Thomas&Betts

Crimping Tools:

An Ergonomic Review of the State-of-the-Art

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Summary

Developing an ergonomically sound manual crimping tool is a significant challenge due to the combination of high manual force application and repetitive task frequency. However, clear strides have been made to reduce injury risk while increasing user satisfaction and performance. An analysis of leading brand-name tools against fundamental ergonomic principles identified several effective design features in the critical areas of strength, clearance, posture and reach. Overall, the *Thomas & Betts Sta-Kon® ERG-4001* (Figure 1) demonstrated the best combination of ergonomic features by incorporating both mechanical solutions and user-centered design techniques, resulting in efficiency, comfort and ease-of-use.

Designing for the Hand

As physicians follow the Hippocratic Oath of first, do no harm, tool designers must strive to minimize the risk of injury to the users of their products. But safety is simply a baseline requirement. The value of a modern tool is determined by its mechanical advantage to perform work efficiently and effectively, as well as comfortably and safely.

To achieve this combination it is necessary to step back from the tool itself and understand the two components of work that the tool brings together: the human hand and the task materials. Baber (2003)[1] articulates the tool's role as an intermediary between the user and the work: The handle, therefore, is the channel through which power is passed to the tool, the means by which control is exerted over the movement of the tool, and the conduit through which feedback from the tool is passed back to the user.

If tools were always used in a consistent manner by people with equivalent physical characteristics, then design would be a simple open and shut case. But even specialized tools must accommodate a range of tasks and user characteristics, making effective ergonomics an ongoing challenge. Fortunately, there is an enormous amount of research and study on the physiology and mechanics of the hand. The critical elements to focus on for manual tool design are hand dimensions and strength. These two factors might seem to have a simple, direct relationship (e.g., larger hands can generally deliver greater force), but the situation is more complex.

Hand size varies considerably with age, gender and ethnicity, but more importantly the hand itself is a flexible instrument that changes form with flexion and extension. The hand position that produces the greatest amount of force is the power grip, in which the fingers are wrapped around the handle and the thumb placed against it (also Figure 1). While there are variations on this grip based on handle and task characteristics as well as user preferences, the requirement for supporting the power grip remains constant.

As a consequence, the same hand might produce 400 N of force with a power grip, but only a tenth of that with a more precise pinch grip. For tool designers, determining the force requirements of the task is a critical first step as it will define the grip necessary to deliver that force, and thereby serve as a prime driver for handle size and shape.

[1] *Cognition and Tool Use,* Taylor & Francis, 2003

Figure 1.

The *Thomas & Betts Sta-Kon® ERG-4001* embodies many of the best ergonomic features in manual crimping tools.

Another perspective on the tight connection between hand size and strength is the so-called power zone, where hand force peaks between 2.0-2.75 inches (50-70 mm) and decreases in either direction outside of that zone as a result of mechanical inefficiency in the hand. As a result, tools that maximize mechanical advantage outside of the power zone can better support user effectiveness and reduce the risk of injury. Again, it is evident that clearly understanding the force requirements for the task will dictate the appropriate tool/handle design.

Designing for the Task

The focus of this discussion is manual crimping, a task that requires considerable manual force. At their most basic, crimpers and other compression-type tools are lever mechanisms for translating broad manual forces to a targeted surface area. Manual crimping tools are typically utilized by a variety of end users, including field service and installation technicians, assembly workers, engineers and lab technicians. Likewise, crimpers are found in all types of field situations, such as assembly line environments and laboratories. They are also used in prototyping and short-run/pilot production of cable assemblies for all types of products (automotive, heavy equipment, white goods, telecom, electronic equipment, electrical equipment, panel builders, etc.). Some tools are used in production environments (e.g., panel builders, short-run cable assembly) where volumes are low and variability of products precludes use of more automated methods.

