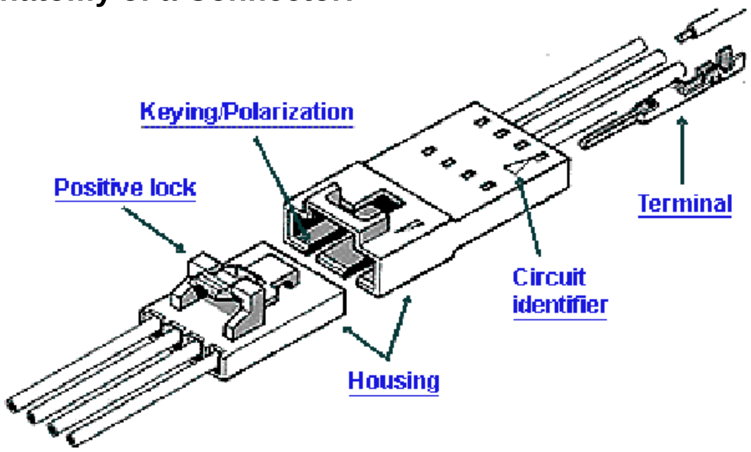
Connectors & Crimping

04/03/05 - by cfh@provide.net.
Information gathered from Molex.com. Most pictures by Molex.

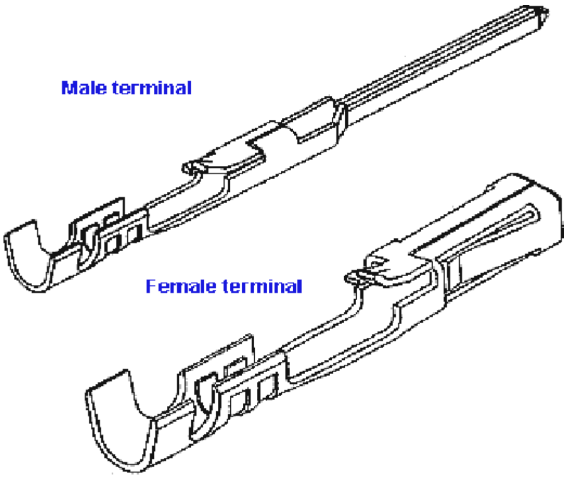
1. Connector Introduction.

Why Use Connectors?
You don't need a connector to complete a circuit. You could older components together. However, imagine the effect soldering would have on assembly manufacturer, repair and upgrades. Using connectors offers several important advantages over permanent connections.

Anatomy of a Connector:



Housing.
Usually made of molded plastic, a housing is a connector's casing. Its main functions are to hold the terminals and protect them from shorting, dust, dirt, moisture, and electrical interference.



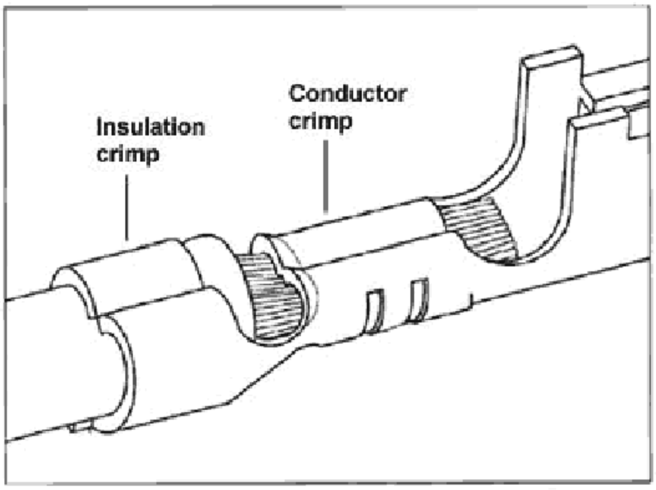
Terminal Pins.

Terminals are the metal components in a connector that conduct current. They are also known as contacts, and they are usually either male or female, as shown on the right. You may hear certain types of male terminals referred to as leads or posts. Terminals are inserted into connector housings. When the connectors mate, the terminals meet and bridge the circuit path.

Methods of Termination.

Termination is a key concept in connector design. It refers to the method used to join a terminal and a conductor. Good termination assures sound electrical contact and maximum strength between the conductor and the terminal (for a gas-tight connection, to prohibit corrosion). The most common termination methods are listed on the right and discussed on the next few pages

- Crimping
- Insulation displacement connector (IDC)
- Surface mount
- Wire wrap (for prototyping)
- Soldering
- Press fit



Termination: Crimping

In crimping, a metal sleeve is secured to a conductor by mechanically crimping the sleeve with pliers, presses, or automated crimping machines. Note that the conductor is crimped in two places – on the wire and on its insulator. The latter is called a strain relief. It provides additional resistance to mechanical stress. A "good crimp" provides a gas-tight connection on the terminal pin, which prohibits corrosion at the wire to terminal pin connection. Since a crimped connection can be easily performed with an inexpensive hand crimper, and provides an excellent gas-tight connection, this is what should be used on most replacement pinball applications.

Crimped connectors also work well in a production environment. Molex makes automatic crimping tools and dies, which can feed terminal pins and wires, doing many many crimps automatically per minute. After talking to the Molex tech advisors, they admitted this: "Hand crimpers are a necessary evil. We don't like them, and wish we didn't have to sell them. They can provide inconsistent crimps, with the possibility of human error. And they can make our highly engineered products fail when they should not fail, if machine installed." So keep that in mind when hand crimping! The end result is all up to you (below is a guide to proper hand crimping.

Termination: Insulation Displacement

In insulation displacement technology (IDT or IDC), an insulated wire is pressed into a terminal slot smaller than the conductor diameter, displacing the insulation to make electrical contact. In application, insulation need not be removed, which is a major advantage of this method of termination using Insulation Displacement Connectors (IDC). That is, the advantage to IDC connectors is that assembly time is dramatically reduced, decreases cost. This is why most pinball manufacturers used this (crappy!) style of connector termination originally. IDC connectos are not used for reliability, they are used to decrease assembly cost. Hence as a replacement, this style connector should be avoided.

IDT/IDC connectors are great for manufacturers. There's no separate step of stripping the wire for connection to the terminal pin, and no crimping step. Basically the only connection step involved is mating the wire to the IDT connector and pressing it in place. In the short time, an IDT connector works fine. But over time, due to the design of IDCs, the "V" that cuts through the wire insulation can also eventually cut the wire strands too (causing a decrease in current handling, which means a burnt connector!) Also the wires can be pulled/ripped from the IDC terminal pin much easier than a crimped connection. And lastly, the tool required to do a good non-production IDT connection is expensive, compared to a hand crimper (I'm not talking about that small IDC mushroomed shaped tool).

Pitch

Pitch is the distance from center-to-center between adjacent conductors. Pitch also affects arcing, which can cause interference between adjacent conductors in a connector. The most common pitch size used is .100" (for low voltage data) and .156" (for power connections).

Connector Levels

There are many types of connectors. However, each type fits into one (or more) of five categories. In the industry, these categories are known as levels. The levels were defined by major connector companies under the auspices of an organization called NEDA.

- Wire-to-Board or Subassembly-to-Subassembly Level
- Box-to-Box or Input/Output Level
- IC Chip or Chip-to-Package Level
- IC Package or Package-to-Board Level
- PC Board-to-Board Level

Signal and Power Connectors

There are two broad types of connectors: signal and power. They are often distinguished by the amount of power they carry. But the key distinction is that signal connectors have minimal resistance to current flow. This minimizes disruption of the relatively weak signals flowing through them.

