MODERN MACHINING & FORMING METHODS

(ELECTIVE - III) Instruction
4 Periods per week Duration of University Examination
3 Hours University Examination
75 Marks Sessional
25 Marks

Unit-IV

Syllabus
Rubber Pad Forming: Principle of the process, process details & its types; Guerin, wheelon, Marfoming & Hydro forming processes & applications.
High Energy Rate Forming (HERF): HERF hammers, principle of explosive forming, Explosive materials, types of explosive forming, stand off operation & contact operation, the pressure pulse, Gas bubble & the process applications.
Electro-Hydraulic forming (EHF): Schematic of the process description & its applications.

Suggested Reading:

1. P.C. Pandey & H.S. Shah, Modern Machining Process, Tata McGraw Hill Publishing Co. Ltd., New Delhi, 1980.
2. A. Bhattacharya, New Technology, The Institution of Engineers (India), 1984.
3. Davies & Austin, Developments in High Speed Metal Forming, The Machinery Publishing Co. Ltd., 1985.
4. Production Technology, HMT.

High Energy Rate Forming (HERF):

Alternate name: **High Velocity Metal Forming (HVMF)**

Difference between HERF & HVF:

HERF uses the energy is stored in some medium directly for the forming process.
HVF uses high velocities for the forming process.

HERF hammers, principle of explosive forming,

Process	Velocity m/sec (f/sec)
Hydraulic press	0.03 (0.10)
Brake press	0.03 (0.10)
Mechanical press	0.03-0.73 (0.1-2.4)
Drop hammer	0.24-4.2 (0.8-14)
Gas-actuated ram	2.4-82 (8-270)
Explosive (HERF)	9-228 (30-750)
Magnetic (HERF)	27-228 (90-750)
Electrohydraulic (HERF)	27-228 (90-750)

Basic introduction

HERF is a process that uses high energy shockwaves produced suitable charge & transferred by a suitable medium to deform the sheet into required shape.
HVF is a process that deforms products in Visco plastic state using very high velocities & extremely high pressures.

- It was discovered more than 100 years ago.
- Metals were being worked upon using HVF techniques as early as the 1930s.
- Due to the nature of the operations it would also be appropriate to name this technique as high velocity deformation rather than high velocity formation.
- The earliest known publication about impulse forming, an English patent, is related to tube joining & tube expansion, by means of an explosive charge [GB 21840].
- The first patent dealing with the explosive forming of sheet metal is [US 939702].

Need for HERF

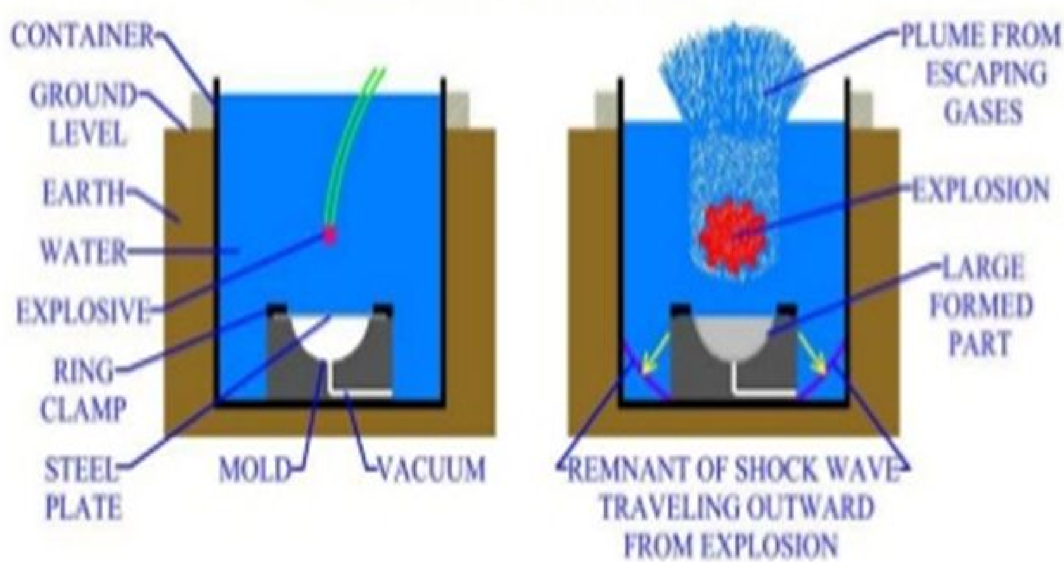
- As strain rate or deformation velocity increases:
    - Flow stress increases.
    - Adiabatic heating raises the temperature of workpiece.
    - Lubrication is improved (if lubricating film is maintained).
- Very very high deformation velocities & pressures are created.
    - Kinetic energy imparted to work before it hits the die.

