SHENZHEN PROMAGTECH CO.,LTD. | High-Performance Magnetic Solutions

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Thermal Design & Temperature-Rise Testing for High-Current Magnetics

Loss sources, the thermal path, ΔT estimation, and how to actually measure temperature rise

Item	Detail
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Document	Thermal Design & Temperature-Rise Testing for High-Current Magnetics
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DATA NOTICE Calculated / simulated values in this document are design references only; final acceptance is per sample test data and the signed approval sheet.

Summary & key takeaways

Bottom line

There is no magic in magnetic temperature rise: ΔT ≈ Rth × (copper loss + core loss). Cooling by design has exactly two levers — cut loss (low-DCR flat wire, AC-loss control, flux control) and cut thermal resistance (surface area, thermal path, airflow, thermally conductive potting). For measurement, three methods each have a role: thermocouple (hot spot), IR camera (surface map), and the ΔDCR method (winding-average rise — the truest measure of what the insulation experiences). The rise limit is derived from the insulation thermal class, not guessed.

Key takeaways:

- **Only two heat sources:** copper loss (I^2R + HF AC) and core loss ($k \cdot f^{\alpha} \cdot B^{\beta}$). Get the loss right before estimating the rise.
- **Four thermal-path segments:** winding → core/potting/bobbin → surface → air (convection + radiation). Each can be improved.
- **Quick estimate:** ΔT ≈ Rth × P; for small naturally-cooled parts Rth can be roughed from surface area; forced air cuts Rth substantially.
- **How the limit is set:** insulation class (155/180/200 °C) − max ambient − margin = allowed rise.
- **Three measurement tools:** thermocouple for hot spot, IR for distribution, ΔDCR for winding average — different roles, not interchangeable.
- **Flat wire is the first thermal lever:** ~30 % lower DCR in the same window removes a large slice of the biggest heat source.

> **Note** Values are typical/illustrative; rise and Rth depend strongly on structure and installation — confirm by sample test under real conditions.

1. Where heat comes from: get the loss right first

The numerator of temperature rise is loss. A high-current magnetic has exactly two loss families:

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Copper:  P(Cu) = I²rms × DCR × (Rac/Rdc)   — Rac/Rdc set by skin + proximity at HF
Core:    P(core) = k · fsᵅ · ΔBᵝ × Ve      — Steinmetz, coefficients from the material datasheet
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- **High current, lower frequency (PFC, storage):** copper loss usually dominates — where low-DCR flat wire pays most.
- **HF transformers (hundreds of kHz–MHz):** core and AC copper loss take over — control ΔB and interleave windings.

> **Rule of thumb** Build a loss-split table (watts of copper vs core) before discussing cooling. Different splits need different fixes — add copper if copper-dominated, cut ΔB or change material if core-dominated.

2. Where heat goes: the thermal path and Rth

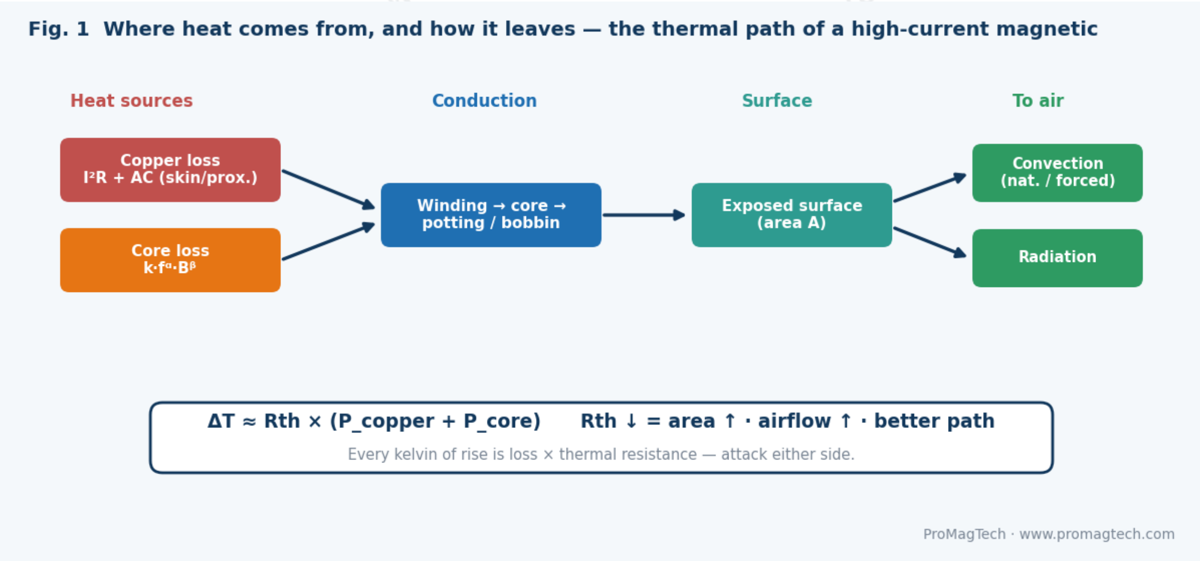

Fig. 1 — The thermal path of a high-current magnetic: sources → conduction → surface → air.

