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Design of Roll Forming Mill

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Abstract *- Sheet metal forming is widely used by the industries in the current scenario. Bending, Spinning, Deep drawing, Stretch forming & Roll forming is the major sheet metal forming processes. In this, roll forming is a unique continuous forming process, where 2D sheet metal is formed into various profiles like Rooftops, Window frames, Storage columns, etc., by using series of mated rollers. This project focuses on design considerations of roll forming tools and process parameters for a roll forming line. This design consideration discusses certain issues in the design of the roll forming tool, which includes Unfold length calculation, Flower pattern design, and Roller design by using an analytical solution. The constant bend allowance (arc) method of flower patterning was used to find the dimensions for the 2D die design. This dimension includes web length, flange length, and radius at each bend for both upper and lower roller. The roller design includes the proper shaft selection, key & keyway selection. This design was done based on force calculation. Major forces are considered to find the torque and bending moment.*

Keywords *- Bending, Spinning, Deep drawing, stretch forming, Roll forming, Stretch forming, Hydroforming, Explosive forming, K – factor, Bend allowance and deduction, Unfold length, Bending moment, Rolling friction, Spring back force, Flower pattern.*

I. INTRODUCTION

In the current scenario, demand for sheet metal products is increasing day by day. Applications like the kitchen sink, storage columns, and sheet metal exhaust system, as shown in figure 1.1, are well-known sheet metal products. Sheet metal forming processes like bending, deep drawing, spinning, stretch forming, and roll forming are those in which force is applied to sheet metal to modify its geometry. The applied force stresses the metal beyond its yield strength, causing the material to plastically deform. Formability states the ability of sheet metal to be formed into the desired shape without cracking or fracture. By doing so, the sheet can be bent or formed into a variety of complex shapes.

Figure 1.1: (a) Kitchen sinks (b) Storage columns

(c) Exhaust systems

II. DIFFERENT SHEET METAL PROCESSES AND PRODUCTS

In the present scenario, demand for sheet metal products is more in almost every utility. For example, home furniture, automobile sectors, and industrial applications. Based on the processes and products required by the user, the sheet metal forming process is alienated from different types of processes.

Bending operation

Bending is typically performed on a machine called a press brake shown in figure 1.2, which can be manually or automatically operated. A press brake contains an upper tool called the punch and a lower tool called the die, between which the sheet metal is located.

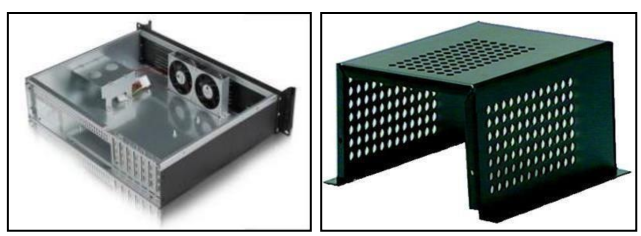


Figure 1.2: (a) CPU Cover and (b) Outer cover

The sheet is carefully positioned over the die and held in place by the back gauge while the punch lowers and forces the sheet to bend. CPU cover and cabinet bending products are shown in figure 1.2.

Spinning

Spinning, sometimes called spin forming, as shown in figure 1.3, is a metal forming process used to form cylindrical parts by rotating a piece of sheet metal while forces are applied to one side.

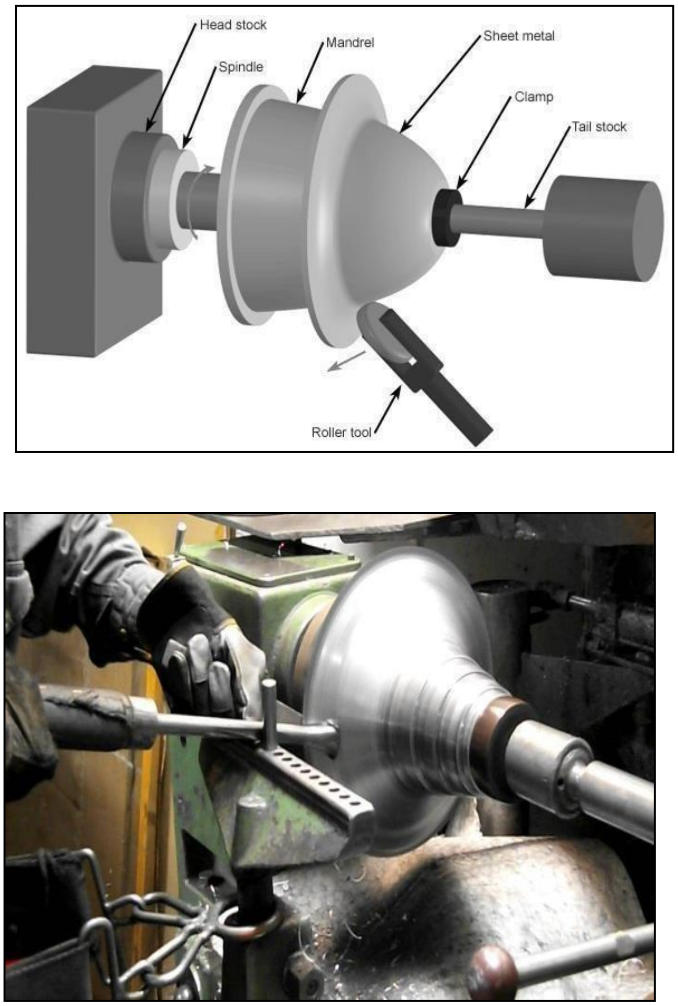


Figure 1.3: Spinning operation

A sheet metal disc is rotated at high speeds while rollers press the sheet against a tool, called a mandrel, to form the shape of the desired part. Spun metal parts have a rotationally symmetric, hollow shape, such as a cylinder, cone, or hemisphere. Examples include cookware and dish antenna, as shown in figure 1.3.

Deep drawing

Deep drawing is a metal forming process in which sheet metal is stretched into the desired part shape, as shown in figure 1.4. A tool pushes downward on the sheet metal, forcing it into a die cavity in the shape of the desired part. The tensile forces applied to the sheet cause it to plastically deform into a cup-shaped part.

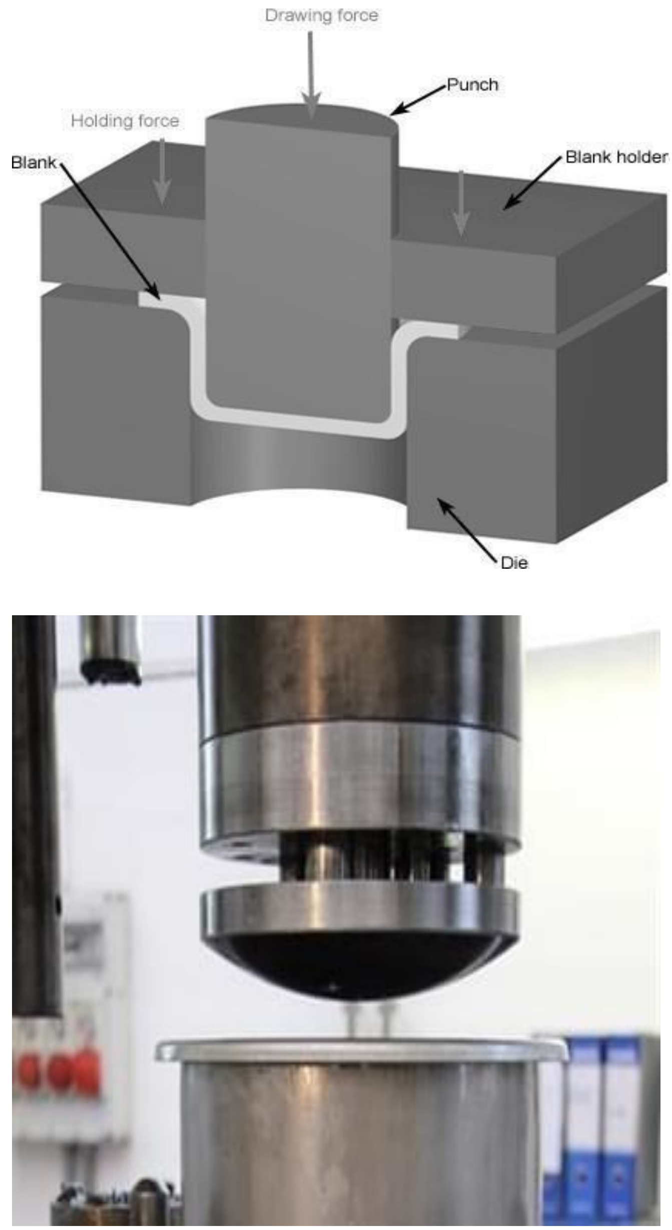


Figure 1.4 Deep drawing process

Deep-drawn parts are characterized by a depth equal to more than half of the diameter of the part. Examples of parts formed with deep drawing include automotive bodies, clutch plate outer cover, kitchen sinks, as shown in figure 1.5.

