

Research Article

Anomalous Heat Effects via Longitudinal and Transversal Excitations in Constantan Wires: Advances in Electromigration and Plasma Generation

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Abstract

We present an integrated set of experiments that advance the long-standing search for Anomalous Heat Effects (AHE) in metal–hydrogen systems, with a decisive shift toward inexpensive materials and dynamic drive conditions. Our working medium is commercial Constantan wire ($\text{Cu}_{55}\text{Ni}_{44}\text{Mn}_1$), selected in 2011 to replace palladium due to its lower cost and higher defect density. The wire is operated in a compact INFN-LNF reactor that reaches internal temperatures of 900°C , while the external jacket remains below 350°C . The wire is simultaneously excited in two orthogonal modes: (i) high-density axial current pulses that drive thermionic emission, electromigration, and the characteristic “wire-breathing” pressure wave; and (ii) a transverse plasma, generated either as a Paschen spark or, more desirably, as a self-quenching dielectric-barrier discharge (DBD) stabilized by a Ca/Sr/Ba low-work-function coating, analogous to those employed in thermionic valve cathodes. Custom dimmer-based power electronics (50 Hz mains frequency, 90–95% efficiency) allow real-time adjustment of fall time (with rise time $<1\ \mu\text{s}$), duty cycle, and polarity. Embedded K-type thermocouples provide in-situ calorimetry accurate to $\pm 1\ \text{W}$. In a 50% H_2 –50% Ar atmosphere at 200 mbar, direct-current operation serves as the “null” line. Pulsed driving lifts the thermal baseline, and adding a pulsed counter-electrode (CE) increases net excess heat to 20–21 W for an 80 W input (peak COP ≈ 1.27 at 60 W). Reducing the pressure to 140 mbar and enlarging the CE coupling capacitor maintains Paschen/DBD activity and yields comparable—or slightly enhanced—AHE, despite incurring an additional 4–5 W of circuit losses. After two weeks of dormancy, the effect diminishes but can be partially recovered through in-situ redox cycling and extended pulsing, consistent with the involvement of metastable vacancy clusters anticipated by the Fukai–Staker super-loading model. Thermionic emission and electromigration show a strong correlation with excess heat generation, in agreement with Preparata’s coherence framework. Future work will investigate tungsten–NiCu multilayer electrodes driven by SiC pulse electronics, complemented by fast optical and X-ray diagnostics to resolve sub-millisecond dynamics. The reproducibility achieved here—using only commodity components—underscores the potential of Constantan-based AHE modules for high-temperature process heat, lightweight aerospace power systems, and distributed micro-grid applications.

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1. Experimental Motivation and Rationale

Our research programme was initiated in the wake of the 1989 announcements by Fleischmann and Pons, as well as Jones, which sparked renewed interest in the possibility of anomalous heat effects (AHE) in metal–hydrogen systems. Early experimental results from our group and others clearly indicated that AHE manifest only under far-from-equilibrium conditions. This insight steered our focus toward the use of high-frequency electromagnetic stimulation as a means to sustain non-equilibrium states in the system. Advances in pulse electronics have since enabled the generation of controlled, microsecond-scale excitations with high precision, which form the backbone of our current experimental approach. Over time, we identified a key principle: AHE is highly sensitive to the material’s defect structure. Ultra-pure palladium showed little to no effect, while defect-rich alloys—such as Constantan—proved far more responsive. Imperfections such as vacancies, grain boundaries, and impurities appear essential to enabling excess heat generation. We also found that dynamic hydrogen movement through the lattice—not just static loading—plays a critical role. By managing the pressure–temperature–composition (P–T–C) matrix, we can achieve transient H/M ratios necessary for triggering AHE. Supporting evidence dates back to Gustav Fralick’s 1989 NASA experiment [1], which showed reproducible excess heat from deuterium flowing through heated porous palladium. This benchmark continues to shape the field. In 2011 [2], we adopted Constantan ($\text{Cu}_{55}\text{Ni}_{44}\text{Mn}_1$) as our main material. Its robustness, defect-rich structure, and compatibility with ordinary hydrogen—not just deuterium—offered practical and strategic advantages. This lowered barriers to experimentation and enabled broader parameter testing. Similar approaches have emerged globally. Takahashi’s group in Japan studied Ni–Cu powders [3]; Iwamura and Mitsubishi developed nanostructured multilayers [4]; and Alexandrov’s team in Canada demonstrated near-instant AHE onset at 960 °C in vacuum-based setups shortly after deuterium immission at 100 mbar [5], [6]. These developments point toward high-power-density applications, including aerospace propulsion. The idea of Cu–Ni alloys for AHE was first proposed by Brian Ahern in 1994 [7], [8], though largely overlooked at the time. Our strategic pivot came in 2020, upon joining the EU-funded CleanHME Project (H2020, Grant No. 951974). Our mission: to develop simple, scalable methods for loading Constantan with H/D and to replace bulky lab equipment with compact, low-cost pulse systems. Dimmer-based electronics emerged as a cost-effective yet powerful tool, achieving high $P_{\text{out}}/P_{\text{in}}$ ratios under stable conditions. These principles—defect-driven reactivity, dynamic hydrogen handling, and efficient pulse control—remain central to our approach. As the demand for clean, decentralised energy grows, these methods offer a promising foundation for turning AHE into practical energy technology.

2. Key Experimental Findings and Future Directions

Our Constantan reactor operates in two orthogonal excitation modes, each compensating for the limitations of the other. Longitudinal stimulation applies high-density current pulses ($100\text{--}500\text{ A mm}^{-2}$) along the wire, transiently elevating the surface temperature by several tens of degrees above the core. The resulting thermal gradient, coupled with Lorentz pinch forces, compresses the lattice while the accompanying electric field drives hydrogen atoms toward vacancies. As the surface cools a few milliseconds later, it effectively “re-inhales” gas from the surrounding chamber. Repeating this cycle at 50 Hz sustains the supersaturated defect clusters envisioned by the Fukai–Staker model [9], [10] and, at temperatures above $\sim 700\text{ °C}$, may even enable the emergence of coherent charge domains, as proposed by Preparata [11]. In practice, pre-loading the wire with hydrogen followed by the application of sharp pulses consistently yields the strongest and most reproducible AHE signatures.

