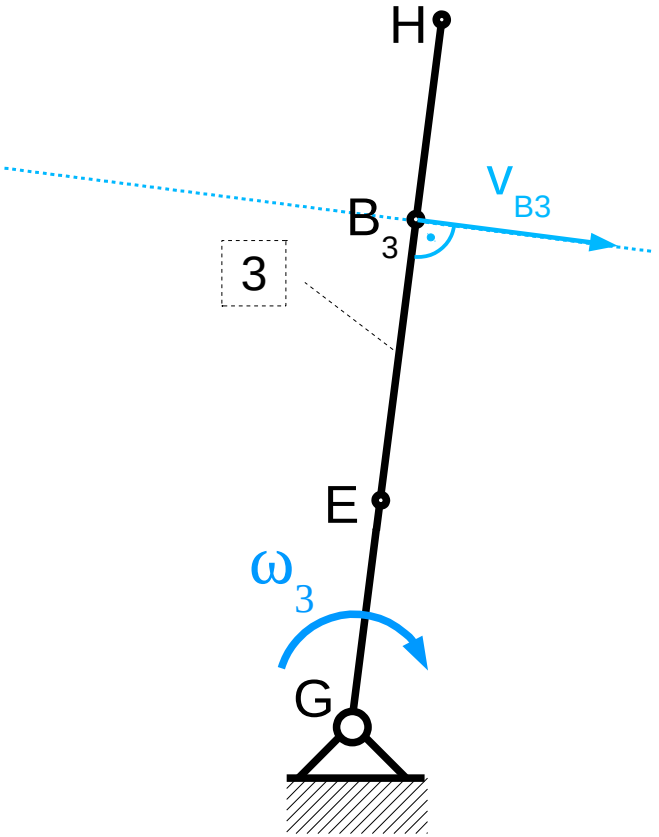


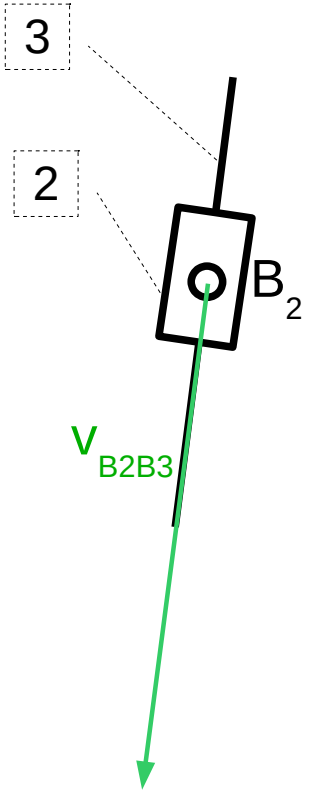
prędkość względna - element 2 porusza się po elemencie 3

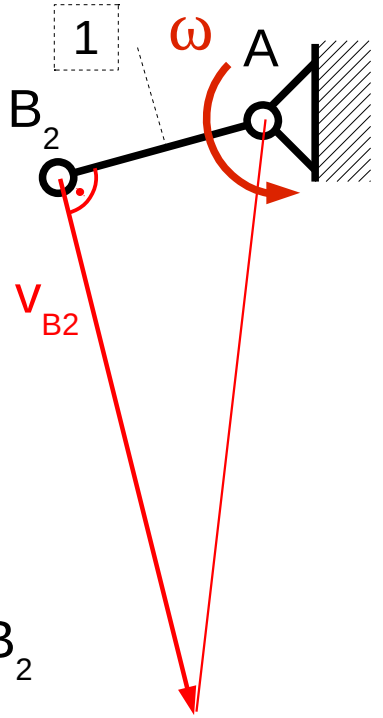
Z wyznaczonej prędkości punktu B_3 określamy prędkość kątową członu 3



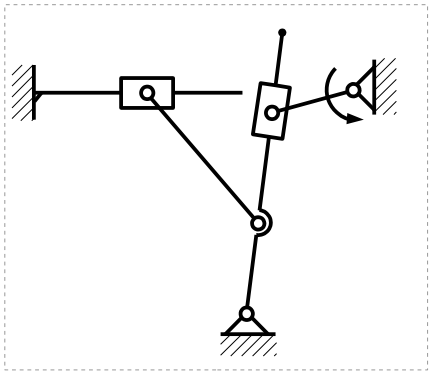
$$\omega_3 = \frac{v_{B3}}{|B_3G|}$$



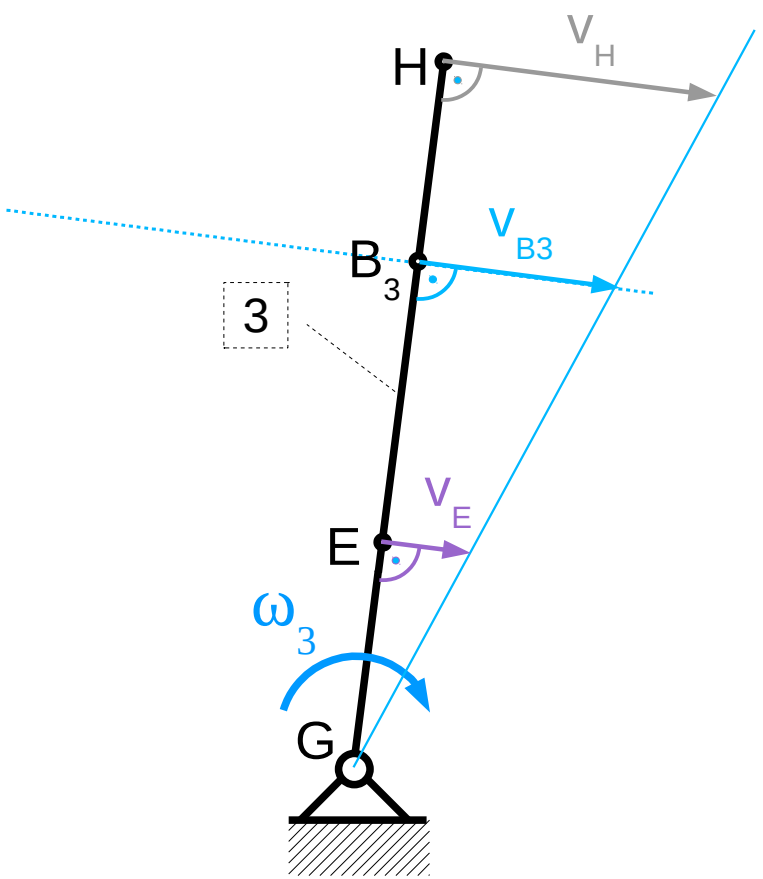


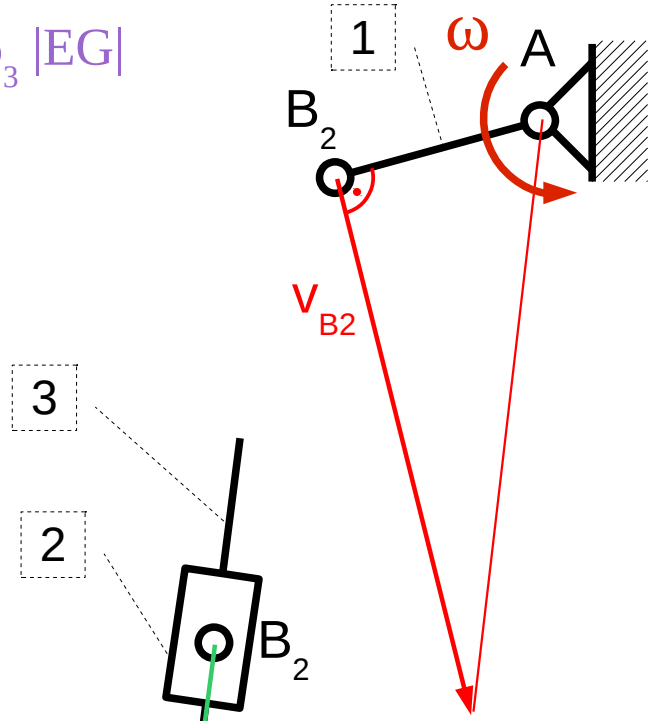


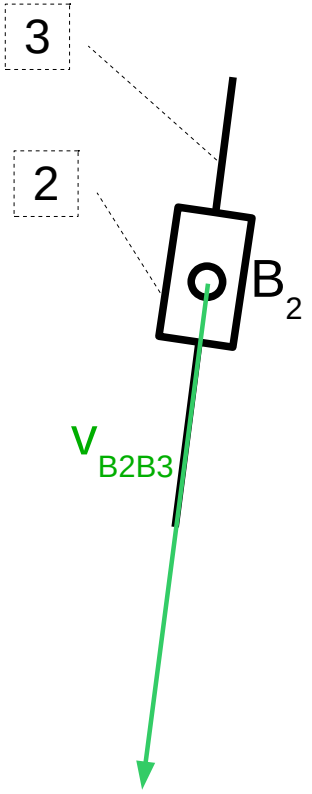
Dzięki wyznaczeniu prędkość kątową członu 3 znajdziemy teraz prędkość dowolnego punktu członu 3, np. punktu E i H



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

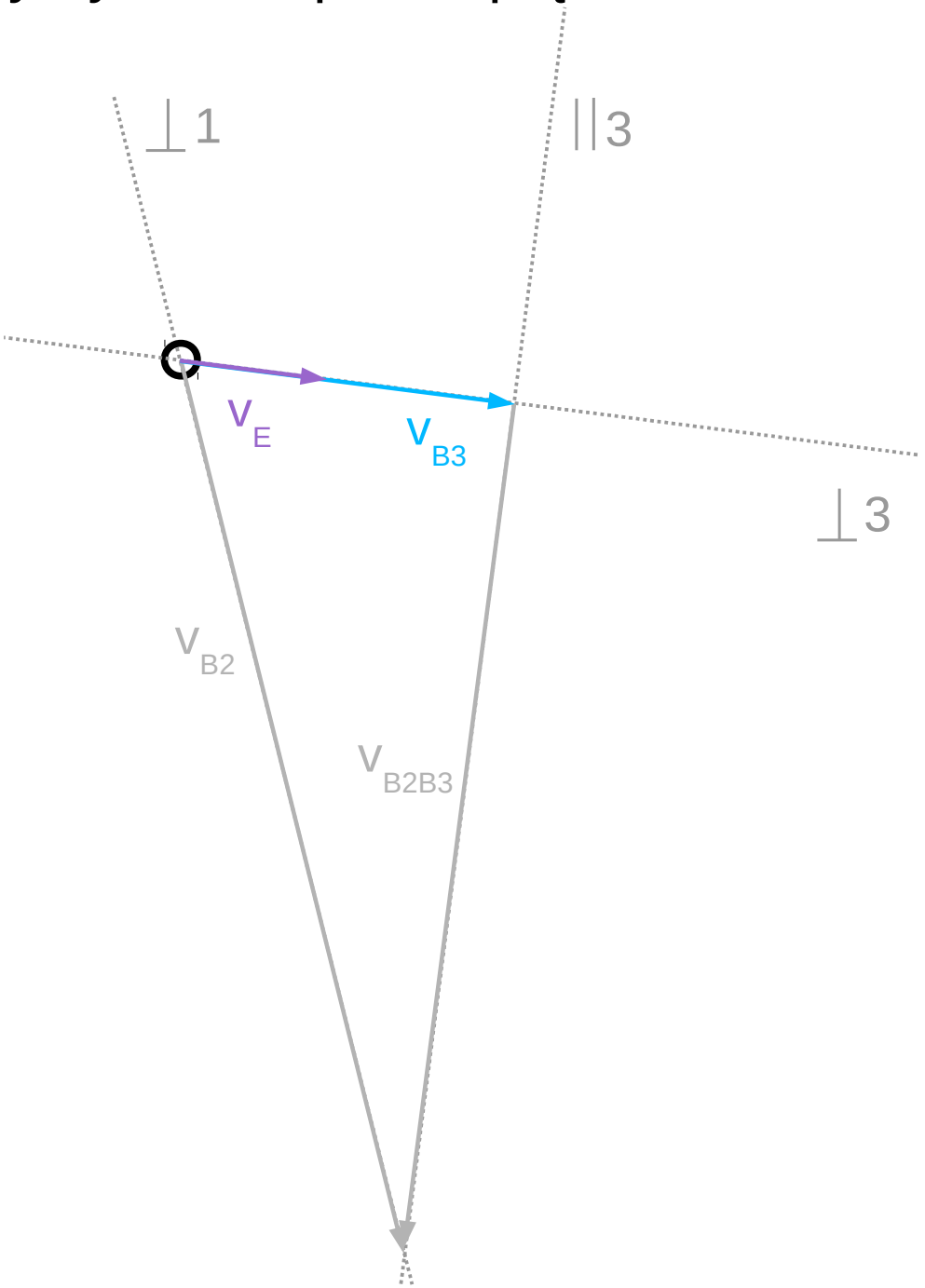






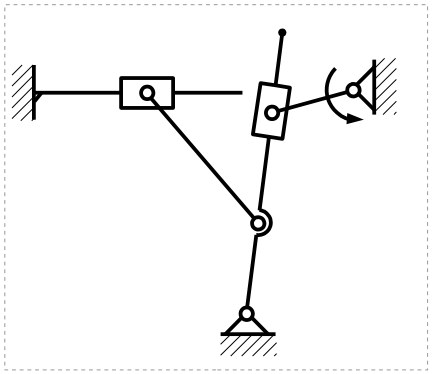
Prędkość punktu E oznaczymy też na planie prędkości

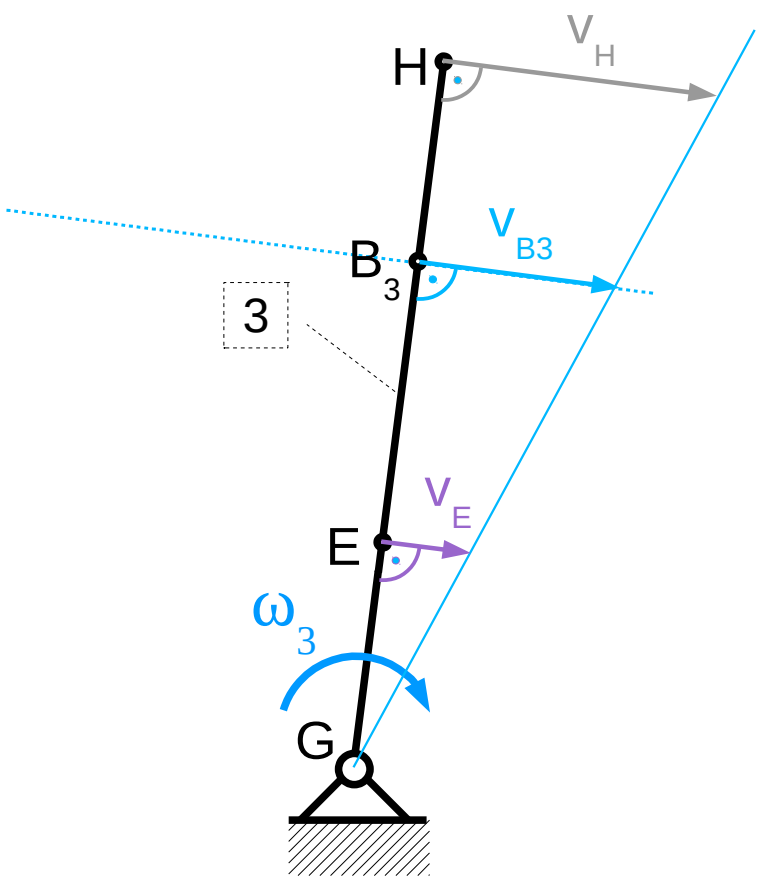
$$\underline{\underline{v_{B2}}} = \underline{v_{B3}} \perp 3 + \underline{v_{B2B3}} \parallel 3$$

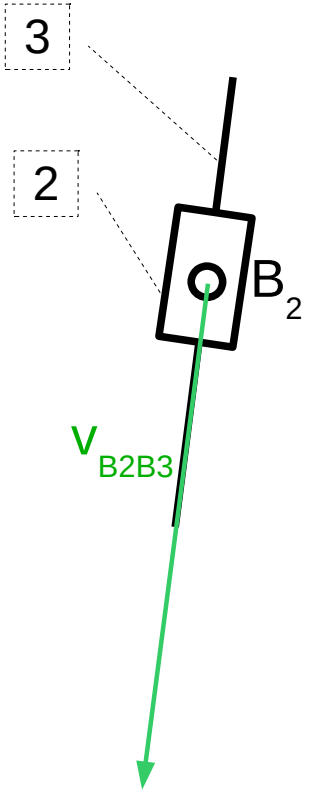


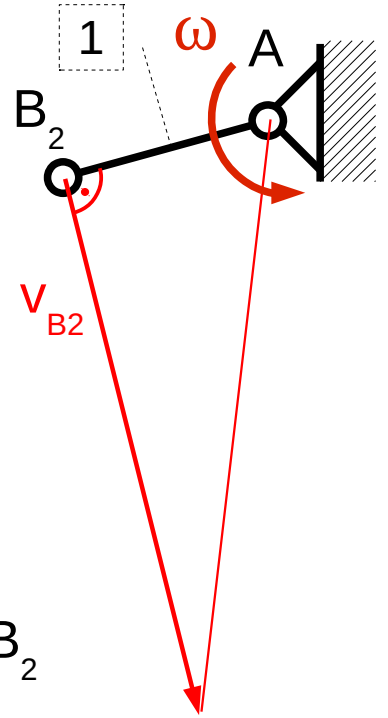
Z proporcji długości odcinków BG i BA oraz długości wektorów V_{B3} i V_{B2} wynika, że

$$\omega > \omega_3$$

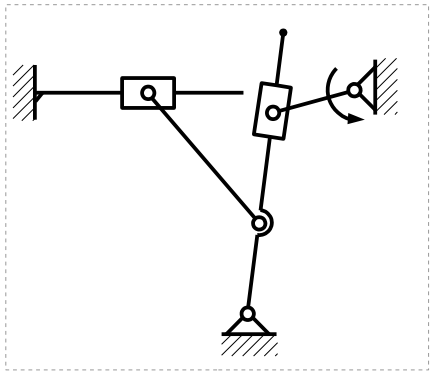




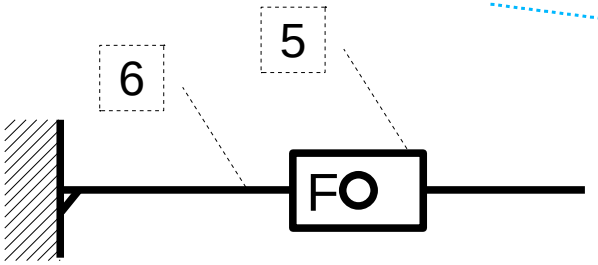


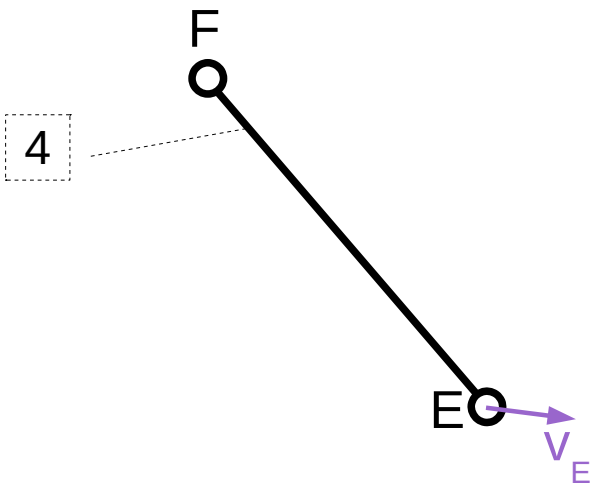


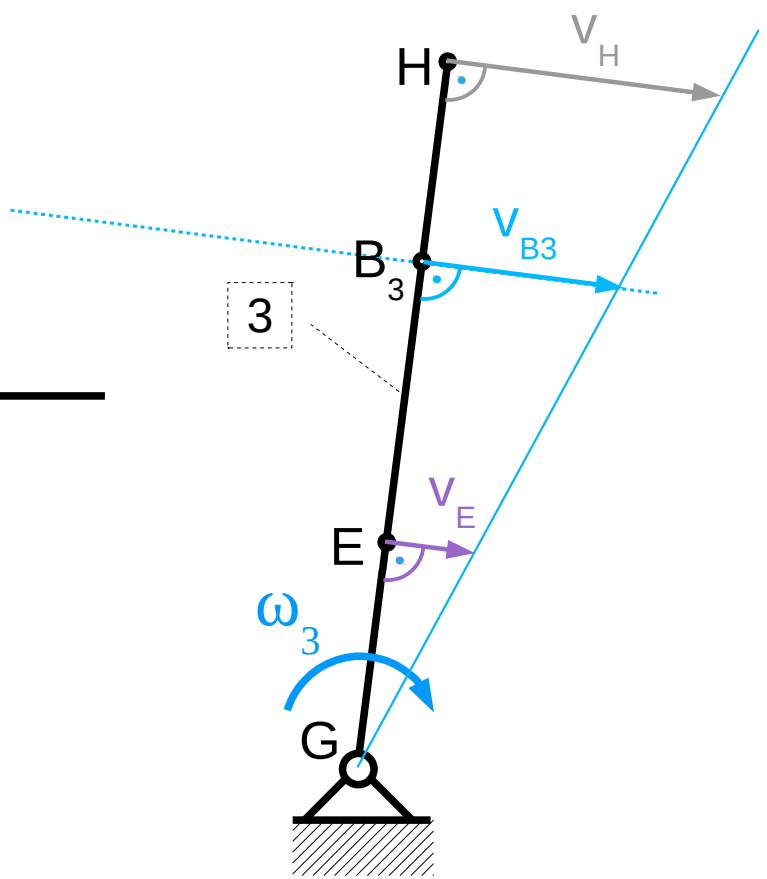
Rozważmy teraz ruch członu 4.
Prędkość punktu F wyznaczymy ze znajomości prędkości punktu E

