



Stamping designs should be based on data of successful prior designs and formability analytical methods. Uncertainty concerning the Manufacturability of complex stampings often results in added expense and delay factors such as:

1. Trial production on temporary tooling to prove process feasibility.
2. Delays in marketing the product containing the stamping while the process or product design is changed.
3. Specifying more operations than should be needed as a safety factor.
4. Choosing alternative processes and materials such as molded plastics.

### **Assuring Easily Manufactured Stamping Designs**

Easy-to-use computer software programs are available to assure that proposed stamping designs can be manufactured with certainty. Other powerful tools are circle grid analysis (CGA), which ties in with the forming limit diagram (FLD). Using these tools avoids costly trial-and-error guesswork.

### **Computerized Analysis Techniques**

Software is available to analyze the amount and type of deformation in a stamping design. Such computer-aided analysis ties in nicely with CAD design of stampings. The analysis should be applied early in the product design process. The CAD math data, which describes the part, is used for computerized formability analysis. Computerized analysis falls into several categories, such as:

1. Simple sectional analysis programs.
2. General analysis programs, which fully model the part, typically based on finite element analysis.
3. Programs, which analyze the stamping, based on the type of deformation that is occurring in individual area.

### **Sectional Analysis Programs**

The sectional analysis programs are useful for determining the amount of strain present in a specific area of a stamping. Here, anticipated problems with a design can be checked easily.

A moderately priced personal computer has sufficient computational capacity to run sectional analysis programs to determine strain conditions. Estimating the effect of surface friction on metal movement is a useful feature of nearly all computerized formability analysis programs.<sup>3</sup>

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<sup>3</sup> M. Tharrett, *Computer Aided Formability Analysis*, presented at an SME Die and Pressworking Tooling Clinic, Dearborn, Michigan, August 25-27, 1987.

## General Analysis Programs

To completely model the part, using the finite element or finite difference method, general analysis programs are required. Stamping the whole part is simulated in three dimensions with a single computer program. Many complex interactions occur during the stamping simulation. A mainframe or super computer may be required.

## Simplifying Computerized Stamping Analysis

Sectional analysis is good for identifying and troubleshooting a number of simple forming conditions. General analysis programs require a lot of computing power and time in order to calculate the interaction of many complex variables occurring throughout the forming process.

A simplified approach is to break down complete stampings into local regions that can be analyzed individually. In this way, a stamping such as that shown in Figure 30 is analyzed as individual zones that interact in a predictable manner as they are formed. Some good programs include an expert systems approach.

# CIRCLE GRID ANALYSIS

## Measuring Deformation

The circle grid analysis (CGA) technique permits measurement of the deformation that occurs when forming stampings. First, a grid is stenciled on the surface of the blank by dye transfer or electrochemical etching. This grid deforms with the blank and allows point-to-point calculations of the deformation that occurred during the stamping operation.<sup>4</sup>

## Press Shop Applications

Figure 2 illustrates a bumper jack hook. The grid of circles, placed on the blank, shows different types and difficulties of deformation required to form the finished stamping. Note that most of the circles are deformed very little, while a few circles, especially one near the lip, show pronounced elliptical patterns. If an assumption is made, this stamping may be thought to fracture at the location where the edge is most severely stretched. However, the lip can stretch easily because it is on the edge, a condition where the metal can stretch easily.<sup>5 6</sup>

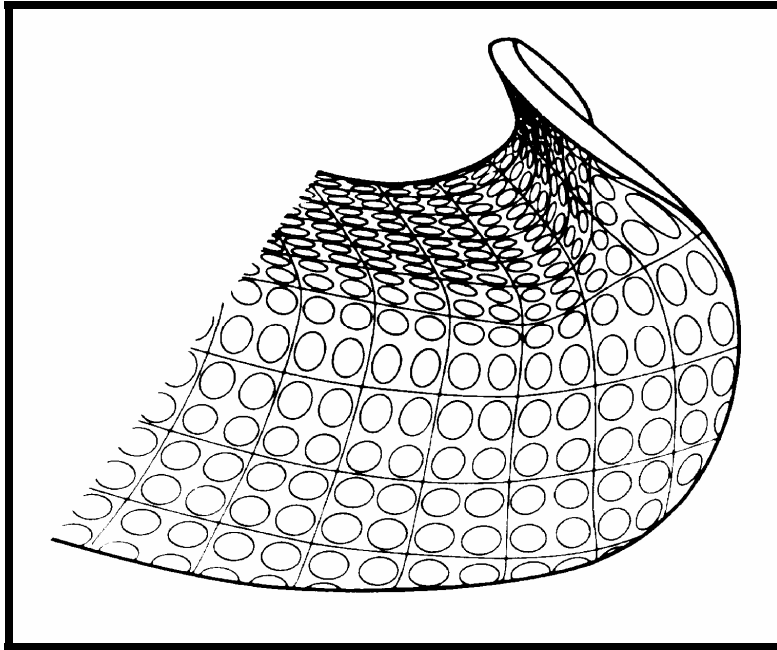
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<sup>4</sup> *Sheet Steel Formability*, © The Committee of Sheet Steel Producers, American Iron and Steel Institute, Washington, DC, August 1, 1984

