Autodesk Inventor Engineer s Handbook

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Transmission Mechanism

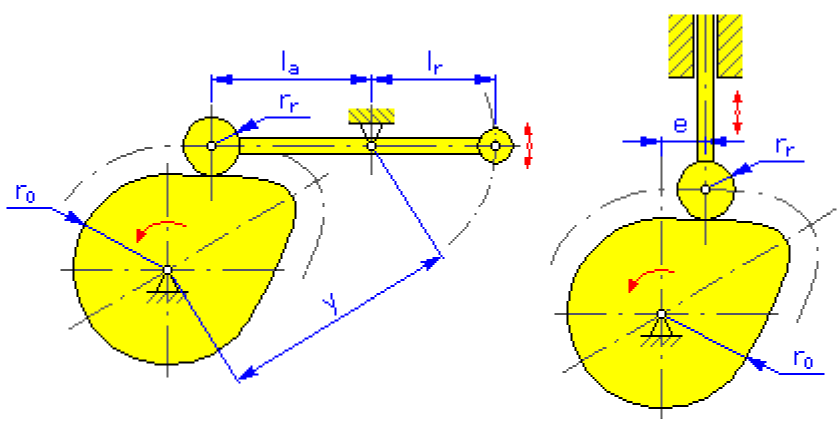
Cam Generator

Calculation Equations

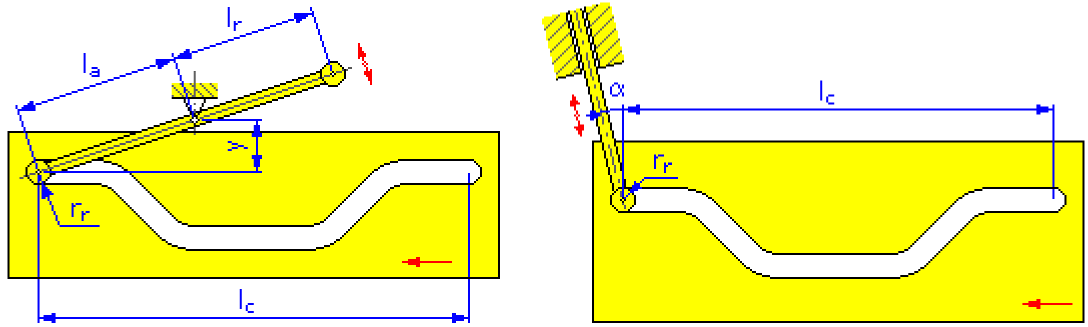
Input data:

- Basic Radius r_0 (Disc and Cylindrical Cams)
- Motion Length l_c (Linear Cams)
- Cam Width b_c
- Roller Radius r_r
- Roller Width b_r (for Follower Shape Cylinder)
- Eccentricity e (Disc Cams for Translating Follower)
- Eccentricity angle α (Linear and Cylindrical Cams for Translating Follower)
- Pivot Distance y (Disc and Linear Cams for Swinging Arm)
- Arm Length l_a (Disc and Linear Cams for Swinging Arm)
- Reaction Arm l_r (Disc and Linear Cams for Swinging Arm)
- Speed ω (Disc and Cylindrical Cams)
- Velocity v (Linear Cams)
- Force on Roller F
- Accelerated Weight m
- Spring Rating c
- Allowable Pressure p_{A1}
- Modulus of Elasticity of Cam Material E_1
- Poisson's Ratio of Cam Material μ_1
- Allowable Pressure p_{A2}
- Modulus of Elasticity of Follower Material E_2
- Poisson's Ratio of Follower Material μ_2

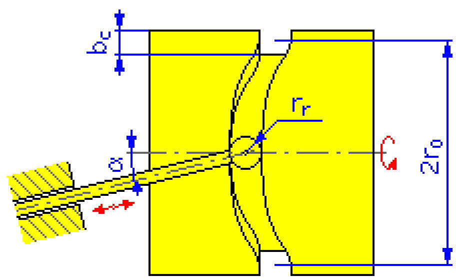
Disc Cam



Linear Cam



Cylindrical Cam



Outside diameter = $2r_0 + b_c$
Inside diameter = $2r_0 - b_c$

Cam Segments

- Motion Function $f_y(z)$ [ul]
- Reverse Ratio k_r (only for motion Parabolic and Parabolic with linear part)
- Linear Part k_l (only for motion Parabolic with linear part)
- Motion Start Position l_0 [°; mm, in]
- Motion End Position l [°; mm, in]
- Segment Motion Length dl = l - l_0 [°; mm, in]
- Lift at Start h_0 [mm, in]
- Lift at End h_{max} [mm, in]
- Segment Lift $d_h = h_{max} - h_0$ [mm, in]

