Incremental Sheet Forming Process

------Lecture Notes

By

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Incremental Sheet Forming

Incremental forming is a new technique for deforming sheet metals by the application of step by step incremental feed to the deforming tool.

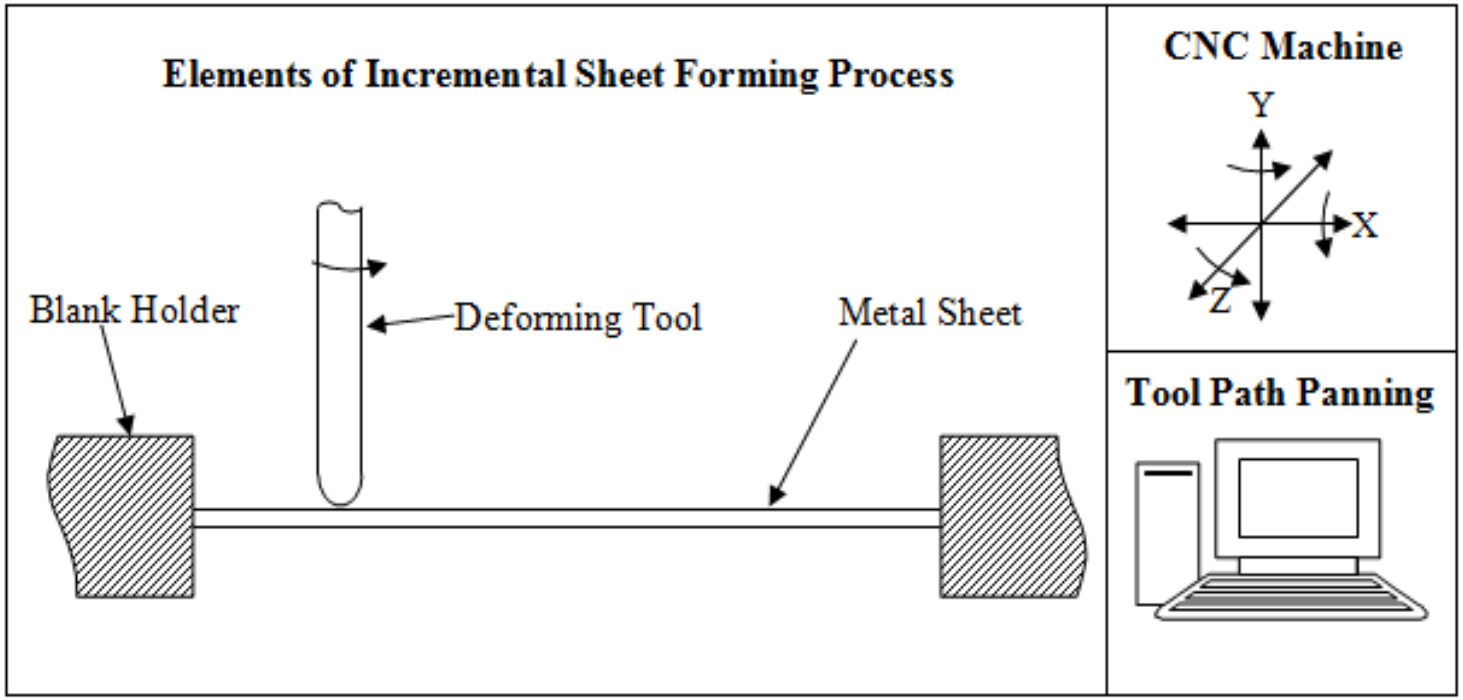


Figure : Incremental Sheet Forming.

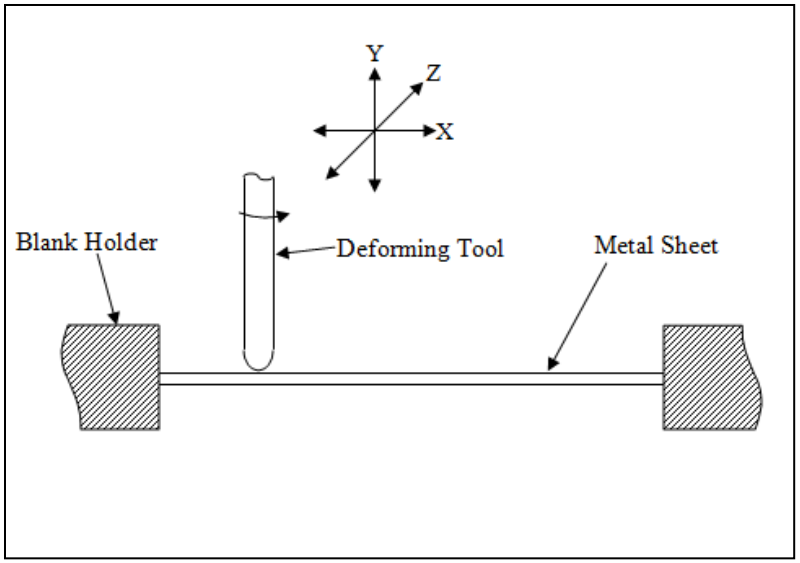
CLASSIFICATION OF ISF

1. Conventional Incremental Sheet Forming (CISF)

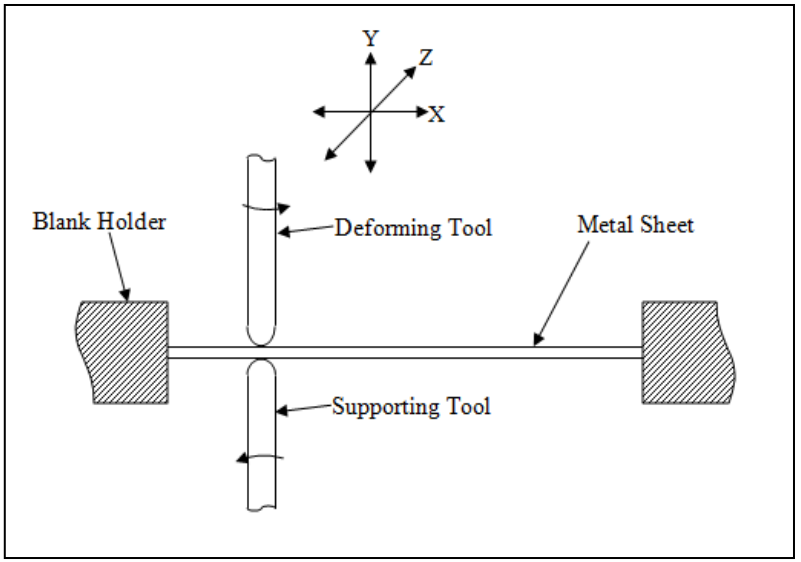
2. Hybrid Incremental Sheet Forming (HISF)

Continued…

Conventional Incremental Sheet Forming (CISF)



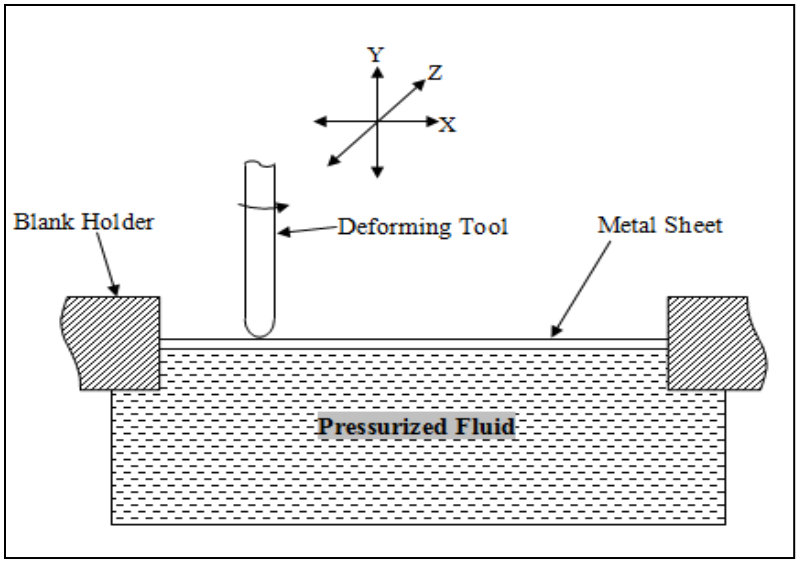
(a) Single Point Incremental Forming (SPIF)



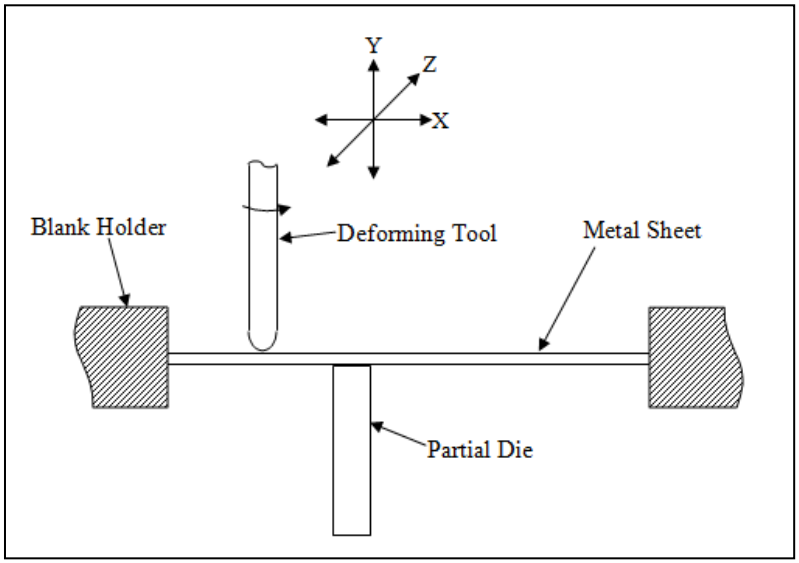
(b) Two Point Incremental Forming (TPIF).

