

Bending Allowance Calculations for Sheetmetal:

Base Discussion:

Back during World War II the need to “simplify” the layout of sheetmetal constructs became quite important. In essence the “**K-Factor**” is a ratio that converts the *OMLR* (*Outside Mold Line Radius*) distance of a “bend” in sheetmetal to the actual “*Neutral Axis*” distance undeformed by the “bend.” The image shown below gives an overview of this concept. This **only** applies to *sheet, plate, and bar stock*.

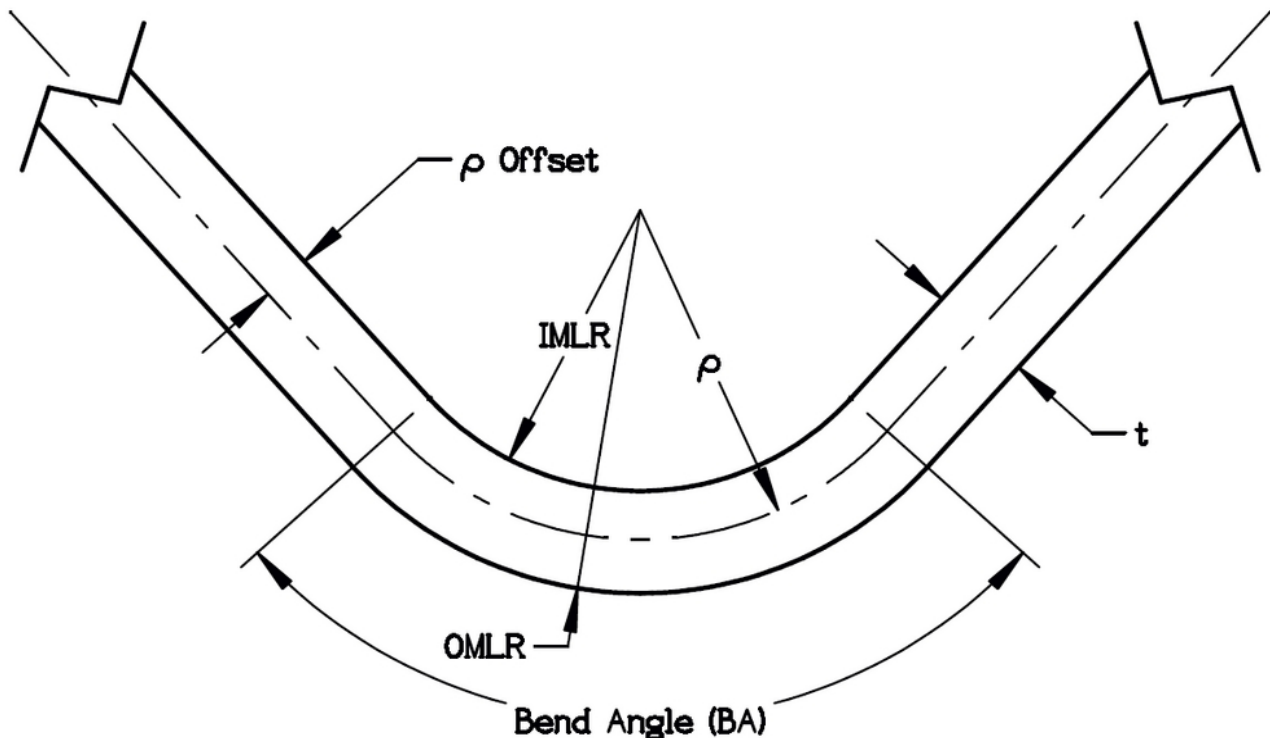


Figure 1: General Layout of a “K-Factor”