Heat leaves the part through four segments, each with its own resistance; the total Rth sets the rise for a given loss:

Segment	Governed by	Improvement
Winding interior → surface	winding structure, varnish/potting	edge-wound flat wire (short layer path), thermal potting
Core/bobbin → surface	contact area, material conductivity	thermal pads/glue, metal-base mounting
Surface → air (convection)	surface area A, airflow	more area, ducting, forced air
Surface → surroundings (radiation)	emissivity, ΔT	matte/dark surface helps slightly

Table 1 — Four thermal-path segments and their fixes

Quick estimates (common empirical form for small, naturally cooled parts):

> $\Delta T(K) \approx [\, P(mW) / A(cm^2) \,]^{0.833}$ (surface-power-density rule; order-of-magnitude only)
> or $\Delta T \approx R_{th} \times P$, with Rth calibrated by sample test and reused for similar builds

> **Caution** Empirical rules are for magnitude checks only. Structure, potting, mounting and neighboring heat sources all shift Rth — final numbers must be measured.

3. Setting the rise limit: derive it from the insulation class

The rise limit is derived, not guessed:

> Allowed rise $\Delta T(max)$ = insulation class − max ambient − design margin
> e.g. class 180 °C (H), automotive Grade 1 ambient 125 °C, 15 K margin → $\Delta T \le 40$ K

- **Why the margin:** hot spots exceed the average rise, and insulation life halves roughly every 8–10 °C.
- **Automotive:** take worst-case ambient by mounting location — see the AEC-Q200 article for Grades.

4. Measuring the rise: three methods, three roles

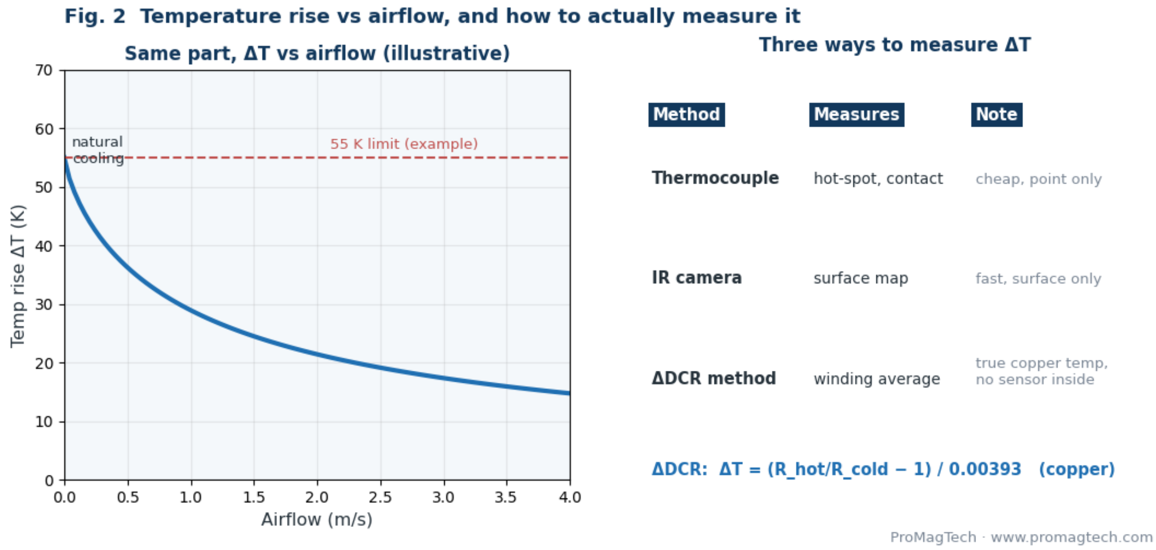

Fig. 2 — Rise vs airflow (illustrative) and the three measurement methods.

Method	Measures	Strength	Limit
Thermocouple	hot-spot (contact)	cheap, direct	point only; wires disturb winding
IR camera	surface map	fast, whole view	surface only; emissivity must be calibrated
ΔDCR method	winding average	true copper temperature, no embedded sensor	an average; hot spot is higher

Table 2 — The three rise-measurement methods

The ΔDCR method is the industry-standard winding-rise measurement — copper resistance varies linearly with temperature, so measure resistance at power-off and back out the temperature:

> $\Delta T = (R(hot) / R(cold) - 1) / 0.00393$ (copper temperature coefficient $\alpha \approx 0.00393$/K)
> Procedure: measure R(cold) → run at full load to thermal equilibrium → power off, measure R(hot) fast → back out ΔT

> **Practical points** (1) Equilibrium criterion: <1 K change over 30 min; (2) extrapolate the resistance back to the power-off instant (multi-point regression); (3) combine with IR/thermocouple hot-spot correction. Using all three is what makes a complete rise report.

