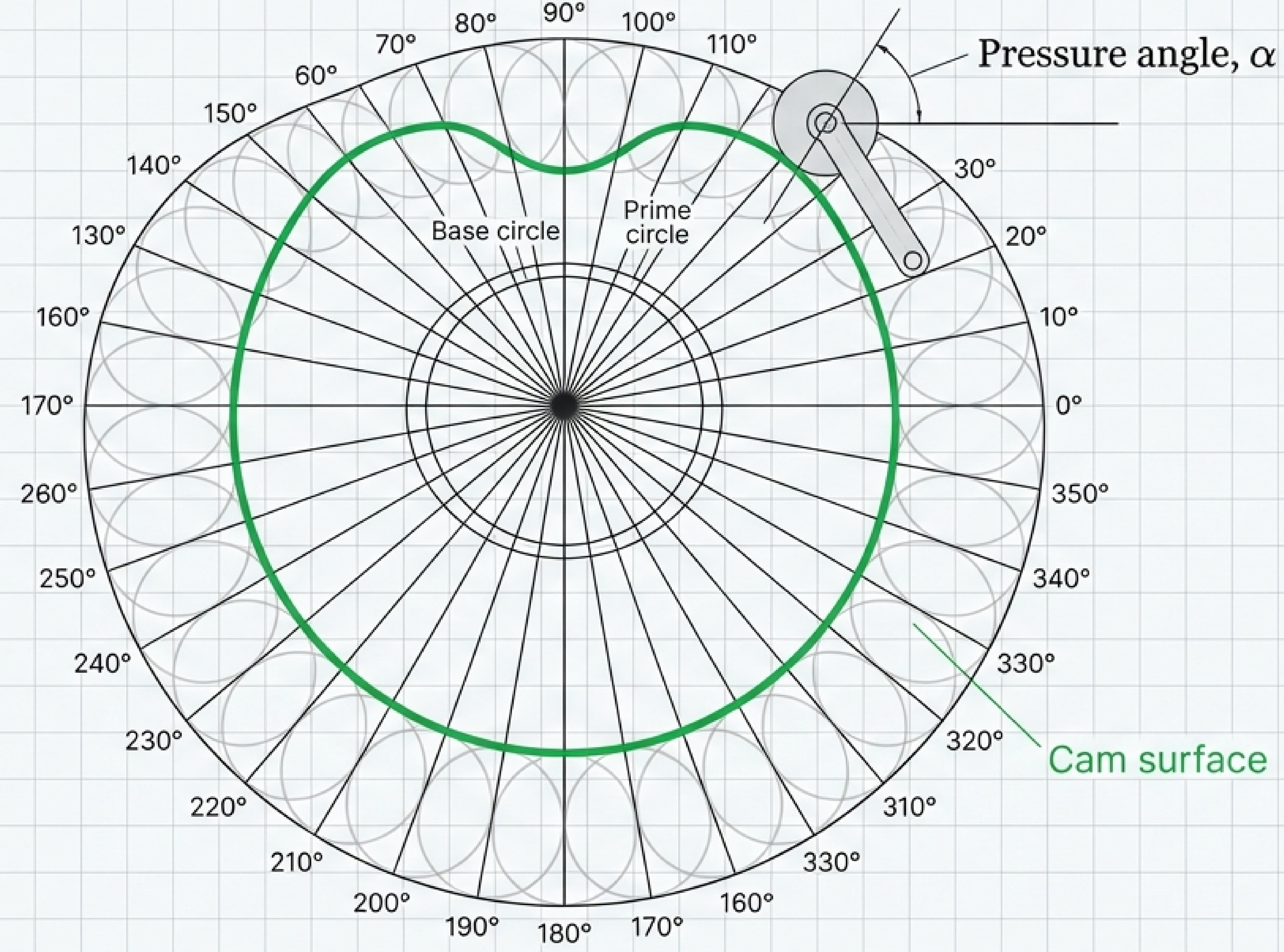
From Blueprint to Reality: Graphical Synthesis of a Radial Cam Profile

A Step-by-Step Guide to Translating a Motion Program into a Physical Cam



NotebookLM

Cam Design is a Two-Stage Process

Stage 1: Kinematic Synthesis of the Motion Program

This initial stage is purely mathematical. It involves defining the follower's displacement, velocity, and acceleration over time (the $y(\theta)$ curve).

The goal is to optimize dynamic performance, often by ensuring finite jerk for high-speed applications (e.g., using Cycloidal or 3-4-5 Polynomial motion).

Stage 2: Generation of the Physical Cam Profile

This is our focus. We take the synthesized motion program from Stage 1 and use it to define the physical geometry of the cam.

The primary method used for this translation is **Kinematic Inversion**,

What is Kinematic Inversion?

It's a powerful graphical technique where we imagine the cam is held stationary (fixed). We then plot the motion of the follower *relative to the cam*. This simplifies the complex geometry and allows for a step-by-step construction of the cam's surface.