Crimpers provide an ergonomically challenging combination of high stress manual force with high frequency task repetition. The resulting user experience typically ranges from muscle fatigue and discomfort to potential cumulative upper limb injury. For example, Seeley & Marklin (2003)[2] found that only 1% of the general population met the strength requirements for peak force in a particular high force electrical utility crimping task (311 N per 72 lbs). Moreover, Seeley, Lazuardi & Wilzbacher (2007)[3] identified that in many cases the actual newtons of force that workers are using in intensive manual crimping tasks are not known. It is worth noting that manual crimping tools are frequently used for production in lower wage countries where ergonomic awareness and support are comparatively low.

Given the potential risk of injuries with manual crimping, ergonomic interventions are suggested. For example, an industry report (EPRI, 2001)[4] recommended replacing heavy-duty manual crimpers with battery-powered crimpers. But for lower-force crimping tasks, battery-powered devices are impractical or not affordable. Therefore, it is important to further understand the ergonomic characteristics of crimping tools, both to gain a better understanding of the risks as well as to identify design features that will support effectiveness and fit.

Ergonomic Evaluations of Crimping Tools

Besides their obvious functional similarities, all crimping tools share a set of basic ergonomic characteristics. Recognizing and addressing these factors can result in effective tool design, while disregarding them will lead to failures.

The four cardinal ergonomic characteristics are (Pheasant & Haslegrave, 2006)[5]:

- **Strength**—The manual force necessary to effectively use the tool
- **Reach**—The amount of extension or distance between touch points on a tool, particularly grip span
- **Clearance**—The space within and around the tool to accommodate hand movement and provide adequate working space
- **Posture**—The degree of deviation from neutral, comfortable body joint angles required to use the tool with maximum effectiveness and comfort

An ideal crimping tool would optimize each of these characteristics for a wide range of users across the set of possible uses. Keep in mind that although these forces will be examined individually, they are by no means independent. For example, a tool that causes over-reaching (e.g., excessive hand span) will inhibit the user's ability to deliver maximum strength.

Strength

As the salient function of a crimping tool is delivering mechanical advantage, strength is considered the primary ergonomic factor for consideration. Human hand strength is non-linear and peaks when the mechanical elements of the tool and hand are aligned to deliver maximum force. Therefore, strength is heavily influenced by design elements that affect the mechanical efficiency of the hand or hands, including handle diameter and grip span.

[2] *Business case for implementing two ergonomic interventions at an electric power utility,* Applied Ergonomics, Volume 34, Issue 5, September 2003, pp. 429-439

[3] *Measurement of handle forces for crimping connectors and cutting cable in the electric power industry,* International Journal of Industrial Ergonomics, Volume 34, Issue 6, December 2004, pp. 497-506.

[4] *EPRI Ergonomics Handbook for the Electric Power Industry Overhead Distribution Line Workers Interventions,* 2001.

[5] *Bodyspace, Anthropometry, Ergonomics and the Design of Work (3rd Edition),* Taylor & Francis, 2006.

Bobjer (1994)[6] discussed specific hand force maximums for squeezing tasks as performed in crimping. For adult males (the predominant users of such tools), a single hand can deliver 112 lbs (500 N) of peak force at handle spans between 2.0-2.75 inches (50-70 mm). Clearly a tool that will be used repeatedly must require a significantly lower force, and Bobjer found force requirements ranging from 52-90 lbs (230-400 N) across a set of crimping tools.

In recent years, a number of improvements have been made in crimping tool design as well as ergonomic force measurement. To gain an understanding of the current state-of-the-art, we benchmarked the crimping forces for *four* commonly used tools:

- Ideal—Crimpmaster 30-500
- Panduit—CT 1570
- Thomas & Betts—ERG-4001
- Tyco/AMP—Procrimper III

These represent the latest crimping tools produced by the leading manufacturers in the industry. The results from the benchmarking study are summarized in Figure 2, where required force is mapped across the grip span for each of these crimping tools.