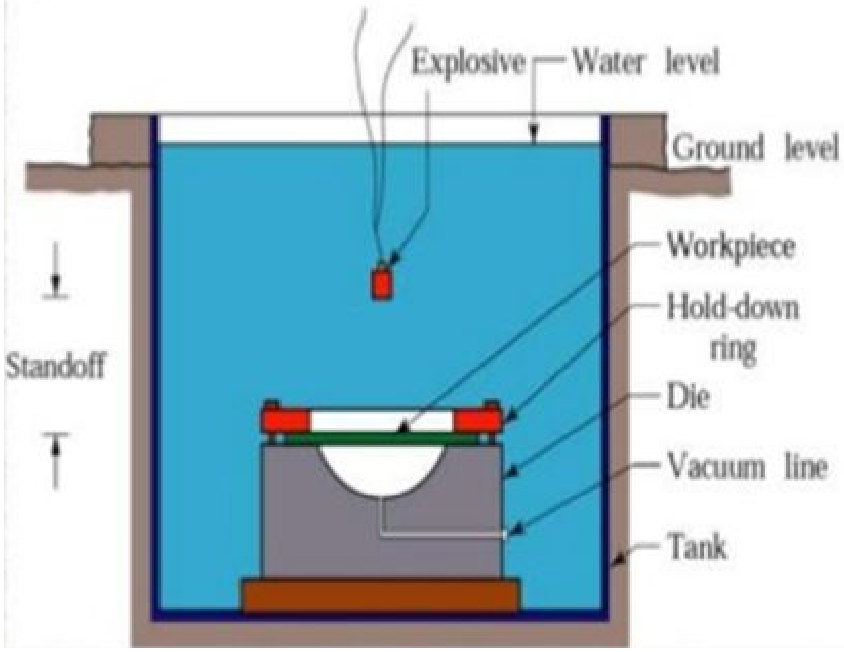
- ○ $KE = mv^2/2$ (Kinetic energy is proportional to the square of the velocity).
    - ■ High accelerations generate much higher velocities.
    - ■ Very high impact energy is transferred to the sheet.
- Choice is based on workpiece, geometry of deformation & safety requirements.
- Steel plates / tubes as thick as 25 mm thick have been has been successfully formed.

Types based on source of pressure / force:

- Explosive Forming
    - Contact type
    - Stand off type
- Electro Hydraulic Forming
    - Restrained
    - Unrestrained
- Magnetic Pulse Forming
- Pneumatic Mechanical Forming

Types of explosive forming, Stand off operation (unconfined)



