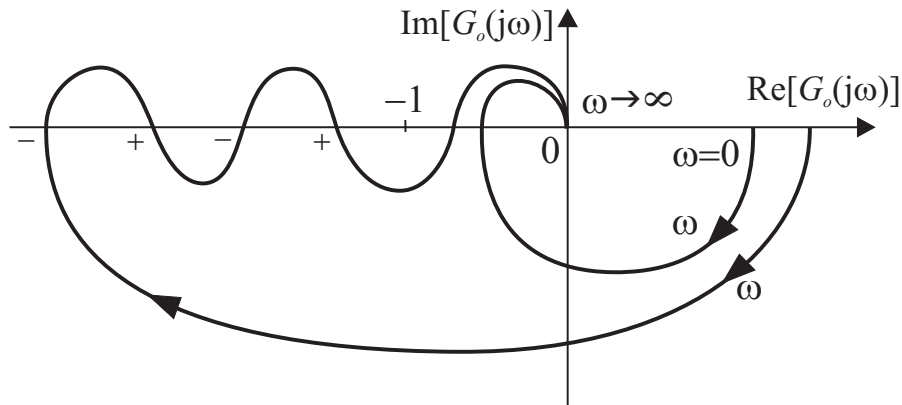


7. Kryterium Nyquista – c.d.

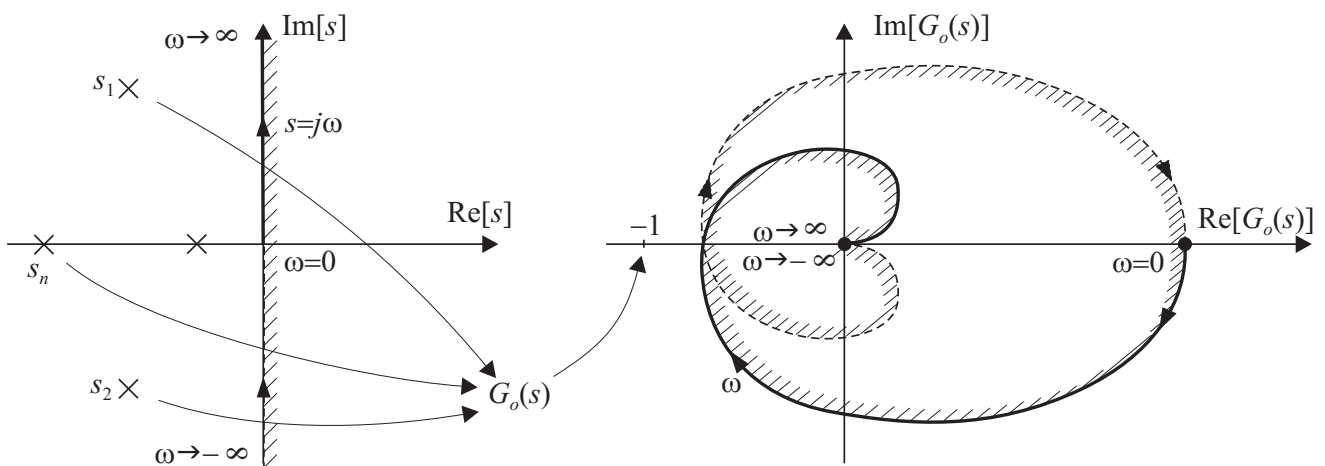
$\Delta\varphi = +2\pi$ między dwoma sąsiedn. przecięciami dodatnimi,
 $\Delta\varphi = -2\pi$ między dwoma sąsiedn. przecięciami ujemnymi,
 $\Delta\varphi = 0$ między sąsiedn. przecięciami dodatnim i ujemnym



