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# BS6 Exhaust Muffler Outlet Bend Pipe Drilling Fixture

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***Abstract: This study presents the design and development of a BS6 exhaust muffler outlet bend pipe drilling fixture to improve accuracy, efficiency, and productivity in automotive exhaust systems manufacturing. The fixture ensures precise hole drilling on complex geometries of bent pipes, which are crucial for the adherence to BS6 emission norms.***
***Challenge is to drill a bigger size diameter 23 mm hole into a BS6 Exhaust Muffler Outlet Bend Steel Pipe having sumptuous wall thickness of 2mm and which is having Curvature Shape due to its peculiar placement in a BS6 Exhaust System of a reputed Diesel Locomotive. The research outlines the design process, material selection, and performance testing of the fixture, demonstrating its potential to streamline production and reduce manufacturing errors. Results indicate significant improvements in operational efficiency and hole-placement accuracy, aligning with the industry's demand for high-quality emission-control components.***
***Keywords: Exhaust Muffler Outlet, Bend Pipe, Fixture, BS6 emission.***

## I. INTRODUCTION

The automotive industry is evolving rapidly, driven by the need to comply with stringent emission norms such as BS6. These standards necessitate significant improvements in exhaust system design and manufacturing. The exhaust muffler outlet, a critical component in emission control, requires precise machining to ensure optimal functionality. Among the challenges is the drilling of bent pipes, which feature complex geometries to navigate confined spaces in vehicle designs. Achieving precision in hole drilling on these pipes is essential for ensuring proper alignment and assembly in exhaust systems

In order to meet Stringent Emission Norms Many OEMs are developing New Tactics and Techniques in their Exhaust Systems. In a similar attempt here we need to Drill a bigger size Hole near Flange End of this Exhaust Bend Pipe at some Specific Position and with the prescribed Orientation to accommodate fitting of DPF (Diesel Particulate Filter) Collector System component.

This research focuses on the development of a bend pipe drilling fixture tailored for BS6 exhaust muffler outlets. The fixture is designed to address the unique challenges posed by the curved geometry of pipes, incorporating robust clamping mechanisms, precise positioning systems, and user-friendly operation. By integrating this fixture into the production process, manufacturers can achieve higher precision, reduce operational costs, and meet the quality standards demanded by modern automotive regulations. As requirement for this vehicle is in terms of Thousands of Units per Month, Adapting Mass Production is inevitable for this kind of operation.

Main hurdle in going for Mass Production for this kind of Drilling operation is Curvature Bend Shape of this Exhaust Pipe and so initially rejection rate for this component climbs up to as high as 25 -30 % of the whole lot.

## II. LITERATURE REVIEW

### *A. BS6 Emission Standards and Their Impact on Exhaust System Design*

The introduction of BS6 emission norms in India, which are equivalent to Euro 6 standards, has driven the need for more efficient exhaust systems. BS6 norms mandate a significant reduction in nitrogen oxides (NOx), particulate matter, hydrocarbons, and carbon monoxide emissions. These requirements have led to the design of more complex exhaust systems, including after-treatment devices like diesel particulate filters (DPFs) and selective catalytic reduction (SCR) systems, as well as advanced mufflers (Sarah et al., 2020). The complexity of these systems, coupled with tighter packaging constraints in modern vehicles, has necessitated the development of precision manufacturing techniques, especially for components like bent pipes, which help optimize space and airflow dynamics.

### B. Precision Drilling on Complex Geometries

Drilling on curved surfaces requires specialized equipment to achieve accuracy. A study by Smith et al. (2020) highlights the issues associated with traditional drilling techniques on bent pipes, such as hole misalignment and inconsistent depths. The authors recommend the use of fixtures equipped with advanced clamping and positioning systems to mitigate these challenges. Their research also underscores the need for repeatability in hole placement, which is essential for proper assembly in exhaust systems.

### C. Bend Pipe Fabrication and Challenges

Pipes with complex geometries are widely used in automotive exhaust systems to navigate the confined spaces within the vehicle chassis while ensuring optimal gas flow. Studies have shown that maintaining accurate dimensions during bending is crucial for the performance of exhaust systems.

According to Han et al. (2019), precise control of bending processes is vital for ensuring minimal deformation, thinning, or wrinkling of pipes. Deviations in pipe geometry can lead to misalignments, poor performance, and even system failure in extreme cases. Moreover, bent pipes present unique challenges for downstream processes like drilling, where hole positioning needs to be highly accurate to ensure proper assembly and functionality.

