

NanoArc Rumi Passive PCM Thermal Cartridge Proposal

Hybrid heatsink / beeswax phase-change thermal cartridge with ACE-assisted forced-air recharge

Field	Value
Document	NanoArc Rumi Thermal Cartridge Proposal
Revision	Rev 0 - concept review draft
Date	2026-08-12
Scope	Cooling concept for RevC / Rumi output-stage thermal management
Source basis	Notebook sketches supplied in conversation, plus current NanoArc thermal architecture discussion

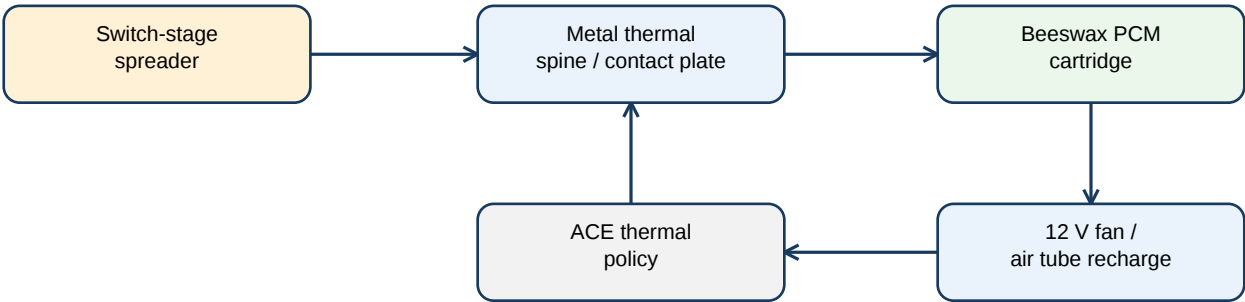
Configuration note

This proposal does not define high-current output construction, pulse-bank sizing, or an energized operating procedure. It defines a passive-first cooling cartridge concept that can be modeled, prototyped and thermally characterized before being credited for duty-cycle improvement.

Core design rule: Passive metal thermal mass keeps the unit safe; the phase-change cartridge buys burst duty cycle; ACE only activates the fan path to speed cooldown and re-solidify the cartridge.

1. Proposal Summary

The proposed Rumi thermal cartridge is a handmade, replaceable thermal buffer for the Weld Energy Stage. It is intended to absorb heat passively through a metal contact face and embedded heat-spreading matrix, then recover faster when ACE commands a small fan or blower through an isolated metal air tube.



Heat is absorbed passively; ACE only speeds recovery by forcing air across the cartridge air path.

The design intentionally avoids proprietary vapor chambers, sealed pressure devices, glycol loops and production-line-only parts. The cartridge body itself is the mold: a commodity metal shell filled with beeswax around a metal heat-exchanger core.

Design intent

- Passive-safe: the unit must remain safe with the fan failed, disconnected or blocked.
- Handmade and replaceable: no critical reliance on a discontinued commercial module.
- Affordable: use common metal stock, beeswax, copper mesh/braid, a standard fan, thermistor and screws.
- Testable: the cartridge must expose temperature and recovery behavior that ACE can monitor.
- Non-energized development path: first prototypes can be tested with dummy heat sources before integration.

Recommended terminology

Preferred name	Meaning
Passive PCM Thermal Cartridge	The replaceable beeswax thermal buffer and embedded metal heat exchanger.
Thermal spine	Rumi metal chassis or switch-stage spreader that conducts heat to the cartridge.
ACE-assisted recharge	Fan-driven cooldown that removes heat from the cartridge and re-solidifies the PCM.

2. Notebook Sketch Context

The following sketches supplied the immediate design context: a beeswax PCM cartridge, embedded airflow tube, wire mesh or metal matrix, cooling shunt, air holes, and a 12 V fan. These figures are contextual concept sketches, not dimensioned CAD.