Rys. 24. Układy stabilne po zamknięciu również stabilne

8. Odwzorowanie płaszczyzny zespolonej s na płaszczyznę zespoloną $G_o(s)$

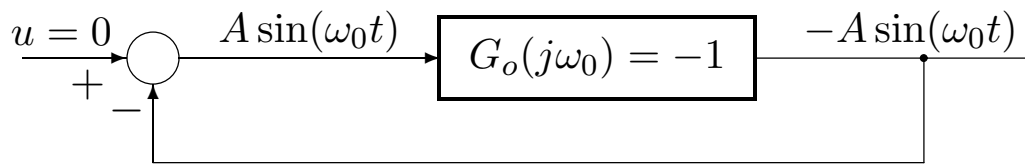
r. char. $M_z(s) = 0$ jest równoważne $1 + G_o(s) = 0$, tzn. $G_o(s) = -1$



Rys. 25.

bieguny transm. ukł. zamkniętego s_1, s_2, \dots, s_n (pierwiastki równ. char. $M_z(s) = L_o(s) + M_o(s) = 0$) $\rightarrow G_o(s) = -1$

9. Kryterium Nyquista – podejście częstotliwościowe



Rys. 26.

10. Kryterium Nyquista dla układu otwartego na granicy stabilności

$$G_o(s) = k_o \frac{(s - \sigma_1)(s - \sigma_2) \dots (s - \sigma_m)}{s(s - s_1)(s - s_2) \dots (s - s_{n-1})} \tag{31}$$

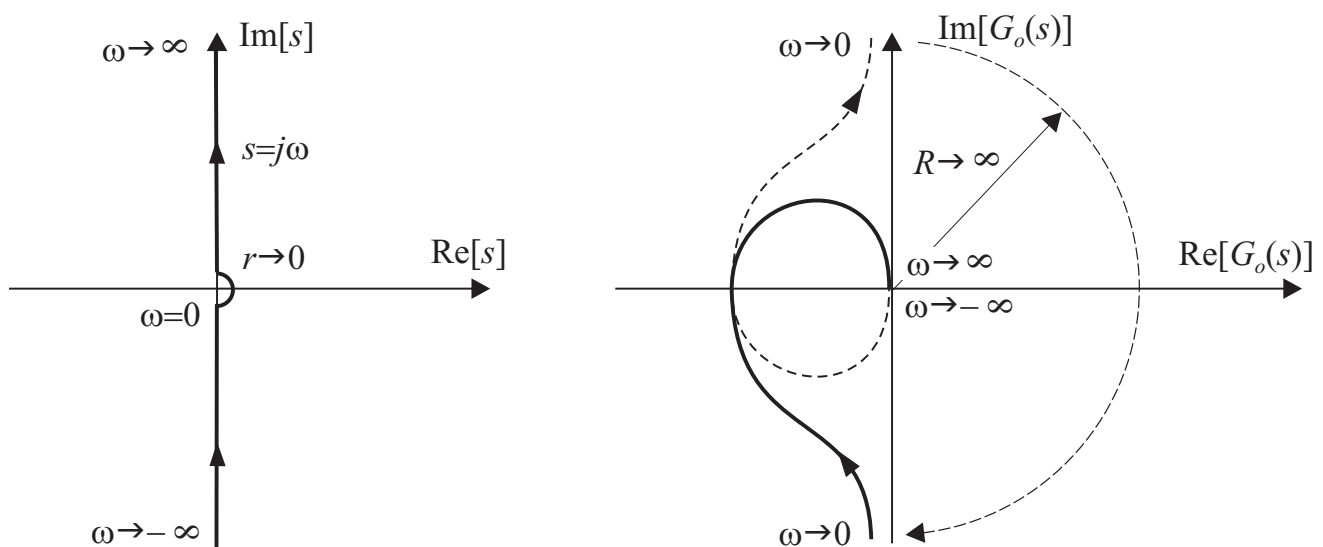
$m \leq n, \text{Re}(s_i) < 0, i = 1, 2, \dots, n - 1$ oraz $\sigma_j \neq 0, j = 1, 2, \dots, m$

$$s = r e^{j\varphi}, \quad \varphi : -\frac{\pi}{2} \rightarrow \frac{\pi}{2}, \quad r \rightarrow 0, r > 0 \tag{32}$$

$$s \rightarrow 0 \Rightarrow G_o(s) \rightarrow \frac{B_o}{s}, \quad B_o = k_o \left(\prod_{j=1}^m (-\sigma_j) \right) / \left(\prod_{i=1}^{n-1} (-s_i) \right)$$

