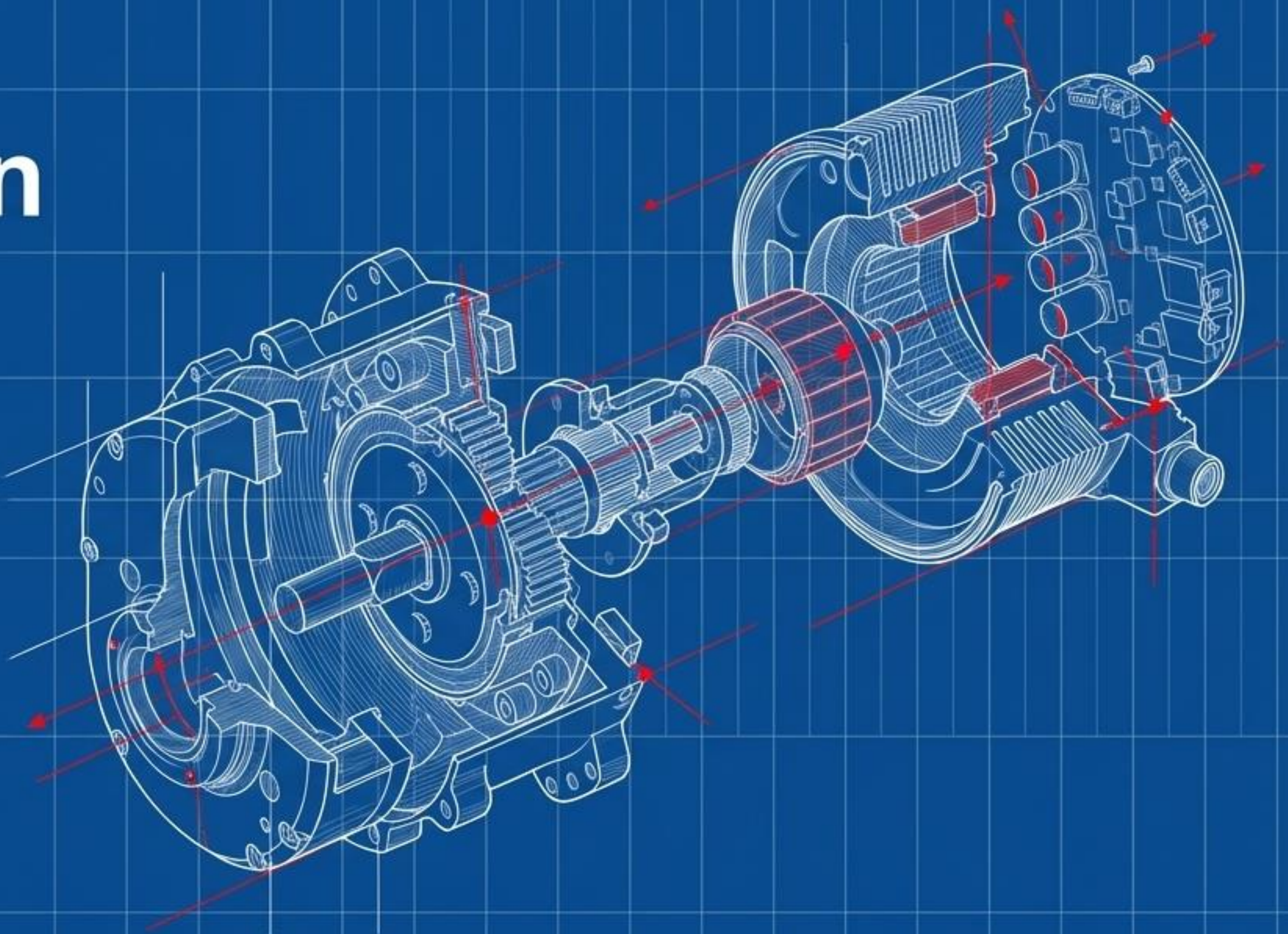
Selection of High-Precision DC Drives

A 6-Step Methodological Algorithm & Mathematical Reference



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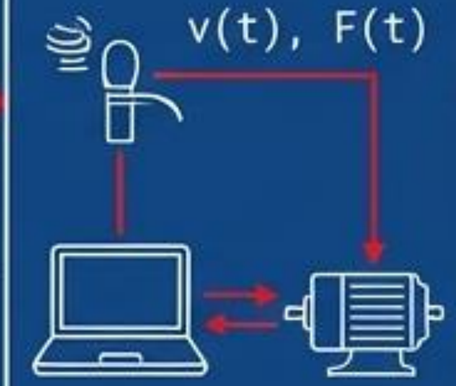
The 6-Step Algorithmic Journey

Step 1
Overview

System boundary conditions & control type.



Step 2
Motion of Load

Forces, torques, time duration.

$F = ma$

$T = I\alpha$

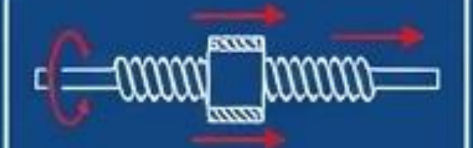
Δt

Step 3
Mechanical Drive

Transformation of parameters.

$\eta = P_{out} / P_{in}$

$ratio = T_{out} / T_{in}$



Step 4
Gearhead

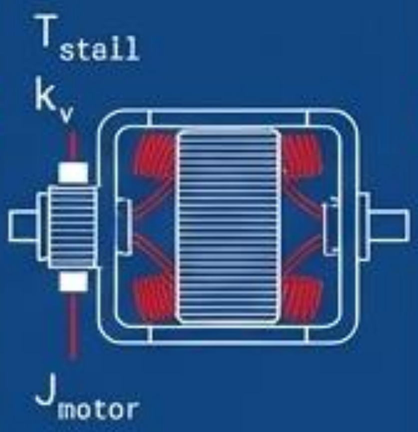
Speed reduction, < 1,000 rpm.

$N_{out} = N_{in} / i$

< 1000 rpm

Step 5
Motor Selection

Torque limits, commutation, winding speed constant.



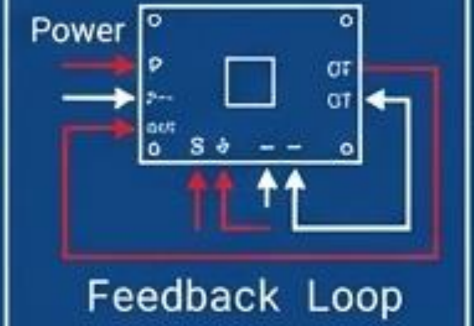
Step 6
Sensors & Controllers

Closed-loop feedback & integration.

