VIBRATION RESISTANT THREAD DESIGN TO PREVENT LOOSENING OF GRAPHITE ELECTRODE JOINTS ON AN ELECTRIC ARC FURNACE

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Abstract

Graphite electrodes used to melt steel in Electric Arc Furnaces (EAF's) are joined together into columns using threaded connections, typically in a socket-pin-socket combination. Various thread designs have been proposed and tried over the years, but the predominant thread design evolved directly from standardized screw fastener thread forms of the nineteenth century. This design utilizes a 60-degree thread flank angle, and has been virtually unchanged for decades in the graphite electrode industry.

Problems are known to arise occasionally in joined electrodes as a result of loosening. Loose electrode joints caused by unwinding have a much higher probability of breaking on the EAF, causing undesirable downtime and production losses for steel producers.

Gerhard Junker demonstrated in the 1960's that transversely applied alternating forces combined with low clamping force create the most severe conditions for loosening of bolted connections. Similarly, the high mechanical loads and vibrations encountered on an EAF may cause the joined electrode thread flanks to slide with respect to one another, in the direction normal to the electrode column axis, thereby inducing self-loosening. Catastrophic joint failure often results.

Various means to prevent such joint loosening have been tried with varying degrees of success. However, a radical new thread geometry completely eliminates flank-to-flank thread contact and has been proven effective in maintaining tight electrode joints, because the sliding of the joint thread flanks with respect to one another is no longer possible. Moreover, this new geometry is compatible with existing standardized electrode joints.

Background

An EAF contains at least one column of graphite electrodes **(Fig. 1)**. The upper end of such a column is retained by a bracket, or mast arm, through which the electrical current for the electrode column is also supplied. When the furnace is in use, the electric arc passes from the bottom tip or lower end of the column into the metal to be melted. The electric arc and the high temperatures in the furnace cause the bottom end of the electrode column to be consumed slowly by sublimation, oxidation, and discontinuous losses (e.g., spalling of material due to thermally induced stresses and subsequent cracking). The shortening of the electrode column is compensated in that it is advanced progressively into the furnace, and further electrodes are screwed onto the top end of the column as necessary.

Individual graphite electrodes are screwed onto a column already situated in the furnace, or electrodes are screwed to a fresh column either by hand or with a machine. Particularly in the case of electrodes having a large diameter of 600 mm or more, significant tightening torque, or screwing effort, must be applied in order to ensure that the clamping force of the joint is high enough to prevent an electrode column from coming apart at the threaded connection, especially under dynamic loading conditions. Secure attachment of a column is vitally important for the functioning of an arc furnace.

When a furnace is in use, considerable forces are exerted cyclically on the electrode column due to the continuous electrically induced vibrations. Moreover, as the scrap melts and the bath level changes, the columns are regulated in an up-and-down motion to maintain a relatively constant arc length; these control oscillations create considerable and varying axial forces on the electrode column. Finally, the electrode column is often exposed to impacts from the charge material, which also places stresses on the secure attachment of the column **(Fig. 2)**. All such stresses – repeated flexing moments, vibrations, axial forces, and impacts – are capable of causing the threaded connection of electrodes to loosen and or break – especially at the top joint. Loosening must be considered to be the result of unavoidable and/or undesirable processes.

Figure 1. DC Electric Arc Furnace with 800 mm Electrodes at Profilarbed, Differdange, Luxembourg.

If the compressive forces on the contact surfaces of adjacent column elements in the top joint are lessened, loosening may progress to the point that all clamping force in the joint is lost and the electrode end-faces may become physically separated from each other. Even very small gaps not visible to the naked eye can cause the top joint to fail due to the extremely elevated localized mechanical stresses that are subsequently induced in the threaded regions as a result of high bending moments and other mechanically induced loads on the column.

If a loose electrode joint does not completely lose end-face contact high in the column and survives to approach the molten steel bath as the column is consumed, it may still loosen further, later, under dynamic loading and repeated heating and cooling cycles between furnace charging and tapping times. In this case, if electrode end-face contact is lost completely, then all electrical current will pass through the connecting pin via the thread contacts, which leads to extreme overheating, high thermal stresses, severe oxidation of the open joint, and eventual loss of the remainder of the electrode below the connecting pin. Typically, a split also develops in the upper electrode socket due to the overheating of the connecting pin; often the split propagates to the next higher joint, causing a repeating cycle of further loosening and subsequent material loss below the bottom connecting pin as it approaches the bath level. This type of failure occurring at the electrode joint closest to the molten steel level is known as a stub-end loss **(Fig. 3)**.

