LINE HEATING

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Originally printed in Boatbuilder Magazine, Volume XVI, Number 2 (Mar/Apr 1998)
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Producing the curved shapes of a boat in steel, especially for classic hull forms, seems a daunting problem for most home boatbuilders.

They know that real shipyards have heavy rolling machines, press brakes, ring presses, furnaces and other massive machines. What they don't know is that in most world class shipyards, these machines are mainly gathering dust, at least as far as shell plate is concerned. Instead, the most productive shipyards are using "line heating", a simple process of heating the steel with a torch and quenching it with a water hose, to form plates. There is even better news for the home builder. The reason these shipyards are not using their heavy machines is because line heating is usually quicker and more accurate than methods using heavy machinery. One shipyard found that the costs associated with furnacing and pressing amounted to 60 man-hours per plate to build plate forming jigs and 17 man-hours of actual forming time per plate. This dropped to just ten hours of forming time with no time for heavy jigs required at all. In addition, the improved accuracy made other assembly tasks easier and reduced rework. As a result of these benefits, many shipyards, including some of the most advanced Japanese and European yards, use line heating almost exclusively for forming shell plate.

Line heating gives small steel boat builders the tools to build much more complicated shapes with only minor investment in new equipment - a couple of hundred dollars at the most. Equipment for line heating consists of a convergent oxy-fuel torch tip - a cutting tip with the oxygen supply turned off - NOT a divergent or "rosebud" tip - with a water spray attached that will rapidly quench the metal adjacent to the torch tip.

The idea is to use heat distortion, normally a problem in metal boat construction, to the builder's advantage. Heat causes steel to expand. If the expansion is restrained in one direction, it will expand more in the other directions. When a small spot on a steel plate is heated to a temperature above about 1100 degrees F, (roughly a dark cherry red) it expands and also becomes soft enough to be readily distorted. By cooling the steel surrounding it, the hot spot is prevented from expanding sideways. It will only be able to expand upwards, and will do so readily because it is softened, thereby making a lump. When the steel subsequently cools and hardens, this lump will remain, so that the surrounding steel will be pulled in to fill the space the lump has left. As a result, the steel plate will distort. If a line on a plate has been heated and cooled, there will be a line of such lumps and the plate will bend. The edges will rise towards the lump. This is the basic principle of line heating.

Parallel lines act like the knuckles from a press brake to produce a rolling effect. If you need a tighter roll, space the lines closer together. You can also make more than one pass over each line, but you should make other passes before returning to the original spot. You can produce cones the same way, but with diverging lines. Without pre-stressing, you will get less additional roll each time, and almost none after the fourth pass in the same spot, but this typically allows a roll radius as tight as ten inches.

The effects of line heating can be increased by pre-stressing or restraining the plate. If you are rolling a cylinder, lift the edges and hold down the middle so that the tendency of the plate to bend away from the heat is restrained, then increase the stress at each pass as the roll gets tighter. You might also try to keep the back side of the plate cool by wetting it to increase the bending effect, particularly in thinner metal.

Most designers will try to make as much plate as possible single curved, or developable, so that not even line heating is required. (A properly laid out developable plate will often lay on the frames from its own weight - if it requires a lot of force, it was lofted wrong or the designer did not actually produce a developable shape.) However, some owners prefer round bilges or similar features that require several curved plates at the bilges, up the stem and perhaps under the transom. These plates are curved in two directions, one along the length of the boat, the other along the beam and are said to be "double backset".

The distance between the surface of the plate and a straight line along one axis of curvature is the "backset" of the plate in that direction. In most cases, the bilge plates on a yacht will have both backsets in the same direction, usually toward the inside of the boat. Although we can profitably use line heating instead of rolls and press brakes to put transverse backset in a plate, the most important use of line heating is for a putting longitudinal backset in a plate that already has transverse backset.

A double backset plate can't be bent easily out of a flat sheet because some parts have to change length to achieve the double curvature. In the case of a plate with both backsets inboard, like a sailboat bilge strake, we must either stretch the middle to form the bulged out portion or shrink the edges to form the sides. Line heating is just what we need to shrink those plate edges in a controlled fashion.

If you move the torch relatively quickly along the plate you will only heat the surface, with less heated area on the back side. This results in a cone of hot steel that will mainly contract to bend the plate along a line. If you move more slowly, the heat will pass through to the back side of the plate and you will get a cylinder of hot steel. This will bend the steel less, but cause it to shrink so that two points across the heat line from each other will come closer together. To see how to use line heating for such a strake, imagine we started with a flat plate and made fast passes fore and aft along the plate to get the approximate backset in the transverse (across the beam) direction. Then we simply heat lines across the plate away from the center, making more passes closer to the edge, and move the torch slower. This shrinks the steel outwards from the enter of the plate, shrinking more at the edges that at the center, giving us the required longitudinal backset.

In some cases such as traditional "wineglass" hull shapes, the backsets are opposite, with one backset inwards and the other outwards. (These are sometimes called "saddle plates".) The center of this type of plate is shrunk instead of the edges. In this case, we turn the plate over so that the first backset is down, and line heat mainly in the center of the plate.