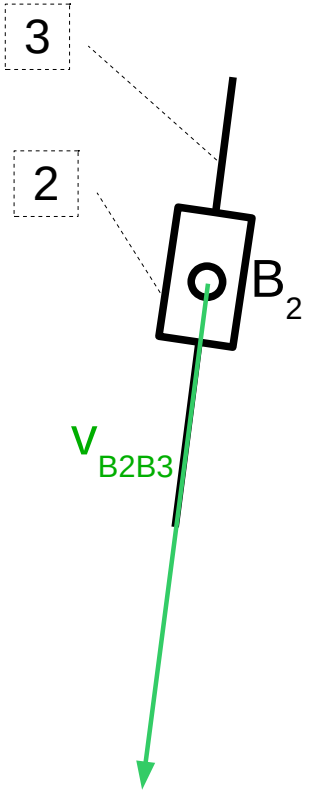


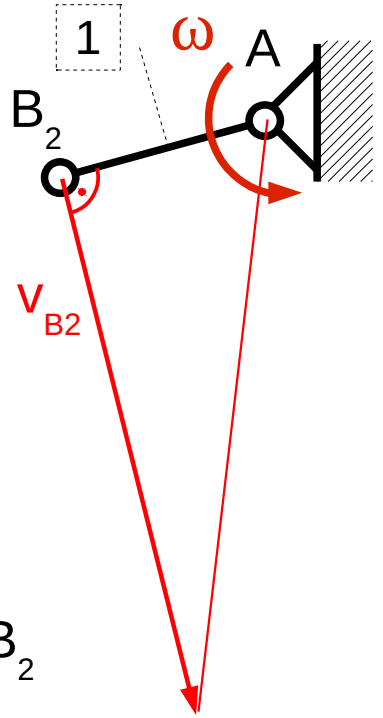
$$\underset{\parallel 6}{v_F} = \underset{\perp 3}{v_E} + \underset{\perp 4}{v_{FE}}$$





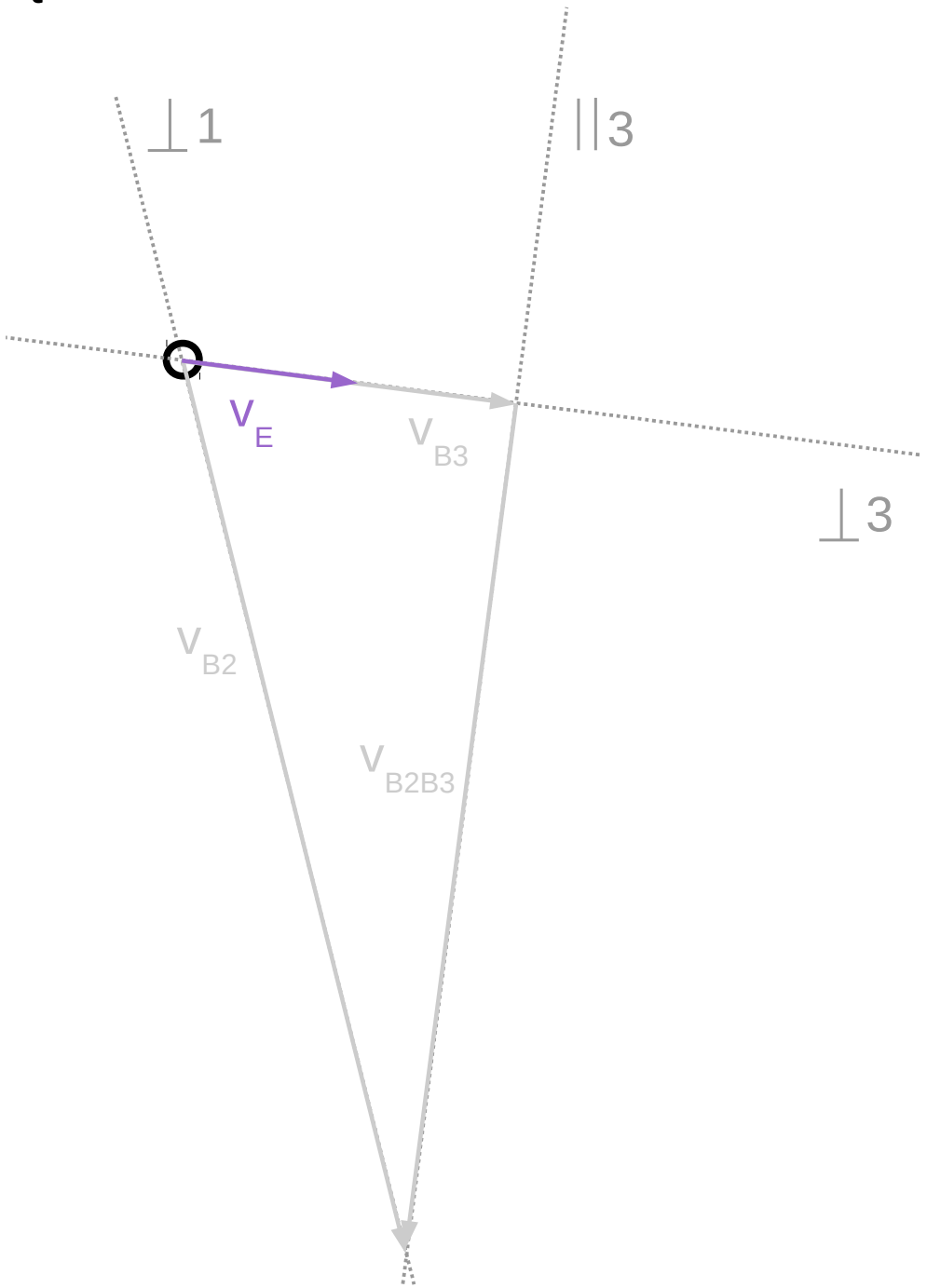






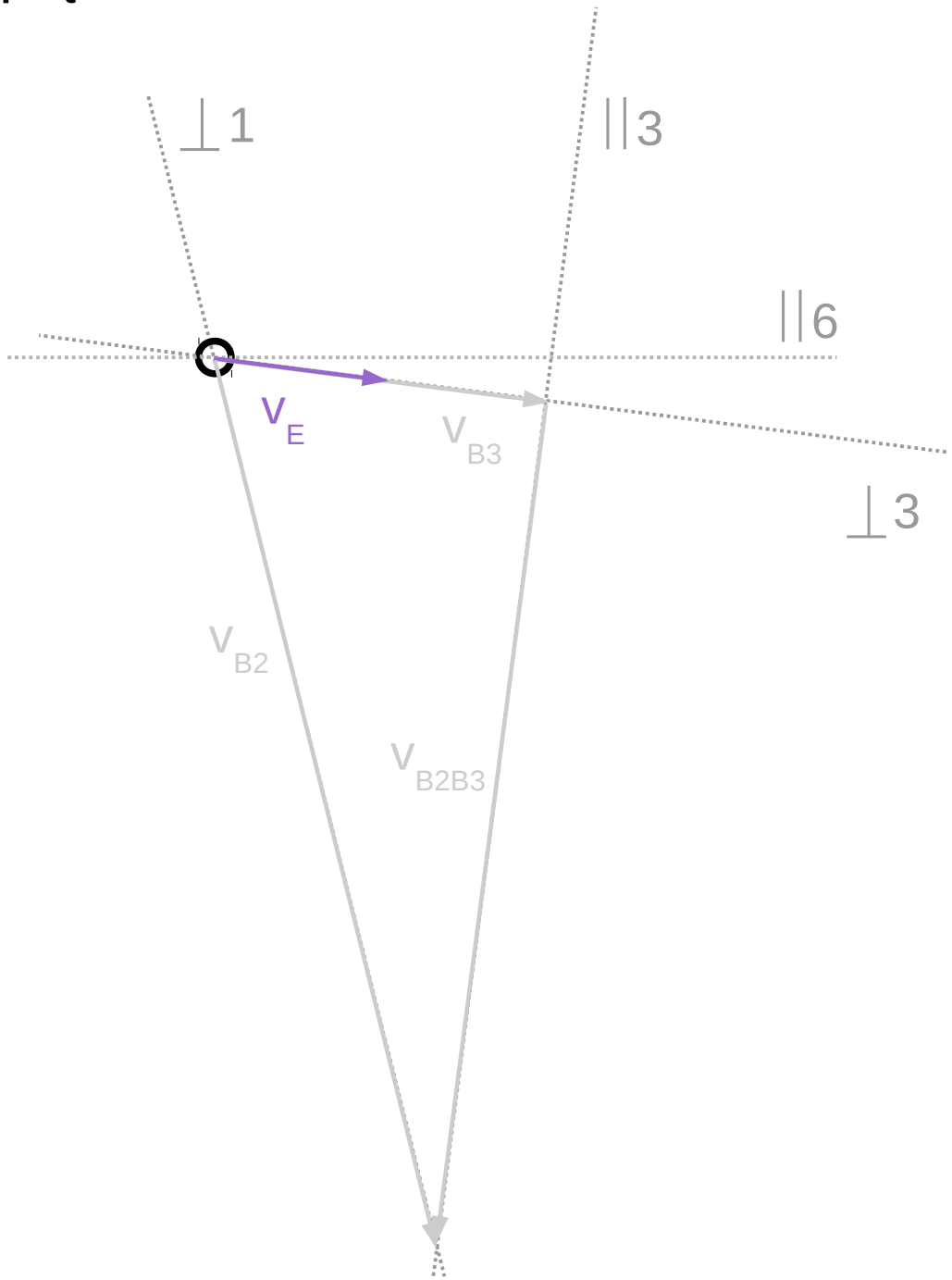
Plan prędkości

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



Plan prędkości

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



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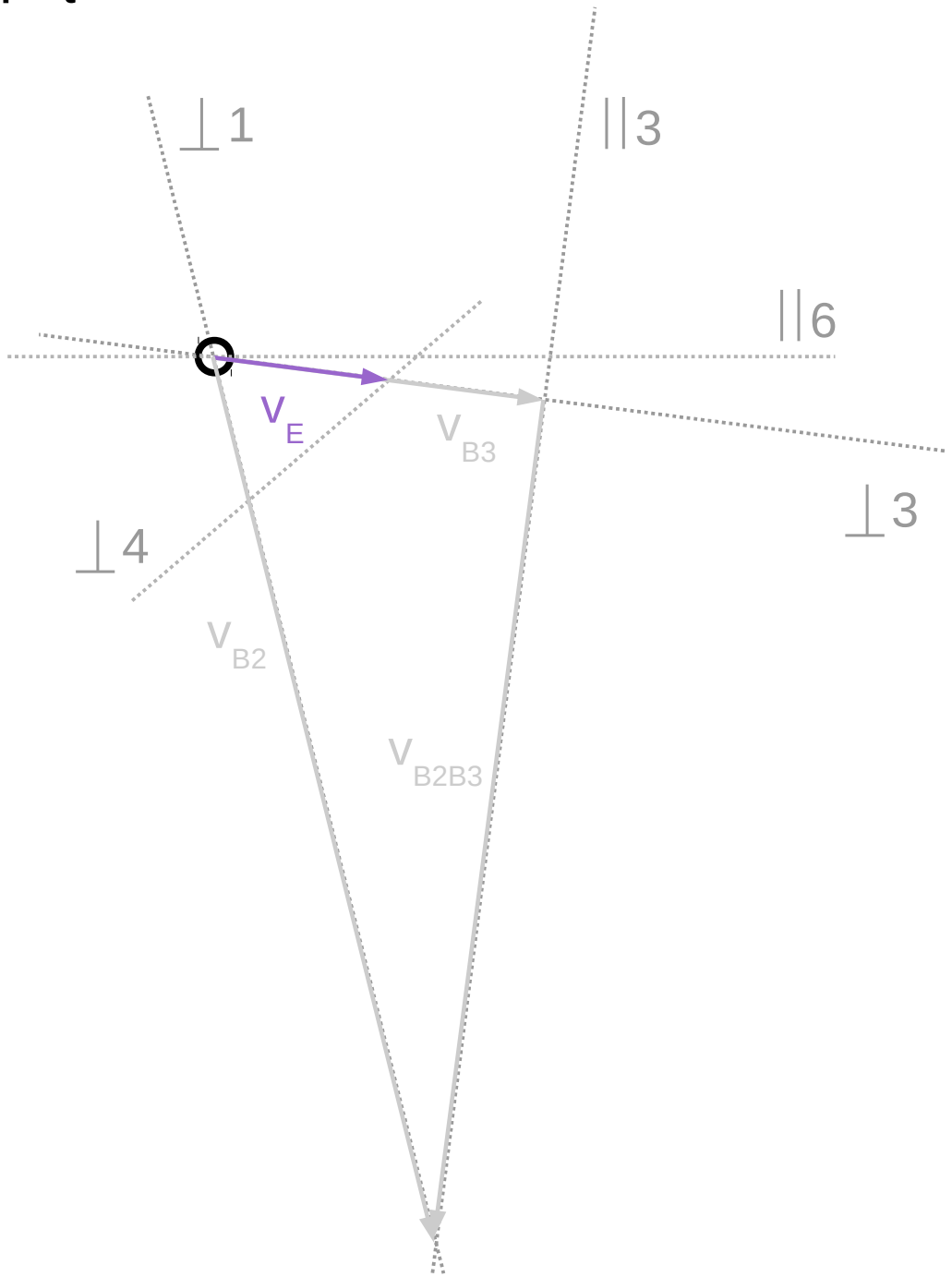
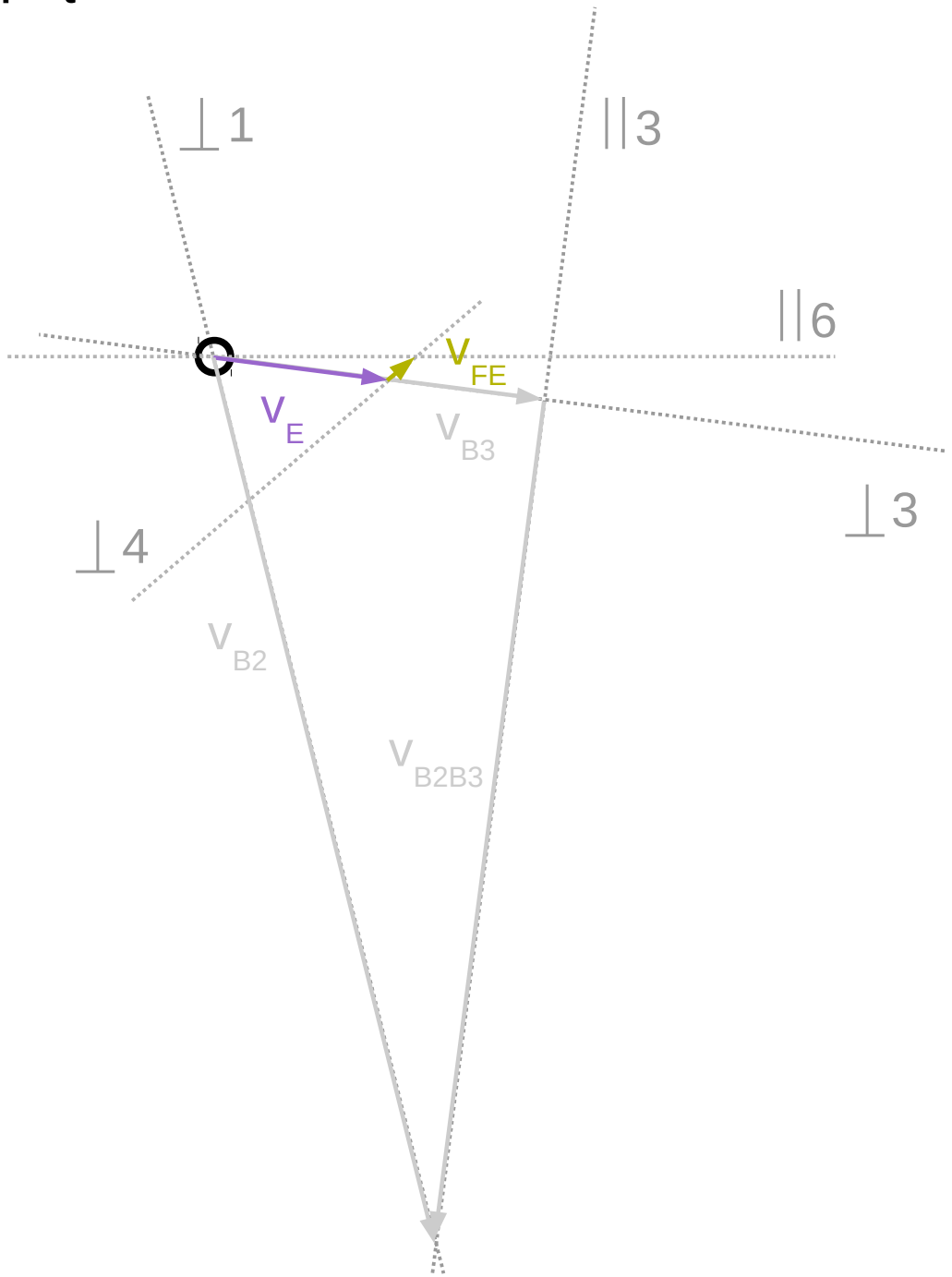
$$\underset{\parallel 6}{v_F} = \underset{\perp 3}{v_E} + \underset{\perp 4}{v_{FE}}$$



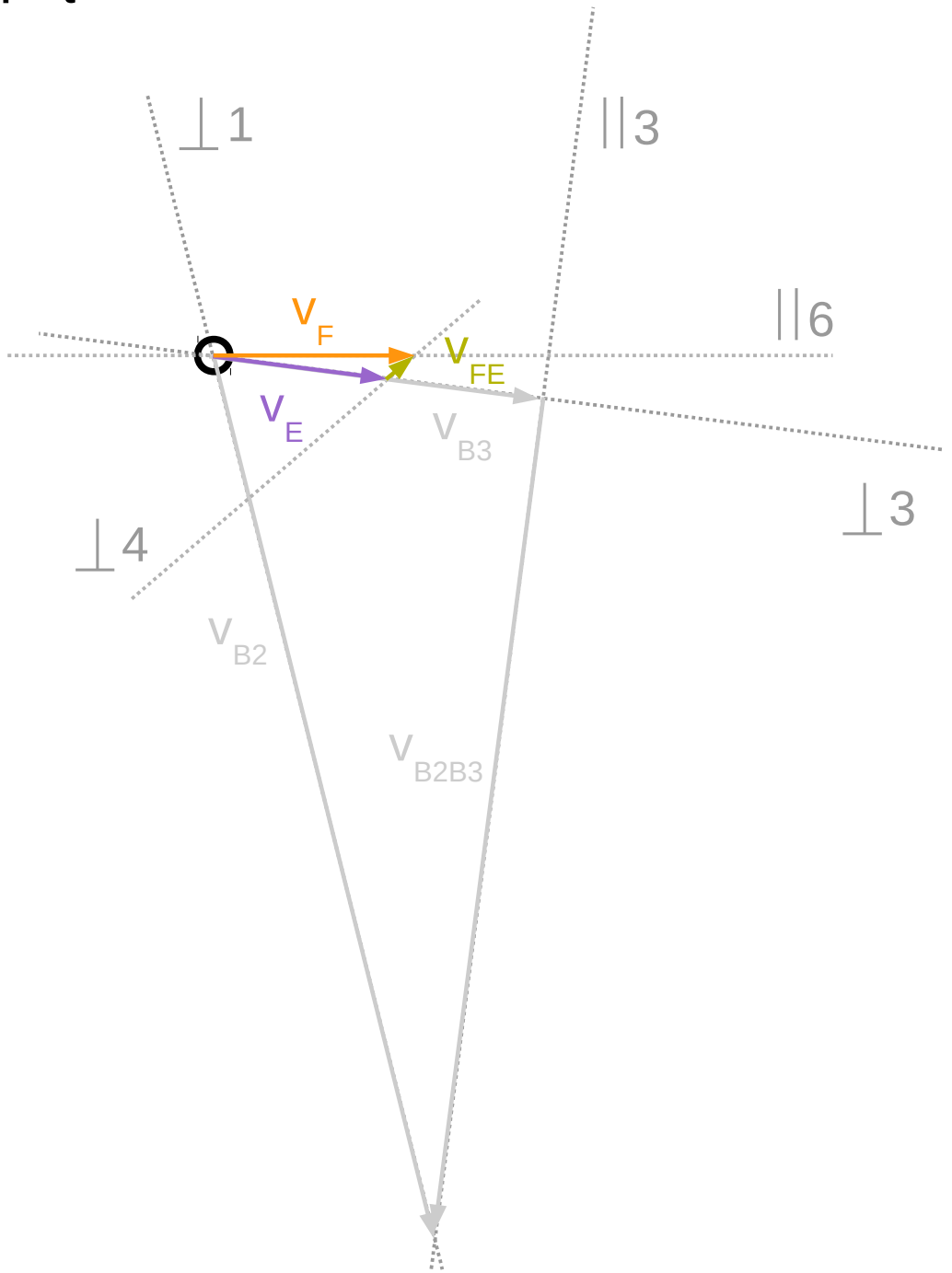
Plan prędkości

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

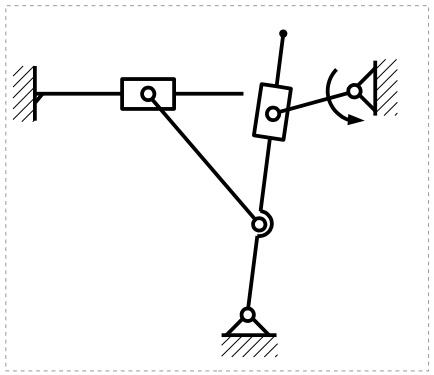


Plan prędkości

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

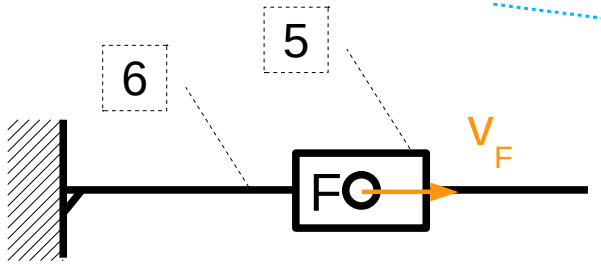


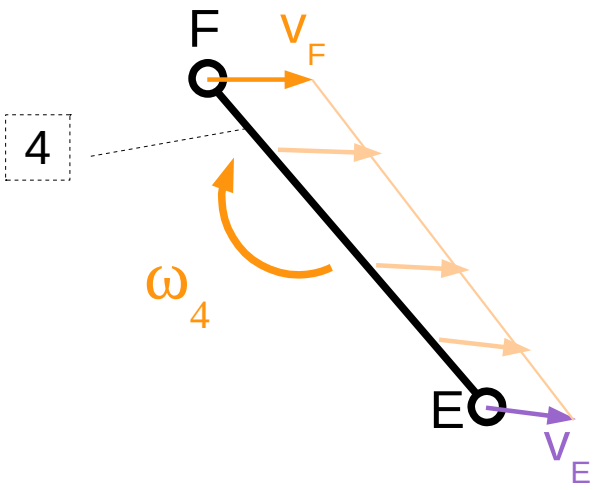
Na zakończenie znajdźmy prędkość kątową elementu 4, jej zwrot wynika ze zwrotu prędkości V_{FE} a jej wartość liczymy