Figure 1.5: (a) Kitchen sink, (b) Outer cover for clutch plate

Stretch forming

Stretch forming, as shown in figure 1.6, is a metal forming process in which a piece of sheet metal is stretched and bent simultaneously over a die in order to form large contoured parts. Stretch forming is performed on a stretch press, in which a piece of sheet metal is securely gripped along its edges by gripping jaws. The gripping jaws are each attached to a carriage that is pulled by pneumatic or hydraulic force to stretch the sheet. The tooling used in this process is a stretch form block, called a form die, which is a solid contoured piece against which the sheet metal will be pressed.

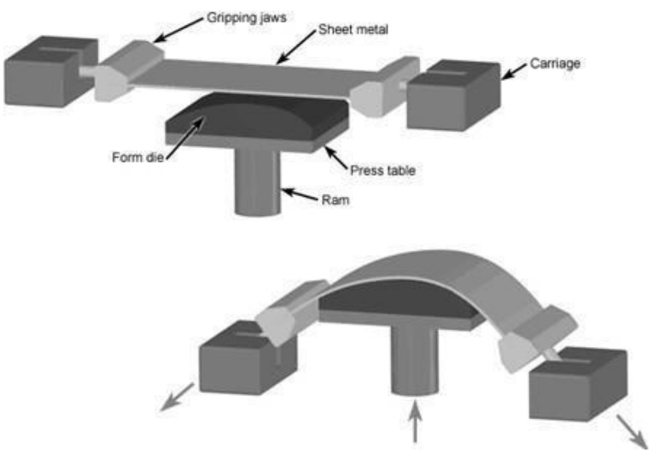


Figure 1.6: Stretch forming process

Stretch-formed parts are typically large and possess large radius bends. The shapes that can be produced vary from a simple curved surface to complex non-uniform cross-sections, as shown in figure 1.6. Stretch forming is capable of shaping parts with very high accuracy and smooth surfaces.

Figure 1.6: (a) Sheet metal arcs used in building and (b) automobile body

Hydroforming

Hydroforming is a specialized type of die forming as shown in figure 1.7 (a) that uses high-pressure hydraulic fluid to press room temperature working material into a die. Tohydro form aluminum into a vehicle's frame, as shown in figure 1.7 (b), aluminum is placed inside a negative mold that has the shape of the desired result. High-pressure hydraulic pumpsthen inject fluid at very high pressure inside the aluminum tube, which causes it to expand until it matches the mold. The hydro-formed aluminum is then removed from the mold.

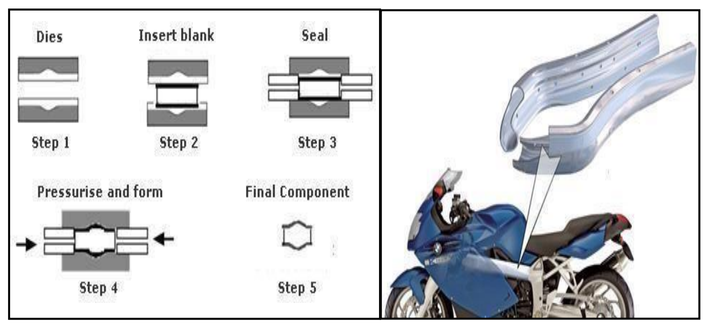
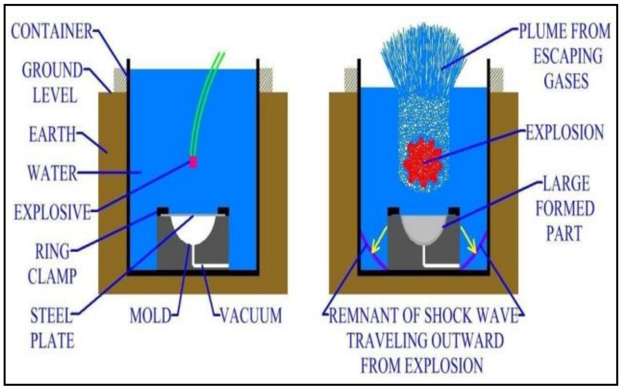


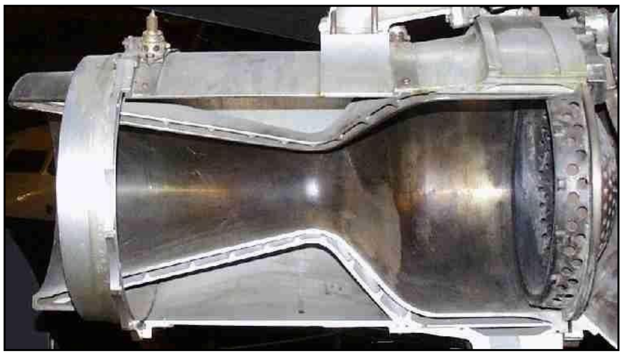
Figure 1.7: (a) Hydroforming process and (b) Side frame in two-wheeler

Explosive forming

Explosive forming, shown in figure 1.8 (a), is a metalworking technique in which an explosive charge is used instead of a punch or press. It can be used on materials for which a press setup would be prohibitively large or require unreasonably high pressure like a rocket nozzle chamber, as shown in figure 1.8 (b), and is generally much cheaper than building a large enough and sufficiently high-pressure press.



(a)



(b)

Figure 1.8 (a) Explosive forming method and (b) Rocket nozzle chamber

Compared to these sheet metal forming processes, Roll forming is distinctive in the way of the continuous forming process. In this study of work, this unique roll forming process is deliberated

Roll Forming Process

Roll forming products have numerous applications, for example, in buildings like rooftops, the automotive sector as well as in furniture and domestic appliances like storage

columns, as shown in figure 1.9. Compared to other metal forming processes, the benefit of this process is that secondary operations, such as punching, welding, clenching, etc., can be included, which makes it possible to produce profiles that are ready to use directly.

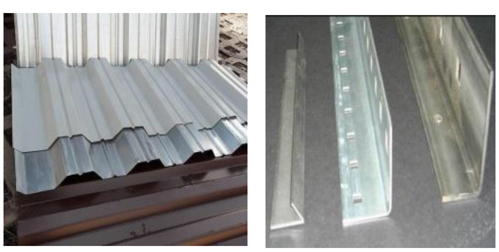


Fig 10: Roof material, Side rack

Explosive forming

Explosive forming, shown in figure 1.10 (a), is a metalworking technique in which an explosive charge is used instead of a punch or press. It can be used on materials for which a press setup would be prohibitively large or require unreasonably high pressure like a rocket nozzle chamber, as shown in figure 1.10 (b), and is generally much cheaper than building a large enough and sufficiently high-pressure press.

Figure 1.10: Hydraulic press, Drive system, and control unit

The roll forming process is a process by which sheet metal is passed through a number of pairs of mated profile rolls. Each roll pair is designed as sown in figure 1.13 to progressively develop a profile by predetermined angle increments. It has the ability to produce long continuous lengths and profiles of a bending process. This roll forming process is different from other metal forming processes like bending, stretch forming, and deep drawing with reference to its profile shape, length, and width of worksheet material. Figure 1.13 shows common roll-forming machine parts. This de-coiler is used to feed the sheet metal to the forming stations. The hydraulic press does the ironing process in the final produced part. Drive system ormotor connected through the machine with chain or belt drive. Top and bottom mated rollers are driven by gear drives.

Concept of Roll Forming Process

Roll-forming is a process, as shown in figure 1.11, in which the shape of a metal panel is developed by gradually bending the metal through a series of roll stands or passes. Each stage must generate the appropriate amount of deformation for which it was designed. The thickness of a sheet metal generally remains constant and equal to the flat strip being into themachine. To reduce the friction between rollers and sheet material, a sufficient roll gap is maintained throughout the process.

In this dissertation regarding roll forming, certain parameters were discussed in the design of the roll forming mill. Designing a forming tool for the roll forming process is a challenging and important task. i.e.

- Number of forming stages
- The geometry of the profile at each stage
- Bend angle progression
- Tool geometry
- The torque required to drive the system
- Roll gap
- Roller material
- Roller shape and size
- Shaft, key, and keyway selection

These are the challenging issues in the design of the roll forming tool. In this study of work, certain design parameters were evaluated with a 'C' type forming profile.

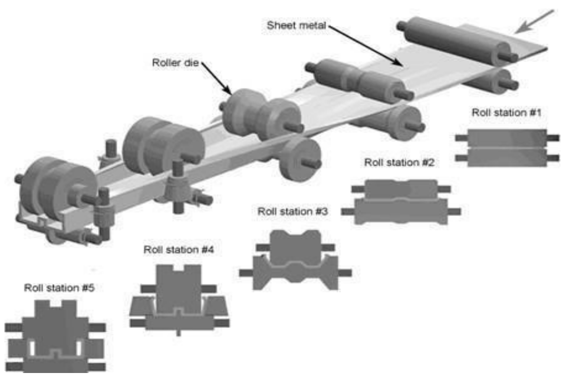


Figure 1.11: Typical roll forming stages

Unfold Length Calculation

To calculate the unfold length (UFL), or in other words, strip or coil width, the final cross-section is divided into straight and curved elements. The significance of this unfold length is to decide the required raw sheet material before bending. This inner side of the bent region falls under

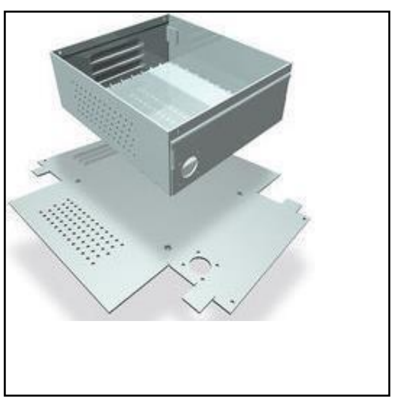


Figure 1.12: Unfolded view and Box type

tension, on the other hand, tension developed at the outer region. The length before and after bending will not be the same. To find the required length before the bending process, unfold length calculation is made.

