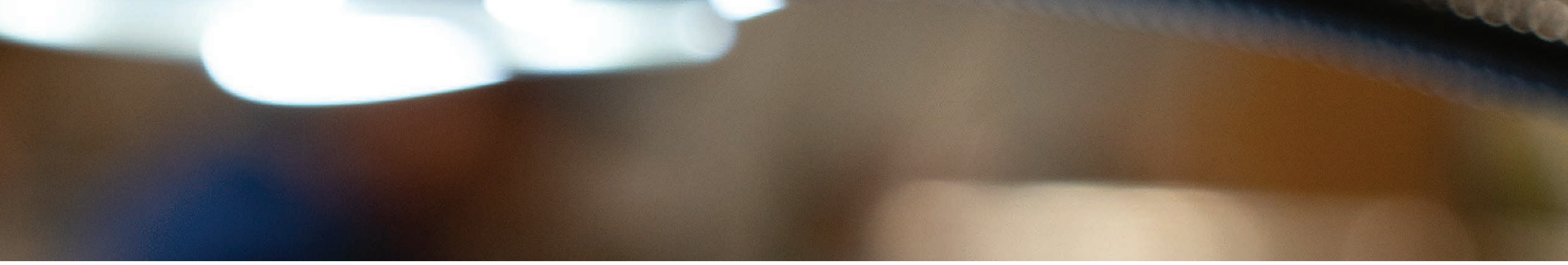

How it Works:
Inductive vs. Resistive Hand Soldering Systems

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METCAL™

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Introduction

There are two main types of hand soldering systems:

1. Adjustable-temperature resistive systems, and
2. Fixed-temperature inductive systems.

Each type offers advantages and disadvantages. However, a third type of soldering system has emerged:

3. Inductive soldering with adjustable temperature control.

This new technology is the basis of METCAL™ brand patented GT series hand soldering solutions that combine the advantages of adjustable temperature with inductive heating technology. And it offers the best-in-class hand soldering performance available.

Adjustable-Temperature Resistive Soldering Systems

Resistive soldering refers to a technology used to heat and melt solder by passing an electrical current through an electrically resistive material.

When electrical current passes through a material resistant to the flow of electrons, heat is generated. The amount of heat produced is dependent upon the amount of current and the resistance of the material that the current encounters.

The main components of typical adjustable-temperature resistive soldering systems include the heating element, temperature sensor, microprocessor-controlled power supply, and soldering tip (Figure 1).

The heating element is commonly made of resistive metals such as nickel-chrome or iron-chrome metallic alloys. The location of the heating element in the system has been shown through testing to affect soldering performance and varies with system design.

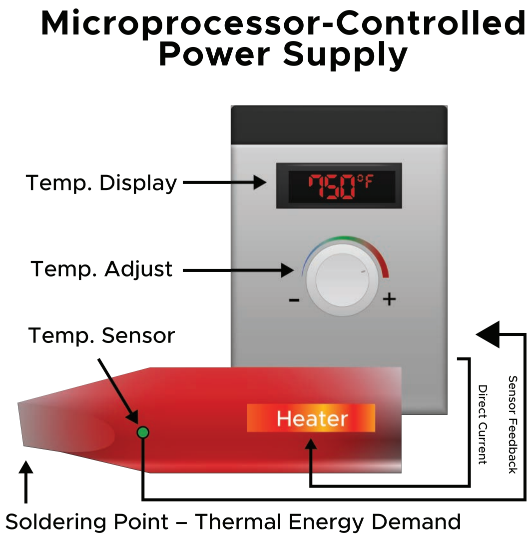

Figure 1: Resistive Soldering System

In some systems, the heater is designed into a cartridge and integrated with and near the soldering tip. In other systems, the heater is designed to be separate and further from the tip.

Temperature is controlled by means of a temperature sensor located between the heating element and the soldering point.

The microprocessor analyzes the temperature reported by the temperature sensor and compares it to the desired set point temperature controlled by the operator. The temperature difference is used to control the current supplied to the heating element.

Soldering tips are typically constructed with a high-grade copper core for maximum heat conductivity. The copper core is then plated with an alloy to protect the core from the severe conditions encountered during the soldering process. Soldering tips are available in hundreds of different sizes, shapes, and metallurgic compositions. Proper tip selection is an essential part of system performance and depends upon the intended soldering application.