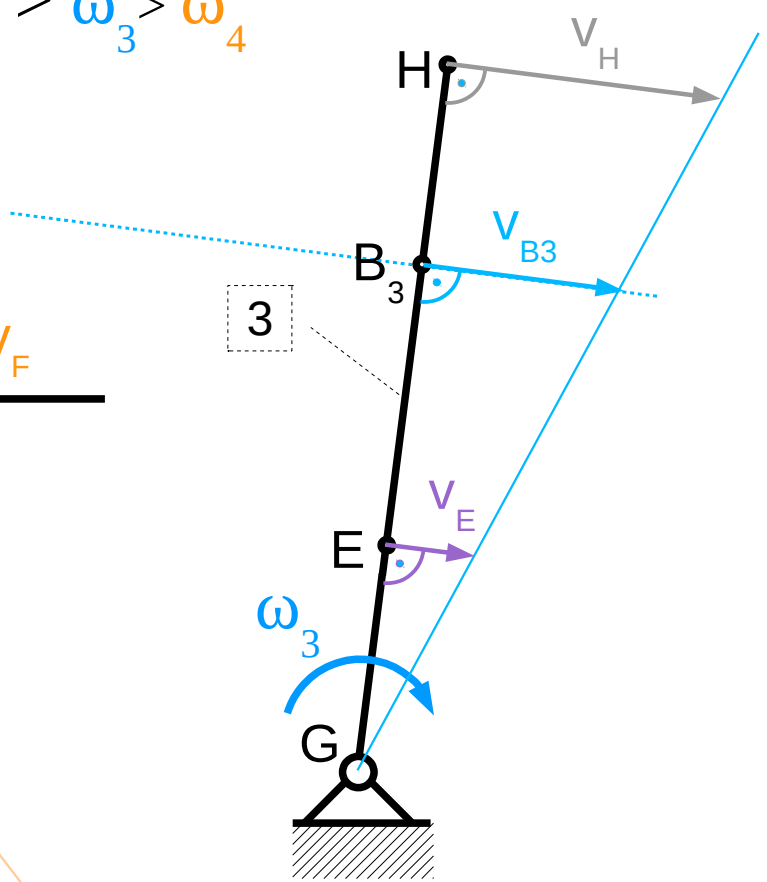


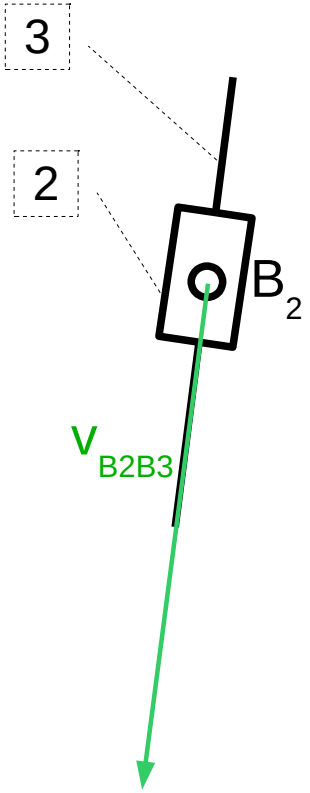
$$\omega_4 = \frac{V_{FE}}{|FE|}$$

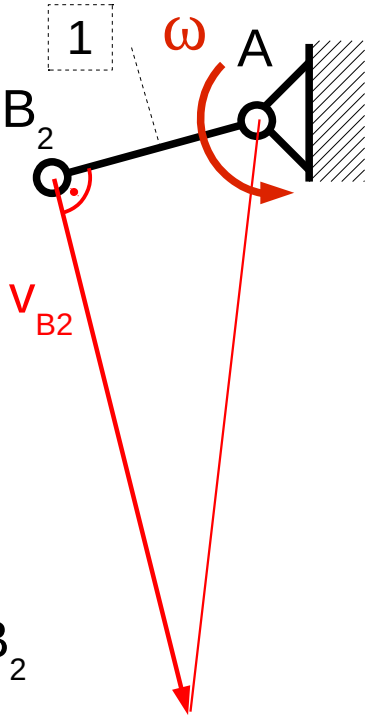
$$\omega > \omega_3 > \omega_4$$



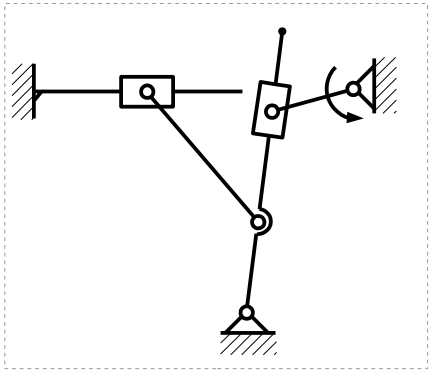


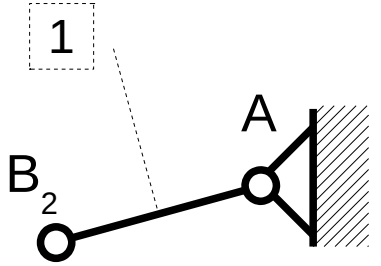




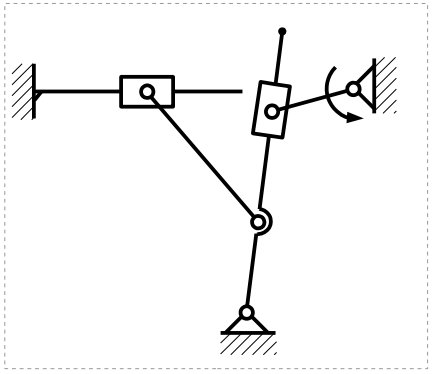


Rozpocznijmy analizę przyspieszeń od członu napędowego

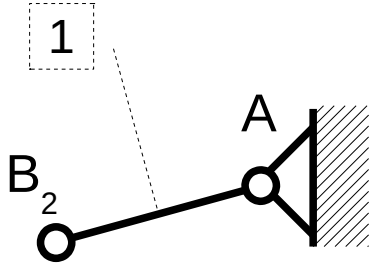




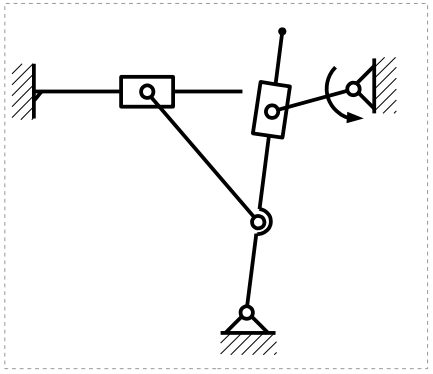
Rozpocznijmy analizę przyspieszeń od członu napędowego



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



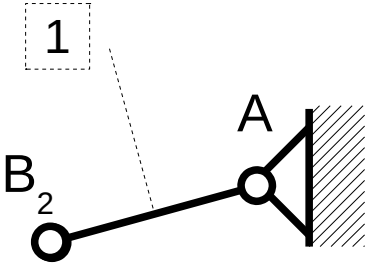
Rozpocznijmy analizę przyspieszeń od członu napędowego



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

p_A: =0

p^n_{B2A}: ||1



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

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

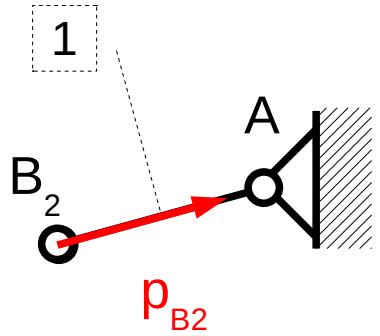
ω z założenia stałe

Rozpocznijmy analizę przyspieszeń od członu napędowego

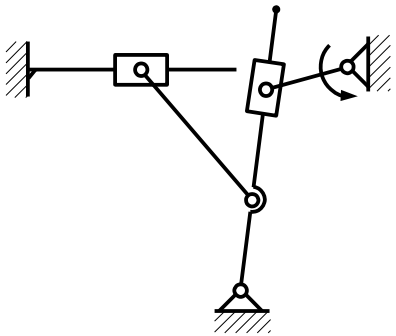
$$p_{B2} = p^{n}_{B2A}$$

$$\| 1$$

$$|p^{n}_{B2A}| = \omega^2 |B_2 A|$$

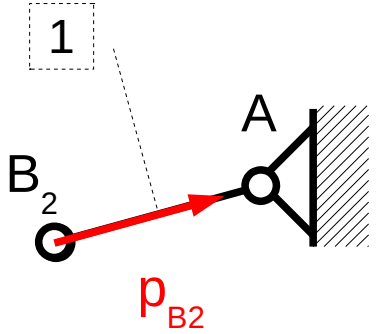


Rozpatrzmy ruch obrotowy elementu trzeciego



$$p_{B2} = \underline{\underline{p^n_{B2A}}} \quad \underline{\underline{\parallel 1}}$$

$$|p^n_{B2A}| = \omega^2 |B_2 A|$$

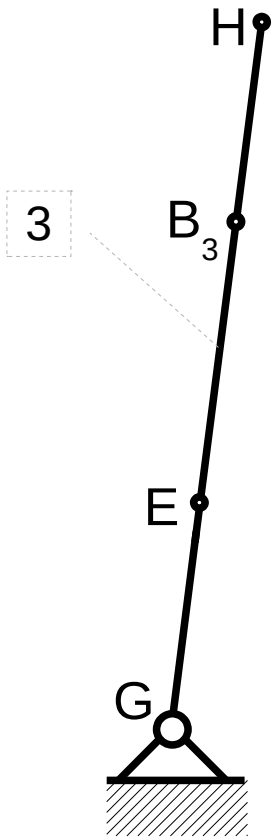


$$p_{B3} = \underline{\underline{p_G}} + \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

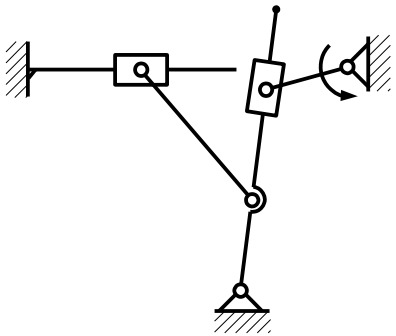
$$\underline{\underline{=0}} \quad \underline{\underline{\parallel 3}} \quad \underline{\perp 3}$$

$$|p^n_{B3G}| = \omega_3^{\,2} |B_3 G|$$

z planu prędkości

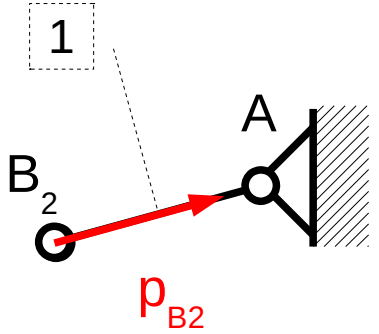


Rozpatrzmy ruch obrotowy elementu trzeciego



$$p_{B2} = \underline{\underline{p^n_{B2A}}} \quad \| 1$$

$$|p^n_{B2A}| = \omega^2 |B_2 A|$$

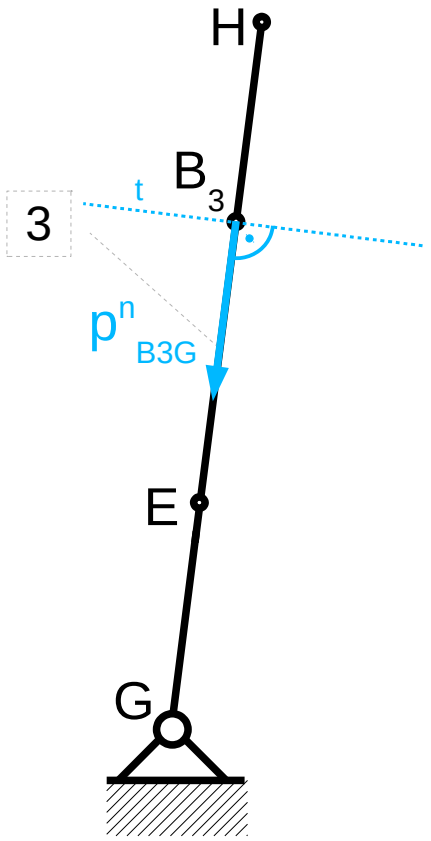


$$p_{B3} = \underline{\underline{p_G}} + \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

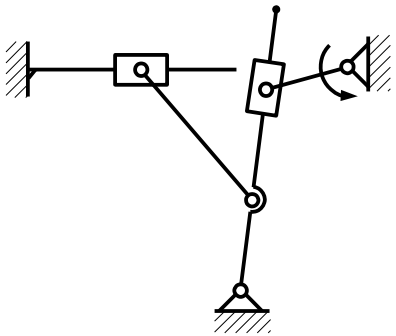
$$=0 \quad \| 3 \quad \perp 3$$

$$|p^n_{B3G}| = \omega_3^{\,2} |B_3 G|$$

z planu prędkości

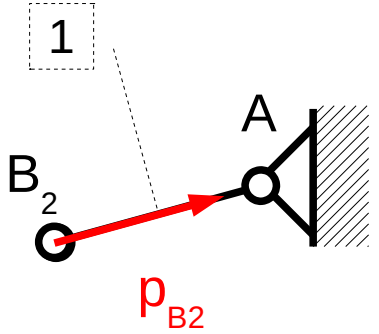


Rozpatrzmy ruch obrotowy elementu trzeciego



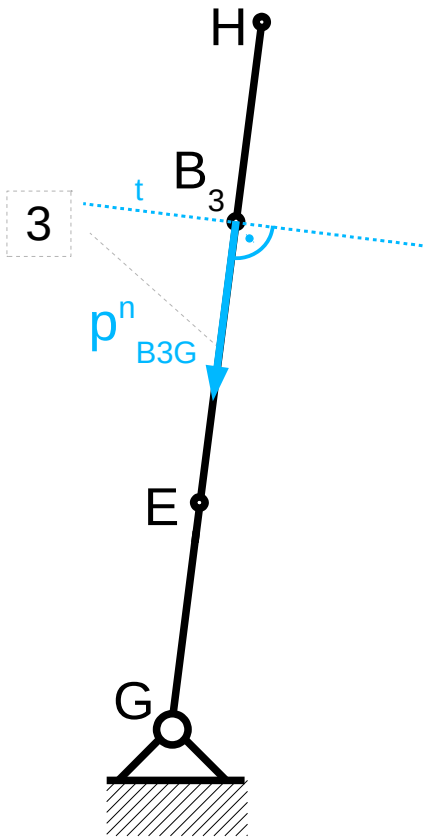
$$p_{B2} = \underline{\underline{p^n_{B2A}}} \quad \underline{\underline{\parallel 1}}$$

$$|p^n_{B2A}| = \omega^2 |B_2 A|$$

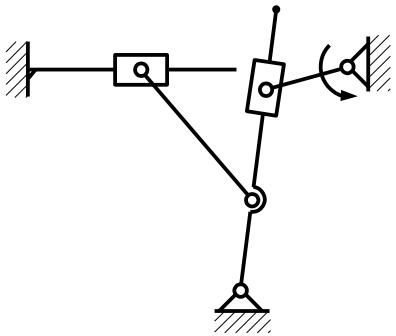


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}} \quad \underline{\underline{\parallel 3}} \quad \underline{\perp 3}$$

$$|p^n_{B3G}| = \omega_3^{\,2} |B_3 G|$$



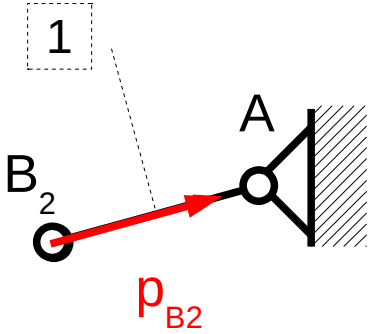
Rozpatrzmy ruch względny elementów 2 i 3



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

$$\underline{\underline{\|1}}$$

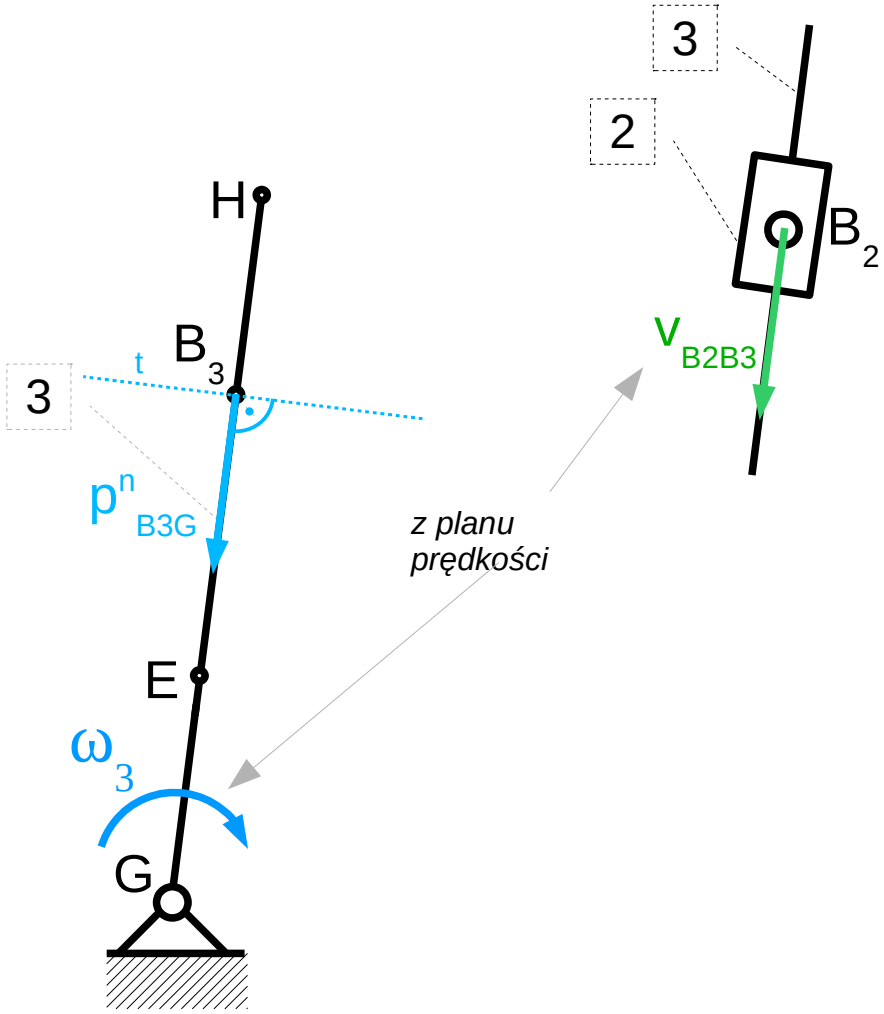
$$|p^n_{B2A}| = \omega^2 |B_2A|$$



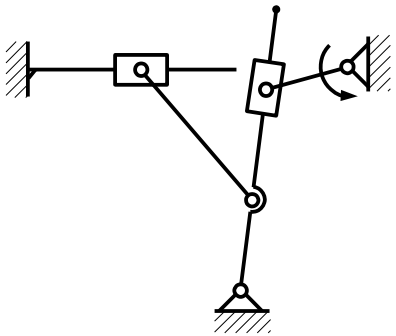
$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$$\underline{\underline{\|3}} \quad \underline{\perp 3}$$

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



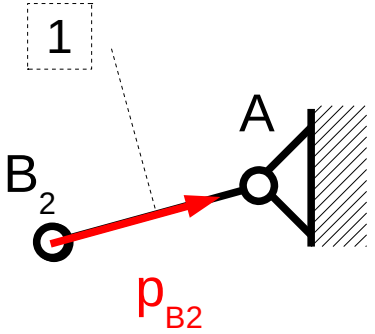
Rozpatrzmy ruch względny elementów 2 i 3



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

$$\| 1$$

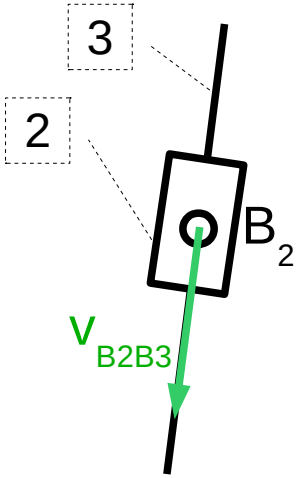
$$|p^n_{B2A}| = \omega^2 |B_2 A|$$

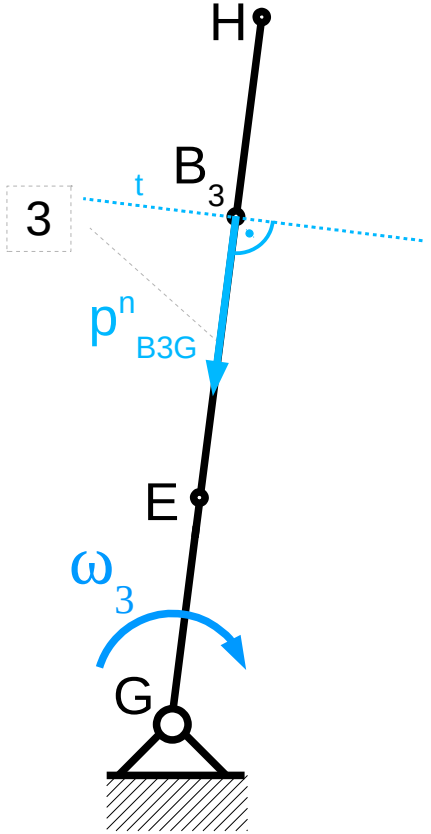


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$$\| 3 \quad \perp 3$$

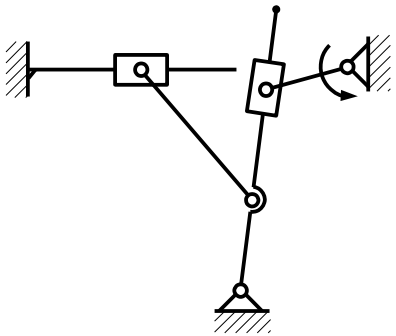
$$|p^n_{B3G}| = \omega_3^{\,2} |B_3 G|$$





RUCH UNOSZENIA: ruch elementu 3
RUCH WZGLĘDNY: ruch elementu 2 wzdłuż elementu 3

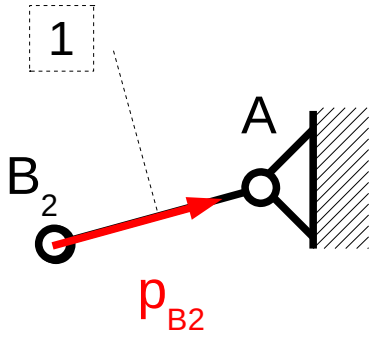
Rozpatrzmy ruch względny elementów 2 i 3