Above figure 1.12 shows unfolded view for a box type final product. After the bending process, this product is made. Before bending progress done on this product, the requirement of the material should be known. The secondary operations should be done before bending the product. The length before and after bend will not be the same in all kinds of bending. This is due to bending at the particular section that plastically deforms the product and elongates the length in an arc and straight elements. This added length will be included in the raw sheet metal, which will be enough to make the product without any error in the dimension of the final product.

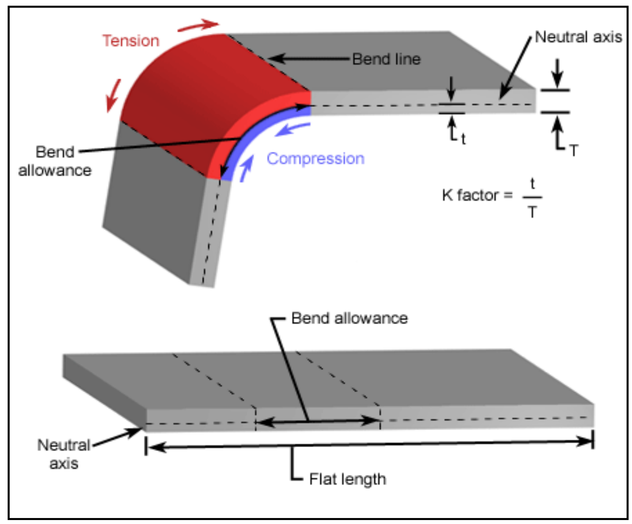


Figure 1.13: Unfolded view of 'L' Bend

Calculation of this unfold length consist of certain sheet metal bending design parameters. I.e., bend allowance, bend deduction, k-factor, the neutral axis of sheet metal. After knowing the final cross-section view of the profile, the above parameters were calculated based on the number of bends in the final section. A number of bends decide the total unfold length for any profile. Increasing the number of bends results in an increment of total unfolded length. This calculation of unfolding length is based on the elastic and plastic behavior of sheet metal.

Parameters To Be Considered In Unfold Length Calculation

As similar to sheet metal bending operation, the following parameters were considered in the calculation of unfolding length for sheet metal roll forming operation. This calculation process is the same for both roll forming and bending sheet metal processes.

Neutral axis

As shown in figure 4.2 at the cross-section of the bend, the neutral axis is the theoretical location at which the material is neither compressed nor stretched. Compression or tension will be zero at this plane or line. This depends on the material yield strength and thickness.

K- Factor

Defines the location of the neutral axis, i.e., where exactly there is no compression or tension occurred. It is measured as the distance from the inside of the material to the neutral axis (t) divided by the material thickness (T).

$$k = \frac{t}{T}$$

Bend Allowance (BA)

The bend allowance is the arc length of the bend as measured along the neutral axis of the material. As shown in figure 1.14, the length of the bending curve between the l1 and l2 flange is equal to the bend allowance.

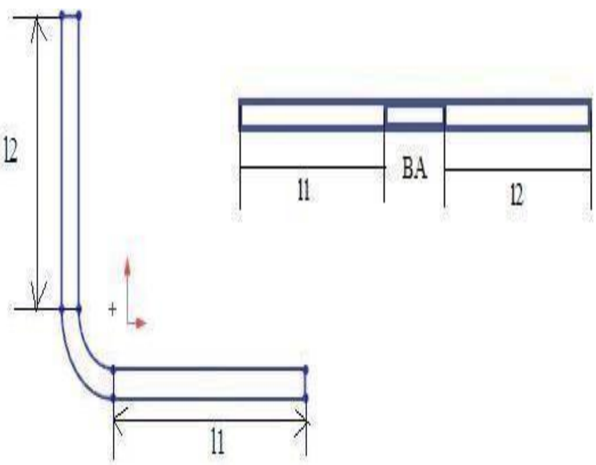


Figure 1.14: Bend allowance for 'L' bend

Bend Deduction (BD)

The Bend Deduction is defined as the material that has to remove from the total length of the flanges in order to arrive at the flat pattern. The flange lengths are always measured to the apex of the bend, as shown in figure 1.15.

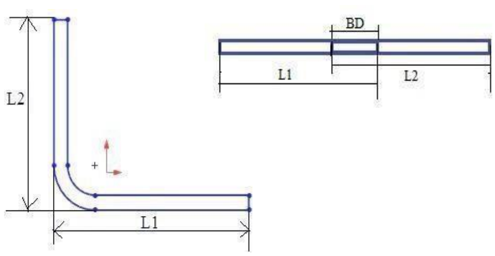


Figure 1.15: Bend deduction for 'L' bend

Relationship Between Bend Allowance And Deduction

From the above parameters, the total unfolded length is calculated. To calculate the bend allowance and bend deduction for any profile, the relationship between BA and BD must be derived. Considering the above 'L' bends, Unfold Length:

$\boldsymbol{L = l1 + l2 + BA}$ (Based on BA method) (1)

$\boldsymbol{L = L1 + L2 - BD}$ (Based on BD method) (2)

For the selected 'L' bend unfold length can be calculated by the above 2 methods. By equating this (1) and (2) equation,

$$\boldsymbol{L1 + L2 - BD = l1 + l2 + BA}$$

Based on the given input, flange length values L1 and L2 are known. The remaining values are takenas unknown, and this can be calculated by the triangle method, as shown in figure 1.14.

Single 'L' bend is taken to find the unknown values like *l1*, *l2*, *BA*, *and BD*. The following figure, 1.15, shows a method for calculating these unknown parameters.

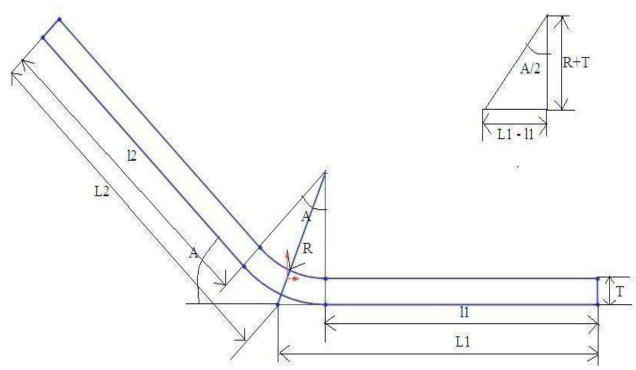


Figure 1.16: 'L' bend – BA and BD Calculation method

From the right angle triangle as shown in figure,

$$\tan\left(\frac{A}{2}\right) = \frac{L1 - l1}{R + T}$$

Modifying the above equation in terms of unknown parameter *l1*,

$$l1 = L1 - (R + T)\tan\left(\frac{A}{2}\right)$$

Similarly for *l2*, $l2 = L2 - (R + T)\tan\left(\frac{A}{2}\right)$

Substituting the above *l1and l2* in equation (3),

$$L1 + L2 - 2(R + T)\tan\left(\frac{A}{2}\right) + BA = L1 + L2 - BD$$

Equation is modified with known parameters L1 and L2.

Solving the above equation will give relationship between BD and BA.

$$\boldsymbol{BD = 2(R + T)\tan\left(\frac{A}{2}\right) - BA} \quad \ldots\ldots\ldots\ldots (4)$$

The above equation is used to find the BD for any given bend. This bend allowance is a function of bend angle (A), bend radius (R), thickness (T), and bend allowance (BA).

BD = f(A, R, T, BA)

Bend allowance is equal to the neutral arc length, which is a function of bend angle (A), bendradius (R), k-factor (k), and thickness (T).