### D. Challenges in Bend Pipe Fabrication

Pipes with complex geometries are essential in automotive exhaust systems to navigate confined spaces while maintaining efficient gas flow. According to Han et al. (2019), achieving precise pipe geometry during bending is critical to avoid deformation, thinning, or wrinkling. Such imperfections not only affect structural integrity but also create challenges in subsequent processes like drilling. Ensuring dimensional accuracy during bending is thus vital for maintaining the overall functionality of the exhaust system.

## III. METHODOLOGY

### A. Design Specifications

Challenge is to Drill a bigger size Diameter of 23 mm hole into a BS6 Exhaust Muffler Outlet Bend Steel Pipe having sumptuous wall thickness of 2mm and which is having Curvature Shape due to its peculiar placement in a BS6 Exhaust System of a reputed Diesel Locomotive.

Designing a holding fixture for mass production of drilling a 23 mm hole into a SUS 439 steel pipe with a bent shape (200 mm length, 44 mm diameter, and 2 mm wall thickness) requires a robust, repeatable, and efficient solution.

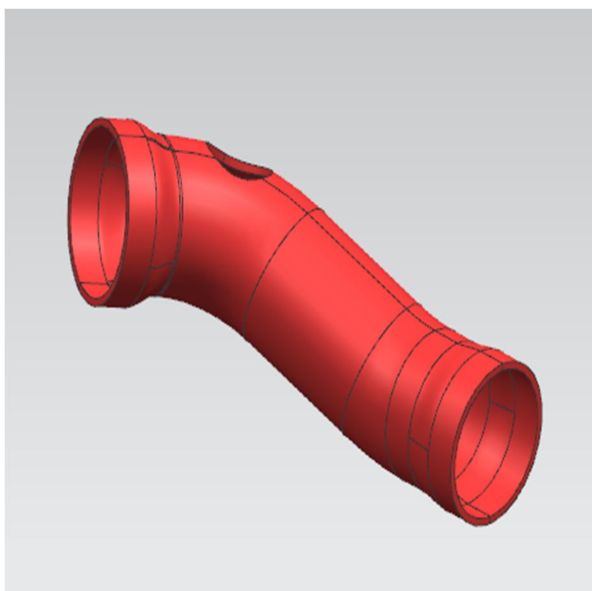

Figure 1

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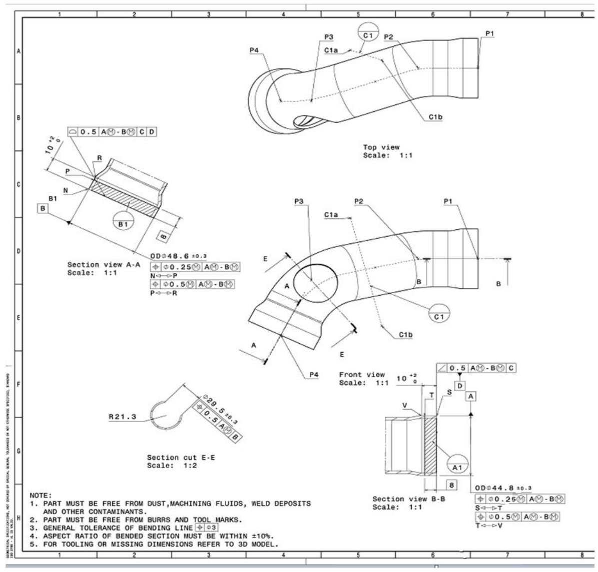


Figure 2

### *B. Input Data*

- Material: SUS 439 (stainless steel)
- Tensile strength ≈ 450 MPa
- Brignell hardness ≈ 160
- Drill diameter (D) = 23 mm
- Cutting speed (Vic): 20 m/min
- Feed rate (f): 0.2 mm/rev
- Drill point angle: 118∘

### *C. Material Selection for Fixture Components*

The selection of materials for the tool and fixture is crucial to ensure durability, precision, and resistance to wear during the drilling process. The following materials have been chosen based on mechanical properties, machinability, and cost-effectiveness:

- Fixture Base and Clamping Elements: High-carbon steel (AISI 1045) is selected due to its excellent toughness, wear resistance, and ability to withstand drilling forces without deformation. It has a tensile strength of approximately 585 MPa and good machinability for creating precise fixtures.
- Bushings and Locating Pins: Case-hardened alloy steel (EN31) is used for bushings and locating pins to prevent wear from repeated use. With a hardness range of 58-62 HRC, it ensures prolonged fixture life.
- Clamping Bolts: High-tensile bolts of Grade 8.8 steel with a proof load stress of 640 MPa provide reliable fastening without failure under high drilling forces.
- Work piece Material (SUS 439 Stainless Steel): Chosen for its high corrosion resistance and adequate strength for exhaust systems. It has a tensile strength of approximately 450 MPa and Brignell hardness of 160, ensuring sufficient structural integrity while being drillable with appropriate tooling.