<sup>5</sup> S. Keeler, *Circle Grid Analysis (CGA)*, National Steel Corporation Product Application Center, Livonia, Michigan, 1986.

<sup>6</sup> S. Keeler, *From Stretch to Draw*, SME Technical Paper MF69-513, The Society of Manufacturing Engineers, Dearborn, MI, 1969.

## A Bumper Jack Hook formed from a CGA Blank



**Figure 2.** A bumper jack hook formed from a circle gridded blank.  
*National Steel Corporation*

### Measuring Forming Severity

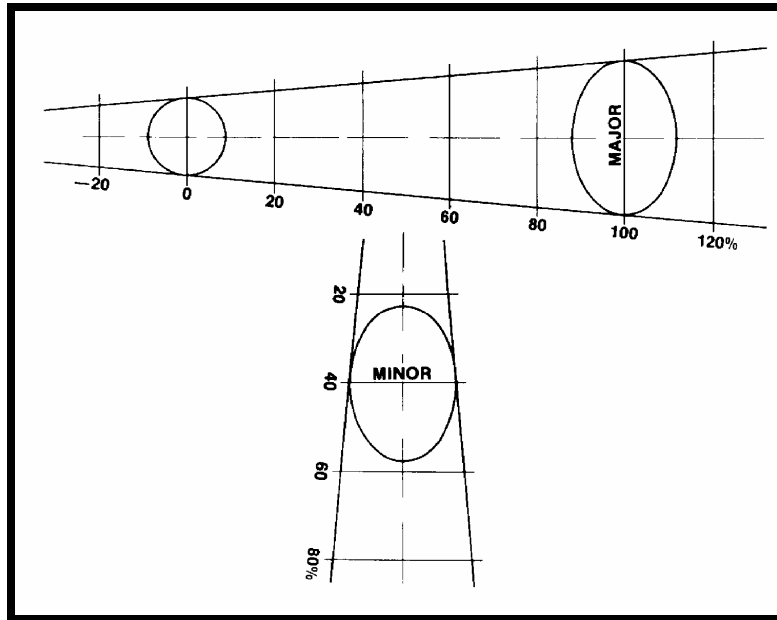
The distribution of stretch is useful information by itself. Location of high stretch concentrations and the direction of the maximum stretch often are sufficient information to suggest solutions to forming problems. However, CGA uses a numerical rating system for the deformation of the circles.

The system of rating forming severity is based on measuring deformation of the circles and plotting the measurements on a graph. Grid measurements are easily made with a transparent Mylar tape imprinted with a calibrated scale, (Figure 3). The tape is flexible and can be laid around a radius or tucked into a tight corner. The calibration of the tape eliminates any need to calculate stretch. The tape is used to measure the major (length) axis of the ellipse first and then rotated to measure the minor (width) axis.

### Stretch Combinations

Many combinations of major and minor circle deformations can be found on different stampings. Figure 4 illustrates five different types of deformation. One special case is shown on the right, where both the major and minor axes of the ellipse are equal--the circle becomes a larger circle. This is called balanced biaxial stretch.