Lift dependencies

Disc and Cylindrical Cam

Cam rotation angle ϕ_i [°]

Actual relative position in segment: $z_i = (\phi_i - l_0) / dl$ (range 0 - 1)

Lift $y_i = dh\, f_y(z)$ [mm, in]

Speed

$$v_i = \frac{dh}{1000} \cdot \frac{360\,\omega}{dl} \cdot f_v(z) \ \ [m/s]$$

$$v_i = \frac{dh}{12} \cdot \frac{360\,\omega}{dl} \cdot f_v(z) \ \ [ft/s]$$

Acceleration

$$a_i = \frac{dh}{1000} \cdot \left(\frac{360\,\omega}{dl}\right)^2 f_a(z) \ \ [m/s^2]$$

$$a_i = \frac{dh}{12} \cdot \left(\frac{360\,\omega}{dl}\right)^2 f_a(z) \ \ [ft/s^2]$$

Pulse

$$j_i = \frac{dh}{1000} \cdot \left(\frac{360\,\omega}{dl}\right)^3 f_j(z) \ \ [m/s^3]$$

$$j_i = \frac{dh}{12} \cdot \left(\frac{360\,\omega}{dl}\right)^3 f_j(z) \ \ [ft/s^3]$$

Linear Cam

Cam motion position l_i [mm, in]

Actual relative position in segment: $z_i = (l_i - l_0) / dl$ (range 0 - 1)

Lift $y_i = dh\ f_y(z)$ [mm, in]

Speed

$$v_i = dh \cdot \frac{v}{dl} \cdot f_v(z) \ \ [m/s,\ ft/s]$$

Acceleration

$$a_i = 1000 \cdot dh \cdot \left(\frac{v}{dl}\right)^2 f_a(z)\ [m/s^2]$$

$$a_i = 12 \cdot dh \cdot \left(\frac{v}{dl}\right)^2 f_a(z)\ [ft/s^2]$$

Pulse

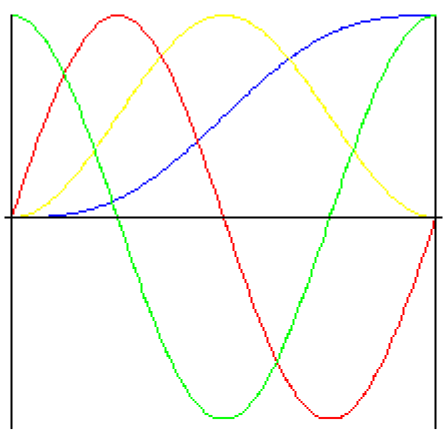
$$j_i = 10^6 \cdot dh \cdot \left(\frac{v}{dl}\right)^3 f_j(z)\ [m/s^3]$$

$$j_i = 12^2 \cdot dh \cdot \left(\frac{v}{dl}\right)^3 f_j(z)\ [ft/s^3]$$

Motion functions

Cycloidal (extended sinusoidal)

This motion has excellent acceleration characteristics. It is used often for high-speed cams because it results in low levels of noise, vibration, and wear.



Lift

Speed

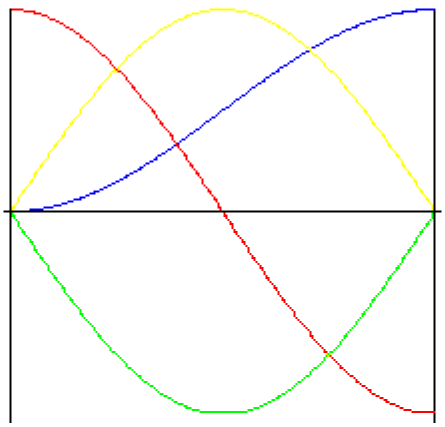
Acceleration

Pulse

Lift $f_y(z) = z - 0.5/\pi \sin(2\pi z)$
Speed $f_v(z) = 1 - \cos(2\pi z)$
Acceleration $f_a(z) = 2\pi \sin(2\pi z)$
Pulse $f_j(z) = 4\pi^2 \cos(2\pi z)$

Harmonic (sinusoidal)

Smoothness in velocity and acceleration during the stroke is the advantage inherent in this curve. However, the instantaneous changes in acceleration at the beginning and end of the motion tend to cause vibration, noise and wear.