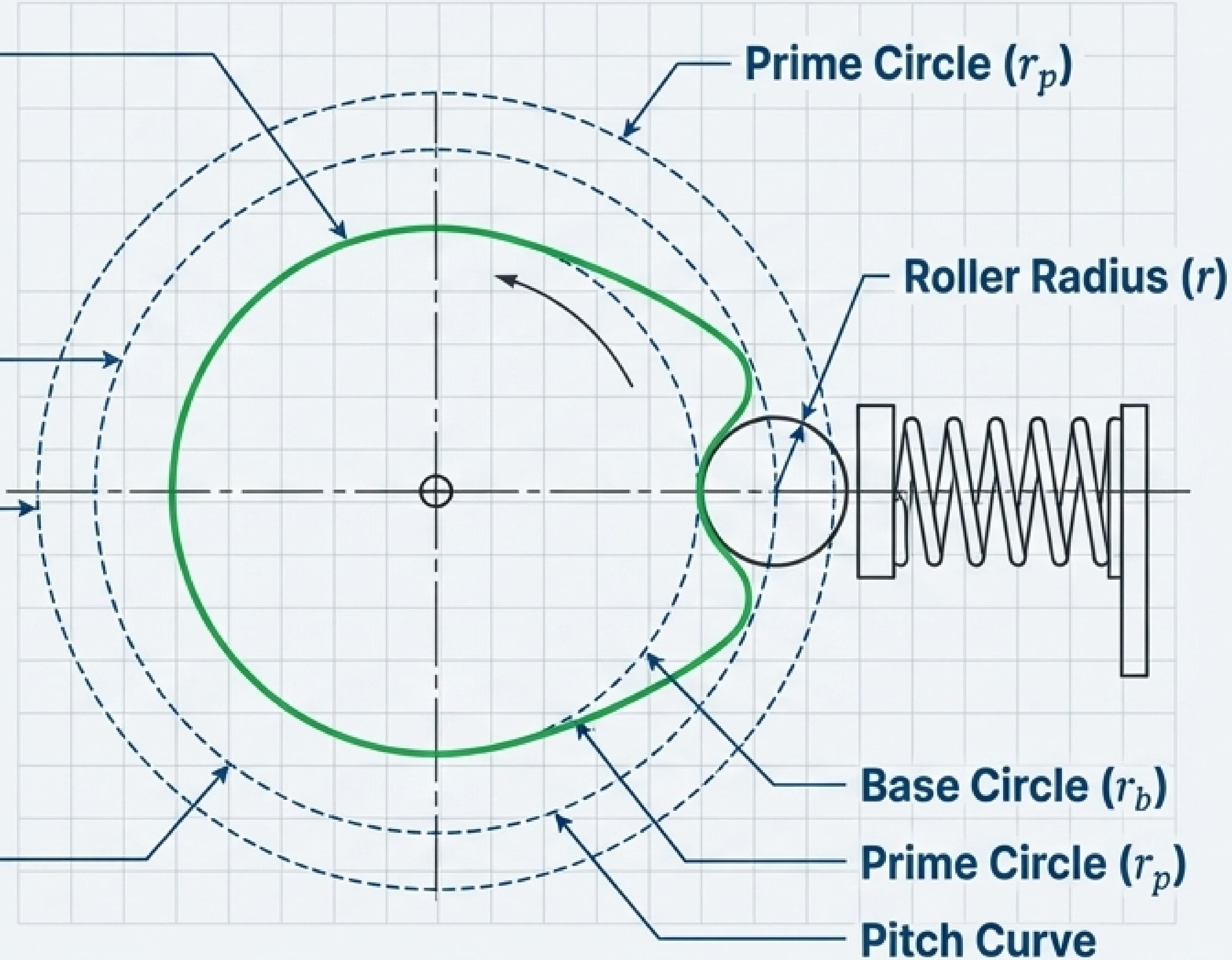
The Anatomy of a Radial Roller Cam System

Base Circle (r_b): The smallest circle that can be drawn tangent to the cam profile, centered at the cam's axis of rotation. It represents the cam's radius at zero follower displacement.

Roller Radius (r): The radius of the roller on the follower.

Prime Circle ($r_{p,}$): A circle defined by the path of the roller's center when the follower has zero displacement. Its radius is calculated as $r_p = r_b + r$. The construction of the cam profile begins from this circle.

Pitch Curve: The path traced by the center of the roller follower as the cam rotates. This curve is generated by plotting the follower's displacement, $y(\theta)$, radially outward from the Prime Circle.



Our Design Case: A Walkthrough of Example 10.3

We will now graphically construct a complete cam profile using a specific set of design parameters. The input motion program and follower specifications have been determined in Stage 1.

Design Parameters

- **Follower Type:** Radial Roller Follower
- **Motion Program:** Harmonic Rise/Return
- **Total Lift (L):** 0.8 in
- **Base Circle Radius (r_b):** 1.5 in (Chosen based on the rule of thumb: $r_b \approx 2 \times L$)
- **Roller Radius (r):** 0.5 in (from a 1.0 in diameter roller)
- **Prime Circle Radius (r_p):** 2.0 in (calculated as $1.5 + 0.5$)
- **Cam Rotation:** Clockwise (CW)

θ	y
0	0
30	0
60	0
90	0
120	0
150	0.4
180	0.8
210	0.8
240	0.724
270	0.524
300	0.276
330	0.076