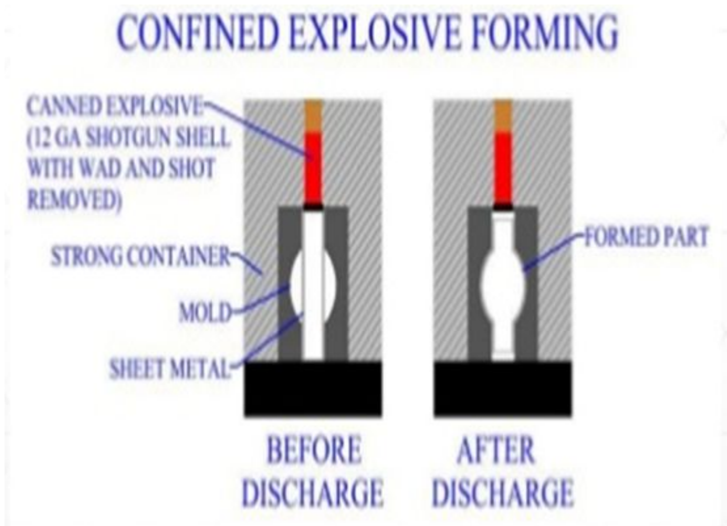


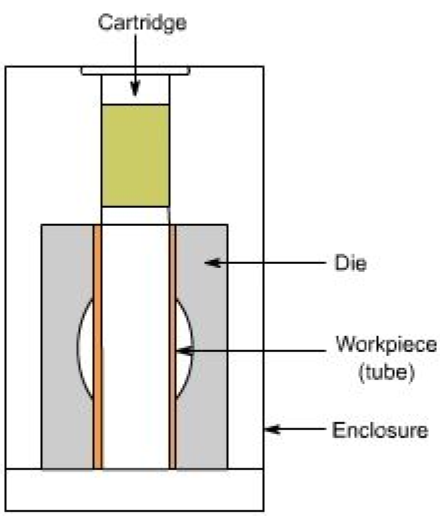
Contact operation,

- The charge is in direct contact with the workpiece (usually tubular).
- Hence energy is directly applied without any transfer medium.
- The tube collapses into die cavity & thus formed.
- Applications: Bulging & Flaring operations
- Advantages:
    - Entire shockwave is utilised as there is no loss in water.
        - More efficient compared to unconfined type.
    - Explosive thickness can be suitably varies as per requirement.

In the standoff operation, the peak pressures are typically lower than in case of the contact operation [Bru68]. The reason is that friction, heat conduction & expansion result in fractional dissipation of the detonation energy.

Furthermore, the explosive is formed to different shapes according to the application. In the standoff operation for drawing of sheets, spherical shapes are used, while tube bulging is done using twines. Cutting, embossing, & cladding of sheets are usually done in a contact operation using foils or powder. [Lan93].


CONFINED EXPLOSIVE FORMING
CANNED EXPLOSIVE (12 GA SHOTGUN SHELL WITH WAD AND SHOT REMOVED)
STRONG CONTAINER
MOLD
SHEET METAL
FORMED PART
BEFORE DISCHARGE
AFTER DISCHARGE


Cartridge
Die
Workpiece (tube)
Enclosure

- The deformation can be controlled by applying external restraints in the form of die or by varying the amount of energy released, Fig 2.

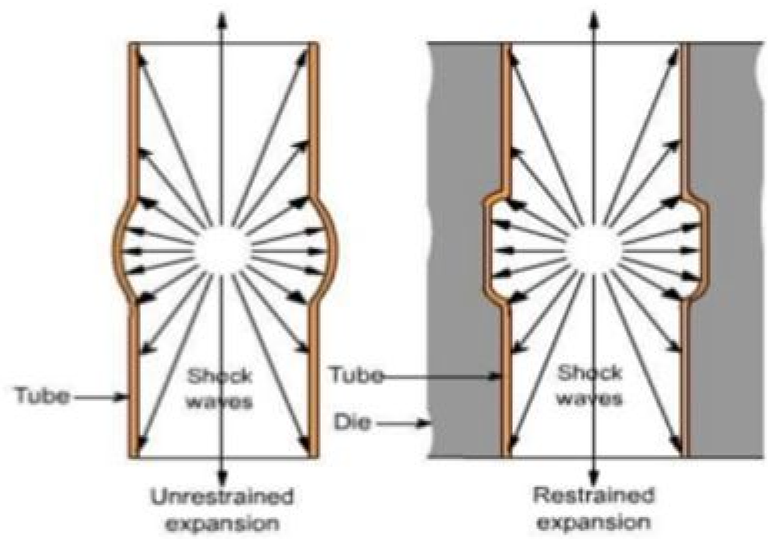


Fig 2 Unrestrained and restrained electro-hydraulic forming process.