Transversal stimulation provides a complementary layer of control. A wire counter-electrode (CE), positioned 2–3 mm from the Constantan filament, is driven either into Paschen breakdown or into a gentler dielectric-barrier discharge (DBD) regime. Classical Paschen theory predicts a breakdown voltage of 900–1000 V at 200 mbar for the gas used, yet ignition is routinely observed at ~ 700 V when pulses with sub-microsecond rise times are applied—highlighting that waveform dynamics can be as critical as the textbook $p \cdot d$ product. The reduced breakdown threshold may also reflect the strong local electric field around the small-diameter wire. When the wire is coated with a porous Ca–Sr–Ba oxide (with minor additions of K, Mn, and Fe), the discharge frequently self-organizes into a stable filamentary DBD. In this regime, the current becomes intrinsically self-limiting—not because of the ohmic resistance of the coating, but due to the alternating buildup and collapse of surface charge across the dielectric layer, which quenches the discharge each half-cycle. As a result, electrode erosion is effectively suppressed. The bombarding electrons typically carry energies in the 5–30 eV range, as estimated from the applied voltage, sheath thickness, and characteristic micro-discharge dynamics reported for low-pressure DBD systems. These moderately energetic electrons strike the already-hot surface, promoting secondary emission and enhanced surface reactions. This energy range is particularly well suited for splitting molecular hydrogen (H_2), while remaining low enough to prevent sputtering or damage to the active surface. Under these combined conditions—longitudinal current flow and transversal discharge—the system is capable of delivering up to 20 W of net excess heat with an input of 80 W. Maintaining surface reactivity while avoiding hot-spot failure remains a central engineering challenge. Figure 2 illustrates the simplified behaviour of electrons under negative unipolar pulses applied to Constantan wires operating in the DBD regime. The combination of low-conductivity mixed-oxide coatings and porous dielectric sheaths sustains stable filamentary discharges while suppressing destructive sparking. By precisely managing voltage amplitude, pulse duration, and duty cycle, the system achieves stable electron flow and enhances Anomalous Heat Effects (AHE), all while avoiding arcing and local overheating. This mild filamentary discharge regime—intentionally maintained below the Paschen breakdown threshold—creates a non-equilibrium state that strongly favours both electron emission and AHE generation. Although such regimes often require complex and costly electronics, we have implemented more economical alternatives. The key parameters currently under active control include: (a) the maximum applied voltage, and (b) the maximum and variable current, with ultra-fast response (≈ 50 ns) and rise times in the 500–800 ns range. Very recently, we began fabricating a hybrid main electrode whose tungsten core ($T_m > 3400$ °C) carries a Cu–Ni shell laced with low-work-function (LWF) oxides. Preliminary tests show earlier discharge onset and no necking after 10 hours at 900 °C. Polarity studies reveal that a negative main electrode and a positive CE produce the most stable plasma—possibly by favouring transient H^- formation, as suggested by Piantelli [12]. Reversed and bipolar configurations will be explored next. Other near-term trials include H_2 –He blends to sharpen the Paschen window, SiC-switch pulse packs for faster rise times, and in-situ optical spectroscopy to capture sub-millisecond events. The precise arrangement of the spectroscopy system is still under study, but the reactor will likely incorporate quartz optical fibers for light collection together with a high-voltage pulse generator based on SiC MOSFETs. **All of this fits within the compact coaxial reactor sketched in Fig. 1**, developed at INFN-LNF since 2019 [2], [13]. Its modular design allows rapid swapping of electrodes, pulse boards, and gas feeds—typically in under an hour—accelerating the iterate–test–refine cycle that drives the project toward a robust, scalable AHE module.

This platform supports systematic studies of AHE under finely controlled excitation and offers a scalable foundation for the development of decentralized, high-efficiency energy systems.

3. Core Physical–Chemical Mechanisms

Since the 1990s, our methodology has prioritized empirical observation over reliance on unverified theoretical models. In response to recent inquiries, we now present a provisional mechanistic framework—anchored in established physical and chemical principles, while deliberately avoiding speculative overreach. Anomalous heat generation in Constantan