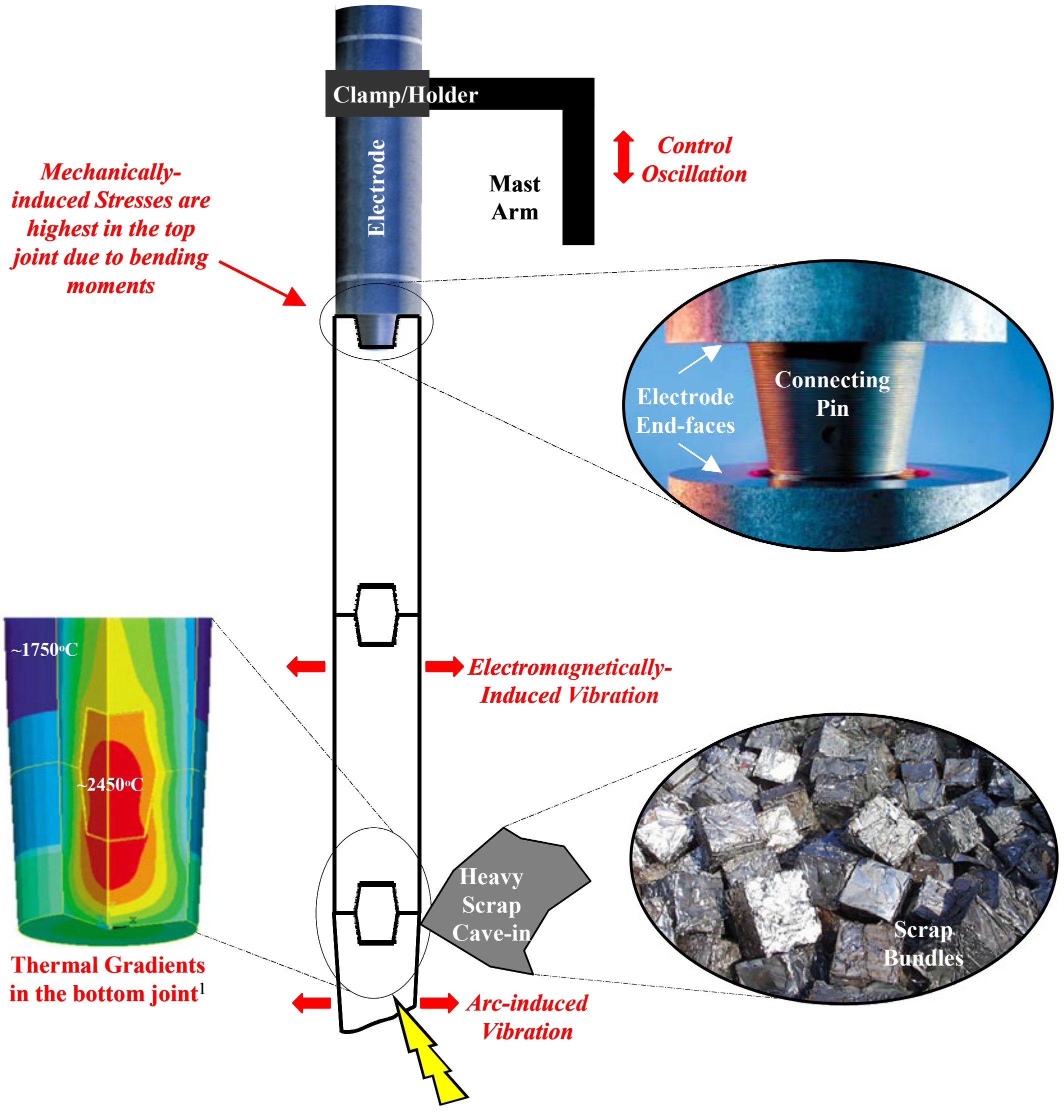

Figure 2. An electrode column is subjected to many factors that may result in loosening of the joints.