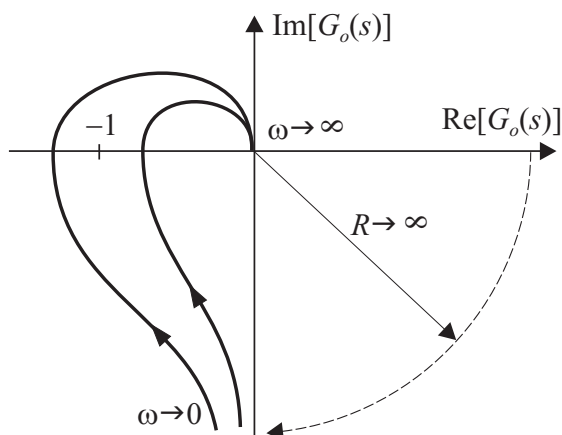
wtedy

$$G_o(s) \approx \frac{B_o}{s} = \frac{B_o}{r e^{j\varphi}} = R e^{-j\varphi}, \quad R \rightarrow \infty, \quad -\varphi : \frac{\pi}{2} \rightarrow -\frac{\pi}{2} \tag{33}$$

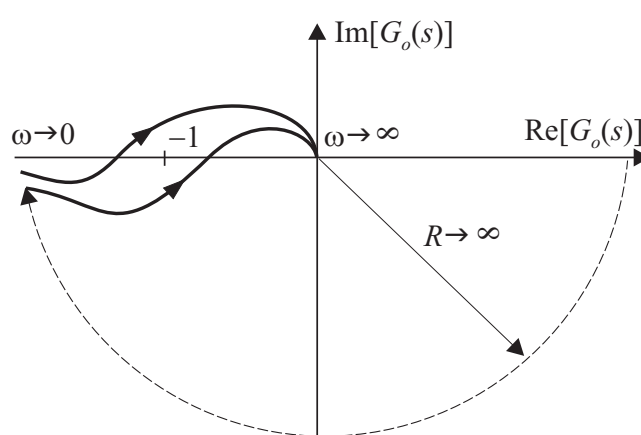


Rys. 27.

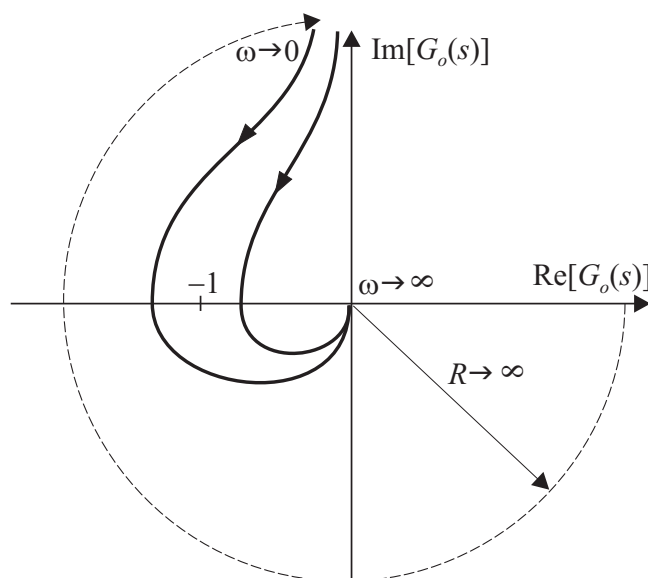
$$G_o(s) = \frac{L(s)}{s^\nu M_1(s)} \tag{34}$$