Advantages of adjustable-temperature resistive soldering systems are:

1. Adjustable temperature, and
2. Good performance for small to medium loads.

Disadvantages of these systems can include:

1. Temperature overshoot,
2. Calibration requirement to maintain temperature setpoint accuracy, and
3. Lower performance for medium to large loads.

Fixed-Temperature Inductive Soldering Systems

Induction soldering refers to a technology used to heat and melt solder by passing an alternating current through a coil to generate an alternating magnetic field around an object made of ferromagnetic material.

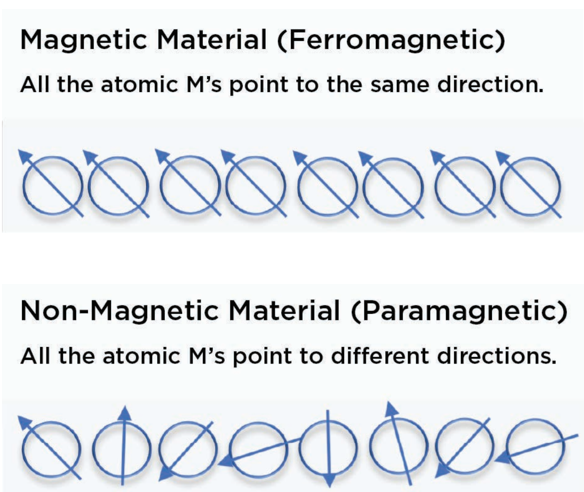

Figure 2: Magnetic Pole Alignment

Ferromagnetic materials, such as iron, nickel, cobalt, and their alloys are highly susceptible to becoming magnetized when in the presence of a magnetic field. When magnetized, the north and south poles of the atoms align to point in the same direction as the magnetic field (Figure 2). When magnetized by alternating current, the atomic north and south poles alternate direction with the frequency of the applied alternating current.

When a ferromagnetic object is placed in a magnetic field, two types of energy losses occur in the form of heat:

1. Hysteresis losses, and
2. Eddy current losses.

Eddy current losses are created when an alternating magnetic field is applied to a ferromagnetic material. Since the ferromagnetic material is also electrically conductive, the applied magnetic field induces an electrical current within the material. These circulating electrical currents flow in swirls or eddies on the surface of the material, hence the name eddy currents (Figure 3). In turn, these eddy currents produce a loss called eddy current loss, equal to (I^2R), where (I) is the value of the current, and (R) is the resistance of the material. The heat generated by eddy current losses is proportional to the resistance of the ferromagnetic material and the current applied to the system.

Eddy currents flow mainly on the surface of the material. This unique phenomenon is known as the skin effect. The skin effect is the tendency of an alternating current to become distributed within a conductive

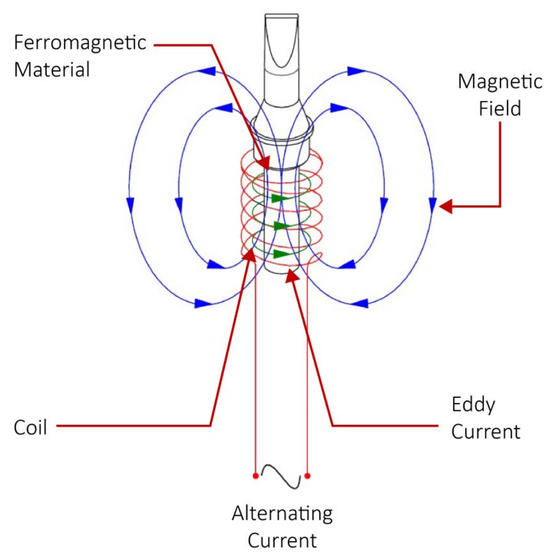

Figure 3: Eddy Current Location

material such that the current density is largest near the surface of the conductor.

The current density decreases exponentially with greater depths toward the center of the material. The skin depth—the depth at which the current density reaches approximately 37% of its value at the surface—is dependent upon the frequency of the alternating current. At high frequencies, the skin depth becomes much smaller. For example, at 60 Hz in copper, the skin depth is about 8.5 mm, and at 1 GHz the skin depth is about 2 μm. Because of the skin effect, the surface of the ferromagnetic object heats up first.