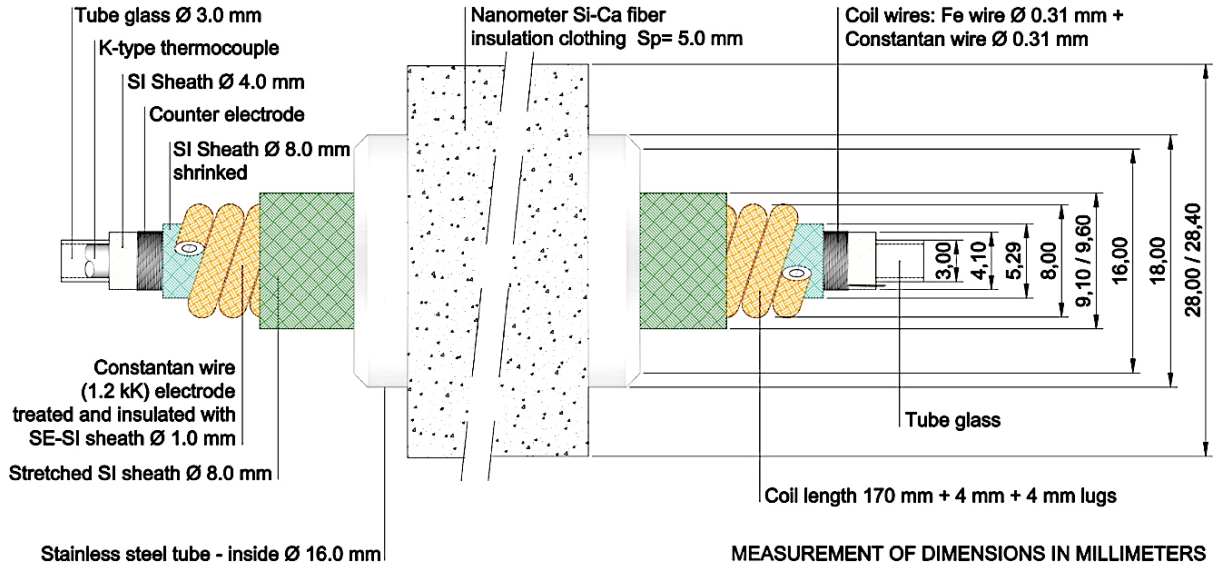


Figure 1. The updated coil-based CE design using Constantan and Fe wires.

appears to result from a tightly coupled sequence of plasma-driven processes. Once the wire exceeds approximately 700 °C, its porous Ca–Sr–Ba oxide coating—characterized by a low work function (< 2 eV)—dramatically increases the effective thermionic-emitting surface area by up to three orders of magnitude. This intense thermionic emission, described as an “*electron geyser*,” injects a dense current that conditions the interelectrode gap for Paschen breakdown. Experimentally, the breakdown voltage is consistently lower than predicted by the canonical Paschen curve. This deviation arises from the steep rise of the excitation pulses and the small diameter electrode geometry, both of which accelerate the avalanche process. Instead of triggering a destructive arc, the oxide coating acts as a dielectric barrier, steering the discharge into a filamentary dielectric-barrier discharge (DBD) glow. Each micro-plasma filament delivers electrons in the 5–30 eV range—sufficient to dissociate molecular hydrogen (H_2) without causing significant sputtering. Concurrently, the wire surface cycles rapidly through oxide $\rightarrow$ metal $\rightarrow$ hydride $\rightarrow$ oxide states, with transitions unfolding on millisecond timescales. We designate this rapid, self-sustaining renewal process as “catalytic breathing”: a dynamic mechanism that perpetually regenerates reactive defect sites, maintains hydrogen supersaturation, and facilitates continuous heat release. All stages of this non-equilibrium process are maintained by a simple, dimmer-based pulser, modestly upgraded with commercial high-current silicon-controlled rectifiers (SCRs) and ultra-fast high-voltage diodes. This setup demonstrates that low-cost, off-the-shelf electronics are fully capable of sustaining the plasma sheath conditions necessary for the observed anomalous heat effects.

4. Contemporary Models and Electrodynamic Phenomena

Explaining Anomalous Heat Effects (AHE) requires moving beyond classical thermodynamics into electrodynamic frameworks suited to non-equilibrium, high-current-density systems. Our thin Constantan wires, pulsed under controlled gas-phase conditions, offer an ideal platform to test such models. One central mechanism is electromigration—the movement of atoms driven by high current densities. While often associated with metal degradation, in our system it refers specifically to hydrogen or deuterium drift within the metal lattice. Pulsed electric fields exceed-

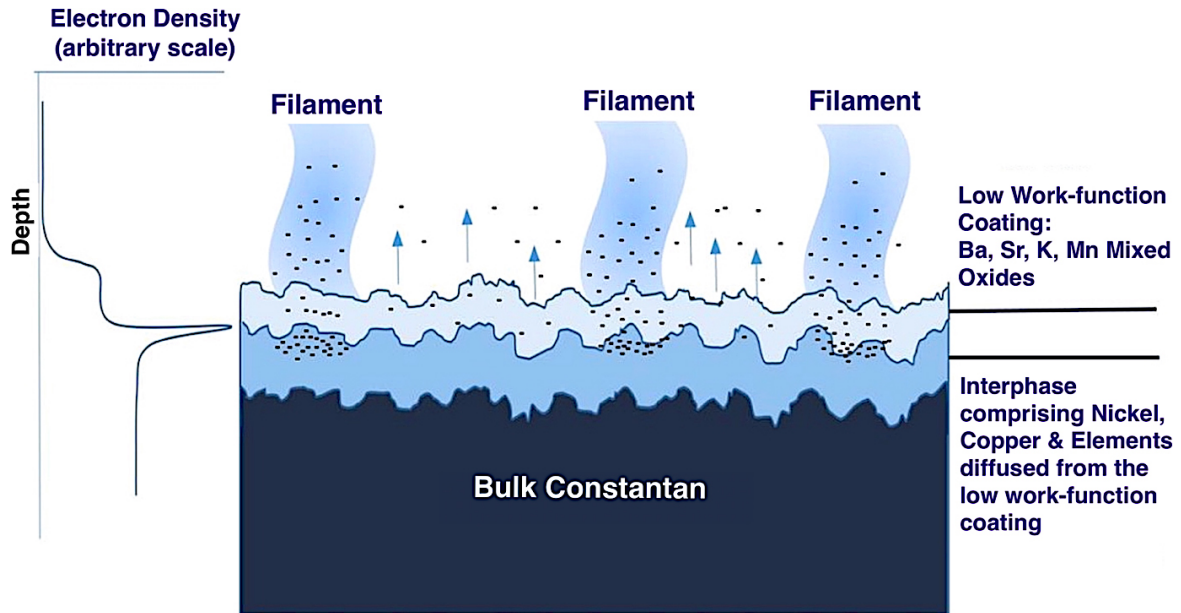


Figure 2. Electron Behaviour During Negative Unipolar Pulsing in Dielectric Barrier Discharge (DBD).