Working principle

- High energy shock waves are generated in suitable medium.
- Sheet/Blank placed in its path is forced to deform into evacuated die cavity.
- Deformation occurs in visco plastic state which allows
  - Greater & efficient deformation (strain-rates) without failure.
- High particle/deformation velocities are involved.
  - Velocity range: 3 to 300 m/s (1000x of that in conventional)

Advantages

- Extremely fast process (deformation within milliseconds).
- Both male & female shapes possible.
- Enables extremely deep forming (much more than conventional stamping)
- Strain hardening results in greater strength in thinner parts.
- Complex shapes can be easily obtained compared to conventional methods.
- Almost zero spring back action even in titanium & tungsten.
  - Greater accuracy & precise tolerance.
- High production rate (Total cycle time is just a few seconds).
  - Single step process (not progressive stamping).
  - stamp / press / spin forming techniques are simulated in a single operation.
  - No intermediate or preforming process required.
  - Shorter time to market
- Overall low production cost due to

    - absence of power hammer / press.
    - Relatively lower die costs.
    - Lower energy cost as it uses less power.
    - Allows welding of dissimilar materials, thus reducing welding cost.
- Equipments take less space (low footprint).
    - Lightweight equipment with optimised constructions
    - Appealing specific design with flowing shapes.
- Uniform distribution of strain / pressure.
    - Minimal damage of the material surface.
- Smart & efficient design by integrating functionalities
- Large parts can be formed efficiently with suitable adjustments.
    - Upto 4’ square or 10’ in diameter.
- Suitable for large range of production volumes (small nos, batches or mass production).
- Improved Metal formability
    - Result: crisper & consistently formed part
    - 10%-60% more elongation without tearing
    - Wrinkling is suppressed allowing for a deeper draw while maintaining a uniform thickness in the part
- Less reliance on lubricants

Disadvantages

- Skilled personnel required to operate.
    - Explosives, electric discharge or electromagnetic waves need special care.
    - Inefficient control may produce undesirable results.
- Not suitable for indoor production due to shock waves & water spillage.
- Not suitable for brittle materials.
- Forming of large parts is expensive (due to vacuum requirement).
- Essential to know the behaviour & establish performance of work metal before hand.
- Bigger dies needed to withstand high energy rates / shocks & prevent cracking.

Applications

- Deep recessing (Cup, Cones)
- Extrusion, die-forging, punching, joining. draw forming, cupping, bulging, swaying, flanging
- die forming cutting, welding & surface hardening.
- Shallow recessing (Beaded panels, irregular shapes)
- (Tubes, Nozzles, ducts)
- Plane contoured parts (Singly curved, compound curvature & reversely curved).
- Materials: magnesium, aluminium, zirconium, alloys steel, beryllium, titanium, carbon & stainless steel, superalloy & the refractory metals.
- Can be used to improve joining methods such fusion welding.
- Impact welding using highly velocity techniques gives better results than the conventional fusion welding techniques

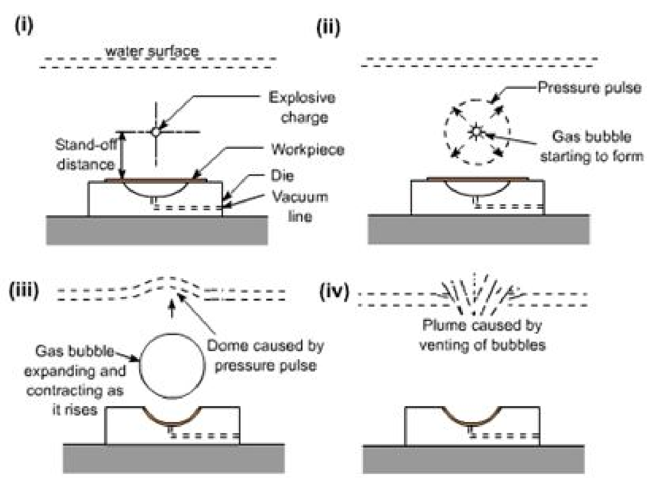
Type 1 : Explosive forming

Equipment

- Explosive materials
  - High energy chemicals – TNT, RDX, Dynamite …
  - Gaseous mixtures
  - Propellants
- One sided die with evacuating hole/s.
- Transfer medium: Water to submerge the explosive charge. It
  - acts as energy transfer medium
  - ensures uniform transmission of energy
  - muffles the sound of explosion (noise reduction)
  - helps in cushioning/smooth application of shockwave energy.