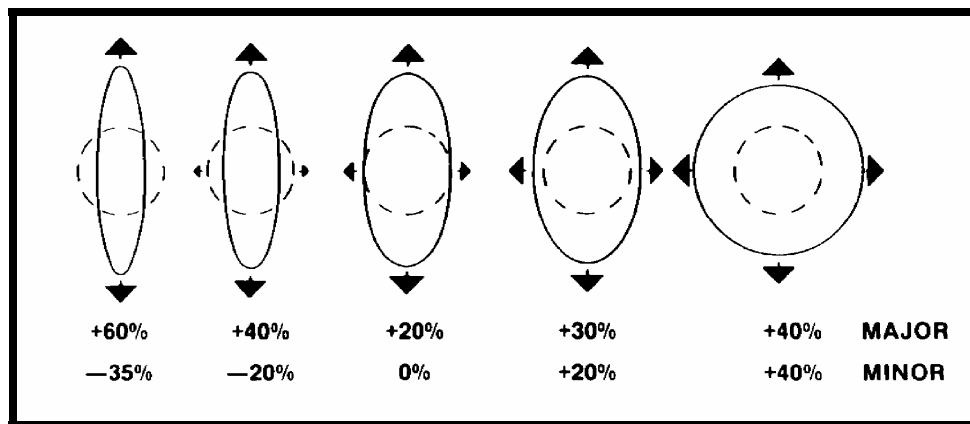
## Mylar Tape Overlay for Measuring Circle Deformations



**Figure 3.** Measuring circle deformation with a Mylar tape overlay.  
*National Steel Corporation*

The middle case also is special. Here the minor stretch component is zero. This is called plane strain. This stretch condition is found over edge radii or across character lines.

The two examples on the left side of Figure 4 illustrate large major elongations while the minor stretch is negative. Circle deformations of this type are observed in the sidewalls of drawn cups, and the corner sidewalls of rectangular drawn shells. This combined compression and elongation, indicates that the metal is subjected to both circumferential compression and tensile stretching as it is pulled toward and over the draw radius.



**Figure 4.** Examples of deformed circles. *National Steel Corporation*

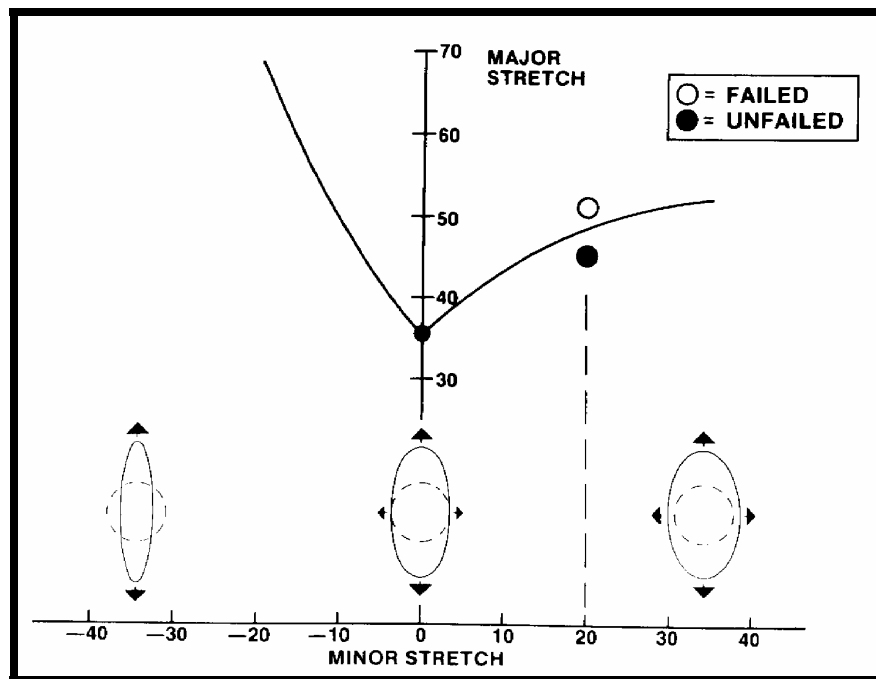
## Plotting Circle Grid Measurements

Due to the variety of combinations, a method for plotting them on a single graph is necessary. The plotting technique used in Figure 5 allows both the major and minor stretch for each circle to be plotted as a single point.

The major stretch is plotted on the vertical axis, while the minor stretch is plotted on the horizontal axis. Circles that plot on the left side of the diagram have negative minor stretch, while circles that plot on the right side of the diagram have positive minor stretch.

Three of the ellipses from Figure 4 are plotted on this diagram. Note that the case of plane stretch (minor stretch equal to zero) is plotted on the vertical axis.

Figure 5 illustrates an unsymmetrical V-shaped curve, which is the forming limit. Circles plotted below this curve show no evidence of necking or fracture, while those above it fail. A graph developed in this way is called a *forming limit diagram* (FLD). The point where the FLD intersects the major stretch axis is called FLDo. Here only plane strain deformation is occurring. To initially develop this diagram, many samples of failed versus unfailed circles from the same material must be plotted.