PID Control

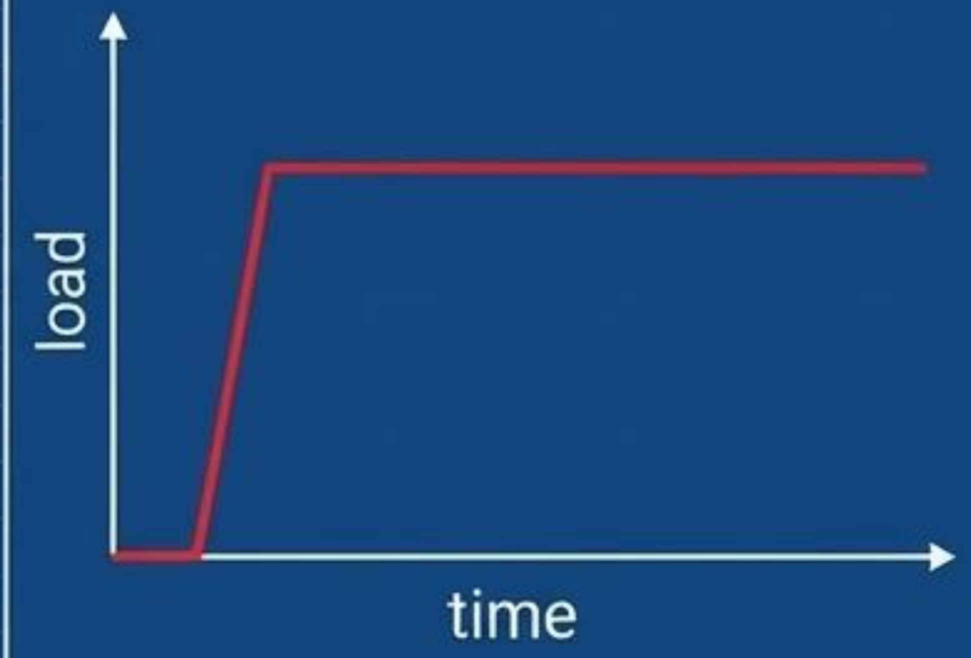
E = set - act

Feedback Loop



Step 1: Defining the Load Cycle Boundary Conditions

S1 (Continuous Operation)

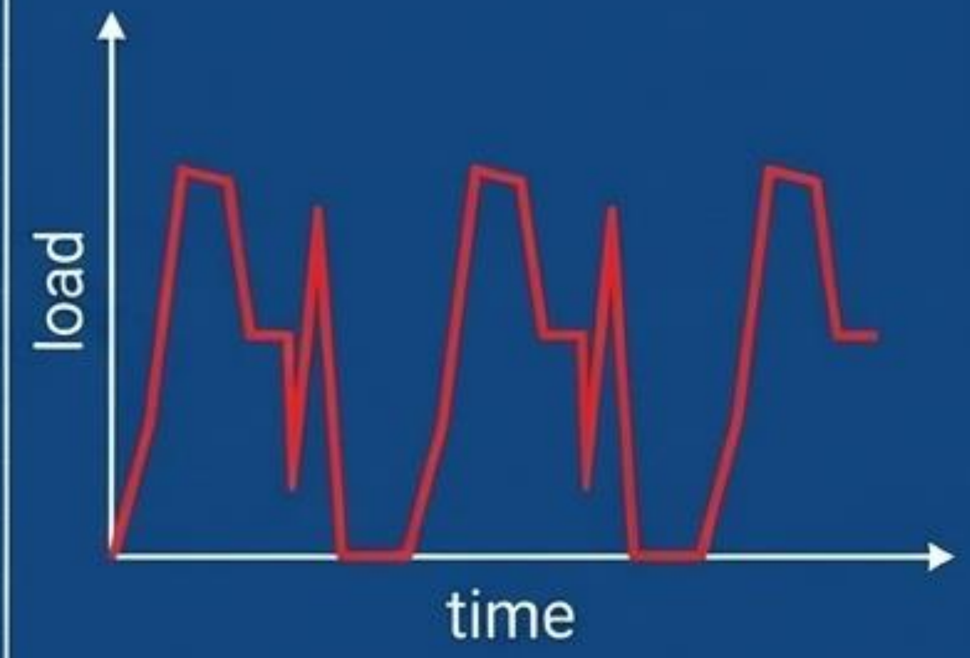


Operating long enough to reach thermal equilibrium.

S2 (Short Time Operation)

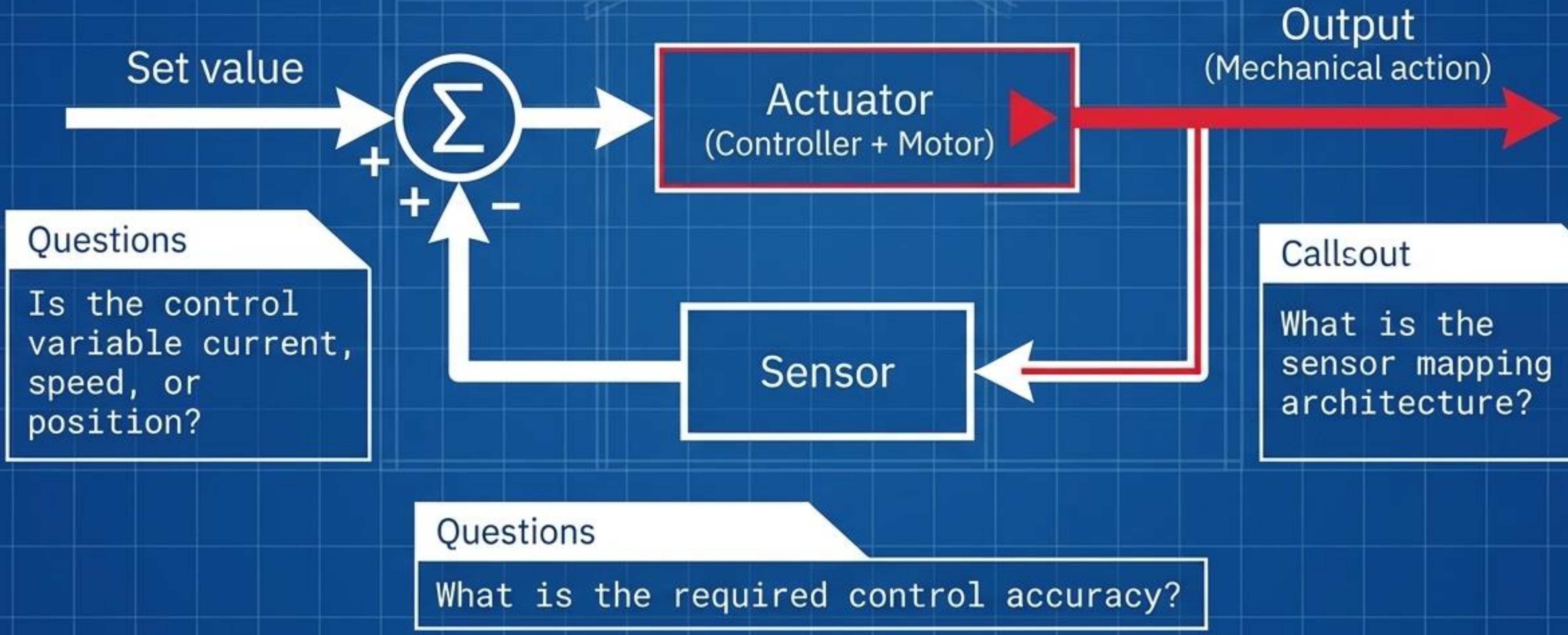
The motor cools completely between cycles.

