Technical Note

Technical Note

High Throughput Soldering & Rework at Lower Temperatures with SmartHeat® Technology

Table of Contents

okinternational

OKi

www.okinternational.com

Abstract

Lower temperatures, higher throughput. This is the nature of competitive PCB manufacturing today. At one end, "No-Clean" fluxes, high density PCBs, and more sensitive components are forcing tip temperatures down. At the other, pressure on throughput and the introduction of lead-free soldering processes are forcing tip temperatures up. With conventional soldering, desoldering, and SMT rework systems, the choice seems to be between compromising product safety or compromising throughput, neither of which is acceptable. Is there a way to break out of the deadlock?

The answer is, "Yes." By rediscovering that it is not tip temperature, but connection temperature that we want to focus on, and by re-examining the principles behind soldering iron technology, we find that through "Direct Power" soldering irons we can bridge the gap.

OK International's SmartHeat® technology utilizes a highly conductive tip positioned closely to an acutely responsive heater element, to deliver power directly to the solder joint—eliminating the need to achieve high tip temperatures in order to transfer heat to the load. This Technical Note describes how OK International and Metcal's "Direct Power" soldering, desoldering, and SMT rework systems, with SmartHeat® technology, can deliver more thermal power at lower temperatures than conventional systems.

Soldering Fundamentals

Soldering involves the formation of a metallic connection by the simultaneous application of heat to a soft melting metal alloy (solder), a component lead, and a PCB "land" or "pad." As the heat is applied, the solder flows across the lead and pad and forms a bond. When the heat is removed, the solder solidifies, completing the solder joint.

The objective of the soldering process is to form the strongest possible electrical and mechanical connection. Coincidentally, a mechanically strong solder joint is also electrically continuous.

One of the key requirements in forming a strong solder joint is raising the connection temperature to the proper level for the proper amount of time. With conventional soldering technology, connection temperature is primarily determined by three parameters:

- Tip temperature
- Dwell time on the joint
- Tip size

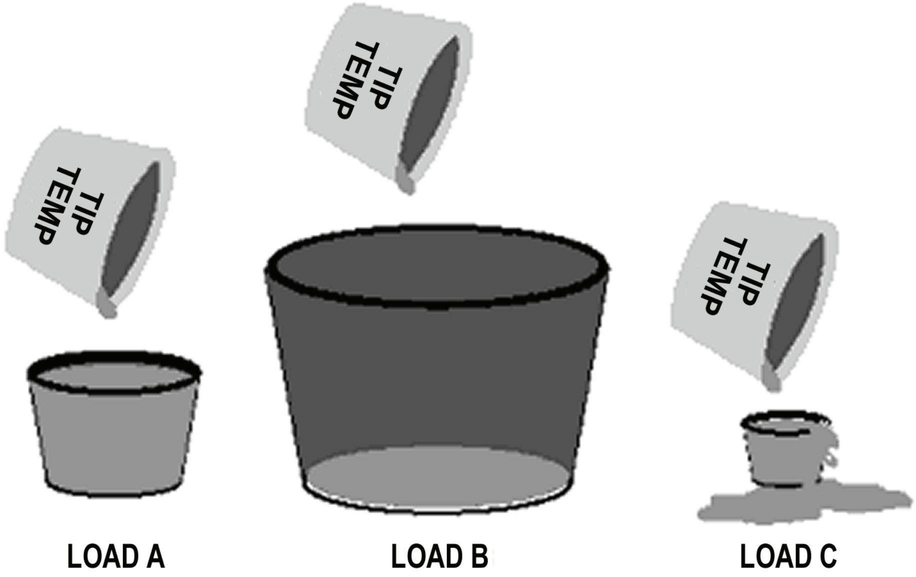
Because of this, conventional soldering iron manufacturers have spent a lot of time and energy on the accurate and precise control of tip temperature. This includes minimizing variability due to changes in tip idle temperature and elimination of overshoot.

However, this focus on controlling tip temperature to yield strong solder joints assumes that control of the tip temperature results in control of the connection temperature—that perfect tip temperature control means perfect connection temperature control. This, however, is not necessarily the case!

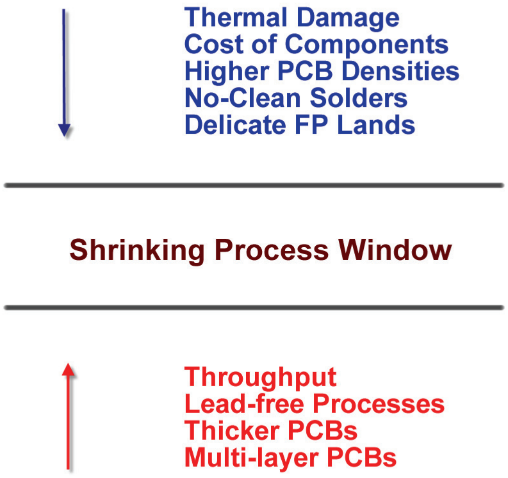
Why? Even if you know exactly how much heat you have at the tip, you don't know how much each joint needs, because different solder joint loads require different amounts of heat to reach the right connection temperature.

In a conventional soldering iron, heat deliverable to the solder joint comes from energy stored in the tip. In a sense, a conventional soldering iron can be pictured as a fixed capacity bucket filled with heat. The tip temperature represents the level of heat in the bucket. To date, conventional soldering iron manufacturers have focused on controlling how much heat is contained in the bucket (tip). What we should be focused on is controlling how much heat is delivered to the solder joint.