(a) $\nu = 1$



(b) $\nu = 2$



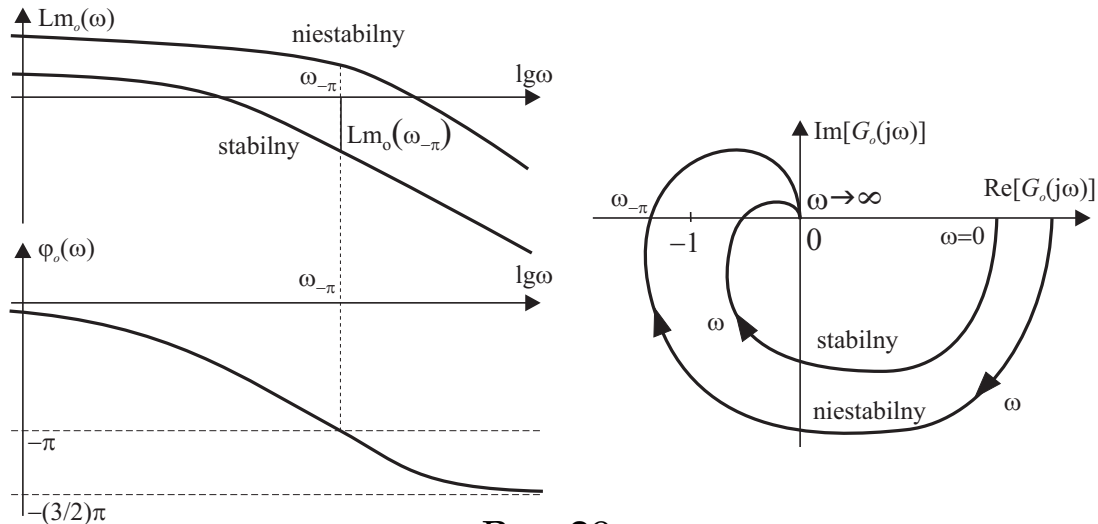
(c) $\nu = 3$

Rys. 28.

11. Logarymiczne kryterium Nyquista

$$Lm_o(\omega) = 20 \lg |G_o(j\omega)|, \quad \varphi_o(\omega) = \arg(G_o(j\omega))$$

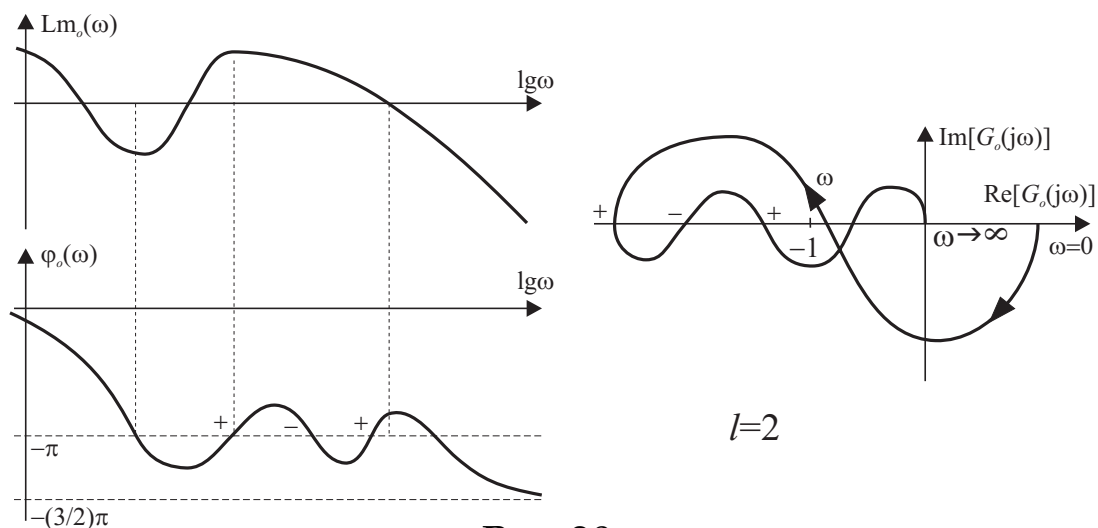
a) układ otwarty stabilny asymptotycznie



Rys. 29.

$$\begin{aligned} Lm_o(\omega_{-\pi}) < 0 &\Leftrightarrow 0 < |G_o(j\omega_{-\pi})| < 1 \\ Lm_o(\omega_{-\pi}) = 0 &\Leftrightarrow |G_o(j\omega_{-\pi})| = 1 \\ Lm_o(\omega_{-\pi}) > 0 &\Leftrightarrow |G_o(j\omega_{-\pi})| > 1 \end{aligned} \tag{35}$$

b) układ otwarty niestabilny (*l* biegunów w prawej półpł.)