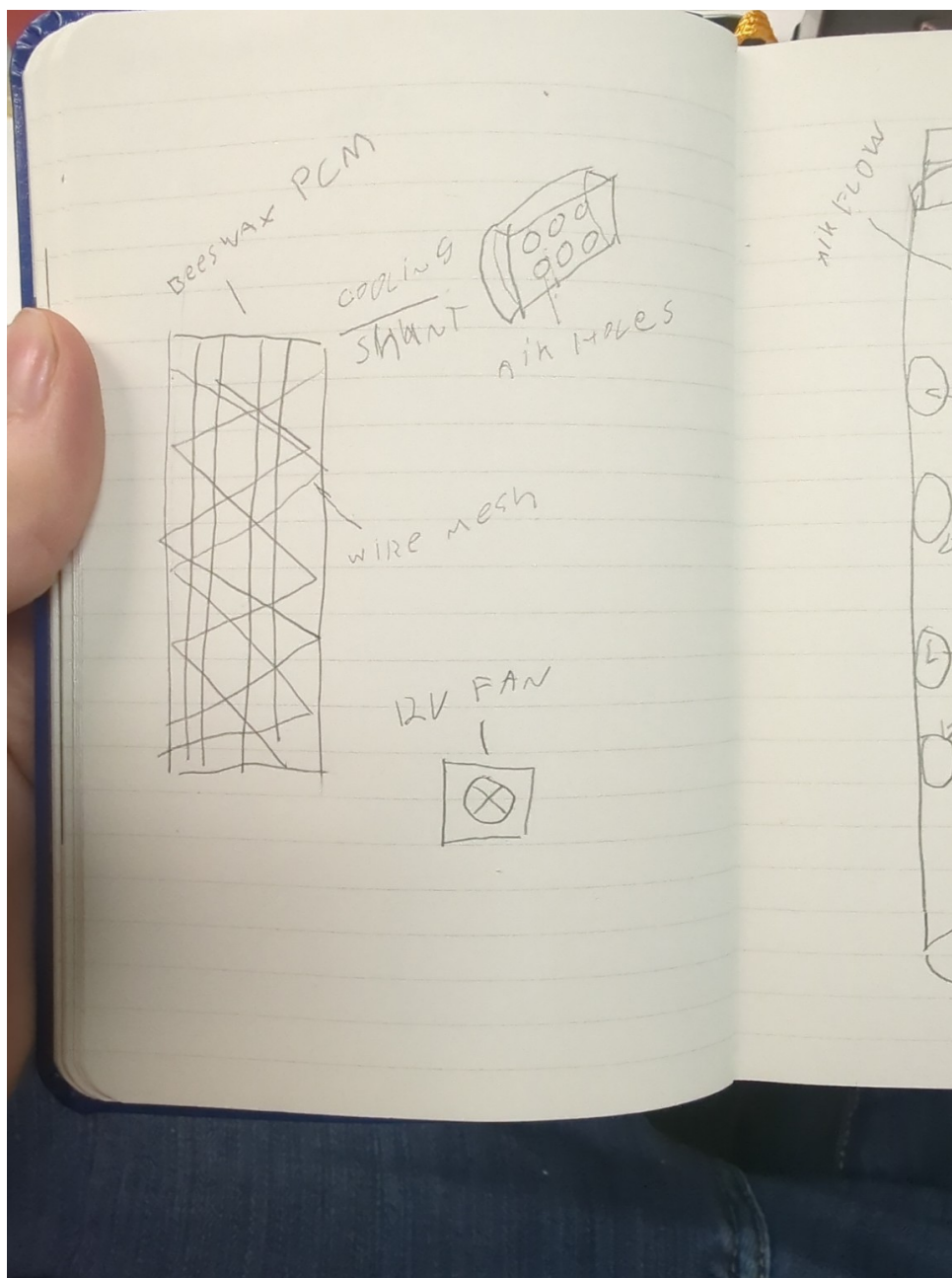


Figure 1. Notebook sketch showing beeswax PCM volume, cooling shunt, wire mesh, air holes and a 12 V fan concept.