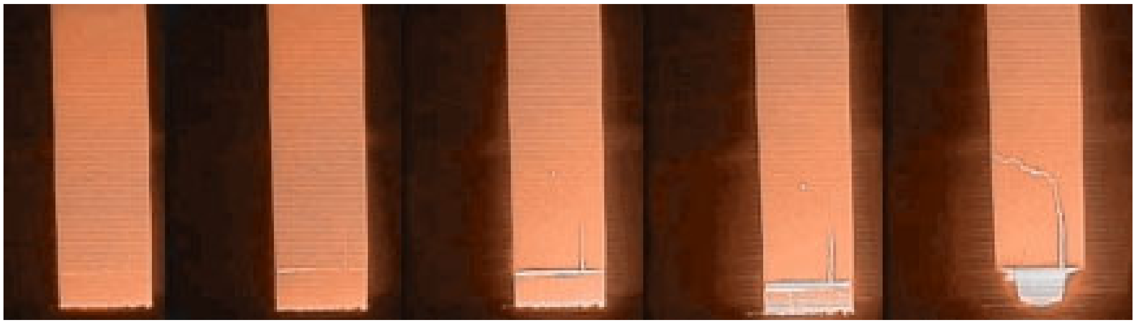

Figure 3. A lower column connection – loosening, crack propagation, and eventual stub-end loss over time.

Discussion

The basic graphite electrode design has not changed in many decades. The joint threads have been adapted from the *American National (Unified)* thread standard, which has been approved in the United States and Great Britain for use on all standard threaded products. The thread angle is 60° and the crests and roots of the thread may be either flat or rounded.

In the 1960's, Gerhard Junker demonstrated that self-loosening of standard fasteners is caused by relative motion of the joint faces. This is frequently referred to as "vibration-loosening", which is somewhat of a misnomer, because transverse motion (which may or may not be due to vibrations) is the fundamental cause[2]. Similarly, the standard design for graphite electrode connections allows such transverse motion when the end-faces slide with respect to one another **(Fig. 4)**.

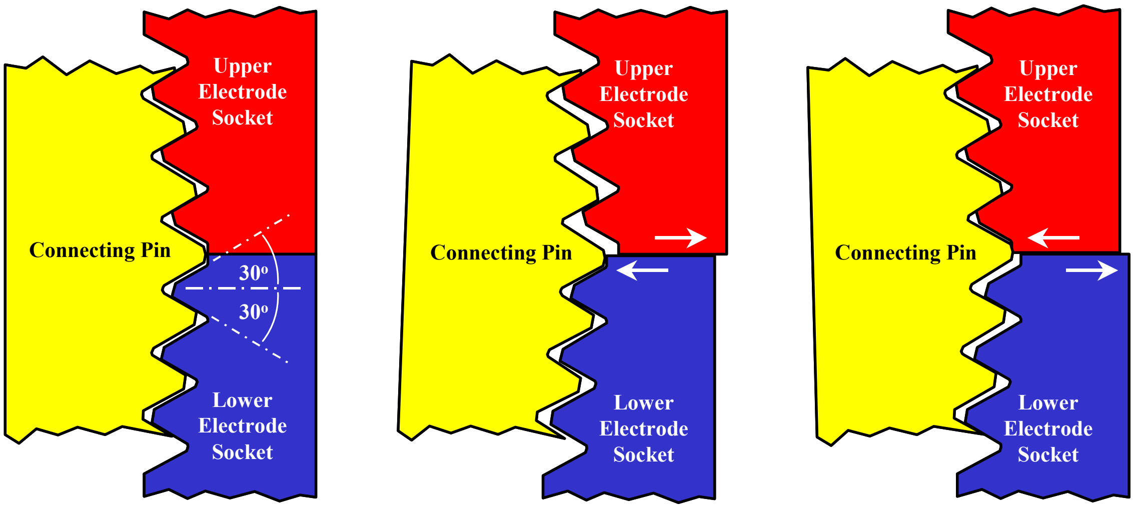

Figure 4. Transverse relative motion of the end-faces with respect to one another causes loosening.

One way to minimize the likelihood of this sliding of the end-faces with respect to each other is to increase the joining torque used to connect the electrodes and/or reduce the friction of the joint contact surfaces. The resulting additional clamping force in the joint (and higher pre-tension in the connecting pin) will counter the effects of joint loading (both static and dynamic) and embedding losses, thereby inhibiting relative sliding/loosening motion. However, it is not always possible to increase joining torque and or reduce the friction of the joint contact surfaces in all applications. Additionally, other negative consequences are possible, such as overstressing of the threads. Therefore, another means to prevent "vibration-loosening" is desired.