### *D. Design Considerations*

The Rest, Locate, Clamp methodology ensures a work piece is securely and precisely held in position during a process like machining or assembly. It involves:

**1.** Rest:

- Provides a stable base for the work piece.
- Supports the work piece to prevent sagging or movement.
- Typically involves flat or contoured surfaces, adjustable supports, or V-blocks.

**2.** Locate:
- Restrains specific degrees of freedom (DOFs) to precisely position the part.
- Uses locators like pins, bushings, or slots.
- The 3-2-1 Principle is a common method:
  - 3 points on the primary datum plane.
  - 2 points on the secondary datum plane.
  - 1 point on the tertiary
  - datum plane.

**3.** Clamp:
- Applies force to hold the part securely against the locators and rests.
- Prevents movement during operations.
- Should exert sufficient force without deforming the work piece.

### *E. Controlling the 6 Degrees of Freedom*
A part in space has six possible degrees of freedom (DOFs):
- 3 Translational: Movement along X, Y, and Z axes.
- 3 Rotational: Rotation about X, Y, and Z axes.

3-2-1 Principle is used to restrict these DOFs:

**1.** Primary Plane (3 Resting Points):
- Eliminates 3 translational DOFs: up/down, left/right, and forward/backward.
- Prevents the part from moving away from or tilting about the primary plane.

**2.** Secondary Plane (2 Locators):
- Eliminates 2 rotational DOFs about the primary axis and the plane.
- Typically, perpendicular to the primary plane.

**3.** Tertiary Plane (1 Locator):
- Eliminates the final rotational DOF.
- Ensures stability and precision.

### *F. Poke-Yoke Concept in Fixtures*
**Poke-Yoke** (Japanese for "mistake-proofing") ensures that errors are prevented or made obvious in the operation process. In fixture design, it involves:

1. Incorrect Loading Prevention:
- Use asymmetric locators, pins, or shaped rests to ensure the part can only be placed in the correct orientation.
- Example: A slotted locator that matches a specific feature of the part.

**2.** Error Detection:
- Include sensors or limit switches that detect improper placement or missing parts.
- Example: A proximity sensor that verifies the work piece is correctly seated.

**3.** Guided Assembly:
- Color-coding or labels for easy identification of fixture components or placement zones.
- Provide clear stops or guide rails to aid positioning.

**4.** Redundant Verification:
- Double-check alignment using tactile or optical feedback.

*G. Resting Provision – Fixture Bottom Half*

Considering Curvature Shape of component, to ensure proper and firm resting area, we have provided **Fixture Bottom Half with** Surface development to ensure positive contact with the Bent Pipe.

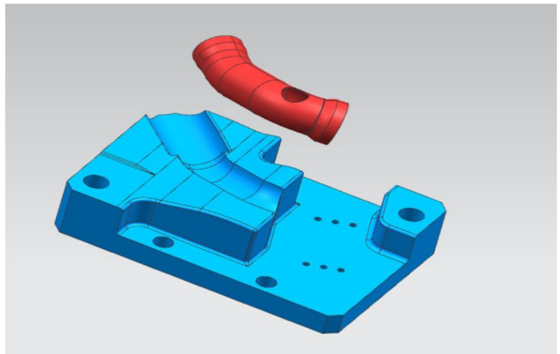

Figure 3

*H. Location Provision – End Face Locator*

Here the End Face Locator Assembly is provided with Shim Arrangement to Arrest and Locate the Bent Pipe End Face after Placing into the Bottom Fixture Half. Due to curvature Bottom resting and Flat end face arrested the Component automatically get aligned itself to the desired position and orientation for drilling operation.

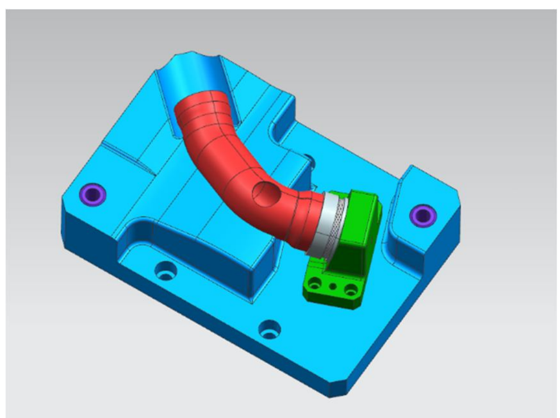

Figure 4

*I. Clamping Provision - Fixture Top Half*

Considering Curvature Shape of component, to ensure proper and firm clamping, we have provided **Fixture Top Half with** Surface development to ensure positive contact with the Bent Pipe assuring Rigid Clamping.