Both hysteresis and eddy current losses result in heating due to friction between molecules that are moving rapidly. However, eddy current losses are usually the main source of heat in induction heating systems. Both hysteresis and eddy current losses depend on the frequency of the applied alternating current. At higher frequencies, more heat is generated.

It is important to note that ferromagnetic materials lose their magnetic properties when heated above a specific temperature called the Curie point (also called Curie temperature, T_C). Curie temperature is a characteristic of the chemical composition of the material and is different for each ferromagnetic substance. For example, T_C of pure iron is about 770°C (1418°F) and T_C of pure nickel is about 360°C (680°F).

The Curie point phenomenon is responsible for the fixed-temperature feature of fixed-temperature inductive soldering systems. As magnetic properties are lost, the ferromagnetic material stops heating. Therefore, maximum temperature is controlled by the Curie point of the ferromagnetic alloy heater.

The main components of typical fixed-temperature inductive soldering systems include the conductive coil, alloy heater, micro-controlled power supply, and soldering tip (Figure 4).

Current passing through the conductive coil creates the magnetic field around the ferromagnetic alloy heater.

The working temperature of the alloy heater is dependent upon its metallurgic composition (Curie point). Once the heater's Curie point is reached, the heater's magnetic property is lost and current can no longer flow, allowing the heater to cool. With cooling, the heater's magnetic property returns, and the heating process begins again. This heating/cooling cycle is happening in the range of microseconds and repeats continuously to regulate temperature. This self-regulating heating process is sometimes called SmartHeat® technology.

The micro-controlled power supply in fixed-temperature inductive soldering systems provides power to the system to be self-regulated. Temperature monitoring by the operator is not required.

Like resistive soldering, tips for fixed-temperature inductive systems are available in hundreds of different sizes, shapes, and metallurgic compositions. Tips are designed to be integrated with the inductive heater in a cartridge assembly.

Proper tip/cartridge selection is an essential part of system performance and depends upon the intended soldering application.

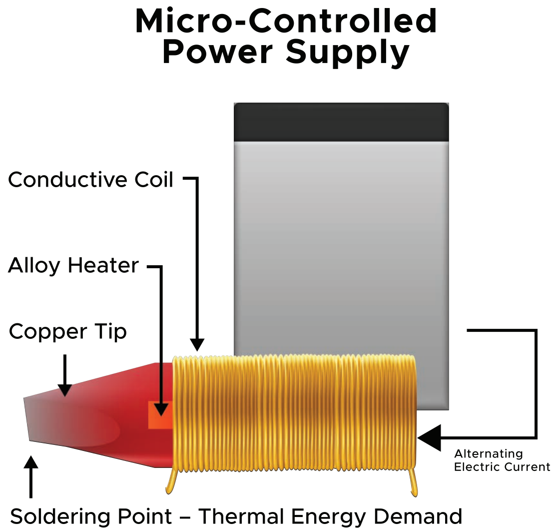

Figure 4: Inductive Soldering System

Advantages of fixed-temperature inductive soldering systems are:

1. Fast heating,
2. Fast recovery, and
3. No thermal resistance.

Disadvantages of fixed-temperature inductive soldering systems are:

1. Changing temperature requires changing the heating element (cartridge).

Adjustable-Temperature Inductive Soldering Systems

METCAL™ GT series hand soldering systems, with patented[1] design, maximize the advantages of inductive soldering technology with the benefits of precision temperature control.

The main components of METCAL™ GT systems include the conductive coil, alloy heater, temperature sensor, micro-controlled PID feedback to controller, and soldering tip (Figure 5).

These systems take advantage of rapid heating indicative of induction due to hysteresis and eddy current losses.

However, these systems have been designed such that they do not experience Curie temperature constraints. The alloy heater employed has an extremely high Curie temperature—so high that the Curie point could never be reached.

The controller is regulating alternating current to extremely high frequencies (around 465 kHz). At these high frequencies, the skin effect restricts the skin depth to about 0.002 inches. At this skin depth, there is an extraordinarily small amount of resistance to the flow of thermal energy. Heat moves very efficiently in these systems.

METCAL™ GT series hand soldering systems utilize patented[2] hardware and software to control and manage tip temperature.