5. Engineering levers to cut the rise (by value for money)

Lever	Mechanism	Typical gain (illustrative)
Edge-wound flat wire vs round	higher copper fill → lower DCR	DCR ↓ ~30 %, copper loss with it
Stack / enlarge the core	turns ↓, H ↓, area ↑	copper loss and rise both fall (see the case study)
Thermal potting	fills internal air gaps	internal hot spot ↓, vibration bonus
Forced air / ducting	much higher convection	1–2 m/s can nearly halve the rise
Metal-base / thermal-pad mounting	conducts heat into structure	opens the bottom path, good for low profile
Reduce ΔB (HF parts)	core loss falls as ΔB^{β}	immediate where core-dominated

Table 3 — Levers to cut temperature rise (gains illustrative; confirm by test)

6. DVP: thermal validation baseline

Validation item	Method / instrument	Acceptance (example)
Loss split	power analyzer + calculation	copper/core match budget
Average rise ΔT	ΔDCR method	≤ limit (derived from insulation class)
Hot-spot temperature	thermocouple + IR	hot spot ≤ class − margin
Thermal equilibrium	continuous monitoring	<1 K change over 30 min
High-temp operating life	HTOL (see AEC-Q200 article)	per project
Batch consistency	sampling	DCR/rise spread < ±spec %

Table 4 — Thermal validation baseline (acceptance per project)

7. Frequently asked questions (FAQ)

Q Judge by average rise or hot spot?

A Both. ΔDCR gives the winding average that drives mean insulation ageing; the hot spot (thermocouple/IR) sets the worst point. Pass criteria apply to both — average against the class, hot spot against the class ceiling.

Q Why does my IR reading sit below the ΔDCR result?

A IR sees only the surface; the winding interior runs hotter, especially in potted parts. IR alone underestimates winding temperature — pair it with ΔDCR.

Q How much does forced air help vs natural cooling?

A As an order of magnitude, 1–2 m/s often cuts the rise to roughly half of natural cooling (structure-dependent). That's why sample rise tests must agree the airflow condition, or data isn't comparable.

Q How much does flat wire help the rise?

A About 30 % lower DCR in the same window, with copper loss falling in step — in copper-dominated high-current parts this is usually the cheapest large slice of thermal gain.

Q What's a typical rise limit?

A There is no universal number — derive it: class − max ambient − margin. 40–65 K is common, tighter in hot automotive environments.

Q Does potting raise the temperature?

A Usually the opposite: proper thermal potting fills internal air gaps and lowers internal hot spots, at the cost of longer time to equilibrium. Choose by conductivity and CTE match.

Q How does ProMagTech report rise data?

A At the agreed operating condition (current, frequency, airflow, ambient) we test with both ΔDCR and hot-spot methods and deliver a rise report with the loss split and equilibrium curve, together with samples.

8. Glossary

- **Rth (thermal resistance) —** Rise per watt of loss, K/W; total Rth sets ΔT.
- **ΔDCR method —** Backing out winding-average rise from copper's linear resistance-temperature relation.
- **Hot spot —** The hottest internal point, usually in the inner winding layers.
- **Thermal equilibrium —** Steady state where rise no longer changes; commonly <1 K per 30 min.
- **Insulation thermal class —** The long-term temperature rating of the insulation system (155/180/200 °C etc.).
- **Steinmetz equation —** Empirical core loss $P=k\cdot f^{\alpha}\cdot B^{\beta}$ with datasheet coefficients.
- **HTOL —** High-temperature operating life test — essentially an insulation-life test.

9. Further reading

This guide is part of the ProMagTech 800 V Power Magnetics Selection Reference; related deep-dives:

- 800 V Power Magnetics Selection Reference (the pillar map)
- Anonymized case: 11 kW totem-pole PFC inductor (a worked loss-rise example)
- Choosing a powder core (core loss & materials)
- AEC-Q200 & automotive reliability (Grades & HTOL)
- Flat wire vs round wire inductors (DCR & copper loss)
- AIDC / energy-storage PCS high-current inductor design
- 48 V AI datacenter: the thermal dead zone of round wire

10. About ProMagTech

SHENZHEN PROMAGTECH CO.,LTD (founded 2013, Shenzhen) designs and manufactures flat-wire inductors, planar transformers, common-mode chokes and PFC inductors for 800 V EV OBC and DC charging, AI-datacenter power, energy-storage PCS, solar inverters and industrial power. Rise testing is delivered with both ΔDCR and hot-spot methods at the agreed operating condition.

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