Continued…

Hybrid Incremental Sheet Forming (HISF)



(a) Incremental Sheet Hydro-Forming (ISHF).



(b) Two Point Incremental Forming with Partial Die (TPIFPD)

Continued…

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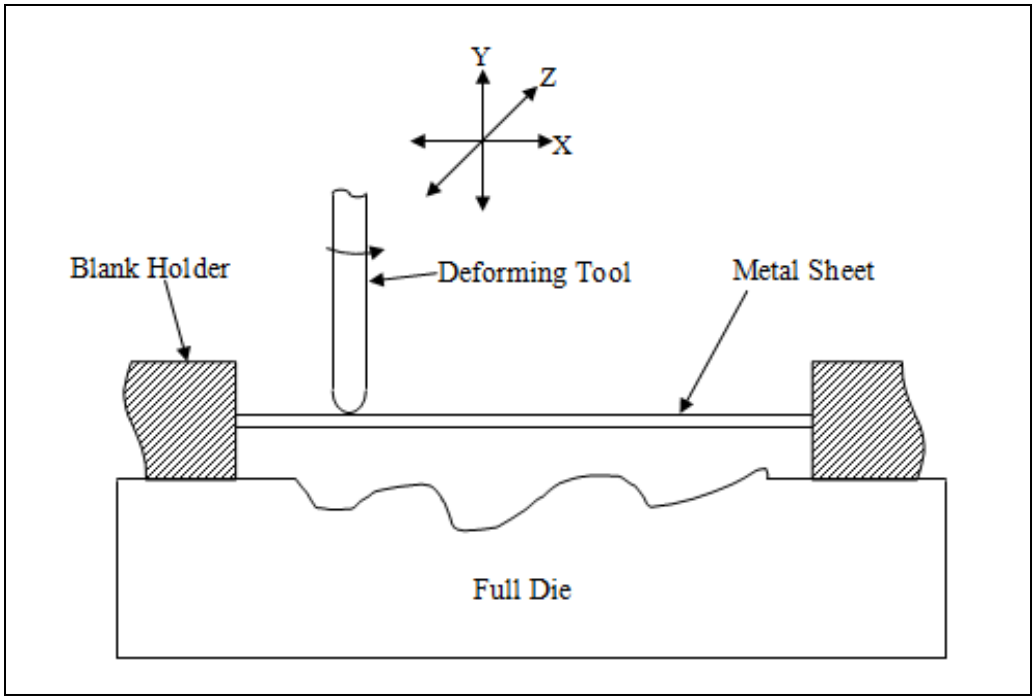


(c) Two Point Incremental Forming with Full Die (TPIFFD).

ADVANTAGES OF ISF

- Direct forming of usable parts from CAD data
  - Minimum specialized tooling
- Dieless - No positive or negative dies needed
- Flexibility - Changes in design sizes accommodated easily and quickly
- Formability better
  - Benefit of small plastic zones and incremental nature.
  - Easier to deform low formability sheet.
- Conventional CNC milling/lathe can be used.
- Making of large sized parts possible
  - Forces do not increase because contact zone/step size remain small.
- Operation quiet and noise free relatively.

DISADVANTAGES OF ISF

- The forming time much higher than competitive processes such as deep drawing.
- Limited to small size batch production.
- The forming of right angles cannot be done in one step, but requires a multi-step process.

APPLICATIONS OF ISF

- Aerospace Industry: Instrument panel, Body panel, Passenger seat cover etc.
- Automobile: Door inner/outer panel, Hood panel, Engine cover etc.
- High customized products: Denture plate, Ankle support, Metal helmet etc.
- Cellular Telephones
- IC Leadframes
- Electronics
- Healthcare
- Miniature Fasteners
- Hard Disc Drives

Basic Terminologies in ISF

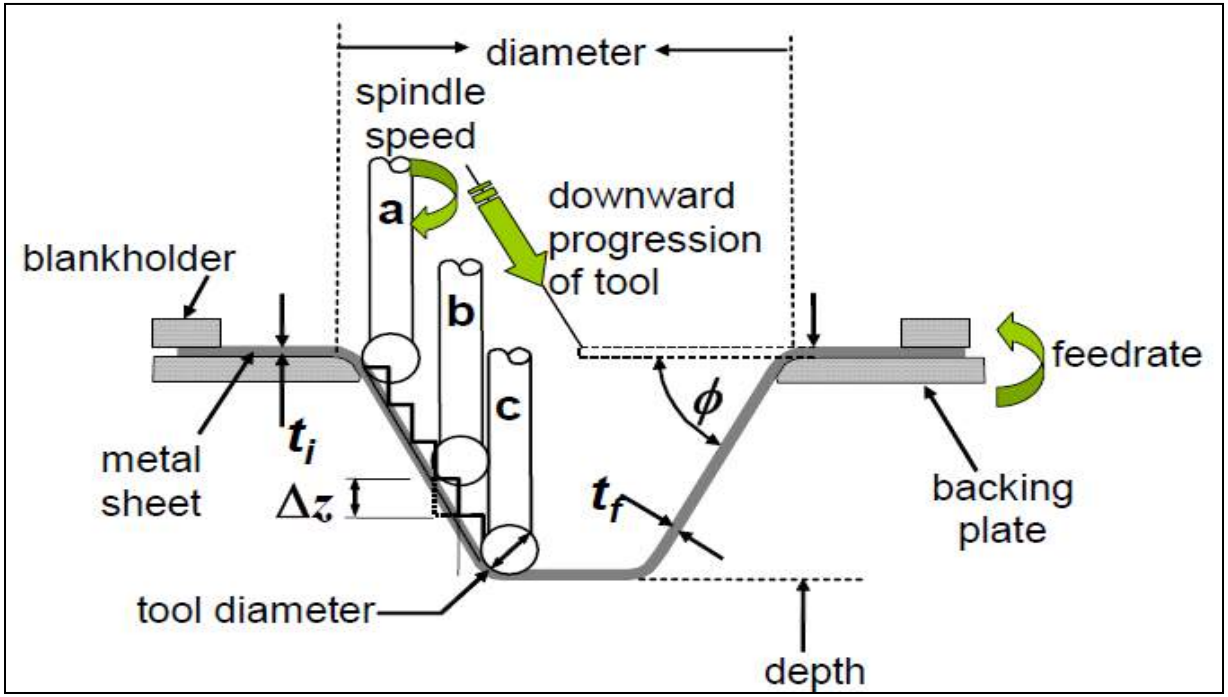
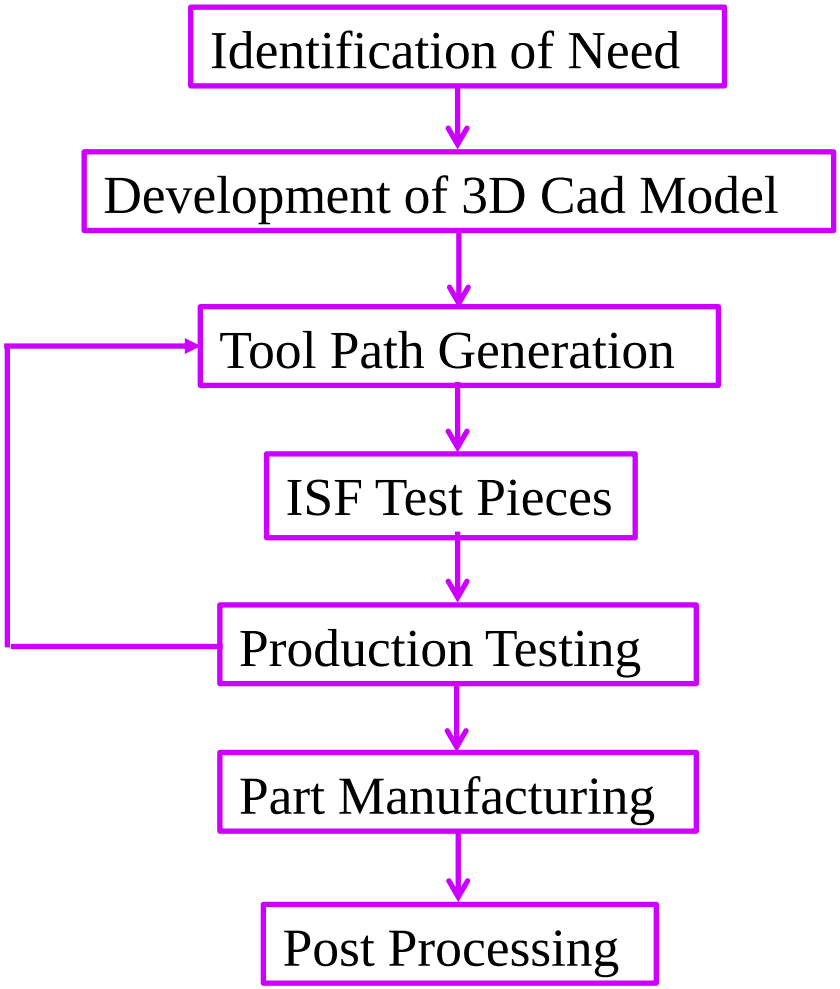


Figure : SPIF Terminology as seen in deformed part (Ham and Jeswiet, Forming Limit Curves in Single Point Incremental Forming 2007).