Solder joint loads can be pictured as empty vessels, the size depending on the thermal load. For example, a solder joint connected to a heavy ground plane can be represented by a large tub, while a fine pitch SMT lead might be pictured more as a small glass.



When a soldering iron transfers heat, it in effect transfers the heat contained in the bucket to the various sized vessels (solder joints). If the amount of heat contained in the bucket is about the same as required by the vessel, no problem—and the joint is brought up to the proper connection temperature. But if the heat contained in the bucket is much less than that required by the load, you now have the situation where you have to wait for the soldering iron heater to turn on, refill the bucket (tip) and transfer that to the load. This is what causes an iron to run out of heat.



Lastly, if the heat contained in the bucket is much greater than that required by the load, too much heat can be transferred, resulting in thermal damage such as measling and lifted pads.

Thus, one drawback of conventional, stored energy tip design becomes apparent. The actual delivery of heat is uncontrolled and is entirely dependent on tip temperature drop. A conventional, stored energy iron, in effect "dumps" heat into the joint.

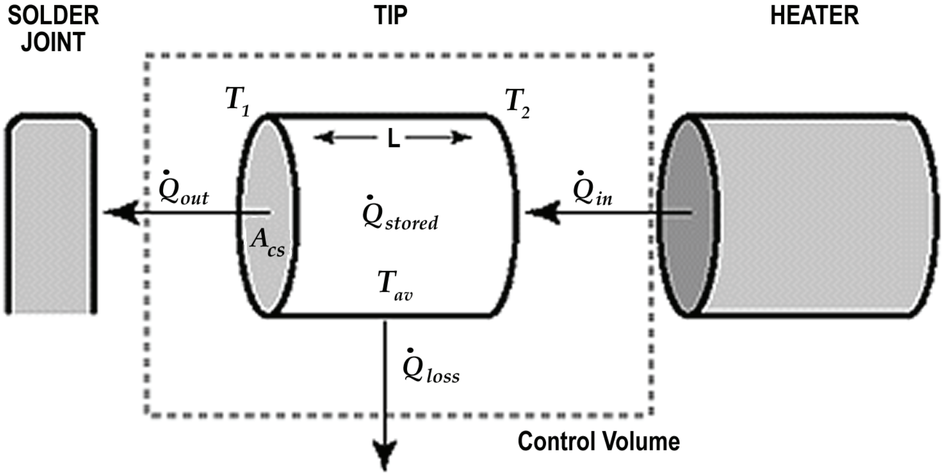
A second drawback of conventional, stored energy soldering irons becomes apparent as we look at trends in the PCB assembly industry. On one hand, the use of more thermally sensitive and expensive components, higher density PCBs, and more thermally sensitive soldering processes like No-Clean are combining to drive soldering and rework temperatures down. On the other hand, increased throughput requirements, thicker, multilayer PCBs with groundplanes, higher pin count components, and the increased thermal demands of lead-free soldering processes are forcing soldering and rework temperatures up.

The net result is a shrinking temperature process window. In many cases, the window has been shut, leaving manufacturers with two bad options: work at lower temperatures and sacrifice throughput, or keep the throughput up and work at higher temperatures, risking more thermal damage. Why? Because as everyone knows that increasing tip temperature means more heat, and decreasing tip temperature means less heat, right?

As it turns out, not necessarily. To see this, we must return to the fundamentals of thermodynamics.

Thermodynamic Fundamentals & Conduction Tool Design

Thermodynamically, a soldering iron can be modeled as a one-dimensional, time-dependent, conductive heat pipe that conducts heat from a heat source at one end to a solder joint at the other. The configuration determines the amount of heat stored in the tip, the ease with which heat is conducted to the connection, and the surface heat losses of the tip.



Performing a simplified energy balance on a control volume established around this heat pipe, one derives:

$$\underbrace{\dot{Q}_{out} + \dot{Q}_{loss}}_{\text{Heat Sinks}} = \underbrace{\dot{Q}_{in} + \dot{Q}_{stored}}_{\text{Heat Sources to Solder Joint}}$$

$\dot{Q}_{out}$ = Power delivered to the solder joint

$\dot{Q}_{loss}$ = Power lost to the environment

$\dot{Q}_{in}$ = Power delivered to the tip from the heater

$\dot{Q}_{stored}$ = Power due to change in stored heat of the tip

The left side of the equation shows heat sinks. **Qout** is the heat delivered to the solder joint. **Qloss** is the heat lost to the environment due to convection and radiation (and will be ignored for the purposes of this discussion). These losses are based on average tip temperature and can be modeled as a single sum.