2. Notebook Sketch Context (continued)

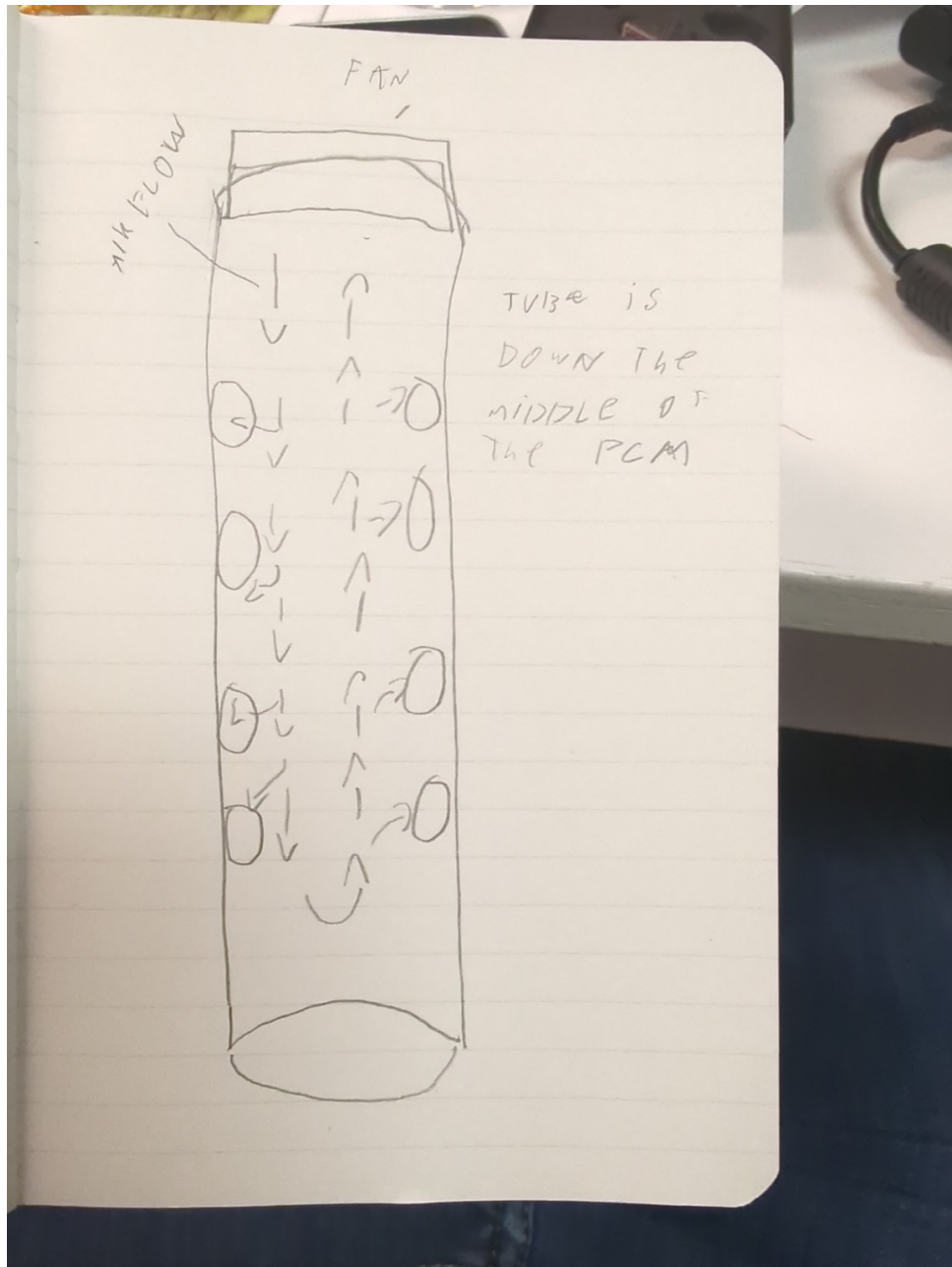
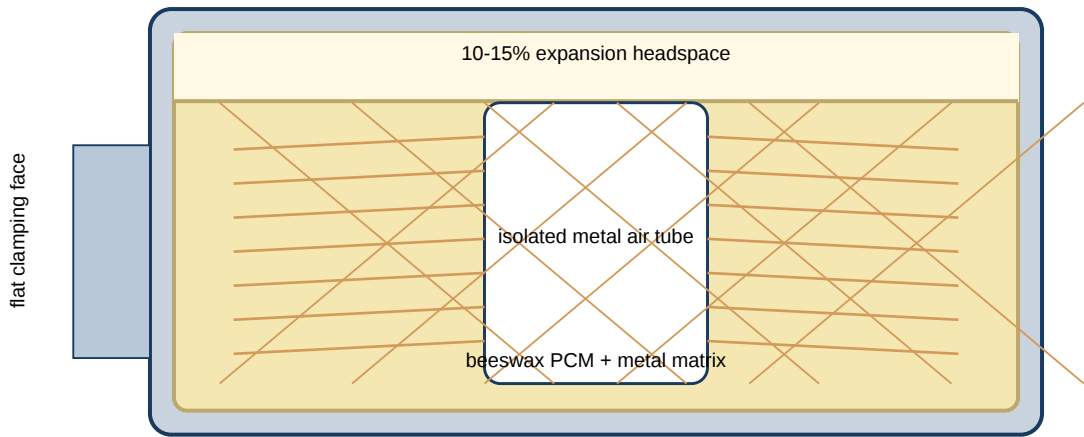