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

$$\| 1$$

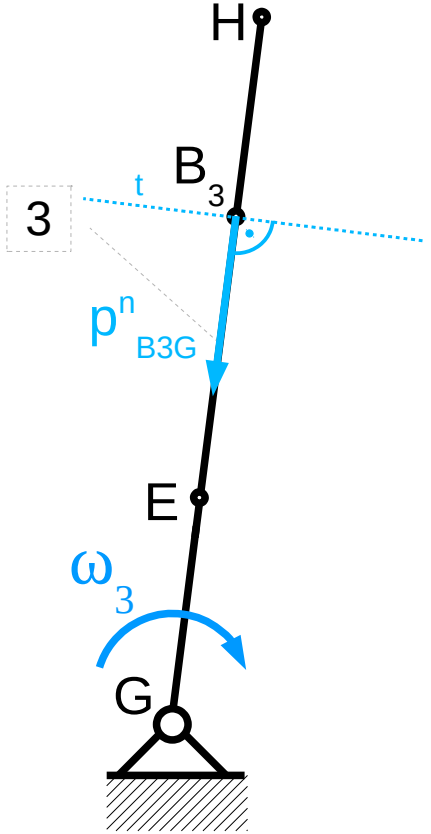
$$|p^n_{B2A}| = \omega^2 \, |B_2 A|$$

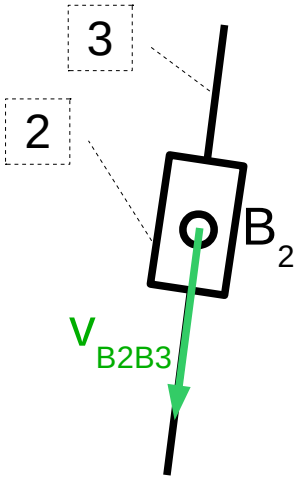


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$$\| 3 \quad \perp 3$$

$$|p^n_{B3G}| = \omega_3^{\,2} \, |B_3 G|$$



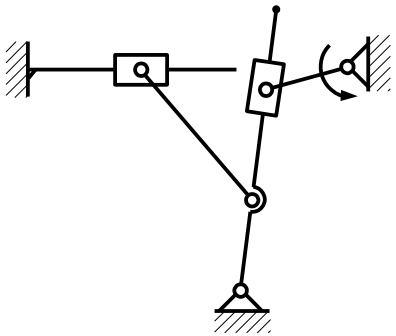


RUCH UNOSZENIA: ruch elementu 3
RUCH WZGLĘDNY: ruch elementu 2 wzdłuż elementu 3

RÓWNANIE RUCHU WZGLĘDNEGO:

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

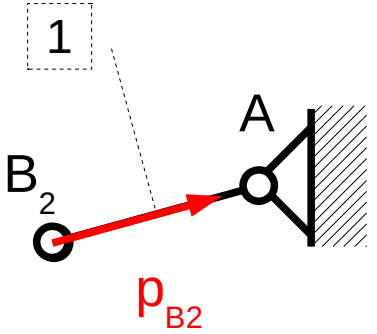
Rozpatrzmy ruch względny elementów 2 i 3



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

$$\| 1$$

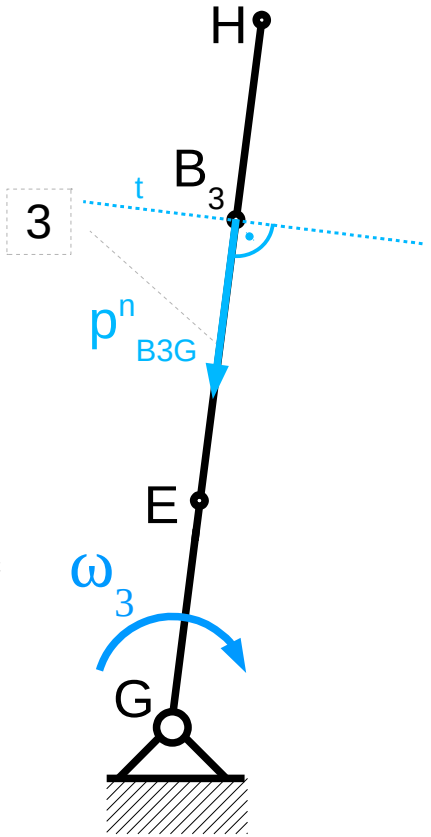
$$|p^n_{B2A}| = \omega^2 |B_2 A|$$

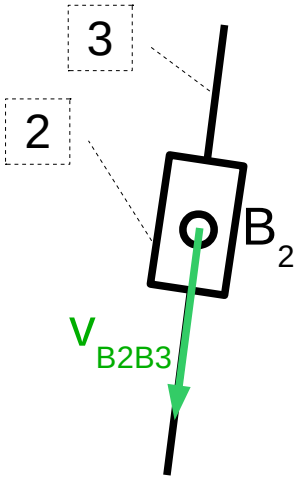


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$$\| 3 \quad \perp 3$$

$$|p^n_{B3G}| = \omega_3^{\,2} |B_3 G|$$





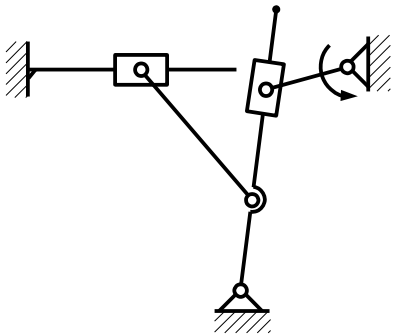
RUCH UNOSZENIA: ruch elementu 3
RUCH WZGLĘDNY: ruch elementu 2 wzdłuż elementu 3

RÓWNANIE RUCHU WZGLĘDNEGO:

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

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

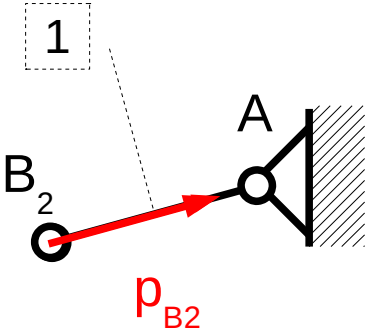
Rozpatrzmy ruch względny elementów 2 i 3



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

$$\underline{\underline{||1}}$$

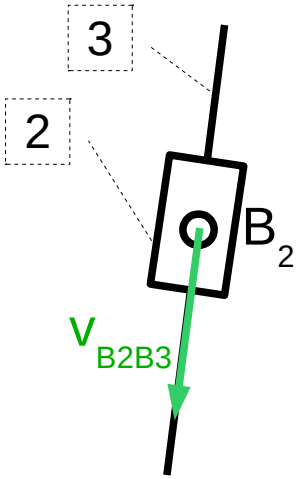
$$|p^n_{B2A}| = \omega^2 |B_2A|$$

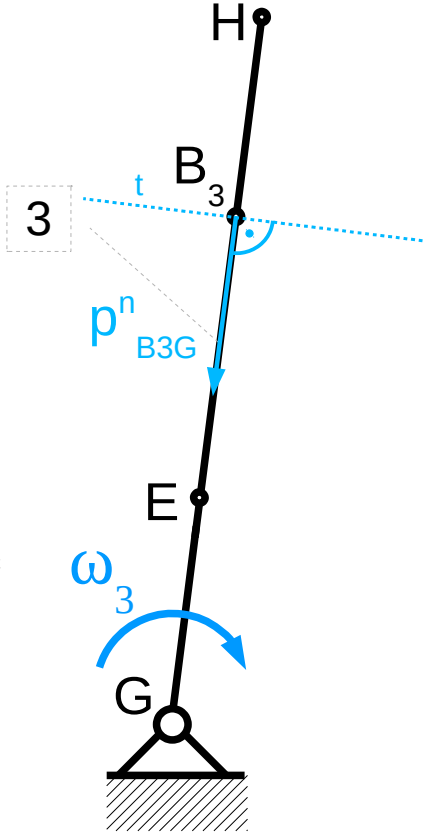


$$p_{B3} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}}$$

$$\underline{\underline{||3}} \quad \underline{\perp 3}$$

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





RUCH UNOSZENIA: ruch elementu 3
RUCH WZGLĘDNY: ruch elementu 2 wzdłuż elementu 3

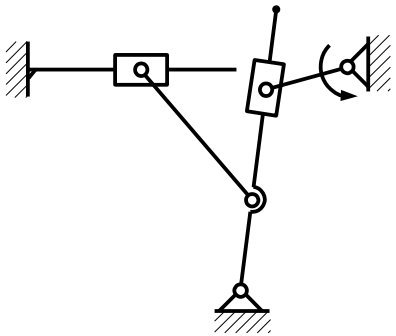
RÓWNANIE RUCHU WZGLĘDNEGO:

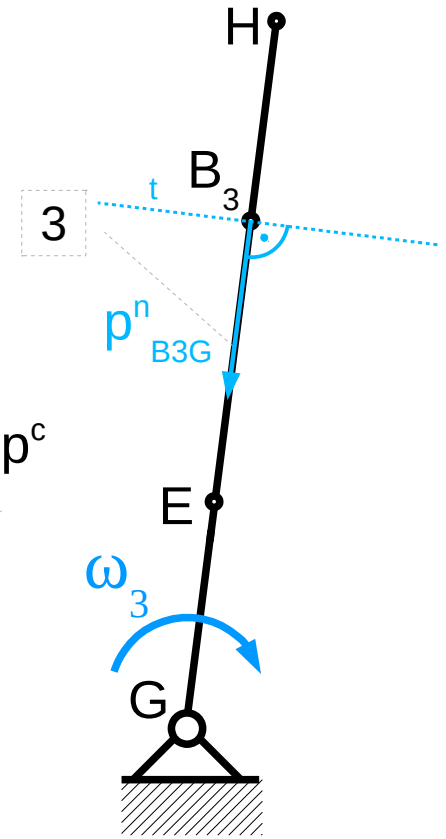
$$p_{B2} = p^u_{B3} + p^w + p^c$$

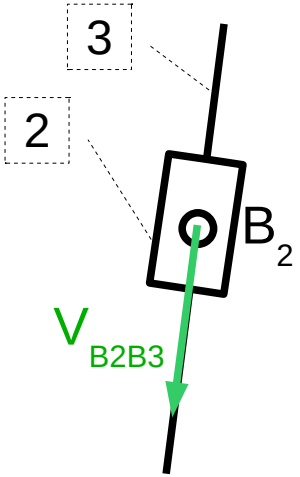
$$\underline{\underline{p^n_{B2A}}} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}} + \underline{p^w_{B2B3}} + p^c$$

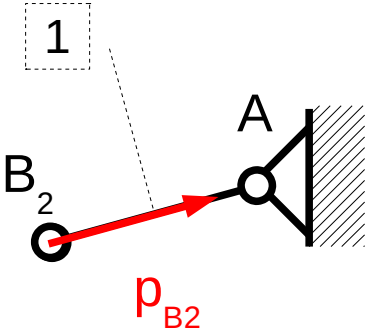
$$\underline{\underline{||1}} \quad \underline{\underline{||3}} \quad \underline{\perp 3} \quad \underline{||3}$$

Przyspieszenie Coriolisa









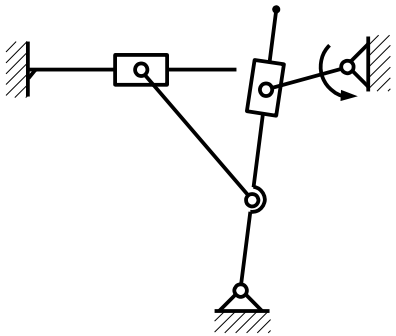
$$p_{B2} = p^{u}_{B3} + p^{w} + p^{c}$$

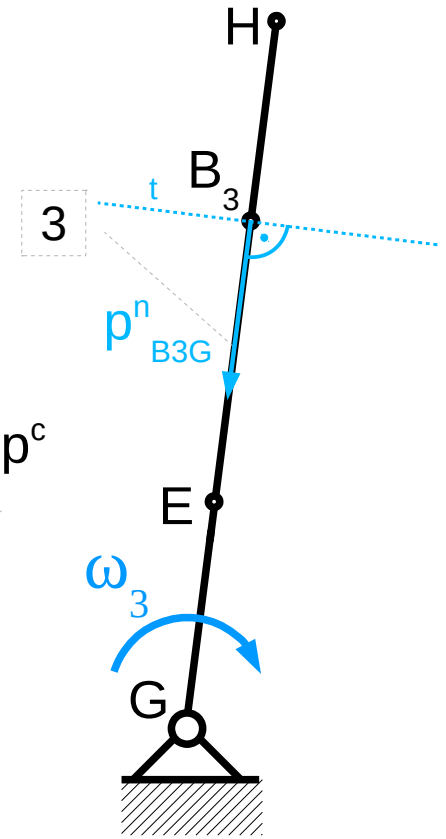
$$\underline{\underline{p^{n}_{B2A}}} = \underline{\underline{p^{n}_{B3G}}} + \underline{p^{t}_{B3G}} + \underline{p^{w}_{B2B3}} + p^{c}$$

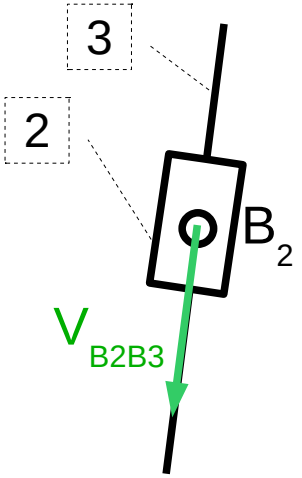
$$\underline{\underline{||1}} \qquad \underline{\underline{||3}} \qquad \underline{\perp 3} \qquad \underline{||3}$$

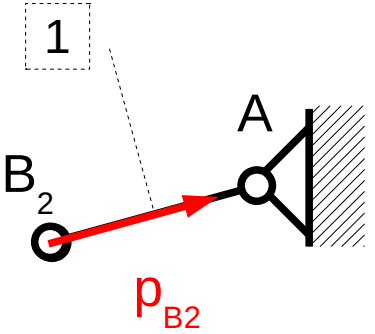
$$p^{c} = 2\omega_{3} \times V_{B2B3}$$

Przyspieszenie Coriolisa









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

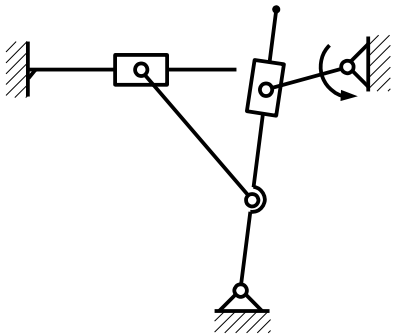
$$\underline{\underline{p^n_{B2A}}} = \underline{\underline{p^n_{B3G}}} + \underline{p^t_{B3G}} + \underline{p^w_{B2B3}} + p^c$$

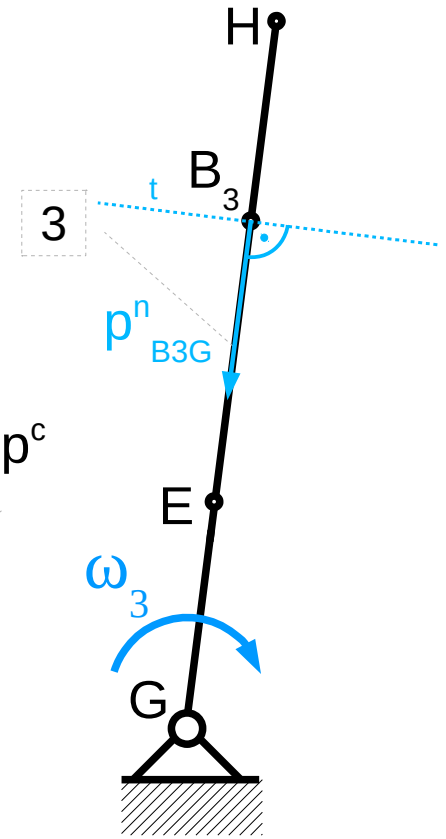
$$\underline{\underline{||1}} \qquad \underline{\underline{||3}} \qquad \underline{\perp 3} \qquad \underline{||3}$$

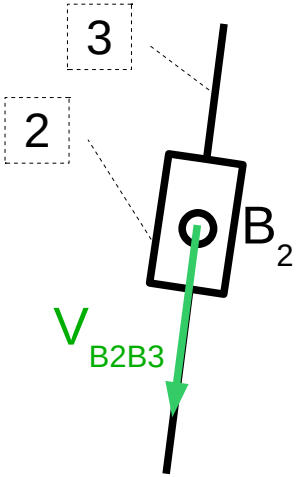
$$p^c = 2\omega_3 \times V_{B2B3}$$

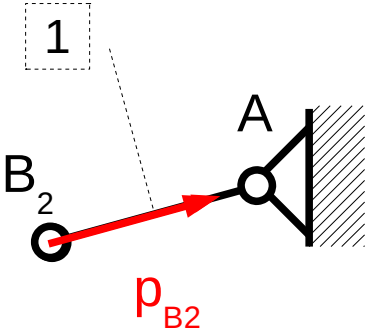
$$|p^c| = 2|\omega_3|\,|V_{B2B3}|\sin(\sphericalangle(\omega_3, V_{B2B3}))$$

Przyspieszenie Coriolisa









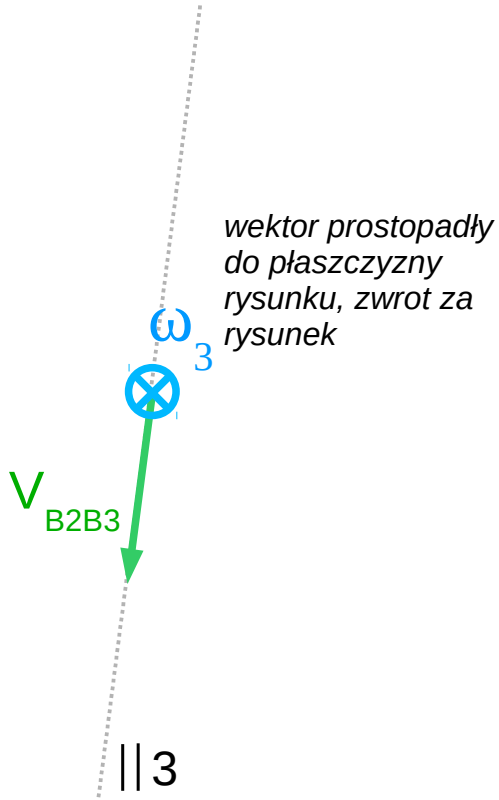
$$p_{B2} = p^u_{B3} + p^w + p^c$$

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

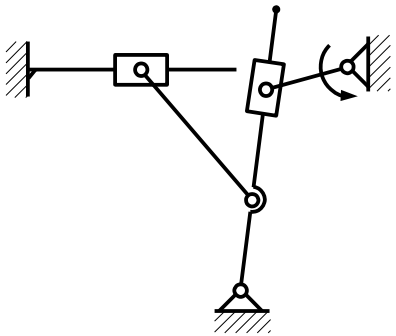
$$\underline{\underline{||1}} \qquad \underline{\underline{||3}} \qquad \underline{\perp 3} \qquad \underline{||3}$$

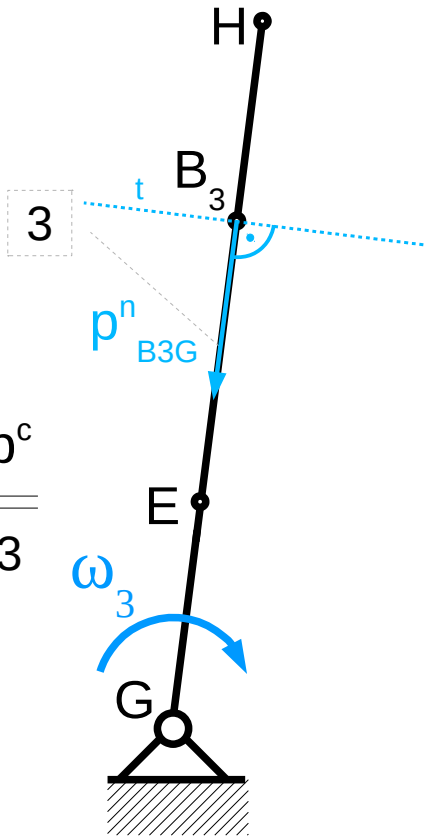
$$p^c = 2\omega_3 \times V_{B2B3}$$

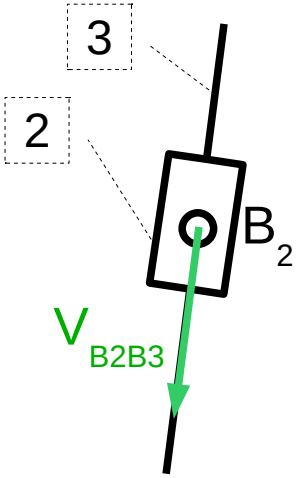
$$|p^c| = 2|\omega_3|\,|V_{B2B3}|\sin(\sphericalangle(\omega_3, V_{B2B3}))$$

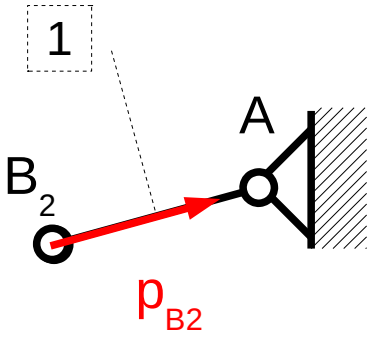


Przyspieszenie Coriolisa









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

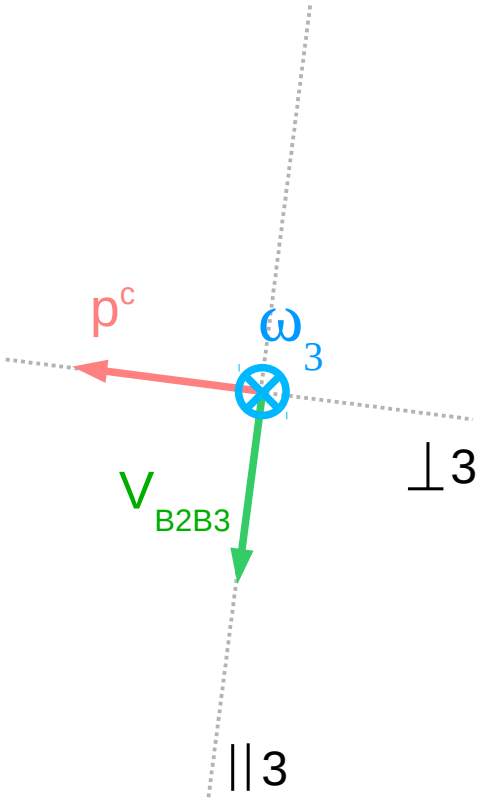
$$\underline{\underline{p^{n}_{B2A}}} = \underline{\underline{p^{n}_{B3G}}} + \underline{p^{t}_{B3G}} + \underline{p^{w}_{B2B3}} + \underline{\underline{p^{c}}}$$

$$\underline{\underline{||1}} \qquad \underline{\underline{||3}} \qquad \underline{\perp 3} \qquad \underline{||3} \qquad \underline{\underline{\perp 3}}$$