Process description

- The work is firmly clamped on the die.
- Die cavity is evacuated.
- A definite quantity of explosive charge is placed in position.
  - The explosive is submerged under water.
- The explosive charge is detonated.
- A pressure pulse & gas bubble (shock wave) of high intensity is produced.
- The pressure deforms metal into the evacuated die cavity.
- gas bubbles vent at the surface of water.



Process variations

- **Contact type**
- **Stand off type**

Process parameters

- Relative velocity
- Friction
- Geometrical stability of the components
- Brisance of the explosive.
- Stand off distance
- the density of the transfer medium
- the humidity of the working medium are decisive with regard to the efficiency of the energy transfer and, consequently, considering the pressure applied to the workpiece.

Wave effect: whenever a shock is transmitted through a medium denser than the blank part, it is partly transmitted & partly reflected back as compressive shock waves. This causes the metal deform towards the die.

pressures (upto 30,000MPa)

Performance characteristics

- Surface finish
- Spring back effect

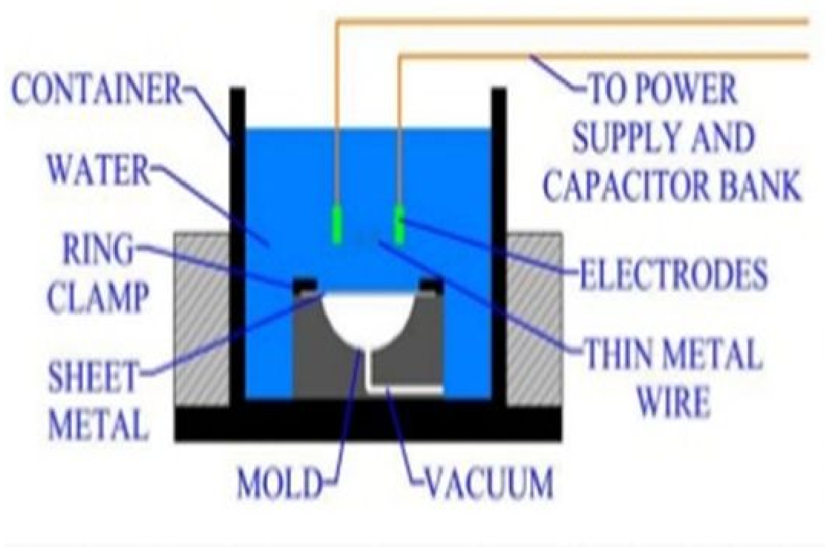
Disadvantages (in addition to HERF)

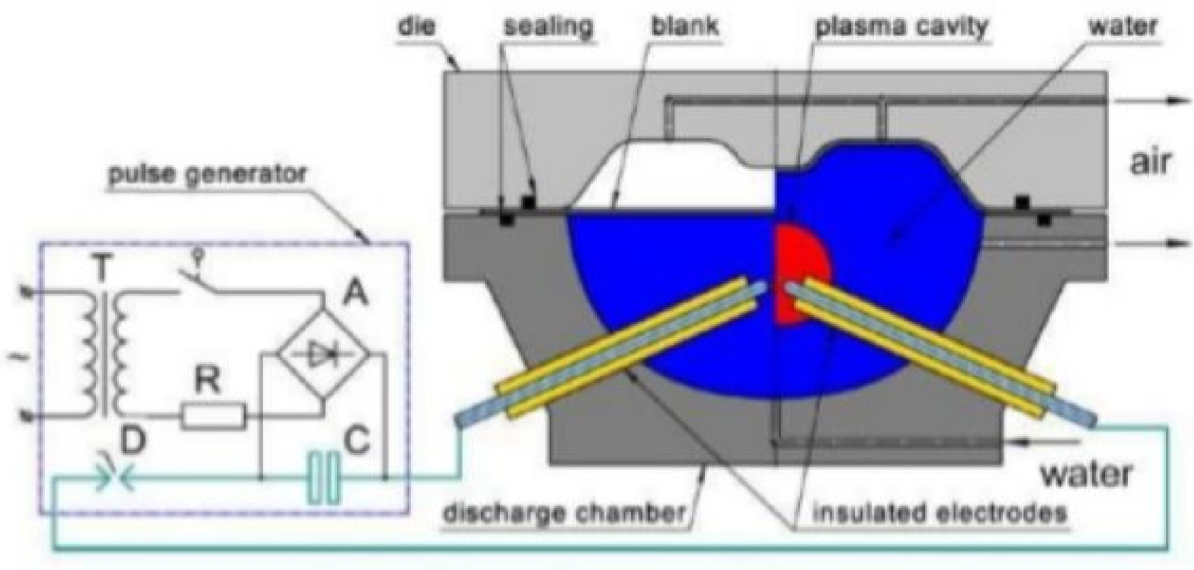
- Lot of government regulations / procedures / safety laws to be followed.
- Impurities formed due to high temperature may give surface defects.

