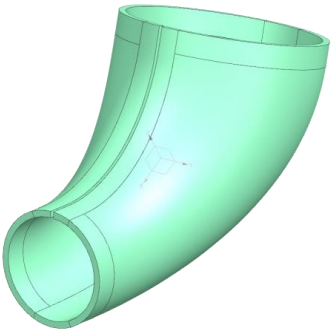
Manufacturing of Silencer parts using Various processes



Silencer Part

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VP (Engineering) – Bajaj Auto

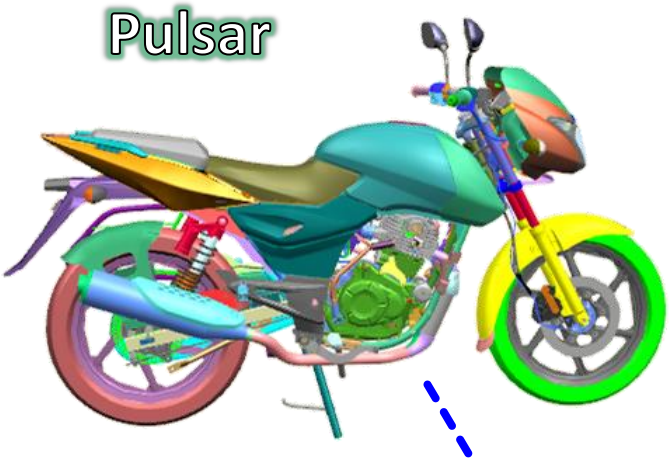
Abstract

Sheet Metal Forming has been used regularly since the Industrial Revolution and is the sole process for manufacturing various parts in the Automotive Industry. The final shape of the part is made from a flat metal sheet by Plastic deformation Using tonnes of force applied from Mechanical or Hydraulic presses. Closed parts are a challenge to be manufactured using Die operations, hence in this study, a combination of U-Forming and Mandrel-CAM operation, along with the simulation results have been presented for a highly curved silencer part. Various other Industrial Manufacturing processes have been briefed too for the desired part.

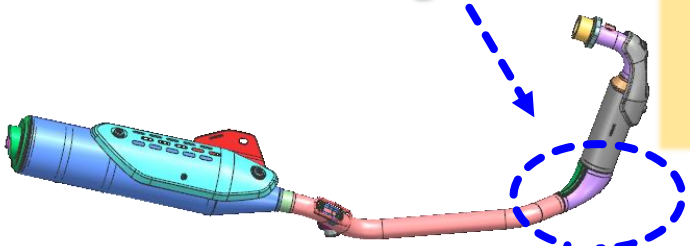
May - July 2022

Contents

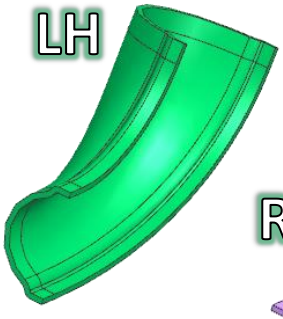
Pulsar



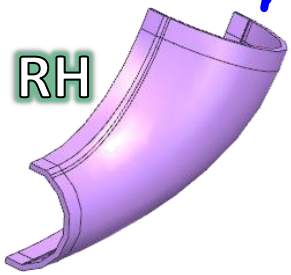
Silencer Assembly



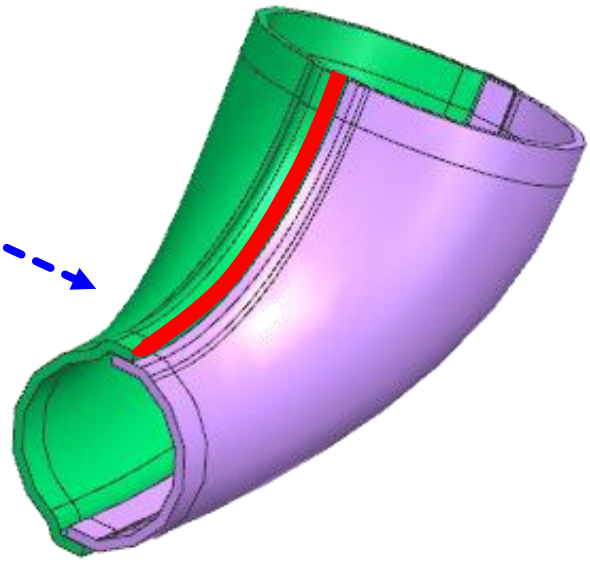
LH



RH



Welded Part



Current Method:

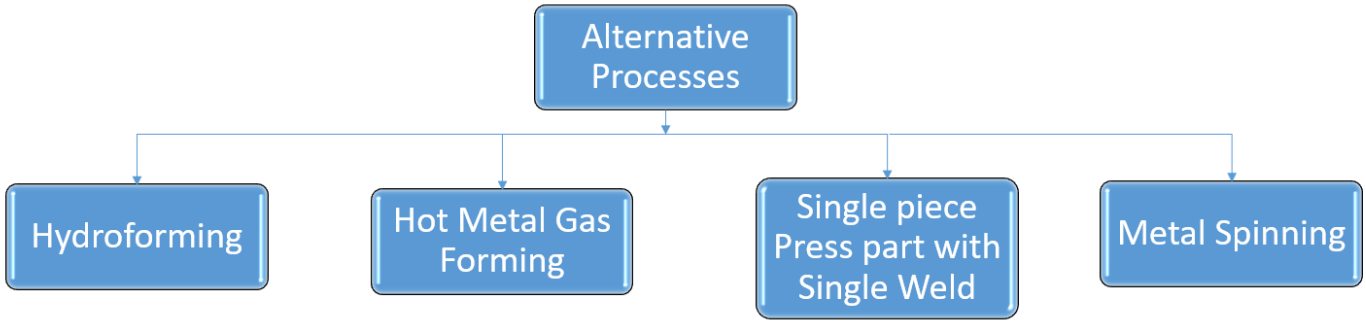
- LH and RH parts separately manufactured and then welded together.

Objectives:

- Various strategies to be developed for the given part.
- Reduce the amount of **Welding** required.
- The method should be cost effective.
- Manufactured from a **Single piece**.
- Good Finish should be achieved.
- Minimum stages of Operation.

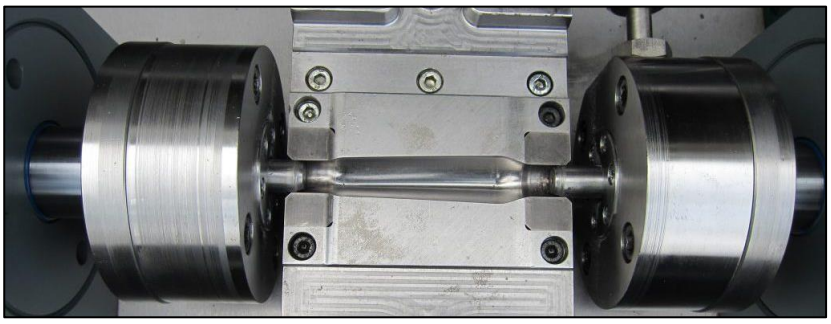
Issues with existing method:

- Shabby welding in Aesthetic area
- Leakage rework required
- Welding of LH-RH on main fabrication line



[1] Hydroforming

- Hydroforming: Metal Tube formed across a die using Fluid pressure.
- Pressure as high as 2000 bars is applied.
- The Tube expands Uniformly along the die surface.
- Compression force exerted from the sides.



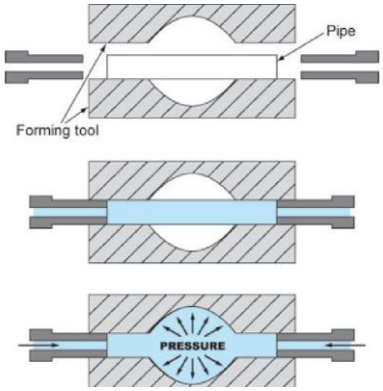
Materials which can be Hydroformed:

- Aluminium
- Brass, Bronze
- Carbon / Stainless steel
- Copper
- Cobalt, etc

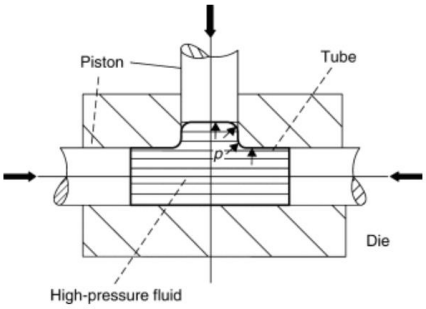
Parts that can be manufactured

- **Exhaust Manifolds**
- **Silencer parts**
- Bumper
- Engine Cradle
- Aerospace components
- Unibody Frames instead of deep drawing
- Instrument panel / Radiator supports

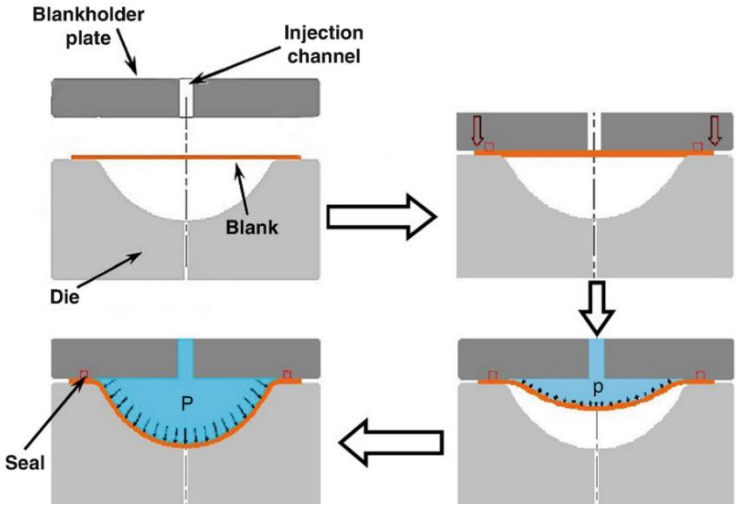
Tube Hydroforming



Section with Hole (T)



Sheet Hydroforming



Advantages of Hydroforming Process:

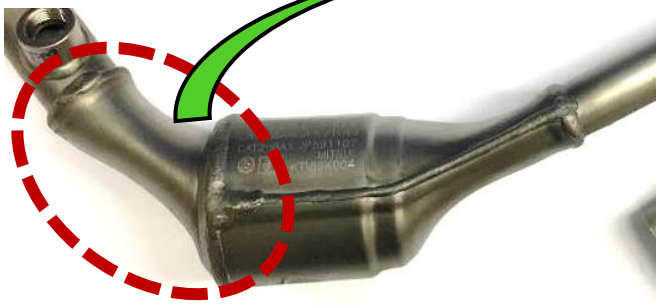
- Die construction is simpler
- Uniform material deformation
- Asymmetric geometries can be achieved
- Possibility to make holes during the process
- Reduced number of joints needed

Disadvantages of Hydroforming Process

- Expensive Equipment (cost effectivity decreases with lower volume projects)
- Relatively higher cycle time than mechanical press
- Cold expansion in Stainless steel is limited
- Sharp corners are not achievable

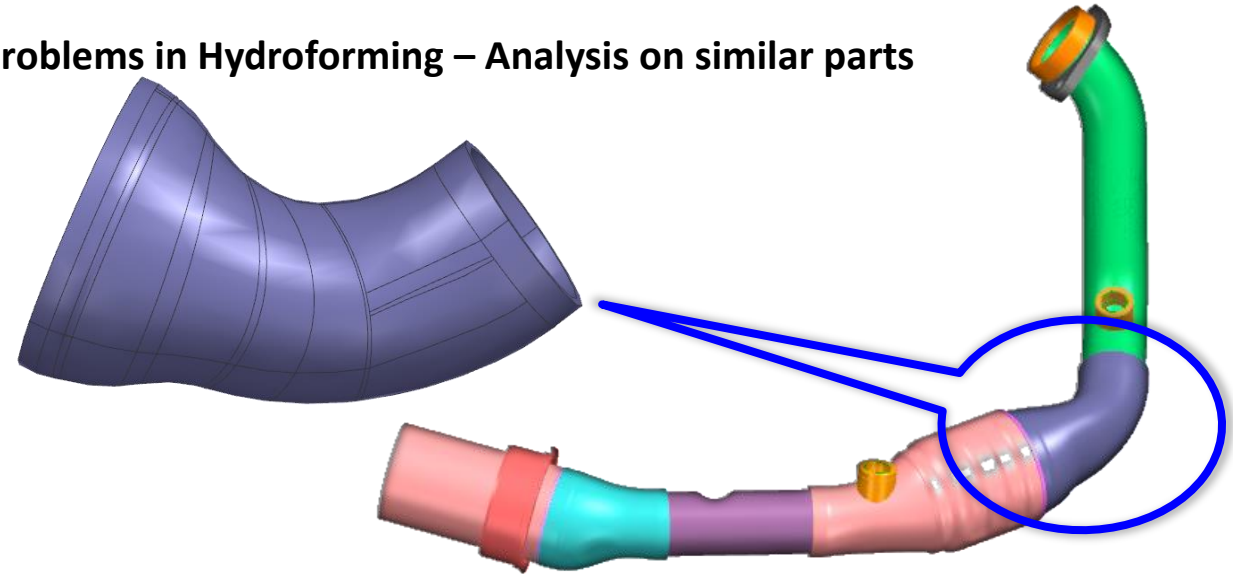
Silencer Entry cone

- Two-piece weld design
- Weld length 175mm
- Finishing and lot of reword needs to be done
- Poor Quality
- Welding -> further deforms the part