Sheet Thinning

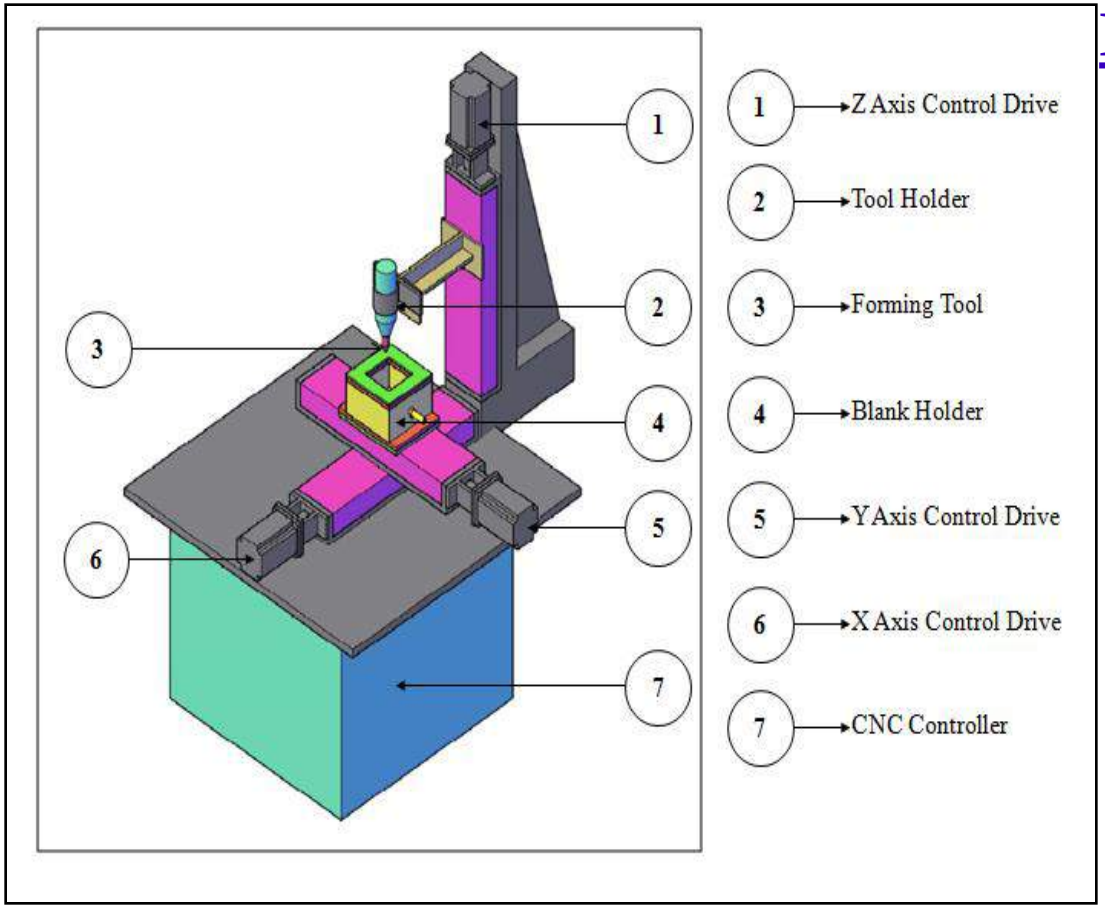
1. Thinning in ISF depends on the wall angle α and is given by the sine law $t_1 = t_0 \sin(90° - \alpha)$

Development of Single Point Incremental Forming Machine



FORMING METHODOLOGY

INCREMENTAL SHEET FORMING (ISF)



MAJOR COMPONENTS

(i) Sheet metal blank,

(ii) Blank holder,

(iii) Deforming tool,

(iv) CNC Machine.