BA = f(A, R, k, T)

$$BA = \frac{\pi}{180}(A) * (R + kT) \quad \ldots\ldots\ldots\ldots (5)$$

Unfold length is calculated for the selected 'C' profile as shown in figure 1.16 based on the BD method. The selected profile has 5 flanges (n) and equal bends in all 4 bends. These symmetrical 'C' profile flanges are taken as L1, L21, L22, L31, and L32

Unfold length for selected 'C' profile:

$$L = [(L1 + L21 + L22 + L31 + L32) - (n - 1) * BD]$$

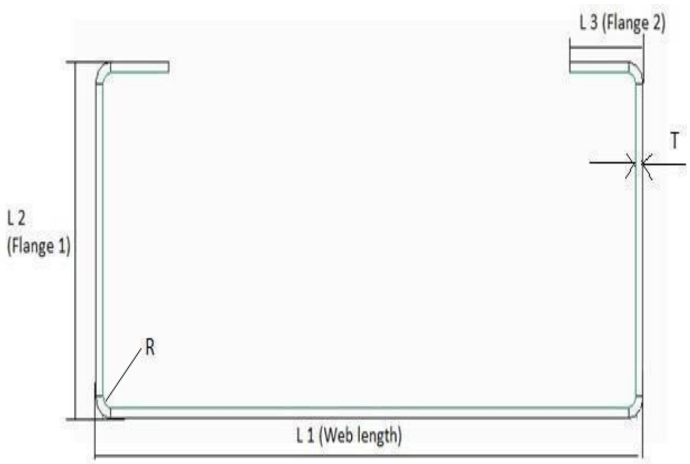


Figure 1.16: Symmetrical 'C' profile

Design of Flower Pattern

Flower Pattern

The basic design begins with a calculation of the bend angle in each stage and individual configurations. In order to visualize the progress from the flat sheet to the final shape, intermediate shapes were designed in the form of flower pattern diagrams. It is a step-by-step representation of bend angle at each stage, as shown in figure 5.1. Based on the angle progression in each stage, bend radius and arc length also vary. This flower pattern design is used to find the dimensions for the die design (Upper and Lower rollers). The replica of this flower design is deciding the die design.

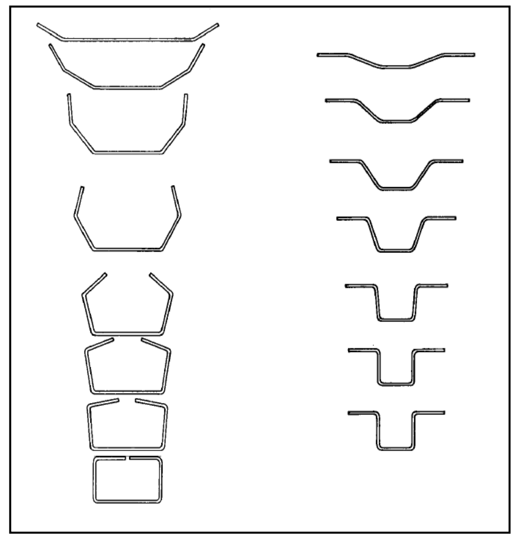


Figure 1.17: Sample flower design

Factors Affecting Bend Angle

The flower pattern design is mainly to represent the bend angle at each stage. To design a flower pattern for forming process, bend angle should be known. This bend angle depends on three parameters.

- Flange length – Flat bent length
- Material thickness – Sheet metal thickness
- Material Yield strength – Strength of the sheet metal

These parameters are the given inputs to design a flower pattern for any profile which affects the bend angle at each stage.

The following model, figure 1.18, shows the relationship between bend angle and the other three affecting input parameters.

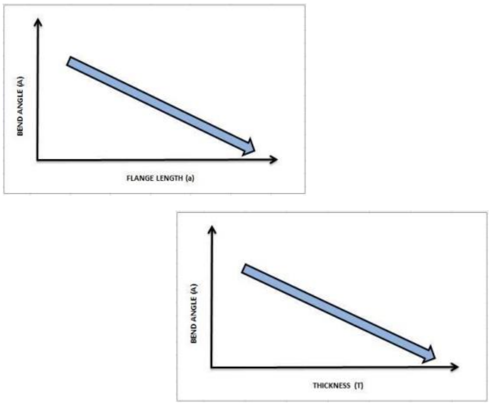


Figure 1.18: Bend angle vs. Flange length, Thickness, Yield strength

The above model graph shows that an increase in flange length, thickness, and yield strength of the material will reduce the bend angle. The combination of these three parameters decides the angle. Bend angle and these parameters are also connected with longitudinal strain produced during every forming station. A sudden increase in bend angle leads to crack growth or failure in the bent area.

Flower Pattern For 'C' Profile

For the selected 'C' type with an asymmetrical profile, the flower pattern is deliberated. The final required profile is shown in figure 1.19.

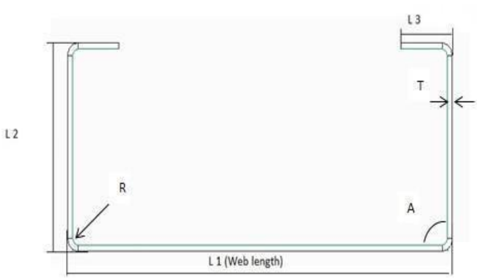


Figure 1.19: Final required product profile

This final required profile, as shown in figure 1.19, is bent in following flower pattern designing. This bend progression shows only bend angle at each stage.

Based on bend angle deciding parameters

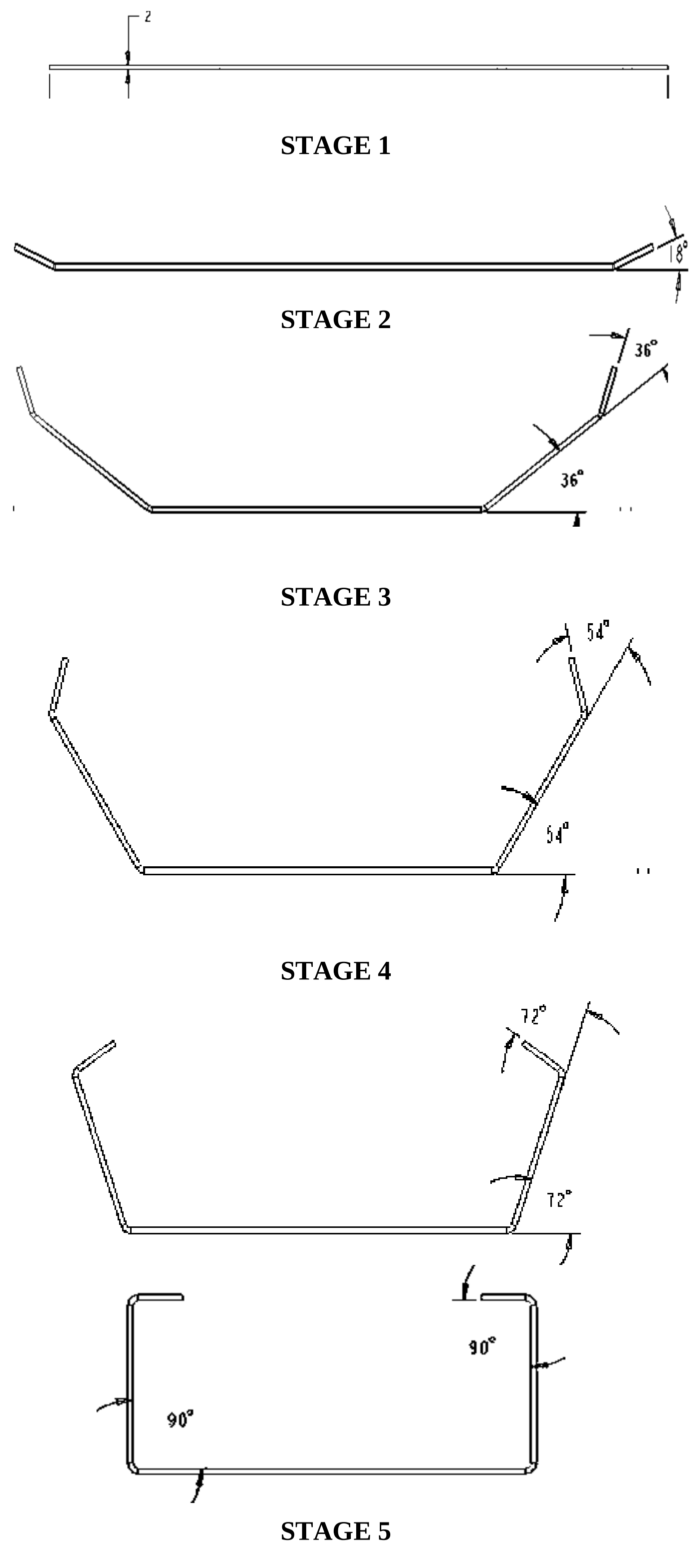


Figure 1.20: Flower pattern design

As shown in figure 5.4, the flower pattern is designed for the selected symmetrical 'C' profile with the incremental method. In this method of designing, a number of stages come around

The first pass was used to guide the sheet metal from the de-coiler to forming station. In this method, a constant 18˚ bend angle increment is given in each stage. In the initial forming stage, sudden change in cross-section profile leads to longitudinal strain and wrinkling effect in sheet metal. So that the profile was made with 18˚ increment and stage 2 separated from stage 3. This 18˚ angle increment taken from the range (15˚ - 25˚) is decided from the literature *S.M. Panton, J.L. Duncan, and S.D. Zhu.* Based on the experimental test, the authors decide the bend angle with deciding parameters flange length, thickness, and yield strength.

Design of Rollers

Roller design starts with machine elements like a shaft, key, and keyway design associated with the rollers, as shown in figure 1.21. The dimensions for the roller profile are obtained from the flower pattern design. Based on the profile at each stage, a die is designed.
This design of the roller includes various parameters that decide the overall roller profile anddesign. i.e.