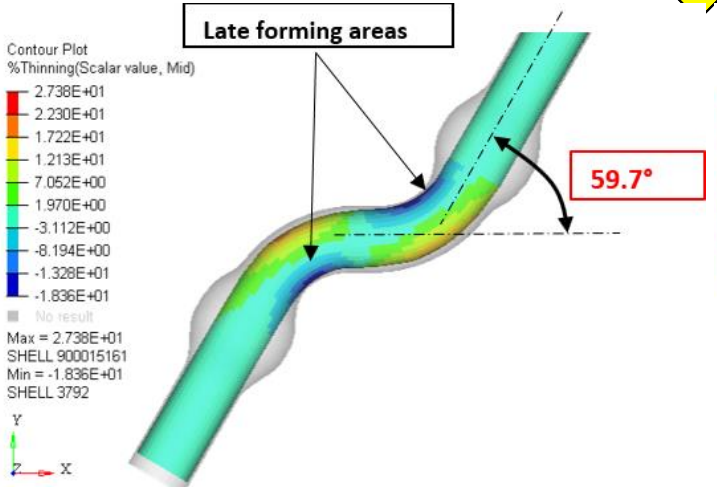
- Single piece Hydroform part
- No welding required
- Good surface finish and quality
- Significantly less rework required

Problems in Hydroforming – Analysis on similar parts



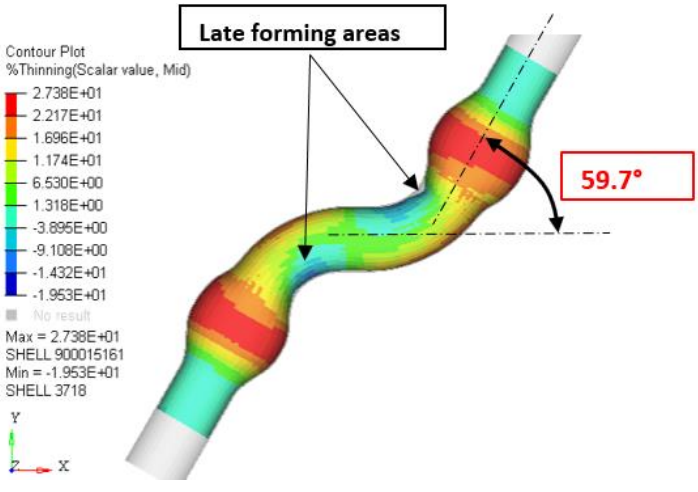
Bend tube

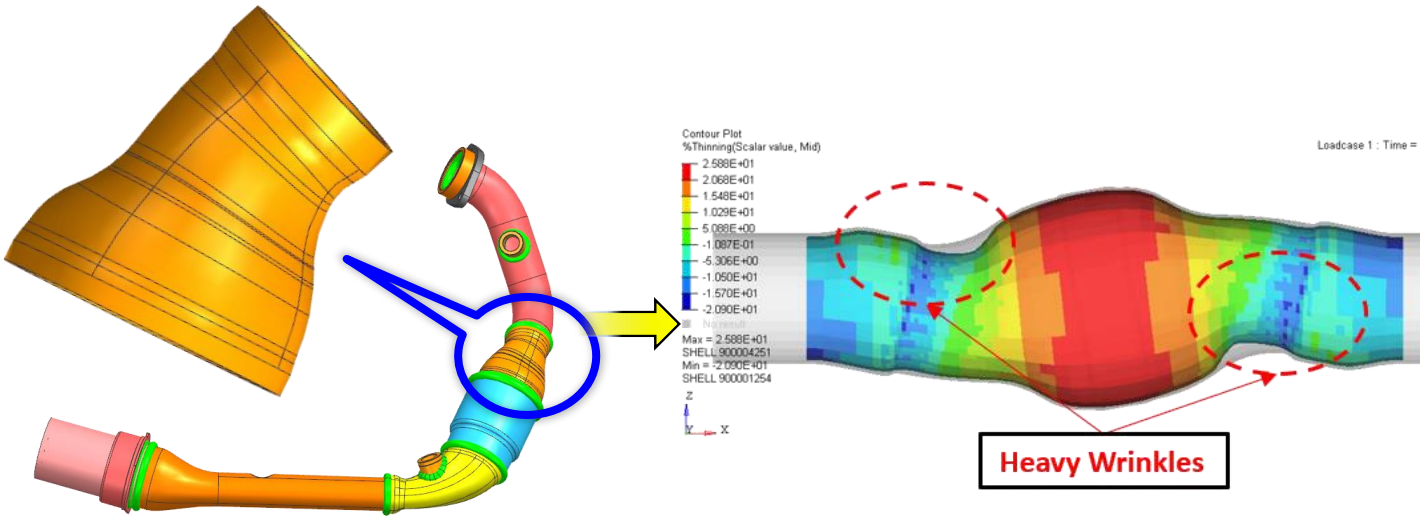
Late forming areas



Hydroforming

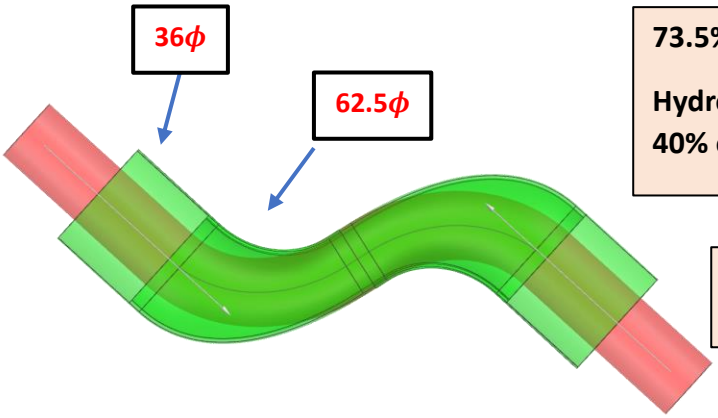
Late forming areas





Problems in Hydroforming: The given Silencer Part

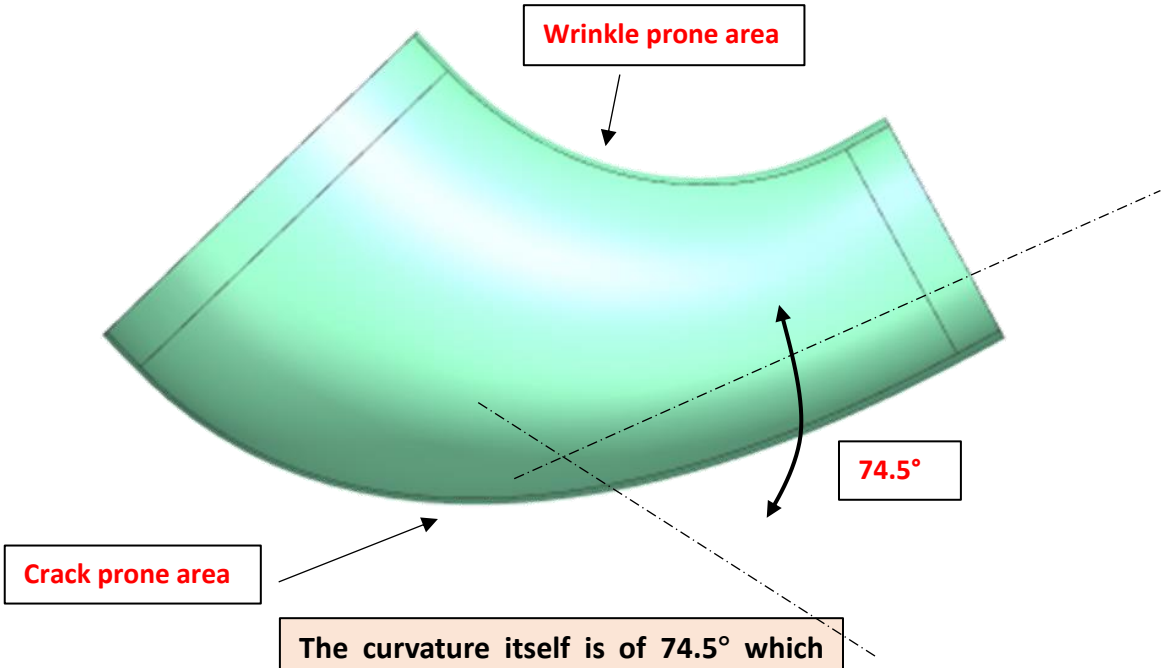
The Expansion percentage should be not more than 40%, or else cracks and extreme wall thinning may occur!



73.5% Increase in the diameter of the original tube!

Hydroforming limits expansion of SS to about 30-40% only in cold working conditions.

A very high amount of preforming required for this part which is not suitable for



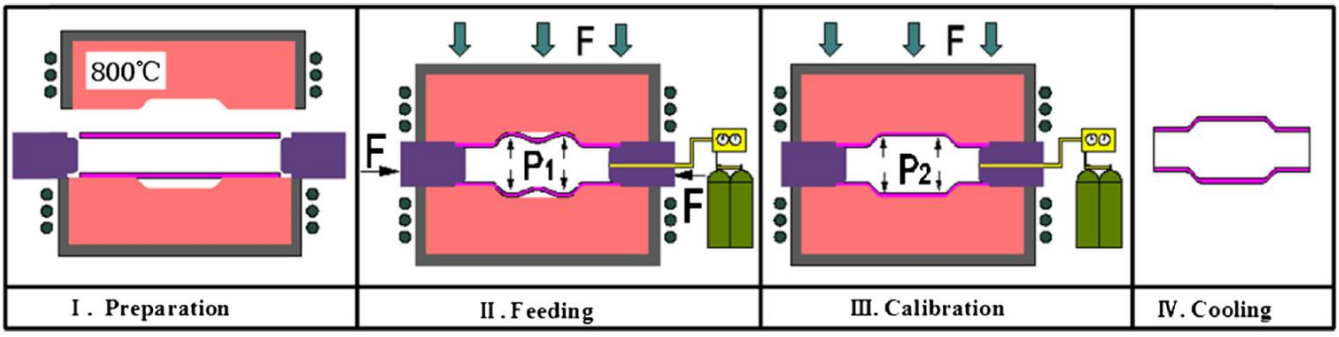
The curvature itself is of 74.5° which tends to crack and wrinkles

New Process to be explored

[2] Hot Metal Gas Forming

Basic Principle:
The Yield stress of the component decreases with the increase in temperature.

- This is a better alternative to Tubular Hydroforming
- First the metal tube is heated to a pliable state which is near to but below the melting point of the material.
- The tube is placed in the negative die and is pressurised internally by a gas, thus forming outward into the shape of the die.

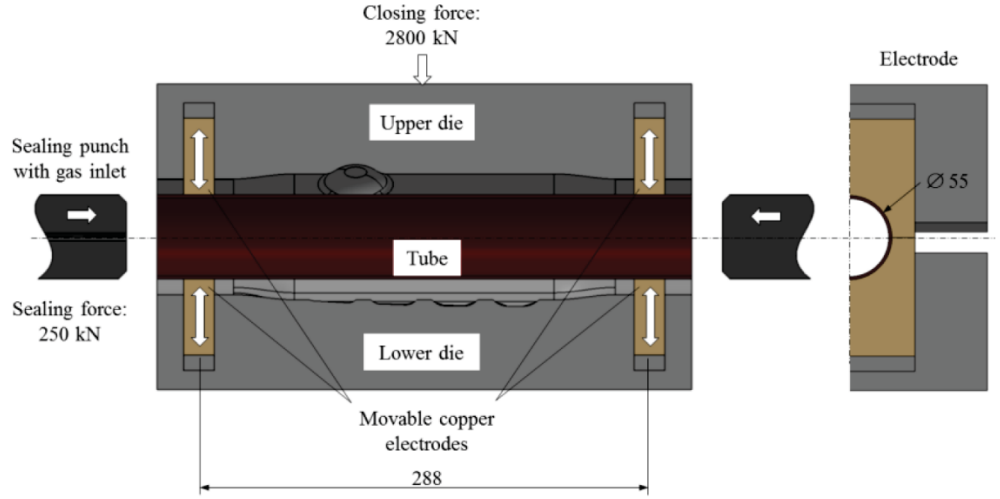


Reference: Liu, Gang, Yong Wu, Dongjun Wang, and Shijian Yuan. "Effect of feeding length on deforming behavior of Ti-3Al-2.5 V tubular components prepared by tube gas forming at elevated temperature." The International Journal of Advanced Manufacturing Technology 81, no. 9 (2015): 1809-1816.