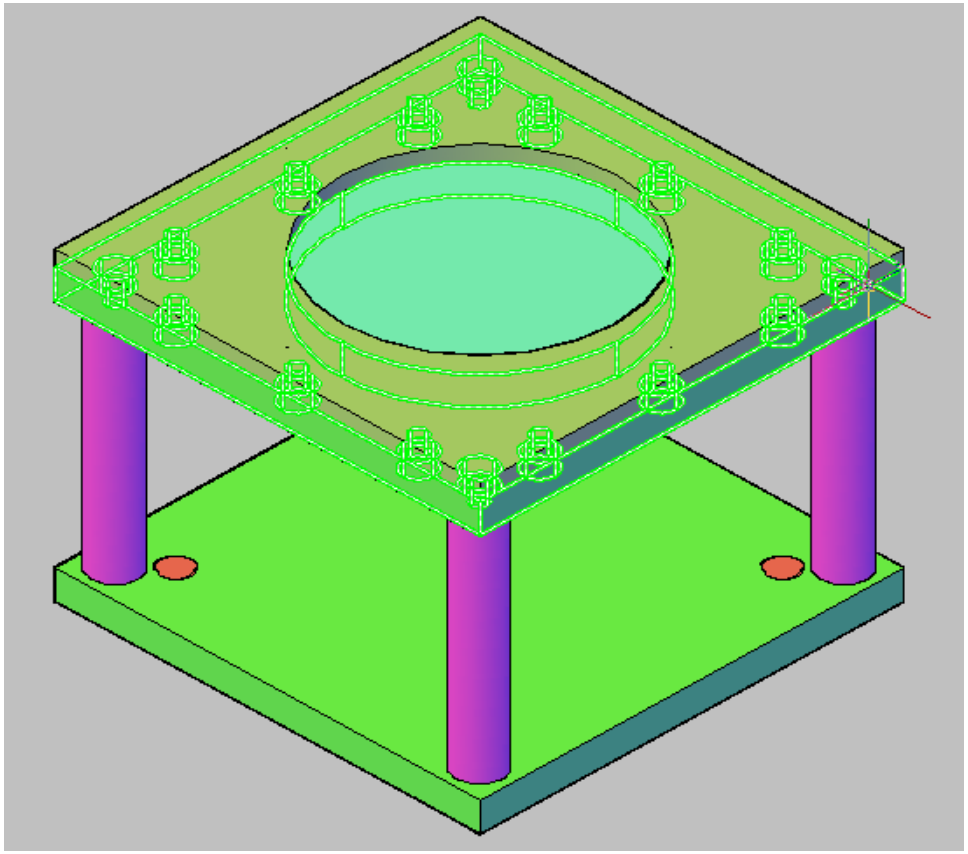


Figure : Blank and Blank holding Arrangement

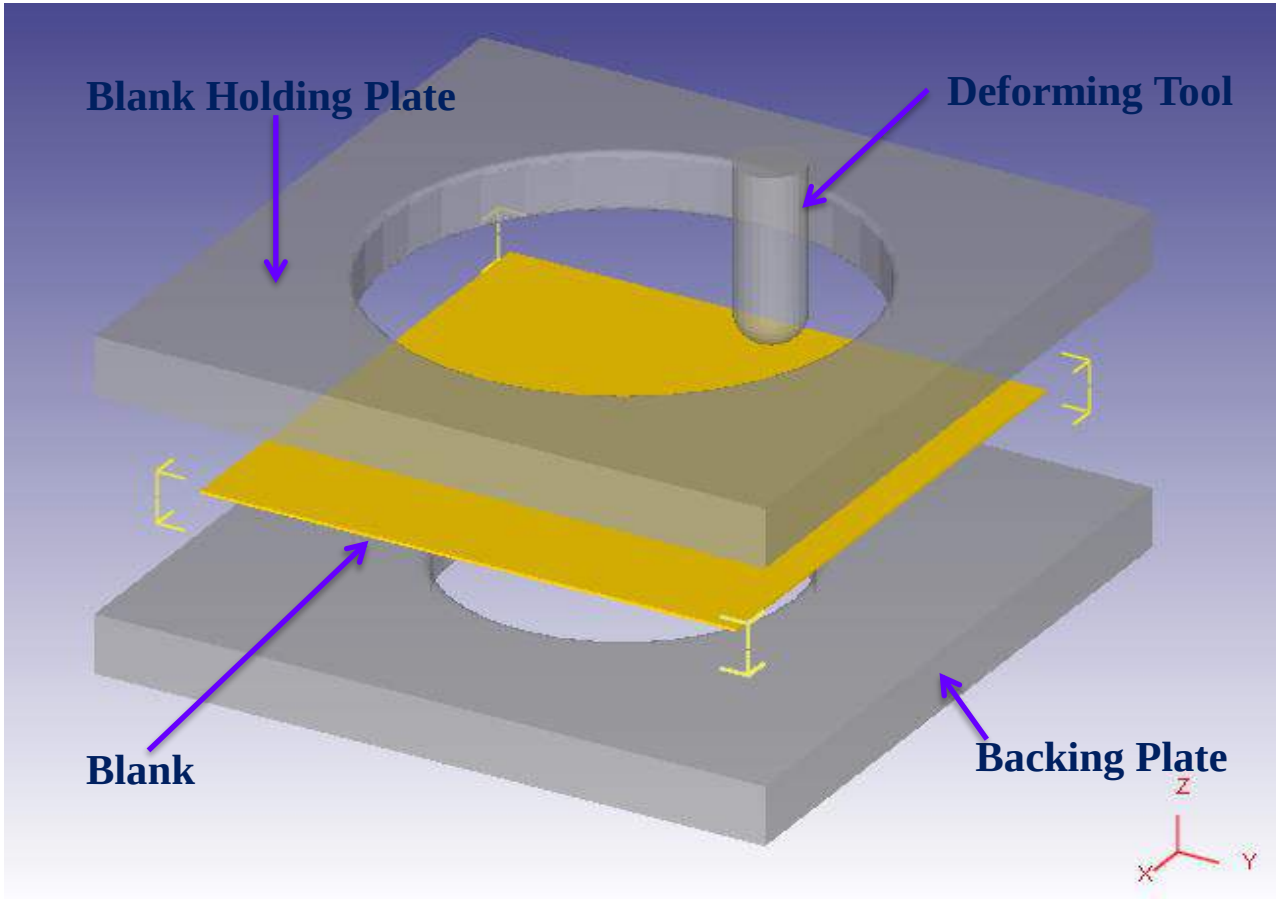


Figure: Exploded view of the Blank and Blank holding Arrangement.

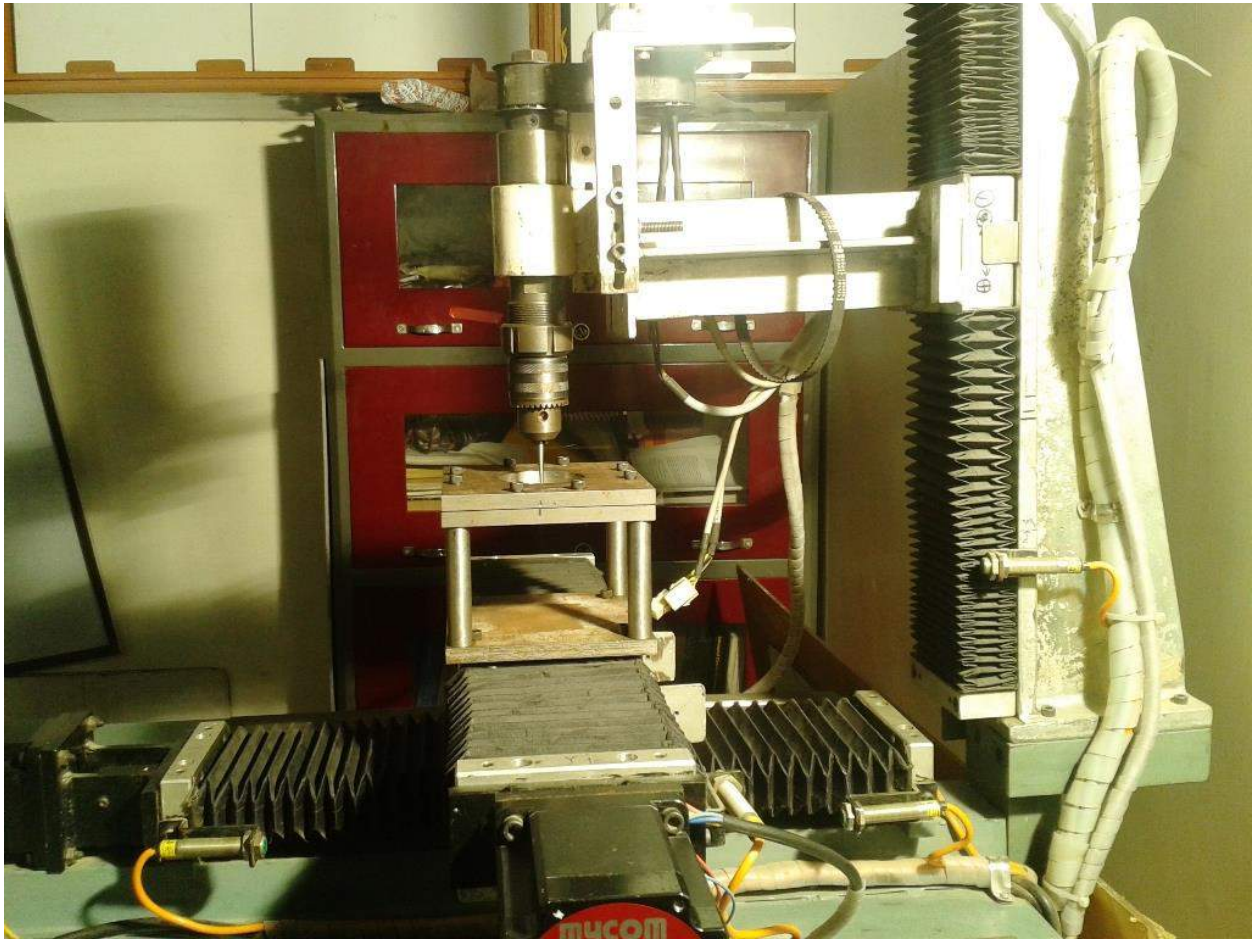


Figure: Single Point Incremental Forming Machine.

FORMING TOOLS

Titanium Blank Size = (80mm*80mm*0.4mm)

Other Blank Size = (80mm*80mm*0.2mm)

Circle Diameter & Pyramid edge= 40 mm, Angle = 45

Figure: Product formed by Dieless Forming Machine

[Top Row : All Aluminum [AL1080A] and Bottom Row from left to Right: 1st Brass, 2nd & 3rd Aluminium and 4th CP Titanium-1].