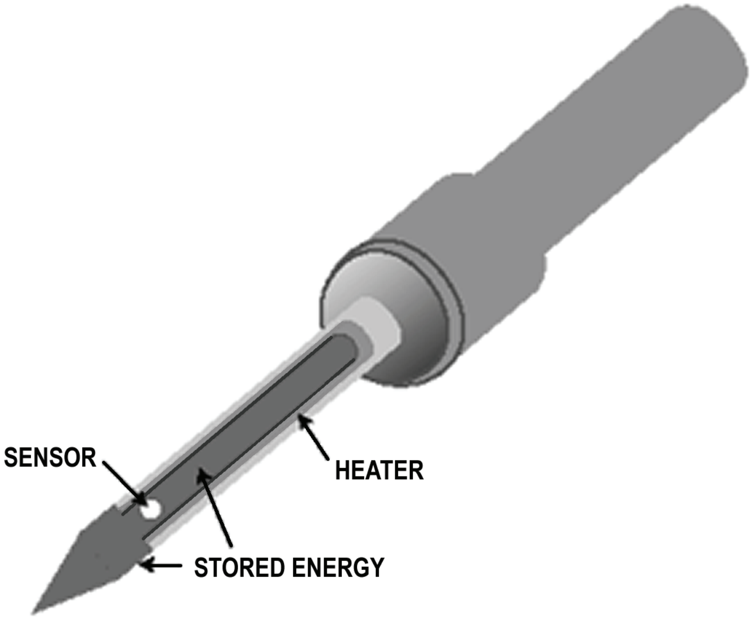
On the right side, there are two sources of thermal power available for delivery to the solder joint. **Qstored** is the power available from heat stored in the tip. When the average tip temperature decreases, power is delivered to the joint. When the temperature increases, power from the heater is moving to and being stored in the tip. When the temperature is fixed, the system is at steady state.

Qin is the power available directly from the soldering iron heater. In a conventional iron, this heat is delivered to the tip, not directly to the solder joint.

With the thermal system defined, the relative impact of each term on the conductive soldering process can be determined. From a tool design perspective, if **Qstored** is dominant over **Q in**, this leads to a conventional, stored energy soldering iron, where heat delivered to the solder joint depends primarily on tip temperature. If the reverse is true and **Qin** is dominant over **Qstored**, this leads to a new type of soldering iron, one where heat delivered to the solder joint comes directly from the heater—what we like to call “Direct Power.”

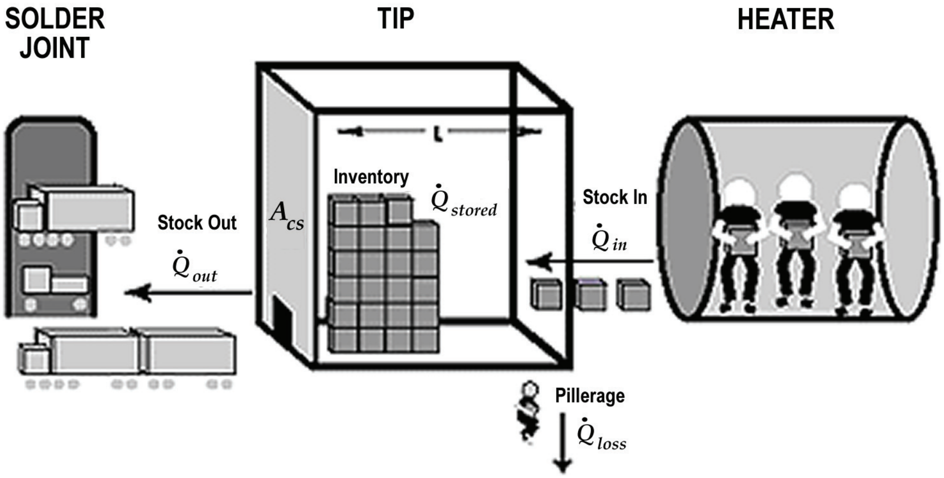
Conventional Soldering Iron Design—Heat Delivery Based On Tip Temperature

A conventional, stored energy iron typically consists of a large tip, a heater, and a thermocouple that senses tip temperature. The function of the heater is to fill and maintain the heat stored in the tip at a pre-set level as indicated by the tip temperature. It is the heat stored in the tip that is then used for soldering.



Because the heater is effectively isolated from the solder joint, heater selection does not depend on responding directly to the thermal load demands of the solder joint but rather on replenishing the stored energy in the tip; the larger the soldering iron tip, the greater the required power rating of the heater.

In fact, a conventional soldering iron system can be closely modeled as an inventory warehouse for heat, with **Qin** analogous to stock from the production line and **Qout** as product being shipped out of the warehouse. **Qstored** then becomes the heat "stock" available to be shipped out of the warehouse, whose stock level (tip temperature) fluctuates in response to supply and demand.



Looking at an expansion of **Qstored** that defines stock (heat) flow in and out of the warehouse (tip):

$$\dot{Q}_{stored} = \frac{(\rho \bullet C_p) \bullet (A_{cs} \bullet L) \bullet (T_{av}(\Delta t) - T_{av})}{\Delta t}$$

Tip design variables:

$\rho \bullet C_p$ = Density and specific heat of material

$A_{cs} \bullet L$ = Tip volume (cross-sectional area x length)

$T_{av}(\Delta t),\ T_{av}$ = Tip temperature as a function of time

This is the design equation for conventional soldering irons. It shows that **Qstored** is dependent on three basic tip parameters—material of construction, tip size, and temperature. The first two terms define the heat storage capacity of the soldering iron tip. These are set by the physical design of the tip.

