4.2 ROLL FORMING

4.2.1 INTRODUCTION

Roll forming is a high speed forming process that can be used to form a variety of automotive body components. The starting material, usually a flat strip in coil form or occasionally in precut strip configuration, is formed and at the same time longitudinally moved by pairs of rotating tools, until the finished shape exits at the end of the mill.

Most roll forming lines process 0.15 to 10 mm (0.006 to 0.390 in.) thick material at a speed of 20-70 m/min (65-270 ft/min). A mill running only 50 percent of the time at approximately 60 m/min (200 ft/min) forming speed produces almost 15,000 m (50,000 ft) of product in a single 8 hour shift. Practically any material that can be formed by other processes can also be roll formed.

4.2.2 GENERAL DESCRIPTION

Products are usually roll formed at room temperature (hence the name cold roll forming) producing straight, longitudinal bend lines without changing the thickness of the material. Roll forming, however, has the capability to shape parts at high temperature, produce curved parts, bend perpendicular to the direction of rolling and change the thickness of the material[1, 2, 3].

Roll forming, like any other manufacturing process, has its limitations but its advantages far outweigh its disadvantages. Because of its high productivity the trend is to incorporate as many other operations into the roll forming lines as is economically feasible. This arrangement permits the production of the finished or semi-finished components from strip within seconds, without material handling and storage between operations. Since roll forming lines can be made flexible and programmable and produce parts with practically no scrap, the roll forming process can easily fit into the concepts of Just in Time Production, Flexible Manufacturing System, or Net Shape Process.

Roll forming is used to manufacture a large variety of products. Typical roll formed automotive components are: frame and panel members, seat adjusting parts, crash barriers, trims, window components, bumpers[4], channels, van components, sun visor supports, radiator parts, and tubular components. Figure 4.2.2-1 and Figure 4.2.2-2 show examples of the roll formed components. Products can be made out of mild or high strength steels, uncoated, galvanized or prepainted, as well as stainless steels or bimetals.

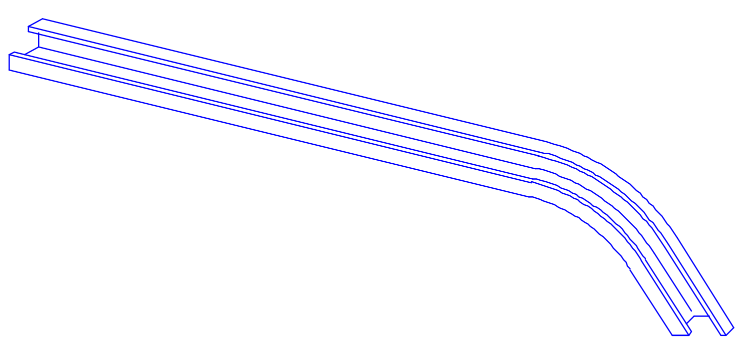

Figure 4.2.2-1 Minivan sliding door track 2 side galvanized 0.075”, Chrysler Corp

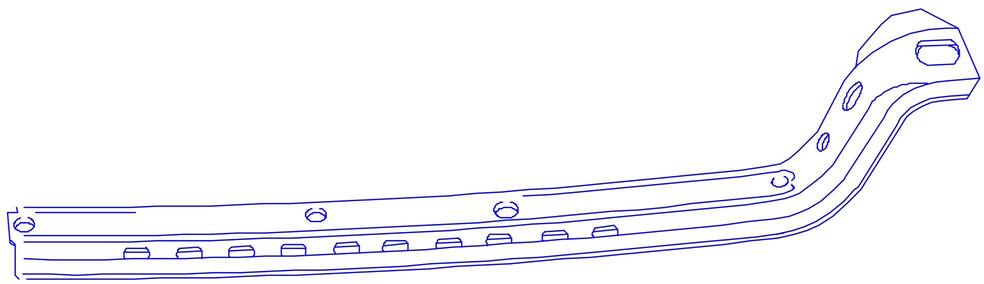

Figure 4.2.2-2 Adjustable curved seat track, A.G. Simpson

Different metallic and nonmetallic materials can be combined into one product in the roll forming process. The different materials can be held together by mechanical joining, welding, adhesive bonding or plastic can be extruded on the metal. Roll forming can produce parts with insulating material attached to it or make laminated sandwich composites.

4.2.3 ROLL FORMING LINE

The basic roll forming line consists of an uncoiler, a roll form mill and a cutoff press. A simple line, however, may consist of a single roll forming mill fed with precut strips. At the other end of the scale are more complex lines that may have two uncoilers; several prenotching presses, cutoff, and/or piercing and forming presses; and two or three roll forming mills. They may contain other production equipment such as resistance, high frequency or other welders; adhesive applicators; rotary piercing or embossing units; automated part feeders and assembly units; curving rolls or blocks; painting and packaging equipment; or robots. Computers or programmable controllers are frequently utilized to manufacture products with variable hole patterns, lengths, widths or weld spacings in one setup.

A small percentage of roll forming lines are fed with precut blanks. Precutting can be done on separate machinery or a cut to length line can be installed ahead of the roll former. If the blanks are precut on separate machinery, they can then be fed into the line manually or by an automatic sheet feeder. The advantage of a precut line is that a cut off die change is not required for each different profile.

The disadvantages of rolling pre-cut blanks are:

1. The length of finished products usually cannot be less than approximately two times the horizontal center distance between roll forming stands.
2. Productivity is lower.
3. It is more difficult to keep tight tolerances.
4. End flare is more pronounced than in sections made from a continuous strip.
5. More forming passes are required to compensate for flare or tolerance problems.

Therefore, most products are made from coils (reels) and are cut to length after forming in the line. Material for so called "continuous" roll forming is supplied in coil form. The coils are placed on an uncoiler (frequently called decoiler or reel) positioned ahead of the roll former. Most uncoilers are equipped with adjustable brakes to prevent unreeling when the line is suddenly stopped and some have an optional drive to ease the feeding of thicker materials or heavier coils. Uncoiler drives are also used when a loop is required between the uncoiler and the next intermittently operated or stationary equipment. They may also be equipped with a peeler table (or feeder) leading the end of the coil directly to the next equipment.

To minimize the unproductive coil change time, double arm uncoilers can be used. While one mandrel (arm) supplies the material to the roll former, the other one can be loaded. For automotive applications double uncoilers are recommended. Occasionally the tail end of the last coil and the leading end of the new coil are welded together in a coil end joiner. If it is advisable to run the roll former without any interruption, such as in the case of welded tube manufacturing or painting, a strip accumulator can be installed between the roll former and the end joiner. The accumulator has enough material stored to supply the mill while the new coil is fed into the line and welded to the tail end of the last coil.