ing 0.5–1.2 V/cm can drive H/D atoms into defect-rich regions, promoting clustering, lattice rearrangement, and increased local reactivity [14], [15]. These effects are consistent with the Fukai–Staker super-loading model, which predicts metastable hydrogen-rich states forming under dynamic, non-equilibrium conditions [16], [9], [10]. A complementary perspective comes from Preparata’s deuterium coherence theory [11], which suggests that under sufficient voltage and spatial confinement, deuterons may form coherent quantum domains. These domains could, in theory, release energy through collective, non-classical mechanisms. While direct experimental validation remains elusive, our sharp-pulse systems—with their steep thermal and electric gradients—may come close to enabling such conditions. Among these models, the super-loading framework remains the most experimentally grounded. It postulates that defects such as vacancies or grain boundaries can trap hydrogen at concentrations far exceeding equilibrium solubility. These supersaturated zones, being energetically unstable, may release energy when subjected to suitable pulse-driven perturbations. Our empirical observations—particularly the progressive buildup of AHE with repeated pulsing—align closely with this interpretation. Together, these models—electromigration, quantum coherence, and super-loading—describe a plausible path for how electrical excitation, lattice defects, and hydrogen mobility may converge to trigger AHE. Rather than being mutually exclusive, these mechanisms likely operate synergistically under real-world conditions. Ongoing experiments aim to clarify their respective domains and guide the optimization of reactor designs to exploit their combined effects.

5. AI-Aided Analysis of Current Density and Stress in Thin Wires

To better understand the stress conditions experienced by Constantan wires during operation, we used AI-assisted tools to model the relationship between current density, thermal load, and mechanical failure modes. These simulations allow for predictive insights into the thresholds beyond which structural degradation, runaway heating, or outright failure may occur. As a reference case, we considered a wire with a diameter of 200 μm , giving a cross-sectional

area of approximately 0.0314 mm^2 . Under pulsed excitation with peak currents reaching 10 A, the resulting current density approaches 318 A/mm^2 . While such a value is tolerable for short-duration pulses, it becomes unsustainable under continuous DC operation. For example, even a 2-meter-long Constantan wire, with a typical resistivity yielding $\sim 16 \Omega/\text{m}$ at 600°C , will experience substantial Joule heating under much lower steady-state currents. At just 3 A, surface heat dissipation can exceed 23 W/cm^2 , driving internal wire temperatures past 1100°C —perilously close to the alloy's melting point of 1200°C . Beyond thermal limits, prolonged operation introduces secondary degradation mechanisms. Evaporation of surface atoms, particularly copper, may thin the wire locally, altering its resistance and destabilising thermal balance. Mechanical deformation, often in the form of folding or buckling, further modifies the geometry and internal stress distribution. Oxidation or subtle compositional shifts from the original alloy can also lead to resistivity drift, creating feedback loops where local overheating becomes more likely. These combined phenomena point to the importance of precise duty cycling, fast-reacting circuit protections, and high-fidelity diagnostics to avoid catastrophic failure and maintain AHE-favourable conditions.

5.1. Electromagnetic and Electron Dynamics

High-current pulses in Constantan wires trigger a cascade of coupled electromagnetic and structural processes that help establish the conditions for Anomalous Heat Effects (AHE). Axial currents generate Lorentz forces that produce a radial magnetic pinch, transiently compressing the wire and potentially destabilizing pre-existing defect structures. At high frequencies, the skin effect confines current and heat to the outer surface. In nickel-containing alloys this effect is particularly relevant—not because of magnetostriction, which is negligible since Ni is paramagnetic at the operating temperatures—but because of their higher resistivity compared to copper and the strong chemical affinity of Ni sites for hydrogen and oxygen. Although simple estimates suggest only a modest skin effect at the nominal drive frequencies, the sharp rise times of the excitation pulses introduce high-frequency components that significantly enhance surface current crowding. These factors are hypothesized to intensify localized thermal gradients, mechanical stress, and chemical reactivity, thereby rendering the skin layer the dominant region for electromigration and surface reactions. The pulses also increase electron drift velocity, promoting enhanced scattering with phonons and defects. Sharp surface asperities, combined with low-work-function (LWF) oxide coatings, amplify field emission and can trigger micro-plasma events, adding further complexity to the near-surface electron dynamics critical for AHE.

Lattice Responses to Pulsing: Joule heating dominates the wire's energy budget. Constantan exhibits nearly linear ohmic behavior up to $\sim 700^\circ\text{C}$ in inert atmospheres, but beyond this point its resistivity increases non-linearly, necessitating active cooling. Each current pulse raises the surface temperature by several tens of degrees. With a linear expansion coefficient of $\alpha \approx 1.8 \times 10^{-5} \text{ K}^{-1}$, this thermal swing imposes a cyclic hoop stress of $\sim 85 \text{ MPa}$ —remarkably close to the $\sim 90 \text{ MPa}$ threshold at which the Fukai–Staker model predicts vacancy-loop punching. Thus, each burst may generate fresh dislocations that serve as hydrogen trapping sites. The high electron flux also drives electromigration, redistributing Cu and Ni atoms, reshaping defect networks, and alternately degrading the wire or generating new AHE-active pathways. The interplay of thermal expansion, magnetic compression, mechanical deformation, and electromigration creates a narrow yet reproducible window in which hydrogen supersaturation is renewed, coherent domains may nucleate, and excess heat becomes detectable.

5.2. Effects in Hydrogen/Deuterium-Loaded Constantan Wires

Hydrogen or deuterium absorption into Constantan wires initiates a cascade of transformations that fundamentally alter system behavior, fostering the non-equilibrium conditions associated with Anomalous Heat Effects (AHE). At the **electronic level**, interstitial H/D atoms perturb local charge density and electric field distributions, particularly

Table 1. Key effects activated in H/D-loaded Constantan wires as a function of current density. At $\sim 318 \text{ A/mm}^2$, multiple AHE-relevant mechanisms are simultaneously active.