The objective of conventional soldering iron design is to maximize **Qstored** by:

- Selecting the highest heat capacity material for tip construction - $\rho \bullet C_p$
- Selecting the largest volume tip possible - $A_{cs} \bullet L$
- Setting the tip at the highest temperature possible - $T_{av}\ (0)$

Material heat capacity is defined by the density and specific heat of the material used in making the soldering iron tip. Using our warehouse model, this is like the shelf density; the more shelves, the more heat that can be stored. All tip manufacturers use copper and copper alloys because they have some of the highest heat capacities per unit volume. Similarly, tip volume is equivalent to warehouse size; the bigger the warehouse (tip), the more heat can be stored. Tip size is limited by accessibility to the solder joint.

So what's the problem?

The problem is that conventional soldering irons deliver heat in response to target heat inventory level (tip temperature) and not to the actual heat demands of the solder joints. This limits the performance of conventional stored energy irons.

Looking at the tip as a heat warehouse, we can see these limitations. In manufacturing, the role of inventory is to buffer the production line from changes in demand. The greater the variation in demand relative to the ability of the line to react, the larger the inventory requirement. If demand is steady and predictable with small variations, a lower inventory is needed. But if demand is unpredictable or has large swings, more inventory is needed.

This means as a rule, conventional soldering irons work best under the following conditions:

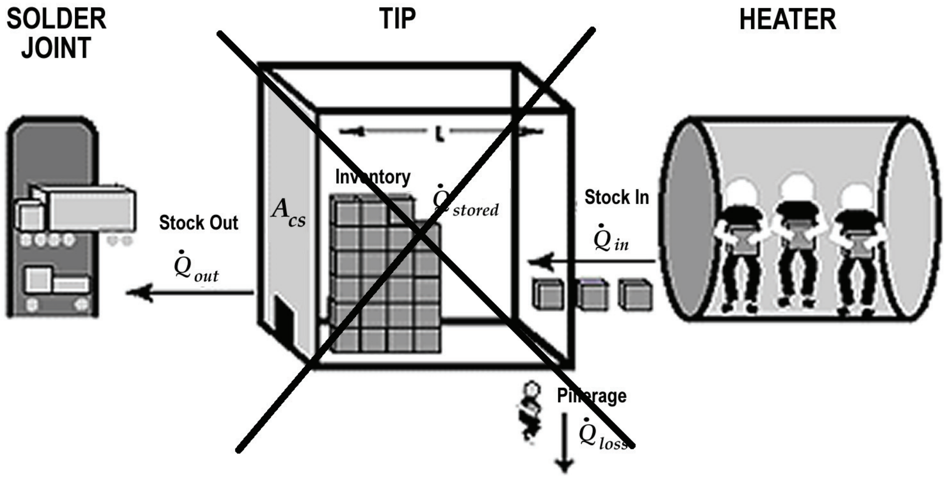
- **Soldering loads are relatively similar.** If loads vary (e.g., one lead connected to a heavy ground plane, the next to a light component), performance degrades.
- **Soldering speed is slow** enough to allow the heater to replenish the heat withdrawn from the tip. But if soldering speed is too fast to allow full tip temperature recovery, performance degrades. The additional thermal demands of lead-free soldering contribute to an increase in the recovery time required.
- **Operator is skilled.** Because the connection temperature is a function of both heat delivery and dwell time, skilled operators can adjust dwell time to compensate for variable loads. But, as competitive pressures increase operator turnover, guaranteeing a high level of operator skill is becoming increasingly difficult.
- **PCBs and components are insensitive to temperature variations.** Depending on the control characteristics, conventional irons can overshoot the setpoint temperature. If the PCB or component is not prone to thermal damage, this is not an issue. But the trend toward SMT is leading to the use of more, not less, thermally sensitive components, while “No-Clean” fluxes, high density PCBs, and the demands of lead-free soldering push connection temperatures higher.

In short, current trends in the PCB assembly industry are pushing conventional irons past their limits.

Direct Power Design—Heat Delivery Based On Connection Temperature

According to the old manufacturing view, inventory was a good and necessary way to buffer the production line from demand variations. But the new view of manufacturing, born of JIT and TQM, says that inventory exists to cover up deficiencies in the production system. Instead of covering up the deficiencies with inventory, fix them.

In iron design and thermodynamics, eliminating inventory is the equivalent of eliminating **Qstored**.



Returning to the energy balance of the first equation, if **Qstored** -> 0, which is the case when the heat capacity of the tip is minimized, in the limit where **Qin** >> **Qstored**, it reduces to:

$$\dot{Q}_{out} + \dot{Q}_{loss} = \dot{Q}_{in}$$

This means the power delivered to the joint plus any heat losses depends directly on the power from the heater. Looking at **Qin** in more detail:

$$\dot{Q}_{in} = \frac{(T_2(t) - T_1(t))}{\left[C_1 + \dfrac{L}{(A_{cs} \bullet K)} + C_2 \right]}$$

$T_1(t)$ = Tip temperature at solder joint side

$T_2(t)$ = Tip temperature at heater side

C_1 = Thermal resistance at tip/solder joint interface

C_2 = Thermal resistance at tip/heater interface

$\frac{L}{(A_{cs} \bullet K)}$ = Thermal resistance due to the tip (K is path thermal conductivity)

This is the design equation for a Direct Power soldering iron. The three lower terms are simply thermal resistances or inefficiencies in heat transfer. By eliminating or minimizing these inefficiencies, **Qin** is maximized.