Lift

Speed

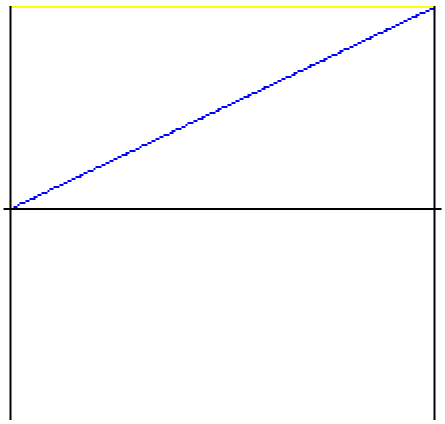
Acceleration

Pulse

Lift $f_y(z) = 0.5(1 - \cos \pi z))$
Speed $f_v(z) = 0.5 \pi \sin(\pi z)$
Acceleration $f_a(z) = 0.5 \pi^2 \cos(\pi z)$
Pulse $f_j(z) = -0.5\pi^3 \sin(\pi z)$

Linear

Simple motion with huge shock at start and at end of motion. Rarely used except in very crude devices. We recommend that you use motion with modified start and end of motion – Parabolic with linear part.



Lift

Speed

Lift $f_y(z) = z$

Speed $f_v(z) = 1$

Acceleration $f_a(z) = 0$

NoteFor z = 0 and z = 1 the proper value should be an infinite value, but the calculation cannot work with an infinite value and uses a zero value.

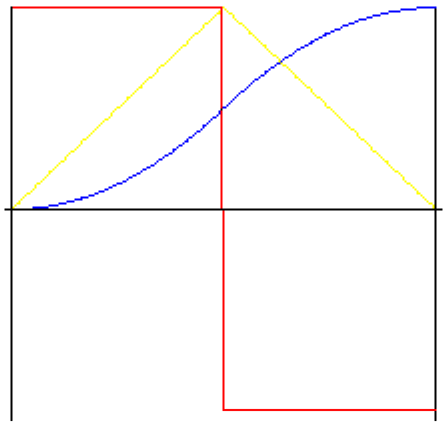
Pulse $f_j(z) = 0$

NoteFor z = 0 and z = 1 the proper value should be an infinite value but the calculation cannot work with an infinite value and uses a zero value.

Parabolic (Polynomial of 2 nd degree)

Motion with smallest possible acceleration. However, because of the sudden changes in acceleration at the start, middle, and end of the motion, shocks are produced. Revese ratio allows “stretch” of middle of motion to allow change in acceleration and deceleration ratio.

symmetrical (reverse ratio $k_r = 0.5$)



Lift

Speed

Acceleration

for z = 0 to 0.5:

Lift $fy(z) = 2z^2$

Speed $fv(z) = 4z$

Accelerationfa (z) = 4

Pulse fa(z) = 0

for z = 0.5 - 1:

Lift $fy(z) = 1 - 2(1 - z)^2$

Speed $fv(z) = 4 (1 - z)$

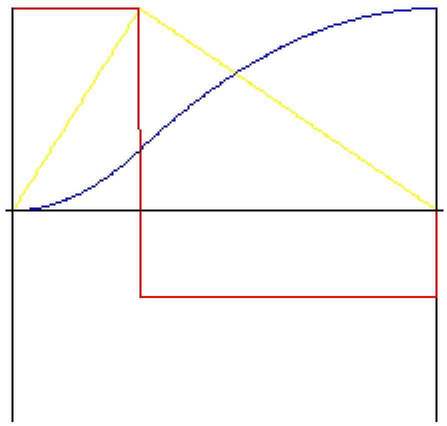
Accelerationfa (z) = -4

Pulse fj(z) = 0

NoteFor z = 0 and z = 1 the proper value should be an infinite value but the calculation cannot work with an infinite value and uses a zero value.