Development of Incremental Sheet Hydroforming Machine

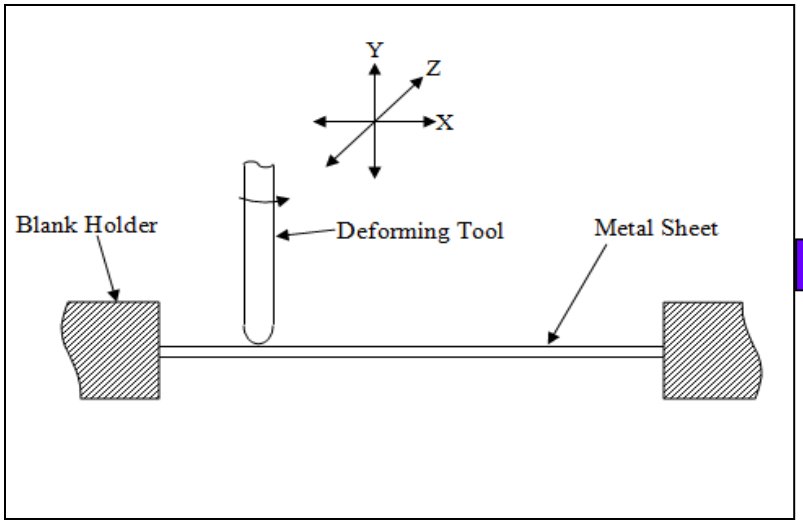


Fig : Incremental Sheet Forming

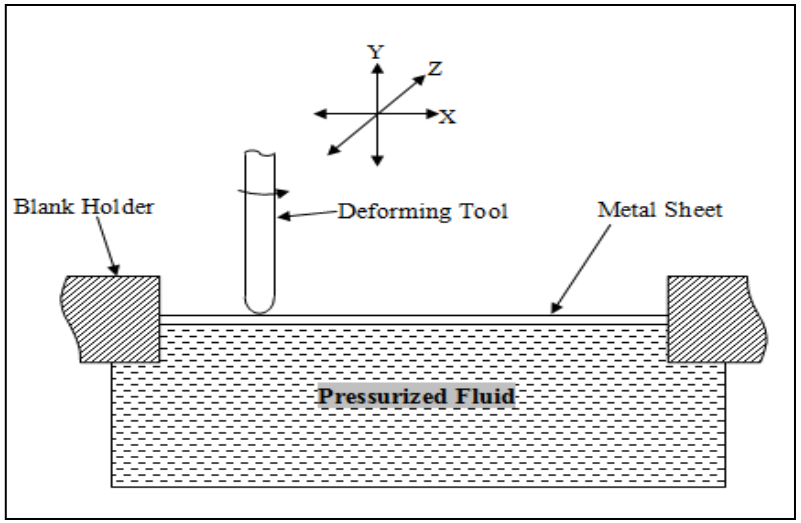
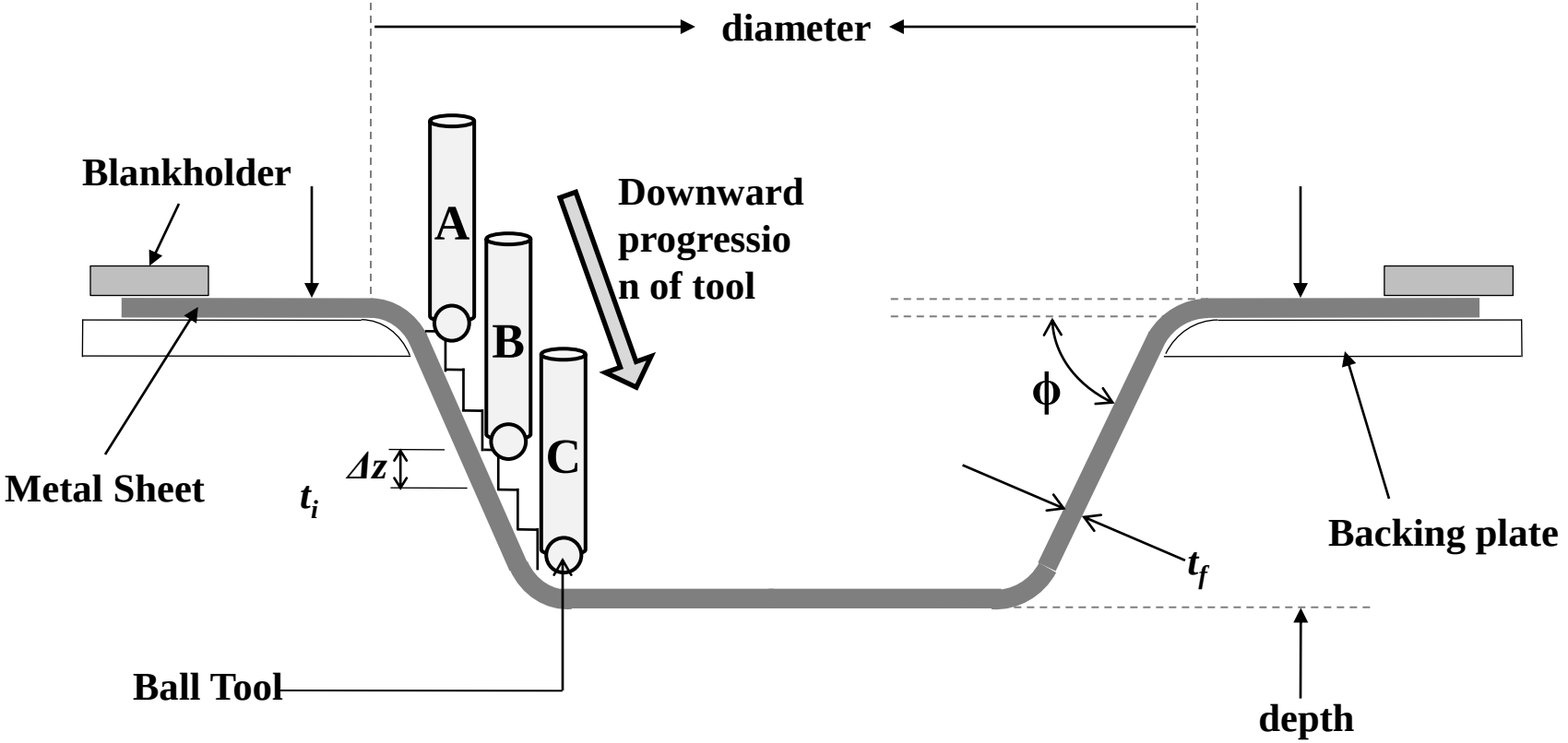


Fig : Incremental Sheet Hydro Forming

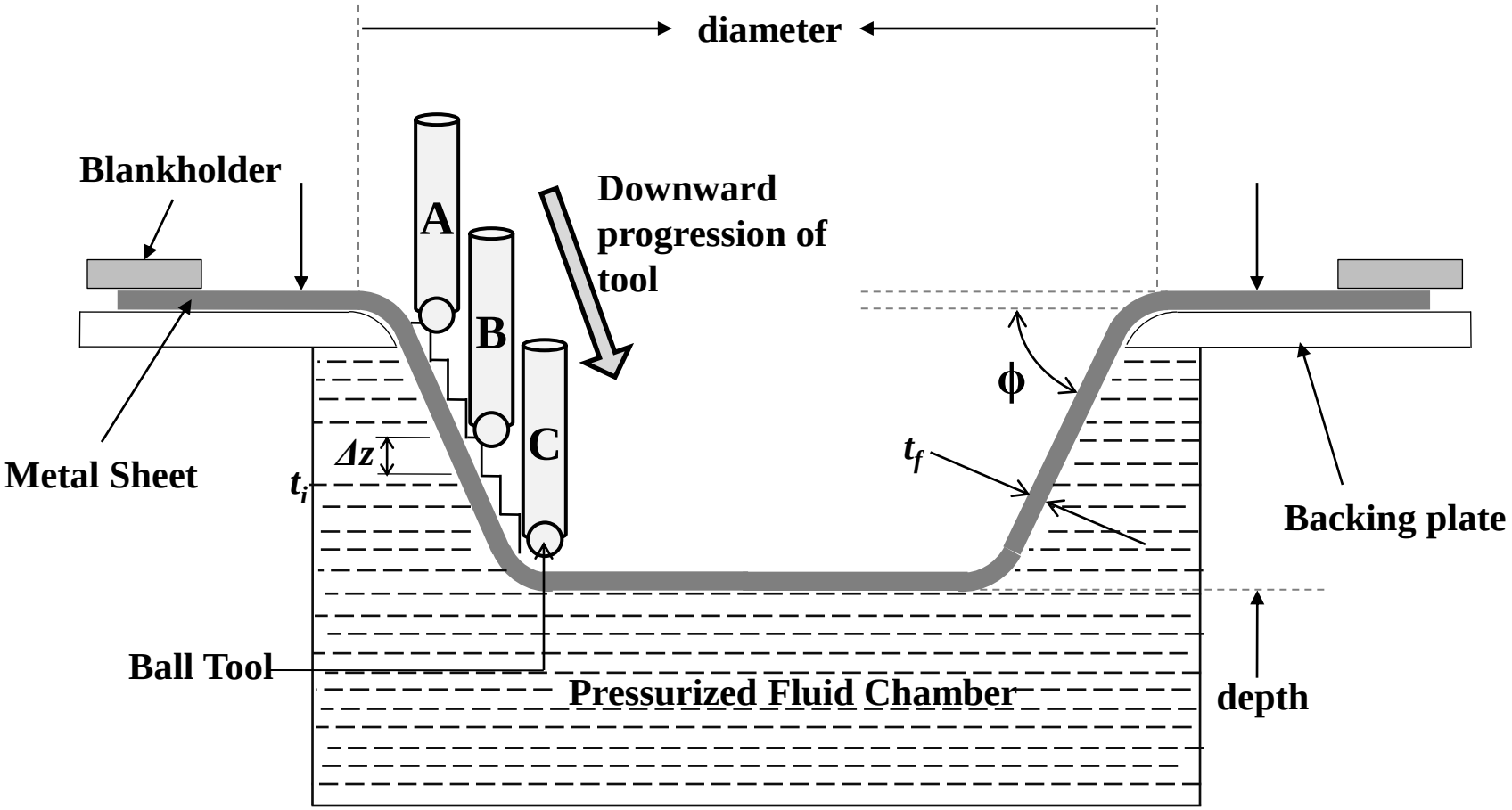
- Strain Distribution : Normal
- Maximum Forming Angle : 67° - 69°
- Geometrical inaccuracies
- Crack formation

- Strain Distribution : Scope for Improvement
- Maximum Forming Angle : Scope for Improvement
- Geometrical inaccuracies : Scope for Improvement
- Crack formation : less chances of cracks

Basic Terminologies in ISF



Basic Terminologies in ISHF



INCREMENTAL SHEET HYDROFORMING (ISHF)