The design objective becomes to maximize **Qin** by:

- Minimizing the heat capacity of the tip (i.e., minimize inventory)
- Eliminating interfaces and minimizing the sources of thermal resistance
- Selecting a heater of sufficient capacity such that **Qheater** >> **Qout** + **Qloss**

Looking first at elimination of thermal inefficiencies:

C1 represents the thermal resistance caused by the interface between the soldering iron tip and the solder joint. This term is minimized by using tips with wettable plating, tinning of the tip, and using molten solder bridges during soldering. How well **C1** is minimized depends on operator technique.

C2 represents the thermal resistance caused by the interface between tip and heater and is determined by technology and tool design. Ideally, if there were no interface boundary between the heater or the tip (i.e., if the tip were the heater), **C2** becomes zero.

$\frac{L}{(A_{cs} \bullet K)}$ This term (to the left) is defined by tip design and selection. To minimize this source of thermal resistance, a design balance must be struck between maximizing the cross-sectional area of the tip and minimizing the length (i.e., short, blunt tips). This optimization occurs somewhat naturally when the heat storage capacity of the tip is minimized.

With thermal inefficiencies minimized, let's turn to the top part of the **Qin** equation. The top terms describe the control response of a Direct Power iron with **Qin** a direct function of the temperature differential **T2(t) - T1(t)**. With thermal resistance parameters fixed, if a heater is designed such that **T2** is fixed, **Qin** becomes directly controlled by **T1(t)**, the solder connection temperature. Rather than in a conventional iron where heat is dumped into the joint, with a Direct Power iron the solder joint itself draws power from the soldering iron in proportion to the load via $T1(t)$. Power delivery is direct and dynamically controlled by the solder joint.

STORED ENERGY

DIRECT POWER

With a Direct Power iron, the solder joint behaves like a sponge for heat; it absorbs only as much heat as it needs to be saturated and no more.

As an additional benefit, Qin is largely independent of changes in the tip's average temperature with respect to time. This means heat delivery is largely decoupled from tip temperature. This independence of power delivery (Qin) from tip temperature (Tav) is the key to avoiding the trade-off between damage and throughput that exists with conventional stored energy irons.

Because temperature and heat delivery can now be controlled independently, we can theoretically reduce the soldering temperature and at the same time increase throughput beyond the limits set by conventional soldering irons. Our ability to do so depends solely on how well we can keep $T2$ fixed.

Keeping T2 Fixed: Heater Requirements & SmartHeat®

In order to access the thermal load response benefits of Direct Power design, the heater temperature $T2$ must be kept fixed. To achieve this demands a heater technology able to meet the following specific requirements:

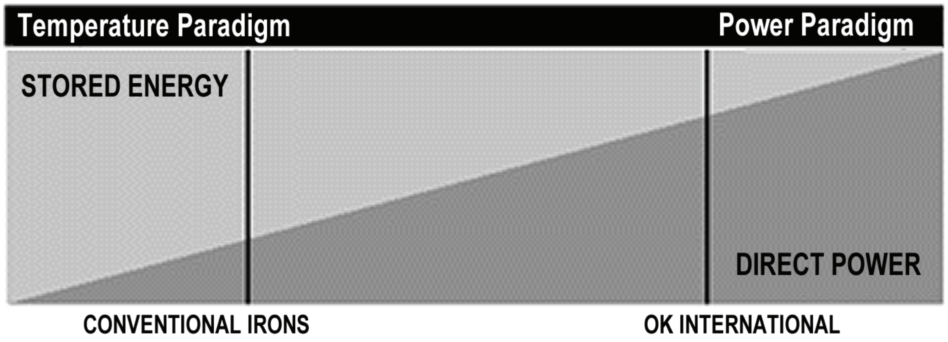
- **The heater should be capable of high watt density output.** High heat generation capability in as small a volume as possible minimizes thermal resistances. It should also have sufficient capacity such that heater output is well in excess of the heaviest thermal loads to be reworked. With the heater as the source of heat–not the tip–more deliverable power, rather than a higher tip temperature, is preferable in handling the heavier thermal loads that may arise from higher pin counts, groundplanes, more PCB layers, and lead-free solder.
- **The heater should be capable of instantaneous control loop response.** Control loop lag times should be eliminated. Ideally, the heater itself should be self-regulating, allowing elimination of any external control loops.
- **The heater should have no temperature overshoot.** While throughput is not a direct function of temperature, thermal damage is. Most damage issues associated with temperature are associated with excessively high temperatures. A heater should be incapable of exceeding its setpoint.

- **Today, only OKi's proprietary SmartHeat® technology meets these requirements.** SmartHeat® is an inherently temperature-stable form of electrical resistance heating. The intrinsic temperature stability built into a SmartHeat® tip not only eliminates the need for external temperature control devices like thermocouples and electronic controllers, but minimizes thermal resistances, eliminates temperature overshoot. SmartHeat® is capable of high watt density heat generation, permitting the design of minimum thermal resistance tips. By minimizing thermal resistances, power is drawn directly from the heater by the solder joint. This allows heater output to be well in excess of the maximum thermal loads to be reworked. For more details on SmartHeat® technology, see Appendix A.

Direct Power in Practice

Today, because of SmartHeat® technology, Direct Power soldering irons are a reality, not just a theoretical abstraction. With the theory underlying Direct Power irons laid out, it should be recognized that in practice, there is no such thing as a pure stored energy or pure Direct Power iron.

All modern soldering irons deliver heat via some combination of stored energy and Direct Power. However, where an iron lies on the design spectrum greatly influences its soldering ability.