Figure 2. Notebook sketch showing a vertical cartridge concept with fan at top, airflow down the middle of the PCM, and side features/ports.

3. Proposed Cartridge Architecture

The cartridge should be built as a metal container with a flat clamping face, a sealed metal airflow tube running through the PCM region, and an internal metal matrix to conduct heat into and out of the beeswax. Air must not pass through open wax; it passes through or across metal surfaces that are thermally bonded to the wax volume.



Conceptual cross-section, not to scale. Air path is isolated from the wax cavity.

Functional stack

- Weld Energy Stage switch/spreader
 - > metal thermal spine / clamp face
 - > cartridge contact plate
 - > embedded copper/aluminum matrix
 - > beeswax PCM melt band
 - > isolated fan-cooled metal air tube
 - > ambient air during ACE-assisted recharge

Key physical features

Feature	Purpose	Notes
Flat contact plate	Moves heat from Rumi thermal spine into cartridge	Must clamp mechanically; do not rely on glue for thermal contact.
Metal shell	Acts as mold, containment and heat spreader	Rectangular aluminum or copper/brass box/tube preferred.
Isolated air tube	ACE fan moves air without contacting wax	Tube interior must remain dry and clear.
Metal matrix	Distributes heat through otherwise low-conductivity wax	Copper braid, mesh, folded sheet or perforated fins.
Expansion headspace	Prevents bulging/leaks as wax warms	Reserve roughly 10-15% internal volume.
Sensor pocket	Lets ACE infer cartridge state	Thermistor bonded to matrix or near contact face.

4. Thermal Operating Concept

The cartridge should operate far below any ignition-risk region for beeswax. Its purpose is to use the melt/softening band as a thermal buffer, not to run as a hot liquid reservoir. If the cartridge ever approaches severe thermal fault temperatures, ACE should already have inhibited operation.

Temperature region	Meaning	ACE action
Below 45 deg C	Cartridge mostly recovered; passive thermal spine handles normal heat	Fan off unless post-test cooldown is requested.
50-55 deg C	Beeswax begins useful softening/melting behavior	Fan allowed after pulses or during cooldown.
55-65 deg C	Primary PCM absorption band	Fan may run; repeat rate can remain within characterized limit.
65-70 deg C	Cartridge/spreader becoming saturated	Derate repetition rate; prompt cooldown if trend continues.
75-80 deg C at switch spreader	Hard thermal boundary for concept phase	Inhibit output; fan forced on; require measured recovery.
90-100 deg C inferred cartridge region	Severe thermal fault territory	Treat as abnormal fault; do not resume until inspected.