- The geometry of the roller
- Shaft design for roller
- Key and Key-way design
- Roller diameter selection
- Positioning of roller

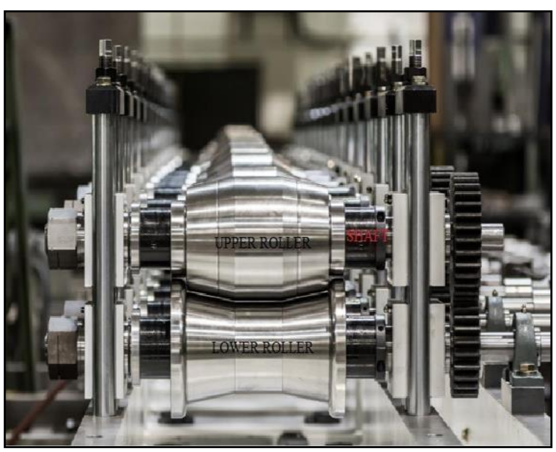


Figure 1.21: Die profile in roll forming machine

The geometry of the Roller

In this design, profile geometry at each stage of the roller is decided based on the flower pattern design explained in the chapter. Figure 1.22 shows the various dimensions included in the geometry design of rollers.

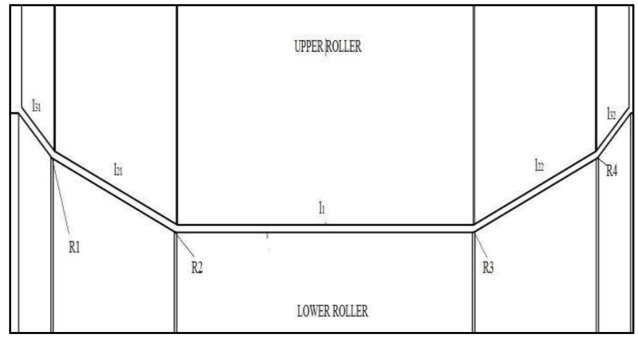


Figure 1.22: Geometry of the roller profile

In this geometry of roller profile from flower design, web length (l1), Flange lengths (l21, l22, l31, l32), and Radius at each bend (R1, R2, R3, R4) are deliberated. The dimensions were obtainedfor both upper and lower rollers.

There are two methods available to decide the radius of the die at each stage, as shown in figure 1.23. Any one of these methods used in design a flower in each bend angle progress.

- Constant bend allowance (arc) method
- Constant radius method

In the constant bend allowance or arc method, the calculated bend allowance for the final profile is kept constant throughout all stages of forming. Bend radius is varied in each stage to make the bend allowance constant. In figure 6.3 circle shows that in the constant bend allowance method, the arc length is the same throughout the final profile. Only the radius is reducing at eachstage.

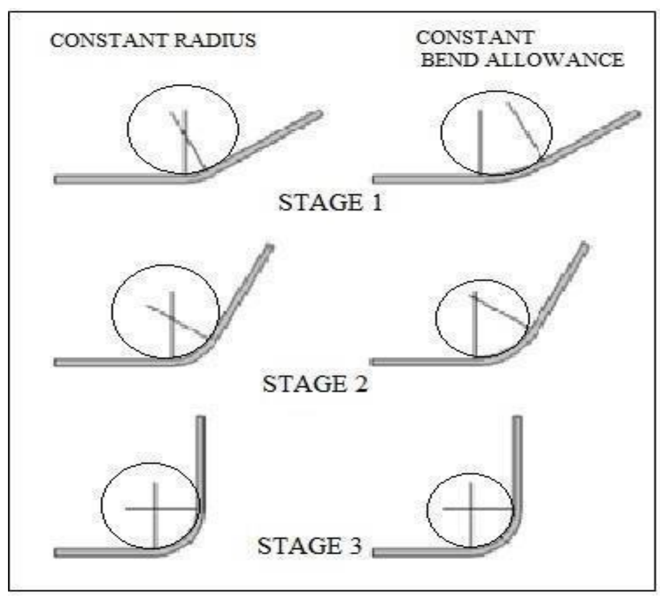


Figure 1.23: Radius and bend allowance in die design

Similarly, in the constant radius method, the final bend radius is kept constant throughout the flower design, and the bend allowance or arc changes in each stage. In this design of flower patterning, the constant bend allowance method is taken, which is most commonly used by designers

Design of Shaft

The roller design starts with the design of the shaft. In the roll forming process, the shaft is a mechanical element that transmits the power from the motor to forming tool. This power is used to give the required torque to overcome the various forces. To finalize the roller design, the diameter of the roller must be known. Before finding the roller diameter, the designer should design the shaft diameter at first, which decides the roller diameter. Forces acting on a shaft should be calculated, which is further converted to torque. Based on the required torque, a diameter of the shaft is decided. This force calculation includes the following major forcesacting in a forming tool.

Shaft Design – Flow chart

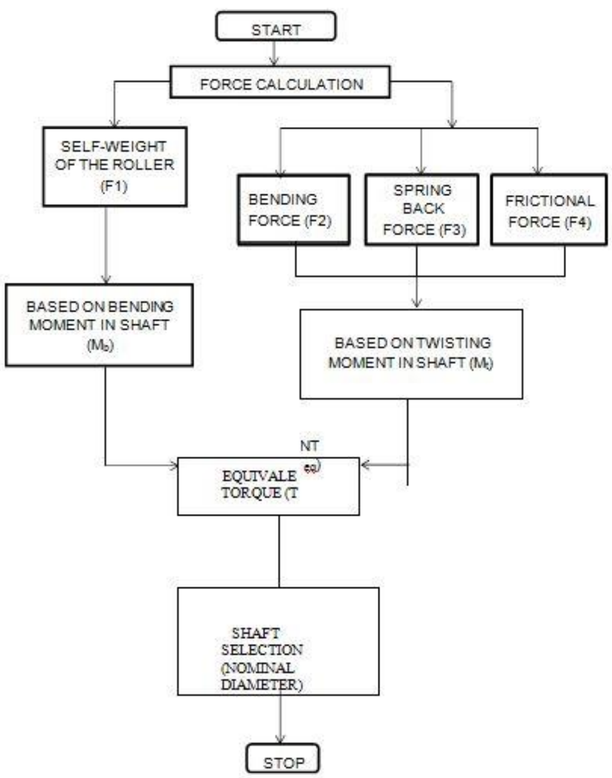


Figure 1.24 Flowchart for shaft design

- Self-weight of the roller (Bending moment)
- Bending force applied to form the sheet metal (Twisting moment)
- Spring back force by work material (Twisting moment)
- Frictional force or Rolling friction (Twisting moment)

Force due to self-weight of the roller

To design a shaft and key, the design must be include the various forces induced in the shaft by external means. In this category of forces, First major force is *"Self-weight of the Roller"*. This force can be calculated by following metho d as shown in figure 1.25.

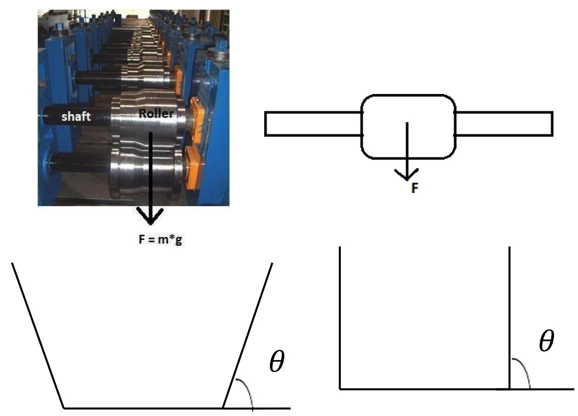


Fig.1.25 Self-weight of the roller

The self-weight of the roller acting on a shaft produce a force. This force can be measured by knowing the roller material density (EN8 = 7850 Kg/m^3).

Mass (F1) = Density * Volume **Volume (v) = $\pi R^2 l$**

$$F1 = \rho * v$$

Where R is the radius of the roller; l is the length of the roller; to find the volume of the roller minimum shaft diameter of 50 mm is assumed from standard nominal shaft diameter from PSG data book.

Bending force to form the sheet metal

The force required to bend the sheet metal in the individual stage of forming is bending force which is shown in figure 1.26. Based on *Christian Mueller* [7] literature, the bending force formula is found to calculate the force in roll forming. This force is a major in torque calculation. This force depends on the yield stress of the material, the thickness of the sheet, the bending angle of the pass, the total forming angle before the pass, and the flange height.