A disk drive uses both signal and power connectors. The power connector bridges the circuit that drives the unit. Because the power current is so strong, a small loss is acceptable. The signal connector, however, carries data in very weak signals. The connector is therefore designed to eliminate signal loss.

Conductors and Insulators

Electrical charge moves through some materials better than others. Substances through which electrons flow freely are called conductors. Substances that resist the flow of electrons are called insulators. In the electronics industry, a more common term for insulator is dielectric.

Copper wire is an excellent conductor because it has a large number of free electrons. If a copper wire is connected between the terminals of a battery, free electrons in the wire move from the negative terminal to the positive terminal. This free flow of electrons is electric current.

Terminals as Conductors

In a connector, current is conducted through the connector by the contacts or terminals, which are made from various metals. Metal is one of nature's best conductors because it has a lot of free electrons. When two metal terminals mate, electrons can flow from one surface to the other, continuing the circuit.

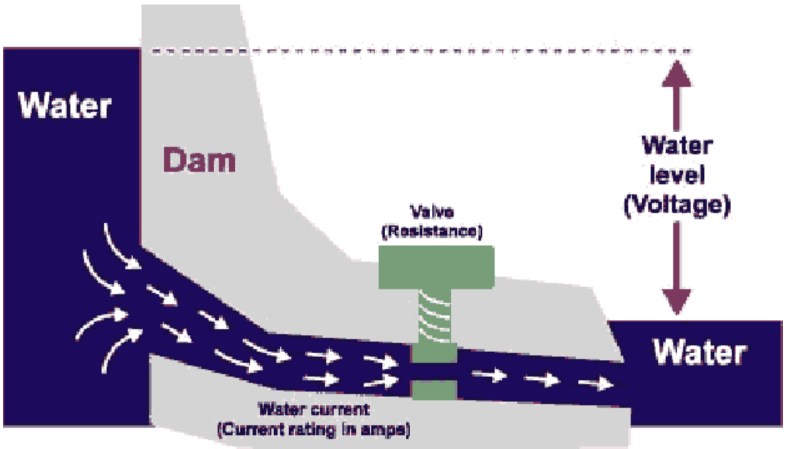
Insulators in Connectors

Plastics are used in connector housings because of their excellent dielectric properties. Like all good insulators, plastic resists the flow of electric current. The electrons of an insulator are tightly bound to their atoms and cannot move freely, even if you apply an external charge. Other common insulators are glass and rubber.

Voltage

Voltage is a force that pushes electric current through a circuit. It causes electrons to jump from one atom to another. Voltage is often referred to as electric pressure, and is indicated by the V symbol. Typical connector voltages are 50V, 125V, 250V, and 600V.

This dammed river image is often used to explain electrical measurements. Voltage is like water pressure. No force actually pushes electrons through a circuit. Rather, like the water level, the difference between the two levels forces the flow. The greater the discrepancy between levels, the greater the flow.



Current Rating and Amperage

Current rating indicates the rate of flow of electricity. It is measured in amperes and is indicated by the letter A. In a connector specification, this figure indicates the maximum amperes at which the connector can be used continuously without electrical or mechanical failure.

Amperage is similar to gallons per minute or gallons per second. It indicates how much electric current flows past a certain point in a given time period. Connector current ratings are usually in the range of 1A to 50A per circuit.

Resistance and Ohms

Resistance is a material's tendency to inhibit electron flow. Resistance is measured in ohms. This specification indicates the maximum resistance of the contact area when the connector is mated. Typically, this is less than 25 milliohms.

In the water example, resistance is caused by the valve. Tighten the valve and the rate of flow decreases. In a conductor, resistance is a property of the

material. It occurs when electrons collide with atoms and give up energy. A conductor like copper has low resistance.

The Relationship between Voltage, Resistance, and Current

It's important to understand that voltage, resistance, and current are not independent of each other. They have an intimate relationship. Their relationship is expressed by Ohm's Law. When selecting a connector, all three must be considered and matched to the application.

Ohm's Law: **The current in an electrical circuit is directly proportional to the voltage and inversely proportional to the resistance.**

Voltage = Current x Resistance

or

Current = Voltage/Resistance.

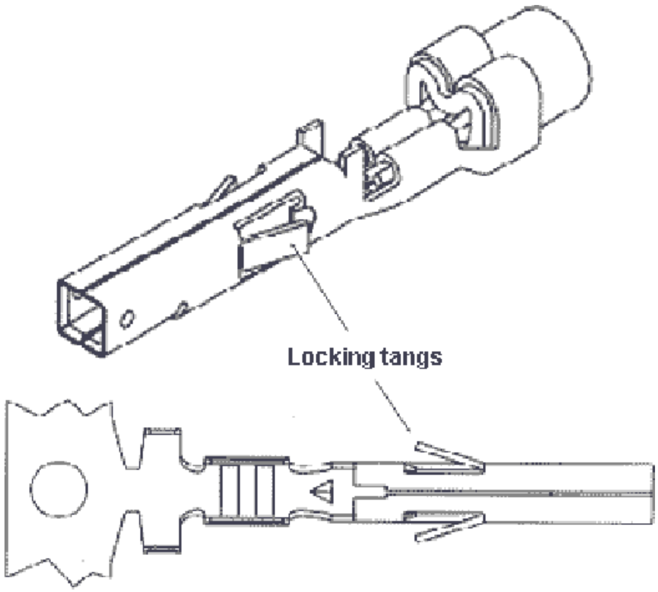
The important point about Ohm's Law is that, when selecting connectors, all the electrical specifications must be considered. All metals have inherent resistance. The greater the resistance, the more voltage is required to push the current through the connector. Using Ohm's Law we can determine the overall efficiency of a connector.

Mechanical Specifications of Connectors

The mechanical specifications of a connector indicate how a connector performs under critical mechanical actions. These are of great importance to customers who must match the right connector to an application.

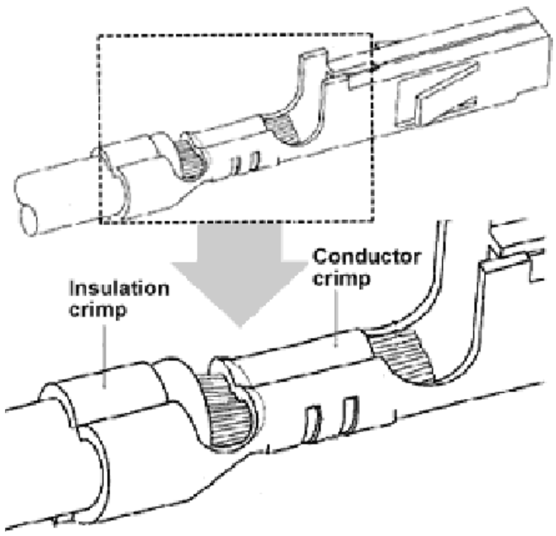
Contact Insertion Force

This specification identifies the mechanical force required to insert a terminal into a connector housing.



Contact Retention to Housing

Contact retention force holds a terminal in a housing cavity. This prevents terminal backout, or the coming loose of the terminal. Typically, locking devices called tangs secure the terminal against the housing walls using spring-like pressure. The contact retention to housing specification describes the force required to remove a properly seated terminal.