S3 (Intermittent Operation)

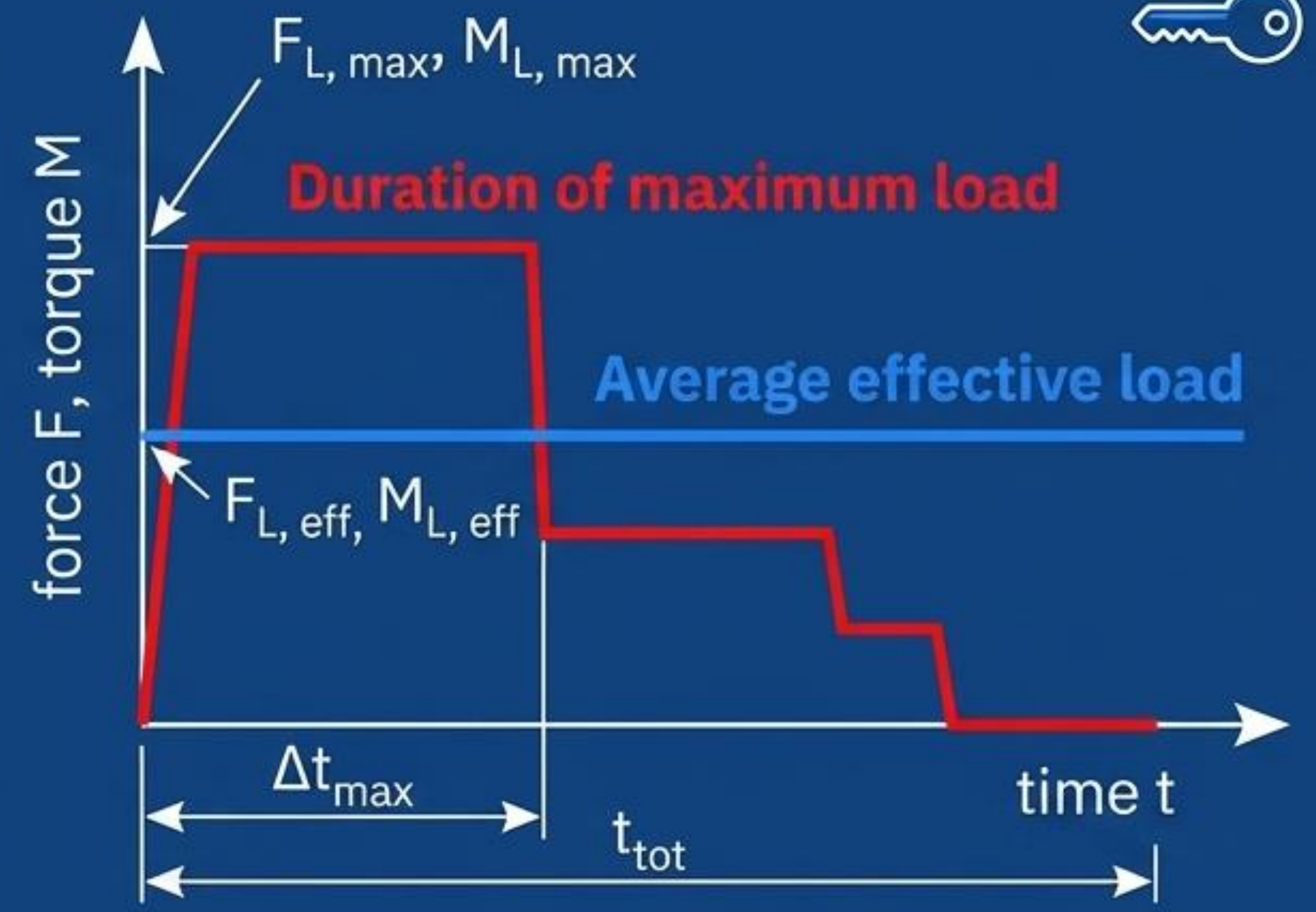


Repetitive duty cycles where the motor does not reach thermal equilibrium or cool down completely.