Rank	Effect	J (A/mm ²)	Status at 318 A/mm ²
1	Joule heating	10–100	Dominant
2	Thermal strain	50–200	Significant
3	Phonon–electron scattering	100–300	Strongly active
4	H/D electromigration	300–500	Likely active
5	Lorentz forces	300–500	Emerging
6	Field emission	500–1000	Possible onset
7	Magnetostriction	500–1000	Magnetostriction is only plausible in Ni domains below the Curie point.
8	Surface plasma	>1000	Unlikely without DBD
9	Field-assisted nuclear effects	>300 (spec.)	Under study

under pulsed excitation. These distortions may induce transient charge separation and the formation of polarized domains, especially under unipolar waveforms—an effect that could contribute to AHE. At the **lattice level**, H/D atoms enhance phonon activity and soften the lattice, thereby increasing hydrogen mobility and strengthening electron–phonon coupling. This dynamic may enable transient, high-reactivity states favorable for excess heat generation. Electromigration further drives H/D transport under applied fields, producing non-equilibrium concentration gradients. Such supersaturated regions may exceed thermodynamic solubility limits, potentially triggering AHE-relevant conditions. At the **magnetic level**, H/D loading modifies electronic states near the Fermi level, altering magnetic susceptibility and domain structures. These effects are most relevant within the nickel-rich matrix, though they become negligible above the Curie temperature. At the **frontier**, high current densities in deuterium-loaded wires may facilitate field-assisted nuclear-scale processes—still speculative, but actively investigated due to persistent anomalous experimental signatures. Table 1 summarizes how the various effects scale with current density. At our operational level ($\sim 318 \text{ A/mm}^2$), multiple mechanisms act in concert, placing the system in a highly reactive, non-equilibrium regime.

In summary, hydrogen-loaded Constantan under pulsed excitation enters a regime where multiple, intersecting processes—thermal, electronic, magnetic, and possibly nuclear—combine to create the right environment for AHE.

6. Circuit Architecture and Pulse Generation

A core innovation in our AHE research is the development of a low-cost, flexible pulsed power system centered around a modified commercial **TECNEL 8034 dimmer**. Unlike traditional lab-grade equipment, this setup enables precise control over pulse shape, voltage, and current, while maintaining **90–95% energy efficiency**—a critical feature for sustaining AHE under non-equilibrium conditions. The dimmer generates sharp, variable-amplitude pulses that significantly enhance electromigration quality, particularly in hydrogen-rich environments where the wire’s resistance drops markedly ($R/R_0 < 1$) [17], indicating active hydrogen–metal interactions. Figure 3 compares different excitation modes, highlighting the improved performance of the dimmer-based configuration.

Peak current monitoring is carried out with precision 1 Ω , 25 W resistors, selected for their stability and accuracy across a broad frequency range (up to 20 MHz) while limiting power dissipation to $\sim 2 \text{ W}$. For transversal discharges—Paschen and Dielectric Barrier Discharges (DBD)—a custom high-voltage transformer with an integrated protection network drives the counter-electrode (CE). This configuration supports safe operation up to +1000 V and 200 mA, with adjustable current limits in 50 mA increments and a 50 ns delay line for fine pulse-timing control. The positive high voltage required for Paschen/DBD excitation is derived from the main negative pulse applied in parallel to the Constantan wire input. The negative pulse passes through a fast, high-voltage ceramic capacitor (100–400 nF) into an inverting toroidal transformer (1:4 ratio, 10 kHz–2 MHz bandwidth). The capacitor value represents a trade-off: larger

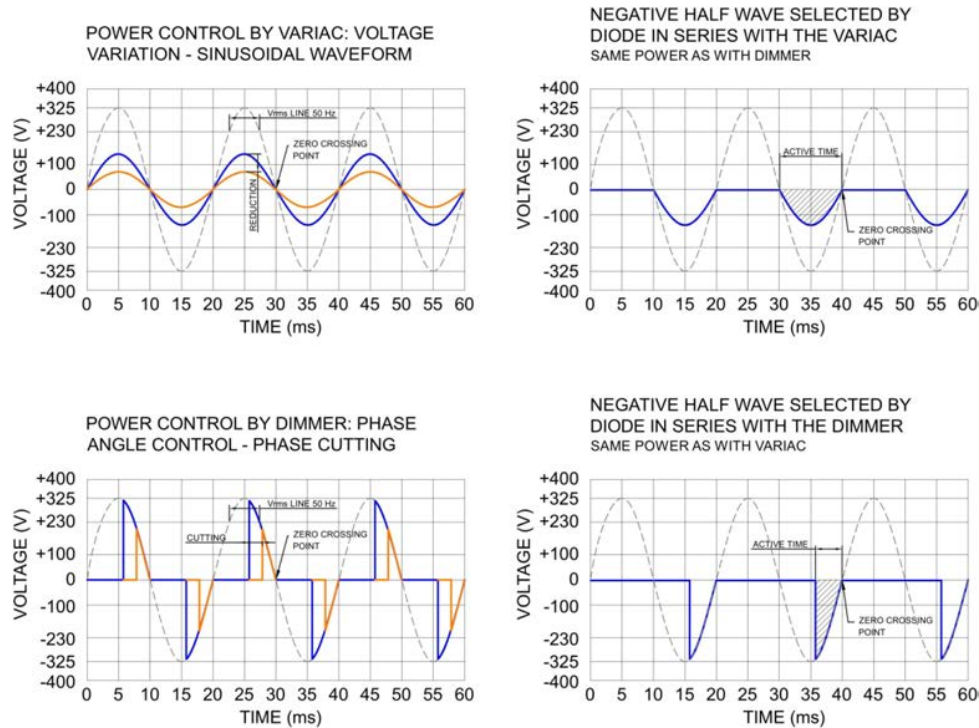


Figure 3. Peak voltage profiles for different excitation waveforms. Dimmer-based pulses provide fine control over AHE stimulation. A reduction in normalized resistance (R/R_0) under hydrogen indicates absorption. Overall system efficiency is approximately 95%.