nonsymmetrical

k_r - reverse ratio (in range 0.01 to 0.99)



Lift

Speed

Acceleration

for $z = 0$ to k_r:

Lift $f_y(z) = z^2 / k_r$

Speed $f_v(z) = 2z / k_r$

Acceleration $f_a(z) = 2 / k_r$

Pulse $f_j(z) = 0$

for $z = k_r$ to 1:

Lift $f_y(z) = 1 - (1 - z)^2 / (1 - k_r)$

Speed $f_v(z) = 2(1 - z) / (1 - k_r)$

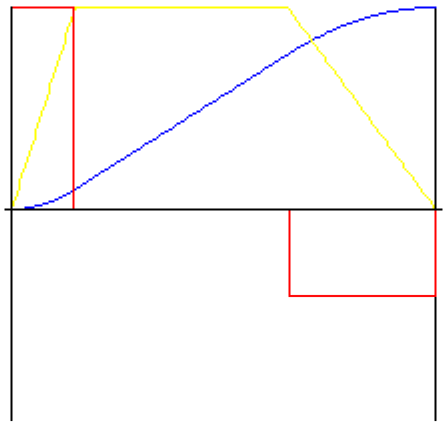
Acceleration $f_a(z) = -2 / (1 - k_r)$

Pulse $f_j(z) = 0$

NoteFor z = 0 and z = 1 the proper value should be an infinite value but the calculation cannot work with an infinite value and uses a zero value.

Parabolic with linear part

Provide more acceptable acceleration and deceleration than linear motion. Revese ratio allows “stretch” of middle of motion to allow change in acceleration and deceleration ratio. Linear part ratio allows set relative size of linear motion part.



Speed

Acceleration

Pulse

k_r - reverse ratio (in range 0.01 to 0.99)

k_l - linear part ratio (in range 0 to 0.99)

$k_z = 1 + k_l / (1 - k_l)$

$k_h = (1 - k_l) / (1 + k_l)$

for $z = 0$ to k_r / k_z:

Lift $f_y(z) = k_h z^2 k_z^2 / k_r$

Speed $f_v(z) = 2 k_h z k_z^2 / k_r$

Acceleration $f_a(z) = 2 k_h k_z^2 / k_r$

Pulse $f_j(z) = 0$

for $z = k_r / k_z$ to $r / k_z + k_l$:

Lift $f_y(z) = (z - 0.5 k_r / k_z) 2 / (1 + k_l)$

Speed $f_v(z) = 2 / (1 + k_l)$

Acceleration $f_a(z) = 0$

Pulse $f_j(z) = 0$

for $z = k_r / k_z + k_l$ to 1:

Lift $f_y(z) = 1 - k_h (1 - z)^2 k_z^2 / (1 - k_r)$

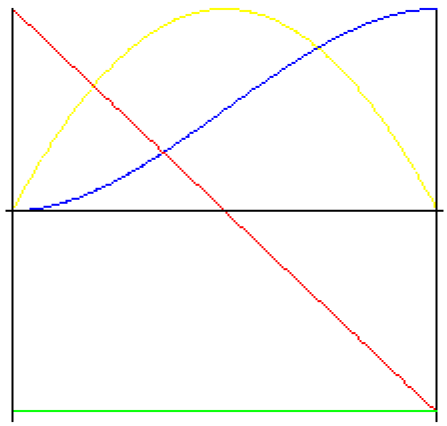
Speed $f_v(z) = 2 k_h (1 - z) k_z^2 / (1 - k_r)$

Acceleration $f_a(z) = -2 k_h k_z^2 / (1 - k_r)$

Pulse $f_j(z) = 0$

Polynomial of 3 rd degree (cubic parabola)

Motion with smaller shocks than parabolic motion.