Step 1: The Preliminary Control Concept

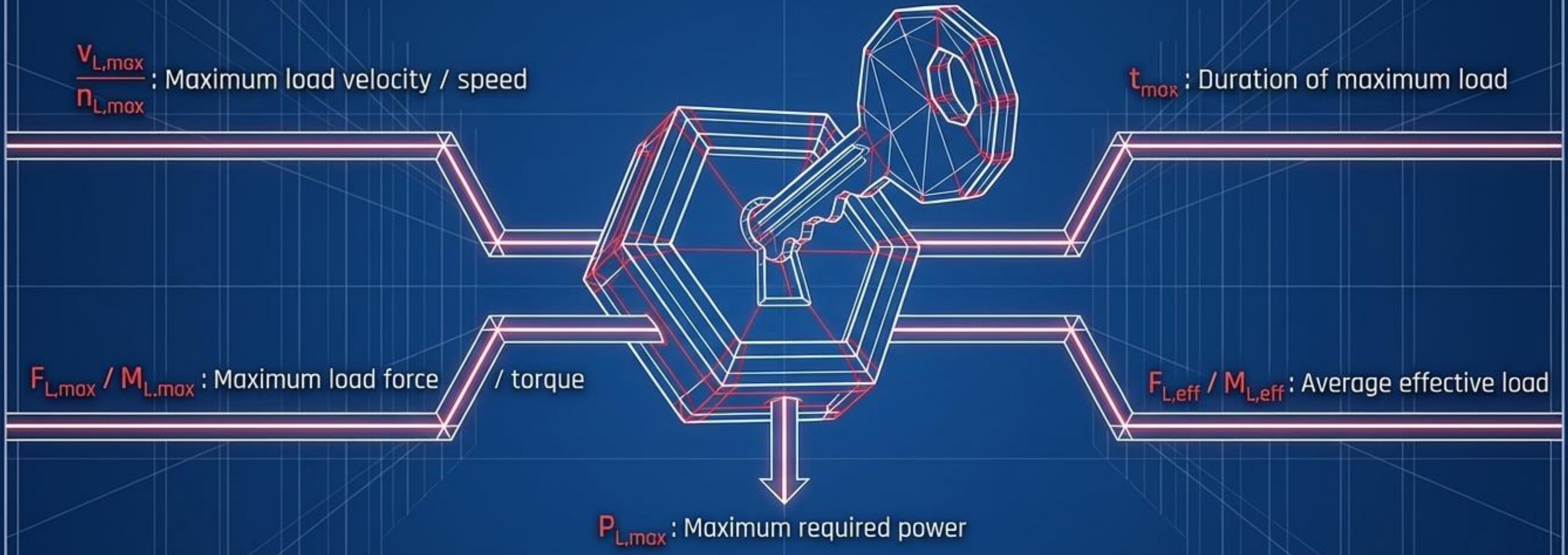


Step 2: Evaluating the Motion Profile



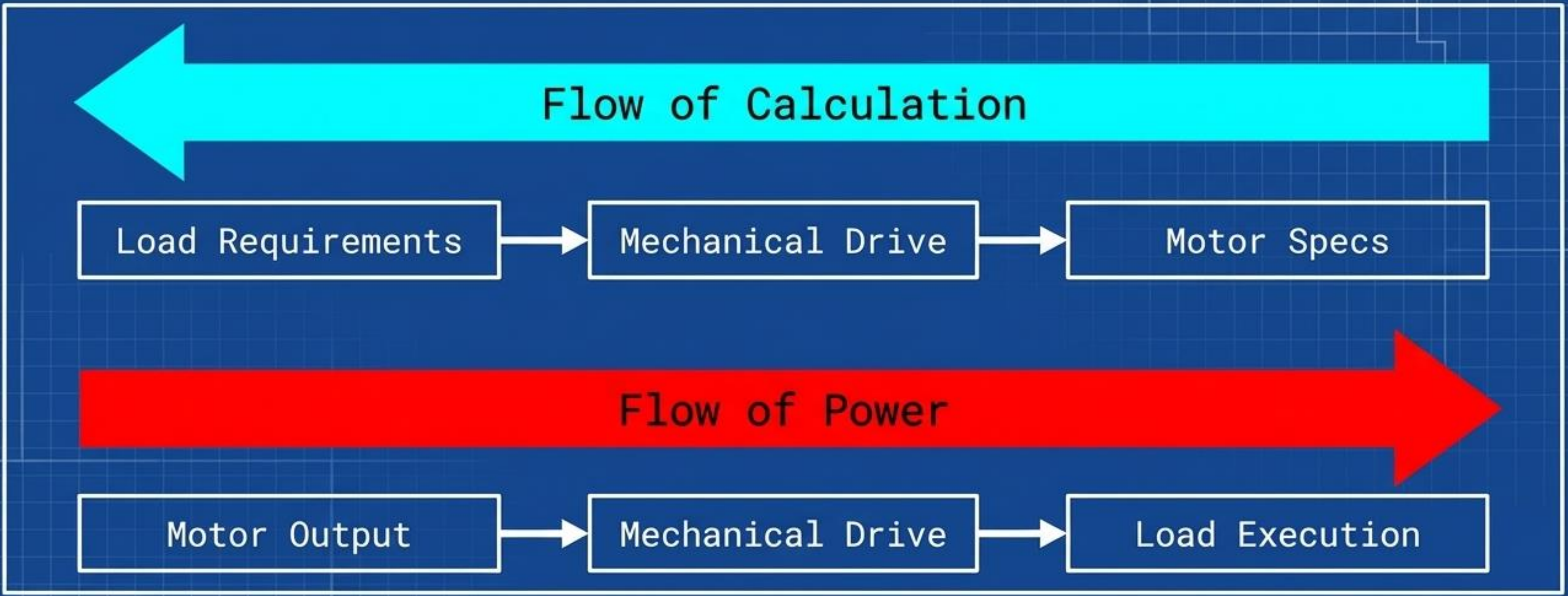
- To find the effective load, components from friction, acceleration, and constant forces are integrated.
- The time-weighted root mean square calculates the average effective load over the entire cycle (including dwell times).

Key Parameters Extracted: The Load Lockbox



These absolute values decouple the engineering math from the physical application, providing the baseline variables for mechanical transformation.

Step 3: Transformation of Parameters



Mechanical drives alter the fundamental physics. Power flows from the motor to the load, but the engineer's calculation must flow backward from the load requirements to determine the necessary motor specs.

Step 3: Evaluating Radial Bearing Loads

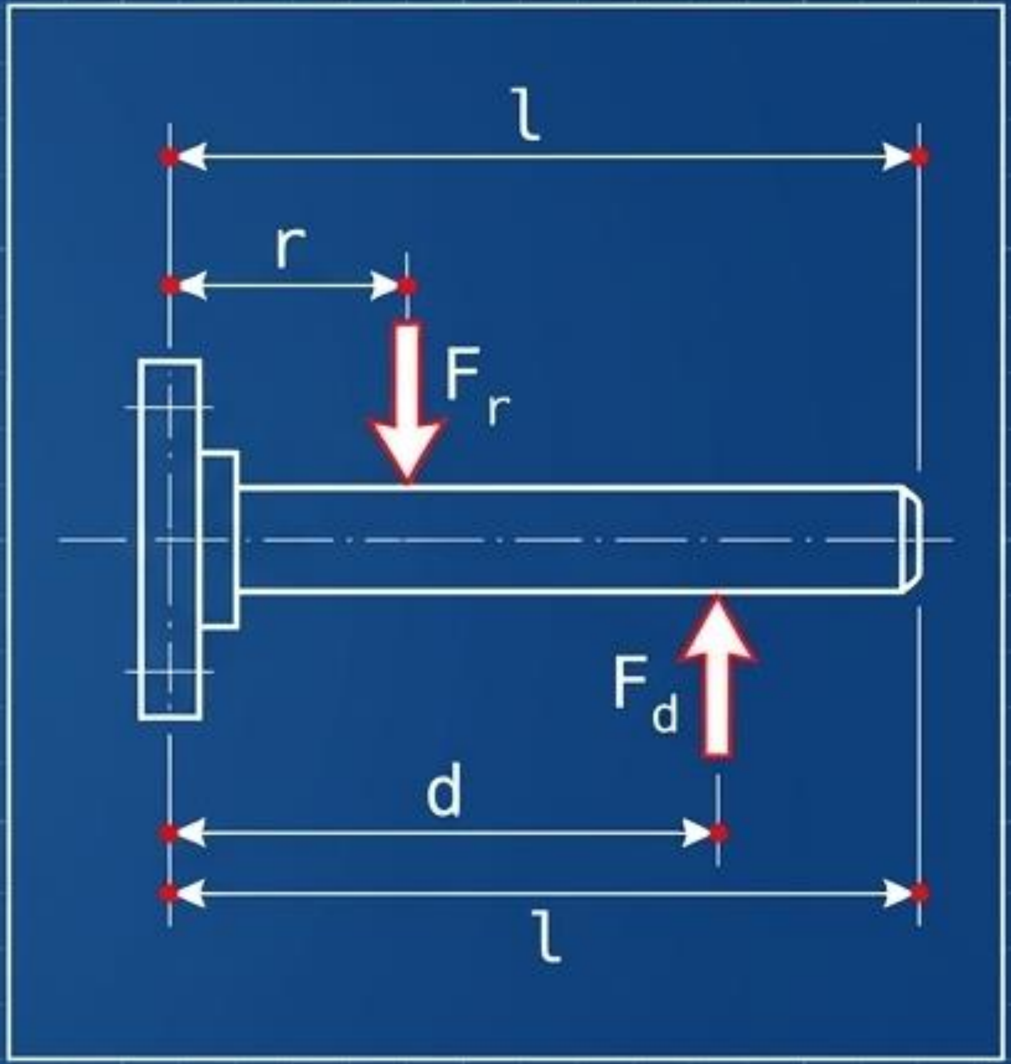
Maximum radial load at distance d from flange (N).