Strip flatteners/straighteners are usually not required for products that are just roll formed. They may be used, however, if products are prepierced before roll forming.

Roll forming mills are available in many variations[5]. They can be divided into two major types: outboard and inboard mills. In outboard mills the rolls are mounted on cantilevered (overhanging) shafts. This type of mill is used to form lighter metal strips or the edges of wider sheets. Two outboard mills facing each other on a common base with adjustable distance between them are called duplex mills. For automotive purposes usually the inboard (standard or conventional) type of mill is used. In this type of mill the shafts (sometimes called spindles or arbors) are supported at both ends. The vertical distance between the shafts is variable and either both top and bottom or at least the bottom shafts are driven. To roll form the products within the specified tolerances, the mill must have enough stands (passes) with adequate diameter shafts. The shaft shoulders, against which the rolls are set, should be aligned within 0.075 mm (0.003 in.) in the vertical and 0.25 mm (0.010 in.) in the horizontal direction.

To minimize tool changeover time and eliminate set up time it is recommended that a rafted type of roll forming mill be used. In the case of rafted mills the stands, shafts and rolls are fastened to removable steel plates. To change the mill from one profile to another only one or a few rafts have to be replaced.

Roll forming mills, in addition to the usual housings, shafts and rolls, have other units to help or complete forming. Among them are the entry rolls, entry guides, side stands, strip supports between stands, rotary piercers, straighteners and curving stands. All these units can play an important role during manufacture of the product.

In most roll forming lines a cutoff press is used to cut the formed product to specified lengths. The cutoff press can be used for piercing, notching, bending, embossing, swageing or for other operations in addition to cutting the product to length. It is common to apply prepiercing presses to pierce holes or to make notches, dimples, embossments, etc. in the flat strip or partially formed section. Most lines contain one prepiercing press, but occasionally three to four presses and two to three mills are combined in a single line to manufacture more complex parts. The maximum speed of the line is frequently restricted by the maximum number of press hits per minute. Therefore high capacity, relatively fast presses should be used for prepiercing and for cutting the pieces to length.

To avoid product buckling and/or distortion of the product during cutting, the cut-off die must be accelerated to the speed of the roll formed section while the material is cut through. Different methods are used to sense the length to be cut and accelerate the die. The combination of the length sensing system, die accelerator and other components will influence the length tolerance[6].

Prepiercing and other operations in the starting strip can be accomplished also with "flying" tools in the so called tight strip arrangement or with stationary dies having a loop ahead and after the press.

4.2.4 COMBINING OTHER OPERATIONS WITH ROLL FORMING

The productivity of roll forming is so high that it is desirable to incorporate as many other operations in the line as is economically and technically feasible. In most cases the combined operations can be executed without additional operators. Therefore, this eliminates the labor cost of the added operations (with the exception of setup cost) as well as material handling and inventory between operations. Some of the operations that can be included in roll forming lines are illustrated in Figure 4.2.4-1.

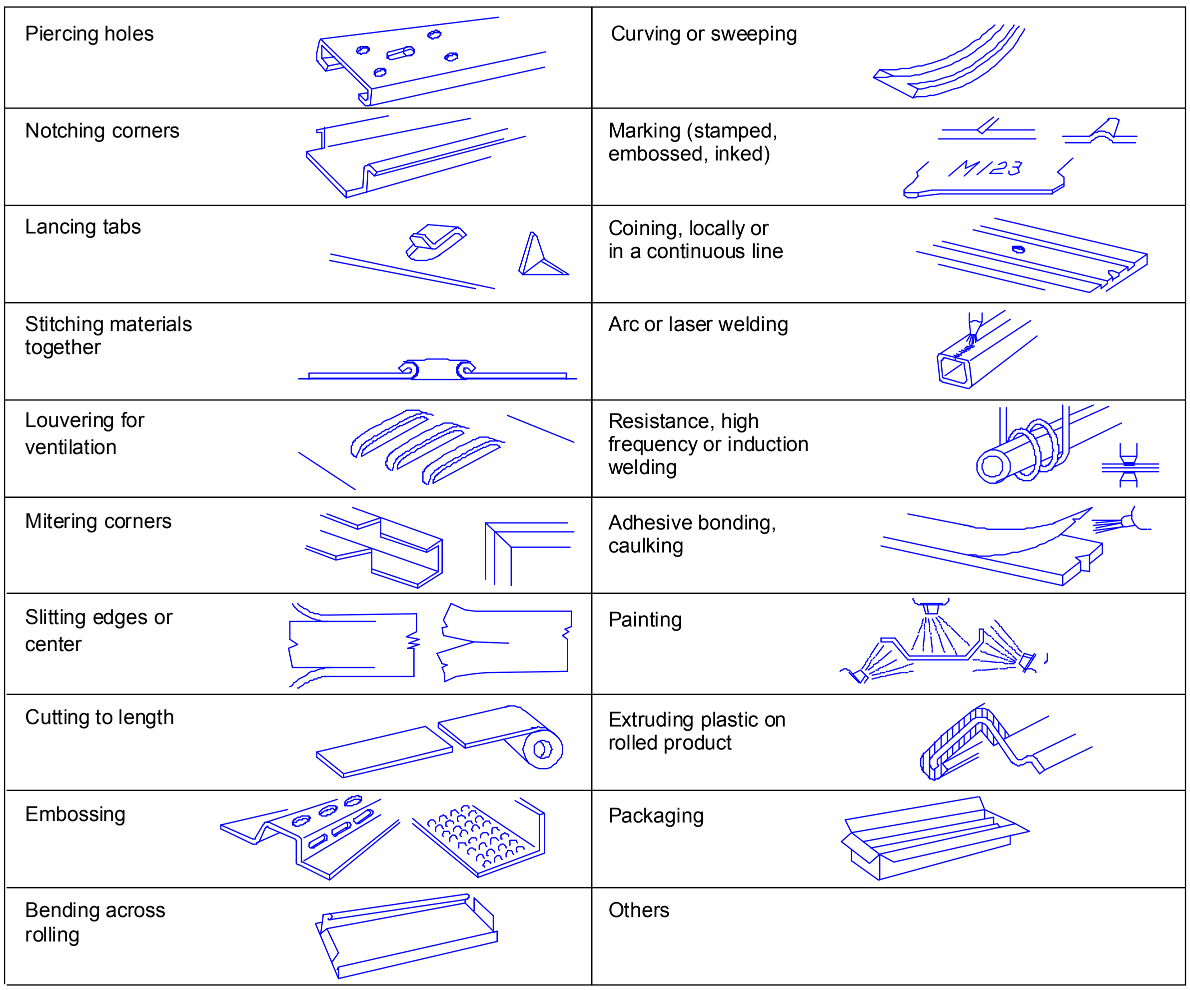

Figure 4.2.4-1 Operations that can be completed in roll forming line

Any of the additional operations can be carried out before, between, or after roll forming. The relative location of the operations are frequently dictated by the product design or availability of equipment. Careful consideration should be given however to the dimensioning and tolerancing of the drawing because it can have a significant influence on the cost of equipment, tooling and manufacturing. (Please refer to Section 3.8 for information on dimensioning and tolerancing.) Close cooperation between the part designer, tool designer and manufacturing personnel can reduce costs and improve quality.