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

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

kąt prosty



Plan przyspieszeń

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

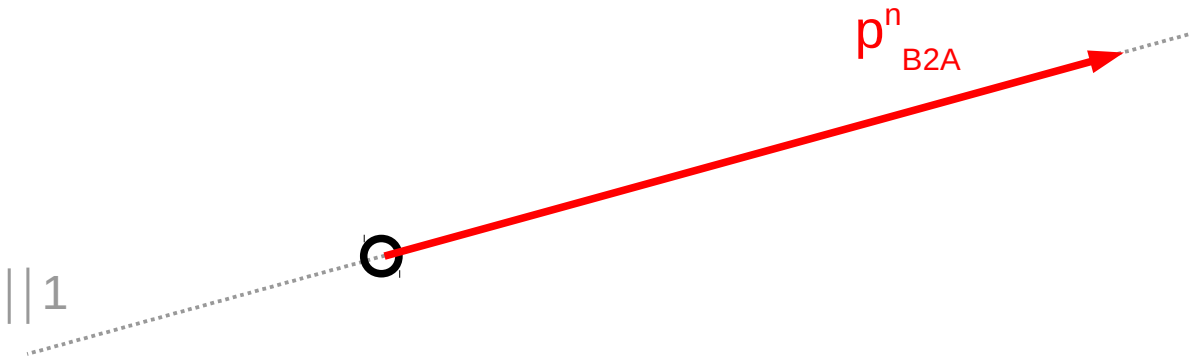
$$\underset{\|1}{\overline{\overline{p^n_{B2A}}}} - \underset{\perp 3}{\overline{\overline{p^c}}} - \underset{\|3}{\overline{p^w_{B2B3}}} = \underset{\|3}{\overline{\overline{p^n_{B3G}}}} + \underset{\perp 3}{\overline{p^t_{B3G}}}$$