Distance of F_r specified in catalog (mm).

$$F_d = F_r * \left(\frac{r}{d}\right)$$

Maximum radial load from catalog value (N).

Distance of actual applied radial load (mm).



Long Motors (length l significantly longer than r or d):	$F_d = F_r$
Flat Motors & Gearheads (length l very short):	Use main equation.

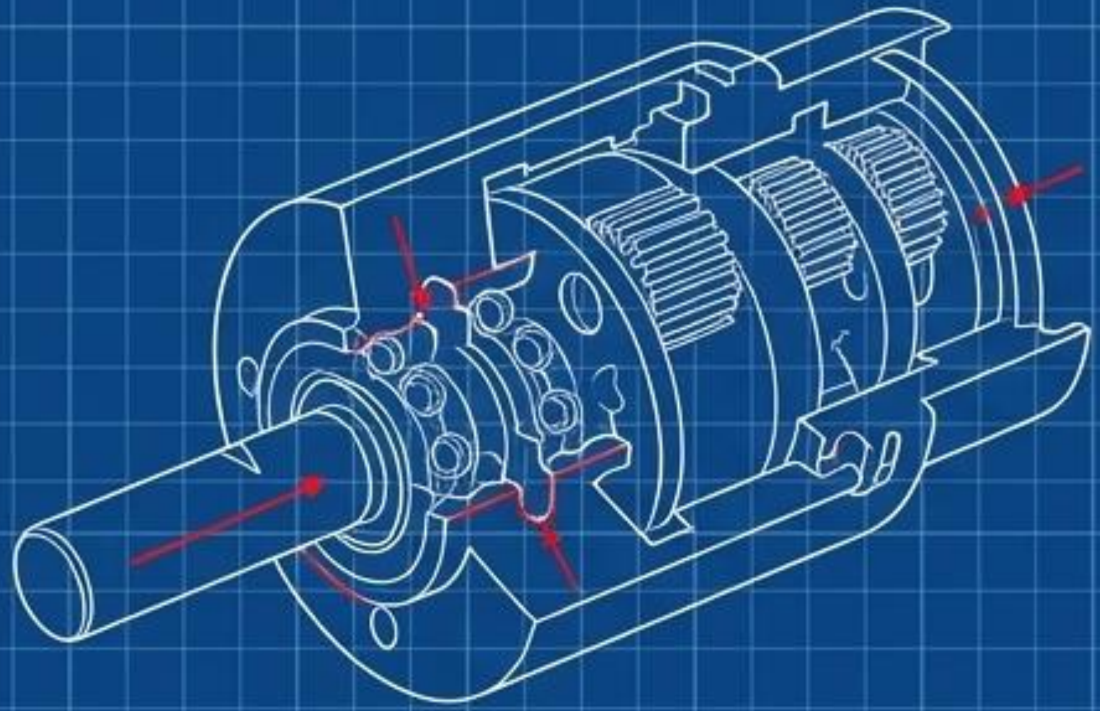
Step 4: Gearhead Power Diagnostics

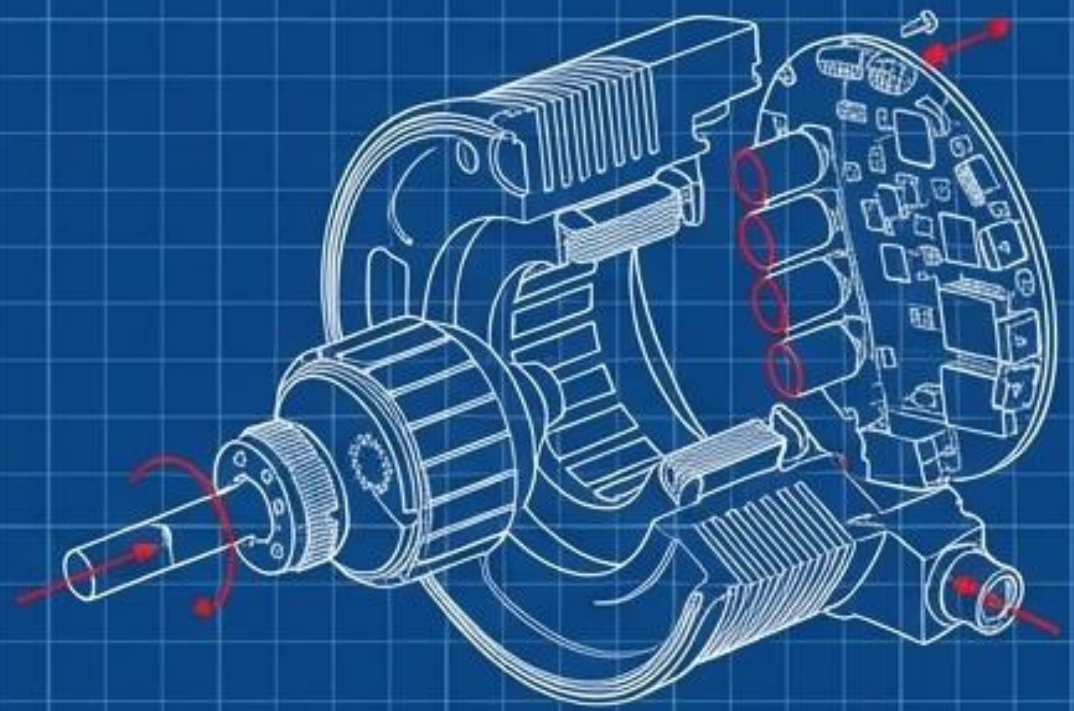
Gearheads are mandatory when required load speeds are below 1,000 rpm, trading speed for torque.