Now the **fact** is that the *Neutral Axis Radius* is all you need to accurately calculate the *undeformed length* that creates a **Flat Pattern** for sheetmetal layout, but for some reason the CAD industry has decided to use the **approximation** inherent in the **K-Factor** system created by the Lockheed Aircraft Corporation:

$$K = \rho \text{ Offset} / t \text{ - (Equation 1)}$$

$$\rho \text{ Offset} = \rho - \text{IMLR} \text{ - (Equation 2)}$$

Thus, if you take the $(\text{IMLR} + K \times t) \times \text{Bend Angle}$ (in Radians) you get the **length** of the *Neutral Axis* across the *Bend Angle* that is the (if you will) “*pre-deformed*” length of the bent section. However, the *Neutral Axis Radius* (ρ) is easily calculated as:

$$\rho = t / \ln((\text{IMLR}+t)/\text{IMLR}) \text{ - (Equation 3)}$$

which gives you (A) the same answer (when multiplied by the Bend Angle in Radians) and has to be calculated anyway to get you the **K-Factor**.

Now there are relationships shown in **Figure 1** that ought to be obvious. $IMLR + t = OMLR$ being one (and the “*IM*” in “*IMLR*” stands for “*Inside Mold*” and “*IMLR*” stands for “*Inside Mold Line Radius*” and the “*OM*” in “*OMLR*” stands for “*Outside Mold*” and “*OMLR*” stands for “*Outside Mold Line Radius*”).

Further Discussion:

One fact that is often overlooked is that metal has to **yield** to stay properly bent when formed. **One** factor in this is the “stretch” that occurs between the *Neutral Axis* and the *Outside Mold Surface* in *Bending*. Now if you remember your basic metallurgy, the *Yield Point* is defined as being the level of **strain** where the sample **deforms** by **.2%** (I.E. a 2.000 inch long sample ends up as being 2.004 inches long after loading).

Thus if the *Outside Mold Length* ($OML = OMLR \times \text{Bend Angle (in Radians)}$) is greater than $1.002 \times \rho \times \text{Bend Angle (in Radians)}$ then the part is unlikely to *Spring Back* to any appreciable degree. So, let’s look at the equation required to calculate this value.

$$\rho\text{-Length} = \rho \times QR \text{ (where “QR” is the Bend Angle measured in Radians) – (Equation 4)}$$

$$OML = OMLR \times QR \text{ – (Equation 5)}$$

$$\rho\text{-Length} = t / \ln((IMLR+t)/IMLR) \times QR \text{ – (Equation 6)}$$

$$\Delta = OMLR / (t / \ln((IMLR+t)/IMLR)) \text{ – (Equation 7)}$$

Thus, if **Equation 7** has a value *Greater Than 1.002* then, for most metals, there will be very little “*Spring Back*” from the bend! This is an analytic technique rarely taught today. If **Equation 7** has a value *Less Than 1.002* then, with exceptions noted in the following *Discussion*, the piece will have to be “*over-bent*” and “*returned*” to eliminate “*Spring Back.*” The “plus side” here is that most sheetmetal workers are familiar and practiced in this technique.

A primary process that must be considered are the *Forces* applied (and, if you will, be amplified) in the use of a *Press Brake* to perform sheetmetal bending. This technique introduces *Hertzian Contact Stresses* that can affect *Forming Stresses* and *Deformations*. A good analysis accounts for these.