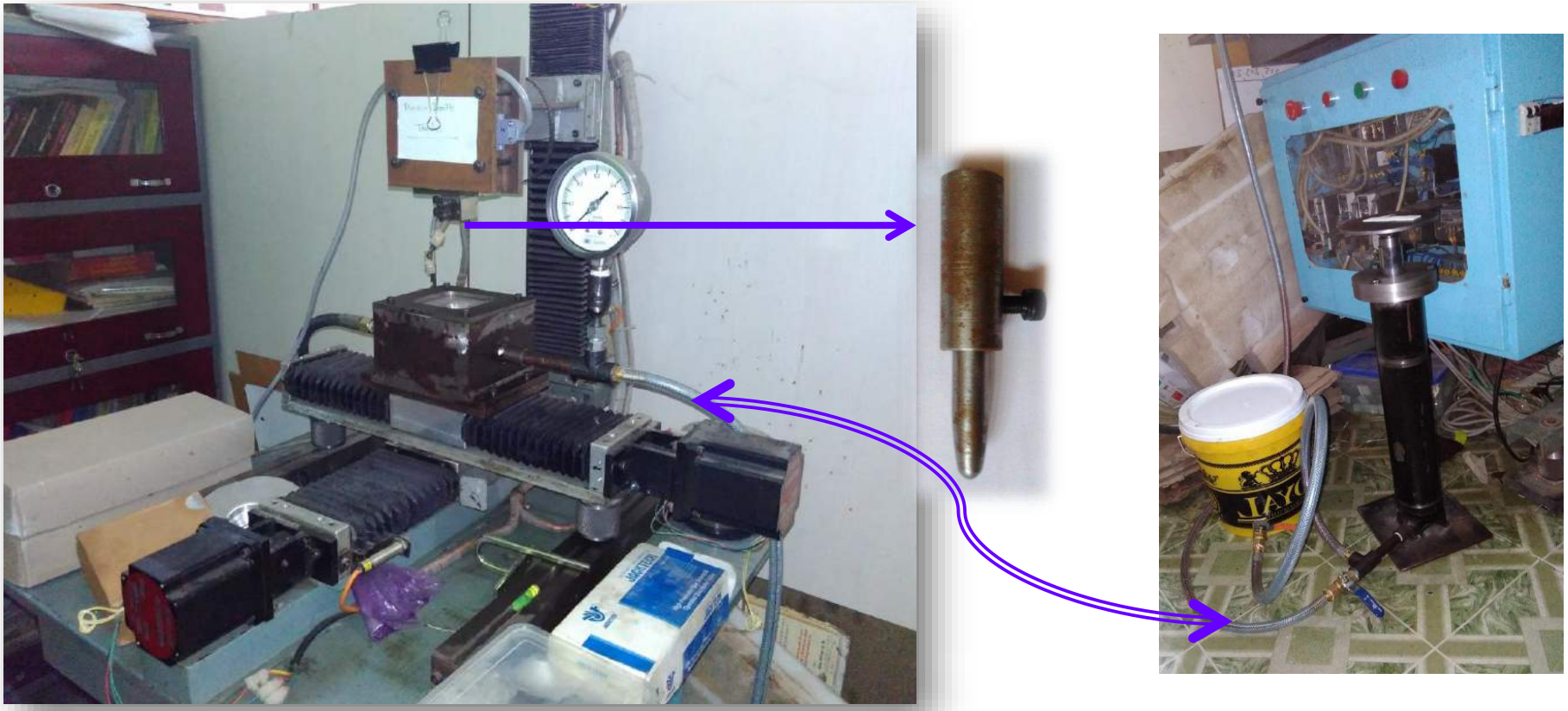
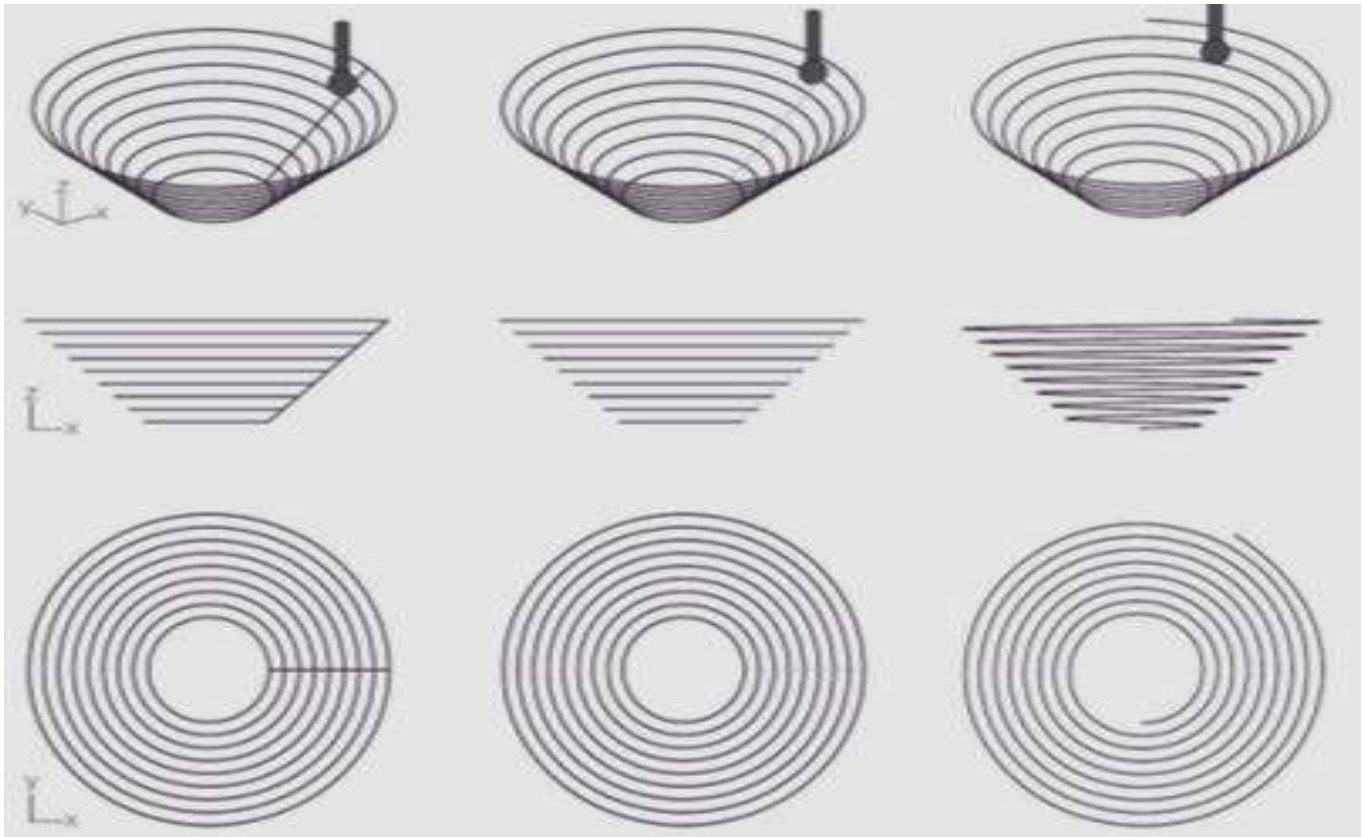


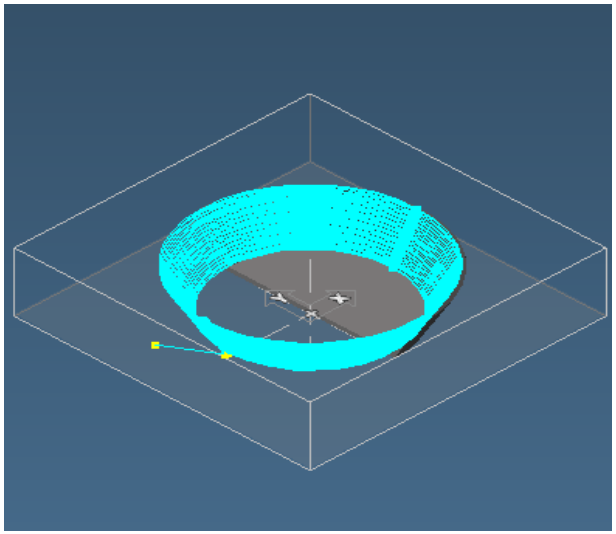
Fig.: Incremental Sheet Hydroforming Machine [Final Modification]

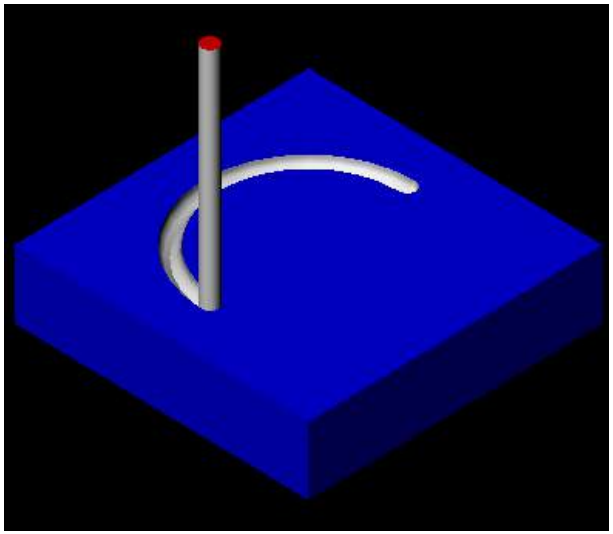
Fig.: FINAL Version of Hydraulic Cylinder