ACE does not activate the PCM directly. It activates airflow. The wax absorbs heat passively whenever the thermal spine is hotter than the cartridge. The fan only accelerates heat rejection from the air tube/fins so the wax re-solidifies faster.

Proposed ACE facts and commands

Signal / fact	Role
TSTAGE	Switch-stage spreader or hot plate temperature. Primary thermal policy input.
TPCM	Optional cartridge temperature near metal matrix/contact face. Strongly recommended for RevC.
TBANK	Pulse-bank temperature; should remain thermally protected from switch hot zone.
THAND	Handpiece/cartridge-adjacent temperature. Used for operator/tool thermal limits.
FAN_ENABLE	ACE-controlled forced-air recharge command.
FAN_TACH_OR_GOOD	Confirms fan motion or at least fan-good state when fitted.

5. Materials and Handmade Fabrication Path

The first practical cartridge should be built with the cartridge body as the wax mold. The mold remains part of the finished assembly. This avoids trying to cast a fragile free-standing wax block and then insert it into a housing.

Candidate build materials

Part	Preferred handmade material	Comments
Outer shell	Rectangular aluminum tube or folded metal box	Needs one flat face for clamping to thermal spine.
Contact plate	Aluminum or copper plate	Sanded flat; thermal paste or pad during testing.
Air tube	Brass, copper or aluminum tube	Sealed from wax cavity; 6-10 mm ID is a reasonable prototype region.
Internal matrix	Copper braid, copper mesh, folded copper sheet, perforated strip	Metal must penetrate the wax volume so heat is not moved by beeswax alone.
PCM	Beeswax	Accepted candidate because it is affordable, workable and handmade-friendly.
Sensor	NTC thermistor in metal pocket	Prototype can use salvaged printer thermistor after calibration/identification.
Fan	Standard 12 V fan or blower	Commodity replaceable part; not safety-critical.

Fabrication sequence for prototype cartridge

- Cut or fold the metal cartridge shell and prepare a flat contact face.
- Fit the metal air tube through the cartridge body and seal the tube from the wax cavity mechanically.
- Install copper mesh, braid or folded fins around the tube and tied to the contact face where practical.
- Add a thermistor pocket or sensor clamp on the matrix/contact face.
- Warm the empty shell gently so wax does not freeze instantly during filling.
- Pour melted beeswax in stages, tapping lightly to release bubbles and wet the metal matrix.
- Leave roughly 10-15% expansion headspace; do not fill completely solid to the cap.
- Close with a removable or inspectable cap. Avoid making a pressure vessel.
- Label mass, fill date, sensor type, and test cycle count.

6. Draft Requirements

These requirements are intended as proposal-level constraints for a RevC-compatible thermal cartridge. They can be promoted into the WES/Rumi thermal specification after bench testing.

ID	Requirement
RUMI-THRM-CART-001	The RevC thermal cartridge shall be noncritical: absence, fan failure, blocked airflow, poor contact or saturated PCM shall reduce duty cycle or inhibit operation rather than permit operation beyond characterized thermal limits.
RUMI-THRM-CART-002	The cartridge shall use a non-proprietary PCM and commodity metal construction so replacements can be handmade without a production line.
RUMI-THRM-CART-003	The airflow path shall be physically isolated from the PCM cavity. Air shall pass through a metal tube or across metal fins, not through exposed wax.
RUMI-THRM-CART-004	The cartridge shall include internal metallic heat-spreading features so heat is not transferred through bulk beeswax alone.
RUMI-THRM-CART-005	The cartridge shall include expansion headspace and shall not be built as a sealed pressure vessel.
RUMI-THRM-CART-006	The cartridge shall be mechanically removable and clamped to the thermal spine through a flat metal contact face.
RUMI-THRM-CART-007	A cartridge temperature fact, TPCM, should be fitted or reserved. If omitted in early prototypes, TSTAGE and cooldown trend shall be used as substitutes.
RUMI-THRM-CART-008	The cartridge shall be oriented and contained so softened PCM cannot drip into ACE electronics, connectors, pulse conductors, switches or vents.
RUMI-THRM-ACT-001	ACE may command a fan or blower to accelerate cartridge cooldown and PCM re-solidification. The fan path shall improve recovery time but not be required for basic safe containment.
RUMI-THRM-ACT-002	A cooldown recovery shall require measured temperature recovery, a minimum cooldown time, and a fresh operator action before another output cycle is allowed.