Another way to minimize the possibility that the electrode end-faces are able to slide with respect to one another is to redesign the geometry of the thread to inhibit such motion. Therefore, a new electrode joint thread design was developed by SGL Group[3] to increase the force component in the radial direction (opposing motion parallel to the end-faces); in fact, flank-to-flank thread contact was completely eliminated by this new design **(Fig. 5)**. Moreover, this new design is fully compatible with standard electrode sockets, so no "transition electrodes" are needed when changing from standard threaded electrode joints to the new design, and back.

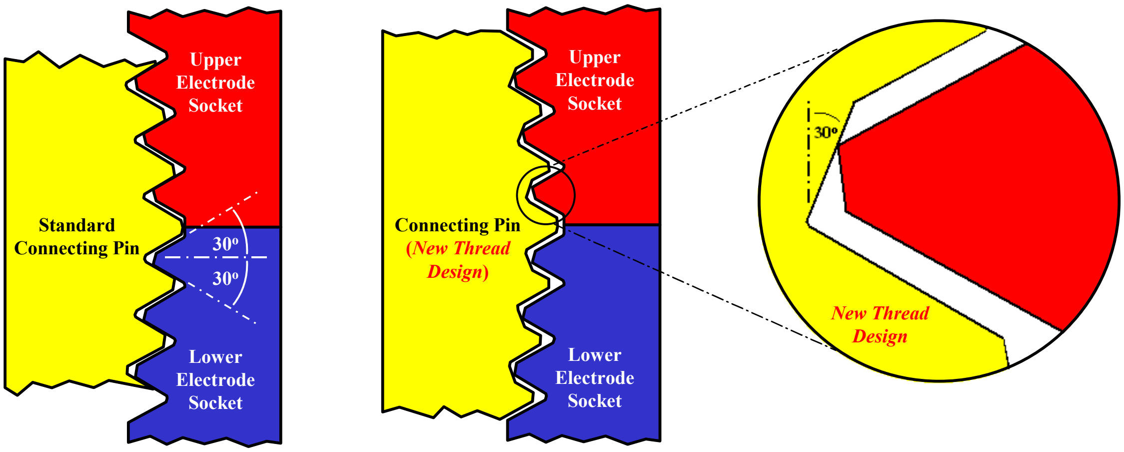

Figure 5. Flank-to-flank contact in the new thread design has been eliminated completely.

In addition to increasing the radial component of the thread forces, the reduced contact area results in a greater and more symmetric distribution of force loads developed in the threads (e.g., the pretension in the connecting pin is carried more evenly and by a greater number of threads). This results in a stronger mechanical connection **(Fig. 6)**. (It is interesting to note that for typical metal bolted connections with standard threads, the first three threads carry most of the load.[4])

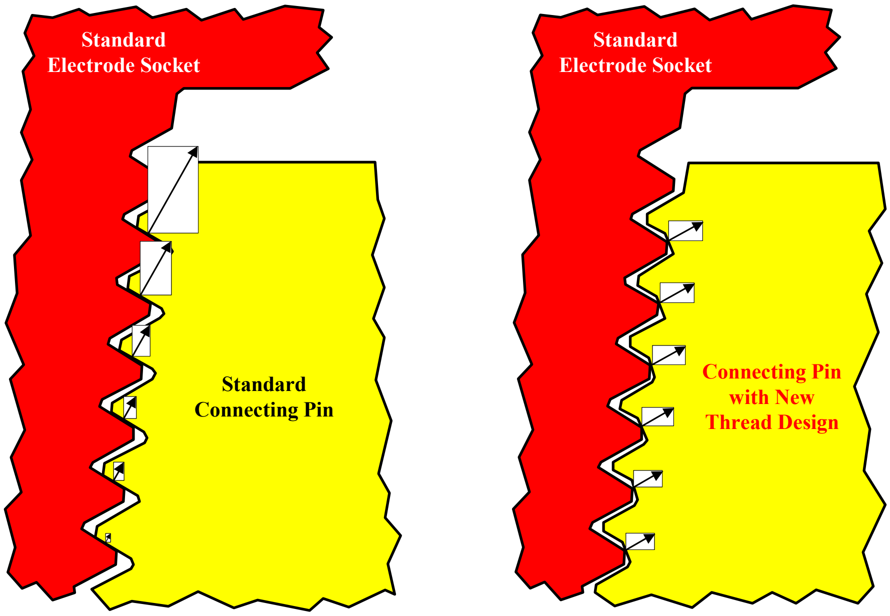

Figure 6. Relative connecting pin thread force distribution in a standard joint (left) vs. new design (right).