Lift

Speed

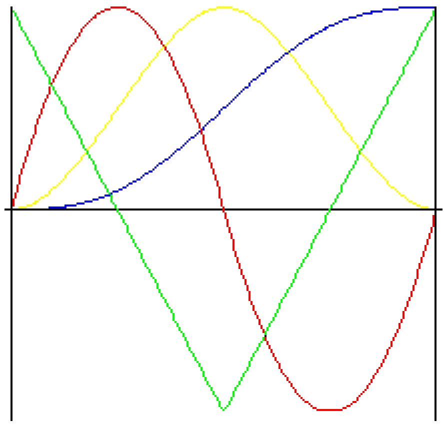
Acceleration

Pulse

Lift $f_y(z) = (3 - 2z) z^2$
Speed $f_v(z) = (6 - 6z) z$
Acceleration $f_a(z) = 6 - 12z$
Pulse $f_j(z) = -12$

Polynomial of 4 th degree

Motion with smaller shocks than Polynomial of 3 rd degree motion.



Lift

Speed

Acceleration

Pulse

for z = 0 - 0.5

Lift $f_y(z) = (1 - z)\,8z^3$

Speed $f_v(z) = (24 - 32z)\,z^2$

Acceleration $f_a(z) = (48 - 96z)\,z$

Pulse $f_j(z) = 48 - 192z$

for z = 0.5 - 1

Lift $f_y(z) = 1 - 8z\,(1 - z)^3$

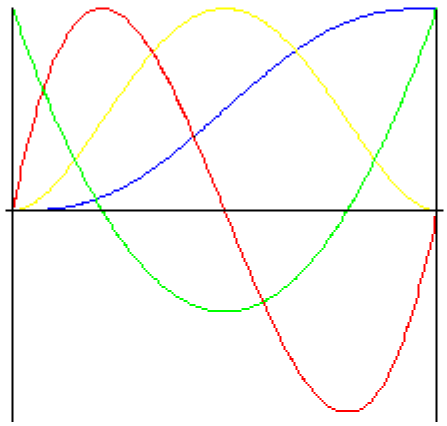
Speed $f_v(z) = (32z - 8)\,(1 - z)^2$

Acceleration $f_a(z) = (48 - 96z)\,(1 - z)$

Pulse $f_j(z) = 194z - 144$

Polynomial of 5 th degree

Motion with smaller shocks than Polynomial of 3 rd degree motion.



Lift

Speed

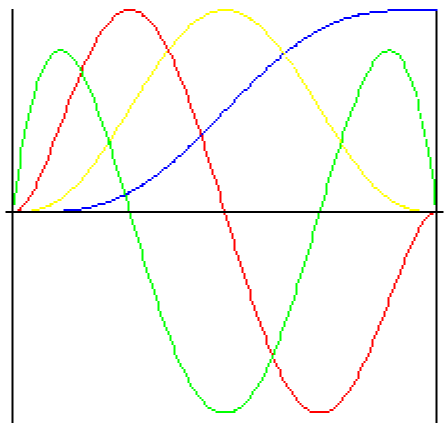
Acceleration

Pulse

Lift $f_y(z) = (6z^2 - 15z + 10)\, z^3$
Speed $f_v(z) = (z^2 - 2z + 1)\, 30z^2$
Acceleration $f_a(z) = (2z^2 - 3z + 1)\, 60z$
Pulse $f_j(z) = (6z^2 - 6z + 1)\, 60$

Polynomial of 7 th degree

Smoothness in all formulas including pulse.



Lift

Speed

Acceleration

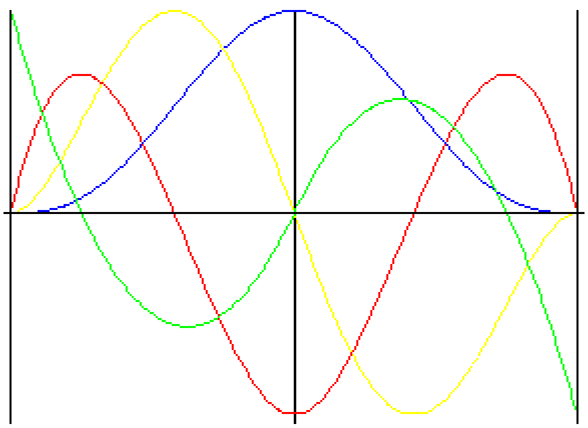
Pulse

Lift $f_y(z) = (-20z^3 + 70z^2 - 84z + 35) z^4$
Speed $f_v(z) = (-z^3 + 3z^2 - 3z + 1) 140z^3$
Acceleration $f_a(z) = (-2z^3 + 5z^2 - 4z + 1) 420z^2$
Pulse $f_j(z) = (-5z^3 + 10z^2 - 6z + 1) 840z$

Nonsymmetric Polynomial of 5 th degree

Similar like Polynomial of 5th degree but with forced lift reversion.