7. Failure Modes and Mitigations

Failure mode	Effect	Mitigation
PCM saturation	Cartridge stops absorbing useful heat; temperatures climb faster	TPCM/TSTAGE trend detection, derate, fan forced on, hard inhibit.
Fan failure	Slow passive cooldown only	Fan-good/tach where possible; operation allowed only inside passive-validated duty cycle.
Blocked air tube	Active recharge ineffective	Compare fan command to cooling slope; flag cooling ineffective.
Wax leak	Mess, loss of PCM, possible contamination	Metal containment, headspace, drip-safe orientation, inspectable cap.
Poor clamp contact	Heat fails to enter cartridge efficiently	Flat plate, clamp force, thermal paste/pad, temperature delta check.
Matrix corrosion/loosening	Lower thermal performance over cycles	Use compatible metals; record cycle count; inspect during service.
Sensor failure	ACE loses confidence in cartridge state	Fail toward derate/inhibit; use redundant TSTAGE trend as fallback.

Bench test plan

The cartridge should be characterized with dummy heat before it is integrated with any real Weld Energy Stage hardware. A simple resistor heater or externally heated metal block is enough to map the thermal behavior without involving the pulse bank.

Test	What to record	Pass / useful evidence
Dry fit / contact test	Contact face flatness, clamp repeatability, sensor mounting	Cartridge mounts without rocking; sensor remains fixed.
Static melt test	Temperature vs time, visible softening, leak behavior	Wax absorbs heat in target band without leakage.
Fan recharge test	Cooldown slope fan off vs fan on	Fan measurably shortens recovery time.
Cycle test	10-25 heat/cool cycles, mass loss, seepage, deformation	No structural failure; performance remains similar.
Blocked fan/tube test	Temperature trend and fault response	ACE policy would derate/inhibit on ineffective cooling.
Orientation test	Leak path if warmed sideways/upside-down	Leak path does not point at electronics or connectors.

8. CAD Inputs and Open Items

The concept is defined enough for a first CAD envelope and a hand-built thermal dummy, but not enough for a final Rumi enclosure freeze. CAD should reserve a cartridge bay, airflow path, fan mount, clamp screws and sensor cable route.

CAD-ready assumptions

- Rectangular cartridge bay with one flat thermal contact wall.
- Fan or blower placed so airflow runs through the isolated metal tube or across cartridge fins.
- Cartridge installs from a service-accessible direction and cannot fall into electronics.
- Thermal spine remains useful even if the cartridge is removed.
- Sensor cable exits into the low-voltage harness region, not the pulse-current path.
- Air inlet/outlet path does not vent wax, debris or condensation toward ACE.

Open items

Open item	Why it matters	How to close
Cartridge size and wax mass	Sets thermal capacity and cooldown time	Dummy-heater thermal test.
Air tube diameter/length	Sets fan flow and heat transfer area	Fan-on/fan-off cooldown comparison.
Metal matrix style	Controls how much wax is actually used	Compare braid, mesh and folded sheet samples.
Contact interface pressure	Determines heat transfer into cartridge	Clamp repeatability and temperature delta test.
TPCM location	Affects how ACE infers saturation	Map sensor positions during melt/recharge tests.
Released material choice	Beeswax is current candidate; salt hydrate remains alternative	Thermal cycle/leak/corrosion testing.

Immediate next action

Build a non-electrical thermal coupon cartridge: small metal shell, isolated air tube, copper mesh/braid, beeswax fill, thermistor pocket, and a fan mount. Heat it with a controlled dummy source and log melt/recovery behavior before giving it any role in a working Weld Energy Stage.