Rys. 30.

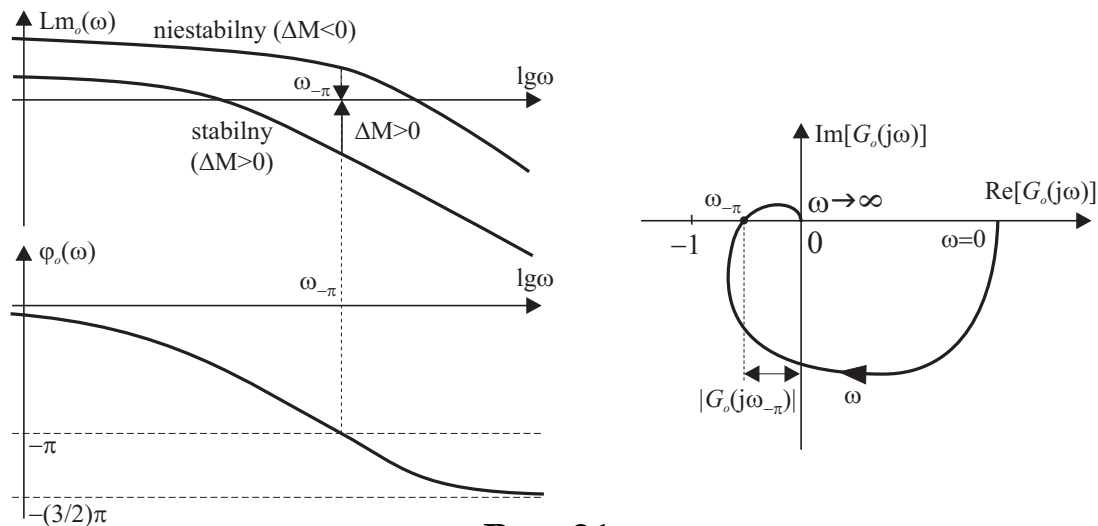
na lewo od $(-1, j0) \rightarrow Lm_o(j\omega) > 0$

12. Zapasy stabilności

Zapas modułu

liniowy: $\lambda = \frac{1}{|G_o(j\omega_{-\pi})|}$ (36)

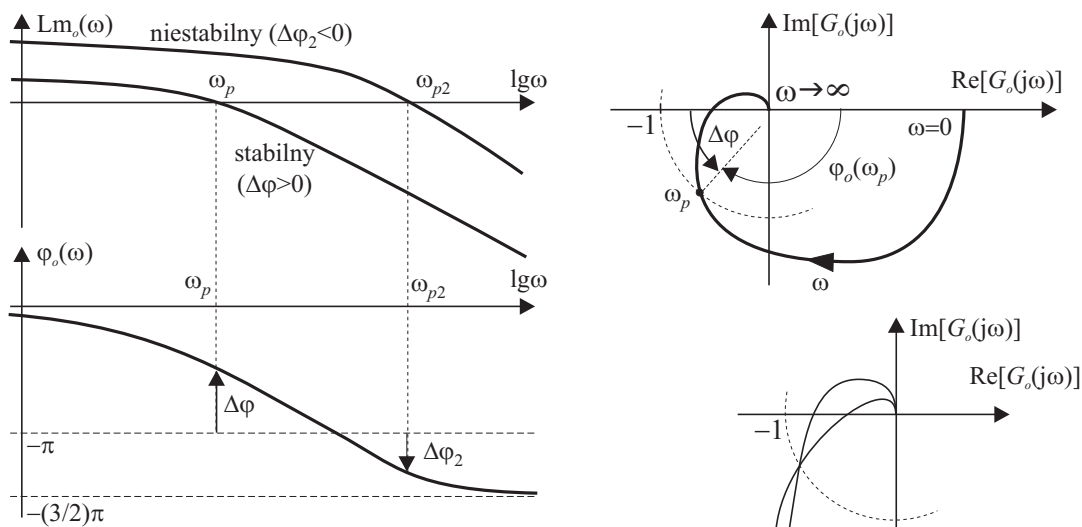
logarytmiczny: $\Delta M = 20 \lg \lambda = -20 \lg |G_o(j\omega_{-\pi})|$ (37)



Rys. 31.