To illustrate, two different sets of data are presented.

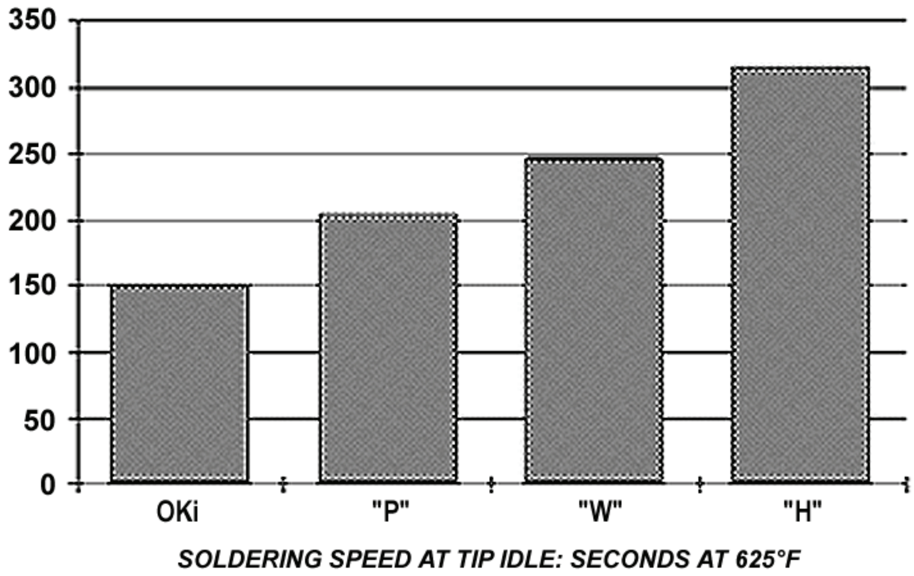
Throughput Comparison at Same Soldering Temperature

A Direct Power soldering iron - the Metcal SP200 by OKi - was tested against three conventional stored energy irons, whom we will call competitor “P,” competitor “W,” and competitor “H.” All four irons used a comparable 1/16" chisel tip from the manufacturer.

Full test set-up information is available in a separate Technical Bulletin, available from OKi.

For this series of test runs, each soldering iron was set to an idle tip temperature of 625° F, and ten joints were brought up to 450° F (the optimum joint temperature for 63/67 Sn/pb solder). Once each load reached 450° F, the iron was moved to the next joint.

Even though all four irons were at the same temperature, throughput was different because heat delivery was different.



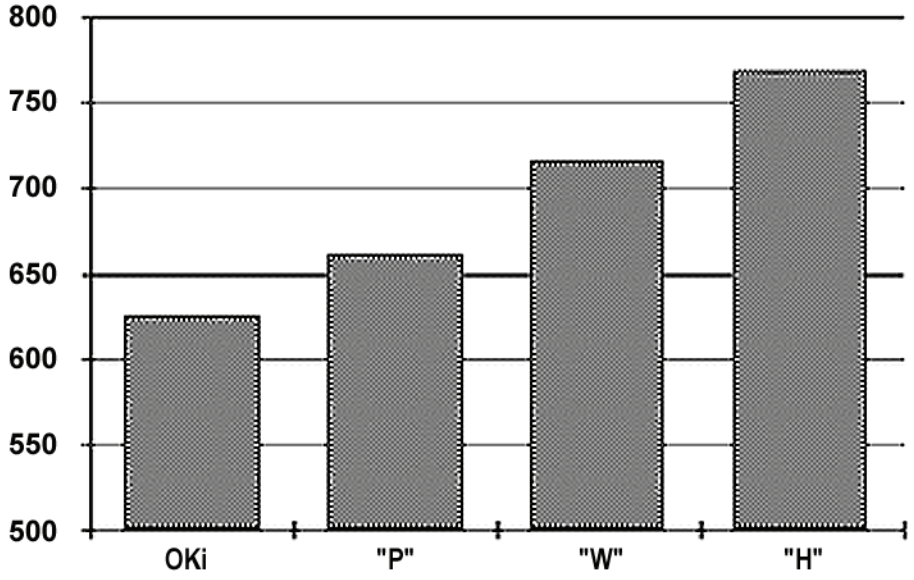
Soldering Iron	**Temp**	**Tip Idle Time to Solder Loads**
Metcal® SP200 by OKi	625° F	150 seconds
Competitor “P”	625° F	204 seconds
Competitor “W”	625° F	245 seconds
Competitor “H”	625° F	316 seconds

For this test at 625° F, the Direct Power Metcal SP200 by OKi soldered 25% faster than the nearest conventional stored energy iron.

Temperature Comparison at Same Throughput

As an illustration that soldering temperatures can be reduced without reducing throughput, the same thermal loads as in the previous experiment were used. The shortest soldering time from the previous experiment (150 seconds) was selected as the benchmark.

The data below shows that the conventional irons required higher tip temperature to achieve the same throughput as the Direct Power iron by OKi.



TIP IDLE TEMPERATURE: °F AT 150 SECONDS

Soldering Iron	**Time to Solder Loads**	**Tip Idle Temperature**
Metcal® SP200 by OKi	150 seconds	625° F
Competitor “P”	150 seconds	661° F
Competitor “W”	150 seconds	716° F
Competitor “H”	150 seconds	768° F

For this test, the tip temperature required to maintain the same throughput was 35° F lower for the Metcal SP200 than for the next nearest competitive iron and over 100° F lower than for the Hakko unit.