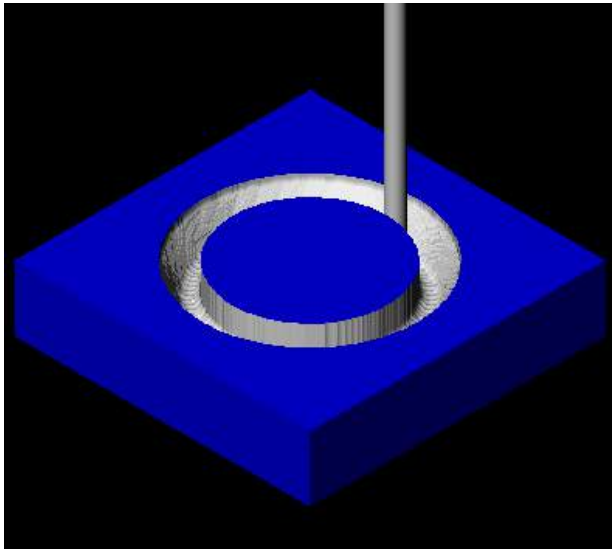
PLANNING FOR TOOL PATH

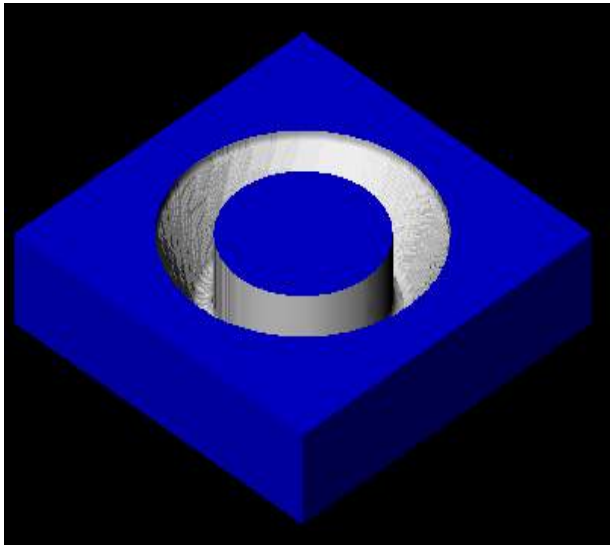


Contoured Stepped Spiral









GibsCAM v.11.2

Wall Angle (60°), Step Size 0.5

```
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G0 Z1.
G1 Z0 F500.0
Y-0.0003 F1000.0
G3 X17.4914 Y0.0001 Z-0.217 I17.5534
J0.0003
X-17.3673 Y0 Z-0.434 I-17.4293 J-0.0001
X17.2432 Z-0.6511 I17.3052 J0
X-17.119 Z-0.8681 I-17.1811 J0
X16.9949 Y0.0001 Z-1.0851 I17.0569 J0
X-16.8708 Y0 Z-1.3021 I-16.9328 J-0.0001
X16.7467 Z-1.5191 I16.8087 J0
X-16.6226 Z-1.7362 I-16.6846 J0
X16.4985 Y0.0001 Z-1.9532 I16.5605 J0
X-16.3744 Y0 Z-2.1702 I-16.4364 J-0.0001
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X-16.1262 Z-2.6042 I-16.1882 J0
X16.0021 Z-2.8213 I16.0641 J0
X-15.878 Z-3.0383 I-15.94 J0
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X-15.3816 Y0 Z-3.9064 I-15.4436 J-0.0007
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X-15.1334 Z-4.3404 I-15.1954 J0
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X-14.1405 Z-6.0766 I-14.2025 J0
X14.0164 Z-6.2936 I14.0784 J0
X-13.8923 Z-6.5106 I-13.9543 J0
X13.7682 Z-6.7276 I13.8302 J0
X-13.6441 Z-6.9446 I-13.7061 J0
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X-7.687 Z-17.3616 I-7.749 J0
I7.687 J0
G0 Z50.
G91 G28 X0 Y0 Z0
M30
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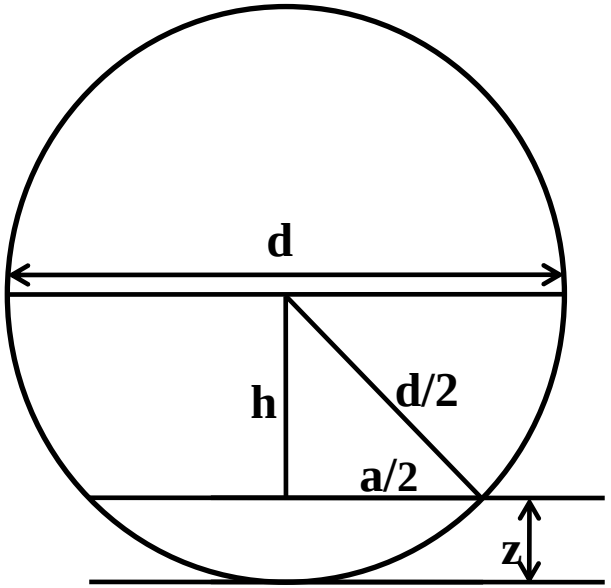
Analysis of Forming Force, Stresses in the contact area and Applied Pressure

z = Step Size
d = ball diameter
a = diameter of the projected circle



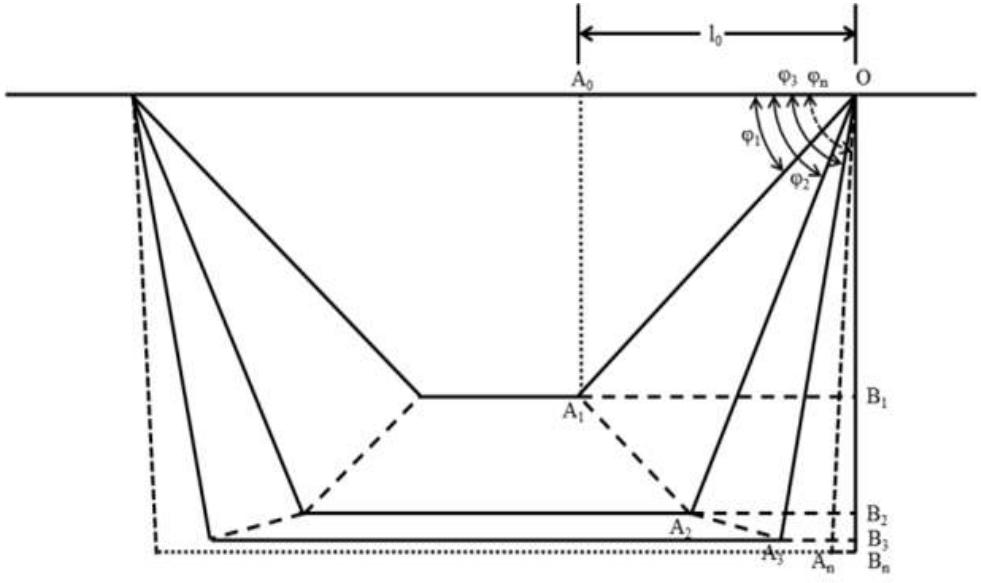
$$A_c = \pi\left(\frac{a}{2}\right)^2 = \pi(dz - z^2)$$

$$\sigma = \frac{F_c}{A_c}$$

$$F_h = p \times A_b = F_c$$

$$p = \frac{F_c}{A_b}$$

Multi-Stage & Multi-Step Forming Strategy for ISHF to achieve high forming angle



l_0 = Initial length of sheet under forming
l_1 = Length of sheet under forming after first step
x_1 = Total increment in X direction in 1^{st} step
l_n = Length of sheet under forming after n steps
X_n = Total increment in X direction in n^{th} step
Z_n = Total increment in Z direction in n^{th} step
From the right angled triangle A_0OA_1

$$l_1 = \frac{l_0}{cos\phi_1}$$
$$X_1 = l_1 cos\phi_1$$
$$Z_1 = l_1 sin\phi_1$$

Figure : Multi-Stage & Multi-Step Forming Strategy

Table : Multi-Stage & Multi-Step Forming Strategy

Step No.(n)	Forming Angle (ϕ_n)	Forming Length (l_n)	X_n	Z_n	ΔZ_n
1	$\phi_1 = \frac{\pi}{4}$	$l_1 = \frac{l_0}{cos\phi_1}$	$x_1 = l_1 cos\phi_1$	$z_1 = l_1 sin\phi_1$	$\Delta Z_1 = t_0$
2	$\phi_2 = \frac{3\pi}{8}$	$l_2 = \frac{l_1}{cos(\phi_2 - \phi_1)}$	$x_2 = l_2 cos\phi_2$	$z_2 = l_2 sin\phi_2$	$\Delta Z_2 = \Delta Z_1/2$
3	$\phi_3 = \frac{7\pi}{16}$	$l_3 = \frac{l_2}{cos(\phi_3 - \phi_2)}$	$x_3 = l_3 cos\phi_3$	$z_3 = l_3 sin\phi_3$	$\Delta Z_3 = \Delta Z_2/2$
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