**Figure 5.** Evolution of the forming limit diagram (FLD). *National Steel Corporation*

The shape of the Forming Limit Diagram (Figure 6) is constant for most low-alloy sheet steel used in the automotive, appliance, agricultural, container, and similar industries. The curve moves up and down the axis for different coils of steel. Thus, the location of

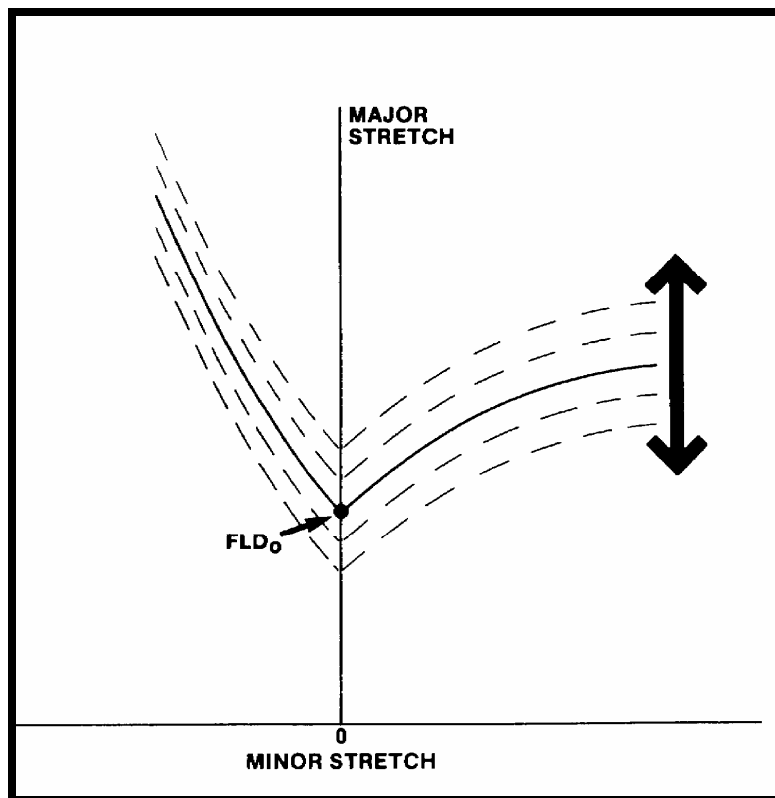
the curve can be described by specifying the intersection of the curve's FLDo with the minor stretch axis.

Figure 6 illustrates how the FLD can raise or lower for different steel sheets. The level of the FLD--as specified by FLDo--is a characteristic of the sheet steel. For example, a thinner sheet of steel would have a lower FLD than a thicker sheet of steel. In addition, higher strength steel would have a lower FLD than lower strength steel.

### Using CGA as a Process Control Tool

CGA is a powerful process control tool. Data on essential areas of the stamping that are near the forming limit should be checked periodically to determine the effect of die wear on formability. Should a production stamping process start to experience problems, a blank of the material can be quickly gridded and analyzed. The CGA results can be compared with the historical data for the part and steel formability specifications.

### Different steels move the FLDo Point



**Figure 6.** Different steels move the FLDo point. *National Steel Corporation*

### Everyday Pressroom Applications

Should the part always be found to run well within the safety zone, often a less costly steel or lubricant can be used. If only a few areas on the stamping are close to failure, a blankholder improvement or minor product change often will ensure the manufacturability of the product.

The circle grid analysis system is excellent for training apprentices. By making tooling, lubricant, and material changes and then observing the metal deformation changes, cause-and-effect patterns can be readily discerned.

### **Making do Without Etching Equipment**

When working in shops that have no etching equipment, the problem areas of the blank to be stamped can be coated with layout blue and circles lightly scribed with dividers. An overlay pattern can be drawn with simple drafting tools and copied onto overhead transparency stock. Another way to make the measurements is the use of a digital dial caliber to measure the amount of deformation before and after drawing and or forming the blank.

The deformation can be read directly from an improvised transparent overlay or accurately calculated using the digital calipers and percentage function on a calculator. The author has resorted to this many times when troubleshooting stampings on a consulting basis.

This method is only field expediency and not recommended as a replacement for the inexpensive electrical etching equipment using chemicals and accurate stencils. CGA is intuitively simple to learn and use. No shop that does pressworking of sheetmetal should be without the equipment to carry out this simple stamping health tracking and troubleshooting process.

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