Advantages of HMGF Process

- Higher temperatures and pliable state offer the metal to elongate and stretch to a much greater extent.
- Less number of ruptures occur than other cold forming processes.
- Complex geometries can be achieved.
- Lower internal pressure required than conventional Hydroforming.

Stainless steel has poor formability at room temperature conditions. The forming medium used is Nitrogen Gas



The copper electrodes heat the SS tube by Induction to appropriate temperatures

Mosel, André, Jon Lambarri, Lars Degenkolb, Franz Reuther, José Luis Hinojo, Jörg Rößiger, Egbert Eurich, André Albert, Dirk Landgrebe, and Holger Wenzel. "Novel process chain for hot metal gas forming of ferritic stainless steel 1.4509." In AIP Conference Proceedings, vol. 1960, no. 1, p. 160019. AIP Publishing LLC, 2018.

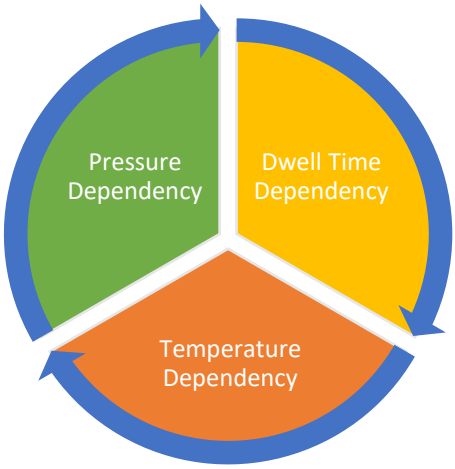
Process Plan of Hot Meal Gas Forming

Preheating of the Tube in Radiation Furnace → Transfer of the tube to the tool → Closing of the tool to "Conduction Position" → Conductive Heating → Pressurised Gas Forming (50 – 70MPa)

Tube Removal Temperatures: 900~1150℃. Max Pressure Achieved: 50~70MPa after 1.5 seconds approx. Max Pressure dwell time: 0.8 seconds

An Infrared Pyrometer is used to measure the Temperature of the Tube

All parts those can be Hydroformed, can be Hot Metal Gas Formed as well



The three main factors that will determine Thinning of sheet!

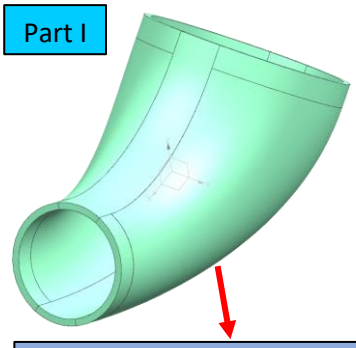
Disadvantage: Need of Furnace and conduction heating

Comparison of Hydroforming with Hot Metal Gas Forming

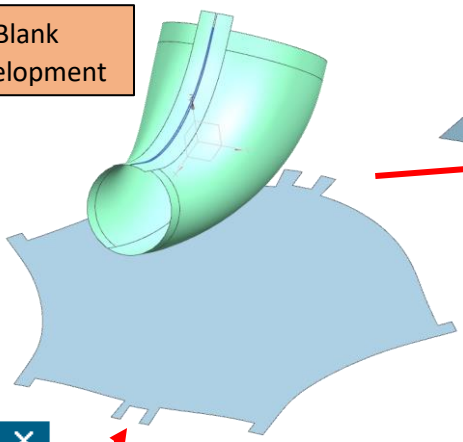
Hydroforming	Hot Metal Gas Forming
• High pressure fluid is **harder to manage**	• High pressure Gas is **easier to manage**
• **Less formability** due to cold forming	• **Higher formability** due to hot forming
• Comparatively **more costly** setup	• Comparatively **less costly** setup
• **More Tear** and **Wall Thinning**	• **Less Tear** and **Wall thinning**
• Comparatively **Lower complex** geometries achieved	• Comparatively **Higher complex** geometries achieved
• **Lesser expansion** percentage	• **Higher expansion** percentage
• Structurally **less strength** parts which are only work hardened due to expansion	• Parts have more Bainite structure and **good strength** due to heat treatment
• There is no need of external heating and furnace	• There is a need of furnace or conduction heating
• No scaling error	• **Scaling Error** due to thermal expansion

[3] U form press + Mandrel Cam Operation

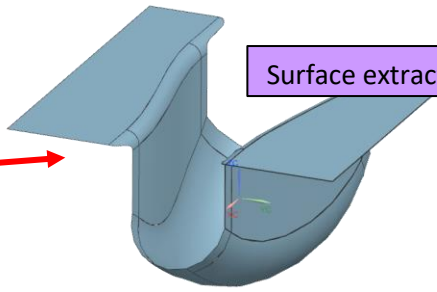
Part I



Blank Development

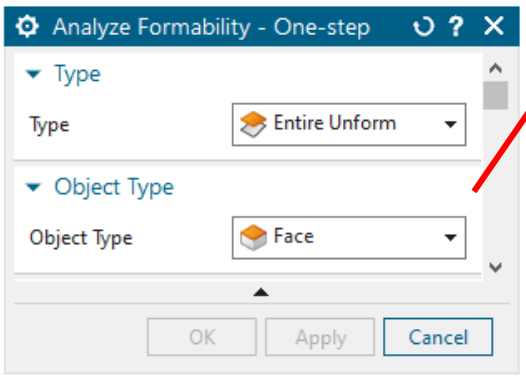


Surface extraction

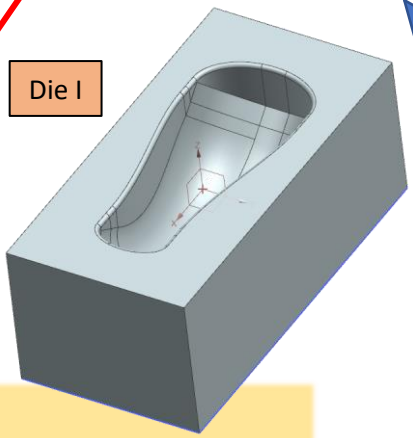


One step formability Analysis

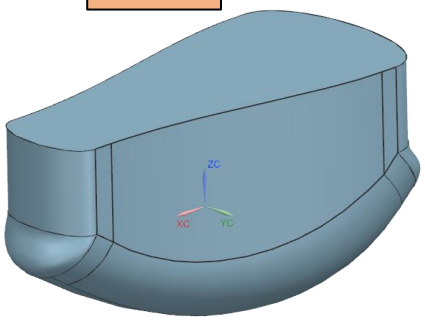
Stage I Semi-finished Blank



Die I



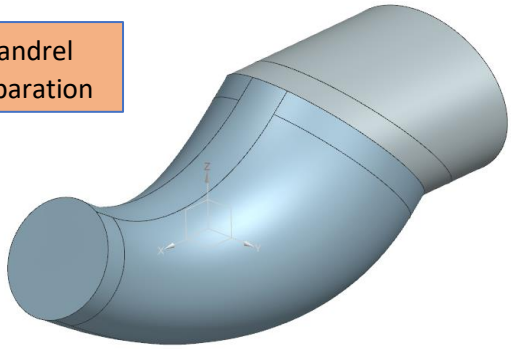
Punch 1



Stage – [1]

- Die for the Half U- form of the lower surface of the part.
- Punch for the respective die.

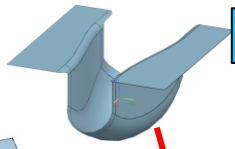
Mandrel Preparation



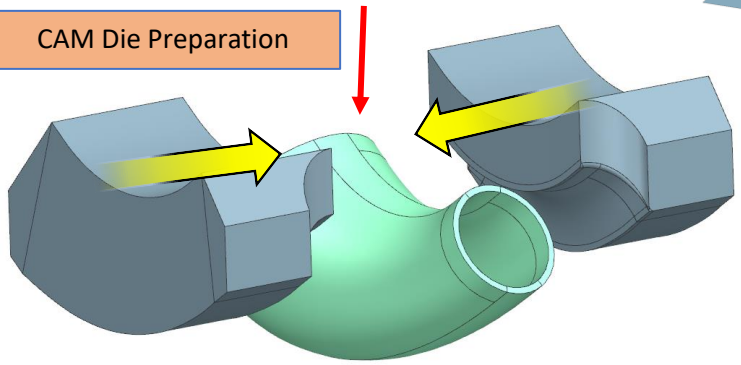
Stage – [2]

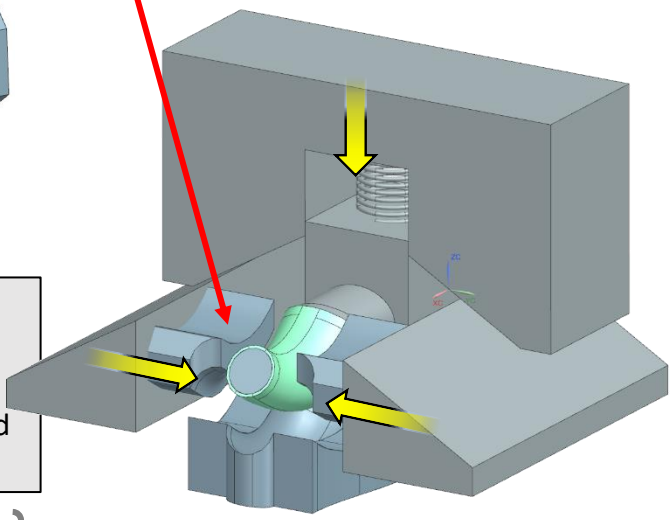
- CAM Dies for the closure of the Stage I semi-finished part.
- Support for keeping the stage I press obtained part.
- Mechanism for Die operation

Stage I Semi-finished Blank

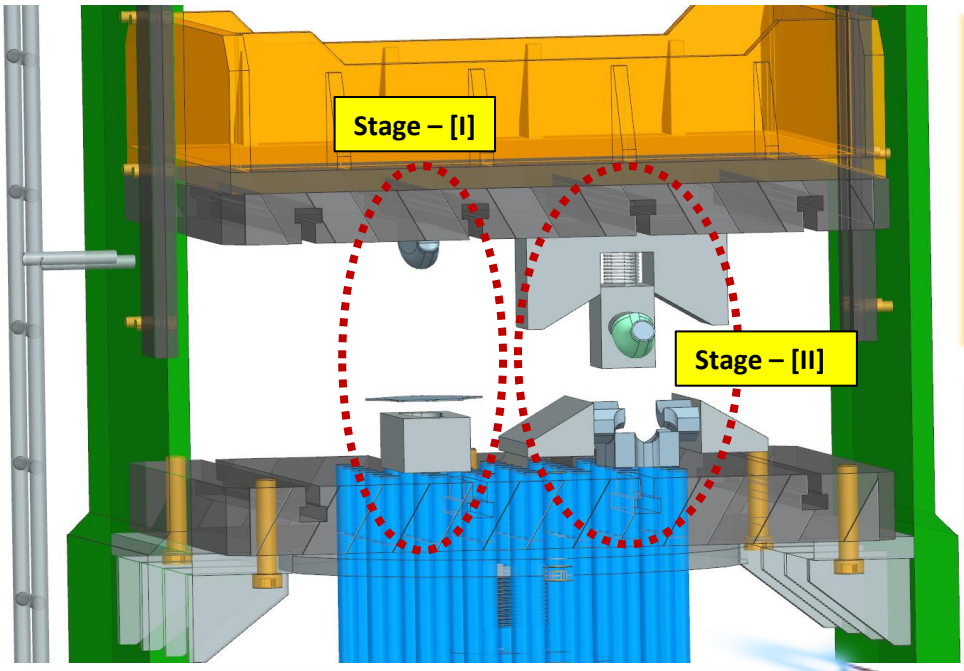


CAM Die Preparation





- As the Mandrel moves down.
- It Applies holding pressure to the stage I semi-finished part.
- Then the Side dies fold the stage I semi-finished sheet and form the completed part.



Stage – [1]

- Here the lower surface of the part is formed using a U form press method.
- Proper blank needs to be manufactured along with part location features for accurate punch output.