Summary

Solder connection temperature, not soldering iron tip temperature, should be the parameter we focus on to ensure reliable solder joints. Unfortunately, because of variable thermal loads on modern PCBs, good control of tip temperature is not enough to ensure good solder joint reliability.

With the contradictory trends towards lower soldering temperatures and higher throughput demands, conventional stored energy soldering irons are being pushed past their performance limits. Because they tie heat delivery to tip temperature, there is no way out of this trade-off.

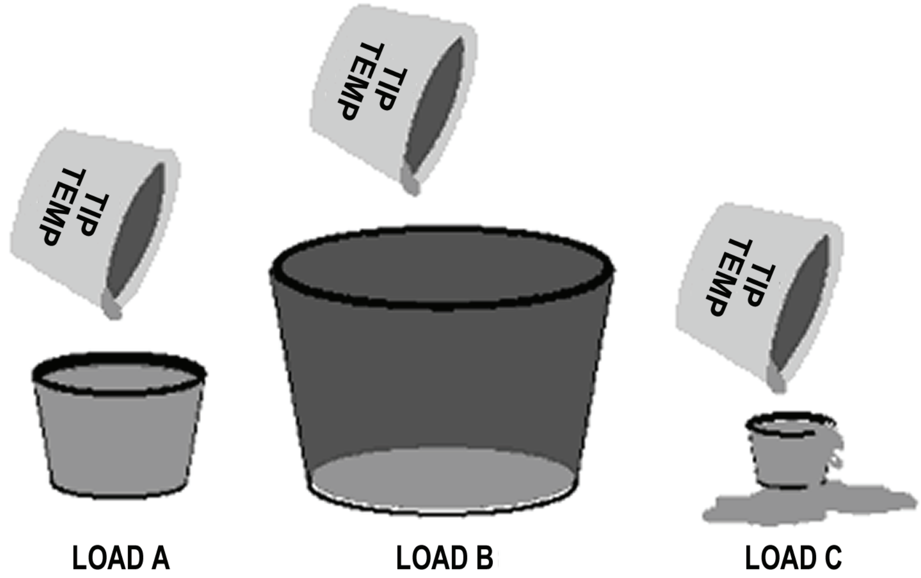
Direct Power soldering irons offer a way out. By decoupling tip temperature from heat delivery, Direct Power irons make it possible to solder faster at lower temperatures. In addition, Direct Power irons interact with the solder joint in such a way that the heat delivered to the joint is controlled directly by the connection temperature—the parameter directly impacting joint reliability.

The ability to access the thermal load response, reduced temperature, and efficient heat delivery benefits of Direct Power design depend on the ability of soldering iron manufacturers to minimize design thermal inefficiencies and on the ability of the soldering iron heater to stay at fixed temperature under variable load. Today, only OKi SmartHeat® technology is capable of meeting the high watt density output, instantaneous response, and no overshoot requirements of a Direct Power heater.

Direct Power Questions & Answers

Q: What's the difference between temperature, heat, and power?

A: To answer this, let's use the analogy of a water in a bucket. Temperature would be equivalent to the level of the water in the bucket as marked by a line on the side of the bucket. Heat would be the actual quantity of water in the bucket as measured by something like cc or liters. Note that if I have three buckets of different sizes and I pour the same amount of water (heat) into each, the level the water reaches (temperature) will be different.

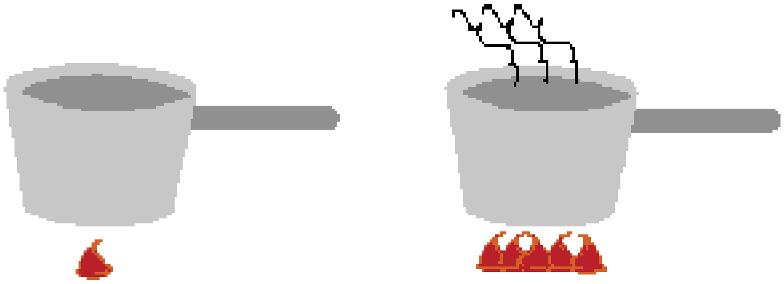


This is the same as with heat. The same amount of heat delivered to a heavy solder joint will raise that joint to a lower temperature than if the same amount of heat is delivered to a light solder joint.

Power is heat per unit of time, and is a measure of how fast (speed) heat is delivered.

Q: How can heat delivery (power) be different if temperatures are the same?

A: Because heat delivery (power) and temperature are different. Take the case of two identical pots of water on a gas stove. One pot is over a gas burner with a large flame, the other over a small flame. If you were to measure the temperatures of each flame, you would find they are identical, because combustion temperature is strictly a function of the type of gas being burned and not its size. But obviously, the pot over the bigger flame is going to boil faster. This is because more heat is being delivered through the larger flame.



Q: Couldn't any soldering iron, even a conventional stored energy iron, be designed more along the lines of the Direct Power design theory?

A: Yes, somewhat. In fact, some of the newer conventional soldering irons, with smaller volume tips and heaters moved closer to the work, which minimizes thermal resistances, are a step in this direction. While these improvements do address the issues of heat transfer efficiency, allowing lower temperature soldering, they do not address the load response benefits of Direct Power design. Remember, the degree to which one can access the load response benefits of a Direct Power iron depends on the degree to which the heater technology conforms to ideal heater requirements. Today, only OKi SmartHeat® technology meets these requirements closely enough to allow the solder joint to control the amount of heat drawn from the iron.