	Continuous Operation	Short-Time Operation
Output Power	$P_{G,cont} > P_{L,out,eff}$	$P_{G,short} > P_{L,out,max}$
Output Torque	$M_{G,cont} > M_{L,out,eff}$	$M_{G,short} > M_{L,out,max}$
Output Speed	$n_{G,cont} > n_{L,out}$	$n_{G,short} > n_{L,out,max}$

RULE SET: Short-time operations are strictly defined as lasting a **maximum of 1 second** AND comprising a **maximum of 10%** of the total duty cycle.

Transformation Complete: Motor Input Lockbox





Variables Collected (Transformed to Motor Shaft)

$n_{L,max}$: Maximum input speed required
$M_{L,max}$: Maximum input torque required
$M_{L,eff}$: Average effective torque required
$P_{L,max}$: Maximum required power at motor shaft

All external mechanical inefficiencies, inertias, and gear reductions have now been mathematically resolved. The problem is now purely electromechanical.

Step 5: DC vs. EC Commutation Architecture

DC Motors (Brushed)	**EC Motors (Brushless)**
- Mechanical commutation (graphite or precious metal brushes).	- Electronic commutation (requires external controller).
- Simple control architecture (direct DC voltage).	- Extremely high maximum speeds (up to 120,000 rpm).
- Lower maximum speeds due to brush wear.	- Virtually unlimited lifespan (limited only by ball bearings).
- Lifespan limited by brush degradation.	- Supports advanced sinusoidal commutation (FOC) for optimal smoothness.

Torque determines the motor size; speed determines the motor type.

Step 5: Calculating the Theoretical Speed Constant ($k_{n,theor}$)

Variable Isolation Card

Theoretical speed constant (rpm/V).

Maximum load speed (rpm).

Speed/torque gradient from catalog (rpm/mNm) -- the steeper the gradient, the weaker the motor.

$$k_{n,theor} = \frac{n_{L,max} + (n / M) * M_{L,max}}{U_{mot}}$$

Maximum load torque (mNm).

Motor voltage available (V).

TAKEAWAY: This formula calculates the exact rpm/V mapping required to achieve the highest physical demand of the cycle at the available voltage limit.

Step 5: Winding Selection & The 20% Control Reserve

$$k_{n,theor} \rightarrow k_n \geq 1.2 \cdot k_{n,theor}$$

Fixed Voltage Source (Uncontrolled)

Select a winding where the catalog k_n is as close to $k_{n,theor}$ as possible.

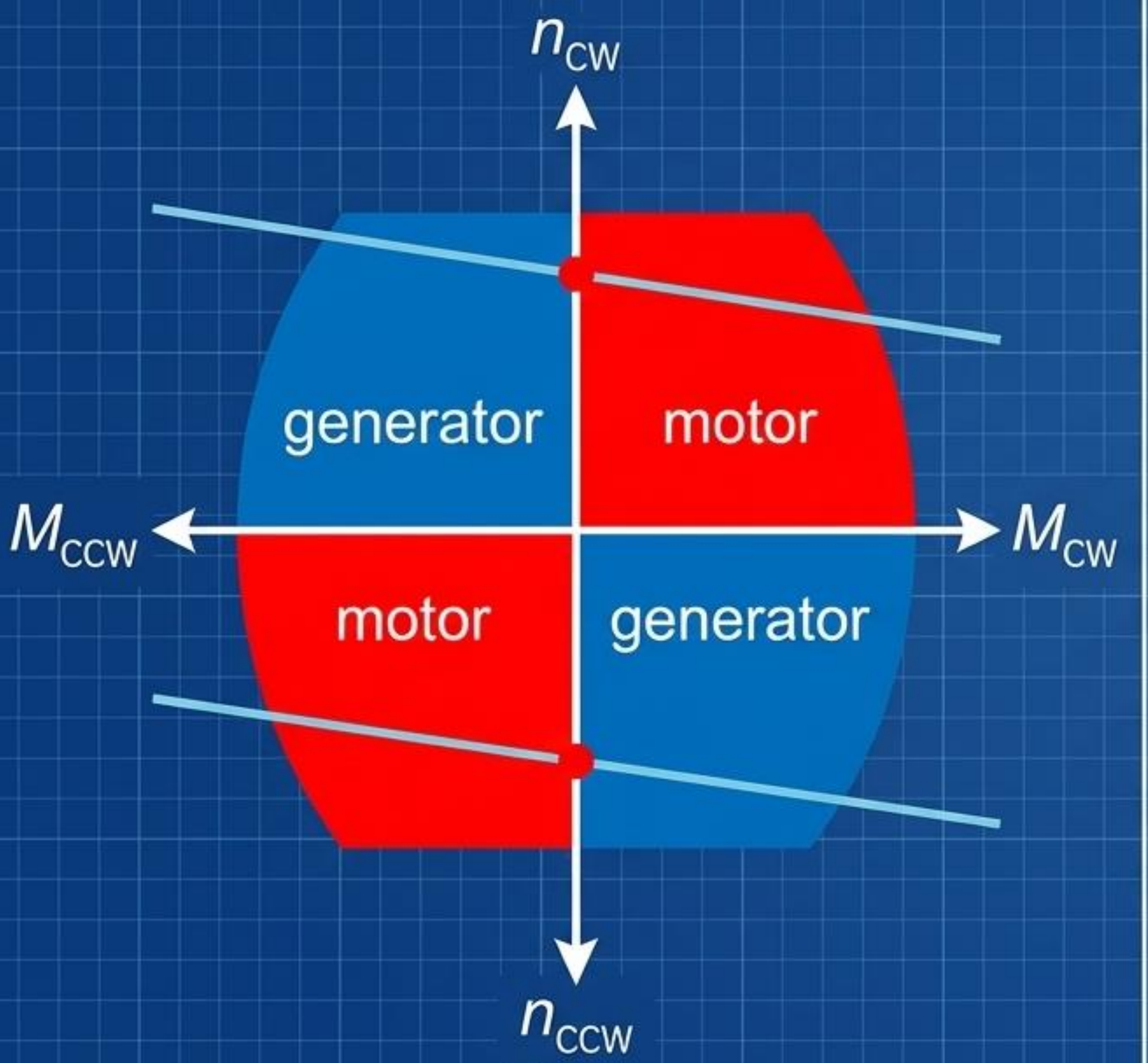
Controlled Operation (Closed Loop)

You must add a 20% safety margin to $k_{n,theor}$ and select the next highest speed constant.