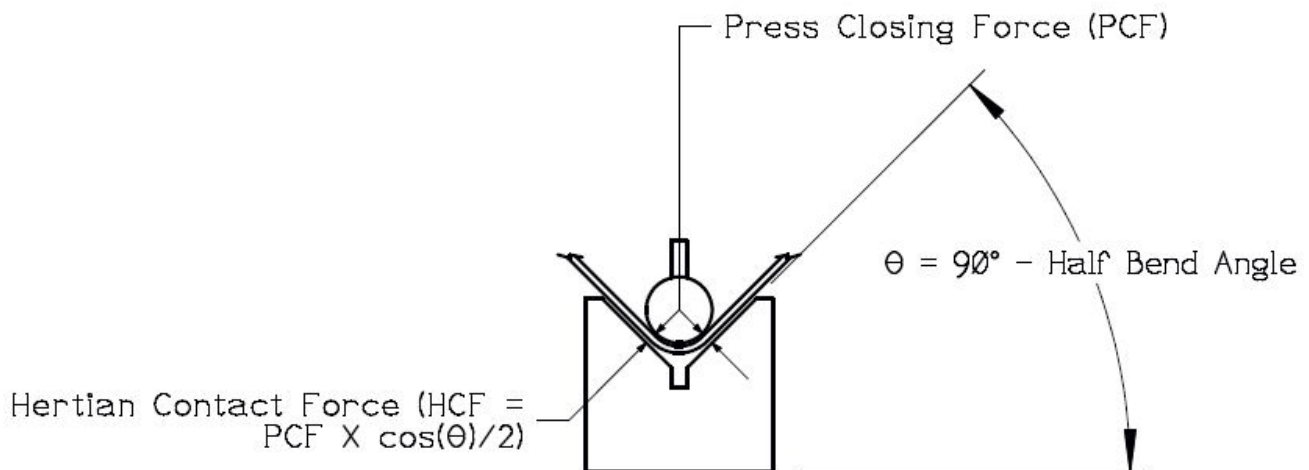


Figure 2: Press Brake Force Layout

Figure 2 above shows a generalized closing of a *Press Brake*. The *Ram* (shown here as a circle) applies **Force** along the *Length of the Bend*. This **Force** is applied to **two** narrow areas of the sheet-

metal being formed. The **Width** of these areas is dependent on the relative *Hardness* of the *Ram*, the *Vee-Block* that actually controls the *Forming*, and the *sheetmetal* being formed itself.

Now in reality the *Contact Stress Area* is dependent upon: the *Hardness* of the components (Ram, Sheet to be Formed, and Die Block), the *Compressive Strength* of the components, the *Compressive Modulus* of the Components, and the *Poisson’s Ratio* of the components. Those data values feed into a set of differential equations that determine (accurately) the value of the *Hertzian Contact Stress*. There is, however, an **approximation** that is reasonably accurate! If the material being formed is (say) low carbon high formability steel, then it may be considered that the *Ram has a Contact Width that is equal to 3.125°*. If the material being formed is (say) low-heat treat aluminum, then it may be considered that the *Ram has a Contact Width that is equal to 4.25°*. If the material being formed is (say) high-heat treat aluminum, then it may be considered that the *Ram has a Contact Width that is equal to 3.5°*. If the material being formed is (say) low-hardness Copper, then it may be considered that the *Ram has a Contact Width that is equal to 5.0°*. Etc. The Table below gives values for this approximation.

Material:	ASTM A366 Steel:	AL 1100-H14	AL 6061--T4	Soft Copper
Angle:	3.125°	4.25°	3.5°	5.0°
Yield Strength:	33,400 psi	13,600 psi	21,000 psi	7,110 psi
Tangent Modulus:	25,480 psi	144,220 psi	64,250 psi	44,833 psi
Poisson’s Ratio:	.2800	.3300	.3300	.3220

Table 1: Contact Stress Angle Approximations

So, if I have a *Ram* with a radius of (say) .125 inches and am forming a piece of *ASTM A366* sheet steel that is (say) 18.00 inches long, then I have a (per side) *Contact Width* of $2 \times .125 \times \sin(3.125^\circ/2) = .0068$ inches – making my *Contact Area* be $.0068 \times 18 = .1227$ in². The *Compressive Yield Stress* for *ASTM A366* steel is 33,400 psi. I want to be **sure** that I have “yielded” the stock, so I will multiply this by 1.15 (to exceed the *Minimum Yield Stress* by 15% – so I will use $(33,400 \times 1.15) = 38,410$ psi for my value. $38,410 \text{ psi} / .1227 \text{ in}^2$ gives me a *Press Closing Force* of 313,032 lbs. Assuming I am making a 90° bend, then I need to set my **Press** to provide $(313,032 / \cos(45^\circ)) = 442,700$ lbs. Simple, right?