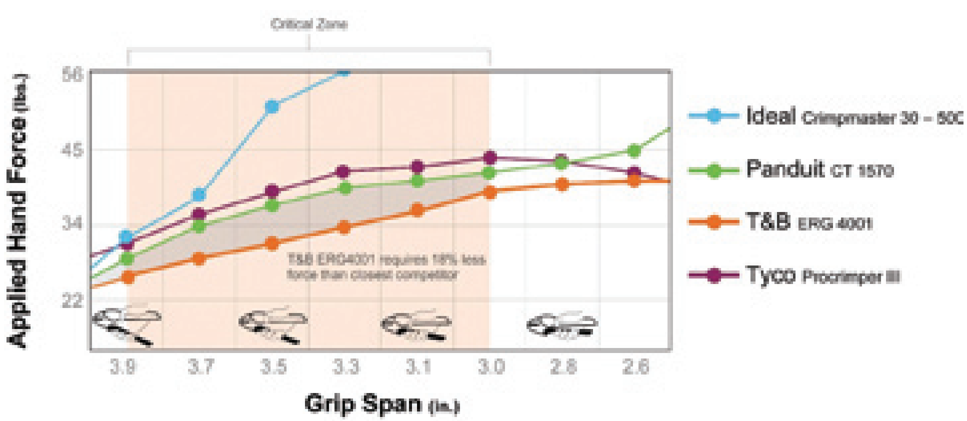
There are several noteworthy observations that can be made from the study. With the exception of the Ideal, all of the crimpers have force demands that fall well below maximum hand strength boundaries. More importantly, no single tool provides the lowest force requirement across the entire grip span. For example, the *Thomas & Betts Sta-Kon ERG-4001* has the lowest force requirements between 3.0 - 4.1 inches (75 - 105 mm) and the Tyco at 2.2 inches (55 mm) and below.

This brings forward a critical design question: *At what grip span is the effective delivery of force most critical and where should tool designers focus their attention?* It was noted earlier that peak hand strength occurs at grip spans between approximately 2.0-2.75 inches (50-70 mm) and drops off significantly at greater grip spans. That is, the hand can more easily apply force at spans below 2.75 inches (70 mm) than it can at larger spans. Consequently, the tool that requires the least force when the hand is weakest (i.e., >2.75 in.) will provide a greater ergonomic benefit than tools that require a greater amount of force in that range.

The *Thomas & Betts Sta-Kon ERG-4001* requires the least crimping force in spans above 2.75 inches (70 mm), which is when the user most needs mechanical advantage. For example, at a span of 3.5 inches (90 mm) the *ERG-4001* requires about 18% less force than the next closest tool (Panduit) and

Figure 2.

Comparative crimping force across the grip span for four leading tools



[6] *Ergonomic Hand Crimping Tools Reduce Stress,* Interconnection Technology, February 1994, pp.14-17.

Table 1.

Crimping Tool Jaw Gap Angle and Distance

MODEL	JAW GAP ANGLE	JAW GAP DISTANCE
Thomas & Betts Sta-Kon ERG-4001	34.9 degrees	10.3 inches
Panduit CT 1570	19.8 degrees	5.3 inches
Tyco/AMP Procrimper III	23.4 degrees	8.5 inches
Ideal Crimpmaster 30-500	24.5 degrees	2.24 inches

65% less force than the Ideal crimper. In short, the *Thomas & Betts Sta-Kon ERG-4001* provides the greatest benefits among all the compared tools by ergonomically mapping mechanical advantage to human strength characteristics.

Clearance

Clearance refers to providing sufficient open space to accommodate the user's interaction with the tool and the task environment. In crimping tools, the ease of inserting and removing terminals into the tool jaws is largely determined by the clearance of the jaw design. Unlike the stronger (but less wieldy) power grip, terminals are handled with the more precise control of the pinch grip. Tools with jaws that provide a wider angle of both tactile and visual access will reduce the level of precision required by users. As part of the force measurement study described above, measurements of open jaw angle and height were collected across various tools (Table 1).

Figure 3 illustrates the difference in clearance between a wide jaw opening (left) and a narrow one (right). Also note that some tools provide color coding to assist with quick placement identification while others rely solely on low contrast lettering.