The Trade-off

This 20% serves as a voltage reserve allowing the controller to dynamically correct errors at peak load. **However, selecting a k_n that is TOO high will inefficiently spike required motor currents.**

Step 5: Generator Operation Mathematics



Variable Isolation

Motor (U_{mot})

$$U_{mot} = \frac{n + \frac{n}{M} * M}{k_n} = \frac{n}{k_n} + R * I$$

Generator (U_{gen})

$$U_{gen} = \frac{n - \frac{n}{M} * M}{k_n} = \frac{n}{k_n} - R * I$$

TAKEAWAY: In generator quadrants, the direction of current I and torque M changes. The generated voltage drops by R * I rather than increases by it.

The Electrical Lockbox: Unlocking Controller Needs

Variables Collected (The Demands on the Controller)

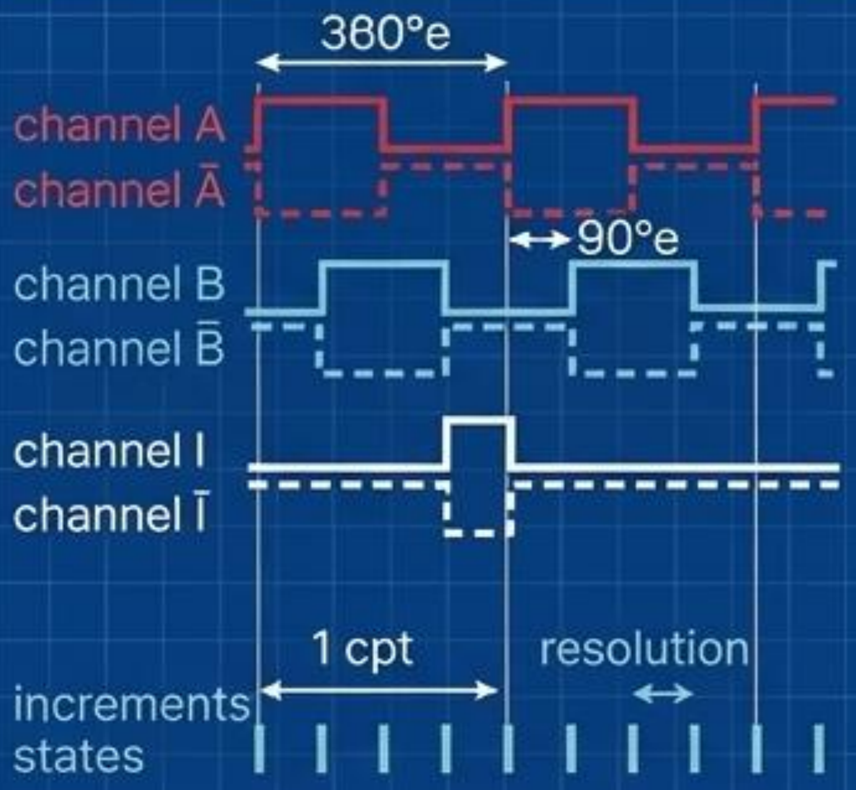
- V_{CC} : Required Supply Voltage
- I_{max} : Maximum required motor current
- t_{max} : Duration of the maximum current draw
- I_{eff} : Average effective RMS current

The mechanical system has now been entirely translated into an electrical footprint. The controller must seamlessly supply these exact electrical values without overheating.

Step 6: Sensor Matrix & Signal Topologies

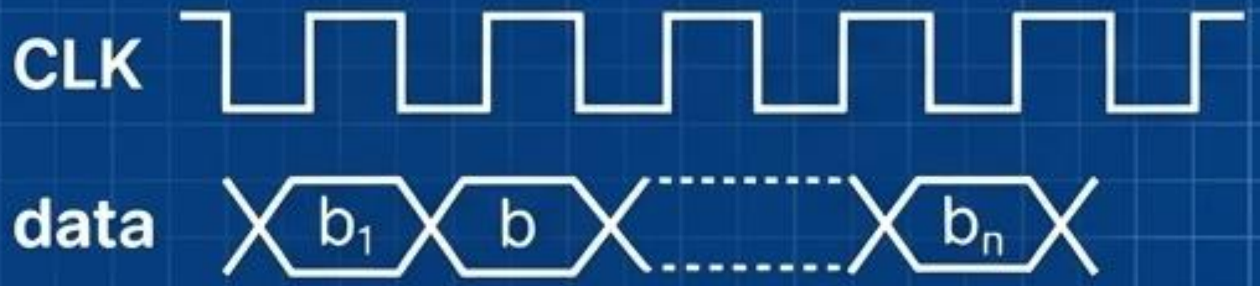
Digital Incremental Encoders

- Generates A and B channels (90 degree phase shifted).
- Requires a homing procedure upon startup.
- Line Driver Standard: Generates complementary signals to violently reject electromagnetic interference in long cables.