Type 2 : Electro-Hydraulic Forming (EHF):

Also called as **Electro Spark Forming**

Schematic of the process description & its applications.





Schematic of sheet metal forming with an EHF chamber die.

Basic Introduction

An electric arc discharge in liquid is used to convert electrical energy to mechanical energy & change the shape of the workpiece.

- A capacitor bank delivers a pulse of high current across two electrodes, which are positioned a short distance apart while submerged in a fluid (water or oil).
- The electric arc discharge rapidly vaporizes the surrounding fluid creating a shock wave.
- The workpiece, which is kept in contact with the fluid, is deformed into an evacuated die.
- The potential forming capabilities of submerged arc discharge processes were recognized as early as the mid-1940s (Yutkin L.A.).
- During the 1950s & early 1960s, the basic process was developed into production systems.
- This work principally was by & for the aerospace industries.
- By 1970, forming machines based on submerged arc discharge, were available from machine tool builders.
- A few of the larger aerospace fabricators built machines of their own design to meet specific part fabrication requirements.

The deformation can be controlled by applying external restraints in the form of die or by varying the amount of energy released, Fig 9.4.

Equipment

- Discharge chamber containing water with 2 passages.
  - 1st passage is at the bottom to supply water into the chamber.
  - Another passage is near the top to allow outflow of air.
- Insulated electrodes with exposed tips placed immersed in the water.
- One sided die with the forming shape & evacuation holes in cavity.
- Blank/sheet is tightly clamped between the two.

- Pulse generator supplies pulsated high energy current to the electrodes.
    - Consists of
        - High voltage low inductive capacitor bank.
        - High voltage/current discharge switch.
        - Charging, amplifying & rectifying circuit.
    - Capacity:
        - Voltage 5 to 25 kV
        - Energy upto 100 kJ.

Process Description / Working:

1. Blank / sheet is clamped between the discharge chamber & die.
2. Water is filled in the discharge chamber & air allowed to escape.
3. Air is evacuated from the die cavity.
4. High energy spark / discharge is induced in the electrodes with current from Bmax system.
    a. Electrical breakdown occurs at the exposed tips of electrode.
    b. Stable plasma channel is formed.
    c. It expands quickly into a bubble.
    d. The bubble expands due to high pressure creating shockwaves.
5. The shockwaves deform the sheet into the die cavity.
    a. Deformation occurs in visco plastic state.
    b. And at Ultra high speed.
6. All of which happens in a matter of milliseconds; total cycle time of seconds including charging time of the system

Process Variations

- More electrodes are sometimes used
    - for larger sheet.
    - for uniform distribution of pressure.
- Deformation can be controlled
    - by external restraints (die) or
    - by varying amount of energy released.

According to the type of spark gap

- electrohydraulic forming with discharge through a wire (i.e. the electrodes are connected to each other by a wire bridge) and
- electrohydraulic forming with discharge through a gap (i.e. there is no connection between the electrodes) can be differentiated.

Process Parameters:

- Stand Off Distance (SOD): To be kept optimum.
- Capacitor size: Affects energy density of pulse.
- Transfer medium: Mostly water is used.
- Vacuum: Prevents adiabatic heating from compressed air in die.
- Deformation velocity: 120 m/s.