Thus we ensure Positive REST, LOCATE and CLAMP arrangements for Bent Pipe ensuring Hole axis should match with the Drilling Axis.

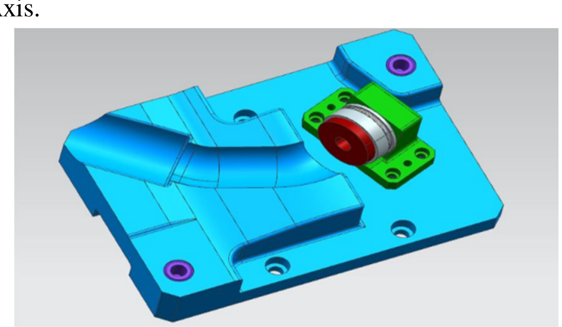

Figure 5

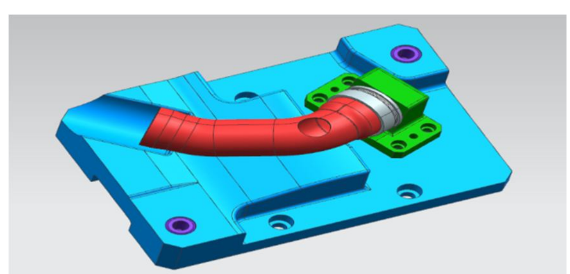

Figure 6

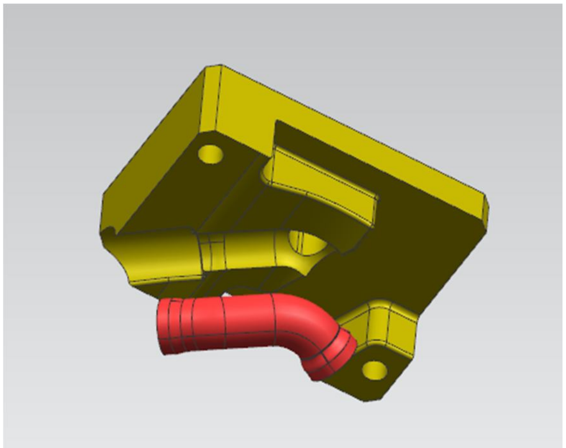

Figure 7

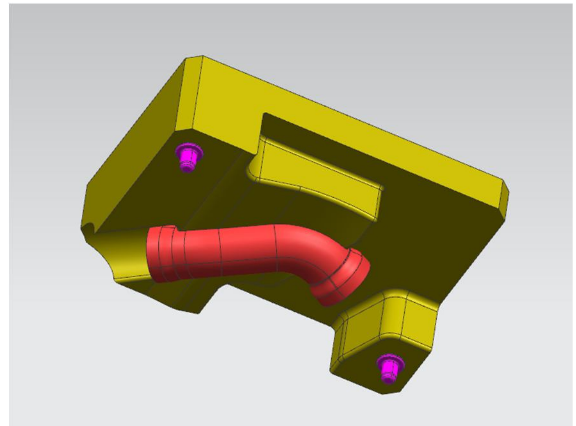

Figure 8

1. Drilling Force Calculation

a. Determine Spindle Speed:

$$N = \frac{1000 \times V_c}{\pi \times D}$$

$$N = \frac{1000 \times 20}{\pi \times 23} \approx 276\,\text{RPM}$$

b. Drilling Thrust Force:

$$F_t = \frac{c_1 \cdot D^x \cdot f^y}{1000}$$

- $c_1 = 0.85 \cdot \sigma_b$ (material-specific coefficient)
- $\sigma_b$ = ultimate tensile strength
- $x = 1.5, y = 0.85$ (empirical constants)

Substituting values:

$$F_t = \frac{382.5 \cdot (23^{1.5}) \cdot (0.2^{0.85})}{1000} \approx 714.5\,\text{N}$$

Thus, the drilling force is approximately 715 N.

Drilling Machine and Tooling Selection

To achieve precise hole placement in the curved 3D bent pipe, a CNC Vertical Drilling Machine with programmable control is used. This machine ensures repeatability, accurate positioning, and minimal operator dependency.