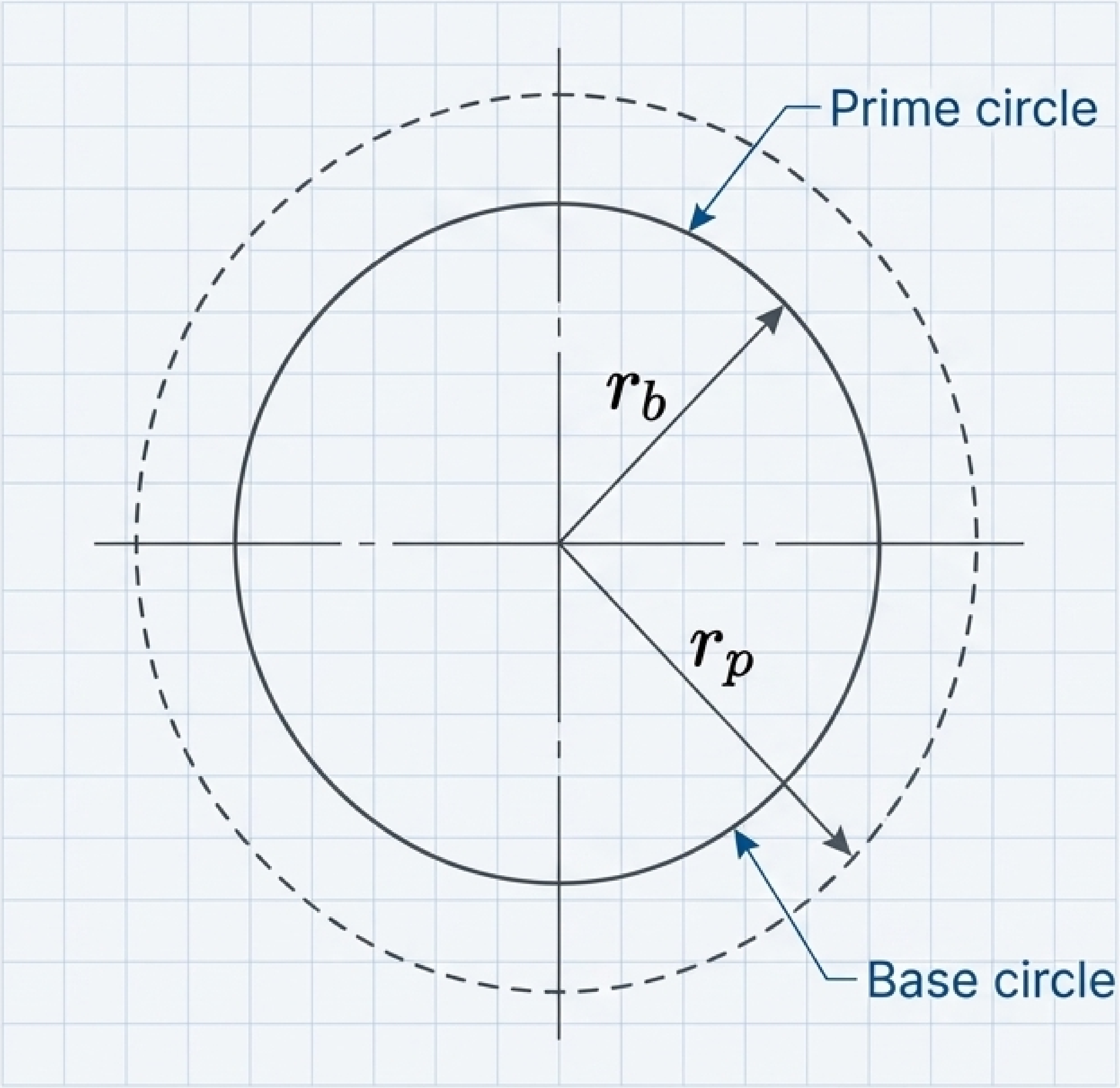
Step 1: Laying the Foundation

The construction begins by drawing two concentric circles to scale: the Base Circle and the Prime Circle.

The **Base Circle** is drawn with radius $r_b = 1.5\,\text{in.}$

The **Prime Circle** is drawn with radius $r_p = 2.0\,\text{in.}$

All subsequent measurements for the follower's motion will be made relative to the Prime Circle.