The *Thomas & Betts Sta-Kon ERG-4001* provided the greatest jaw clearance with respect to both angle and distance measurements. Jaw gap angle ranged from a minimum of 19.8 degrees (Panduit) to a maximum of 34.9 degrees (*Thomas & Betts Sta-Kon ERG-4001*), while distance ranged from 0.2 inches (5.3 mm) for Panduit to 0.4 inches (10.3 mm) for *Thomas & Betts Sta-Kon ERG-4001,* both differences of greater than 40%.

Another tool mechanism where clearance comes into play is the release, which allows the user to unlock the compressed jaws prior to completing the crimping action (e.g., to reset the terminal position). In many crimping tools, the release trigger is placed

Figure 3.

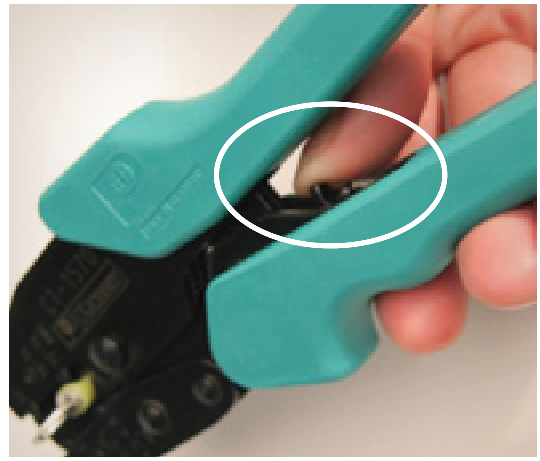
Measurements of jaw opening angle and height for two representative crimping tools.

Thomas & Betts Sta-Kon ERG 4001

Figure 4.

Comparison of release lever position in two tools, illustrating sufficient clearance when release is external to handles (left) and reduced clearance when release is between handles (right).

Thomas & Betts Sta-Kon ERG-4001
Release switch is placed external to handles.



Panduit—Release switch is positioned between partially closed handles.

between the handles (Figure 4). This makes access difficult, particularly when the handle span is being compressed. Only the *Thomas & Betts Sta-Kon ERG-4001* directly addresses this clearance issue by placing the release touch point on the side of the tool for unobstructed access, regardless of the handle span. As with strength, the *Thomas & Betts ERG-4001* again embodies the most effective ergonomic approach to clearance, providing a clear emphasis on ease-of-use and efficiency.

Reach and Posture

Perhaps more so than any other ergonomic characteristic, reach is the most difficult factor to optimize in crimping tools. The ability to operate and grasp controls without over-extending the hand is pertinent to grasping the handles in a tool's expanded state. The necessity of wide handle spans is driven by the need to maximize mechanical advantage, a case of one ergonomic demand (strength) taking precedent over another (reach). In some situations, crimping tools are used as two-handed instruments, thereby negating the concerns of one-handed reach. But two-handed use is not always convenient or possible (e.g., other hand may be holding wires).

Given the mechanical constraints on handle span, tool designers have looked to compensatory solutions to assist users. Handle contour design is the primary means to support wide grasp. The majority of the tools examined provide a sloped or stepped anchor point towards the top of the forward handle. This provides leverage or resistance to maintain grip when the hand is in an extended position. For example, the *Thomas & Betts Sta-Kon ERG-4001* and the Panduit provide versions of both upper and lower bound touch points towards the top of the handle to support force transfer from the user's fingers to the tool.

The *Thomas & Betts Sta-Kon ERG-4001* also provides a unique cleat or foot (Crimp Assist®) as a resting point at the base of the forward handle (Figure 5). This feature was added to support the common crimping behavior of using a surface (e.g., table top, wall) as a second set of hands. This feature also allows the user to work in a greater range of positions and postures for preferred comfort (e.g., one hand, two-handed, or hand and surface).