4.2.5 FLOW OF MATERIAL AND TOOLING

During roll forming the flat strip entering the mill is gradually formed, step by step, until it reaches its final shape. Figure 4.2.5-1 shows in a simplified way how a flat strip is formed into a U channel. While the corner line AB travels in a straight line, the edge DF travels a longer, helical way and must be elongated by EF to have continuity. Once it is fully formed, the edge FG is compressed back to the same length as the corner BC. Naturally, the longer the leg (FB distance) and the shorter the distance between the first and last pass in the roll forming line (AB distance), the greater is the strain created. Further strain is created by the brake applied to the uncoiler, by the surface speed differential between rolls, by the complexity of shape and by the lateral movement of the flat surfaces, as shown in Figure 4.2.5-2.

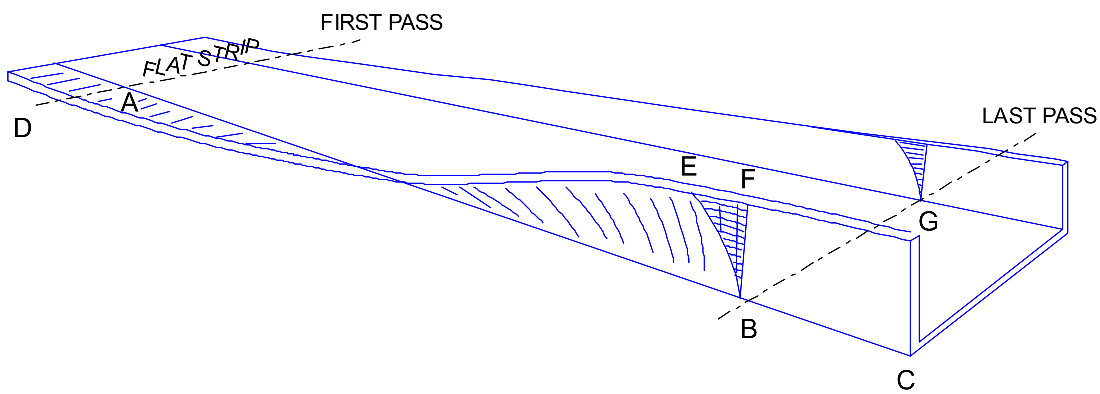

Figure 4.2.5-1 Theoretical flow of material during forming of a “U” channel. (Total elongation EF developed in DF distance is “compressed” back at F).

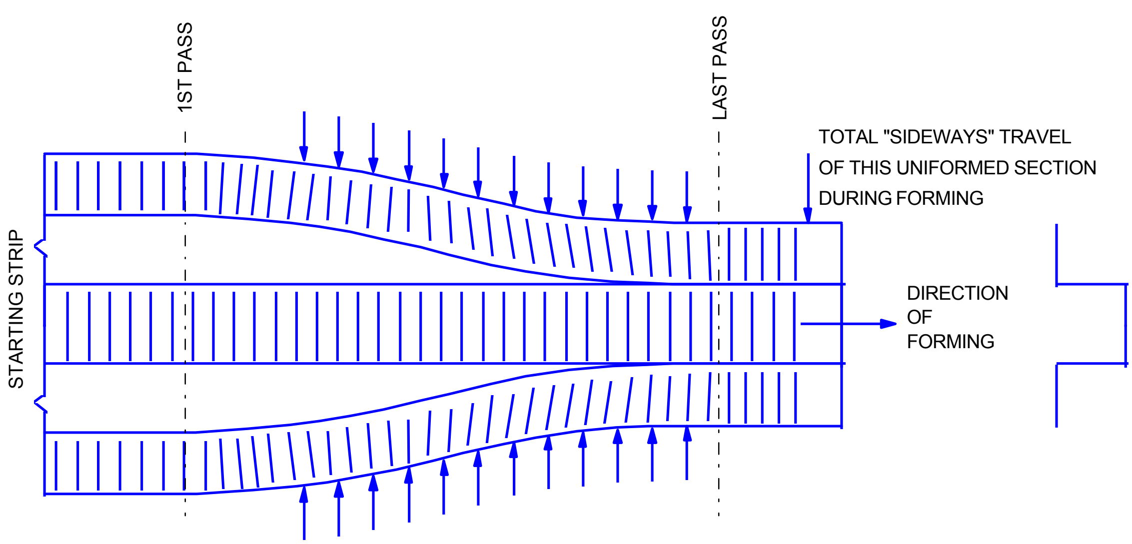

Figure 4.2.5-2 Flow of material with legs and bottom remaining in horizontal position

The actual strain will be even larger than the anticipated one caused by the idealized smooth flow shown on the previous two figures because frequently the deformation is concentrated in a short distance[7] where the material enters the rolls.

Further stresses and strains will be created by the imperfections of the incoming strip such as camber, twist, uneven thickness, wavy edge or wavy center. Roll forming mill and tool discrepancies, such as misaligned uncoiler or entry guides, bent shafts, misaligned tools, and worn or incorrectly designed tools can also contribute to the stresses developed in the part during forming.

The residual stresses in the different segments of the finished shape can deform the final product. In addition to springback, a variety of deviations from the straight line may occur as shown in Figure 4.2.5-3. Springback, affecting both the formed angle and formed radius, is affected by the modulus of elasticity. It will be amplified by increased work hardening properties, as well as by increased forming radius, increased gap between rolls and by reduced material thickness.