Wire Pull-Out Force

This specification describes the force required to separate a wire from a terminal by pulling them apart. This is primarily a function of the termination method and the quality of the termination. In a crimped terminal, for example, both the insulation

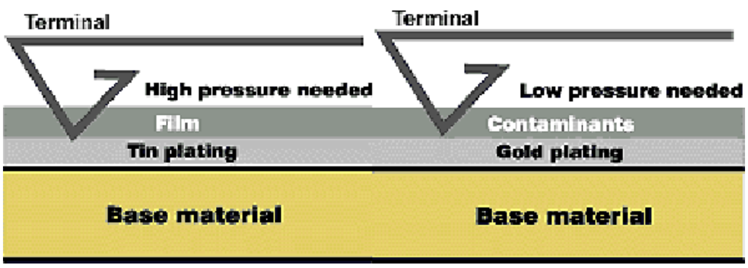
and conductor are crimped to assure maximum wire pull-out force.

Mating and Unmating Force

This specification describes the force required to join and separate two halves of a connector. This is the sum of contact mating forces plus any additional force necessary to overcome minor misalignment of connector halves and any dimensional variations in the housings.

Normal Force

Once terminals are mated, normal force is the pressure applied perpendicular to the terminal interface. This pressure assures a gas tight condition between the terminal surfaces. This is considered the most important mechanical specification because it assures a consistent and high quality electrical contact.



Durability of Terminal Pins and Header Pins

Durability indicates the number of times a terminal can be mated and unmated without degrading performance. Durability is measured in "cycles" (the number of times a connector can be removed or installed). As shown above, durability varies with the materials used.

Stamping Materials

Terminals and pins are made of a variety of metals, each with different properties. Because of their atomic structure, metals are excellent conductors of electricity. Metals also have mechanical properties that make them ideal for connector terminals.

The properties of metals that are of interest to connector manufacturer are:

- Electrical conductivity
- Mechanical strength
- Formability
- Resilience (ability to return to its original shape after slight deformation)

Plating

Metals that have good mechanical properties do not always have ideal electrical properties. Plating is the process of coating terminals of base metal with a layer of nickel, tin, or gold to improve their electrical performance.

Common stamping metals include brass, phosphor bronze, beryllium copper, and other copper-based alloys. As you have learned, these metals have good strength, spring, and formability. Yet each of these metals has electrical deficiencies. To overcome these deficiencies, terminals made from them are plated with gold, tin and tin-based alloys, and palladium/nickel alloys.

Copper-based alloys have ideal mechanical properties, but they do not meet other connector design requirements. They are plated to improve:

- Electrical performance
- Solderability
- Corrosion protection

Tin versus Gold Plating

Terminals plated with tin or tin alloys oxidize and are contaminated by gasses, water vapor, and organic molecules. This film degrades conductivity, so sufficient wiping pressure must be applied to break the film. This pressure also removes tin plating, which decreases durability. Gold Plating Oxide film does not form on gold, so wiping pressure can be lighter to penetrate only the contaminants. Durability is much higher, often in the hundreds of cycles. This is why modular phone jack terminals, which may be mated and unmated many times, are usually gold plated.

Selective Gold Plating

The process used to plate gold only in selected areas of a terminal. Selective plating assures that critical terminal areas are plated, but non-critical areas are not. This reduces costs.

Do NOT Mix Gold and Tin Terminals and Headers!

It is not a good idea to mate a gold terminal to a tin header (or vice versa), or mix any other dissimilar connector metals. Use the same metal for both contacts! The contact resistance will go up with dissimilar metals, causing all sorts of problems (depending if it is a logic connector or power connector).

Connector Tools & Parts Needed

The right tools and parts are needed, so just honker down and buy them.

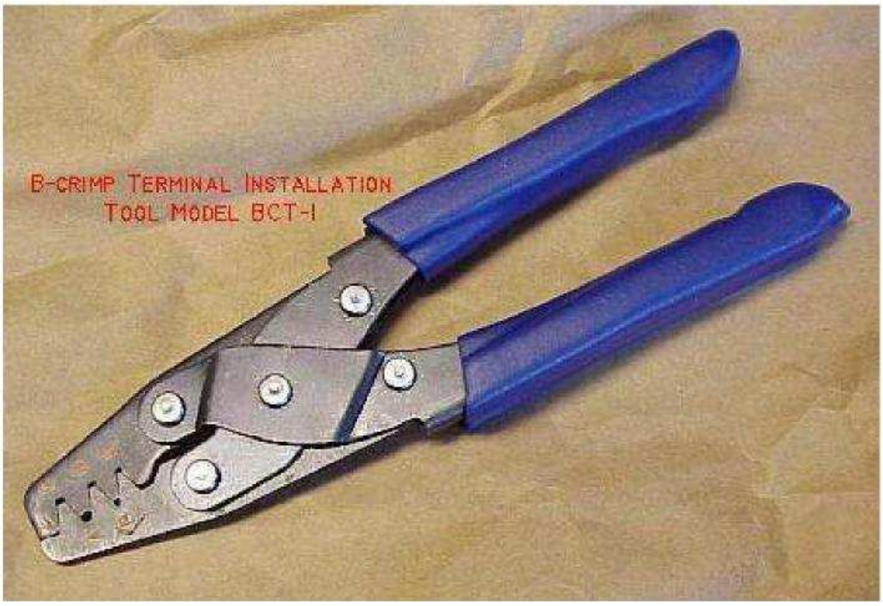
Tools Needed

Here are the minimum connector tools required.

- **Terminal Pin Hand crimper. These are used for all the different styles of Molex terminal pins**
- **Round Pin Extractor**

How to Perform a Good Connector Crimp

Info from [www.molex.com/tnotes/crimp.html,](www.molex.com/tnotes/crimp.html) but re-edited, modified, and embelished with emphasis on hand crimping. All pictures from Molex.

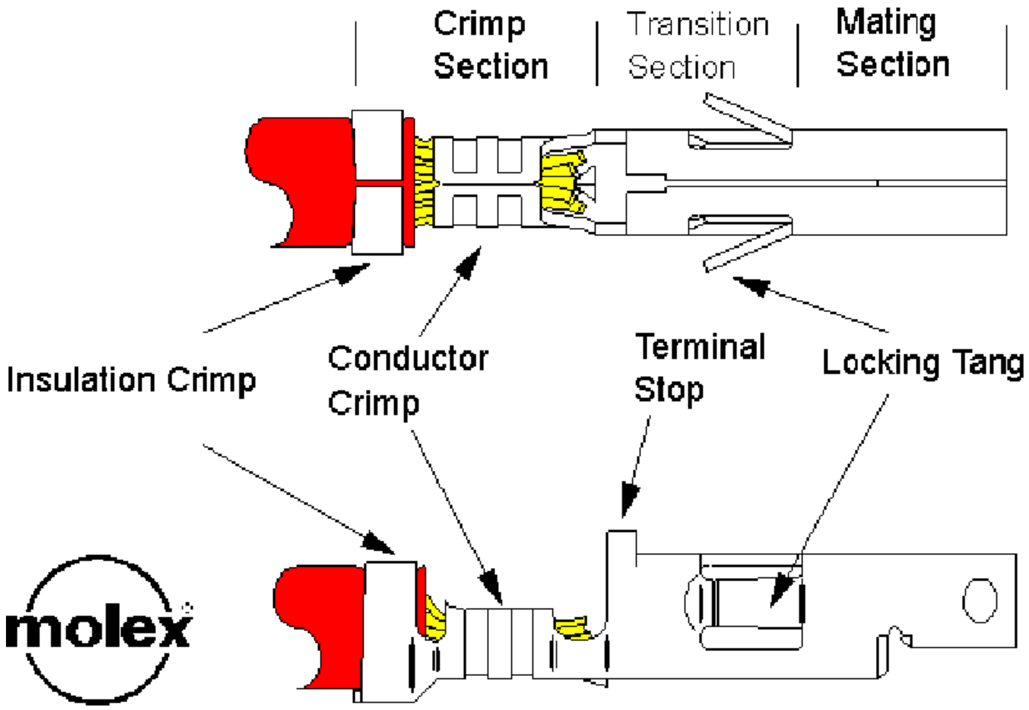


The BCT-1 hand crimper for crimping Molex connector pins

Before proceeding, you'll need some sort of hand crimper. Several hand crimpers are available from Molex and other sources. Before proceeding, acquire a good hand crimping tool.