Stage – [2]

- The semi-finished part is placed on the support.
- Then the mandrel travels vertically down, applying a holding force on the part.
- The upper block then pushes the side cams, resulting in the closure of the semi-finished part by CAM operation.

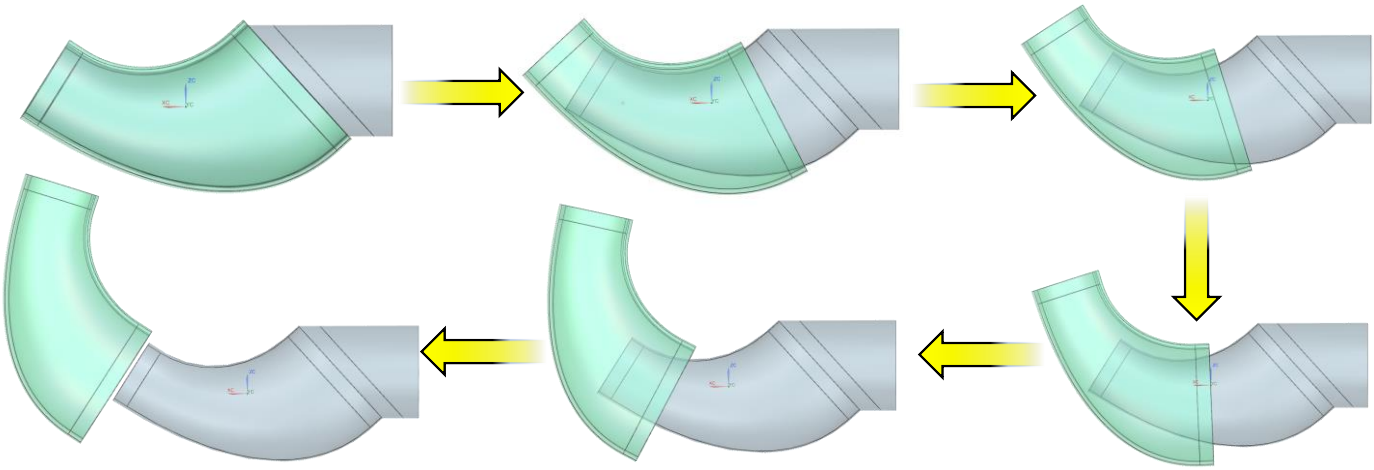
Stage – [3]

- Single Stroke welding is done for closing the gap of the semi finished stage II part

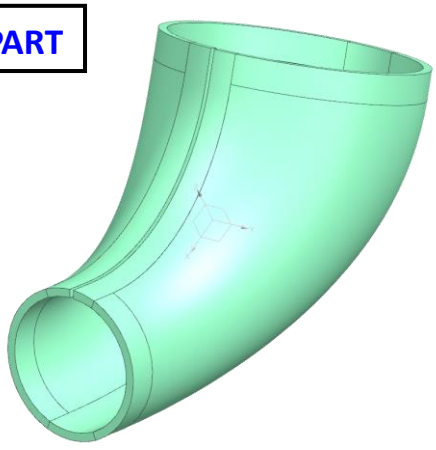
Stage – [4]

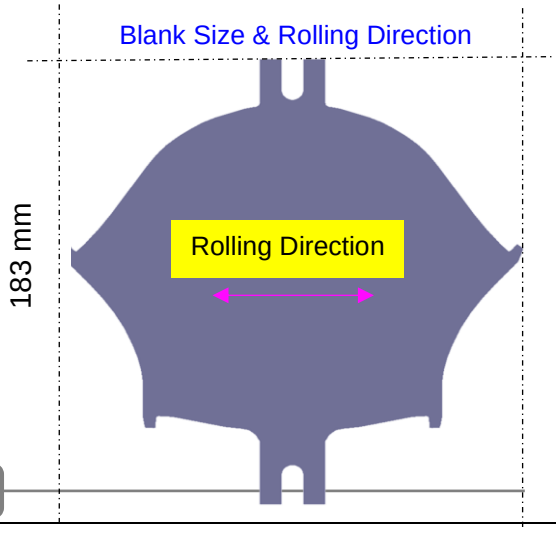
- Trimming extra scrap sheet material
- Finishing and surface polishing

Removal of Part from Mandrel – [Collision Check]

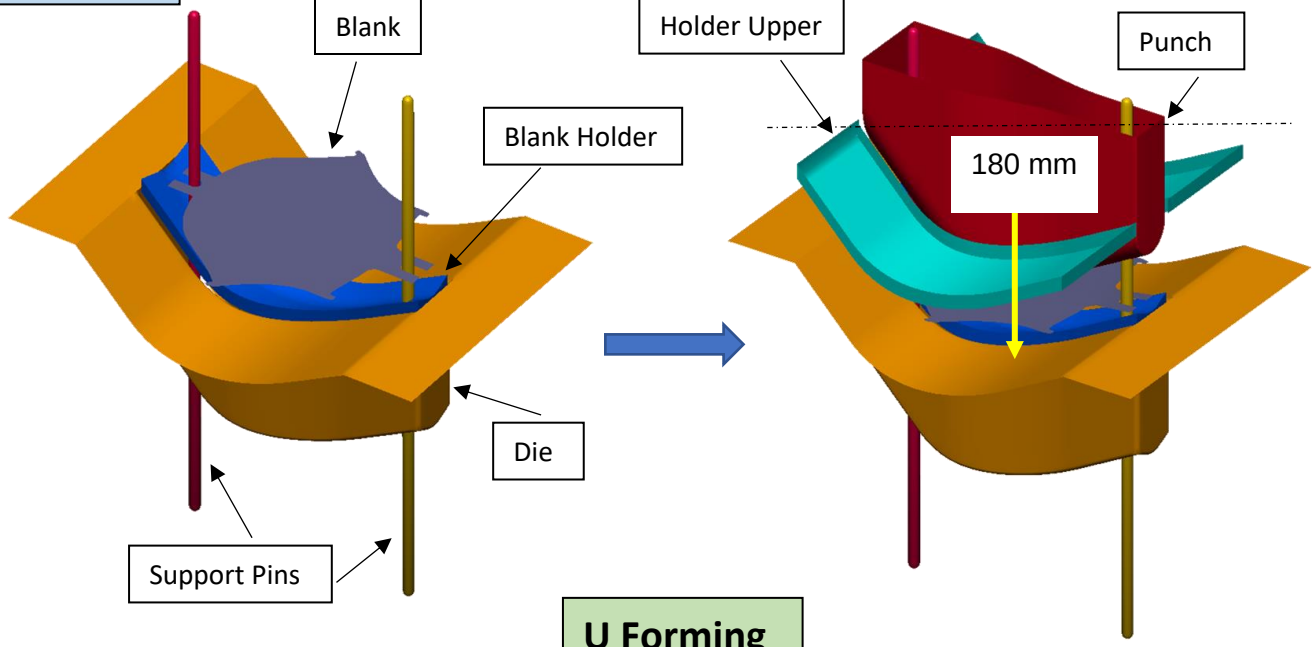


R&D PART

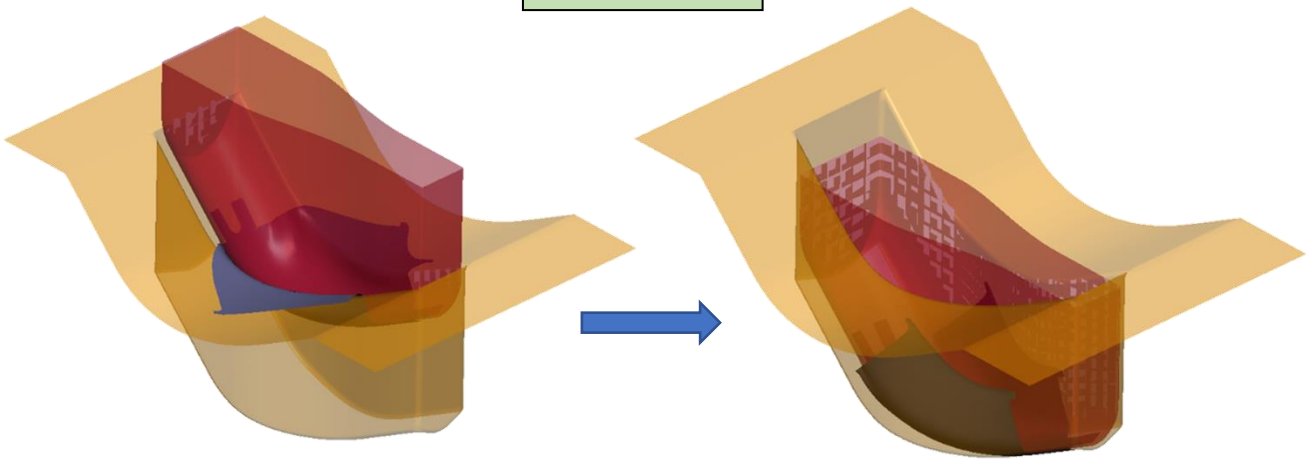




Process Plan



U Forming



Stage – [1] Force Curves

- Punch Force = 11Ton
- Die Force = 1.2Ton
- Lower Pad = 9.8Ton

Experimental Result:

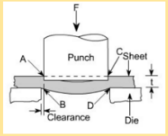
- Punch Force = Die Force + Lower Pad force

Now we will take FOS = 50%

- Therefore the Punch will be designed for 16.5Ton

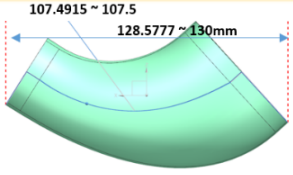
Theoretical Calculation:

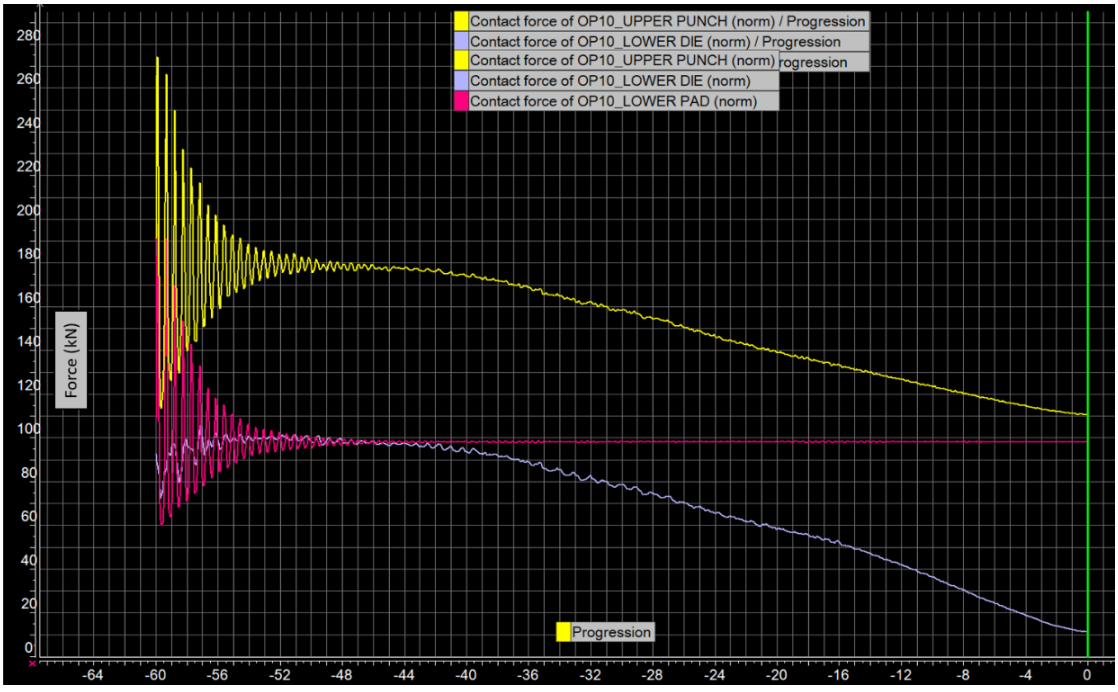
- $F = L * S * U$
- 130*2*565
- = 14.6Ton



Here:

- *F = Punch Force*
- *S = Thickness*
- *U = Ultimate Tensile*





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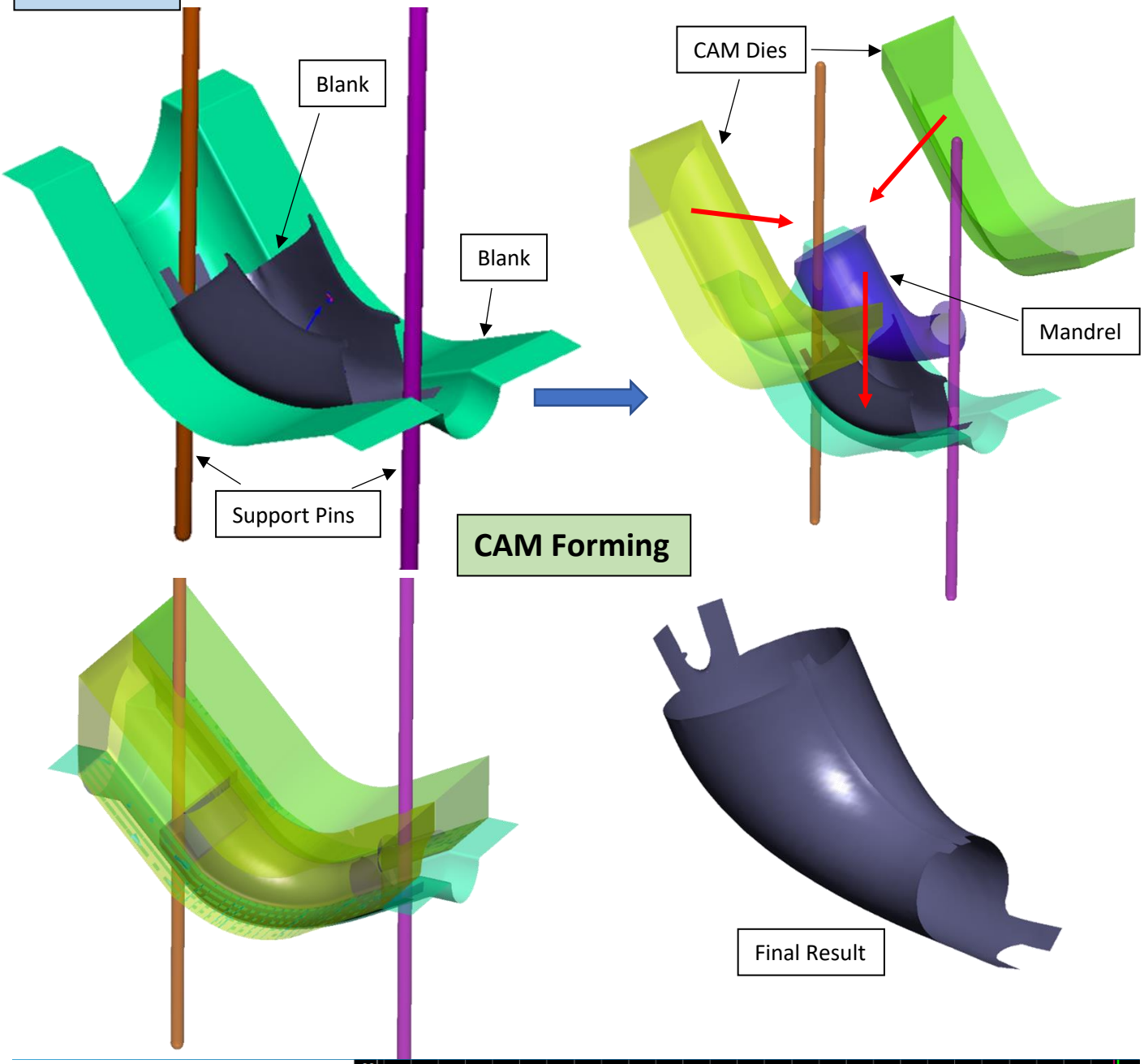


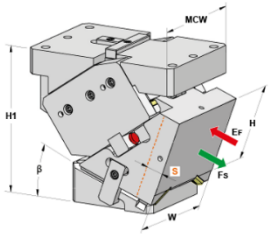
CAM Forming

Final Result

CAM: Aerial CAM $(\beta) = 45°$

Stage – [2] Force Curves

- Punch Force = 14Ton
- With 50% FOS = 21Ton



$$F_s = \frac{R_m * S_p * L}{1000}$$

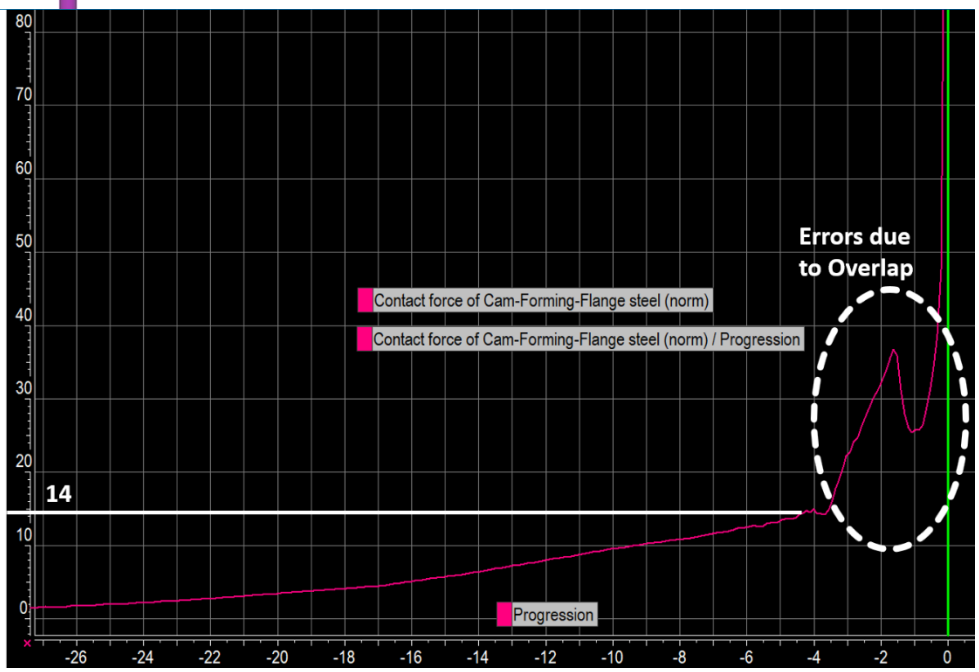
$R_m(Tensile\ strength) = 510{\sim}620 * 10^6 N/m^2$

$L\ (Trim\ profile\ length) = 0.1405548m$

$S_p(Thickness) = 0.002m$

$$F_s = 158.8827 \sim 159kN$$

$$= 15.9\ Ton$$



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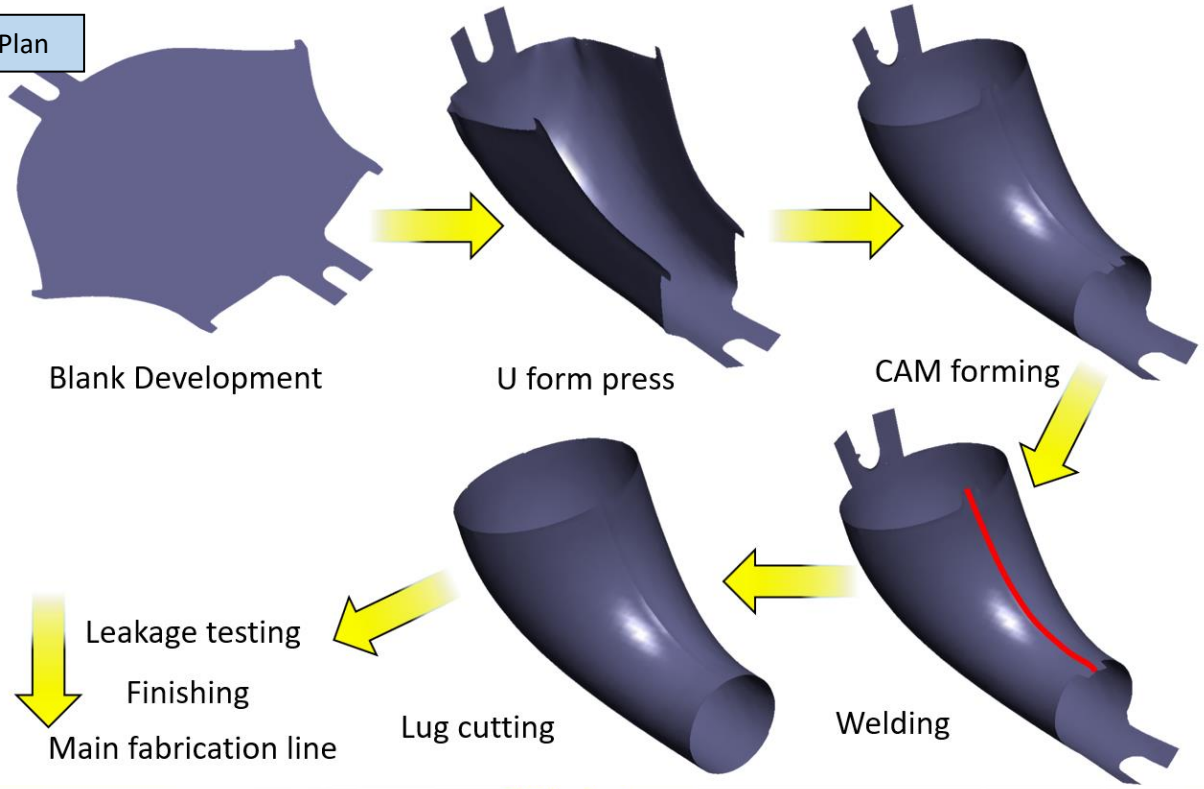
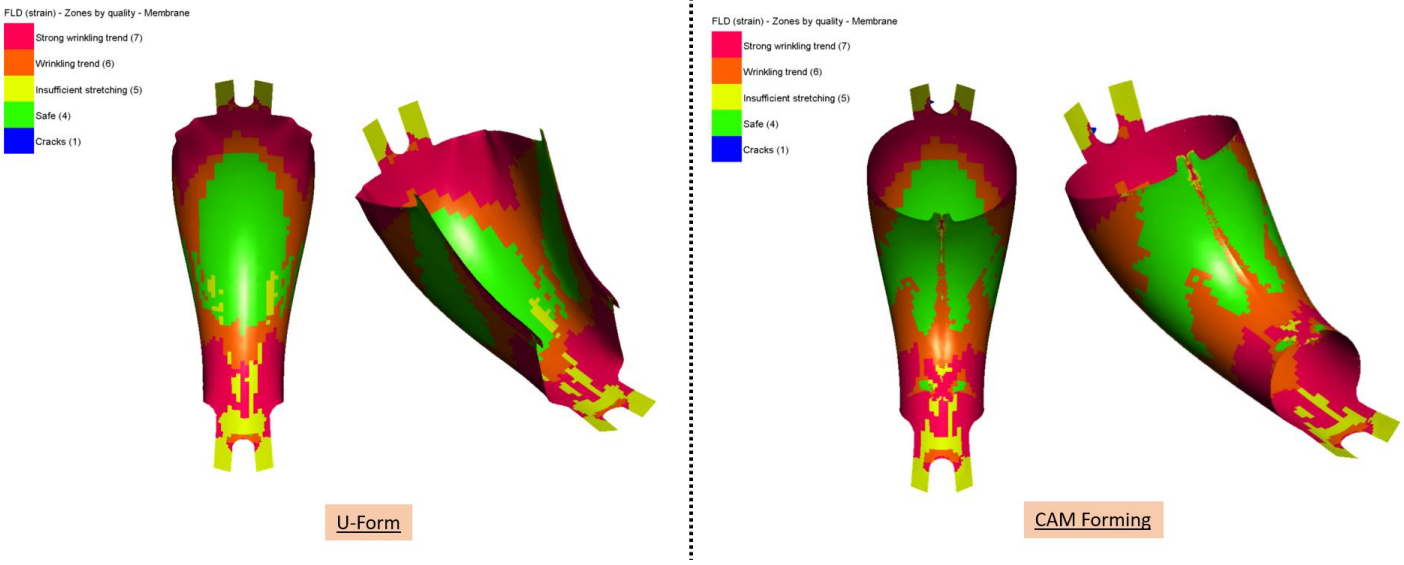
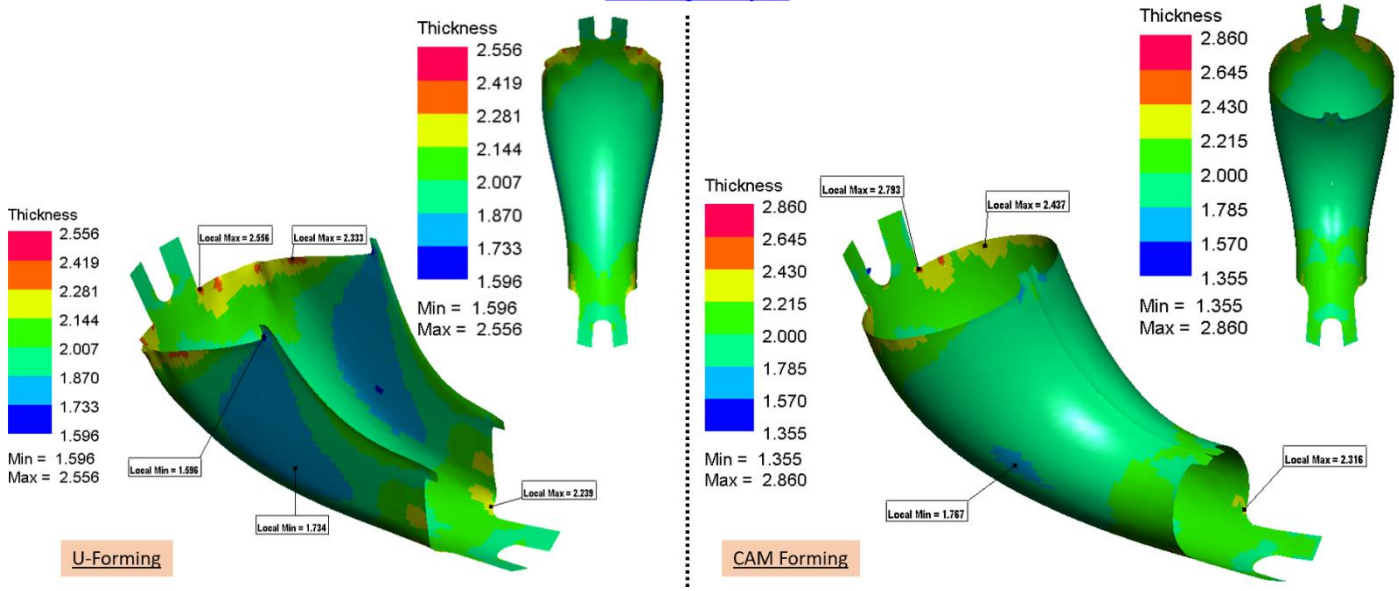