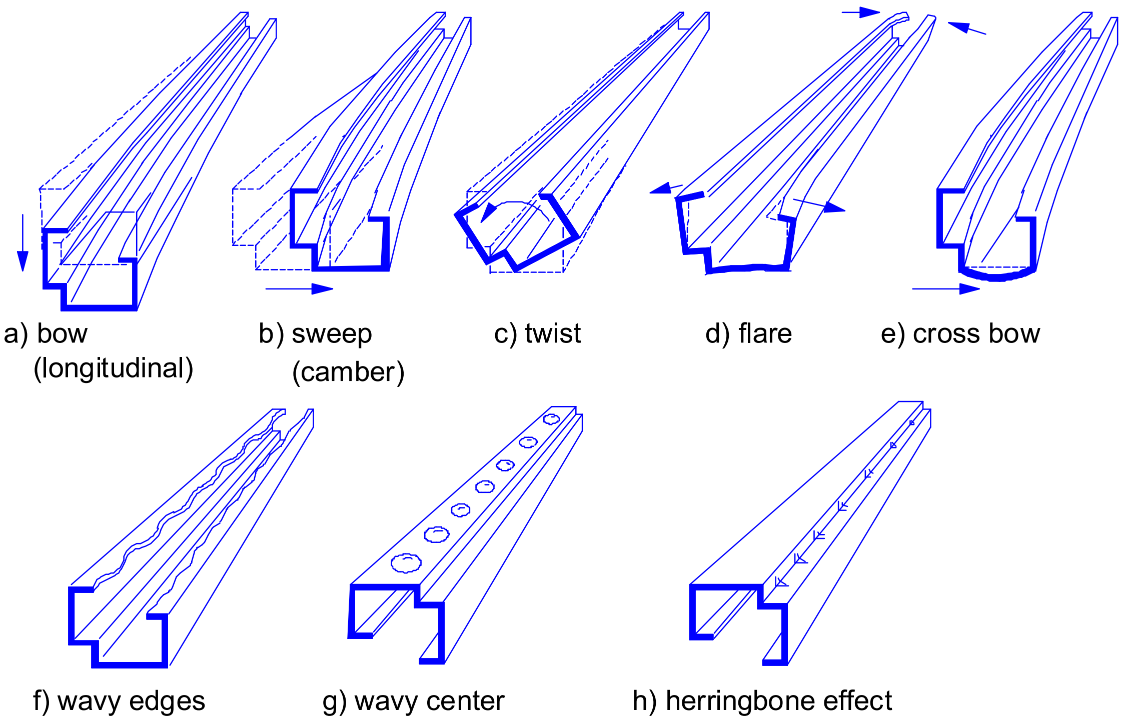

Figure 4.2.5-3 Residual stresses in material may create undesirable effects

The designer of the rolls establishes the number of passes required to produce the shape within specified tolerances. In addition to anticipating the flow of material through the mill, the tool designer must also consider the following:

1. Finished section: length of legs, open or "blind" corners, width of nonstiffened segments, etc.
2. Orientation: how the section will exit from the mill (any critical surface should be on the top side for visual inspection), direction of burrs, position of tools for any subsequent operations in the line (punching, welding, cleaning, painting, etc.)
3. Material: maximum and minimum thicknesses (including tolerances), deviation in mechanical properties, scratch sensitivity of surfaces, etc.
4. Other operations: before, between, or after roll forming.
5. Equipment: roll forming mill shaft diameters, number of passes, horizontal and vertical shaft distances, side roll stands, availability of lubrication, press capacity, etc.

The roll material or roll surface treatment specified by the tool designer will depend on the anticipated quantities to be manufactured, the type of material to be formed and the consistency of the shape required. For automotive purposes rolls are usually made out of D2 (high chrome, high carbon) tool steel, heat treated to 59-62 HRC and polished. Chrome plating is occasionally specified but it is not required for hot rolled, pickled and oiled or cold rolled material. Other surface treatments such as titanium nitride will considerably increase the tooling cost, but they provide excellent wear resistance and longer tool life.

Tool costs may appear to be high at first glance, but considering that millions of parts may be produced before replacement is required, the cost per piece of a well designed tool is relatively low. The tool designer must rely on information provided by others. Therefore, the product drawings and other documents should give all the necessary information needed for good tool design.

4.2.6 MATERIAL TO BE FORMED

Practically any steel specified for formed products in an automobile can be roll formed. Frequently, the material specification for roll formed products are less critical than they are for other operations; for example, killed or semikilled steels are usually not required for roll forming. Minimum bending radii for different steels specified in suppliers recommendations and in standards can be followed. In certain cases even smaller bending radii can be used than shown on the tables. Cold rolled, hot rolled, pickled and oiled, galvanized or prepainted steel can be processed through roll forming lines.

Metallic coated steel, however, requires good lubrication to avoid coating pickup by the rolls. Roll forming lines can handle steels with a wide variety of mechanical properties, including high strength steels[8]. Due to different springback properties, ranging from 0° to 30° per 90° bend, the rolls to form products to tight tolerances must be designed for a specific material and for a specific thickness. Material with more uniform mechanical properties and uniform thickness will produce more uniform products.

High strength steels, especially in the 690 to 1,380 MPa (100 to 200 ksi) yield strength range, having low elongation and high springback properties, will have higher residual stresses after roll forming. These stresses may cause extensive end flares or objectionable deformations around prepierced holes and will make secondary operations such as curving difficult. Careful roll design can reduce these undesirable effects although a large fluctuation in mechanical properties across the width of strip makes it more difficult to form to tight tolerances.

Strip dimensions seldom represent restrictions; equipment to roll form 0.15 to 10 mm (0.006 to 0.390 in.) thick and 3 to 1520 mm (0.125 to 60 in.) wide steel strips are commonly available.

4.2.7 DESIGN CONSIDERATIONS

The design of automotive components is covered by other sections of this manual. This section will give additional guidelines about the influence of roll forming on product design. It also highlights some of the advantages provided and restrictions created by roll forming.

4.2.7.1 Bending Radii

The minimum bending radii for different material thicknesses and qualities are available in supplier's data sheets and standards. The inner radii of the forming rolls are usually made to match the specified minimum radii, based on the maximum material thickness (including thickness tolerance) to be formed.

It is possible to form sharp inner corners in profiles made out of steel by grooving the flat strip as shown in Figure 4.2.7.1-1. The reduced strength of corners due to reduced material thickness and notch effect should be taken into consideration.