Now that you have the proper hand crimping too, it's time to talk about how to use it properely to make a "good crimp". To begin with, it helps to understand that a terminal has three major sections: Mating, Transition and Crimping.

ANATOMY OF A TERMINAL PIN

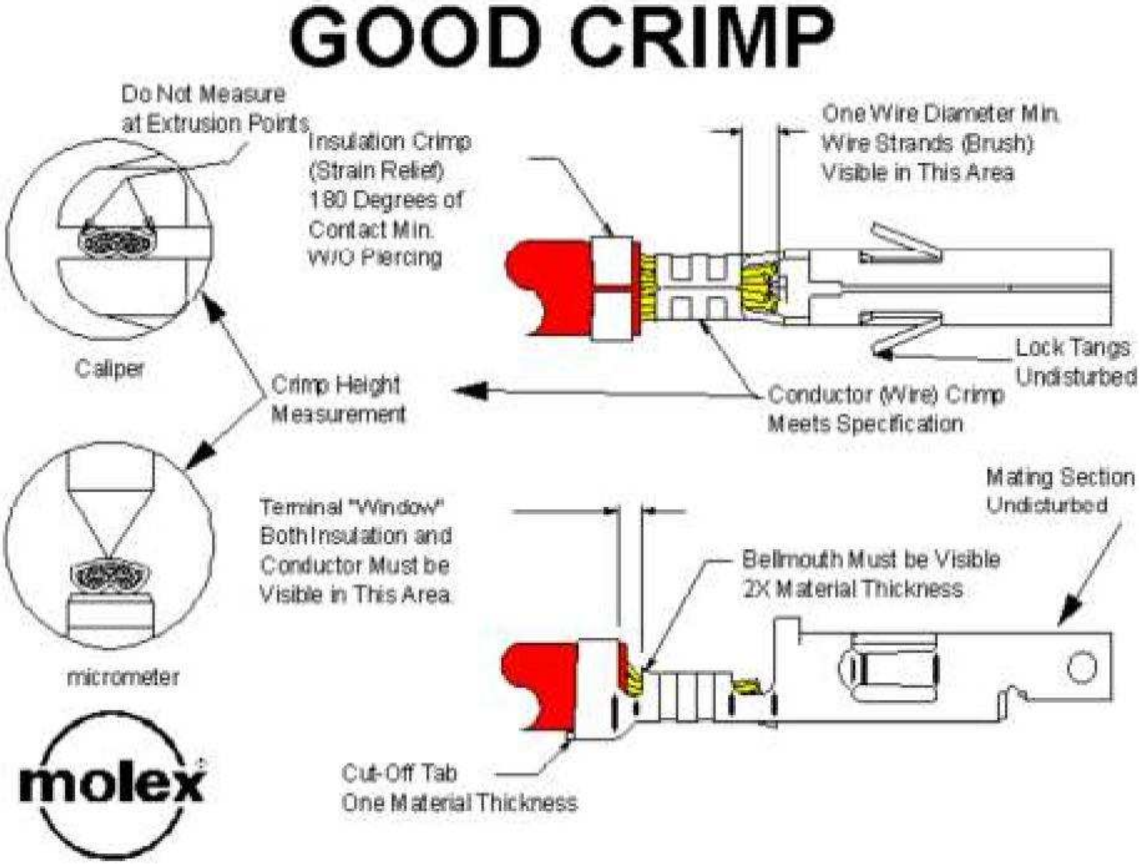


The Mating section, as the name implies, is the section of the terminal that mates, or becomes the interface, with the other half of the connection. This section was designed to mate with a terminal of the opposite gender and to perform in a certain manner by the connector design engineer. Anything done that deforms the Mating Section, especially during the crimping process, will only reduce the connector's performance.

The Transition Section is also designed so not affected by the crimping process. Here again, anything done that changes the position of the Locking Tangs or Terminal Stop affects the connector's performance.

The Crimp Section is the only section that the crimping process is designed to affect. Using a good quality hand crimper, the crimp section is deformed so it can be securely attached to a wire. Ideally, all the work done to crimp a terminal onto a wire occurs only in the Crimp Section.

An example of a properly performed crimp is seen below:



In the picture above, the insulation crimp compresses the insulation without piercing. The wire strands (or brush) protrude through the front of the conductor crimp section by at least the diameter of the wire's conductor. For example, an 18 AWG wire would protrude at least .040". Both the insulation and conductor are visible in the area between the insulation and the conductor Crimp Section. The conductor Crimp Section shows a bellmouth shape in the leading and trailing ends, while the Transition and Mating Sections remain exactly the same as they were before the crimping process.

If a crimped terminal does not look like the terminal in the above illustration, the problem was probably caused by something that went wrong during the crimping process. Below are the most common problems that may occur during the crimping process, and how to avoid them.