Plan przyspieszeń

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

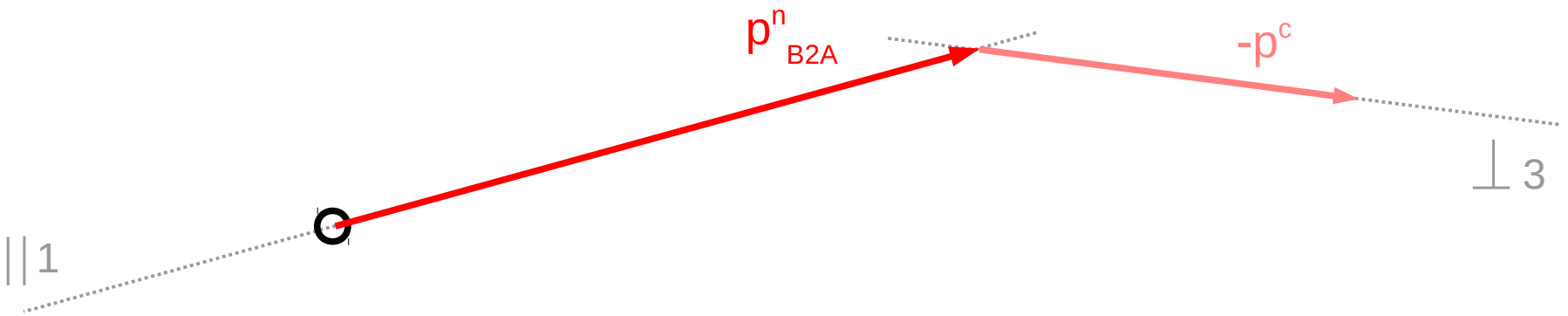
Plan przyspieszeń

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



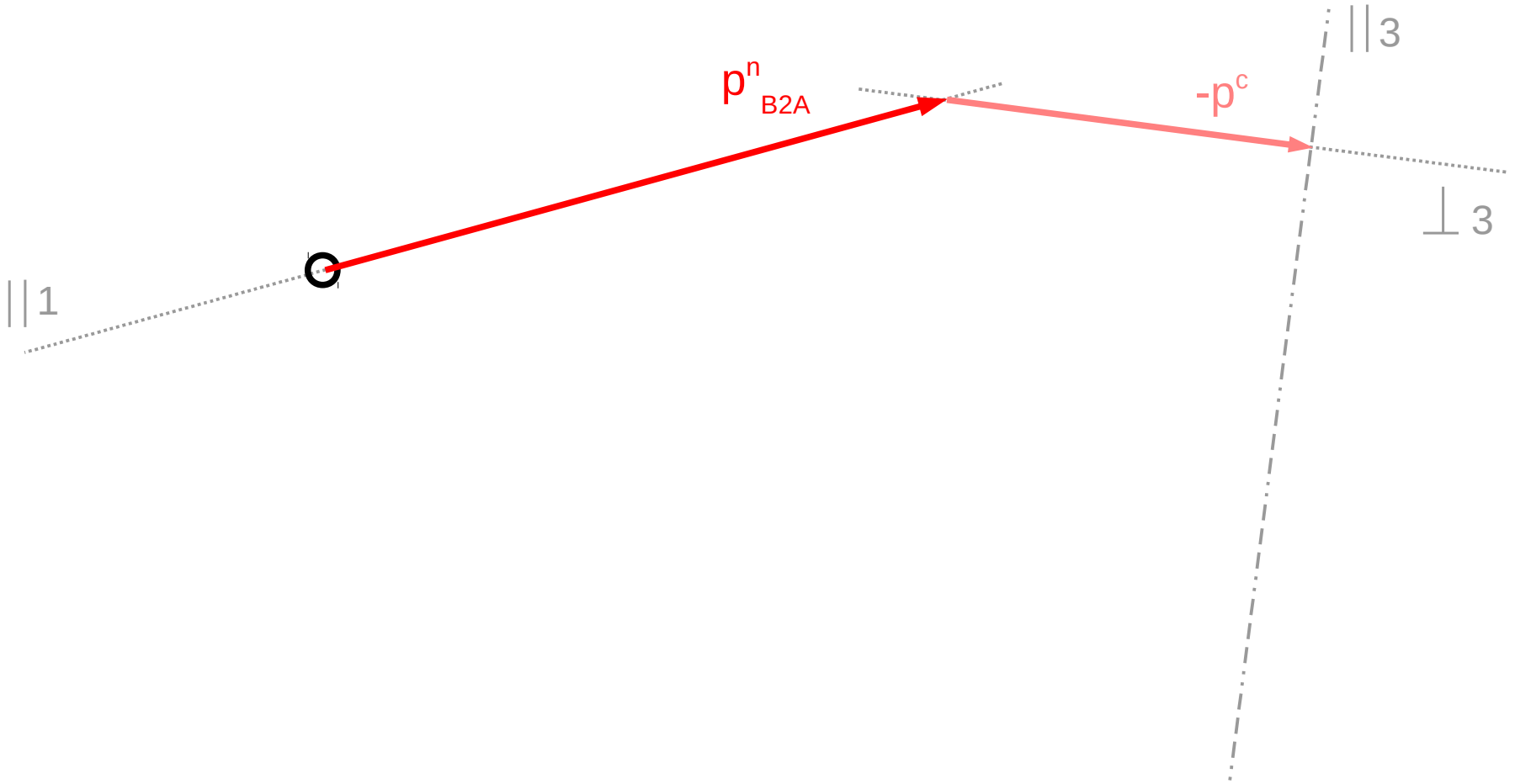
Plan przyspieszeń

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



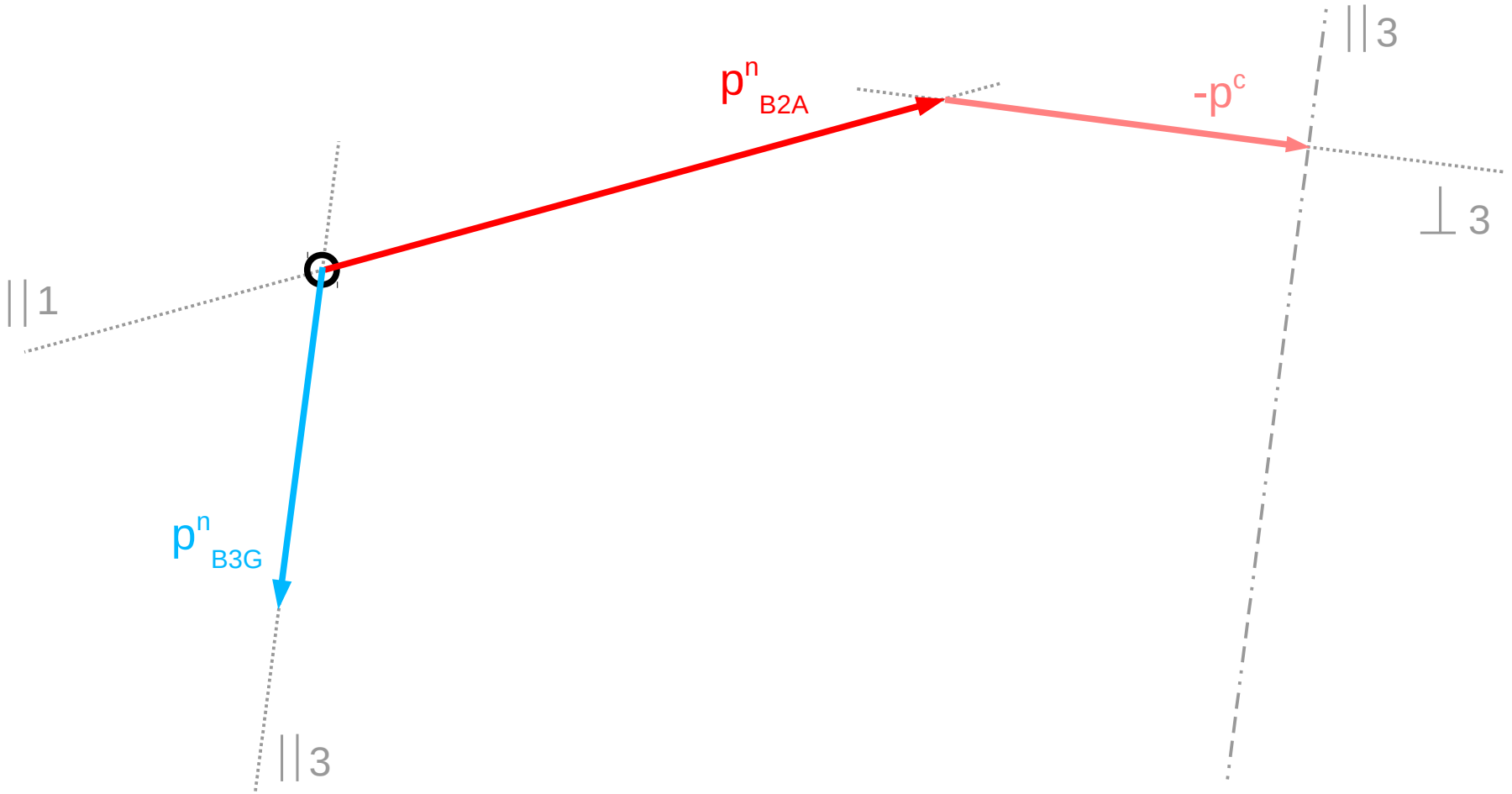
Plan przyspieszeń

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



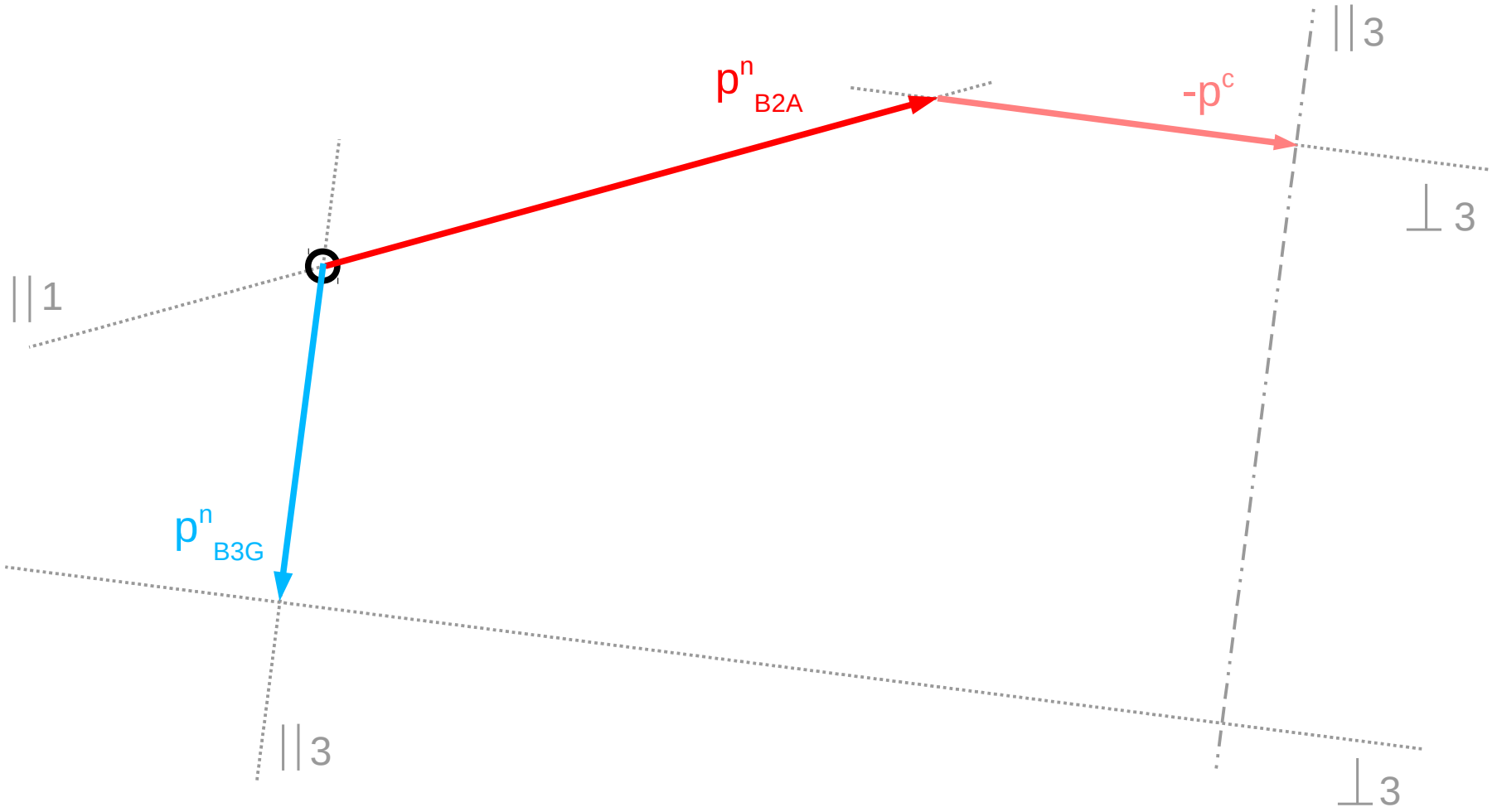
Plan przyspieszeń

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



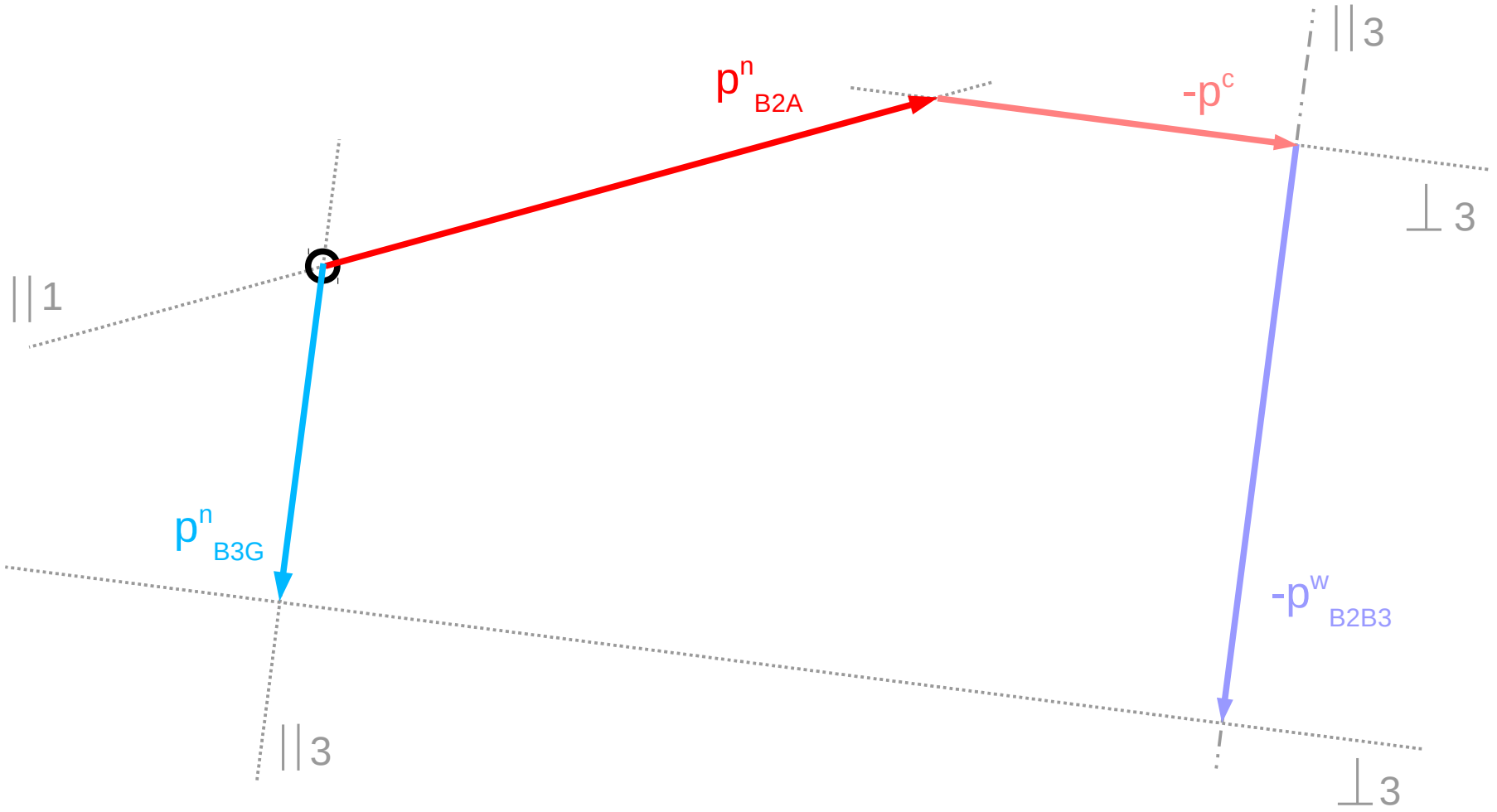
Plan przyspieszeń

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



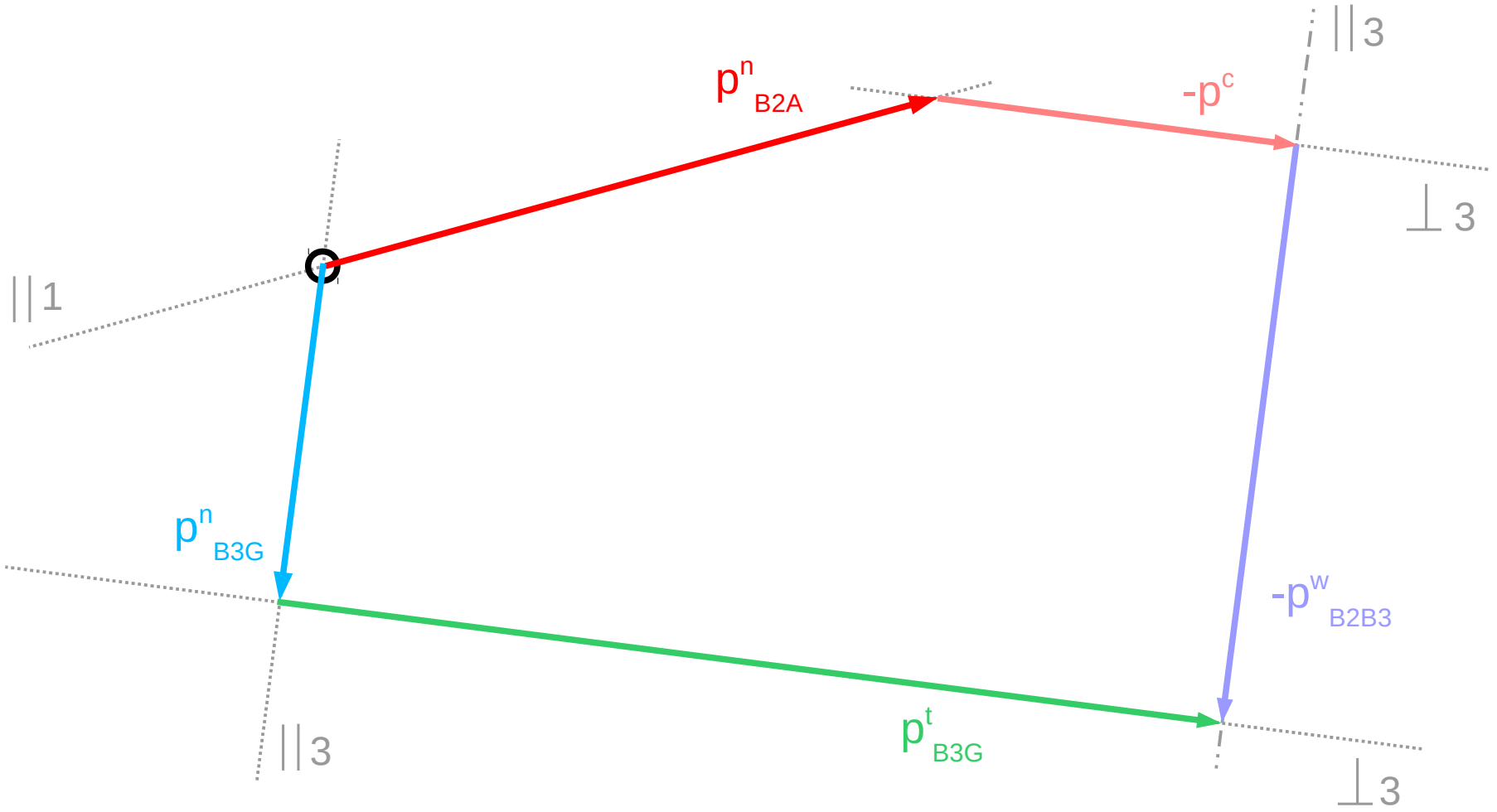
Plan przyspieszeń

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



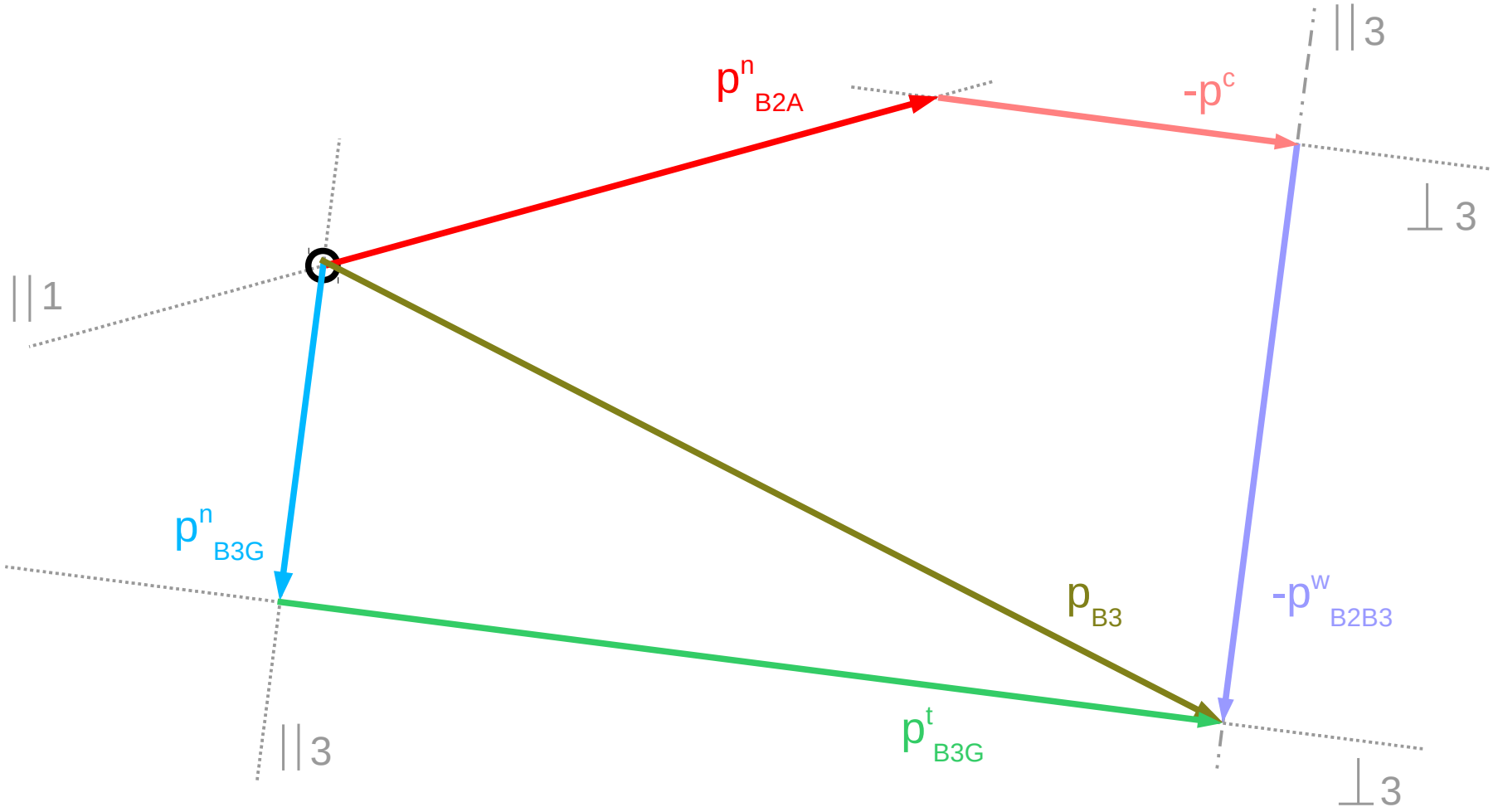
Plan przyspieszeń

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

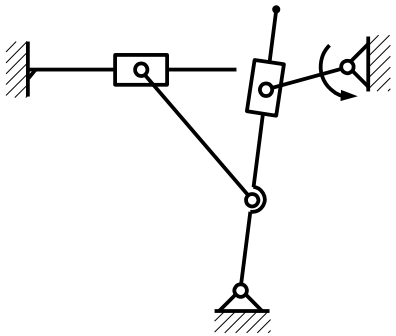


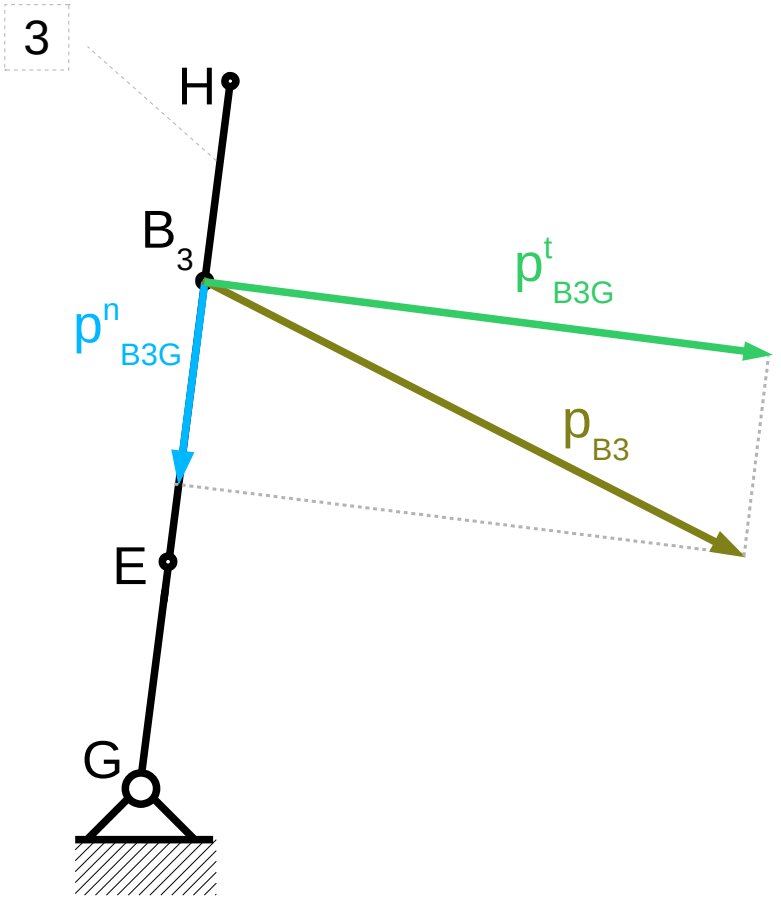
Plan przyspieszeń

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

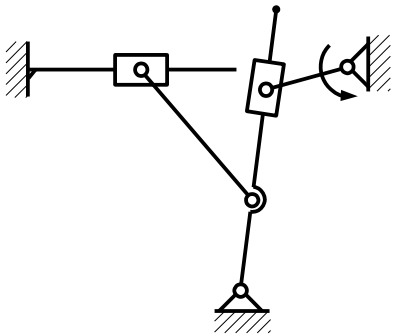


Przyspieszenia dla elementu 3

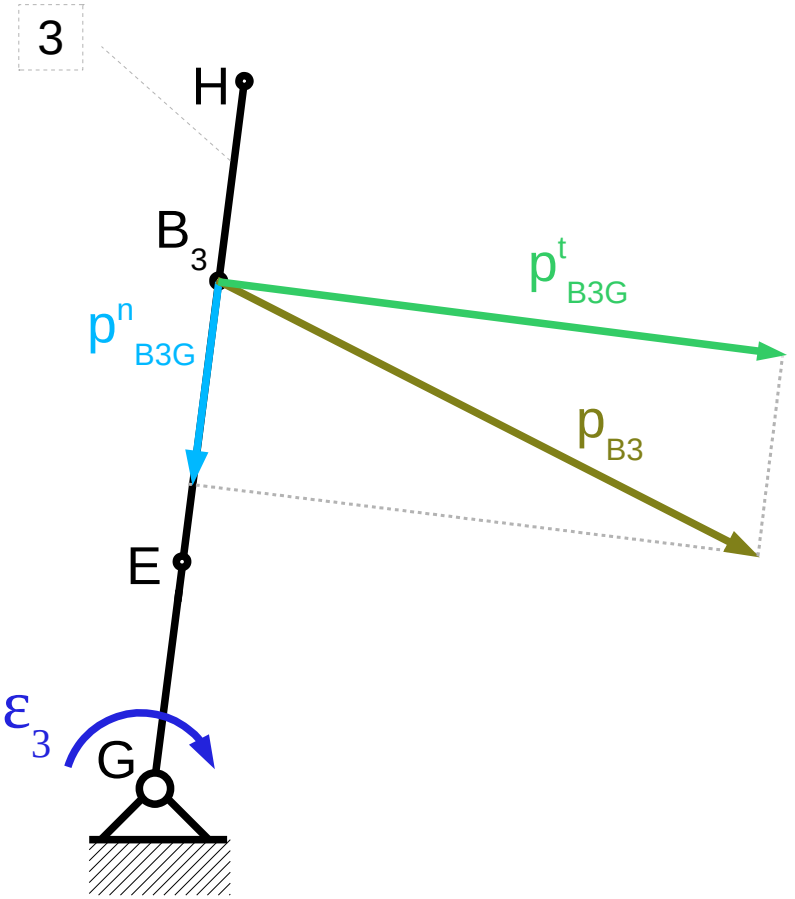




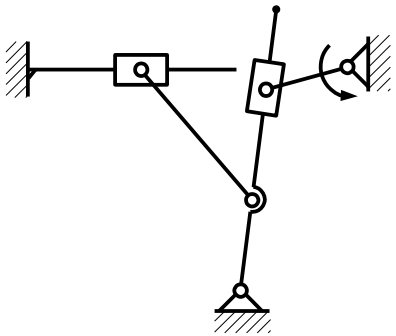
Przyspieszenia dla elementu 3



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



Przyspieszenia dla punktu E

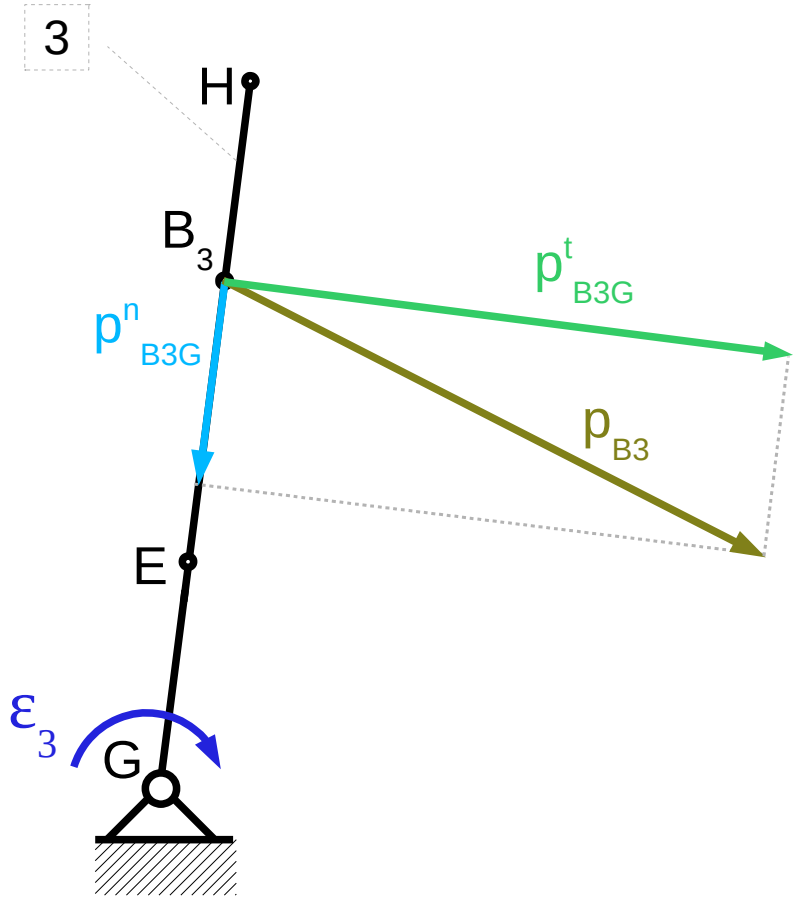


$$\varepsilon_3 = \frac{|p^t_{B3G}|}{|B_3G|}$$

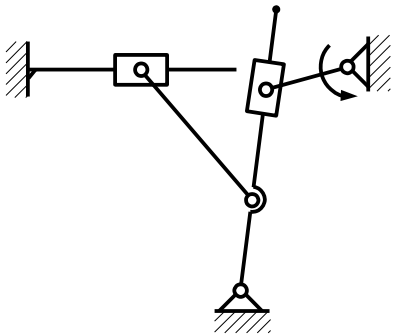
$$p_E = p_G + p^n_{EG} + p^t_{EG}$$

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

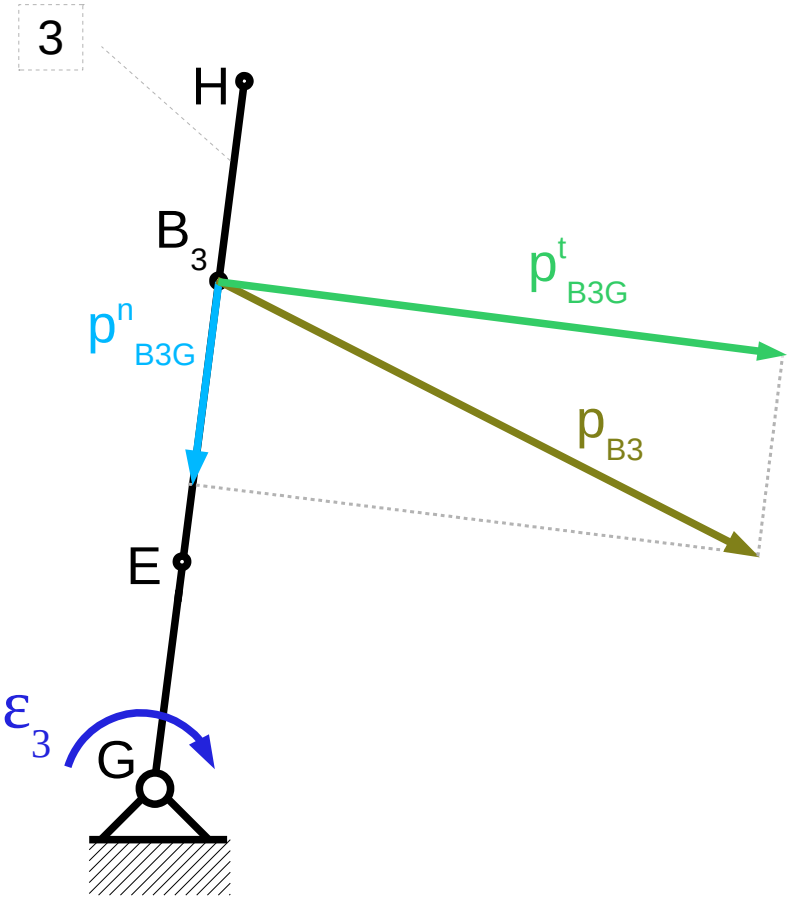
$$|p^t_{EG}| = \varepsilon_3\,|EG|$$



Przyspieszenia dla punktu E



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



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

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

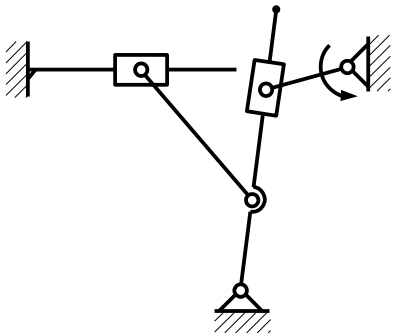
$$|p^t_{EG}| = \varepsilon_3\,|EG|$$

podstawiamy zależności

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

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

Przyspieszenia dla punktu E



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

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

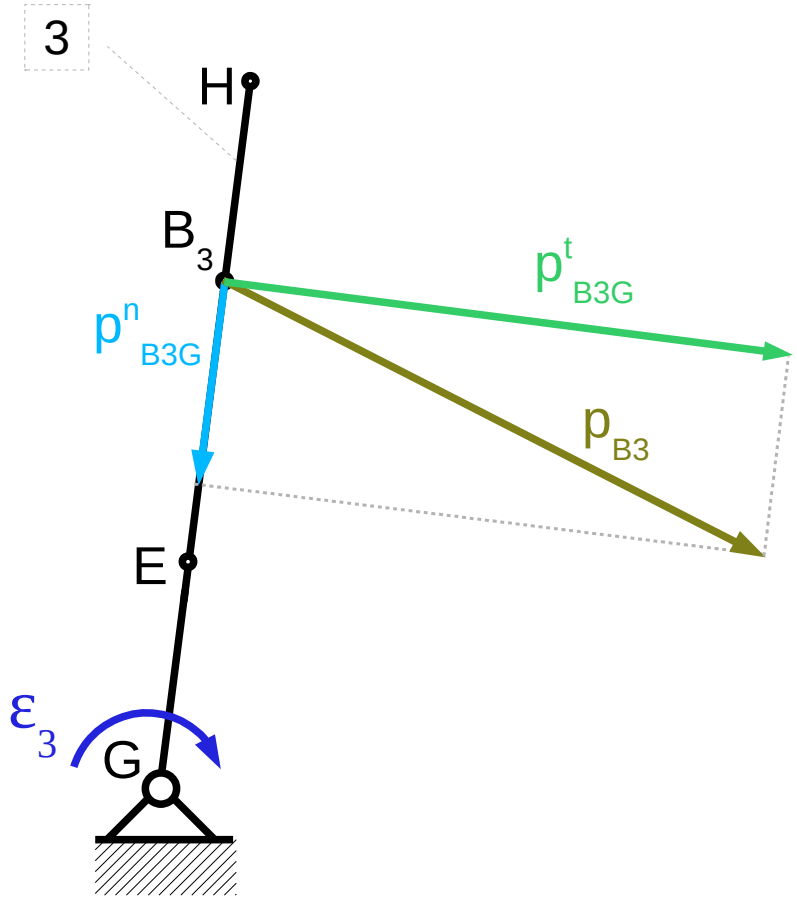
$$|p^n_{EG}| = \omega_3^{\,2}\,|EG| = |p^n_{B3G}|\,\frac{|EG|}{|B_3G|}$$

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

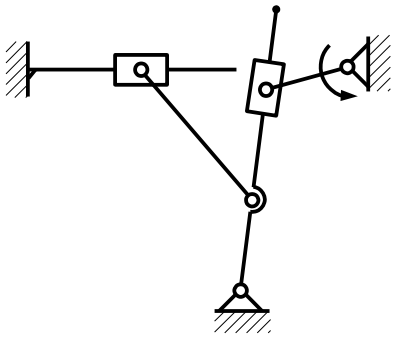
podstawiamy zależności

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

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



Przyspieszenia dla punktu E



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

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

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

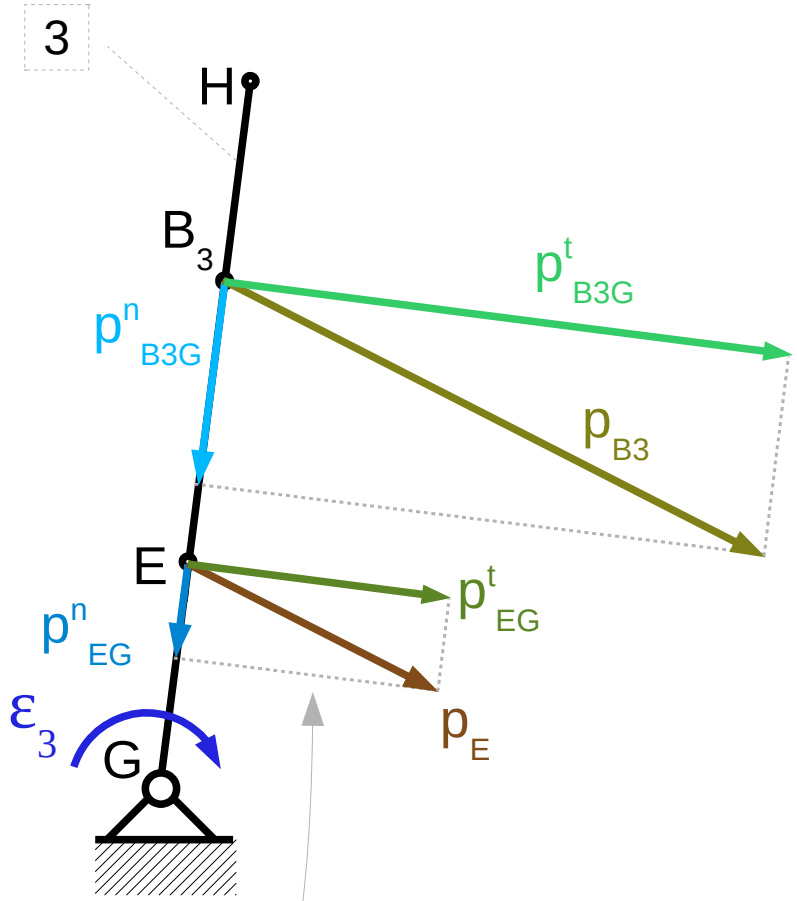
$$|p^t_{EG}| = \varepsilon_3\,|EG| = |p^t_{B3G}|\,\frac{|EG|}{|B_3G|}$$