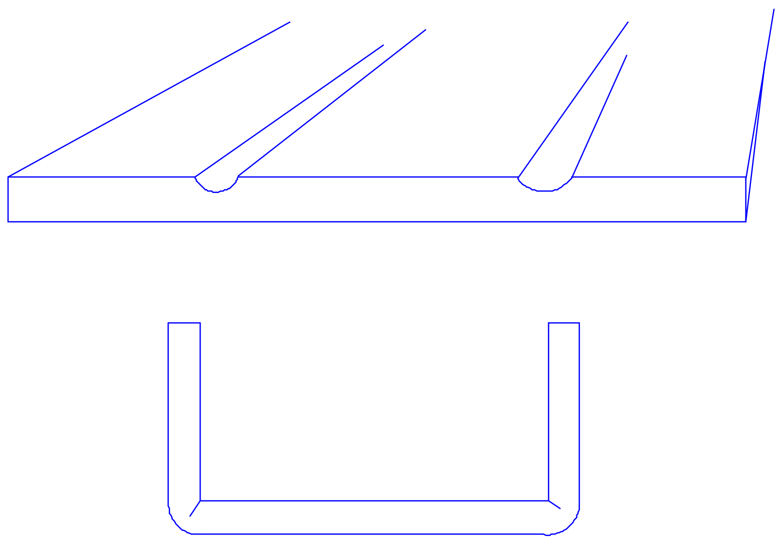

Figure 4.2.7.1-1 Grooving strip to form sharp corners

High strength steels require larger bending radii (typically two to five times material thickness) and considerable overbend to compensate for springback. The designer should provide sufficient space for overbending (Figure 4.2.7.1-2).

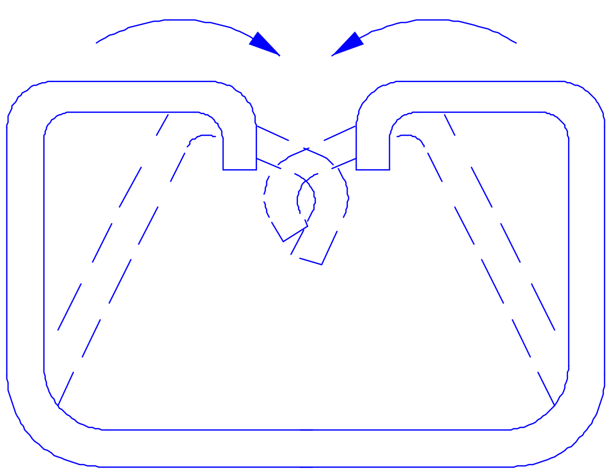

Figure 4.2.7.1-2 Space for overbending must be provided when springback is significant

Forming angles under 90° is usually simple. Bending over 90° requires more passes. When part of the section is bent over 90°, or another part of the formed section is covering the corner to be bent, a blind corner is created. The male die can not reach into the blind corner and the pressure applied on the segments to be formed may bend other segments as shown in Figure 4.2.7.1-3. Some of these difficulties can be overcome by creating a false break to provide access to the corner as shown in Figure 4.2.7.1-4, then eliminating the false break.

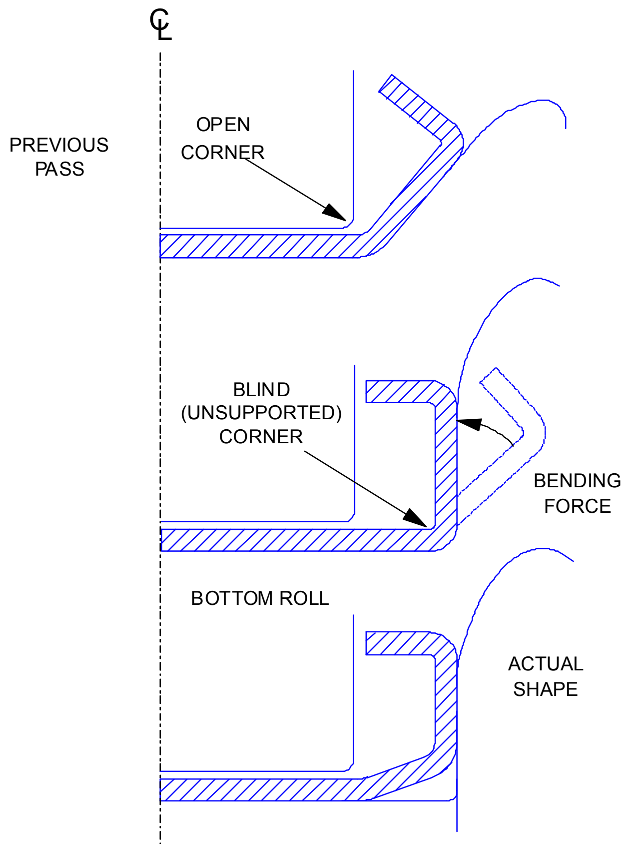

Figure 4.2.7.1-3 Possible additional bendline at unsupported section

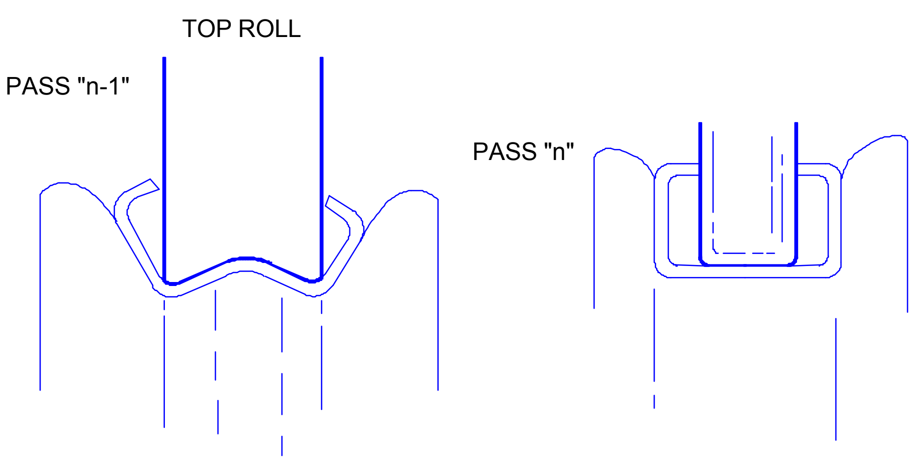

Figure 4.2.7.1-4 "Straightening back" false break

Roll designers prefer to work with reasonably tight radii which helps to set the profile. Forming very large radii as shown in Figure 4.2.7.1-5 requires only one or two passes. The strain in the material, however, barely exceeds the elastic limit. As a result of the limited permanent deformation the tolerance may be large on the radius and chord.