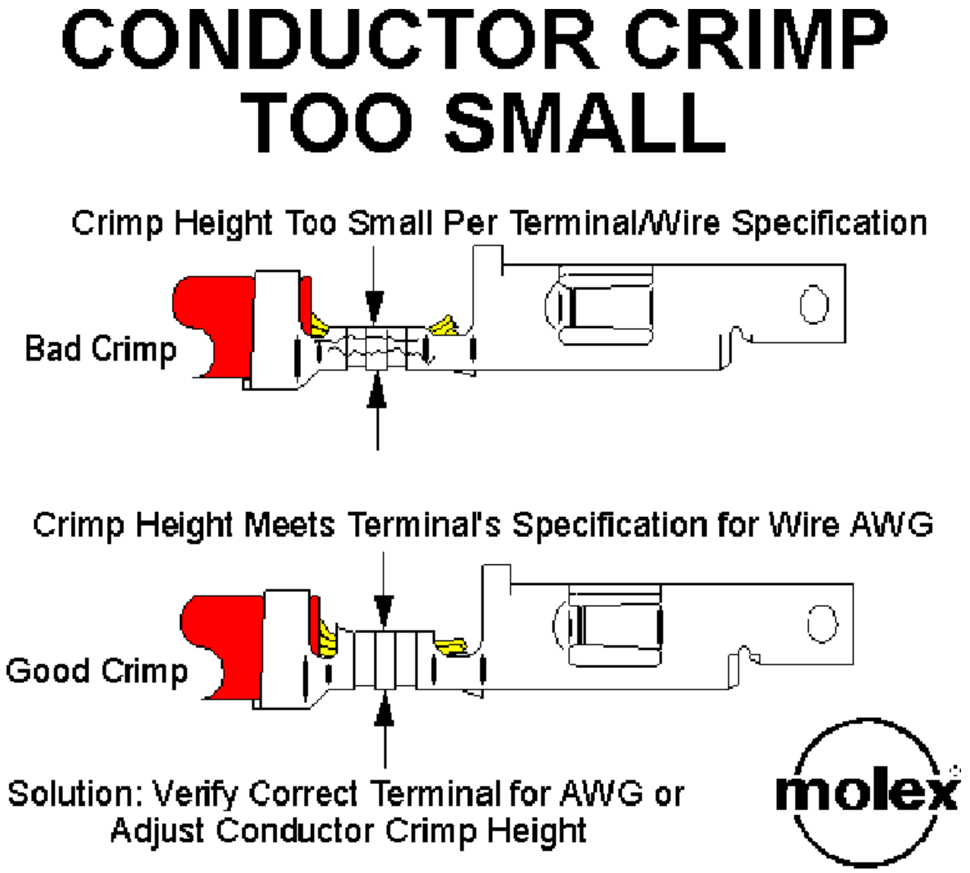
Crimp Height is Too Small

The crimp height, which is the cross sectional height of the conductor Crimp Section after it has been crimped, is the most important characteristic of a good crimp. The connector manufacturer provides the crimp height for each wire size

for which the terminal was designed. The correct crimp height range or tolerance for a given wire may be as small as 0.002".

With a specification this tight, getting a perfect hand crimp can be difficult. And forget measuring the crimp height; terminal geeks would measure this with a "point micrometer", something I can guarantee you don't have in your toolbox!

But still, the information is good to know. So keep in mind that an over-crimped terminal (crimp height too small) is just as bad as an under-crimped (crimp height too large) terminal.



A crimp height that is either too small or too large will not provide the specified crimp strength (terminal retention to the wire), will reduce the wire pull out force and current rating, and may generally cause the crimp to under perform in otherwise normal operating conditions. A crimp height that is too small also may cut strands of the wire or fracture the metal of the conductor crimp section.

Crimp Height Too Large

A crimp height that is too large will not compress the wire strands properly. This causes excessive voids in the Crimp Section because there is not enough metal-to-metal contact between the wire strands and the metal of the terminal. This also compromises the Gas Tight seal that a good crimp offers.

The solution to problems the above problems is very simple: adjust the conductor crimp height. With a hand crimper, either press harder or lighter to adjust the crimp. Also make sure the right crimper is being used (remember there is a different hand crimper for .100" and .156" terminal pins).

Crimp Width

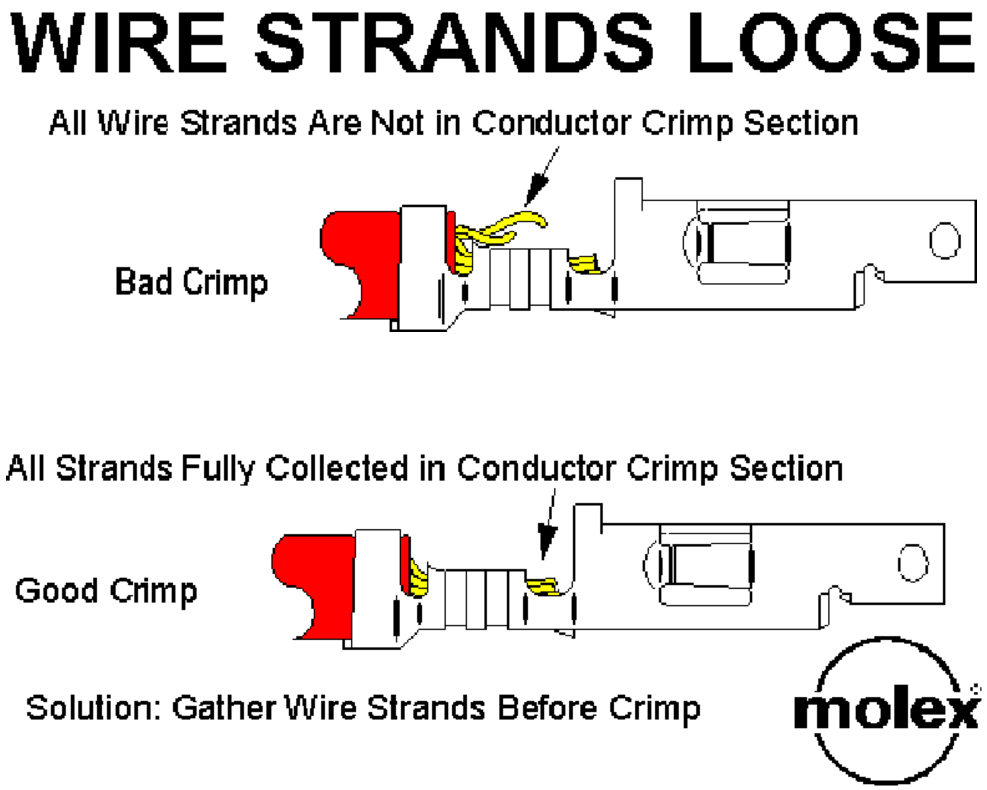
Crimp width is just as important as crimp height. For optimum crimp performance, the cross sectional area needs to controlled. For the most part, the crimp tool geometry will produce the proper crimp width, when the terminal is crimped to the recommended height. This assumes you're using the manufactures recommended crimp tool. If using a different crimp tool, the width may be incorrect. Therefore, the resultant cross section will be too large or too small.

So what's the bottom line here? Buy a Molex hand crimper designed for .156" or .100" terminal pins. This will ensure a better hand crimp.

Insulation Crimp Too Small or Too Large

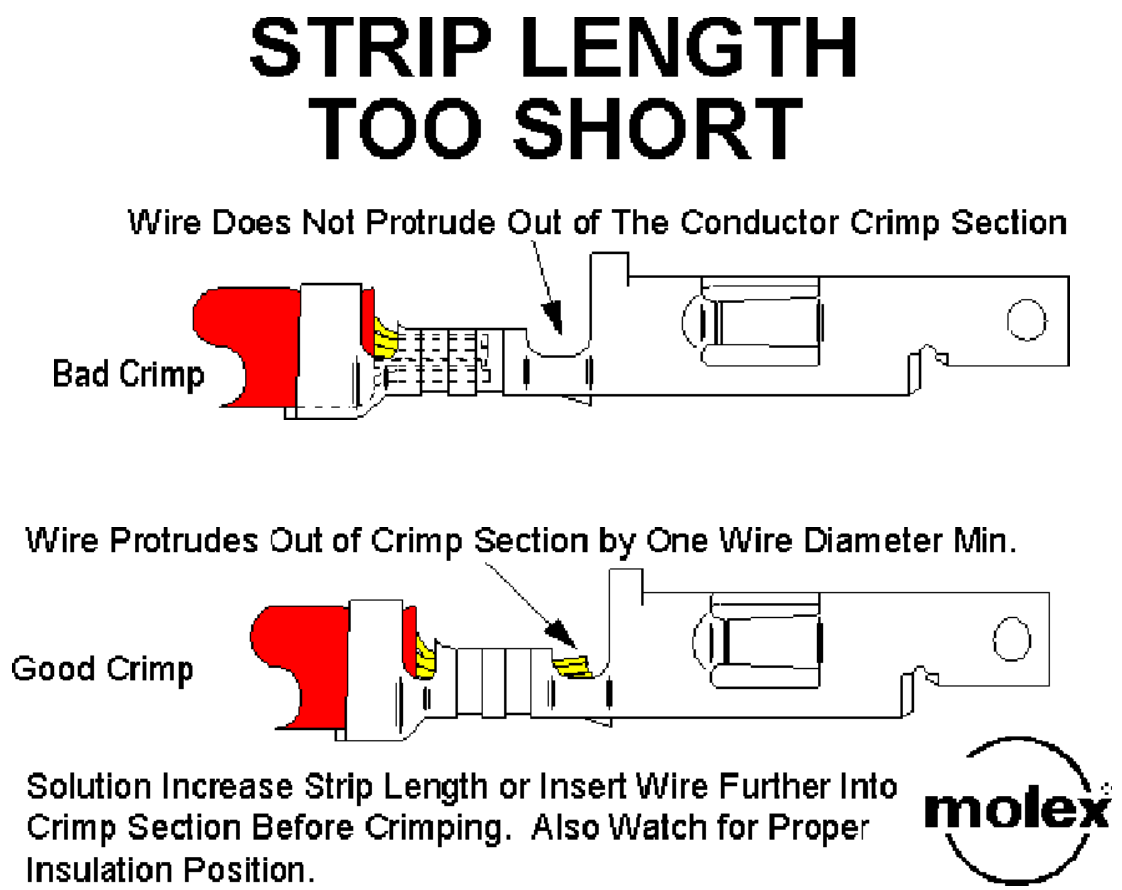
Connector manufacturers do not typically supply a crimp height for the insulation due to the variety of insulation types and thicknesses. The insulation crimp provides a strain relief for the conductor Crimp Section so that as the wire flexes, the wire strands do not break. An insulation crimp section that is too small may overstress the metal in the insulation Crimp Section, weakening the strain relief function (and potentially breaking the wire).

