Conduction Soldering – Facts, Fiction and Best Practices

Poor hand soldering results are costing electronic manufacturers thousands of dollars every year. There is no secret to producing a good solder joint; the challenges comes with repeating this feat for all joints in the assembly, at production speeds.

The characteristics of a good solder joint are well understood, and established soldering standards such as IPC J STD-001 provide an accurate guide to achieving satisfactory results. Yet production departments frequently experience yield and throughput deficiencies equating to more than the cost of employing an additional operator. Finding a solution can make an appreciable difference to business performance.

Understanding four factors will help to establish a robust and consistently repeatable soldering process, resulting in lower defect rates and lower cost of ownership. These include optimizing the flow of energy from the soldering iron to the joint, and then understanding how performing multiple soldering operations in rapid succession can alter this flow. With this knowledge, the relevant equipment performance parameters can be assessed. The results will surprise most operators, but can be used to make the link between speed and cost of ownership.

The Tip-Heater Interplay

Figure 1 describes how energy is transferred into the connection, from the soldering iron, to raise the joint to a suitable soldering temperature. The IPC J STD-001 soldering standard - as well as many proprietary standards based on its recommendations - specify this as 40°C above the solder-alloy’s melting point. Best practice is then to keep the iron on the joint for between two and five seconds. This is the accepted methodology to produce a solder joint that has an intermetallic layer of around 1-micron thickness, which is considered optimal for maximum electrical performance and physical reliability. In fact, figure 1 focuses on energy transfer as the mechanism that drives temperature rise. This analysis will help to demonstrate how the properties of the soldering iron influence the formation of a series of solder joints.

When the soldering iron tip first comes into contact with the pad, thermal energy stored in the tip is transferred to the site of the joint. As this stored energy is dissipated, the soldering iron heater becomes the main source of the energy necessary to form the joint. Efficient delivery of heater energy, through the main body and face of the tip, will lead to rapid melting of the solder alloy as its temperature increases.

This energy-flow model highlights two important aspects of the soldering iron's performance. Firstly, the thermal properties of the tip, including its mass, dimensions and constituent materials, are crucial in delivering the heater energy to the site of the joint to be created. Secondly, the heater must respond quickly to the sudden application of a thermal load, so that the joint can attain the recommended temperature quickly and smoothly without experiencing excessive temperature drop or overshoot. Examining the performance of popular commercial soldering irons shows an appreciable difference between indicated temperature and actual tip temperature during creation of a soldered joint. This can prevent operators from meeting the conditions recommended in applicable soldering standards, leading to the risk of sub-standard or rejected joints.

Tip Characteristics

Clearly the size and shape of the tip has an important influence on heat-transfer efficiency. If the tip has low thermal mass compared to that of the joint, the amount of stored energy will be low and the initial temperature rise will be slow. If the face size is insufficient to ensure a suitable contact area with the solder joint, the transfer of stored energy and heater energy will be impaired, which will also act to slow down the rate of temperature rise. Figure 2 shows the effect of choosing an incorrect tip that maintains only 50% contact with the joint, resulting in failure to reach the IPC-recommended soldering temperature. During the heater-power phase, the length and width of the tip will determine how efficiently the heater energy can be conducted to the tip face.

Hence if the tip is long and thin, with low thermal mass, and having a small face size compared to the joint, its ability to deliver thermal energy to the site of the joint will be low. This will result in a slow temperature rise, leading to slow joint formation. Figure 3 compares the thermal performance of three soldering iron tips spanning the extremes of tip shapes currently available.

However, an over-large tip is not desirable: excessive stored energy may damage the PCB pad, and a face-size that is too large may result in bridging. Hence, selecting a suitable tip size for the operation in hand is important if operators are to produce large numbers of acceptable solder joints at a high rate of throughput.

The tip-plating thickness also has an appreciable effect on the transfer of energy. A thick plating may be applied to extend the lifetime of the tip, but will negatively influence thermal conductivity. The shape of the tip also affects thermal performance. Some tips on the market are unnecessarily stylized, for example with various flats, step-downs and constrictions along the length. These may look attractive, and may in some cases serve some minor functional purpose, but actually restrict the thermal performance of the tip.

The best possible tip shape, therefore, is not excessively long, is smoothly tapered, has a chisel-shaped face that should be matched in size to the joint, and does not have excessive plating thickness. It should have sufficient mass to help deliver the necessary energy into the thermal load to raise the solder-alloy above its melting point within an acceptable time.

Many operators expect to use only one size and type of tip while soldering. In practice, having the freedom to choose a different tip for certain tasks will enable operators to accelerate production of good joints.

Heater-Control Strategy

Assuming the operator has chosen the optimum tip for a given sequence of soldering tasks, solder joint formation depends on effective management of the heater power. Bearing in mind the role of the tip, implementing a heater of higher wattage - rather than setting a higher tip temperature - is the most effective way to quickly raise the solder to its molten state. In addition, the tip will experience a smaller temperature drop when applied to the load, and will also recover its normal operating temperature more quickly after completion. Both of these factors are important if operators are to produce large numbers of high-quality solder joints in rapid succession.

Ensuring adequate heater power for the range of soldering tasks to be performed is a pre-requisite. However, controlling that power is vitally important if other hazards such as potentially damaging thermal overshoot are to be avoided.