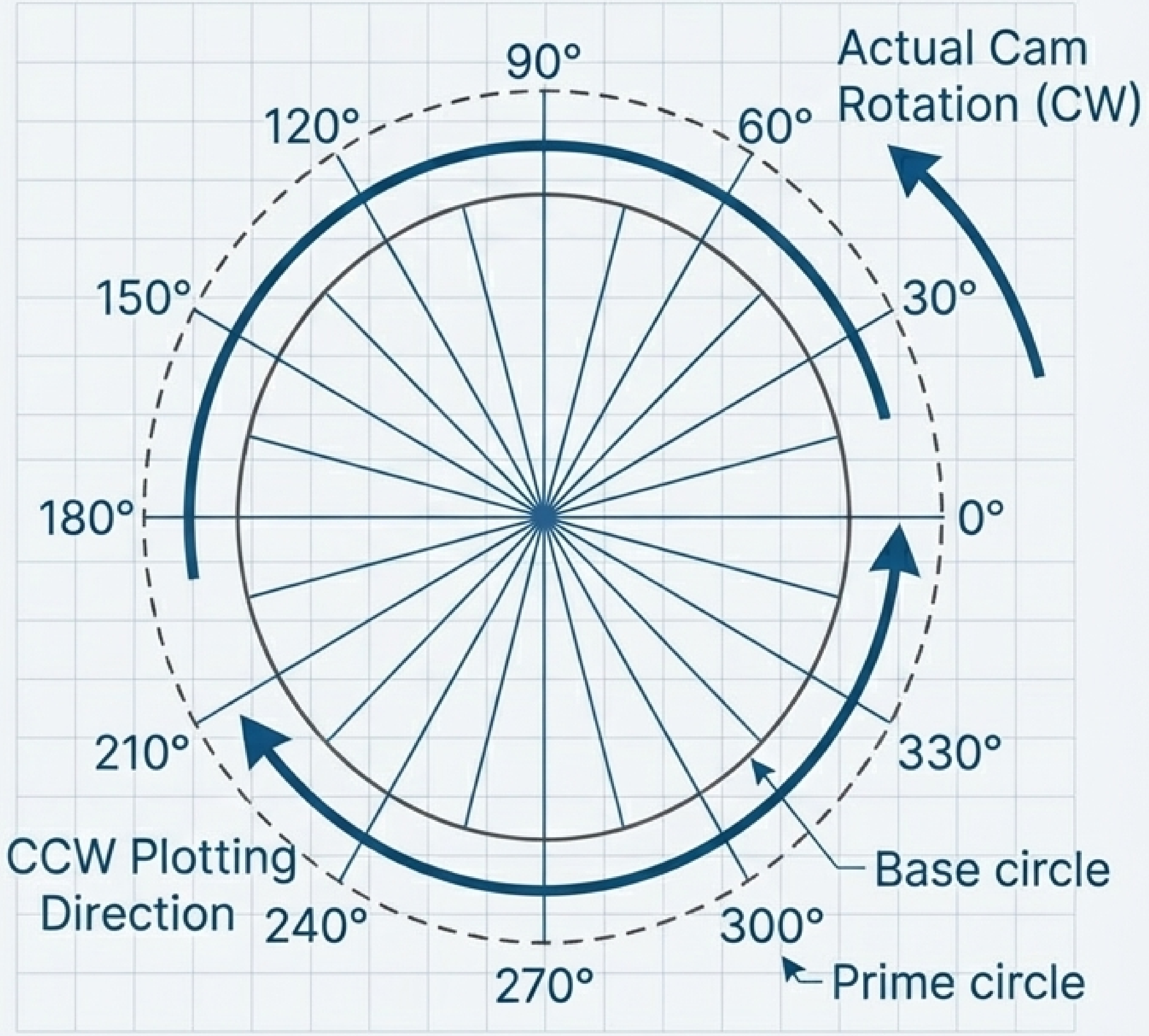


Step 2: Applying Kinematic Inversion

We apply the principle of Kinematic Inversion to plot the follower's motion relative to the fixed cam.

- **Rule:** Because the cam rotates **Clockwise (CW)**, we must plot the follower's positions in the **Counter-Clockwise (CCW)** direction.

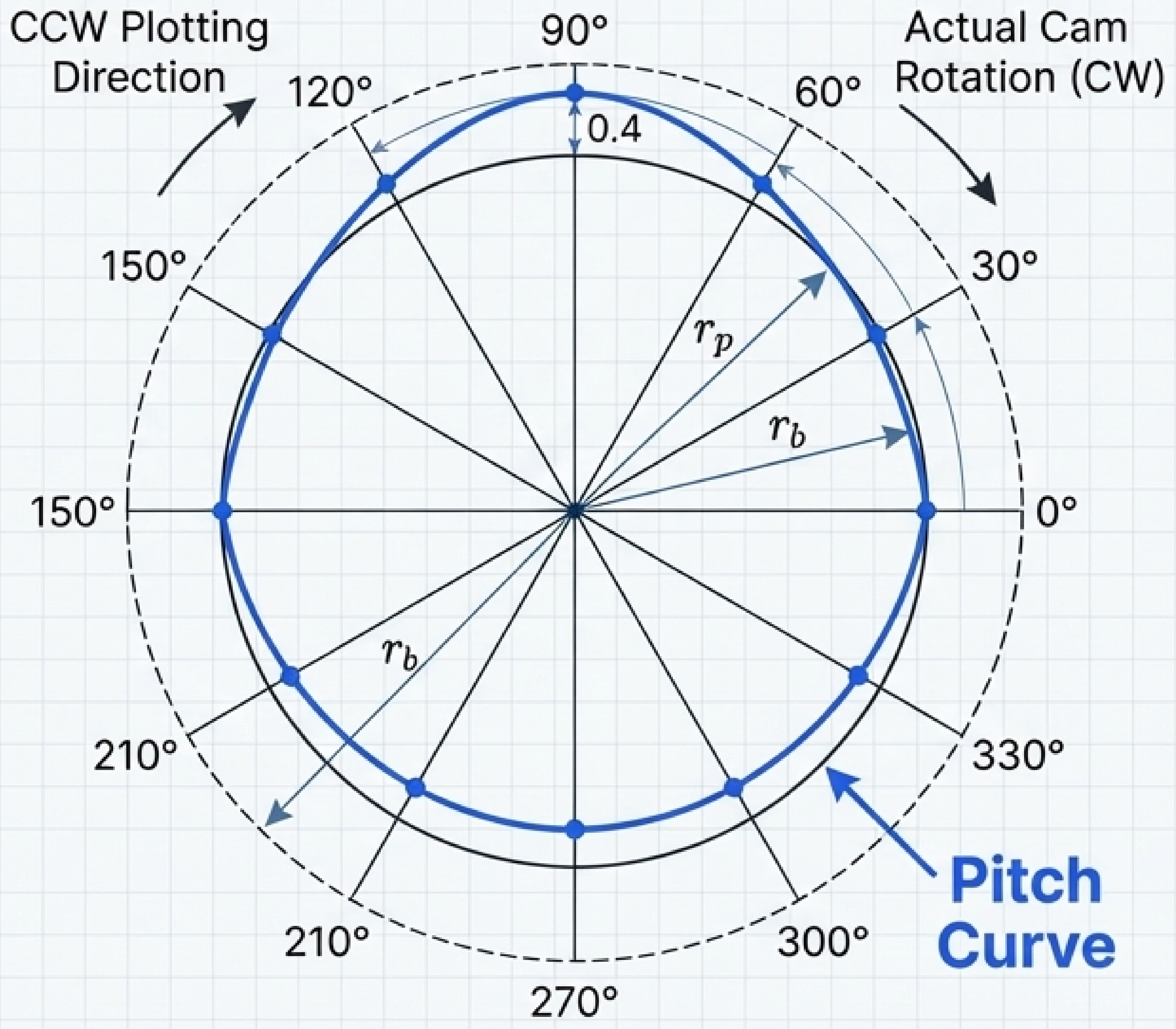
We divide the circle into angular increments (the example uses 30°). Radial "ray" lines are drawn from the center at each increment.