Zapas fazy

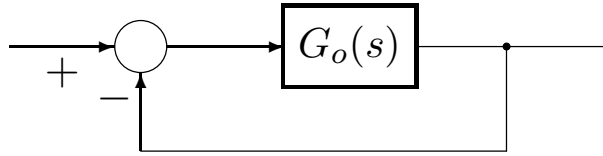
$$-\pi + \Delta\varphi = \varphi_o(\omega_p) \Rightarrow \Delta\varphi = \varphi_o(\omega_p) + \pi \quad (38)$$



Rys. 32.

Przykład

$$G_o(s) = \frac{1}{s(s+1)^2}$$



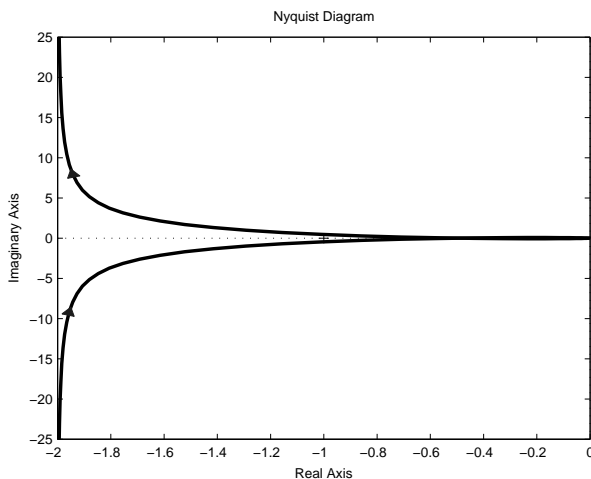
Rys. 33.

```
Go = tf(1,[1 2 1 0])
```

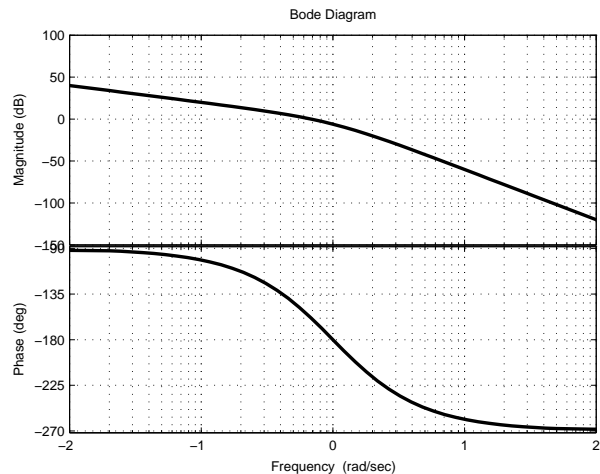
```
nyquist(Go)
```

```
zoom
```

```
bode(Go), grid on
```



(a) char. ampl.-faz.



(b) char. logarytm.

Rys. 34.