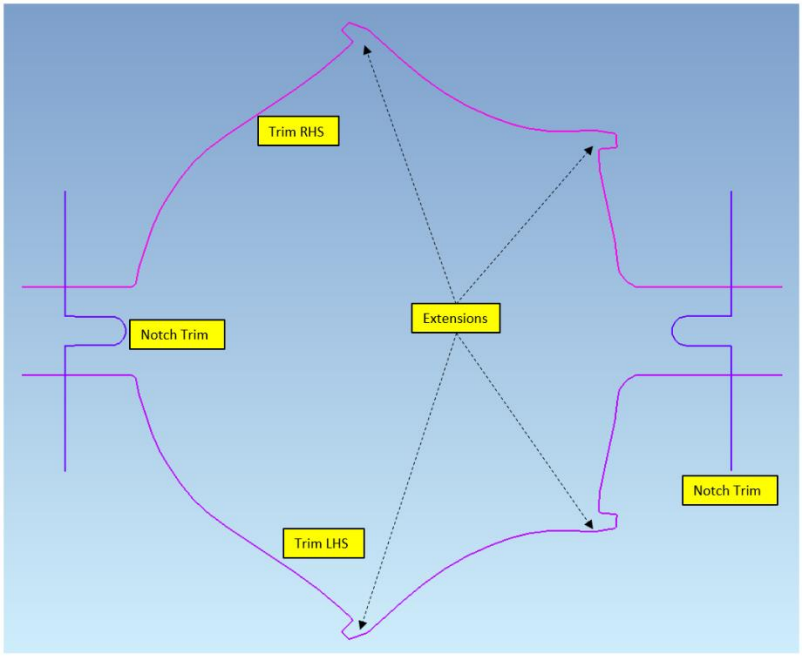
FLD Analysis



Thinning Analysis

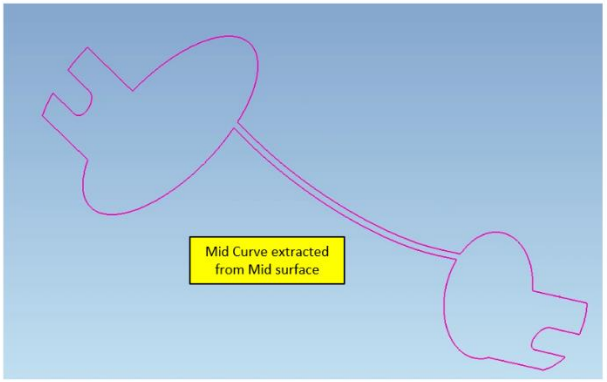


Optimization procedure for Accurate Results



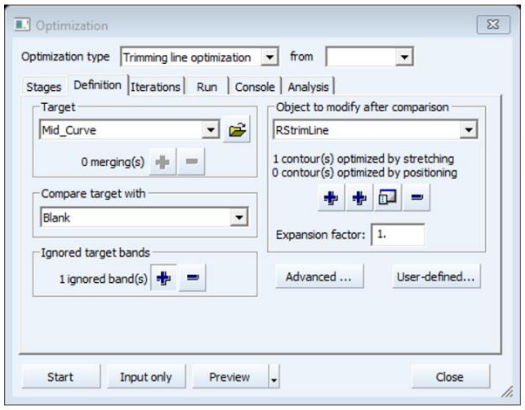
Trim Lines:

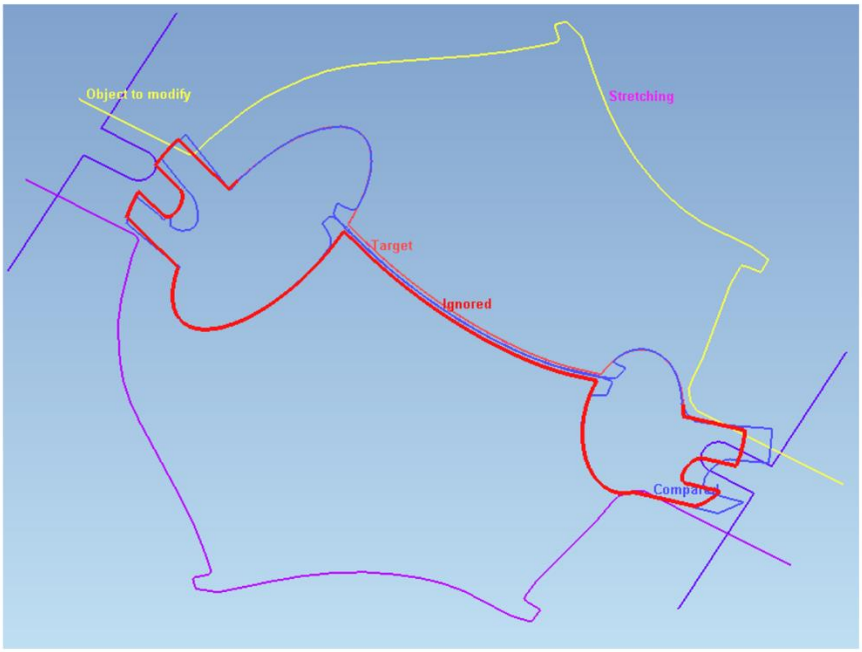
- Trim Lines extracted from the blank, obtained by opening the part in PAMSTAMP
- Divided into two sections
- Notches are trimmed for Locator pins
- Extensions are given to avoid bead formation after welding

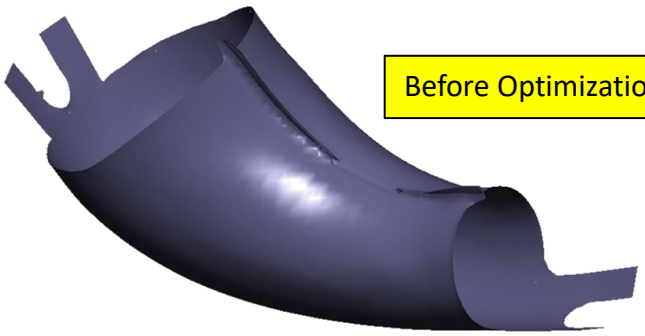


Optimization:

- One side is optimised at a time
- Target is the Mid surface curve
- Compared with the Blank obtained in simulation
- Object to be modified is the Trim Line
- Half part of the Mid surface curve is ignored
- And then the Optimization is started for one side

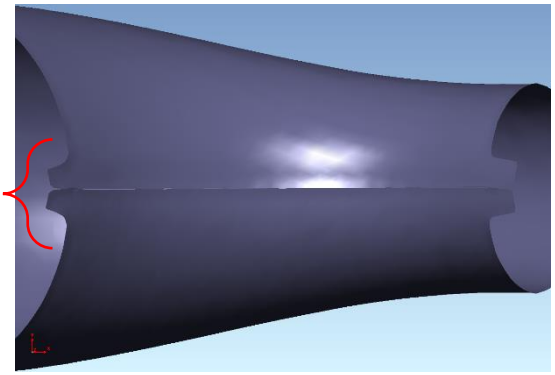






Before Optimization

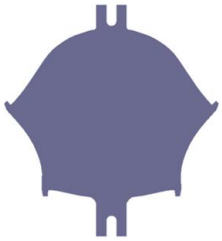
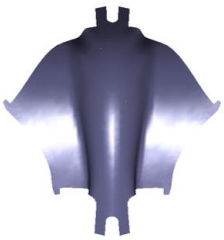
After Optimization



Negligible gap and blank extensions provided for the welding

U Forming

Wrinkle Analysis-Shading Steps

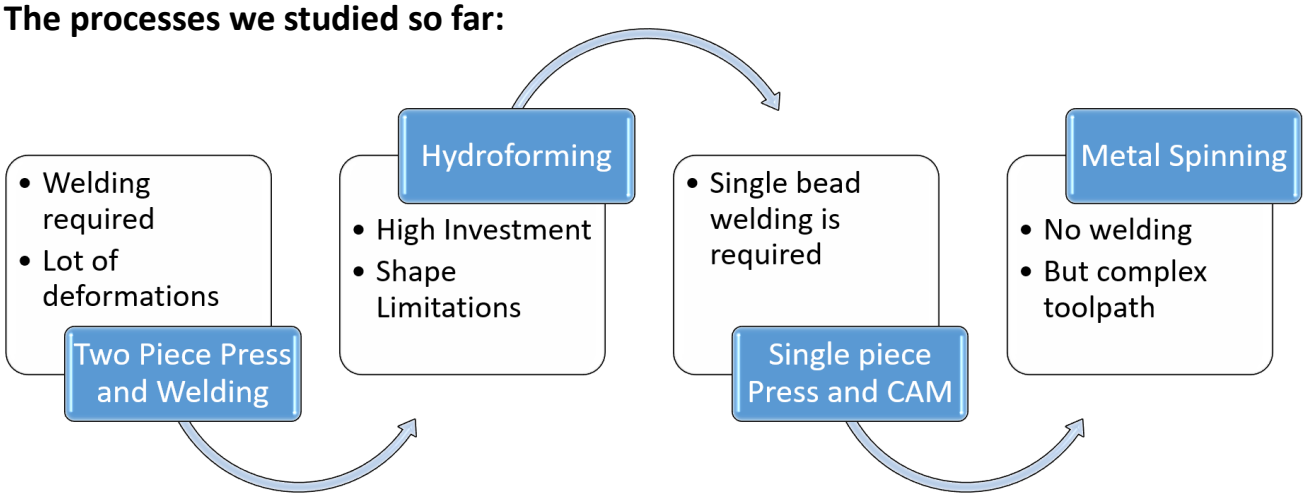
 Closing stage 150mm	 120 mm	 100 mm	 80 mm
 Forming stage 60mm	 40 mm	 15 mm	 0 mm

CAM Forming

Wrinkle Analysis-Shading Steps

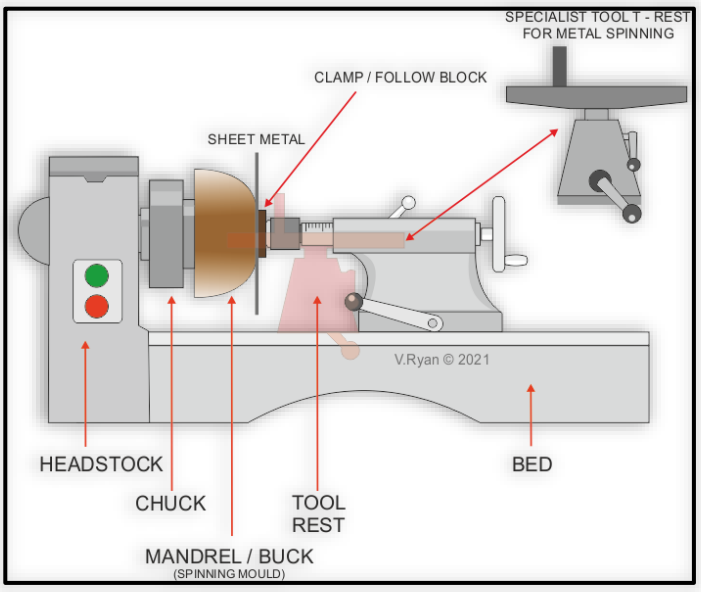
 Flanging stage 120mm	 100 mm	 40 mm	 20 mm
 10 mm	 4 mm	 2 mm	 0 mm

The processes we studied so far:



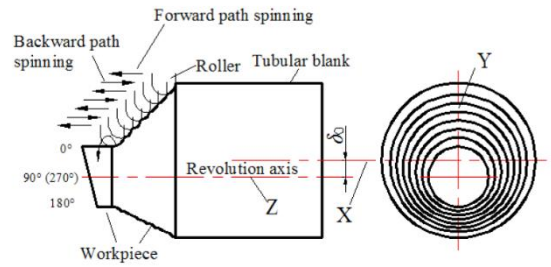
[4] Metal Sheet / Tube spinning (Incremental Forming)

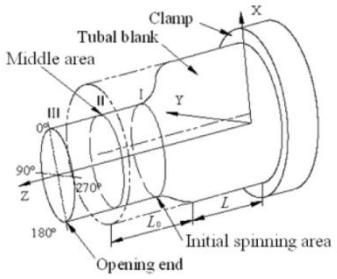
- Metal Spinning is widely used for manufacturing of Axisymmetric, thin walled-thickness and hollow circular cross-sectional parts.
- A roller is fed towards a metal blank or a tube, rotating together with the main spindle of the machine.