Step 3: Plotting the Pitch Curve

For each radial line (at each angle θ), we measure the follower's displacement, $y(\theta)$, radially outward from the Prime Circle. The location of the roller's center at any angle θ is at a distance of $r_p + y(\theta)$ from the cam's center.

Connecting these marked points with a smooth curve reveals the Pitch Curve, which represents the represents the path of the roller follower's center relative to the cam.

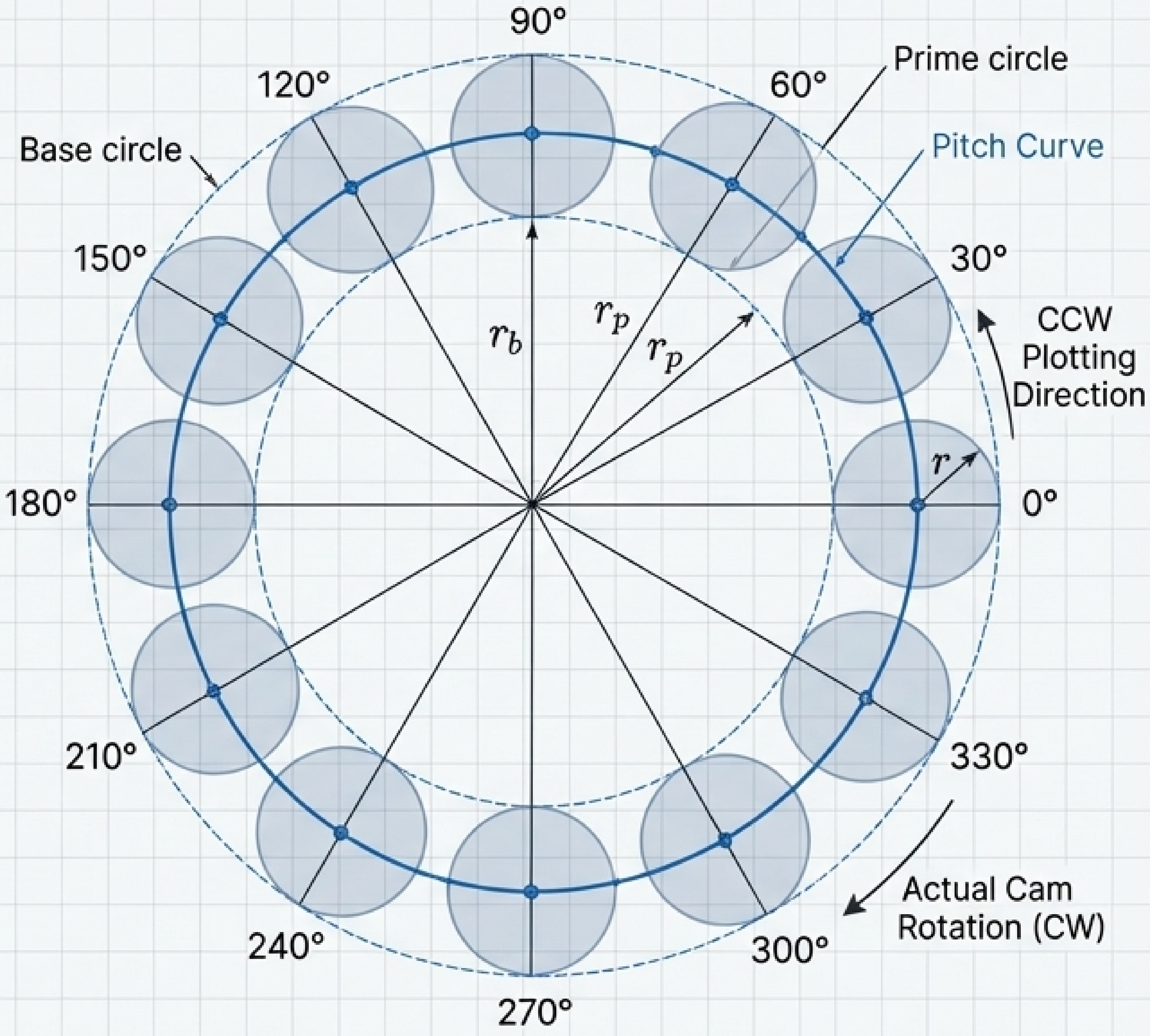


Step 4: Drawing the Follower Positions

The Pitch Curve defines the location of the roller's center. To represent the physical follower, we draw a circle at each marked point on the Pitch Curve.

- Each circle is drawn with the radius of the roller follower, $r = 0.5\ \text{in.}$

This collection of circles represents the series of positions that the roller occupies relative to the fixed cam throughout one full rotation.