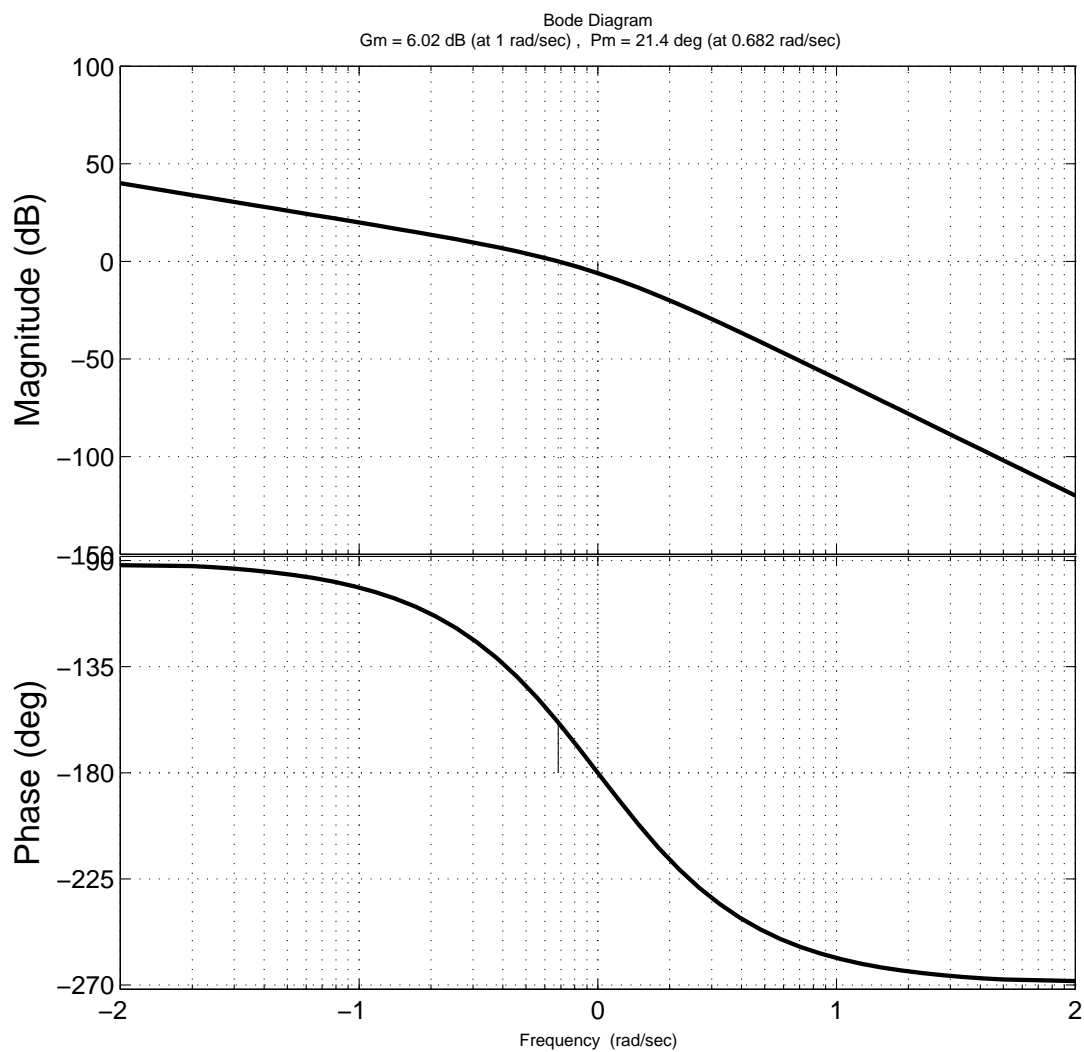
```
s = tf('s')
```

```
Go = 1/(s*(s+1)^2)
```

LTI (Linear Time-Invariant) Viewer:

```
ltiview('bode',Go)
```

margin(Go), grid on



Rys. 35.

```
[Gm, Pm, wg, wp]=margin(Go)
```

```
Gm = 2.0000
```

```
Pm = 21.3877
```