podstawiamy zależności

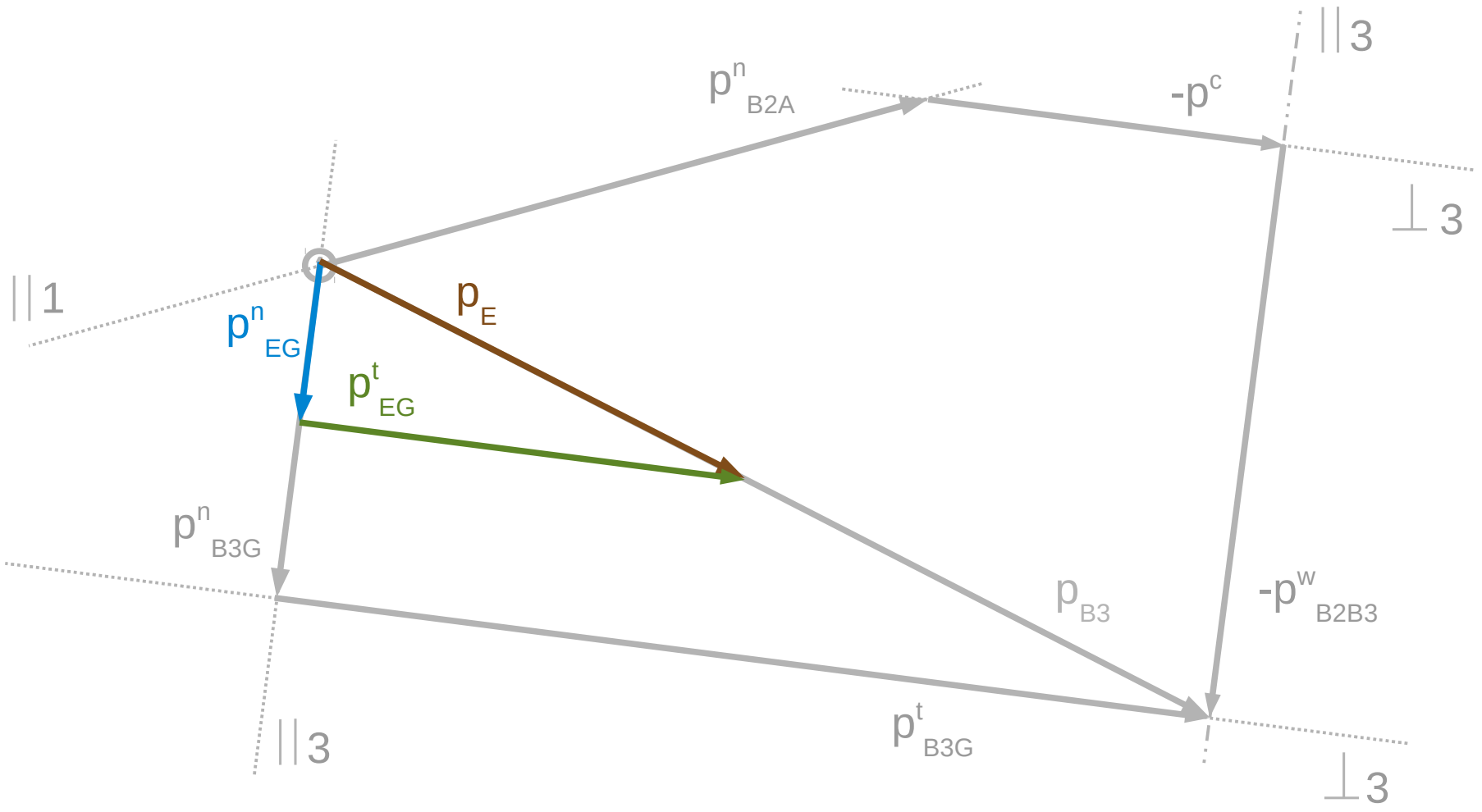
$$|p^n_{B3G}| = \omega_3^{\,2}\,|B_3G|$$

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

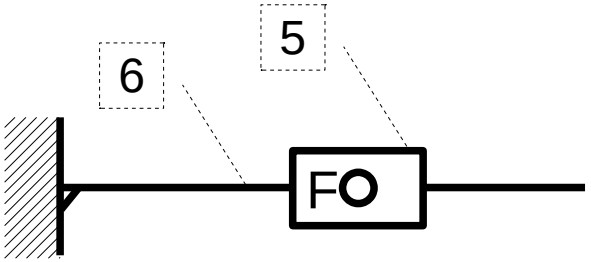
i mamy proporcjonalnie mniejsze przyspieszenia

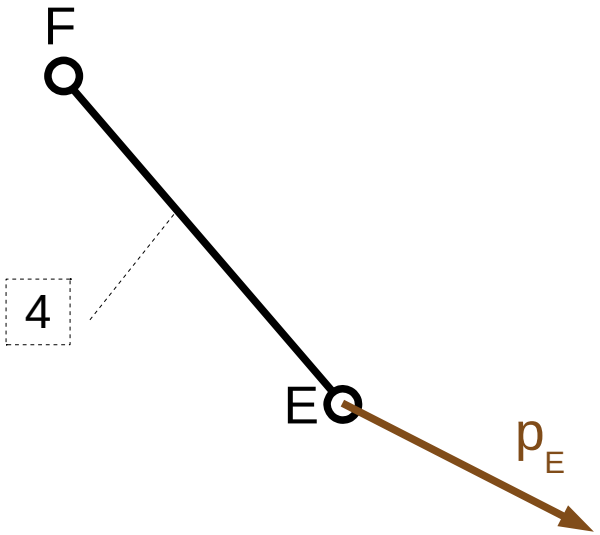


Plan przyspieszeń



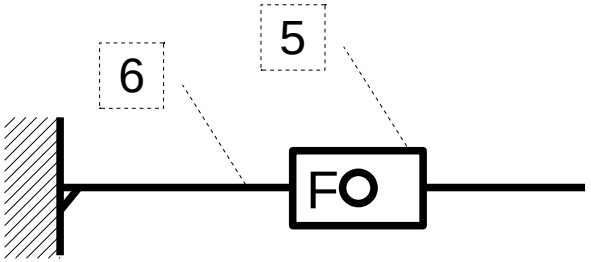
Przyspieszenia punktów elementu 4

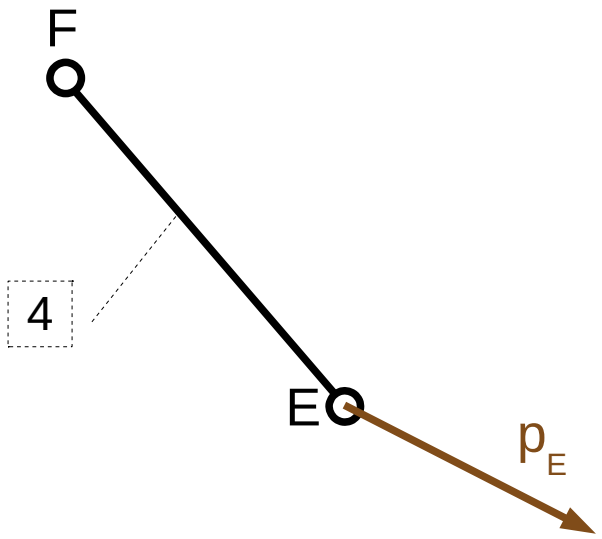




Przyspieszenia punktów elementu 4

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





Przyspieszenia punktów elementu 4

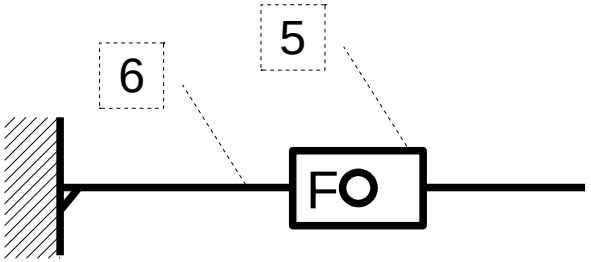
$$\underline{\underline{p_F}} = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} + \underline{p^t_{FE}}$$

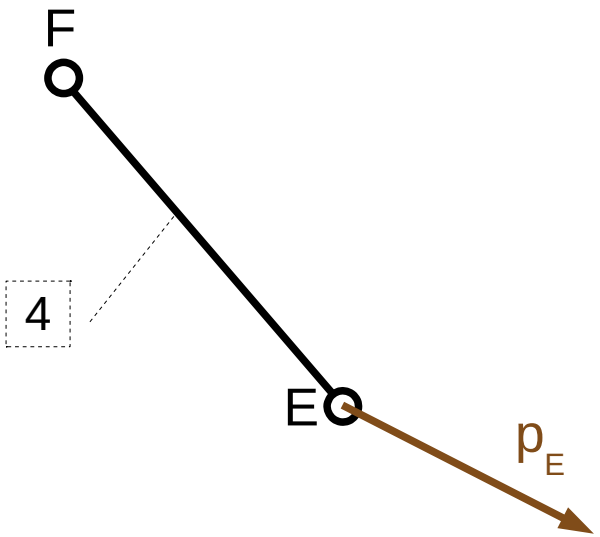
$$\underline{\underline{p_F}} = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} + \underline{p^t_{FE}}$$

$$\underline{\underline{p^n_{FE}}} \;\|\; 4 \qquad \underline{p^t_{FE}} \perp 4$$

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

z planu prędkości





Przyspieszenia punktów elementu 4

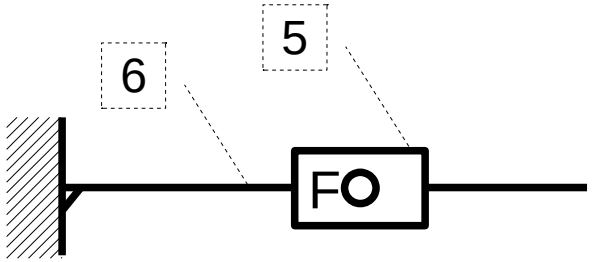
$$\underline{p_F} = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} + \underline{p^t_{FE}}$$

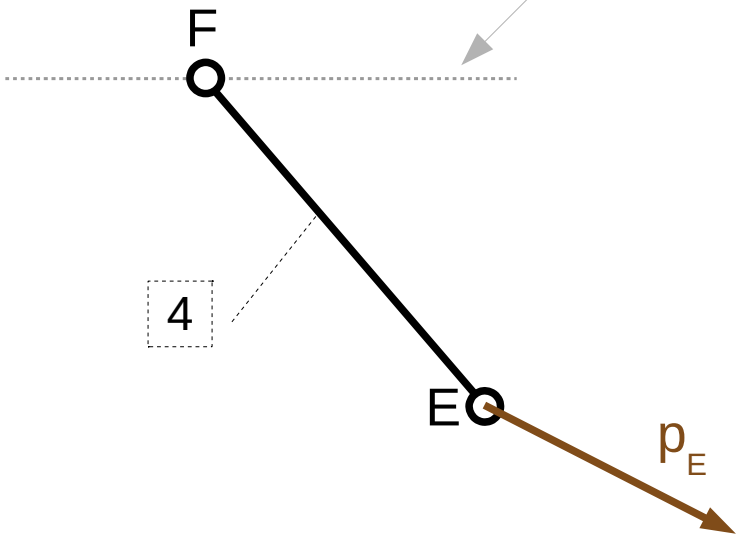
$$\underline{\quad}\ \|6 \qquad \underline{\underline{\quad}}\ \|4 \qquad \underline{\quad}\ \perp 4$$

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

z planu prędkości

punkt F porusza się po nieruchomym elemencie 6 – przyspieszenie jest styczne do toru ruchu

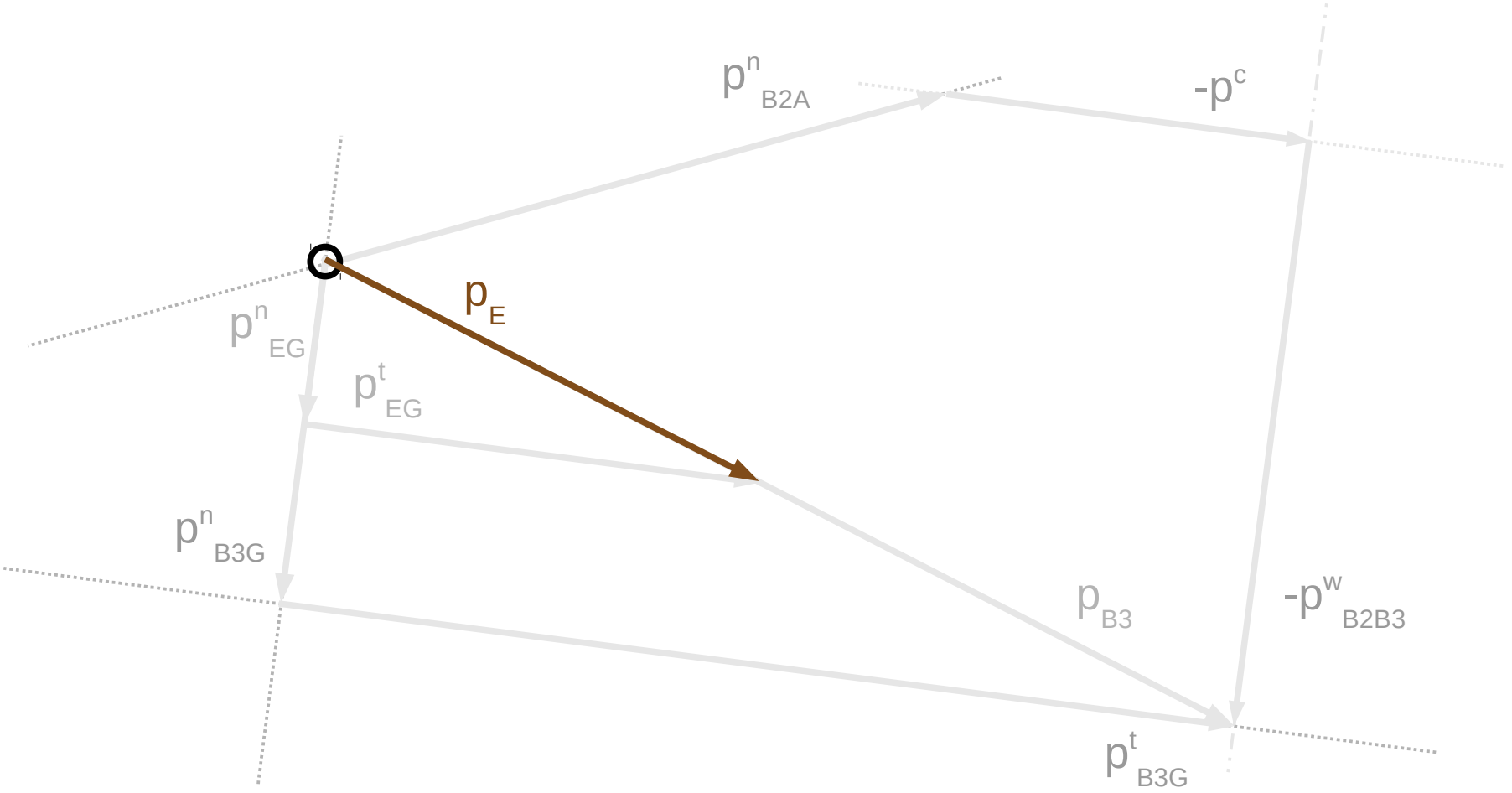




Plan przyspieszeń

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

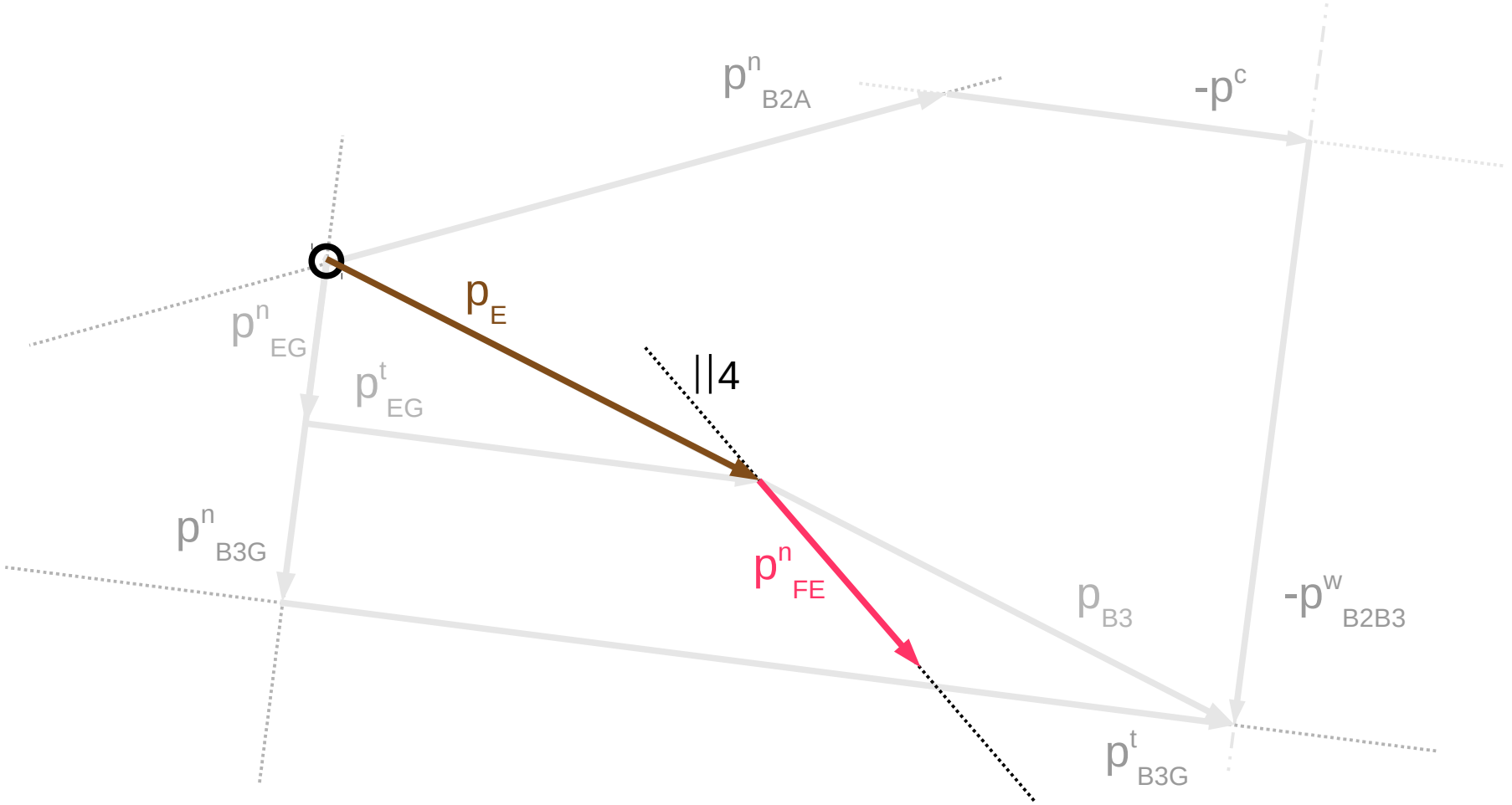
$$\underline{\underline{p_F}} \parallel 6 \qquad \underline{\underline{p_E}} \qquad \underline{\underline{p^n_{FE}}} \parallel 4 \qquad \underline{\underline{p^t_{FE}}} \perp 4$$



Plan przyspieszeń

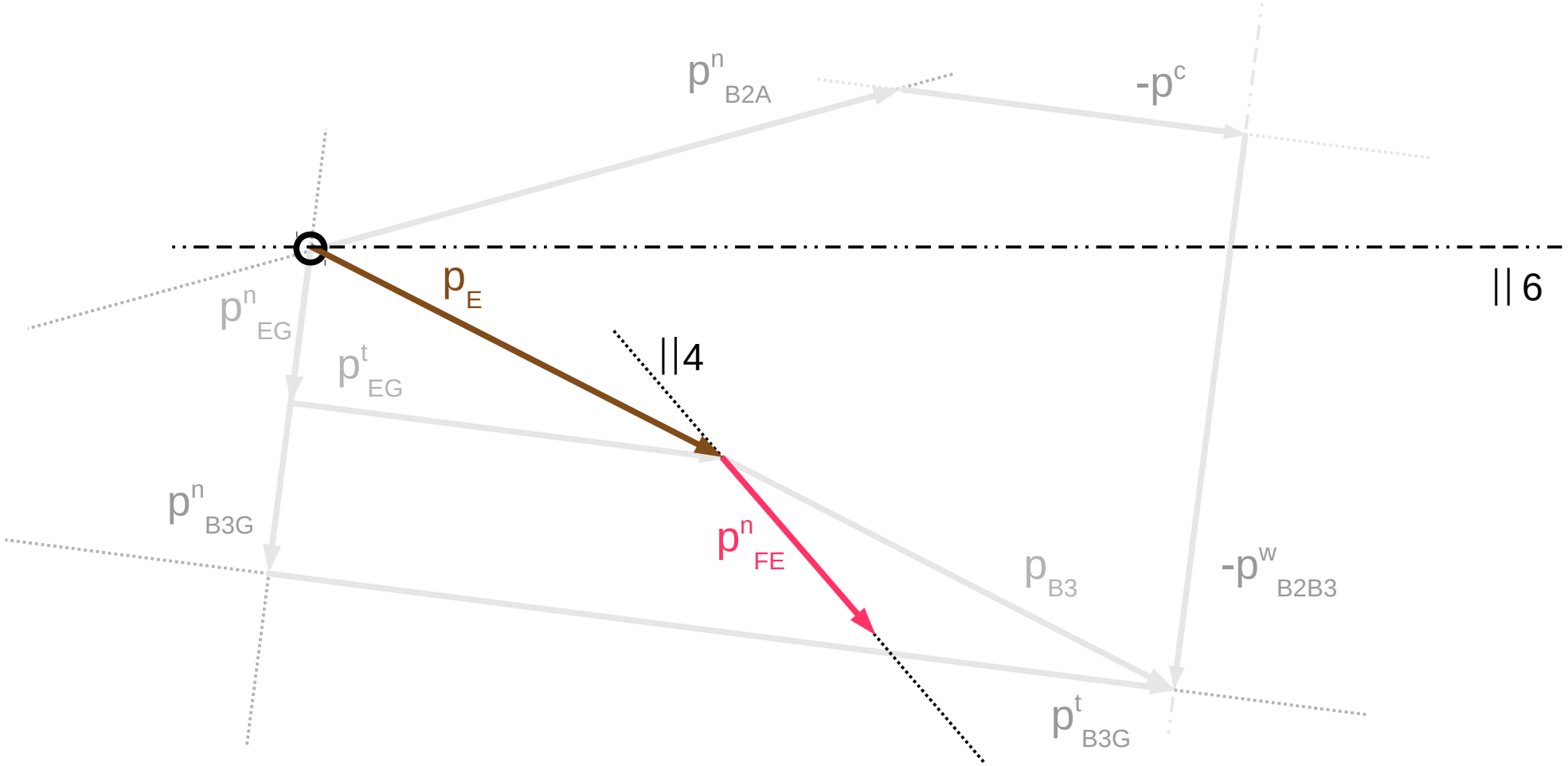
$$\underline{p_F} = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} + \underline{p^t_{FE}}$$