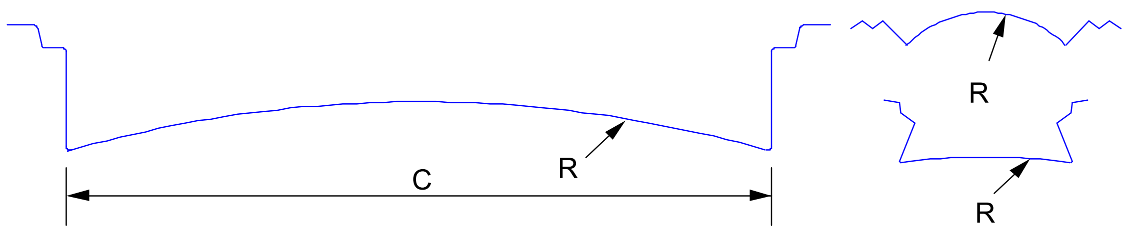

Figure 4.2.7.1-5 Tight tolerance is difficult to maintain on a large radius

4.2.7.2 Width of Nonformed Sections

An unformed segment that is too wide or too narrow, located between the edge of the strip and the first bend line or between two bend lines, can create problems. Figure 4.2.5-1 shows how the edges are stretched during forming. The longer the leg, the greater will be the strain. If the strain at the edge is beyond the elastic limit, it is difficult to compress the thin metal back at the straight section and the result will be a wavy edge (Figure 4.2.7.2-1). Waviness may be eliminated by applying an additional stiffening bend closer to the edge as shown on the right hand side of Figure 4.2.7.2-1. Starting with a strip that has a wavy edge or excessive camber can contribute to the waviness of the finished product.

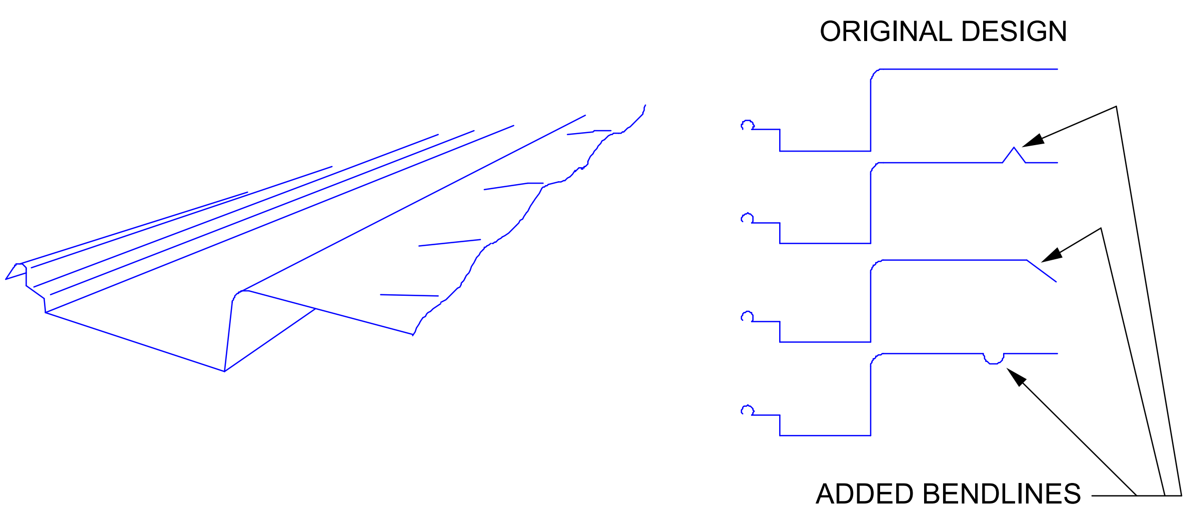

Figure 4.2.7.2-1 Edges of wide unstiffened sections have a tendency to wave.
Added bendline(s) shown on right hand side can eliminate wavi ness.

Too short a leg may create forming problems (Figure 4.2.7.2-2). For easier forming and for better tolerances it is preferred to keep the length of the leg at least four times the material thickness.

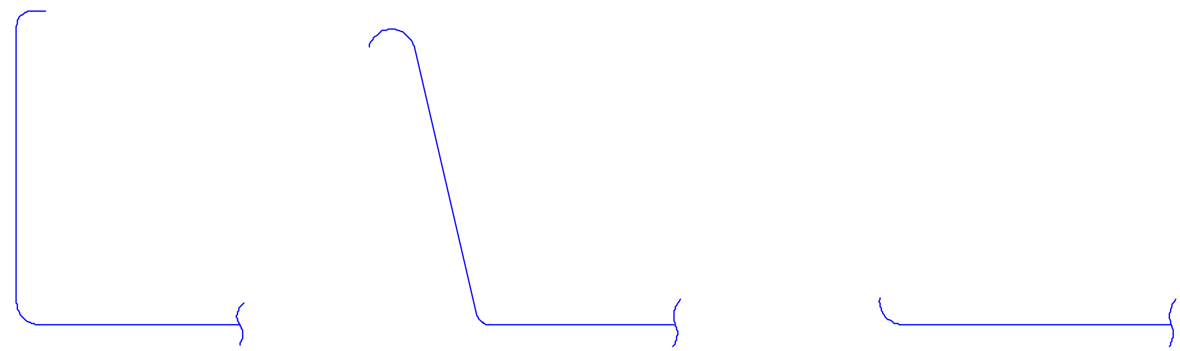

Figure 4.2.7.2-2 A short leg is difficult to form

When stiffeners or other ribs are designed, the slenderness of the mill dies should be considered. Thin rolls (Figure 4.2.7.2-3) can easily chip or break, stopping production for one to three days. Extreme side pressure can easily be exerted on the rolls if the gap between the rolls at one side becomes smaller than the material thickness.