This process is advantageous because there occurs localised material deformation where the roller meets the metal blank / tube. Some of the advantages are listed below:

- **Lower forming loads**
- Simple tooling
- Good dimensional accuracy
- **High material utilization**
- Lower production costs
- Improved mechanical properties due to **work hardening**
- Lightweight parts can be easily obtainable
- Flexible for manufacturing

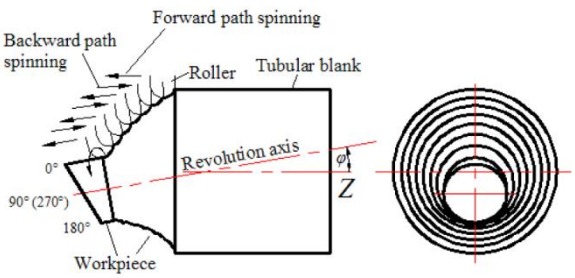


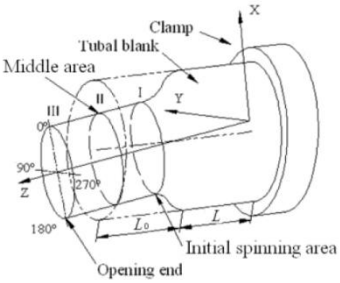


(a) offset tube.

For Non-Axisymmetrical parts we can:

- Offset Revolution axis
- Make the Revolution axis tilted (Oblique)





(b) oblique tube.

Xia, Qinxiang, Gangfeng Xiao, Hui Long, Xiuquan Cheng, and Xiangfei Sheng. "A review of process advancement of novel metal spinning." International Journal of Machine Tools and Manufacture 85 (2014): 100-121.

The main parameters that influence the process of spinning are:

- The Nominal reduction of the blank radius per path, Δ $\left(\Delta = \frac{D_0 - D}{2}\right)$, where D_0 is the initial diameter of the tube and D is the final diameter of the workpiece.
- Feed rate f
- Offset amount δ
- Oblique angle α

a 

b 

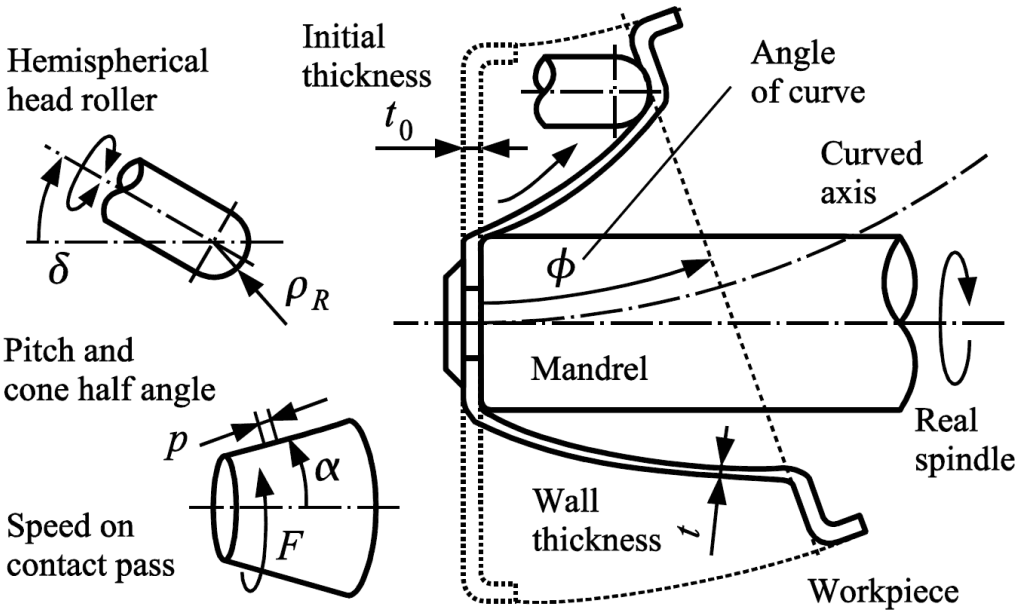
c 

a) offset tubes. (b) oblique tubes. (c) tube with offset and oblique end

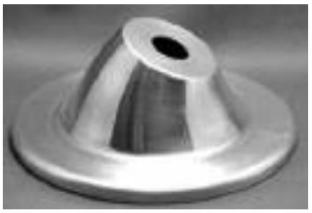
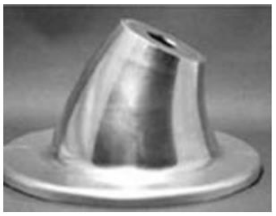
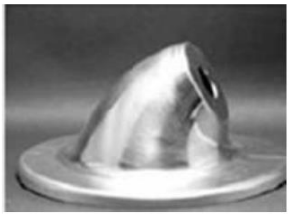
Sekiguchi et al. developed a spinning method which can be used to produce curved shaped and non-axisymmetric sectional shaped without using a dedicated die.

For this a NC Lathe was used. We can also go with any Robotic operation programmed to follow a complex curved path to obtain various complex spined geometries!

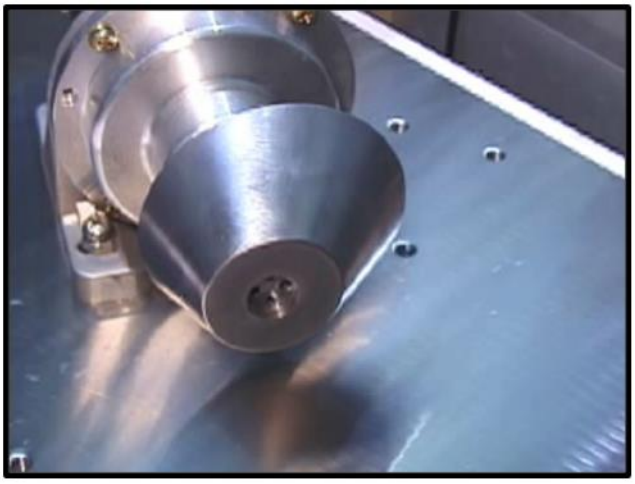
The desired trajectory of the spherical head tool can be easily calculated based on the final product shape.

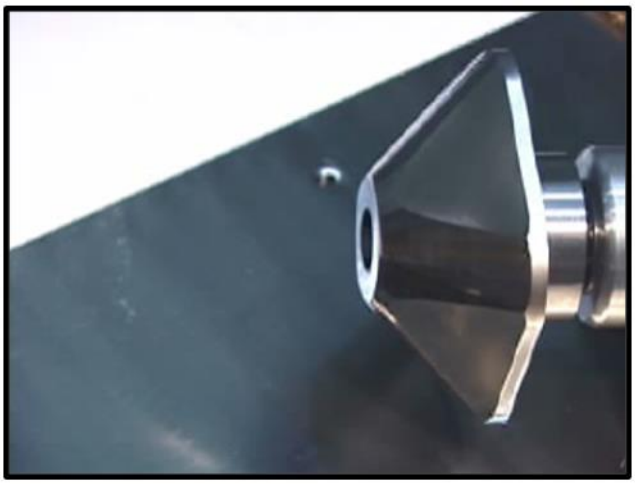


Sekiguchi, Akio, and Hirohiko Arai. "Synchronous die-less spinning of curved products." Steel research international 81, no. 9 (2010): 1010-1013.