Although the new thread design may be used in either the electrode joint socket or connecting pin, the latter is generally preferred to simplify manufacturing.

A helical contact groove is impressed into surface between the thread flanks of the new thread form in the connecting pin by the thread crests of the standard socket. This groove is visible in a disassembled joint; the constant depth and thickness of this impression is proof of the even distribution of force loading over the full length of the threaded joint **(Fig. 7)**. Therefore the likelihood of thread shearing and/or socket breakage is significantly reduced. Additionally, the lack of flank-to-flank contact minimizes the influence of thread form deviations and machining variation on the clamping force and joint stresses, and leaves more room for axial thermal expansion of the connecting pin in both joint sockets in the event of overheating.

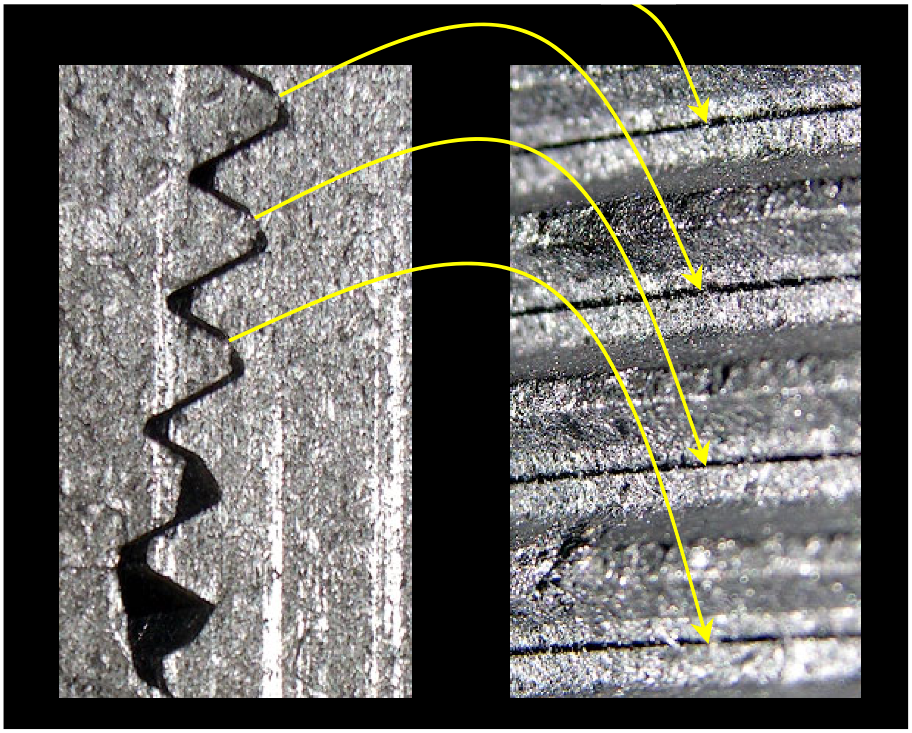

Figure 7. The contact grooves are shown above (right); the electrode end-faces are visible (lower, far left).

Summary and Results

Field-testing of this new thread design in several EAF's has been conducted using 600 mm graphite electrodes with promising results until now. It has been particularly successful on EAF's that historically average several electrode joint breaks per month – fewer (and shorter) stub-end losses have been reported, and no top joint breaks have been attributed to the new design. Electrode end-faces in the hot joint have been observed to stay together longer and more often than those of a conventional joint; even in cases where a visible gap between end-faces in the lower joint has been observed in the test columns, the tendency has been for those joints to survive longer than would be normally expected. Net electrode consumption is thus improved using the new thread due to the reduction of stub-end losses, and gross consumption at the time of this writing is significantly improved due to the absence of top joint breaks.

References

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