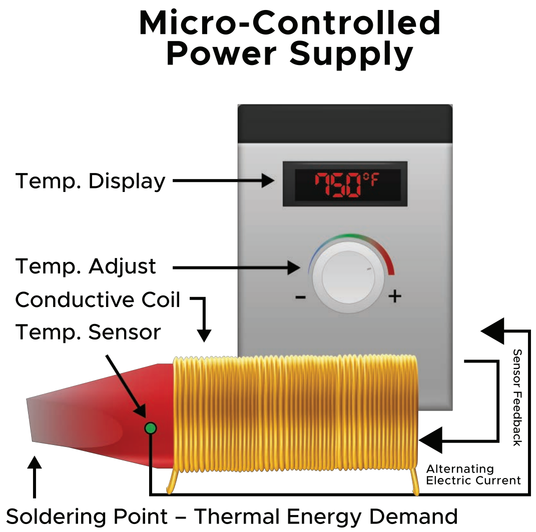

Figure 5: Adjustable-Temperature Inductive Soldering System

The temperature sensor, with a proportional-integral-derivative (PID) feedback loop to the micro-controller, produces continuously modulated temperature control. The tip temperature can be meticulously controlled for optimal performance through precision management of the alternating current applied to the system. These systems allow the operator to create a profile for preheating the tip and ramping up temperature for optimal soldering results.

METCAL™ GT series hand soldering systems accept a wide variety of tips and cartridges. Proper tip/cartridge selection is an essential part of system performance and depends upon the intended soldering application.

Advantages of adjustable-temperature inductive soldering systems are:

1. Fast recovery time,
2. High thermal performance,
3. No thermal resistance,
4. High efficiency, and
5. Ease of temperature control.

[1]Reference Patent No. US 10,176,220 B2 & US 10,645,817 B1

[2]Reference Patent No. US 10,751,823 B2 & US 10,751,822 B2

System Performance

A high-performance soldering system will deliver exceptional throughput with consistent quality measured by visual inspection, time to temperature, dwell time, recovery time, and throughput (see Appendix A for key performance metrics definitions).

Testing[1] has shown that performance of a hand soldering systems depends on the following three factors:

1. Heating technology employed,
2. Whether the system is used with tips or cartridges, and
3. System power.

Although, power plays an important role in the performance of hand soldering systems, the heating technology employed and whether the system is used with tips or cartridges have greater effects.

Systems using cartridges outperform those utilizing standard tips. This occurs because by design, cartridges integrate the heating element with the tip. And the closer the heater is to the tip, the faster the tip will heat up.

Inductive technology outperforms resistive technology due to differences in thermal resistance and thermal responsiveness that are inherent in their corresponding technologies.

And the METCAL™ GT series adjustable-temperature inductive soldering systems used with cartridges exhibit best-in-class performance overall.

Conclusion

METCAL™ GT series adjustable-temperature inductive soldering systems are:

- Faster and more responsive due to superior thermal performance inherent in inductive heating technology, resulting in higher quality solder joints and best-in-class thermal performance.
- Designed to utilize cartridges that integrate heater and tip. There is virtually no thermal resistance in the design.
- Designed with patented[2] precision temperature control hardware and software for best-in-class thermal control.

For more information on METCAL™ GT120 and METCAL™ GT90 adjustable-temperature inductive soldering systems, please visit metcal.com.

[1]For more information on performance testing, see white paper titled "Inductive vs. Resistive Heating Technology Used in Soldering Systems – A Performance Comparison."

[2]Reference Patent No. US 10,751,823 B2 & US 10,751,822 B2

Appendix A – Definitions of Key Productivity and Manufacturing Metrics

Visual inspection refers to several methods, such as manual visual inspection, automated optical inspection, and x-ray inspection, that can be used to detect the presence of defective solder joints. Clues to the quality of a solder joint include its size, texture, uniformity, smoothness, color, brightness, and other surface characteristics like cracks or voids.

Time to temperature is measured by how fast a soldering iron heats to an initial ready-to-solder temperature.

Dwell time, sometimes called temperature stability, is the time it takes a soldering iron to solder a specific joint. Dwell time is related to how well the soldering system can keep tip temperature stable. This can be especially problematic for high thermal demand applications where the tip temperature can dip significantly during the soldering process due to heat transfer.

Recovery time is the time it takes the soldering iron to return to initial ready-to-solder temperature after completing a solder joint.

Throughput in manufacturing is the amount of time needed to complete a manufacturing process. Typical hand soldering process time is in the range of 2 to 4 seconds. Lead-free alloys take longer to hand solder due to higher melting point and minor wetting.

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