Most types of production crimp tooling allow the insulation crimp height to be adjusted independently of the conductor crimp height. The correct adjustment allows the terminal to grip the insulation for at least 180 degrees without piercing the insulation. An insulation displacement, or compression where the outside diameter (OD) of the terminal's insulation crimp and the OD of the insulation are approximately the same, is ideal.



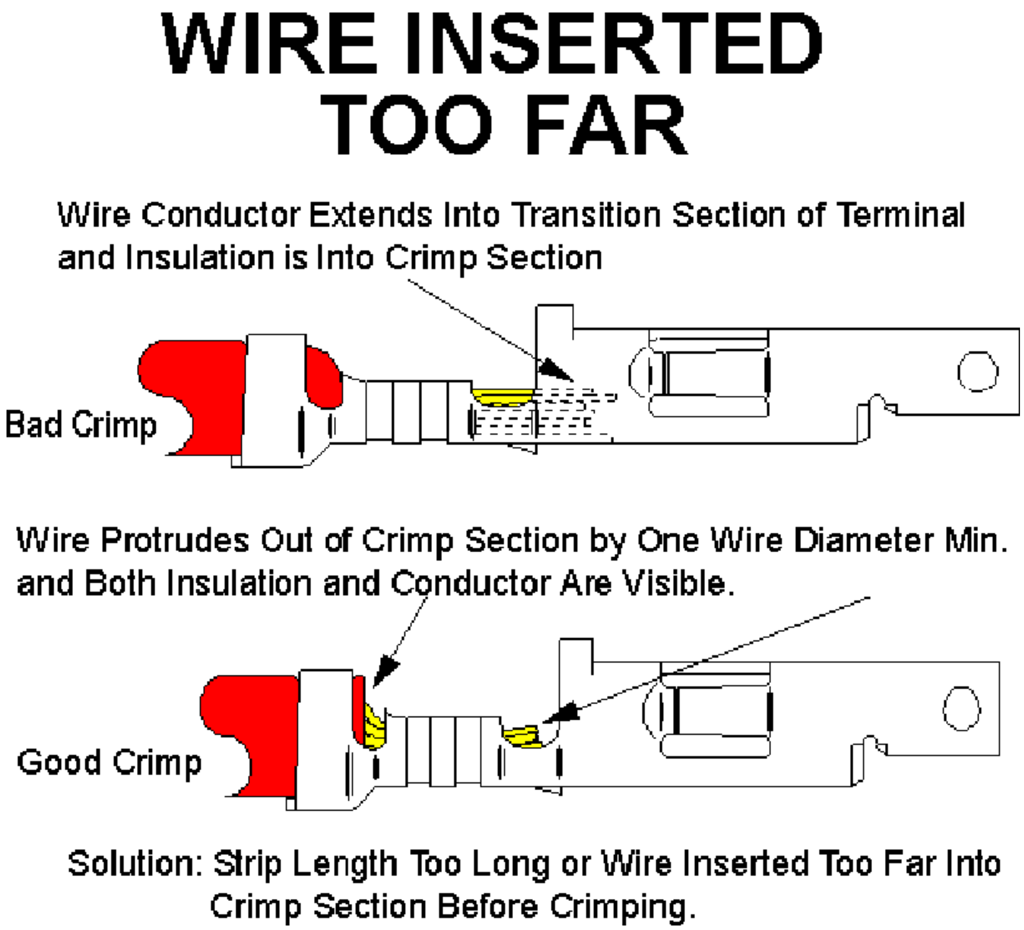
Loose Wire Strands

Loose wire strands are another common cause of crimping problems. If all the wire strands are not fully enclosed in the conductor Crimp Section, both the strength of the crimp and the current carrying capability may be greatly reduced. To get a good crimp you need to meet the crimp height the connector manufacturer specifies. If all the strands are not contributing to that crimp height and therefore crimp strength, the crimp will not perform to specifications. Generally, the problem of loose wire strands is very easy to solve by simply gathering the wires back into a bunch before inserting them into the terminal to be crimped. Using a "strip and retain" process for insulaton removal, where the insulation slug is not completely removed from the wire until it is ready to have a terminal crimped onto the wire, helps minimize the problem.



Too Short Strip Length

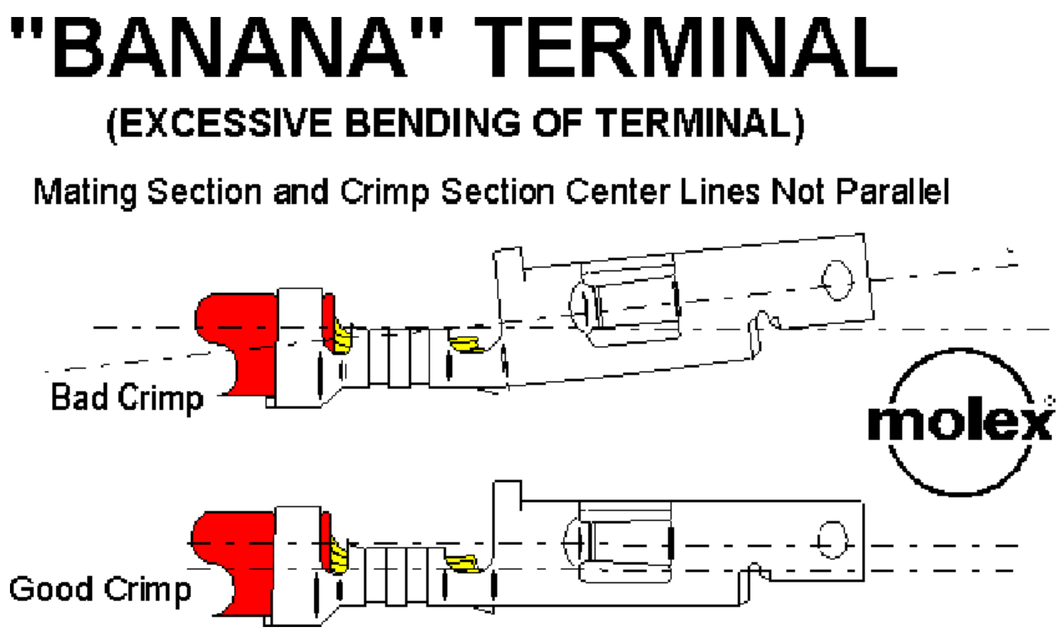
If the strip length is too short or if a wire is not fully inserted into the conductor Crimp Section, the termination may not meet the specified pull force because the metal-to-metal contact between the wire and the terminal pin is reduced. As shown in the figure above, the strip length of the wire is too short (note that the insulation is in its proper position), not allowing the required one wire outside diameter (OD) extension in front of the conductor Crimp Section. The solution is simple: increase the strip length of the wire stripping equipment to that specified for that specific terminal.