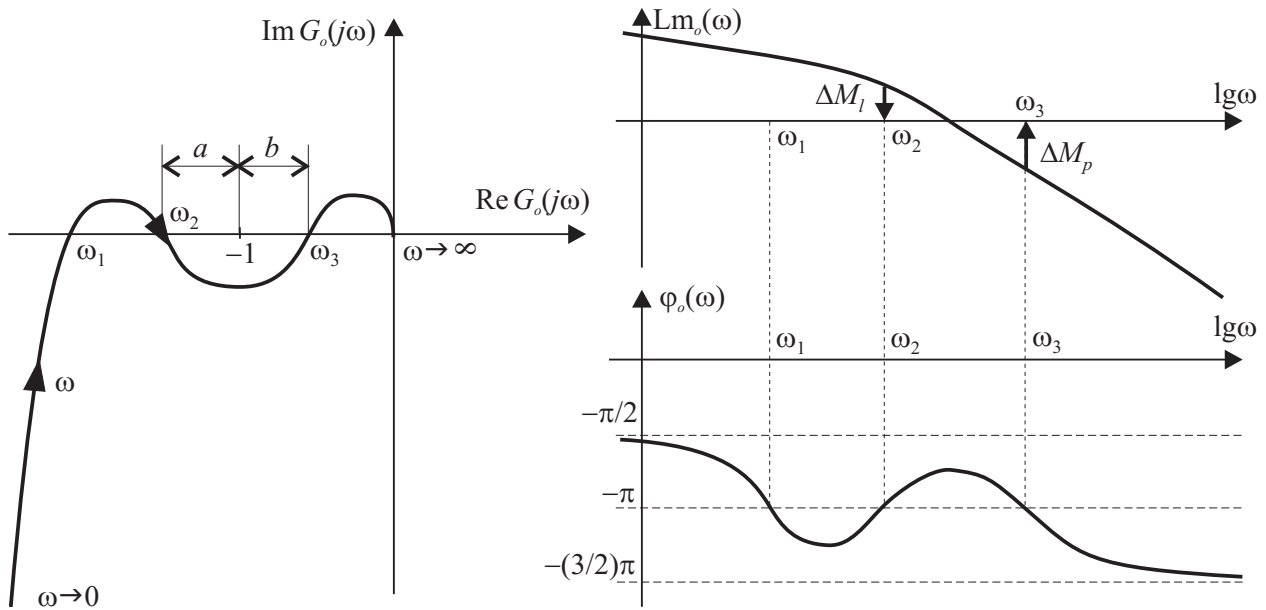
```
wg = 1
```

```
wp = 0.6823
```

```
[Mag, Phase, w]=bode(Go) ;
```

```
[Gm, Pm, wg, wp]=margin(Mag, Phase, w)
```

13. Układy warunkowo stabilne

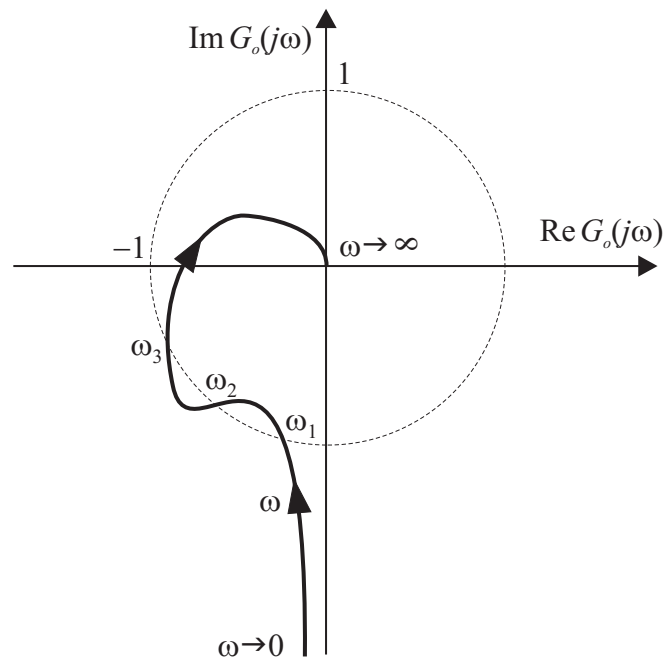


Rys. 36.

$$\lambda_l = 1/a, \quad \lambda_p = 1/b,$$

$$\Delta M_l = 20 \lg \lambda_l = -20 \lg a, \quad \Delta M_p = 20 \lg \lambda_p = -20 \lg b$$

układ stabilny: $k \in (0, k_1) \cup (k_2, k_3)$



Rys. 37.