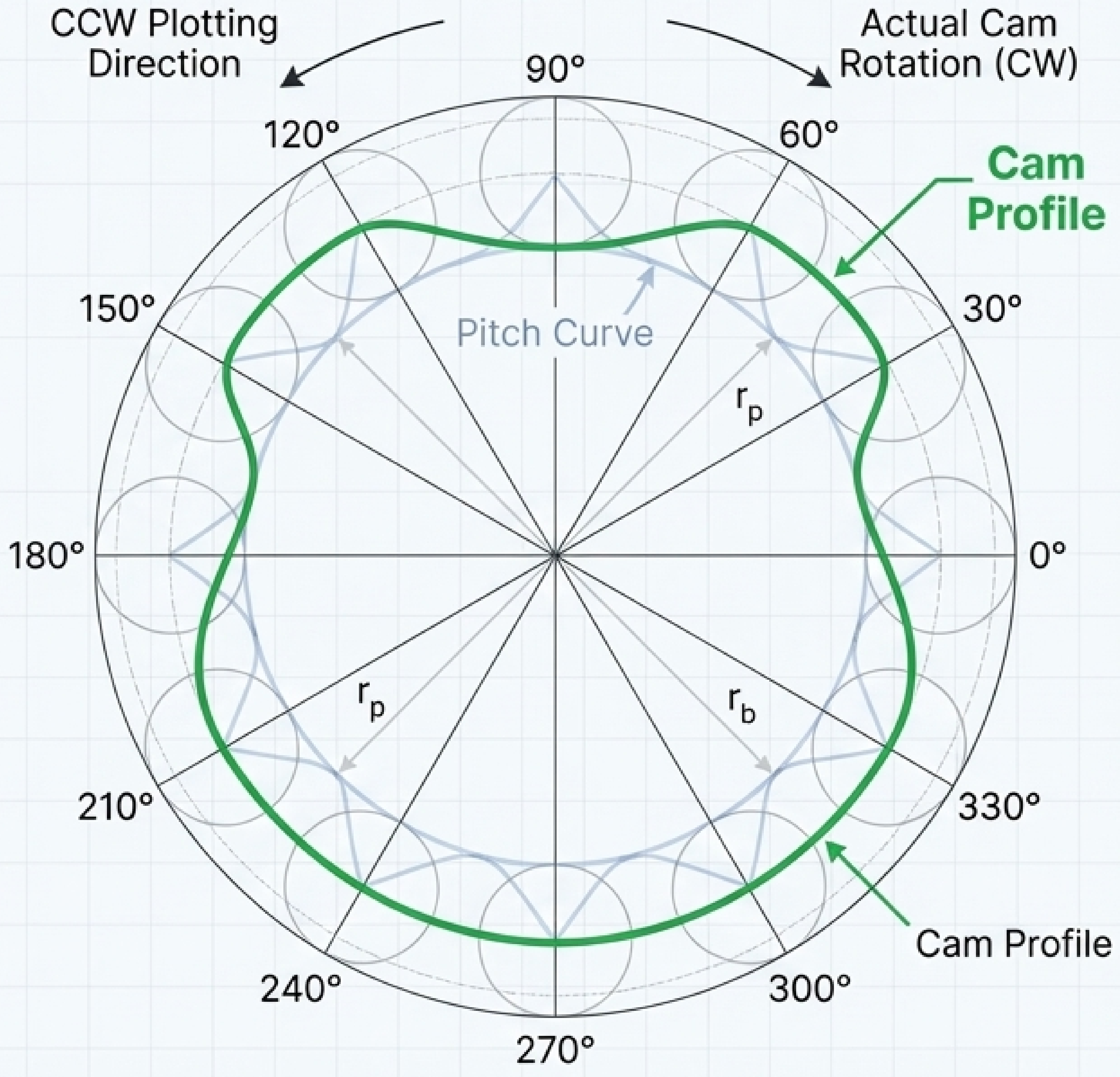


Step 5: Revealing the Cam Profile

The final cam surface is the smooth curve that is tangent to the *inside* of all the roller follower circles drawn in the previous step.

This curve is known as the **envelope** of the family of follower position circles.

By carefully drawing this tangent line, we define the exact physical profile that must be manufactured to produce the desired harmonic motion.



Design Check 1: The Pressure Angle (α)

Definition: The **pressure angle (α)** is the angle between the direction of the follower's motion and the normal to the cam surface at the point of contact.

Why It Matters:

- A high pressure angle creates a large side-thrust force on the follower stem.
- This leads to excessive friction, wear, and potential for the follower to bind in its guide.
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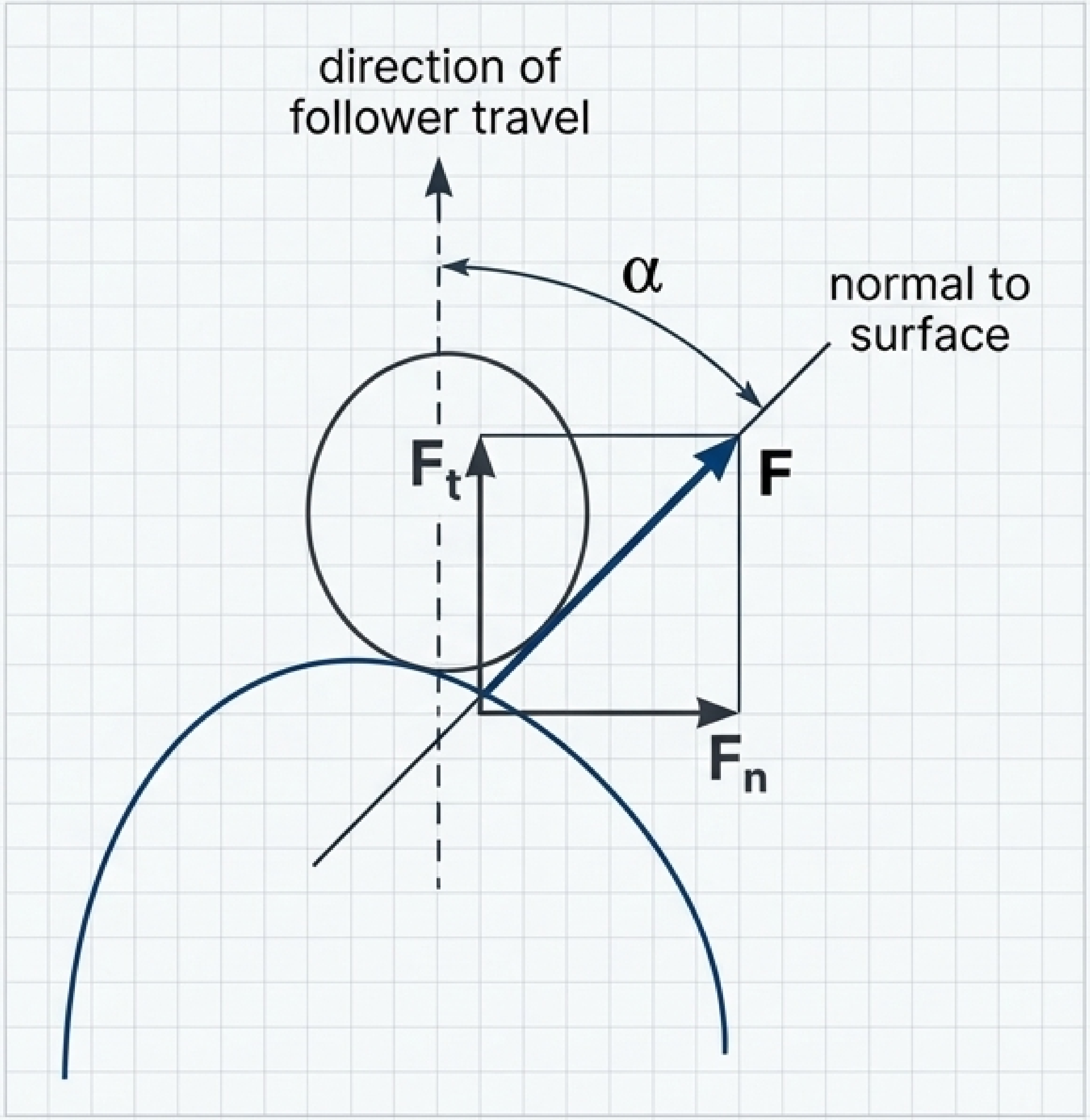
- **Constraint:** For smooth operation, the pressure angle should generally be kept within **±30°**.

The Remedy:

If the pressure angle is too large, the primary solution is to **increase the base circle radius (r_b)**. A larger cam results in a smaller maximum pressure angle.



Design Check 2: Radius of Curvature (ρ)

Definition:

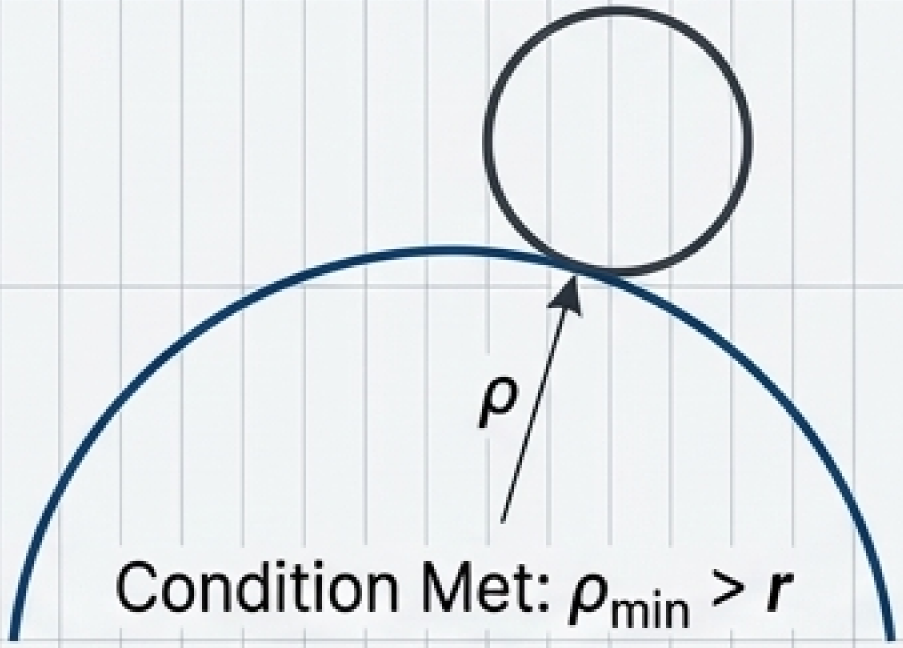
- The cam profile's radius of curvature (ρ) **describes how sharply the cam surface curves**. For a roller follower, this curvature has a critical limit.

Why It Matters:

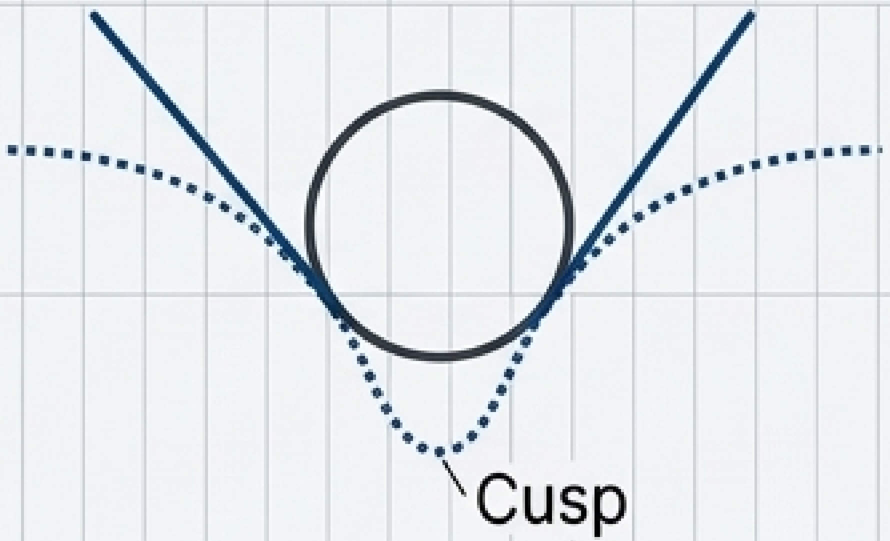
- **Constraint:** The minimum radius of curvature of the cam profile (ρ_{min}) **must always be greater than the roller follower's radius** (**r**).
- **Risk:** If the cam profile has a concave section that curves too sharply (where $\rho < r$), the roller cannot follow the intended path. It will bridge across the "hollow," causing the actual motion to deviate from the synthesized program. An extreme case is a **cusp** ($\rho = 0$), which is physically impossible for a roller follower to trace.