Wire Inserted Too Far

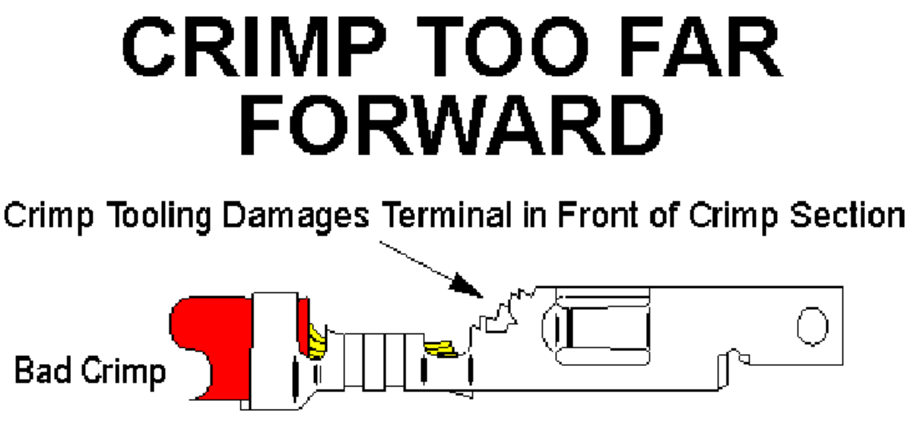
Another crimping problem that relates to a too short strip length occurs when the wire is inserted too far into the crimp sections. As the figure above shows, the insulation is too far forward of the insulation Crimp Section and the conductors protrude into the Transition Section. This may cause as many as three failure modes in the actual application. Two relate to a reduced current rating/wire pull out force due to a reduction of the metal-to- metal contact in the conductor Crimp Section. A metal-to-plastic contact isn't as strong, nor does it conduct electricity, as well as metal-to-metal.

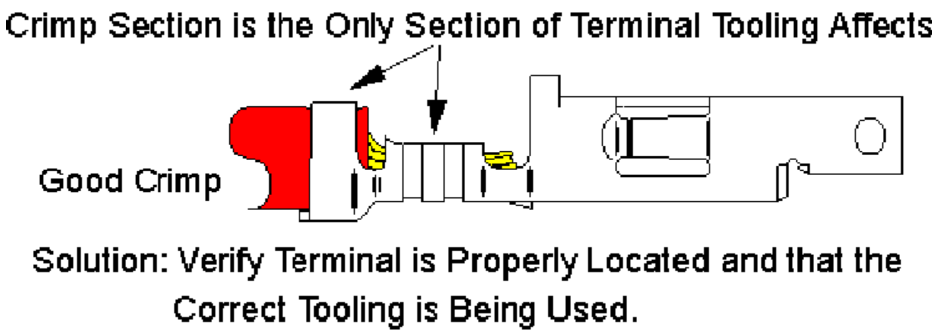
The third failure mode may occur when the connectors are mated. If the wire protrudes so far into the Transition Section that the tip of the male terminal hits against the wire, it may prevent the connectors from fully seating or it may bend the male or female terminals. This condition is known as "terminal butting". Under extreme cases, the terminal may be pushed out the back of the housing even though it was fully seated in the housing.



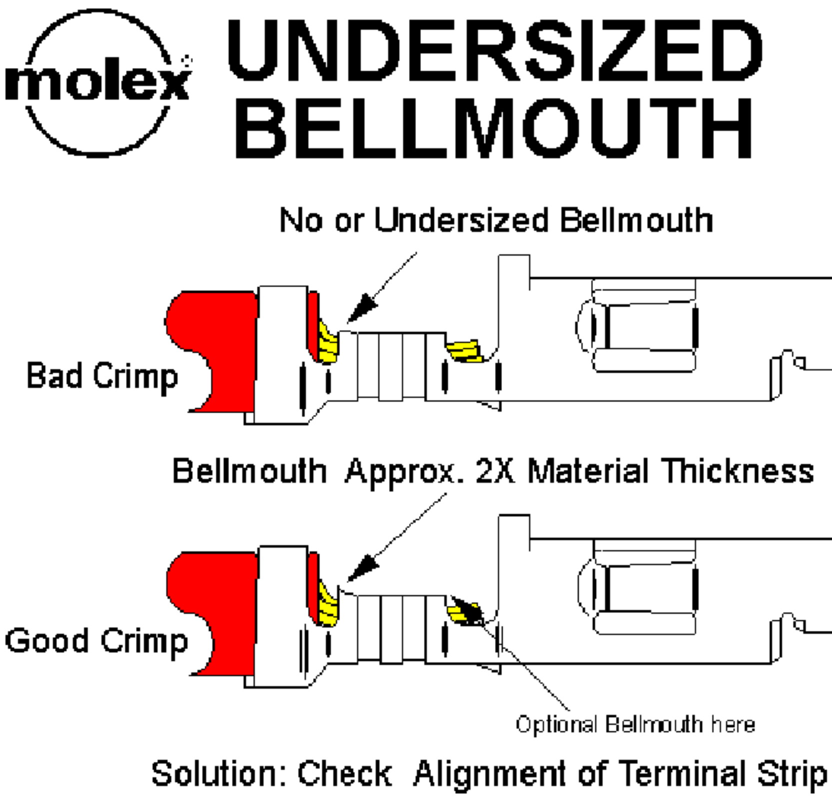
"Banana" (Excessive Bending) Terminal

One of the most descriptive crimping problems is known as a "banana" crimp (figure above), because the crimped terminal takes on a banana shape. This makes it difficult to insert the terminal into the housing and may cause terminal butting. This problem is easy to solve by not squeezing the hand crimper so hard!