Now, mind you, this *Angular Area* approach is a **rough approximation** of the real solution and only gets you into the “about right” range of answer. Let us be very clear about this! The *Yield Strength* values in **Table 1** do come from *MIL-HDBK-5* and represent *minimum* values for reputable smelting companies. This *Contact Angle Stress Approximation* is a technique developed in the mid-19th century in what became the *State of Prussia* in modern Germany. It is “crude, rude, and unrefined” by today’s standards, but is **was** the “working technique” for more than a century! A lot of “industry” was created with this “approximation!”

Calculating *Bend Allowance*:

Let us first look at forming sheetmetal with a *fold-forming* tool (also known as a *Box & Pan Brake* – shown below in **Figure 3**) introduces **no Hertzian Contact Stress** (to speak of). Therefore the only *forming strain* that needs to be considered is the difference between the *Neutral Axis Length* (ρ -Length = $t / \ln((IMLR+t)/IMLR) \times QR$ – Equation 6 above) and the *Outside Mold Radius Length* ($OML = OMLR \times QR$ – Equation 5 above). If the OML is not greater than $1.002 \times \rho$ -Length then the *Fold* will **have** to be “extended” until it is at least $1.002 \times \rho$ -Length to prevent *Spring Back*. Thus a **reduction** in the ρ -Length of 2% is required to make the *Bend Allowance* come out correctly for *Parts* formed in this manner.



(Figure 3): Box & Pan Brake

Continuing on with the (*ASTM A366*) example started just after **Table 1**, I am applying a *deformation stress* of $(38,410 - 33,400 =) 5010$ psi. This *stress* when divided by the *Tangent Modulus* gives me the **Volume** (on a *per inch per inch basis*) being deformed. Thus, $5010 \text{ psi} / 25,480 \text{ psi} = .1966$ inch/inch of crushing. So, if my original sheet stock thickness was (say) 16 gauge (.0597 inches thick) then I **lose** $(.0597 \times .1966 =) .0111$ average inches of thickness over my nominal $(.0068 \times 18 =) .1227 \text{ in}^2$ of area for an average *compressed volume* of $(.0111 \times .1227 =) .0015 \text{ in}^3$ of volume. When applied to a “face” that is 90° from the applied **Force** that volume gets reduced to a value of “ $1 - 2 \times \text{Poisson's Ratio}$ ” or, in this case, $1 - 2 \times .2800 = .44$. This means that instead of a reduction in volume of $.0015 \text{ in}^3$ across the “*flat pattern allowance*” we only reduce the volume of the “*flat pattern allowance*” by $.44 \times .0015 \text{ in}^3 = .0007 \text{ in}^3$! [This is an application of *Poisson's Ratio* that is rarely taught.]

Our nominal *Bend Allowance* (from **Equation 3** above) was ρ -Length = $t / \ln((IMLR+t)/IMLR) \times QR = (.0597 / \ln((.125 + .0597)/.125)) \times \pi/2 = .2402$ inches. When multiplied by the *Length* and *Thickness* to be bent, we get $(.2402 \times 18 \times .0597 =) .2581 \text{ in}^3$ of *Formed Volume*. **That** gets reduced by the 0.0007 in^3 (calculated immediately above) and divided out (as $(.2581 - .0007) / (18 \times .0579)$

=) .2395 of *Bend Allowance*. Not so simple, but not that hard either. Please note that the “*ignore Hertzian Contract Stress Deformation*” value is .2402 inches and that the “*account for Hertzian Contract Stress Deformation*” value is .2395 inches. The **difference** is (.2402 - .2395 =) .0007 inches which is often within the “press aligning allowance” and may often be ignored – but **we** want to do better than that, right?