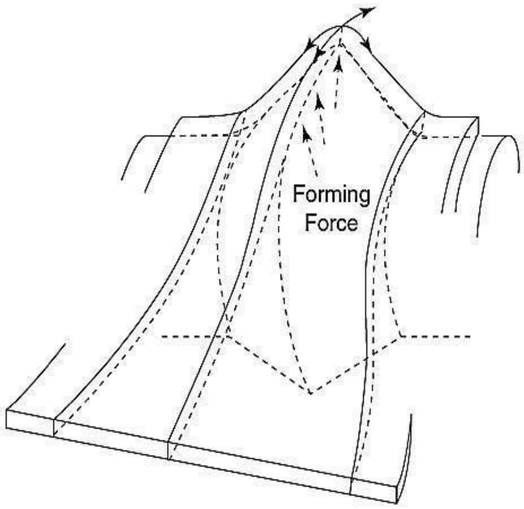


Figure 1.26: Forming or bending force

$$F2 = y\left(\theta p + \frac{3\theta c}{2}\right)\sqrt{\frac{2aT^3\theta p}{3\sin^2(\theta c + \theta p)}}$$

Yield strength of roller material (y)
The thickness of the sheet (T)
Bending angle of the pass (θp)
Total forming angle before the pass (θc)
Flange height (a)

Spring back force by work material

Due to elastic stress stored in the sheet metal, the material tends to obtain its original state. This reaction force in a sheet metal produces a spring back, as shown in figure 1.27. This force depends on the yield strength of sheet metal. More yield strength produces more spring-back force. This can be calculated by using the bending force formula (F2) by changing the yield strength (Sheet metal) and angle of spring back (Based on sheet material – E.g., Aluminum sheet spring back 1.5˚ to 2.5˚).

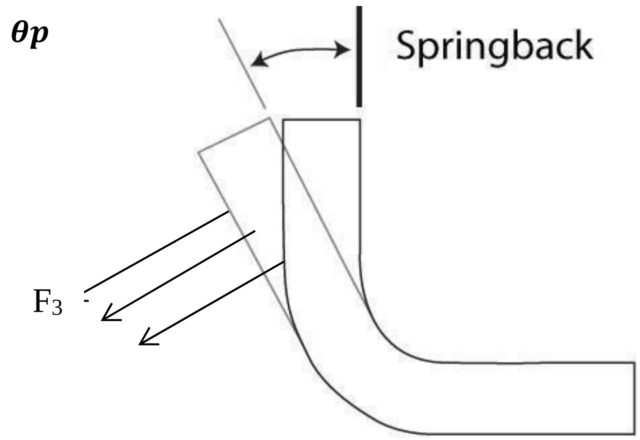


Figure 1.27: Spring back force

$$F3 = Ys\left(\theta p + \frac{3\theta c}{2}\right)\sqrt{\frac{2aT^3\theta p}{3\sin^2(\theta c + \theta p)}}$$

Yield strength of sheet material (Ys)
The thickness of the sheet (T)
Initial angle before spring back (θp)
Final angle after spring back (θc)Flange height (a)

Frictional Force or rolling friction

The final major force that influences the overall torque in the shaft selection is the frictional force. Friction between roller and sheet material produces a frictional force against a roller direction. Both top and bottom rollers affect the friction force, as shown in figure 1.28. This friction comes under the steel-to-steel rolling friction ($\mu = 0.05$). This can be calculated by using normal friction formula,

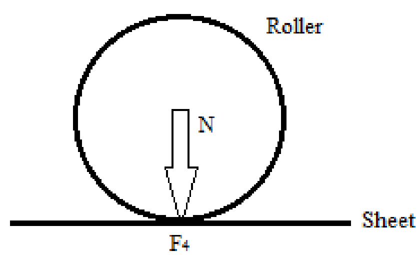


Figure 1.28: Rolling friction

$$F4 = \mu N$$

$$F4 = \mu F1$$

(Where, μ – Co-efficient of friction (0.05); N – Normal force equal to F1). After the calculation of these major forces, it converted to bending moment and twisting moment.

Shaft Diameter Calculation

$$M_b = F_1 * (L/2)$$
$$M_t = (F2+F3+F4)*(d/2)$$

$$Teq = \sqrt{Mb^2 + 2Mt^2}$$

$$d = \sqrt[3]{32\, Teq\, kt/\pi(\tau)}$$

Figure 1.29 Formulae to find shaft diameter

After calculating the major force in the forming tool, the torque required to rotate the shaft is found by using analytical calculation. The preferred shaft is found from the PSG design data book from pages 7.22 to 7.25. The flowchart fig.1.29 shows the steps in shaft selection.

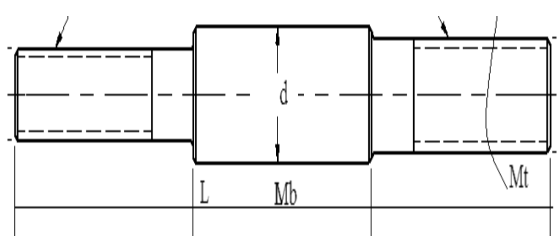
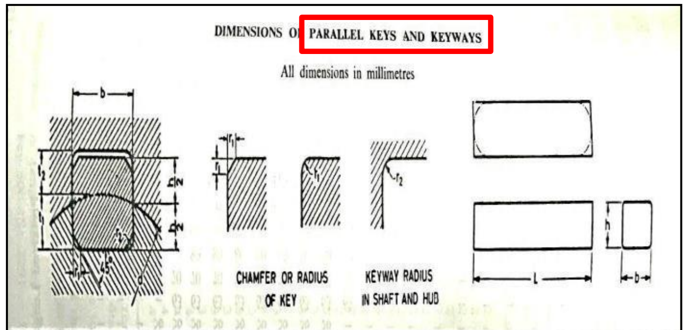


Figure 1.20 Shaft design

Where,
Teq – Equivalent torque (n/m) Mb – Bending moment (N-m)
Mt – Turning moment (N-m)d- Shaft diameter (m)
Kt – Stress factor
L – Length of the shaft τ- Shearing stress(N/m^2)

Key And Key Way Selection

Key is a machine element used to connect a rotating machine element to a shaft. In roll forming, it connects the shaft with a roller. During the forming operation, more torque is required to rotate the roller. This high torque induces a shear force between shaft and key. So the key must withstand high torque. The width and height of the key & keyway are selected based on the shaft diameter by using PSG data book pg. 5.16, as shown in figure 1.21.



DIMENSIONS OF PARALLEL KEYS AND KEYWAYS

All dimensions in millimetres

CHAMFER OR RADIUS OF KEY

KEYWAY RADIUS IN SHAFT AND HUB

For shaft diameters	Above	6	8	10	12	17	22	30	38	44	50	58	65	75	85	95	110	130	150	170	200	230	260	290	330	380	440
	Up to	8	10	12	17	22	30	38	44	50	58	65	75	85	95	110	130	150	170	200	230	260	290	330	380	440	500
Key cross section	Width b	2	3	4	5	6	8	10	12	14	16	18	20	22	25	28	32	36	40	45	50	56	63	70	80	90	100
	Height h	2	3	4	5	6	7	8	8	9	10	11	12	14	14	16	18	20	22	25	28	32	32	36	40	45	50
Keyway depth (nominal)	in Shaft t_1	1.2	1.8	2.5	3	3.5	4	5	5	5.5	6	7	7.5	8.5	9	10	11	12	13	15	17	19	20	22	25	28	31
	in hub t_2	1	1.4	1.8	2.3	2.8	3.3	3.3	3.3	3.8	4.3	4.4	4.9	5.9	5.4	6.4	7.4	8.4	9.4	10.4	11.4	13.4	12.4	14.4	15.4	17.4	19.5
Tolerance on keyway depth	t_1	+0.1						+0.2												+0.3							
	t_2			+0.1										+0.2									+0.3				
Chamfer or radius of key r_1	Max	0.25			0.35			0.55					0.80					1.30				2.00			2.95		
	Min	0.16			0.25			0.40					0.60					1.00				1.60			2.50		
Keyway radius	r_2 Max	0.16			0.25			0.40					0.60					1.00				1.60			2.50		
Length of key L	Min	6	6	8	10	14	18	22	28	36	45	50	56	63	70	80	90	100	110	125	140	160	180	200	220	250	280
	Max	20	36	45	56	70	90	110	140	160	180	200	220	250	280	320	360	400	400	400	400	400	400	400	400	400	400

Figure 1.21 Parallel key data from PSG design data book

Design of Roller Diameter

The roller is designed by using the dimensions obtained from the flower pattern design. The diameter of the roller is designed by using the height of the cross-sectional profile. To find the minimum diameter (Dmin), 3 parameters should be considered. I.e., Shaft diameter (d), Key size (k), and material thickness (T) [13].

$$D_{min} = d + 2(k + m)$$

m – Minimum Roll wall thickness (Selected b1sed on material thickness) as shown in figure 6.12. Maximum Roller diameter is obtained by adding the Final profile section depth (h) to it.

$$D_{max} = d + 2(k + m) + h$$

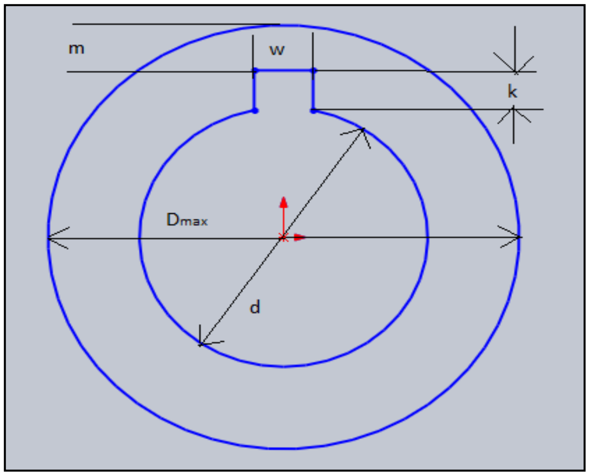


Figure 1.22 Dimensions of roller

Material wall thickness (m)	
Material thickness(T)	m
Up to 1.9 mm	7.5 – 10 mm
1.91 – 3 mm	12 – 15 mm
3.1 – 12.7 mm	20 – 40 mm

Table 1.0: Material wall thickness (m)

Results And Discussions

Unfold Length For 'C' Profile

As per the methodology explained in chapter 4 for unfold length calculation is used to find the required solution for the profile given by the user. Given 'C' profile is shown in figure 1.23, which has 4 bends with a symmetrical profile. Other required input values are mentioned in table 1.1.