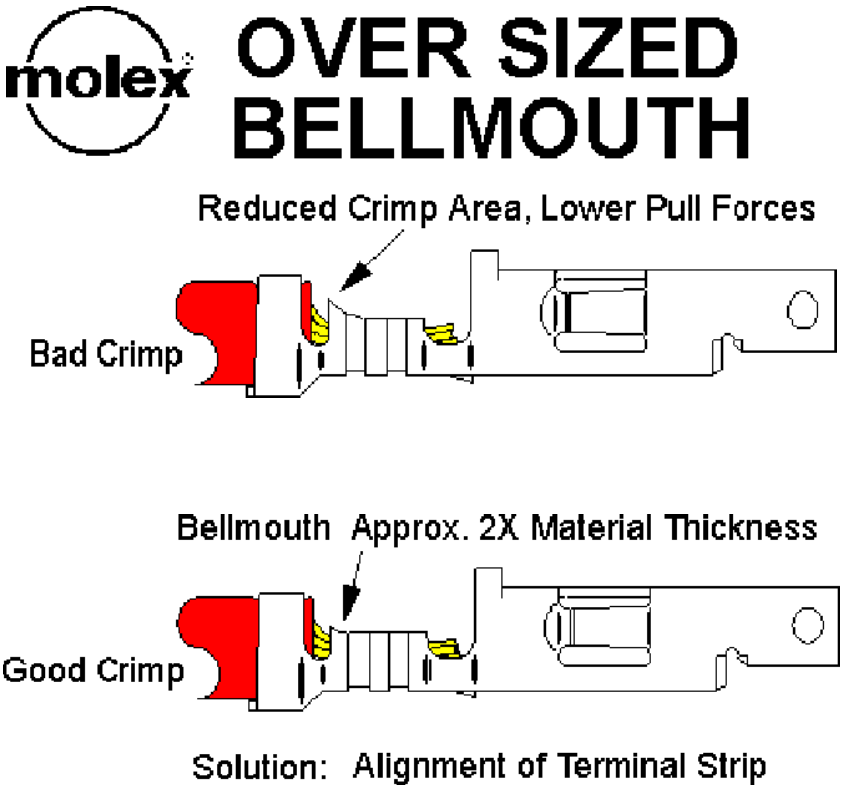
Crimp Too Far Forward
One of the more obvious crimping problems is when part of the Transition Section is damaged, as shown above. In the terminal shown, the tab sticking up is a design feature called a "terminal stop". Its function is to prevent the terminal from being inserted too deeply into the housing. If the stop is extremely damaged, the terminal can actually be pushed all the way through the housing.



Undersized Bellmouth

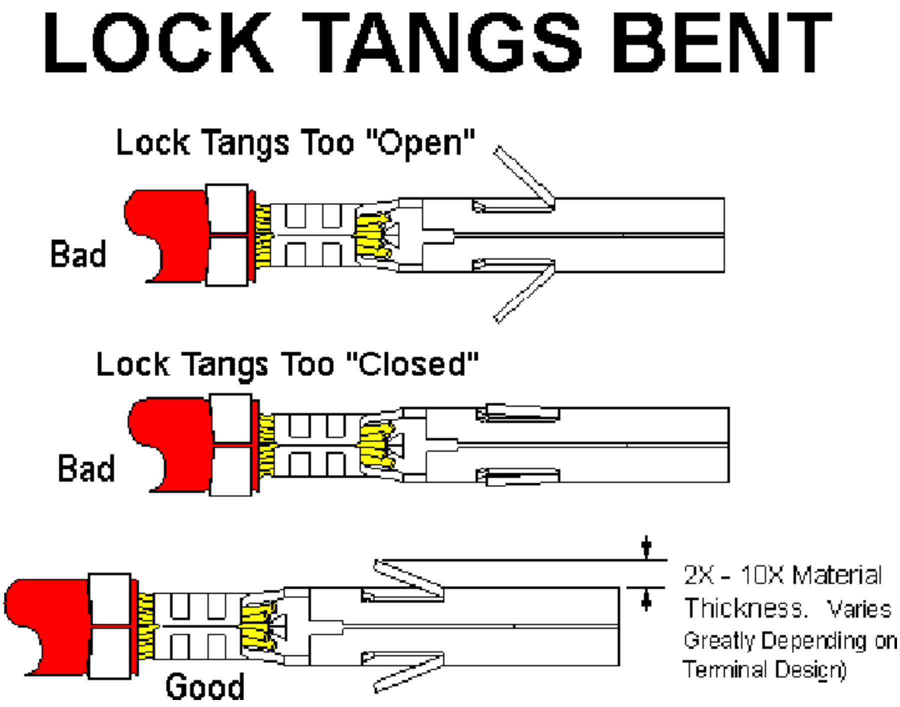
The correct size for a bellmouth (see above) is approximately 2X the thickness of the terminal material. For example if the terminal is made from material that is .008" thick, the bellmouth should be approximately .016". While a few thousands of an inch either way will not materially affect the terminal's

performance, if the bellmouth is missing or if it is less than one material thickness, there is a risk of cutting the wire strands. The fewer strands that remain, the lower the termination strength.



Oversized Bellmouth

There is also a problem if the bellmouth is oversized (above), because this reduces the total area that the crimp section of the terminal has in contact with the wire. The less the wire-to-terminal interface, the lower the wire pull out force. If the crimp height is correct, then it is likely the problem is caused by a worn hand crimper, which should be replaced.



Bent Lock Tangs

Although bent lock tangs are not necessarily the result of a poor crimping process, the connector can fail just the same. Lock tangs (see above) may be bent either in or out too far, which impacts the terminal's ability to completely lock into the shelf in the housing that was designed for this purpose. The tangs may be damaged by handling after the terminals are crimped onto the wires, or if the wire is soldered to the terminal pin (not recommended!)

Rules

While there are problems that may be caused during the crimping process, there are just four simple rules that will help ensure a successful connector application:

1. **Choose the right connector for your application requirements.**
2. **Use the crimp tooling specified by the terminal manufacturer (there is a different hand crimper for .156" and .100" terminal pins!)**
3. **Properly inspect the crimp tooling to make sure it is not worn.**
4. **Replace the hand crimping tool if worn, as the parts that displace metal conductor and insulation wear.**

Should Connector Terminal Pins be Soldered?

Now if there is a bad or improper crimp on a terminal pin, solder can increase the performance of a crimp. Granted, in most applications the performance increase is negligible versus an unsoldered crimp, even a bad crimp. And the potential of doing "more harm than good" is very high when soldering a terminal pin (unless the user follows the terminal soldering method outlined below).

The risk of problems when soldering a terminal pin far out-weigh the benefit in most cases. For example, adding solder to a terminal pin can get solder on the "locking tangs", making it unflexible. This in turn can ruin the connector housing, and make the pin nearly impossible to remove.

Soldering a terminal pin can also cause the terminal pin/wire insulation joint to fail. Or in the worse case, it can melt the insulation back beyond the pin, possibly causing a short.

Another problem with soldering terminal pins is having flux wick down and end up being left on the connector surface. This can interfere with connectivity to the header pin.

Lastly, though unlikely unless extreme heat is used, the plating on the terminal pins can be damaged by soldering.

Properly Soldering a Terminal Pin (if you must!)

With the potential problems of soldering a terminal pin known, some users may still want that additional "insurance". Or if a good crimp can not be performed (wrong tool or wire gauge?), soldering may be necessary to overcome the bad crimp. Molex reconizes that some user may not following their crimping directions, and may solder a terminal pin anyway. If this is the case, here is the ONLY terminal pin soldering technique Molex (relucantly) recommends. This information came from John Luthy, Molex's connector product division manager:

- **Before crimping the terminal pin, tin the end of the bare wire with some solder (best method is to dip the wire end into a hot solder pot).**
- **Crimp the terminal properly (see the notes above!) using a good quality hand crimper (Molex WHT-1921 part# 11-01-0015, Molex part# 63811-1000, or Amp 725).**

- **After the wire is properly crimped, using a temperature controlled soldering station (750 degree maximum), heat the terminal pin momentarily, right where the tinned wire is crimped in the terminal pin. The tinned wire's solder should heat and reflow, spreading to the terminal pin. Do NOT add any additional solder!**