n	$\phi_n = \frac{\pi}{2}(1 - \frac{1}{2^n})$	$l_n = \frac{l_{n-1}}{cos(\phi_n - \phi_{(n-1)})}$	$x_n = l_n cos\phi_n$	$z_n = l_n sin\phi_n$	$\Delta Z_n = \Delta Z_{n-1}/2$

The analytical modeling to predict the sheet thinning in final product.

Table : Experimental Details : Multi-Stage & Multi-Step Forming Strategy [Experiment No. 1]

Step No.(n)	Forming Angle (ϕ_n)	Forming Length (l_n)	X_n	Z_n	ΔZ_n
1	45^o	$l_1 = 14.14mm$	$x_1 = 10.00mm$	$z_1 = 10.00mm$	$0.5mm$
2	67.50^o	$l_2 = 15.31mm$	$x_2 = 5.86mm$	$z_2 = 14.14mm$	$0.25mm$
3	78.75^o	$l_3 = 15.61mm$	$x_3 = 3.05mm$	$z_3 = 15.31mm$	$0.125mm$

Table : Experimental Details : Multi-Stage & Multi-Step Forming Strategy [Experiment No. 2]

Step No.(n)	Forming Angle (ϕ_n)	Forming Length (l_n)	X_n	Z_n	ΔZ_n
1	45^o	$l_1 = 21.21mm$	$x_1 = 15.00mm$	$z_1 = 15.00mm$	$0.5mm$
2	67.50^o	$l_2 = 22.96mm$	$x_2 = 8.79mm$	$z_2 = 21.21mm$	$0.25mm$
3	78.75^o	$l_3 = 23.43mm$	$x_3 = 4.57mm$	$z_3 = 22.98mm$	$0.125mm$

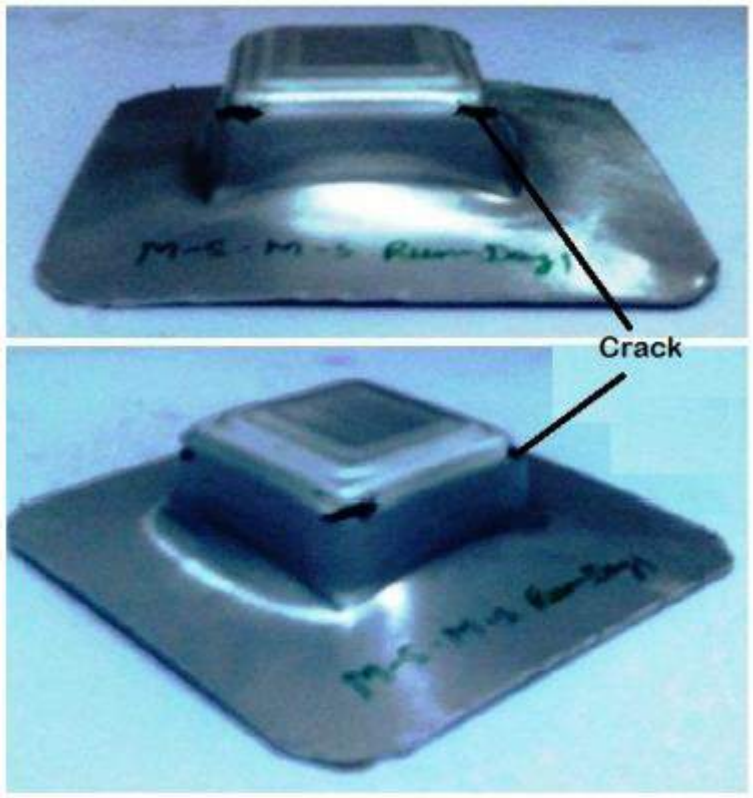


Figure : Crack Formation in Multi-Stage & Multi-Step Forming Strategy for first experiment

Figure : Crack Formation in Multi-Stage & Multi-Step Forming Strategy for second experiment

Scope for Improvement in Multi-Stage & Multi-Step Forming Strategy

Thickness = 0.5 mm
Angle = 90°
Blank Diameter : 125 mm

Figure : Failure in Circular Component at angle 90°

Analytical Model for Modified MSMS Forming Strategy

$$t_{Wall} = \frac{t_o}{2}\left(1 - \frac{l}{2R}\right) \quad (1)$$

$$t_{Bottom} = \frac{t_o}{2}\left[\frac{\left(1 - \frac{5l}{6R}\right)}{\left(1 - \frac{l}{3R}\right)}\right] \quad (2)$$

t_o = initial sheet thickness
R = radius of circular section
l = depth of circular section
t_{Wall} = final thickness at depth l in vertical portion of sheet at corner
t_{Bottom} = final thickness l in horizontal portion of sheet at corner

Experimental Results

$$\Delta Z_h = \frac{\Delta Z_o}{2}\left(1 - \frac{h}{2R}\right)$$

$$p_h = \frac{p_o}{2}\left[\frac{\left(1 - \frac{5h}{6R}\right)}{\left(1 - \frac{h}{3R}\right)}\right]$$

Figure : Final product after implementation Modified MSMS Forming Strategy

Multi-Feature Products using ISHF

Figure : Multi- Feature Case 1

Multi-Feature Products using ISHF

Figure : Multi- Feature Case 2

Stretch Forming

Stretch Forming

Sheet metal is stretched and simultaneously bent to achieve shape change

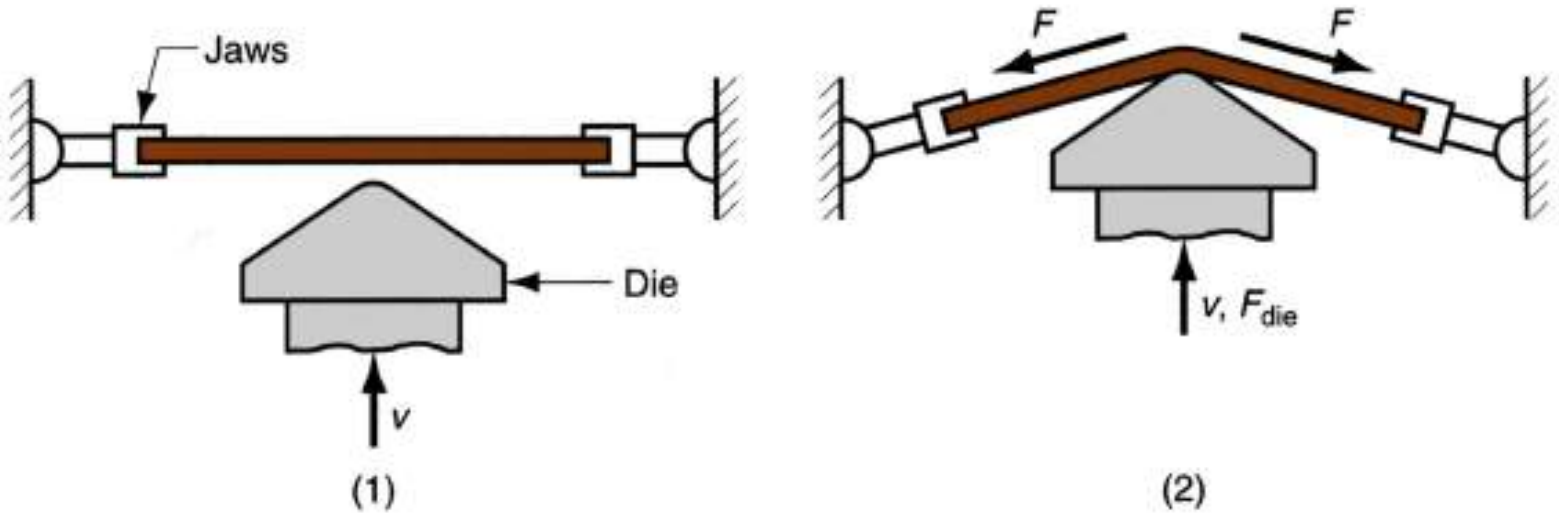


Figure: Stretch forming: (1) start of process; (2) form die is pressed into the work with force Fdie, causing it to be stretched and bent over the form. F = stretching force

Spinning

Spinning

Metal forming process in which an axially symmetric part is gradually shaped over a rotating mandrel using a rounded tool or roller

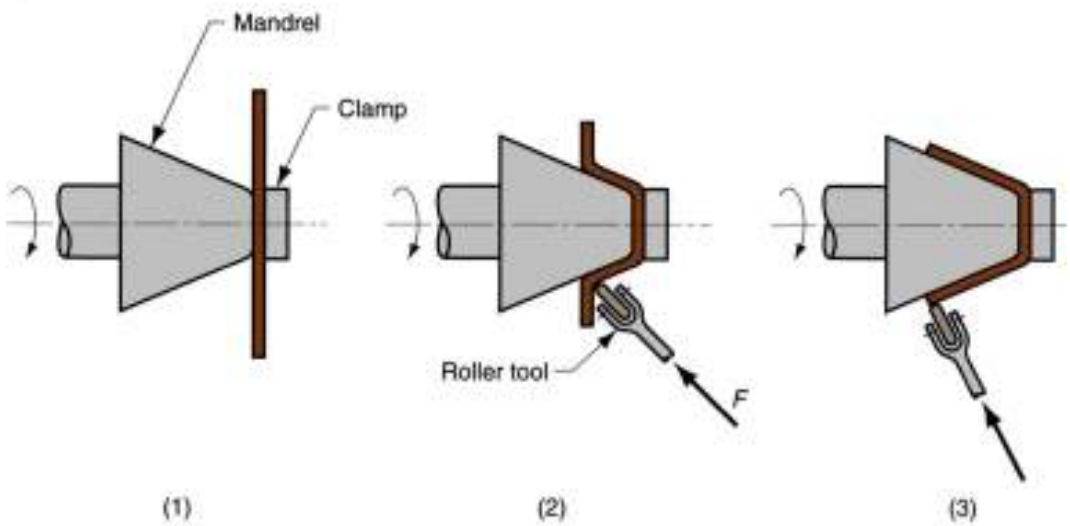


Figure: Conventional spinning: (1) setup at start of process; (2) during spinning; and (3) completion of process