capacitance improves energy transfer from the main pulse but increases low-frequency losses in the transformer. A 400 nF capacitor was ultimately chosen, as it enhances plasma ignition stability, although it introduces $\sim 4\text{--}5$ W of additional dissipation within the transformer and limiting circuitry. Waveform measurements highlight the dynamics: under standard conditions, a full-power pulse delivers 69 W to the reactor, with the voltage pulse driving longitudinal current through the Constantan wire (see Fig. 4). Importantly, the input briefly peaks above 1150 W (green trace, value divided by four), illustrating the sharp, non-equilibrium excitations required to trigger Anomalous Heat Effects (AHE).

Figure 5 documents a successful Paschen-like breakdown at 1150 V peak-to-peak, accompanied by a -150 V main electrode (ME) response—clear evidence of full gap ionisation and plasma formation. This compact yet robust platform enables flexible exploration of both longitudinal and transversal excitation modes without requiring bulky infrastructure. Its combination of geometric simplicity, waveform adaptability, and controlled discharge behavior makes it well suited for scalable AHE experimentation across varying operating conditions and reactor geometries. At the lower end of the stimulation frequency range investigated (50 Hz), the nominal DBD regime frequently collapses into a pulsed, **low-pressure spark or arc across the 1 mm hydrogen gap**. While generally undesirable—due to electrode erosion and unstable discharge localization—this transient arc paradoxically produces the strongest AHE enhancements. The effect may stem from the arc's pinpoint current channel, which generates exceptionally high current densities and introduces arc-specific phenomena such as bursts of highly ionized hydrogen, impulsive UV/soft X-ray emissions, and electromagnetic shock fronts. This behavior is reminiscent of Mills-style spark experiments [18], though the current lack of spatial control limits the ability to draw firm conclusions.

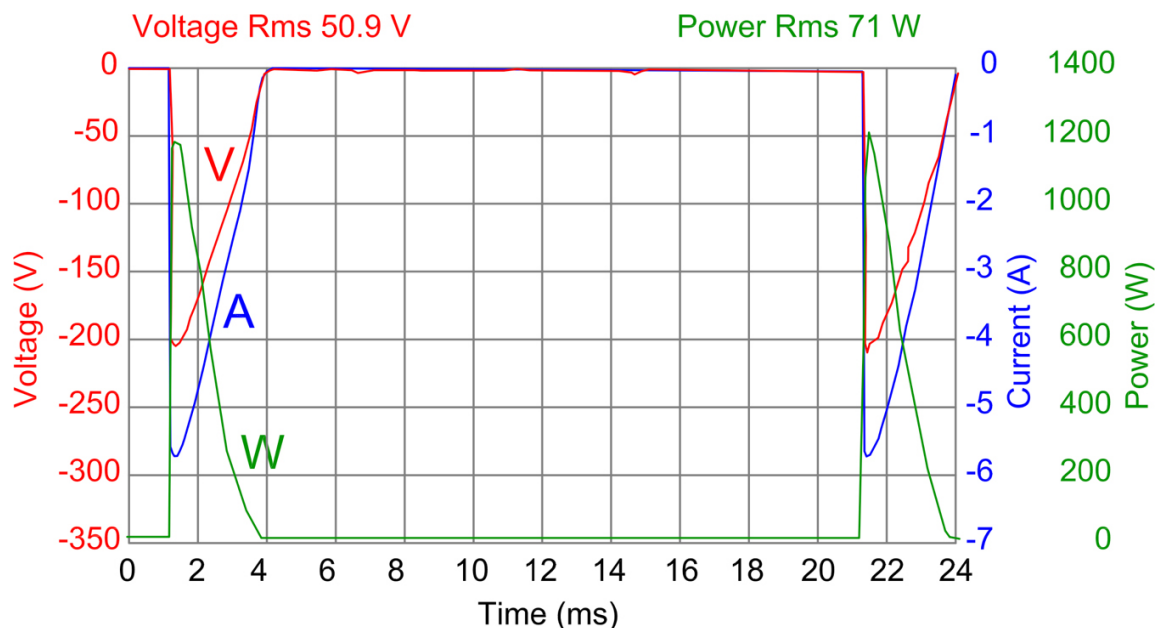


Figure 4. Pre-discharge waveform at 69 W RMS. With no plasma yet ignited, the voltage–current trace is smooth and free of spikes. Net electrical input is 69 W; 2 W of that is lost in the 1 Ω sensing resistor. Momentary peaks reach ≈ 1150 W—about $16 \times$ the RMS level—providing the sharp, high-power bursts needed to trigger also Paschen or DBD breakdown once the threshold conditions are met.

7. Some Results

A series of side-by-side runs compared two 50 mol % gas mixtures at 200 mbar: inert He/Ar (control) and reactive H₂/Ar. Under direct current (DC) operation, the control showed no excess heat, while the H₂/Ar trace defined the zero reference line. Pulsed operation increased the H₂/Ar signal, with a further rise observed when the counter-electrode (CE) was also pulsed. After subtracting the 2–3 W consumed by the pulser, the net power output rose to approximately 20 W for an 80 W input, yielding a coefficient of performance (COP) of about 1.27 at only 60 W input—double the best result from earlier 170 W trials (Fig. 6). The reactor core exceeded 900 °C, while the jacket remained at approximately 280 °C. Excess power was determined from the slope of the ΔT curve, where $\Delta T = T_c - T_a$, with T_c representing the reactor wall temperature and T_a the ambient temperature. This slope was referenced against a calibration curve obtained under inert-gas conditions. Full experimental details are provided in earlier publications [19]. Subsequently, the pressure was reduced to 140 mbar while maintaining the same H₂/Ar blend. To restore Paschen/DBD activity, the CE coupling capacitor was increased from 100 nF to 400 nF, adding an estimated 4–5 W of power loss but sustaining a stable plasma. Despite this added dissipation, the excess heat matched—or slightly exceeded—the 200 mbar result (Fig. 6 and 7), indicating that careful discharge tuning can offset lower gas density and may even enhance performance.