Performance Characteristics

- Intricate details & sharp edges possible easily.
- Extremely deep forming possible.
- Gives even distribution of thickness
- High strength in thinner materials.

Advantages (in addition to HERF)

- Safer in handling than the explosive forming.
- No hazardous chemicals for cleanup
- No electromagnetic emissions
- Not limited by size (upto 3-5 m^2 sheets can be formed).
- Forming chamber is self balanced.
- Better suited for automation due to:
    - Fine control of multiple sequential energy discharges.
    - Relative compactness of electrode media containment system.
- EHF can form hollow shapes with much ease & at less cost compared to other forming techniques.

Disadvantages (in addition to HERF)

- Fluid draining/replacement required for each cycle.
- Large capacitors needed for equivalent power of little explosive.
    - Hence, expensive for large parts.

Applications

- All materials that can be formed by conventional forming processes.
- Metals: Titanium, Tungsten, Aluminium & alloys, Stainless Steel, Inconel 718, nickel alloys,
- Not suitable for materials with low ductility or critical impact velocity < 30 m/s.
- Suitable for smaller radar dish, cone & other thinner smaller works.
- Aerospace: low volume components.
- Electronic industry: Miniature fancy equipment with complex profiles.
- Automobile: inside components of passenger car door.

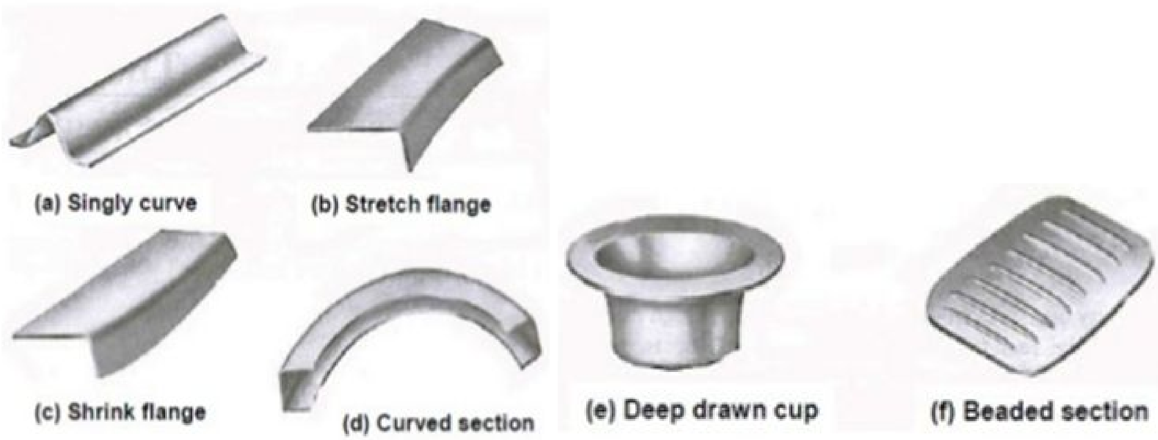
Extra

According to [Wil64], the setup with a wire bridge is more efficient & can be operated at lower voltages & longer distances between the electrodes, while in case of the setup with discharge through a gap, the process preparation is easier & faster.

The efficiency of an electrohydraulic process can be increased by using a suitable reflector. The reflector design needs to be done taking into account the specific forming task & considering that every redirection of the pressure war is related to energy losses. As shown in [Kle01], the shockwave can be focused by using an elliptic reflector geometry. Spherically spreading from the spark gap, which is positioned in the first focal point of the ellipse, the shockwave is reflected

& converges in the second focal point. Other reflector geometries can be used for bulging tubes of different dimensions.

Accuracy depends on the control of both the magnitude & location of energy discharges & on the dimensional accuracy of the dies used.
Modern equipment allows precise control of the energy within specified limits.
External dimensions on tubular parts are possible to achieve within ± 0.05 mm with the current state of technology.


(a) Singly curve
(b) Stretch flange
(c) Shrink flange
(d) Curved section
(e) Deep drawn cup
(f) Beaded section