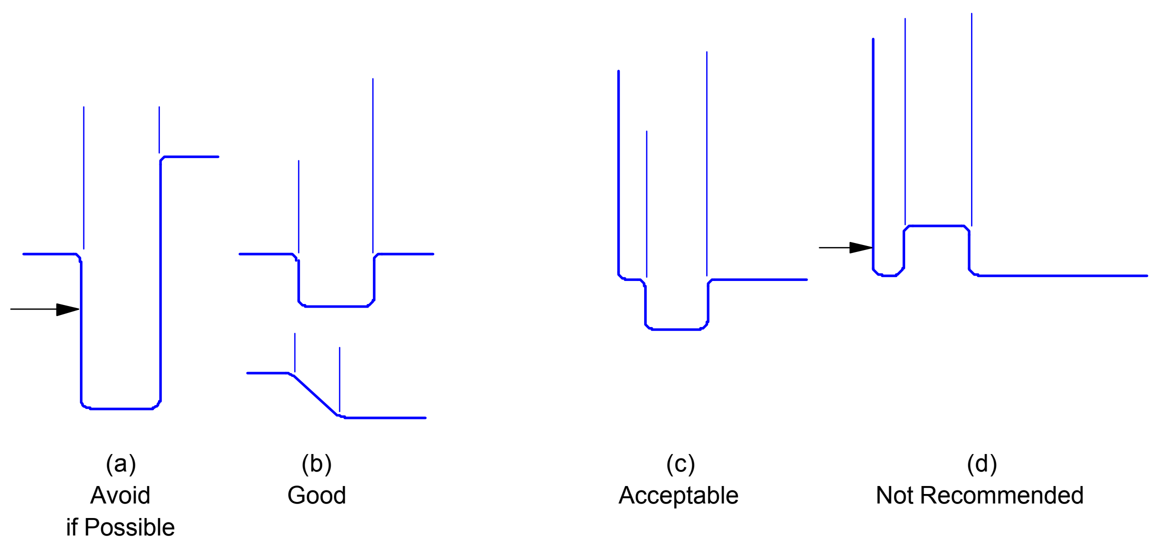

Figure 4.2.7.2-3 Stiffener rib designs

4.2.7.3 Bend Line Discontinuity

The designer usually recognizes that bend lines increase the strength of the section, but the weakness introduced by any discontinuity of the bend line may be overlooked.

Figure 4.2.7.3-1 illustrates a few examples where, by design or by incorrect forming, the straight bend line is discontinuous or damaged. Even corner embossing, which greatly increases the strength in one direction, will reduce the strength of the section in the other direction.

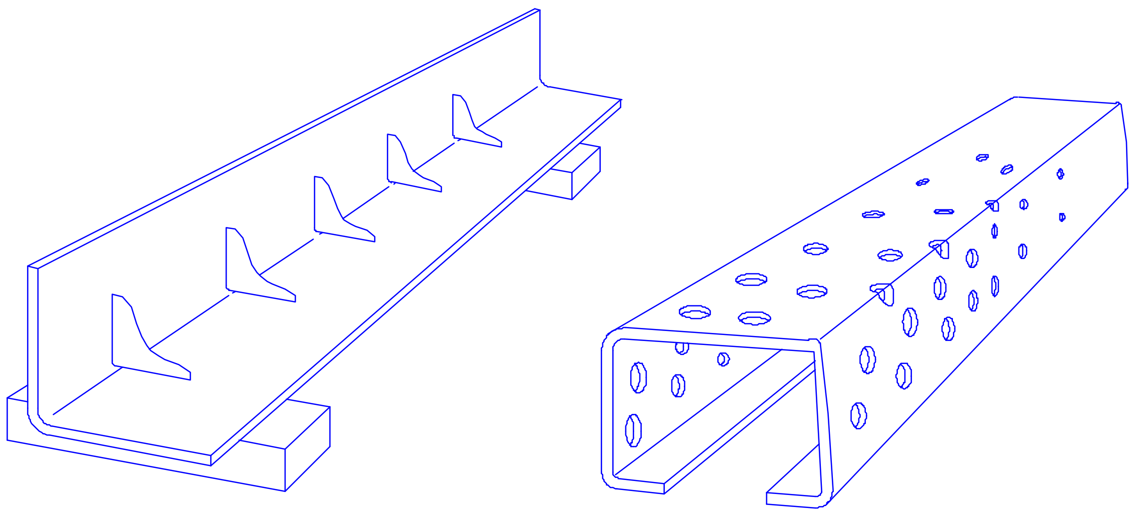

Figure 4.2.7.3-1 Discontinued bendlines have reduced strength

Cutouts at the bend line may represent another problem. If the cutout is too close to the bend line, the leg may be too short to be bent, and remain in its original plane after forming (Figure 4.2.7.3-2). Holes too close to the edge of the strip may leave too little material outside the hole, which stretches to such a degree during forming that it will buckle inward or outward in the final shape (Figure 4.2.7.3-3). Holes pierced in the flanges of curved panels may show even more severe deformation in the compressed elements (Figure 4.2.7.3-4).