Additional Human Factor Considerations

Beyond the four cardinal ergonomic principles discussed above, there are several other effective design elements that can also contribute to ease-of-use. These are also exemplified in the *Thomas & Betts Sta-Kon ERG-4001:*

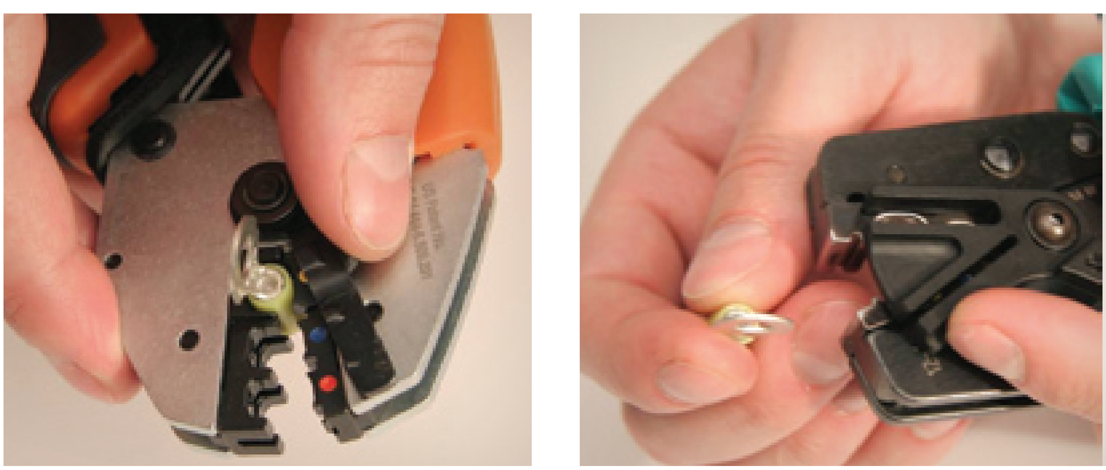
Figure 5.

Illustration of Crimp Assist foot at base of handle (inset) on *Thomas & Betts Sta-Kon ERG-4001* serving as a second hand for leverage and stability.

- Handle materials play a critical role in comfort and grasp. Lindqvist (2007)[7] provide recommendations for effective handle design that include providing sufficient friction for force transfer, even with gloves and sweaty hands, but avoiding form-fitting handles as they will not comfortably accommodate the full range of hand characteristics. A rigid plastic handle is durable and supports the application of manual pressure, but lacks comfort. However, over-molding a softer grip on top of the base layer of plastic will provide an effective combination of comfort and strength.
- Handle texture can aid the stability of grip, if designed properly. Many so-called ergonomic handles employ overly obtrusive ridges that limit freedom of movement and create pressure points. More subtle texture elements (Figure 1) give the benefits of a better grip when needed but can be ignored when not.
- A terminal locator (Figure 6) is a useful option to limit the movement of the wire assembly when crimping. Both the *Thomas & Betts Sta-Kon ERG-4001* and the Panduit provide this feature, which supports the accurate positioning of the terminal for proper crimping.

Figure 6.

Detail of terminal locator on the *Thomas & Betts Sta-Kon ERG-4001* (left) and comparable feature on Panduit (right), which aids user in aligning terminal and wires.



[7] *Power Tool Ergonomics,* Atlas Copco, 2007.

Conclusions & Recommendations

This review of current crimping tools has identified areas of design/ergonomic strength. The modern ergonomic tool, best represented by the *Thomas & Betts Sta-Kon ERG-4001,* addresses the unique constraints of manual crimping tasks by:

- Providing peak mechanical advantage where it is most needed relevant to human hand strength characteristics
- Accommodating ease-of-use through generous tactile and visual clearance for inserting and removing terminals and accessing the release mechanism
- Supporting grip span reach and comfortable posture through thoughtful placement of finger and surface touch points on the forward handle
- Appropriately applying handle materials and textures for comfort and grip support

These attributes should be considered as baseline requirements for new crimping tools, but this is merely a starting point. The effective implementation of such features across task applications, as well as the development of new ergonomic innovations, is dependent on continued research in the lab and the field.

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