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



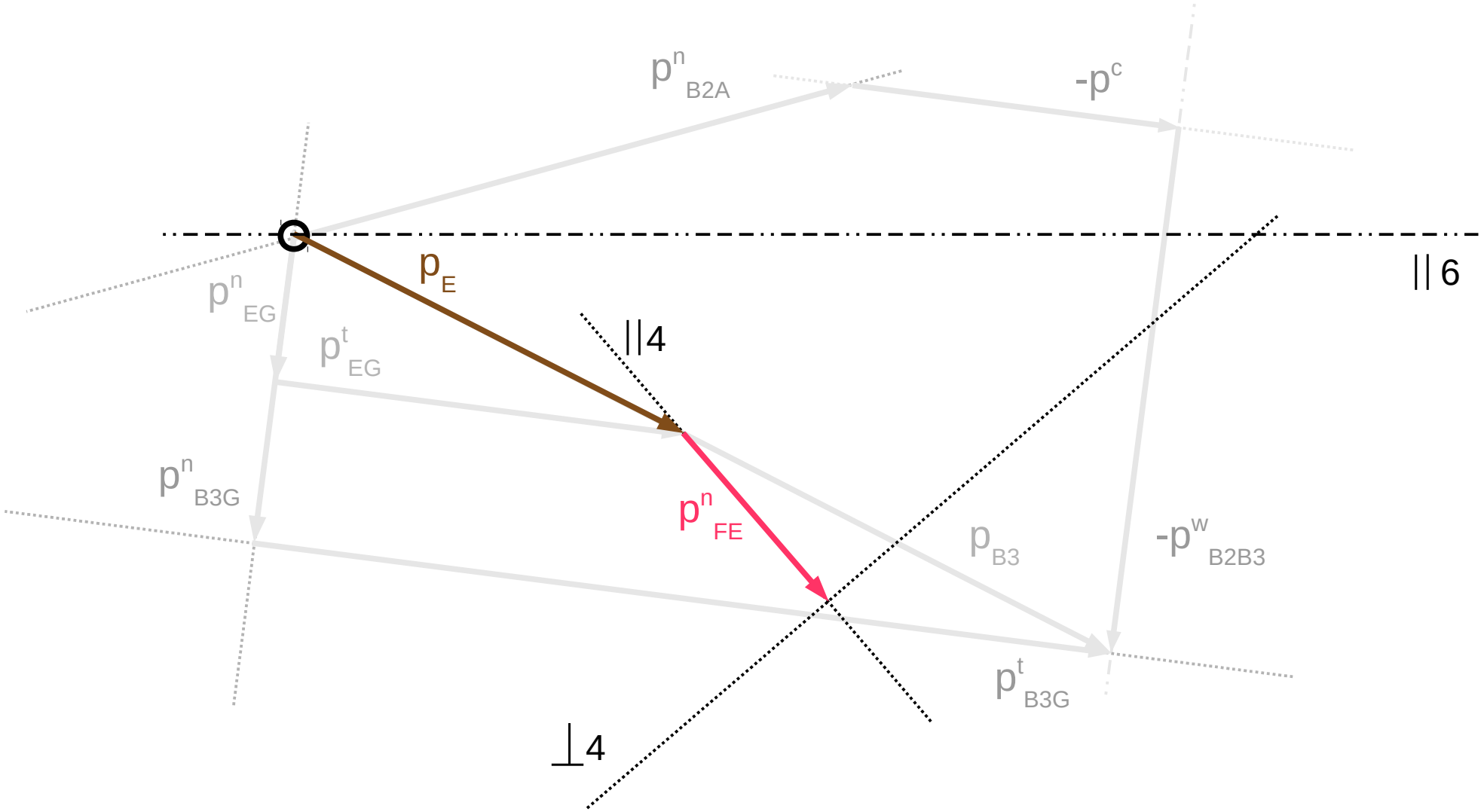
Plan przyspieszeń

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



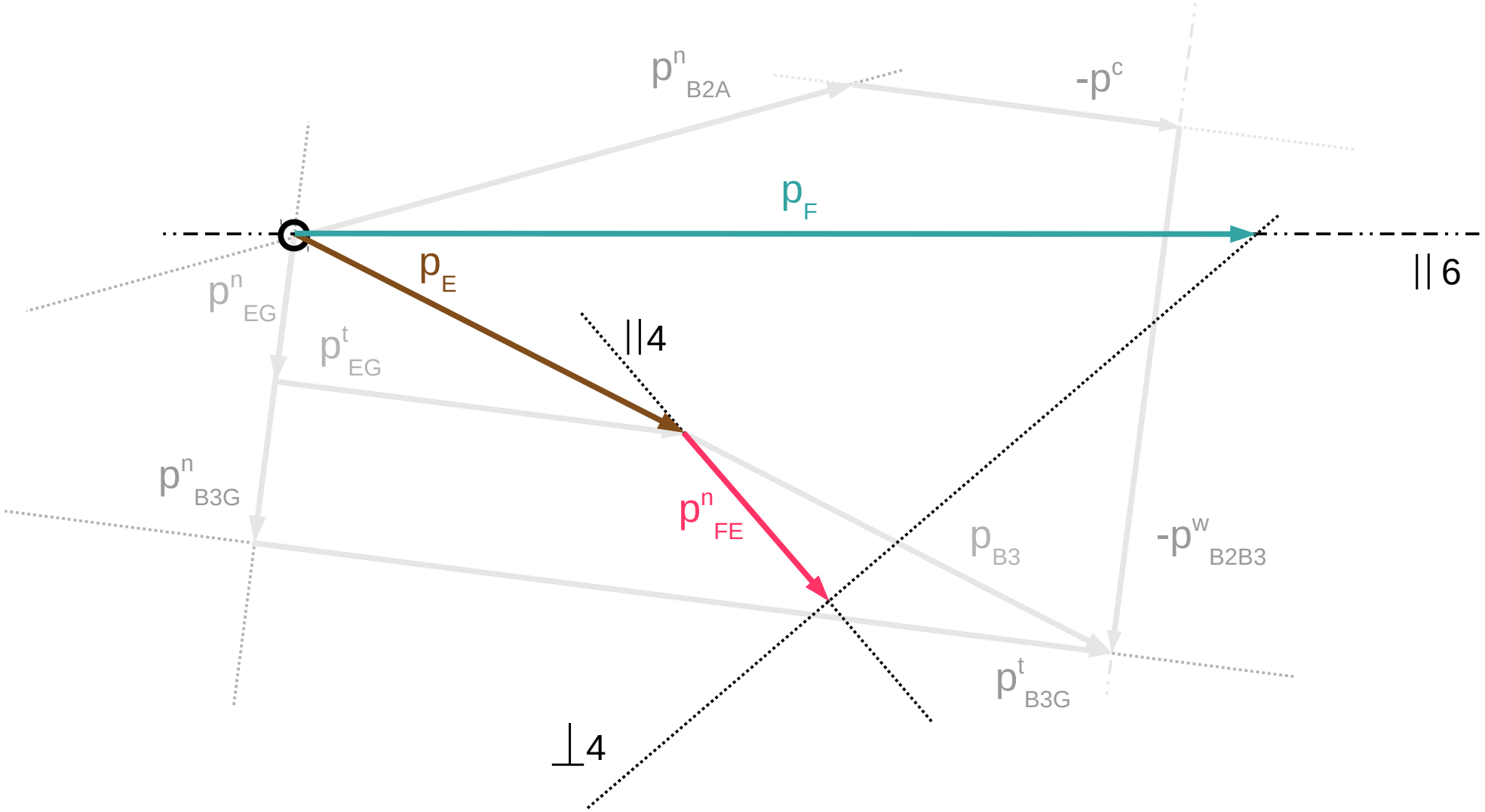
Plan przyspieszeń

$$\underline{p_F} \;(\,||\,6) = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} \;(\,||\,4) + \underline{p^t_{FE}} \;(\perp 4)$$



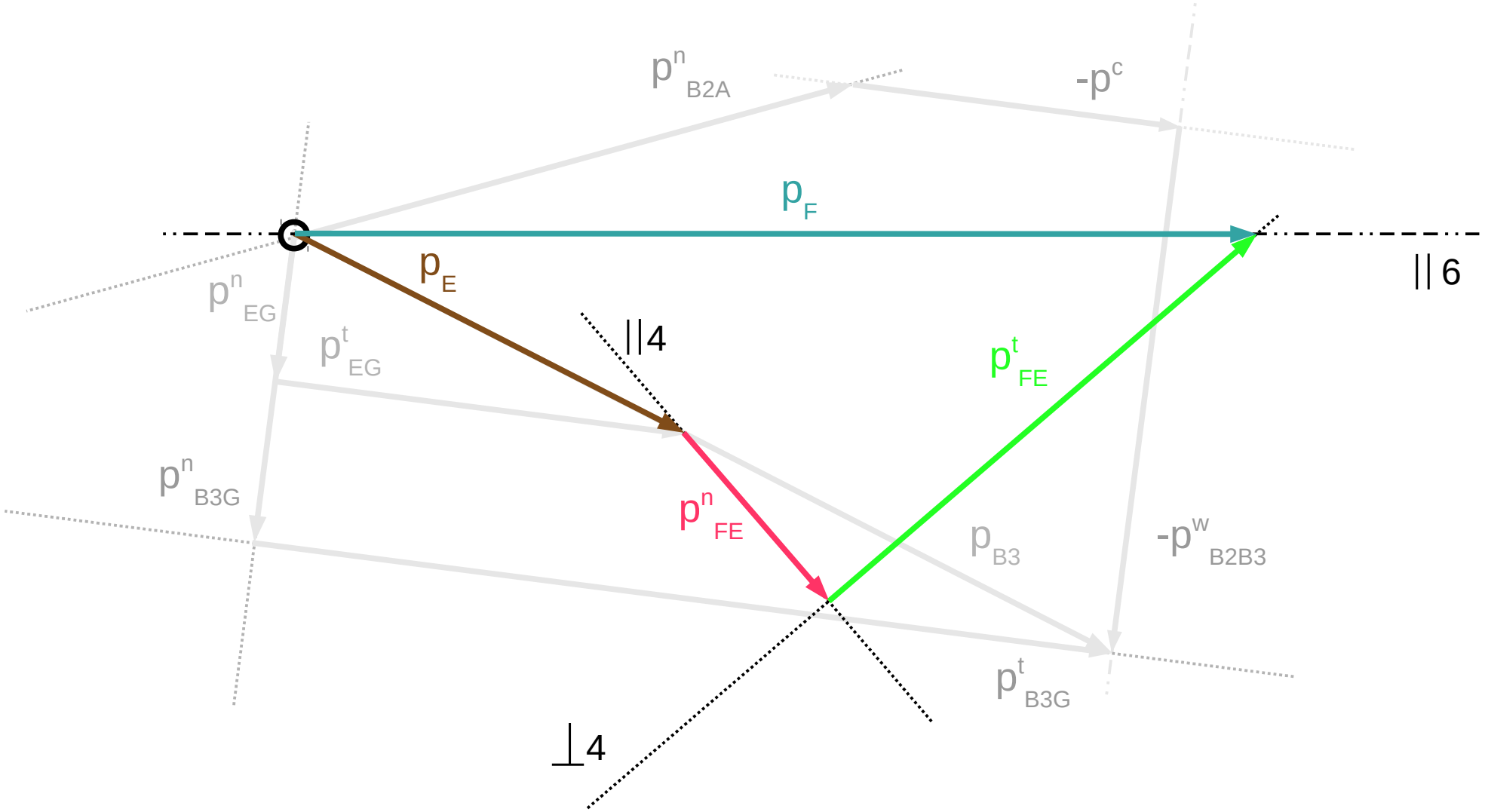
Plan przyspieszeń

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

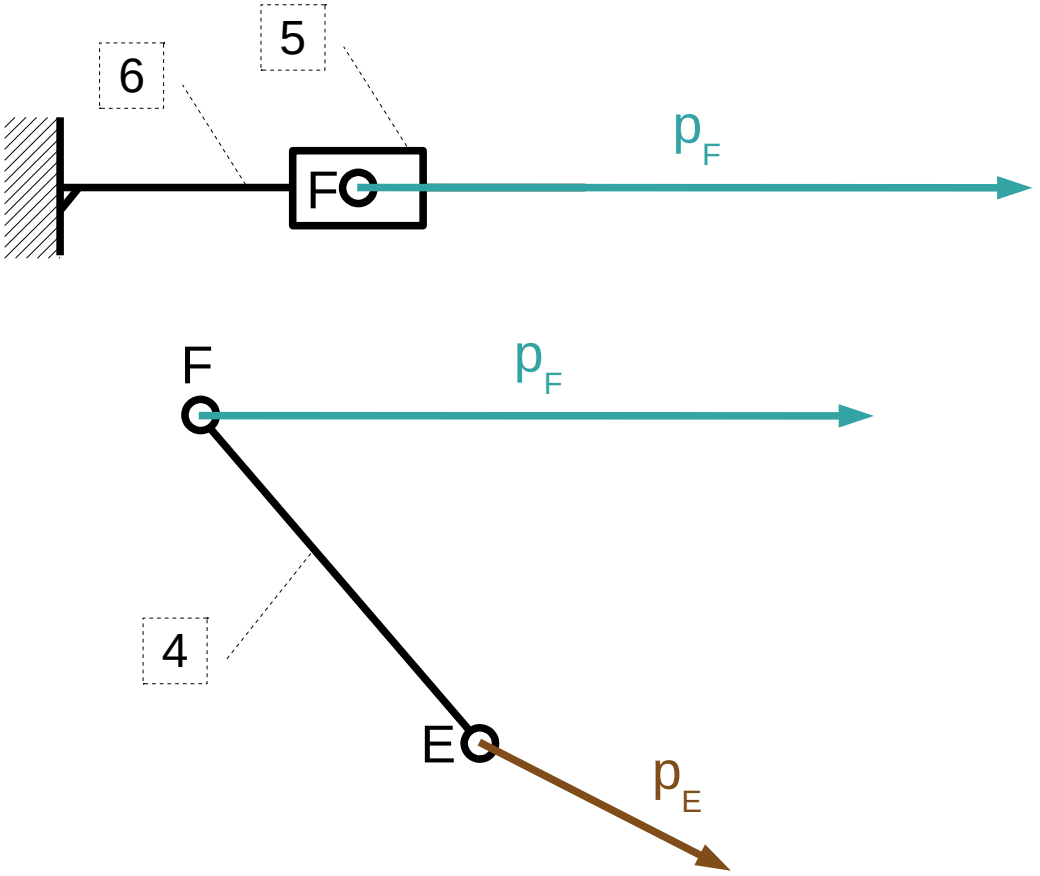


Plan przyspieszeń

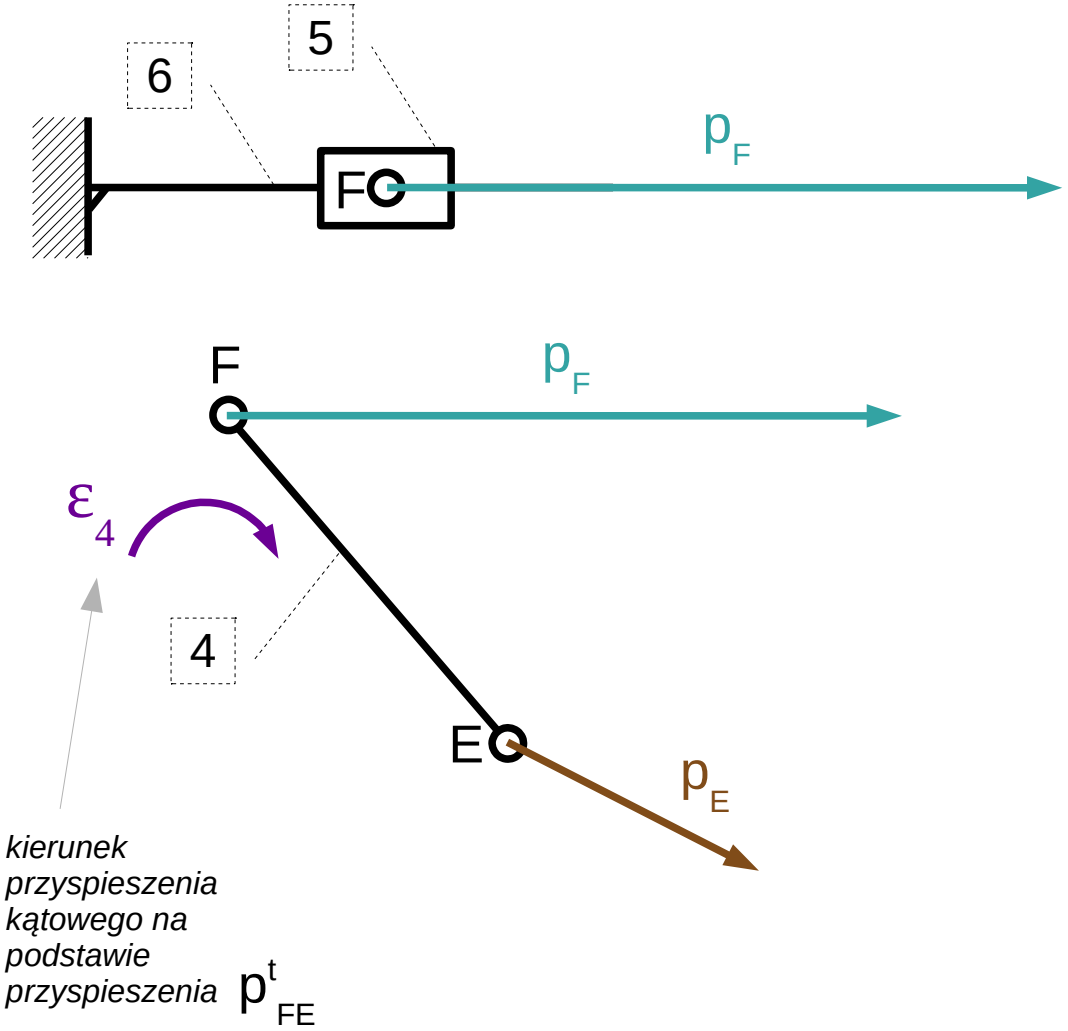
$$\underline{p_F} \;(\parallel 6) = \underline{\underline{p_E}} + \underline{\underline{p^n_{FE}}} \;(\parallel 4) + \underline{p^t_{FE}} \;(\perp 4)$$



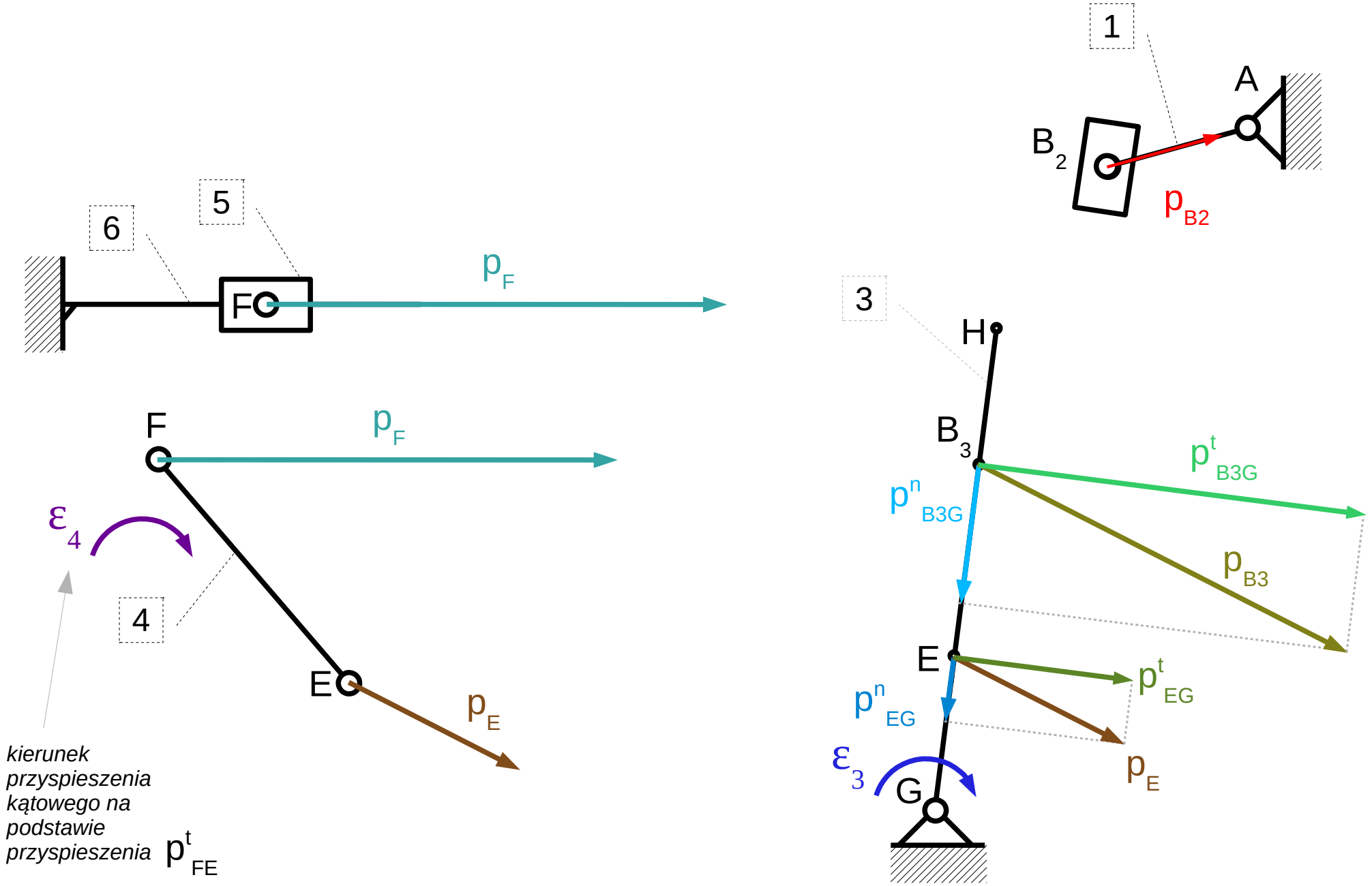
Przyspieszenia punktów elementu 4



Przyspieszenia punktów elementu 4



Przyspieszenia w całym mechanizmie



Wybrane przyspieszenia w mechanizmie