NoteRequire combination of part 1 and part 2.



Lift

Speed

Acceleration

Pulse

Part 1

Lift $f_y(z) = 1 - (8 (1 - z)^3 - 15 (1 - z)^2 + 10) (1 - z)^2 / 3$

Speed $f_v(z) = (2 (1 - z)^3 - 3 (1 - z)^2 + 1) (1 - z) 20 / 3$

Acceleration $f_a(z) = -(8 (1 - z)^3 - 9 (1 - z)^2 + 1) 20 / 3$

Pulse $f_j(z) = (4 (1 - z)^2 - 3 (1 - z)) 40$

Part 2

Lift $f_y(z) = (8z^3 - 15z^2 + 10) z^2 / 3$

Speed $f_v(z) = (2z^3 - 3z^2 + 1) z 20/3$

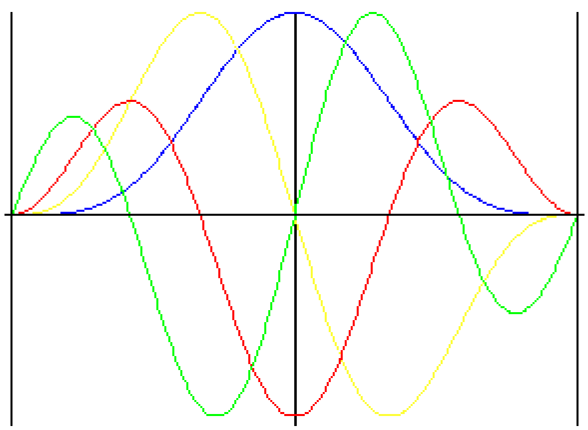
Acceleration $f_a(z) = (8z^3 - 9z^2 + 1) 20/3$

Pulse $f_j(z) = (4z^2 - 3z) 40$

Double Harmonic

Smoothness in all formulas including pulse with forced lift reversion..

NoteRequire combination of part 1 and part 2.



Part 1

Lift $f_y(z) = \cos(0.5\pi (1 - z))^4$

Speed $f_v(z) = \pi (0.5 \sin(\pi z) - 0.25 \sin(2\pi z))$

Acceleration $f_a(z) = 0.5 \pi^2 (\cos(\pi z) - \cos(2\pi z))$

Pulse $f_j(z) = \pi^3 (-0.5 \sin(\pi z) + \sin(2\pi z))$

Part 2

Lift $f_y(z) = 1 - \cos(0.5\pi z)^4$

Speed $f_v(z) = \pi (0.5 \sin(\pi z) + 0.25 \sin(2\pi z))$

Acceleration $f_a(z) = 0.5 \pi^2 (\cos(\pi z) + \cos(2\pi z))$

Pulse $f_j(z) = -\pi^3 (0.5 \sin(\pi z) + \sin(2\pi z))$

Comparison of maximal relative values

Motion	Speed	Acceleration	Pulse
Cycloidal (extended sinusoidal)	2	6.28	39.5
Harmonic (sinusoidal)	1.57	4.93	15.5
Linear	1	∞	∞
Parabolic (Polynomial of 2 nd degree)	2	4	∞
Polynomial of 3 rd degree	1.5	6	12
Polynomial of 4 th degree	2	6	48
Polynomial of 5 th degree	1.88	5.77	60
Polynomial of 7 th degree	2.19	7.51	52.5
Nonsymmetric Polynomial of 5 th degree	1.73	6.67	40
Double Harmonic	2.04	9.87	42.4

Other dependencies

Force on roller

$F_i = F + m\, a_i + c\, y_i$ [N, lb]

Normal Force

$Fn_i = F_i / \cos(\gamma_i)$ [N, lb]

Moment

$T_i = F_i\, r_i \tan(\gamma_i)$ [Nmm, lb in]

Specific (Hertz) Pressure

$$p_i = \sqrt{\frac{\frac{Fn_i}{\pi b}\left(\frac{1}{r_k} - \frac{1}{r_{ci}}\right)}{\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}}} \quad \text{[MPa, psi]}$$

$b = \min(b_v, b_k)$

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