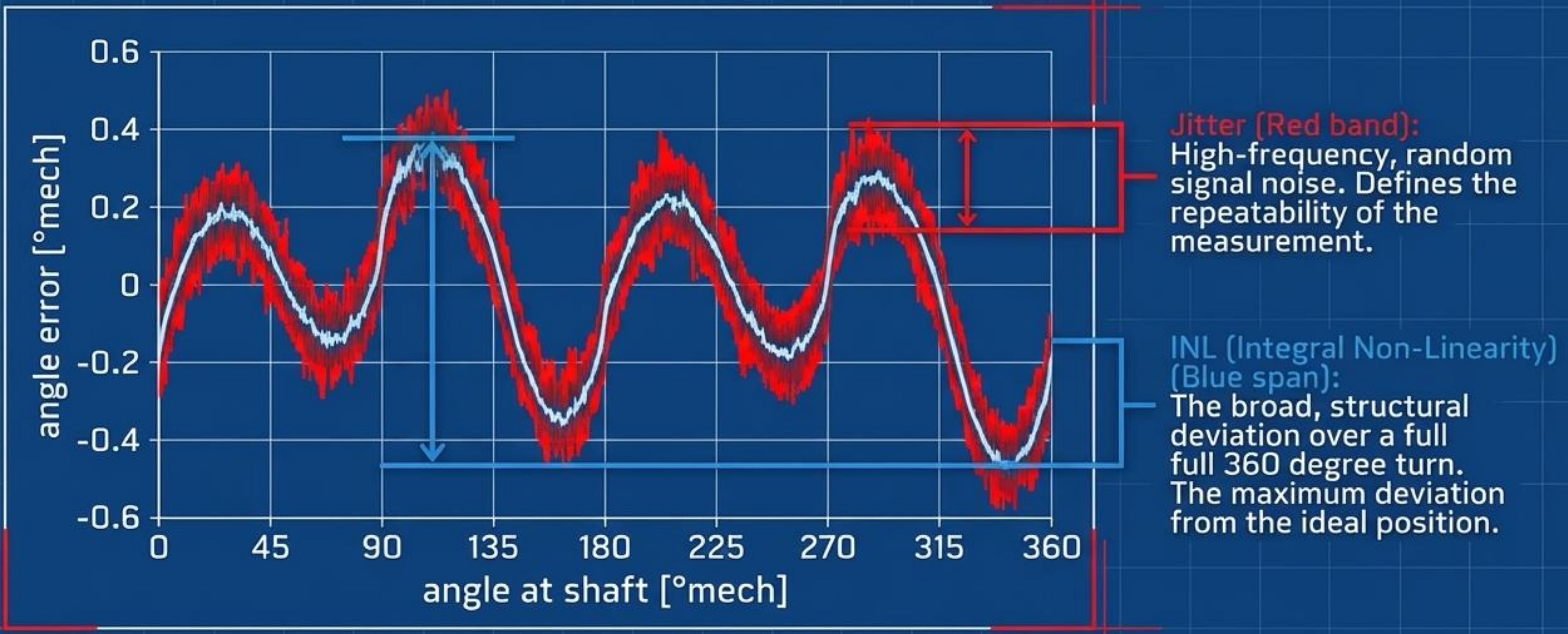


Digital Absolute Encoders

- Reports exact angular position immediately via data string.
- No homing procedure required.
- Protocols: SSI or Biss-C.



Step 6: Deconstructing Sensor Accuracy



High resolution (counts per turn) does not automatically equal high accuracy. Accuracy is dictated by manufacturing tolerances of the codewheel and the magnitude of INL.

Step 6: The Controller Integration Hub

Power Consideration

Must handle V_CC and I_max.

System Communication

CANopen, EtherCAT, RS232, or simple I/O logic.

Motor Compatibility

DC vs EC, block vs sinusoidal (FOC) commutation.

Feedback Integration

Adapters, 5V logic supply, understanding line driver/SSI inputs.

Step 6: The Final Voltage Verification

Variable Isolation Card

Available supply voltage from the power unit (V).

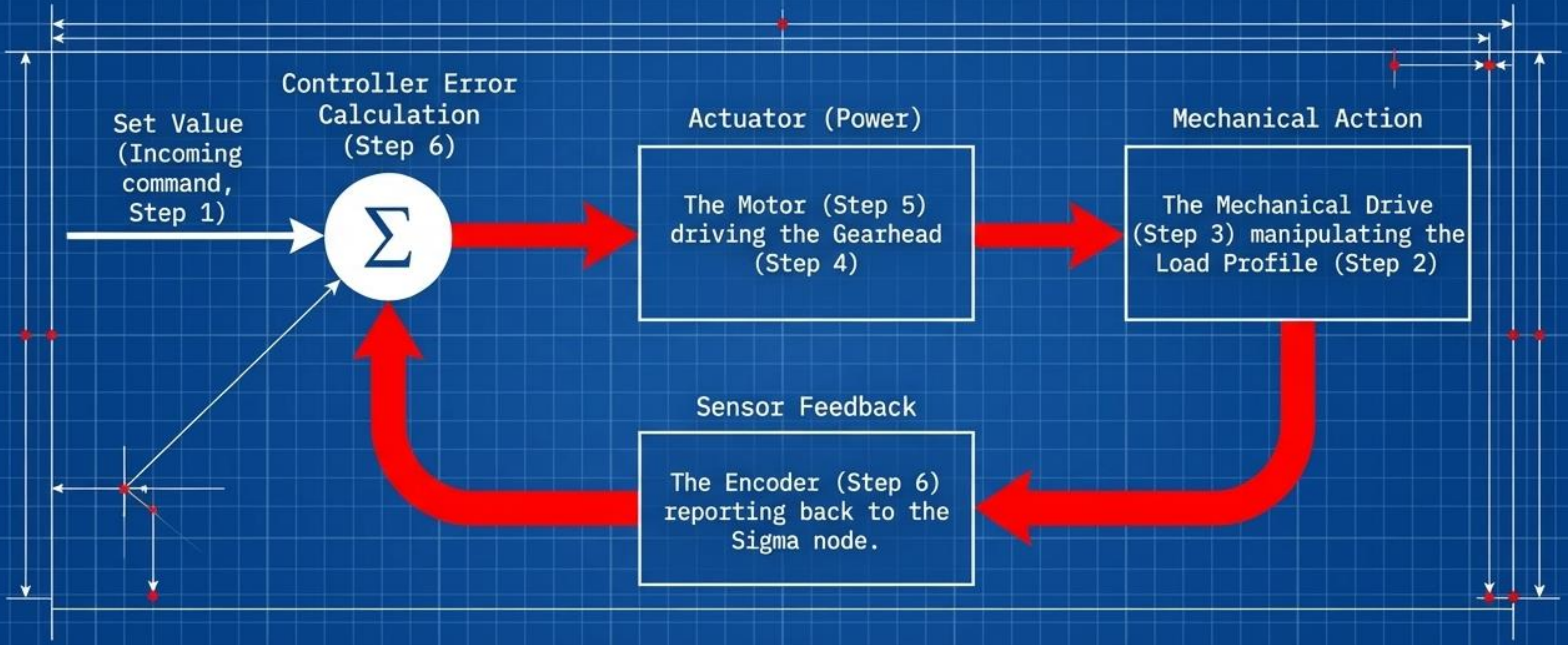
$$V_{CC} >= U\_mot + U$$

Required motor voltage for extreme operating point (V).

Voltage drop within the controller's power stage (Typically 1% to 10% depending on PWM topology).

The controller is not a perfect conductor. If the power supply V_{CCC} cannot overcome both the motor's voltage demand AND the controller's internal voltage drop, the extreme operating point is physically impossible.

The Grand Reassembly: The Closed-Loop System



The 6-step algorithm is not linear; it is circular. Every calculation ensures this loop remains stable under maximum dynamic stress.

The maxon Methodology Blueprint Reference

Step 1 | Situation	Defines Duty Cycles (S1/S2/S3) & Base Accuracy.
Step 2 | Load	Extracts $F_{L,max}$, $M_{L,max}$, t_{max}, $P_{L,max}$
Step 3 | Mech Drive	Inverts Power Flow into Calculation Flow.
Step 4 | Gearhead	Validates $P_{G,cont}$ and transforms to $M_{L,in}$, $n_{L,in}$.
Step 5 | Motor	Calculates $k_n \geq 1.2 \cdot k_{n,theor}$ yielding I_{max} and U_{mot}.
Step 6 | Controller	Verifies $V_{CC} \geq U_{mot} + U$ & closes the sensor loop.

End of Masterclass // Reference: The selection of high-precision microdrives, maxon academy 2025