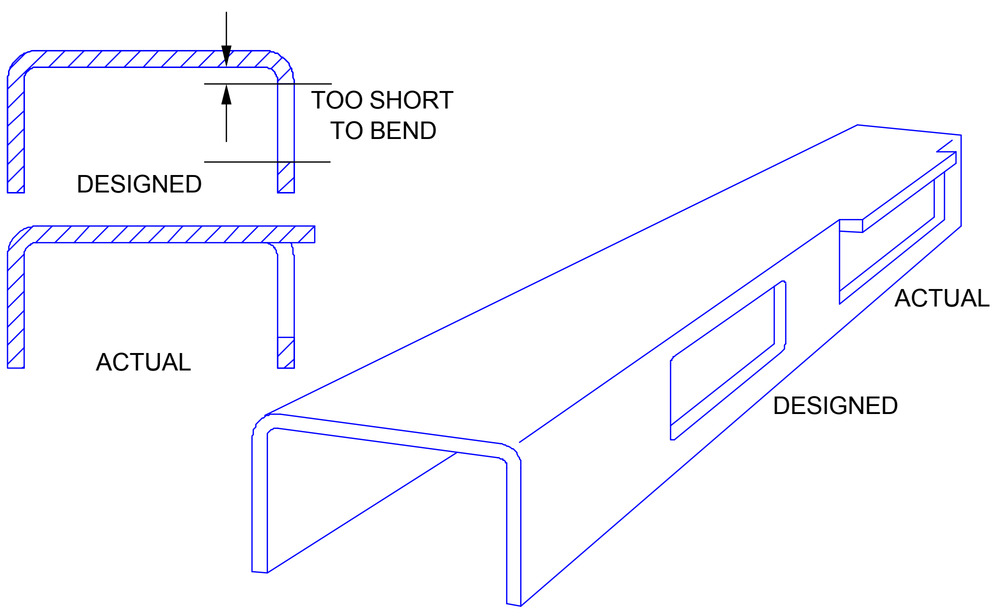

Figure 4.2.7.3-2 Effect of cutout too close to bendline

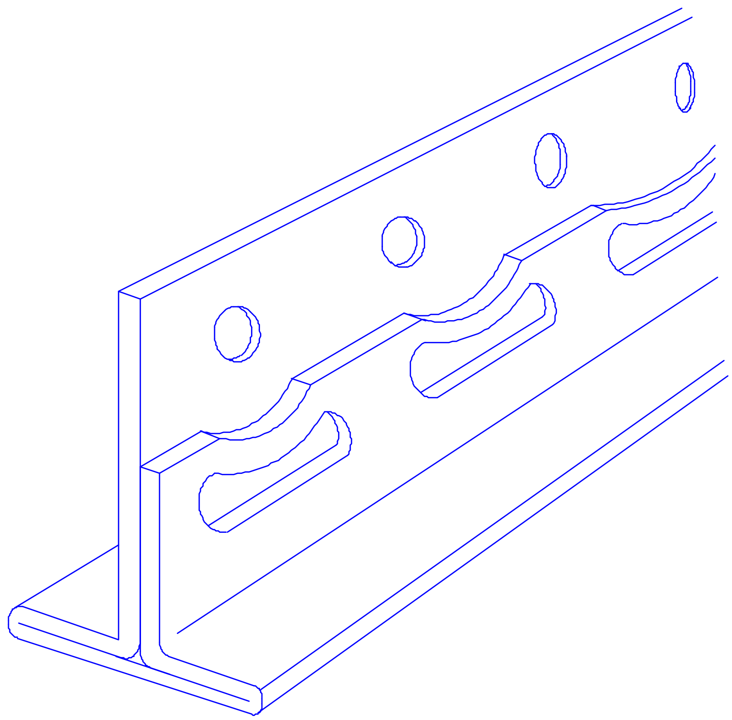

Figure 4.2.7.3-3 Effect of overstretched edge when holes are close to edge (effect was eliminated by modifying rolls)

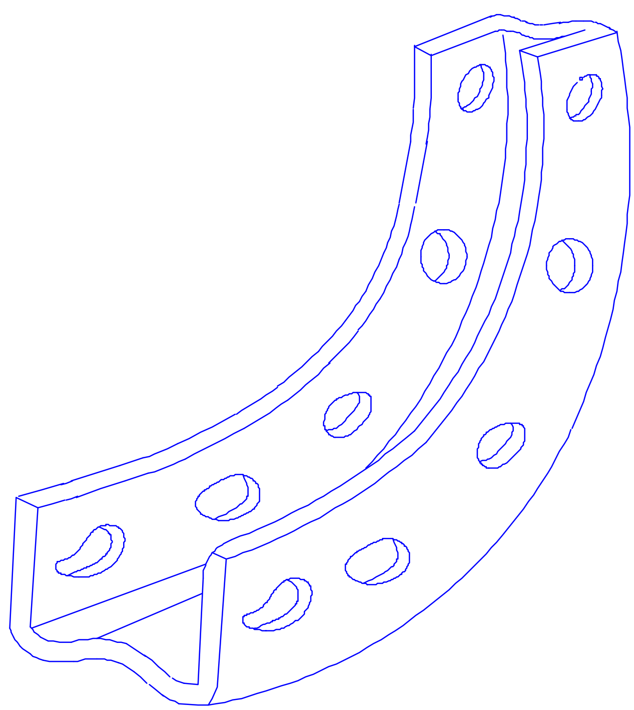

Figure 4.2.7.3-4 Tension and compression caused by curving can significantly distort pre-pierced holes

4.2.8 SPECIAL CONSIDERATIONS AND SPECIAL APPLICATIONS

The primary considerations of a part designer are the function, appearance and cost of the product. The method of manufacturing, however, should not be overlooked because it will influence all three basic considerations. Therefore, it is highly recommended that the tool designer and manufacturing personnel experienced in roll forming be involved in the conceptual stage of product design. At this stage, certain minor details, which can greatly influence the cost and quality of the finished part, can still be changed or modified. In most cases newly designed parts are roll formed with existing equipment. Therefore, the capacities of the equipment must also be taken into consideration.

There are some special cases where new equipment can be built to produce new parts. In these cases, only the available funds and time restrictions will restrict the introduction of new or unusual manufacturing methods. Some examples related to roll forming are:

1. Interrupted roll forming: It is possible to lift the upper forming rolls by hydraulic cylinders, servo motors, or cams, to create noncontinuous forming operations. For example, grooves in a product may be stopped at a certain distance before the end[9].
2. Variable hole, welding or other patterns: Specific punches or other equipment can be activated or deactivated in the line by the command of a computer, N/C or programmable controller.
3. Variable width product: Nonparallel edges of pie shaped sections can be roll formed with special equipment or special arrangement.
4. Variable radii curving: With appropriate control, products can be curved to two or more radii.
5. Very short pieces: Simple methods are available to roll form very short, (3 mm or 1/8 in.), pieces.
6. Forming at elevated temperature: Roll forming of preheated material in conventional mills is possible, but special mills can be built to roll form at high (hot forming) temperatures.
7. Ring forming: Rings can be produced in two different ways. One method is to roll form the section, curve it and cut it to length in the line. The cut ends are then welded together as in the case of bicycle rims. The other method starts with a flat, welded, continuous ring formed in several steps to its final shape as in the case of manufacturing automotive wheel rims.
8. Forming "dogleg" shapes in the longitudinal directions: Variable radii curving method mentioned previously can be applied or longitudinal sections may be bent by equipment similar to the automatic tube benders in the line.

The above list shows only a few possibilities to utilize roll forming lines for unusual applications. Although the major portion of the roll formed product will be formed on conventional roll formers, the high volume automotive components can provide opportunities to employ some existing, unusual methods or to develop new technology for profitable production.

REFERENCES FOR SECTION 4.2

1. High Production Roll Forming, Source Book; SME, January 1983.

2. Metals Handbook, "Forming", Volume 4, ASM, (1973).

3. Tool & Manufacturing Engineers Handbook, "Forming", Volume 2, SME, (1984).

4. Ferry, J.W. Techniques and Limitations for Cold Roll Forming High Strength Steel Bumper Components, "High Procuction Roll Forming", Source Book: SME, January, 1983.

5. Halmos G.T., Guidelines for Purchasing Roll Forming Lines, "Technology of Roll Forming Conference", Toronto, September, 1984, SME.

6. Halmos G.T., "Length Tolerances for Roll Formed Parts", Precision Metal; December 1981, Vol. 39, No. 12, p. 33-36.

7. Bhattacharyya D., Development of a Logical Flow Chart for Selection of Roll Schedules,Symposium on Sheet Metal Forming, Theory and Practice", McMaster University, Hamilton, Ontario, May, 1986.

8. Halmos, G.T., "Roll Forming HSLA Steels", International Conference on Technology and Application of HSLA Steels, Philadelphia, Pennsylvania, October, 1983, ASM: also The Fabricator, July/August, 1984, Vol. 14, No. 5, p. 12.

9. Pugh, G.H., "Interrupted Roll Forming; Sheet Metal Industries", April 1970, Vol. 47, No. 4.