a  b  c  d 

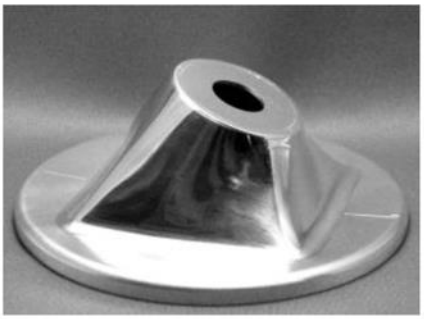
With Mandrel Operations

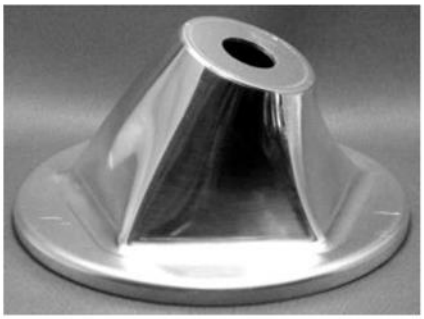


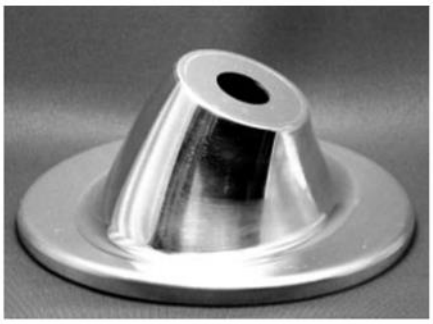


Polygon base

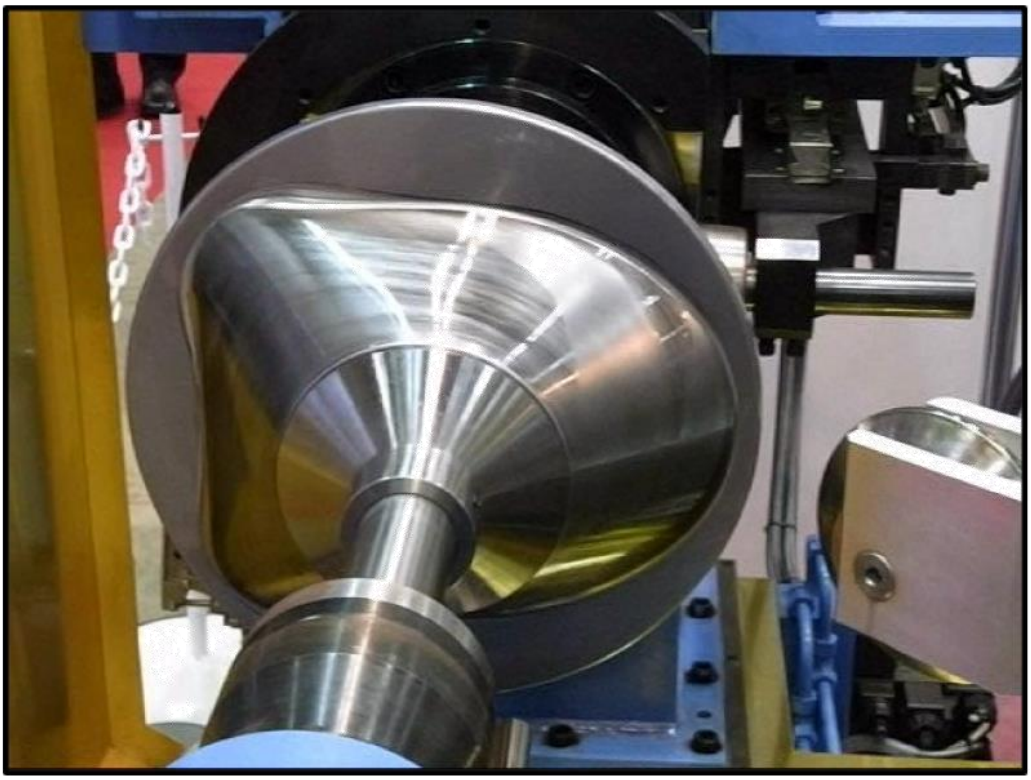
Elliptical base



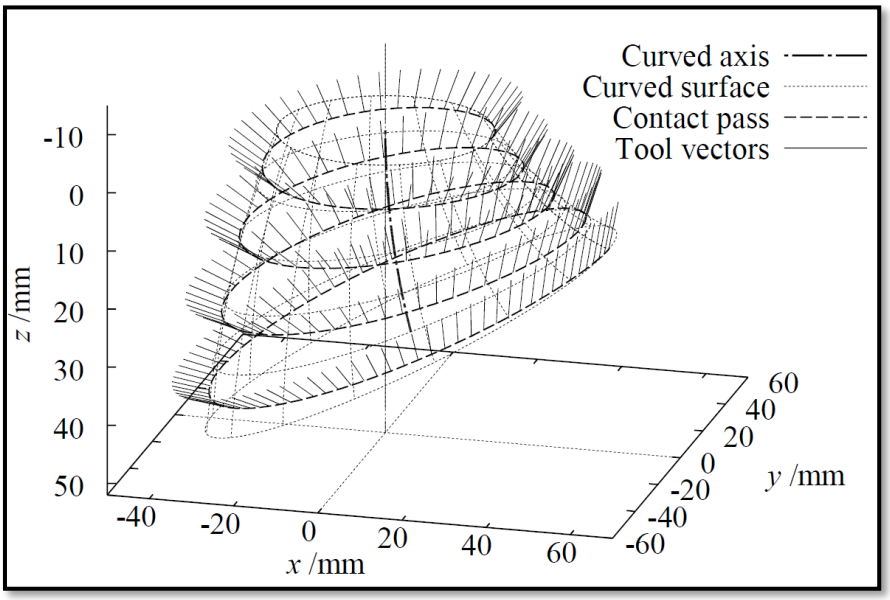




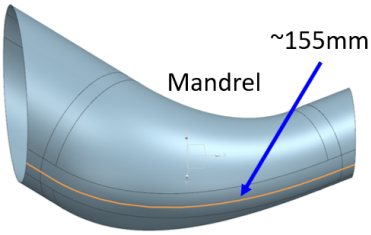
Without Mandrel Operations

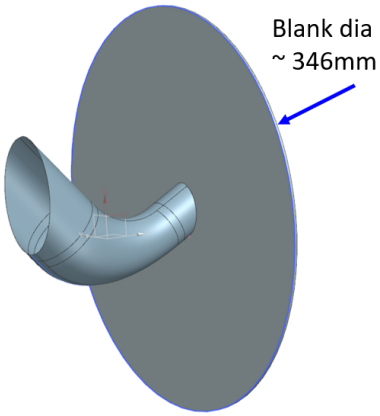


Sekiguchi, Akio, and Hirohiko Arai. "Synchronous die-less spinning of curved products." Steel research international 81, no. 9 (2010): 1010-1013.



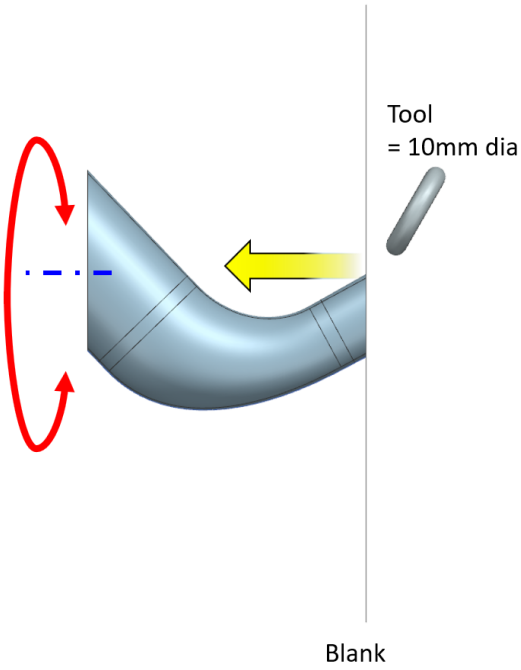
- The CAM tool moves on a curved axis.
- The workpiece Revolution axis could be placed at an offset as well as at an angle (oblique).
- Tool path needs to be generated for the complex manoeuvre of the CAM tool.
- Can be formed from both Sheet and Tubular blanks.



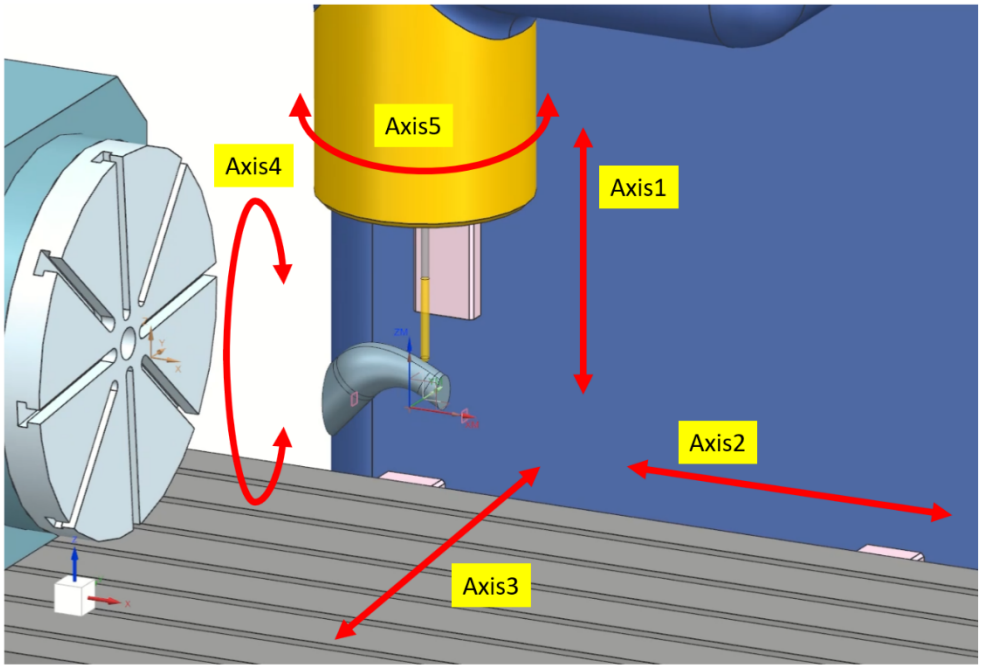


Sheet metal Spinning:

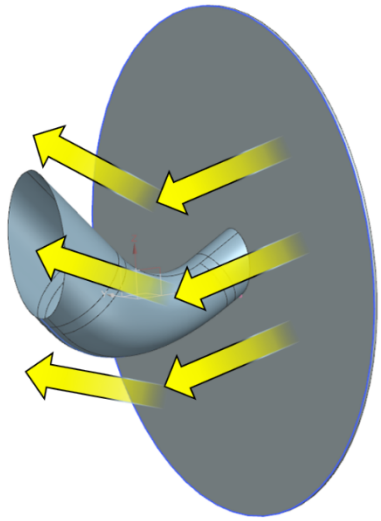
- The blank is loaded on the Mandrel
- A rounded disc shape tool travels to and fro along the surface of the mandrel with calculated safe stepovers
- The blanks then starts forming locally and takes the shape of the Mandrel
- A 4 axis Turning machine with a tilted CAM axis or a 5 axis Turning Machine is required for such operation



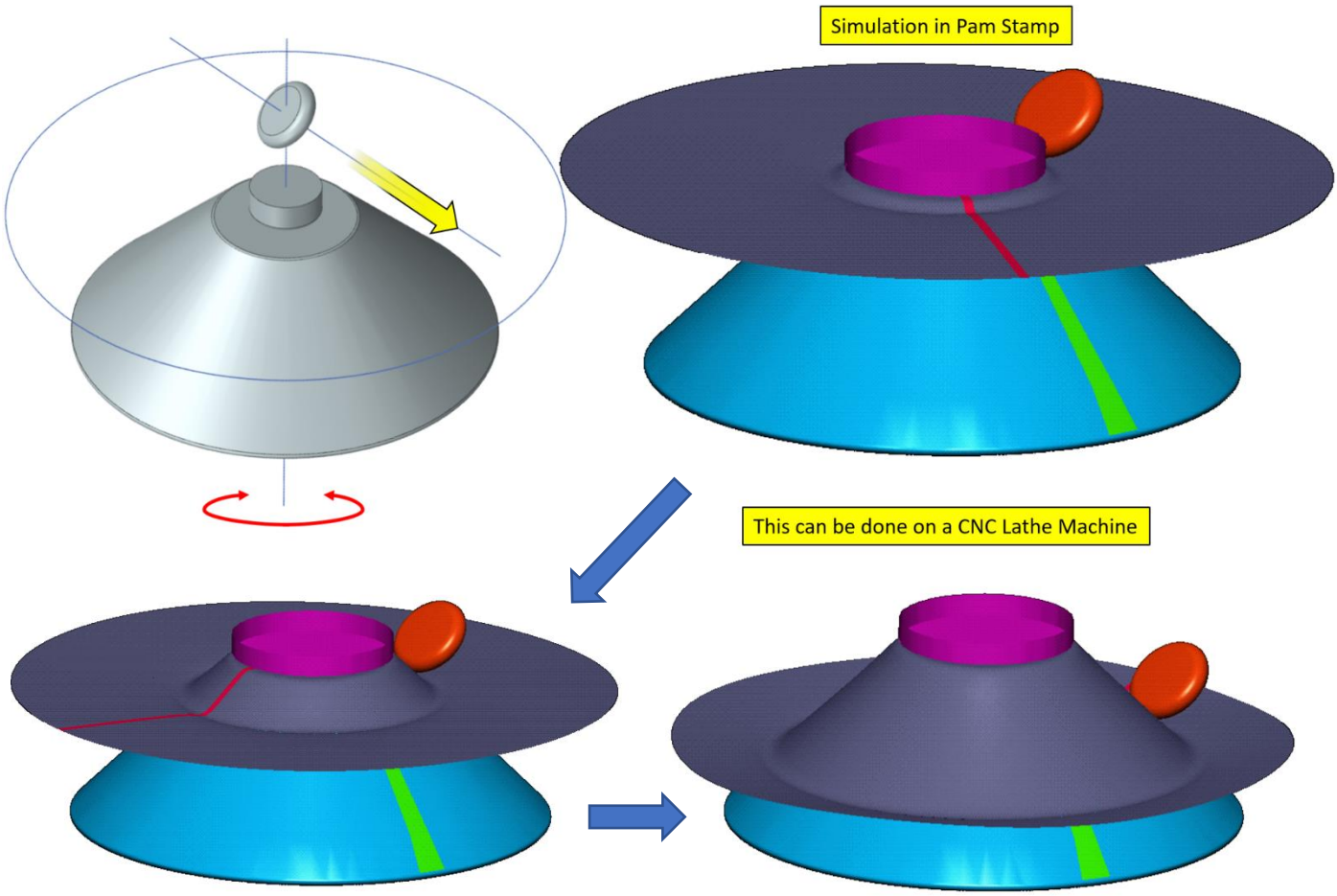
5Axis Simulation on Fanuc Machine in NX CAM



- 5 axis VMC used.
- Sheet metal takes shape of the Mandrel.
- Easy removal of part from Mandrel.



Simplified Spinning Simulation in Pam Stamp



PQCD Analysis:

	P	Q	C	D
[1] Hydroforming	Low • High cycle time • ~ 1 Strokes per minute	High • No weld required	High • Investment cost • Process cost	Medium • Development Time
[2] Hot Metal Gas Forming	Low • High cycle time • ~ 1 Strokes per minute	High • No weld required • Higher Formability	High • Investment cost • Process cost	Medium • Development Time
[3] U Press and CAM	High • Short cycle time • ~ 3-4 Strokes per minute	High • Welding Required • Additional Finishing	Low • Investment cost • Process cost • Additional Weld and Finishing cost	Low • Development Time
[4] Tube Metal Spinning (Incremental Forming)	Low • Very High cycle time • ~2 minutes for a single piece	High • No weld required • Forming lines removed by polishing	High • Investment cost • Process cost	Medium • Development Time

Conclusion:

- Learned Siemens NX and Pam-Stamp software.
- Manufacturing processes analyzed and compared:
    - Hydroforming
    - Hot Metal Gas Forming
    - U-Forming and CAM Operation
    - Metal Spinning
- U-Form and CAM method proved successful and the most cost effective from PQCD Analysis.
- Simulation results matching Theoretical calculations.
- Blank Optimization performed in Pam-Stamp.
- Studied various Research papers on Oblique and Offset Metal spinning process and did basic simulations.
- Went to company visits.
- Tour of full Bajaj Auto Chakan and Akurdi plant Assembly lines.