If the heater has a fixed power rating, this will impair its ability to provide suitable control. It can only operate at its rated power to maintain the preset tip temperature as energy is transferred from the tip to the solder joint. In addition, the tip-temperature sensor is usually located in the main body of the soldering iron, away from the face. Hence it will always suffer from some inherent lag as the tip temperature fluctuates.

A soldering iron station with a built-in digital temperature meter may appear to offer a solution. The user can preset the operating temperature and can test that the tip matches this preset value by touching against a built-in test point. Many production managers believe that this offers a satisfactory assurance of correct soldering iron adjustment, and expect that the tool will deliver repeatable performance on the factory floor. In fact, the load placed on the soldering iron during such a test is appreciably lower than that imposed during a soldering operation. Hence it is essentially a static test that, in practical terms, simply confirms the calibration of the tip temperature sensor against that of the test sensor. The operator can gain no representative information regarding how the soldering iron will perform when working to complete a sequence of, say, eight or more solder joints performed in rapid succession.

Under thermal load, the temperature of a typical soldering iron tip can be shown to diverge markedly from that indicated by the digital temperature gauge. Fitting a thermocouple close to the end of the tip and recording its response in relation to the digital temperature gauge during a soldering operation has produced the results shown in figure 4. This shows a large drop in actual tip temperature as the tip is placed on the joint. The instrument’s digital temperature indicator does not show this drop. The temperature reading is damped due to the action of the sampling and averaging circuitry placed between the tip-temperature sensor and the gauge. Figure 4 also shows an appreciable temperature overshoot as the heater control over-compensates for the detected fall in tip temperature. Since the recommended temperatures and time periods indicated in the soldering standards do not take such oscillations into account, these can result in sub-standard joints, or will slow down joint formation with a corresponding effect on productivity. A temperature overshoot carries the potential to damage the board or component, and in any case indicates below-optimal process control.

Manage Energy, not Temperature

The key to the problem lies with the fact that temperature-controlled soldering irons are philosophically not designed to manage thermal energy. Instead, the heater, which is usually a ceramic heater, is turned on if the embedded temperature sensor reads too high, and off if the sensor reads too low. In practice, when the heater controller receives the signal to turn on the heater, the tip temperature will have already fallen below its set point. The heater is then run at its maximum power to increase the tip temperature, and will invariably cause the temperature to overshoot.

As an alternative to a conventional thermostatically controlled heater, inductive heating allows the maximum temperature of the tip to be governed without using temperature-sensing or control circuitry. An inductive heater suitable for use in a soldering iron comprises a copper slug coated with magnetic material, which is wound with the current-carrying coil to form the heater. The properties of the magnetic coating can be adjusted so that its Curie temperature coincides with the preset maximum temperature for the soldering iron. At the Curie temperature, the coating loses its magnetic properties so that the inductive heating action ceases. The temperature of the slug can never overshoot this natural maximum. When a thermal load is applied by placing the iron on the solder joint, the slug falls below the Curie temperature and the coating begins to reacquire its magnetic properties. Inductive heating is then reactivated. In this way, an inductive soldering-iron heater is not only able to operate without a temperature sensor or control circuitry, but also recommences supplying thermal energy automatically, as soon as the tip is placed in contact with the joint. The tip temperature is effectively capped and can never overshoot the preset maximum.

Speed and Cost

As a practical comparison between temperature control and thermal-energy management, consider a soldering comparison between a conventional soldering iron and an inductively heated unit. Figure 5 compares the time taken by both irons to produce a series of nine solder joints. Thermocouples were inserted into the tips of both soldering irons, close to the tip face, to monitor the temperature of each tip continuously and in real-time. The conventional soldering iron takes progressively longer to regain its preset temperature, as the test progresses. In contrast, the enhanced energy-management capabilities of the inductively heated iron enable a more consistent production rate. The inductively heated iron also does not suffer from temperature overshoot.

The slowdown in joint production over the course of this demonstration translates into a significant loss of productivity, leading to higher costs for production operators. Measuring the extra time taken to complete the test allows an estimation of the additional cost to a business. This is significantly more than the purchase price of a soldering iron station, and can also exceed the cost of an entire extra operator.

Assuming an operator works a total of 2000 hours in 50 working weeks of 40 hours, and that 30% of that time is spent performing hand soldering. This equates to 600 hours of soldering time using the fastest soldering iron described in figure 5. Since the next fastest tool is 18% slower, the operator will take an extra 108 hours to complete the same work. Assuming a total burden cost of labor of $14.50 per hour (real figures will vary depending on geographical location), this corresponds to $1711. If 10 operators are employed, all using the slower equipment, the cost to the corporation is $17,110.

The same estimate applied to the next slowest soldering iron reveals an even larger loss. Since this unit is 39% slower, the extra cost of having 10 operators working at this enforced lower rate will be $33,785.

This calculation shows that businesses can quickly recoup the larger capital investment to acquire better performing soldering irons. In some cases, the savings can exceed the cost of employing an additional operator. Going further, to consider the total cost of ownership of the soldering process, including the cost of consumables as well as lost productivity due to unsatisfactory production quality, under-powered soldering irons displaying poor energy control represent an even greater cost to the enterprise.

Conclusion

Control of the soldering temperature is an adequate strategy when performing isolated soldering operations at a low rate of repetition. In a practical production environment, where high throughput and productivity are required, fast and efficient transfer of thermal energy is required. This can be achieved through optimum tip selection and by ensuring accurate management of heater power without exceeding the temperatures recommended in established soldering standards.

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