8. Speculative Model, Ongoing Adjustments, and Outlook

Our current working hypothesis—better described as a structured thought experiment than established physics—is that a “breathing” Constantan filament, pulsed in sync with a surface DBD micro-plasma, functions as a persistent hydrogen pump. Each microsecond current burst heats the outer tens of microns, compresses the skin layer via Lorentz forces,

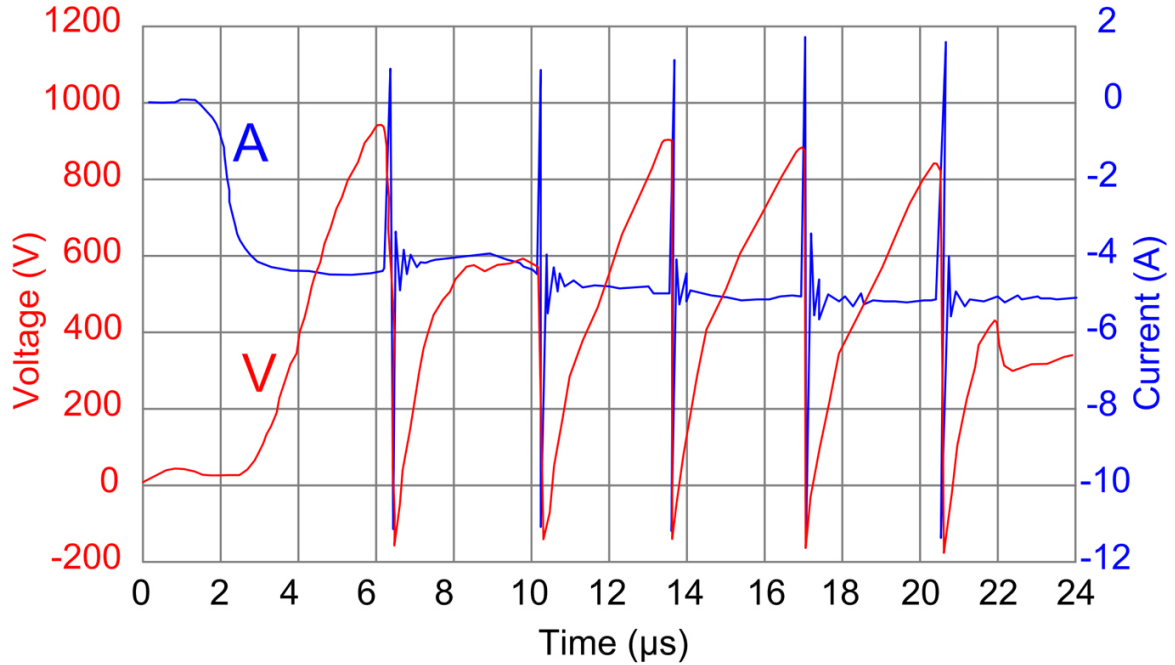


Figure 5. Counter-electrode (CE) voltage under positive-bias operation. The red trace, representing the voltage between the Constantan wire and the counter-electrode (CE), demonstrates a stable cyclic Paschen-type discharge (low-pressure spark). The clean, quasi-sawtooth waveform exhibits a consistent peak-to-peak amplitude of approximately 1150 V, confirming that the reactor pressure and electrode gap are well within the breakdown window and thus support sustained discharge.

and then releases it. This cyclic action may cause the filament to inhale hydrogen into vacancies during compression and exhale it as the lattice rebounds. The sequence unfolds as follows: Joule heating initiates the thermal pulse; magnetic and structural forces drive hydrogen inward; thermal expansion cracks surface oxides; and slower electromigration redistributes hydrogen longitudinally. Together, these effects generate defect clusters faster than they anneal, maintaining the supersaturated, vacancy-rich state highlighted in the Fukai–Staker model as conducive to anomalous heat effects (AHE). The oxide layer plays a dual role: enabling thermionic emission while also serving, together with the quartz glass fiber sheath, as the dielectric for localized filamentary DBDs. When the hot skin expands, both the local temperature and electric field increase, igniting a plasma filament. As cooling sets in, charge accumulation in the oxide quenches the discharge before it evolves into an arc. Each “breath” therefore resets the surface charge, while the transient filament bombards the wire with electrons in the **5–30 eV range**—energies inferred from typical DBD electron energy distributions under similar conditions [20]. These are sufficient for H_2 dissociation but generally too low to cause significant sputtering. This pulse–plasma feedback loop keeps the wire chemically reactive and structurally dynamic. We view it as a centimeter-scale *pulse–plasma engine*: compact, cyclic, and currently the most consistent source of excess heat in our work. Its fragility, however, is evident. After a two-week interruption during relocation from INFN-LNF to Frosinone, the excess power output dropped from 15–20 W to just 2–6 W, despite identical gas composition and pulsing parameters. This suggests that once the lattice cools and vacancy clusters relax, the feedback