Appendix A: How OKi SmartHeat® Works

SmartHeat® is an inherently temperature-stable form of electrical resistance heating. The intrinsic temperature stability of SmartHeat® eliminates the need for external temperature control devices like thermocouples and electronic controllers, thus eliminating control loop time delays and temperature overshoot. SmartHeat® is capable of high watt density heat generation, permitting the design of minimum thermal resistance tips. This allows the heater output to be well in excess of the maximum thermal loads to be reworked.

SmartHeat® technology uses:

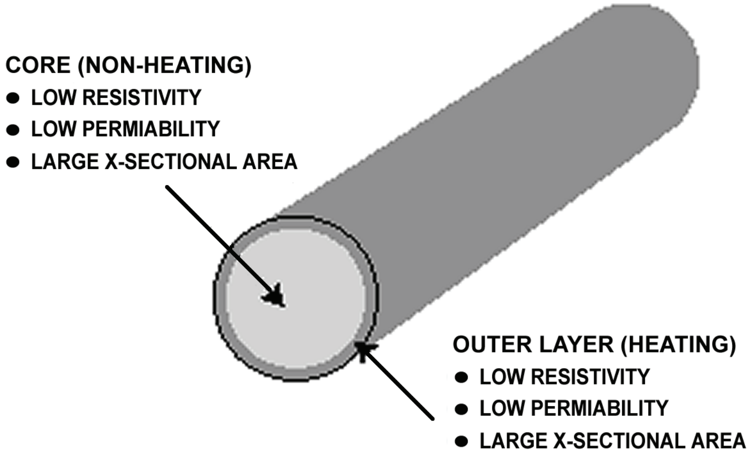
- A heater structure made of a high resistance ferromagnetic laminate over a low resistance copper core
- A high frequency alternating current created by a power supply
- Curie temperature which affects the position of the current flow in the heater

These elements have been combined to form a fixed temperature heat source, the key pre-requisite to unlock the benefits of Power Paradigm soldering.

Resistance Heating: Heat Generation

When an electric current flows through a metal, heat is generated. The amount of heat produced depends on the resistance of the metal, determined by the atomic structure or the metal itself, its length, and its cross-sectional area. The higher the resistance of the metal, the more heat is produced. This is known as resistance heating.

An OKi heater consists of a low resistivity copper core covered by a layer of high resistivity ferromagnetic alloy. When current flows mainly through the low-resistance copper core, little heat is created (heater is off). But when current flows mainly through the high resistance ferromagnetic alloy, a great deal of heat is generated (heater is on).



By alternating between current flow through the core and current flow through the outer alloy, the heater can be switched on and off. To do this, SmartHeat® uses the principles of the AC skin effect phenomena and Curie Temperature.

AC Skin Effect: Controlling Current Position

When alternating current flows through a magnetic metal, it tends to concentrate near the metal's surface. This phenomena is known as the "AC skin effect." The degree to which the current concentrates near the surface, or the "skin depth," is inversely proportional to the magnetic permeability of the metal and the frequency of the current, i.e. the skin depth is shallower and tighter with increasing permeability and frequency.

$$\text{Skin depth} = 0.503 \times 10 \bullet \sqrt{\frac{\rho}{f \bullet \mu_r}}$$

ρ = Material resistivity (micro-ohms-cm)

f = Frequency (MHz)

μ_r = Relative conductor magnetic permeability

With the laminated structure of an OKi heater, this means that as long as the outer ferromagnetic alloy stays magnetic, most of the current will flow through it due to this skin effect. Because the alloy has high resistance, it produces heat.

But if the outer alloy becomes non-magnetic, the bulk of the current will shift into the copper core. Since the copper core has low resistance, little heat will be produced.

Curie Temperature: Self-Regulating Current Switch

It turns out that ferromagnetic alloys become non-magnetic when heated to their Curie Temperature. Curie Temperature is an inherent property of the alloy composition itself. This means that when the alloy is below its Curie Temperature, it is magnetic. Since the alloy is magnetic, most of the current will flow through it due to the skin effect. Because the alloy is of high resistance, it will heat rapidly.

When the alloy reaches its Curie Temperature, it becomes non-magnetic. Most of the current drops immediately into the copper core, stopping the heating process.

As heat is drawn away from the alloy during the soldering process or just heat loss, the alloy cools back down below its Curie Temperature. Current flow immediately moves back to the outer heating layer. As it reaches Curie Temperature again, current flow drops back into the non-heating core. The heater automatically self-regulates. Because of the Curie Temperature limit, the heater cannot overshoot.

The Curie Temperature is set by the atomic structure of the alloy. This means that by switching the alloy composition, different temperature heaters can be created.This is how OKi produces different "Series" tips, from 500 to 800.

Implications of SmartHeat® Technology

Because of the way SmartHeat® technology operates, this means:

- Temperature is fixed and self-regulating
- Temperature cannot overshoot
- Temperature control, recovery, and thermal response is instantaneous
- No external temperature control elements are needed or used
- And, most importantly, power is varied rather than temperature to affect heat delivery.

This allows OKi and Metcal Systems to achieve higher throughput even at lower temperatures.