Shapes such as beams or frames can be curved by heating as well. In this case, triangle heating, a variation of line heating, is used. To bend a flat shape in the flat plane ("the hard way"), mark an equilateral triangle about half the depth of the beam with the wide end on the edge to be shrunk. Then apply the torch at the apex of the triangle without cooling until it gets red hot. Apply coolant at this spot and weave the torch from side to side of the triangle working out to the edge. This technique can be used on both flat bars and on shapes such as angles or tees.

Diagonal line heating, with the lines on opposite sides of the plate criss-crossing, creates twist. This technique is most commonly used to twist longitudinals as they wrap around the frames, but sometimes designers of hard chine boats will use warped plates, instead of developable plates. (These hull shapes can be recognized because they have straight frames that are not parallel.) These plates are hard to fair up with other techniques but diagonal line heating will get them to lie on the frames.

Traditionally, curved plates were made on massive steel jigs, called "mocks", that were required to resist the forming forces. Line heating eliminates the need for such mocks, but without them, how do you measure the plate to form it to the required shape? The answer is sight line templates.

Sight line templates are curved pieces that match the required curves across the plate, with marked staffs connected to them roughly at right angles to the curve. They look like a bunch of tee squares with a curved cross head and a roughly perpendicular staff with a mark on one edge. The sight template is set on the plate with the cross head down, touching the plate and the staff pointing upwards, along designated lines on the plate.

If the plate is the correct shape, the cross heads will lie on the plate without gaps, and all marks on the staffs will lie in a straight line. This is determined by sighting along the marks, hence the name. Sight templates can be cut out of wood or metal. Boats that are Computer Numerically Cut (CNC) often have the cross heads computer cut out of scrap areas of metal at the same time the rest of the parts are cut. These cross heads are clamped to reusable staffs with adjustable sight marks. Other shipyards use fully adjustable templates. The curved part of the cross head is formed of a flexible material pushed out by screws passing through a fixed part. The curves are set using offset tables or from curves plotted by computer or by hand from the loft.

Lofting sight templates is quite easy once you understand the basics of lofting in general. For plates where the frames meet the metal at roughly right angles, just locate stations that cross the plate in the body plan. Draw a line approximately at a right angle to a line joining the two seams. The line should be about three feet long, so it will be a convenient height above the floor with the plate lying backset up. The shape of each frame from seam to seam is the shape of the cross head at that frame. The line you first struck is the staff at each frame and the end of the line is the sight point. You also have to measure the angle (bevel) between an athwartships line at each frame and the staff line. This is because in general, the sight templates will not be perpendicular to the plate, and you have to place them on the plate at the right bevel. (Determining bevels is covered in most lofting texts.) In some cases you may need to level the plate on the loft floor so that the bevels on the templates will not be too small. (This means that the staffs don't run in an athwartship plane.) Again, this process is covered in good lofting texts.

Once you have sight templates, you just keep making passes, adjusting the speed, spacing and number of passes until the plate fits the templates. Besides travel speeds, tip height and gas and water flow are also important variables in the process. You should experiment on scrap to get a feel for it, but for thin steel (under 3/8"), you would typically use a neutral flame about 5/8 inch away from the plate (just outside the blue cone) and move the torch at least three feet per minute. Adjust the water flow for convenience and once you have a good combination of all four variables, keep everything but pass speed constant for the actual job.

Line heating is also used for removing distortion. You can remove bends the same way you produce bends, just heat the opposite side. Another common use is removing buckles or other out-of-plane distortion in flat panels, especially after welding. The welding heat around the edges, or along stiffeners, has shrunk the panel at those points and the extra metal left over in the middle is bulging. Remove this extra metal by line heating patterns in the middle of the panel. One common pattern is "pine leaf" consisting of scattered short lines like pine needles scattered on the panel. The "hungry horse" distortion produced by welding stiffeners can also be removed by lines parallel to the stiffener.

The ability to form steel by simple heating also means that it is possible to correct minor inaccuracies. This means that you can line heat to get exact fits between premade construction modules. This in turn reduces the risk in modular construction, so it is more feasible. Since modular construction has significant benefits for reducing labor, and especially for home builders, reducing facility costs, this is potentially an important benefit.

Line heating has been shown not to adversely affect most ship steels and is approved by ABS for most uses. Certain high strength steels have to be specially controlled while line heating, but these steels would rarely be used for boat construction. You cannot, however, line heat aluminum. All marine alloys are adversely affected by this type of heating. Aluminum must be formed mechanically.

Line heating is an important tool for builders working in steel that increases the range of shapes they can produce and reduces labor. There is a lot more to learn about this technique and it is well worth the effort to explore it.

Detailed reports, photographs and training aids for line heating are available through the National Shipbuilding Research Program Documentation Center at the Transportation Research Center, University of Michigan, Ann Arbor, on the Web at under www.nsnet.com.