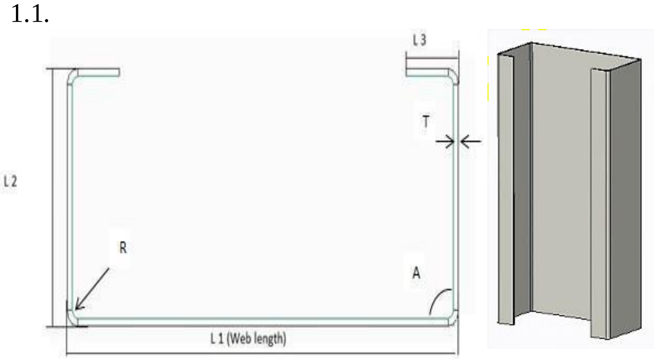


Figure 7.1: 'C' Profile given by user

Material wall thickness (m)
Material thickness (T) m
Up to 1.9 mm 7.5 – 10 mm
1.91 – 3 12 – 15 mm
mm
3.1 – 12.7 mm 20 – 40 mm

BEND ANGLE (A1)	90
BEND ANGLE (A2)	90
BEND ANGLE (A3)	90
BEND ANGLE (A4)	90
FINAL BEND RADIUS(R)	2
K-FACTOR (k)	0.41
THICKNESS (T)	2
CONSTANT 1 (Pi)	3.14
CONSTANT 2	180

L1	**L2**	**L3**	**L4**	**L5**
150	**165**	**165**	**120**	**120**
n (No. of Flanges)	**5**			

Table 1.1: Input data for 'C' profile

For any given input, regardless of its profile shape, as stated above, the corresponding output will be produced based on the given formula. BA & BD for each bend were calculated. Change in bend angle, radius and thickness will produce a corresponding output.

Unfold length (L) = f (BA, BD, R, T, A, k, L1….Ln)

BEND ALLOWANCE (BA1)	**4.4274**	**BEND DEDUCTION (BD1)**	**3.566231921**
BEND ALLOWANCE (BA2)	**4.4274**	**BEND DEDUCTION (BD2)**	**3.566231921**
BEND ALLOWANCE (BA3)	**4.4274**	**BEND DEDUCTION (BD2)**	**3.566231921**
BEND ALLOWANCE (BA4)	**4.4274**	**BEND DEDUCTION (BD3)**	**3.566231921**

Table 1.2 Calculated bend allowance and bend deduction for each bend

UNFOLD LENGTH (L) =305.7350723

Flower Pattern Bend Progression

As explained in chapter 5, flower pattern designed forgiven 'C' profile in two methods. Based on this pattern design, the sheet metal is processed through the forming stations. The following table 1.3 shows bend progression of flower patterning

BEND ANGLE								
STAGE NO'S	**BEND 1**	**Inc.**	**BEND 2**	**Inc.**	**BEND 3**	**Inc.**	**BEND 4**	**Inc.**
STAGE 1	0	0	0	0	0	0	0	0
STAGE 2	18	18	0	0	0	0	18	18
STAGE 3	18	0	18	18	18	18	18	0
STAGE 4	36	18	36	18	36	18	36	18
STAGE 5	54	18	54	18	54	18	54	18
STAGE 6	72	18	72	18	72	18	72	18
STAGE 7	90	18	90	18	90	18	90	18
STAGE 8	90	18	90	18	90	18	90	18

Geometry For Roller At Each Stage

Roller die dimensions for both tops and bottom rollers are found based on the methodology explained in chapter 6. The following figure 7.2 shows common 2D profile dimensions for both methods explained in flower pattern design. The data shown in Tables 7.5 and 7.6 are calculated based on the constant bend allowance method.

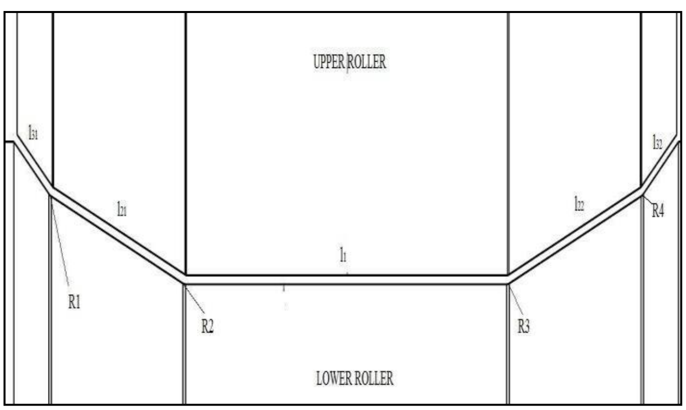


Figure 1.23: 2D common geometry die profile

Dimensions of bend progression

The following results (as shown in table 7.5 and 7.6) for both upper and lower roller design had obtained of bend progression. Common formulae for flange length and radius at each stage are shown below.

$$l = L - (R + T)\tan\left(\frac{A}{2}\right)$$

$$R = \frac{BA * 180}{\pi * A} - kT$$

Upper roller:

STAGE NO'S	*R1*	*R2*	*R3*	*R4*	*l1*	*l21*	*l22*	*l31*	*l32*
STAGE 1	UFL	UFL	UFL	UFL	UFL	UFL	UFL	UFL	UFL
STAGE 2	13.28	UFL	UFL	13.28	UFL	UFL	UFL	17.5811	17.58113305
STAGE 3	13.28	13.28	13.28	13.28	145.16227	60.1623	60.1623	17.5811	17.58113305
STAGE 4	6.23	6.23	6.23	6.23	144.65472	59.6547	59.6547	17.3274	17.32735996
STAGE 5	3.88	3.88	3.88	3.88	144.01152	59.0115	59.0115	17.0058	17.00575955
STAGE 6	2.705	2.705	2.705	2.705	143.16781	58.1678	58.1678	16.5839	16.58390667
STAGE 7	2	2	2	2	142.00637	57.0064	57.0064	16.0032	16.00318404
STAGE 8	2	2	2	2	142.00637	57.0064	57.0064	16.0032	16.00318404

Table 1.4: Dimensions for upper roller (Method 1) (*Dimensions are in mm)*

Lower roller :

STAGE NO'S	*R1*	*R2*	*R3*	*R4*	*l1*	*l21*	*l22*	*l31*	*l32*
STAGE 1	UFL	UFL	UFL	UFL	UFL	UFL	UFL	UFL	UFL
STAGE 2	15.28	UFL	UFL	15.28	UFL	UFL	UFL	17.2645	17.26452743
STAGE 3	15.28	15.28	15.28	15.28	144.52905	59.5291	59.5291	17.2645	17.26452743
STAGE 4	8.23	8.23	8.23	8.23	143.35575	58.3557	58.3557	16.6779	16.67787271
STAGE 5	5.88	5.88	5.88	5.88	141.97462	56.9746	56.9746	15.9873	15.98731042
STAGE 6	4.705	4.705	4.705	4.705	140.26359	55.2636	55.2636	15.1318	15.13179473
STAGE 7	4	4	4	4	138.00955	53.0096	53.0096	14.0048	14.00477606
STAGE 8	4	4	4	4	138.00955	53.0096	53.0096	14.0048	14.00477606

Table 1.5: Dimensions for lower roller *(Dimensions are in mm)*

Where,

l_1, l_{21}, l_{22}, l_{31}, l_{32} – Web and flange length (in between bends)R1, R2, R3, R4 – Radius at each bend
UFL – Unfold length

Selection of Tool Material

Based on the study on tool material for forming tool applications, *Carbon steel* is selected as a tool material for roll forming applications. This carbon steel available in 3 types.
I.e., lower carbon steel (% C < 30%), medium carbon steel (% of C 30 to 45 %), and higher carbon steel (% of carbon above 50 %). Considering the mechanical considerations of forming application, higher carbon steel is preferred. By incorporating the cost factor in tool material, medium carbon steel (EN8 or C45) with proper heat treatment process as

HEAT TREATMENT PROCESS PARAMETERS

PROCESS: HARDENING MATERIAL: EN8 (C45) DIM: (L 100 X φ20) mm

TEMPERATURE: 850˚c

HEAT TREAT TIME: 30min

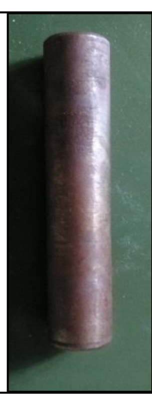
COOLING MEDIUM: QUENCHING OIL WITH CHEMICAL BATH 39

COOLING TIME: 45 min (30˚c)

shown in figure 7.4 is preferred for the tool material.