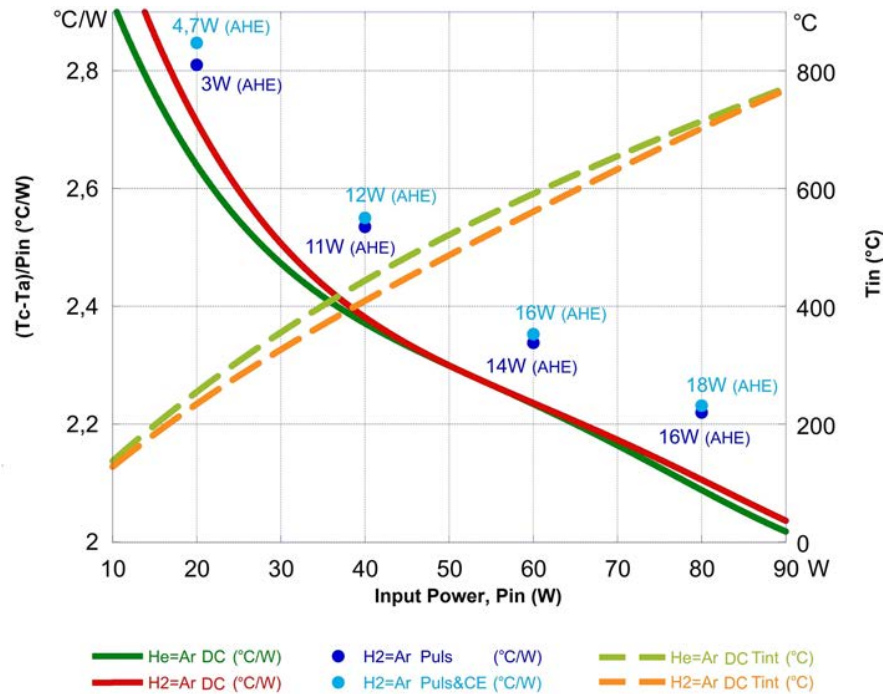


Figure 6. AHE at 200 mbar. Net excess heat vs. input power for DC, pulsed, and pulsed + CE modes in 50 % H_2/Ar (control He/Ar shown for reference).

loop stalls. Recovery is being pursued through oxidation–reduction cycling and extended pulse sequences, particularly with the counter-electrode (CE) energized.

Temperature remains a decisive gatekeeper. Paschen-type discharges rarely ignite below ~ 650 $^{\circ}\text{C}$ unless local hotspots facilitate field breakdown. In one unusual case, a discharge initiated at only 250 $^{\circ}\text{C}$, hinting that surface geometry or field-enhanced emission can bypass the conventional Paschen $p \cdot d$ rule. Mild gamma irradiation from thorium-doped TIG rods (enclosed in stainless steel tubing) also appears beneficial above 650 $^{\circ}\text{C}$ —possibly by liberating electrons from low-work-function oxides or directly ionizing the gas. Although CE pulsing can enhance AHE, it incurs a 2–5 W power penalty. To address this, we are developing hybrid main electrodes: tungsten cores clad with Ni–Cu–Fe alloys doped with Ca/Sr/Ba oxides. The goal is to suppress hotspots without suppressing surface reactivity, enabling stronger “breathing” at higher duty cycles and with larger wire diameters. Future comparisons will focus on DBD excitation versus spark discharges. While sparks applied via the CE may eventually exceed the filament’s tolerance, a spark gap integrated along the main Constantan wire could combine strong longitudinal impulses with the mechanisms described above. Scaling remains the critical challenge. AHE appears to arise from a delicate interplay of nonlinear, temperature- and geometry-sensitive processes—where even slight variations in pulse rise time or oxide morphology can switch the system between dormant and active states. Yet the guiding principles first outlined in our 1990s framework remain valid. By tuning current density, waveform, gas pressure, and defect chemistry, we are narrowing in on a repeatable activation window. Should this window be broadened, Constantan-based modules may evolve into off-grid heaters, micro-generators, or—if the pulse–plasma engine proves scalable—even novel propulsion elements.

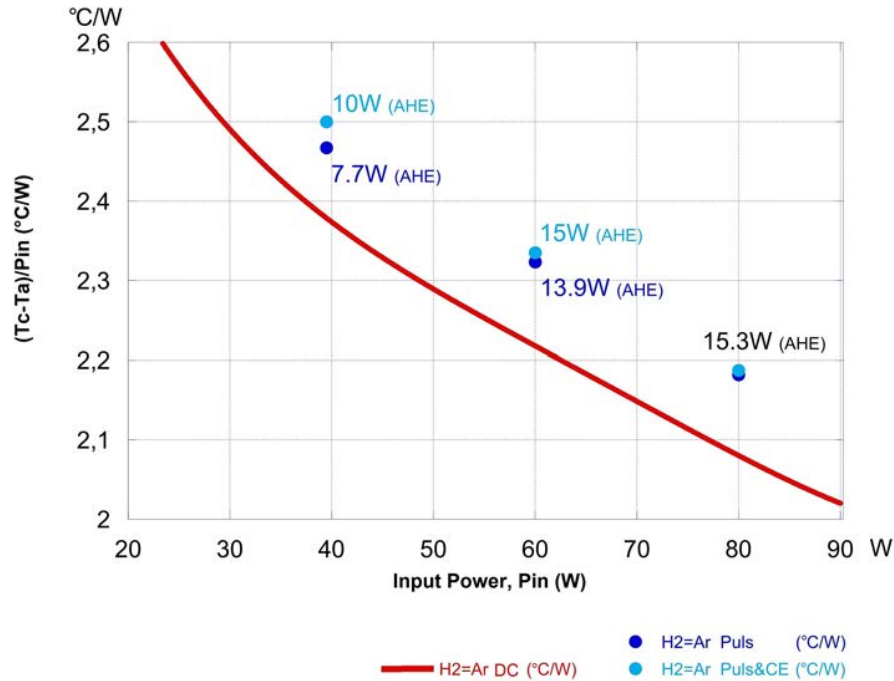


Figure 7. AHE at 140 mbar. Same H₂/Ar mix at reduced pressure; larger coupling capacitor restores strong discharge and sustains AHE with only minor efficiency loss.

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