The Remedy:

- If the radius of curvature is too small, the solution is again to increase the base circle radius (r_b).



Good Design



Bad Design

Conclusion: From Drawing to Precision Machine

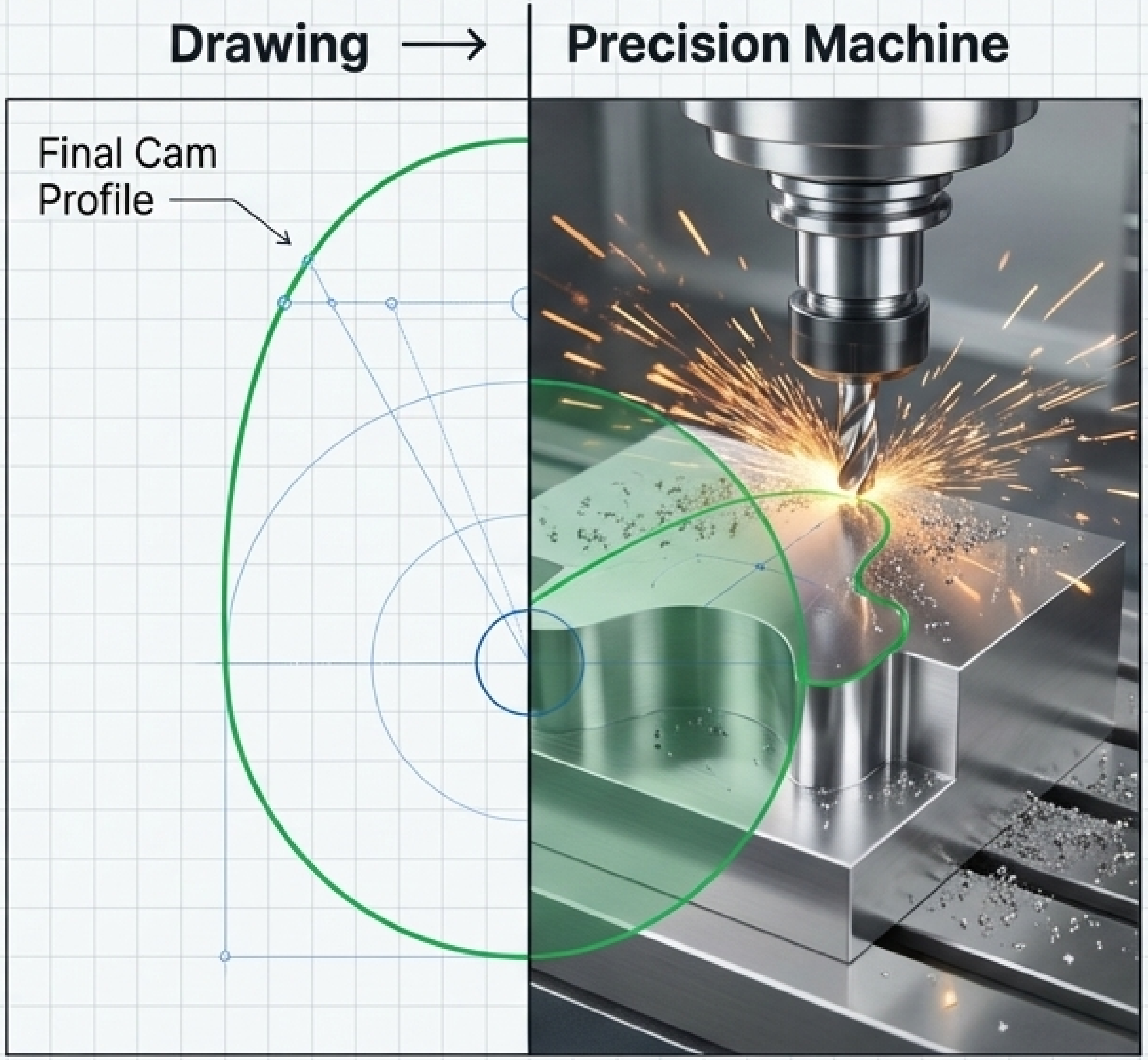
Recap

We have followed the two-stage design process:

1. **Synthesizing** an ideal motion program (Stage 1).
2. **Generating** the physical profile using the graphical method and validating the geometry (Stage 2).

The Manufacturing Imperative

The theoretical benefits of a well-designed motion program—smoothness, finite jerk, and controlled dynamics—are meaningless without a precisely manufactured cam.



Key Takeaway

Achieving the intended performance requires **extreme manufacturing accuracy**. The geometric profile we have designed must be translated into a physical part using high-precision methods like CNC milling and grinding to ensure the follower's actual motion matches the mathematical ideal.