Quenching medium

Pit Furnace



Heat treated sample

Figure 1.23: Tool material processing

Hardness test comparison

Rockwell hardness test is taken for selected sample (L 100 X φ20) mm before and after the heat treatment process. Hardness property decides the strength of any material that withstands a force. The following table 7.9 shows a hardness test comparison.

S. NO	MATERIAL	HARDNESS BEFORE HEAT TREATMENT (HRC)	HARDNESS AFTER HEATTREAT MENT(HRC)
1	Low carbon steel	20	35
2	Medium carbon steel	35	50
3	High carbon steel	55	-

Table 1.6 Hardness comparison

Incorporating the cost factor in material selection, Medium carbon steel (EN8) provides efficient material compare to high carbon steel. Hardness is improved in medium carbon steel that nearly equals high carbon steel by using a heat treatment hardening process. Hardening the high carbon steel increase the brittleness property in the material, which leads to failure in shafts.

KEY & KEY-WAY SELECTION

S.No	Parameters	Results
1	Key cross section width	25 mm
2	Height	14 mm
3	Key-way depth in shaft	9 ± 0.2 mm
4	Key-way depth in roller	5.4± 0.2 mm
5	Chamfer of key	(0.6-0.8) mm
6	Chamfer of key-way	0.6 mm

Table 1.7: Key and Key-way results

Parallel Key and Keyway are selected (withstand more shear stress and high torqueproduced). Table 1.7 shows selected parallel key parameters. **Designation:** A Parallel key of width 25 mm, Height 14 mm, and length 150 mm shall be designated as**: "Parallel key 25 x 14 x 150 IS: 2048 – 1962."**

Other Obtained Results

Other obtained results from calculations for the given profile illustrated in the following table 1.8. Based on the methodology explained in chapter 6, the force produced in the stage 1 roller is shown in the table below. Similarly, the calculation can be obtained for all other forming stages. Based on the obtained results, shaft diameter and roller diameter will differ.

Model calculation

Self-weight of the roller F_1 = 7850 * (3.14*0.0075*.310)
F_1 = 57.3 *9.81 = 562 N
Bending force F_2 = 55*18*((2*20*8*18)/0.286) ^ (1/2)
= 143.41 KN
Spring back force F_3,
= 15*1.5*((2*20*8*1.5)/0.00205)^(1/2)
= 10.87 KNFrictional force F_4 = 562*0.05
= 28.1 N

S. NO	PARAMETER NAME	RESULT
1	Self-weight of the roller (Stage 1)	562 N
2	Bending force to form a sheet metal (Stage 1)	143.41 KN
3	Spring back force	10.87 KN
4	Frictional force	28.1 N
6	Shaft diameter	85 mm
7	Roller diameter	140 mm
8	Tool material	EN 8 (HRC 50)

Table 1.8: Other obtained results

Moment calculation:

Bending moment M_b = (562)*(0.310/2) = 87.11 N-m

Twisting moment M_t = (143410+10870+28.1)*(0.050/2)
= 3857.7 N-m
Equal torque T_{eq} = ((87.11^2)+2*(3857^2)) ^ (1/2)
= 5455.31 N-m Shaft diameter d,
= (32*5455*2/3.14*525^7) ^ (1/3)
= 0.085 m = **85mm**

The following table 1.8 shows the consolidated results for shaft and roller dimensions

Prototype Model
Unfold Length & Flower Design For Prototype

In this prototype model, bend allowance and bend deduction at each bend are neglected due to the radius factor not considered in this unfold length and flower design. For the calculation of unfolding length, only flange and web length is added together, as shown in figure (a). For flower design, the number of stages is 3. 30˚ bend angle increment is given in each stage to obtain the final 90˚ profile as shown in the figure.1.24

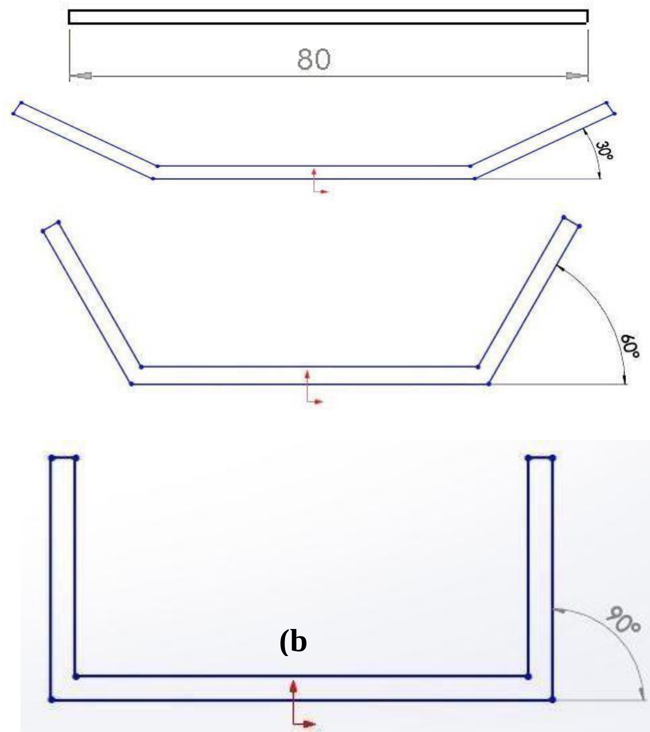


Figure 1.24: Unfold length and Flower pattern design

Material Requirement & Machining Process

Polypropylene (PP) material is selected as roller material for the prototype model. Polypropylene billet raw material is shown in figure 1.24. Based on the required diameter, raw

Material is bought from the material shop. Before the material collection, a detailed drawing is made for the prototype, and the approximate requirement of the material is determined. Detailed drawings are attached in the appendix for reference. For supporting material, SKF bearing (b) with proper size is used.
For the side frame and base material, ordinary wooden plate (c) is machined with a proper wood cutting machine.

Figure 1.25: (a) Poly-propylene (PP) material (b) Machined wooden plate and (c) SKF bearing

Prototype – Assembled View

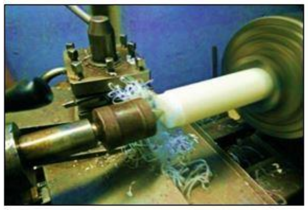


Figure 1.26: (a) Machining of poly-propylene (b) Machined components

Polypropylene is machined with an ordinary lathe, as shown in figure 1.25. During the machining process, and chip propagation should be taken care of. Chip from PP is continuous, which is rolled around the tool itself. This induces the tool to melt the chip on it. Proper guidance was given to chip flow over the tool.

Based on the design, polypropylene material is machined, and the assembled prototype is shown in figure 1.27. The inner diameter and outer diameter of the bearing are designed with a proper shaft for the material. During the machining process, the radius of 2mm machining is difficult to achieve. This can be rectified in precision machining.

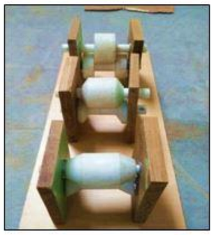


Figure 1.27: (a),(b)Assembled prototype model

Conclusions

As demand for the roll forming process increases in the current scenario, the claim for theroll forming mill also increases. Compared to other sheet metal forming processes, Roll forming is distinctive in the way of processing the sheet metal and continuous forming with a high production rate. Based on the requirement by the industry, evaluation of certain parameters in the design of roll forming mill was made on ‘C’ type symmetrical profile, which has 4 equal bends.

From the literature and basic principles, design consideration was started from the unfold length calculation for the given profile. This unfold length decides the required length of sheet metal. Based on the number of bends in a given profile, bend allowance and bend deduction were calculated that decides the total unfold length. After the calculations of bend allowance and unfold length, the flower pattern was designed for the given profile with reference to the literature. Constant bend allowance or arc method was followed to ease the dimensions for roller design.

A roller design including top and bottom rollers was made for the obtained flower pattern design and unfolds length calculation. Dimensions (web length, flange length, and radius at each bend) for both top and bottom rollers for all stages were done. Shaft, key, and keyway selection for the roller design were made with the help of force and torque calculation.Only major forces were considered for the design of the shaft. Based on the study made on roll forming tool materials, EN8 (C45) medium carbon was selected, and a proper heat treatment process was done to improve the forming property. Finally, a prototype model was made with polypropylene material to visualize the geometry of the profile at each stage.

There is a scope for further improvement of this design consideration for the roll forming process. Roller dies design of 2D profile can be automated by integrating modeling software with excel with the help of script files and macros. Flower design can be optimized with artificial neural network techniques to know the bend progression in each stage.

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