- Machine Model: HAAS VF-2 CNC Vertical Mill
- Drill Type: Solid Carbide Twist Drill with Tail coating for enhanced heat resistance and prolonged tool life
- Coolant System: Flood coolant is used to minimize heat build-up and improve drill longevity
- Hole Positioning Accuracy: ± 0.05 mm

2. Holding Force for the Component

The holding force must counteract the drilling force and provide safety against vibration and sliding.

Factor of Safety (FOS):

A typical FOS of 3–5 is recommended.

Assume FOS=4.

$F_u = F_t \cdot FOS = 715 \cdot 4 = 2860N$

3. Nut-Bolt Size for Clamping

To calculate the bolt size, use the total holding force and bolt strength properties.

Bolt Load Calculation:

The force required to clamp the fixture is distributed across the bolts.

$$F_b = \frac{F_h}{\text{Number of bolts}} = \frac{2860}{2} = 1430\,\text{N per bolt}$$

Bolt Material Properties:

For a standard high-tensile steel bolt (Grade 8.8):

- Proof load stress ($\sigma$ proof) = 640 MPa

Bolt Diameter:

$$A_s = \frac{F_b}{\sigma_{\text{proof}}}$$

Substitute values:

$$A_s = \frac{1430}{640} \approx 2.23\,\text{mm}^2$$

From standard bolt tables, select M6 bolt.

(stress area = $20.1\,\text{mm}^2$).

4. Forces Acting on Bolts

a. Drilling Thrust Force ($F_t$)

- Source: Resistance to the downward movement of the drill bit into the material.
- Magnitude: Already calculated as 715 N.
- Direction: Vertical (along the drilling axis).

b. Tangential Cutting Force ($F_c$)

- Source: Force due to the rotational cutting action of the drill bit.
- Estimation: Empirical relationship:

  $F_c = 0.5 \cdot F_t$

  $F_c = 0.5 * 715 = 357.5$ N

Direction: Tangential to the hole being drilled (perpendicular to $F_t$).

c. Radial Force ($F_r$)

- Source: Force due to the eccentric motion or imbalance of the drill bit.
- Estimation: Empirical relationship:

  $F_r = 0.3 \cdot F_t = 0.3 \cdot 715 = 214.5$ N

Direction: Radial, acting outward from the drilling axis.

d. Reaction Force from Fixture ($F_u$)

$$F_{\text{total}} = \sqrt{F_t^2 + F_c^2 + F_r^2}$$

Substituting Values :-

$$F_{\text{total}} = \sqrt{715^2 + 357.5^2 + 214.5^2} \approx 821.6\,\text{N}$$

5. Load Per Bolt

$$F_{\text{per bolt}} = \frac{F_{\text{total}} + F_v}{\text{Number of bolts}}$$

Substituting values:

$$F_{\text{per bolt}} = \frac{821.6 + 107.25}{2} \approx 464.4\,\text{N per bolt}$$

6. Shear Force on bolts

The bolts will experience:

- Axial tension due to Fr.
- Shear force due to Fe and F.

Using vector decomposition:

Shear load per bolt:

$$F_{\text{shear}} = \frac{\sqrt{F_c^2 + F_r^2}}{\text{Number of bolts}}$$

Substituting values:

$$F_{\text{shear}} = \frac{\sqrt{357.5^2 + 214.5^2}}{2} \approx 214.4\,\text{N per bolt}$$

7. CAD Model

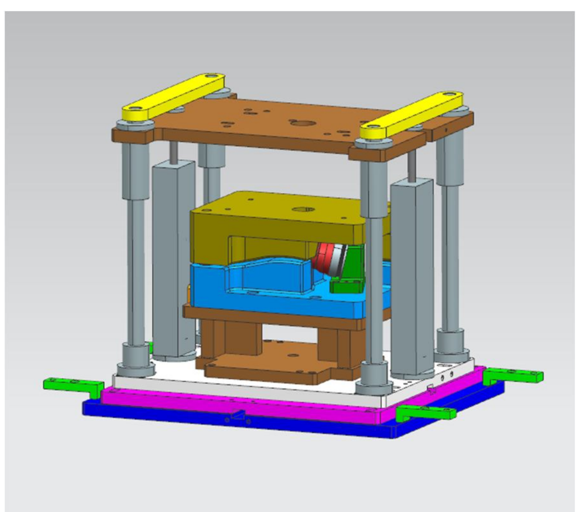

Figure 9

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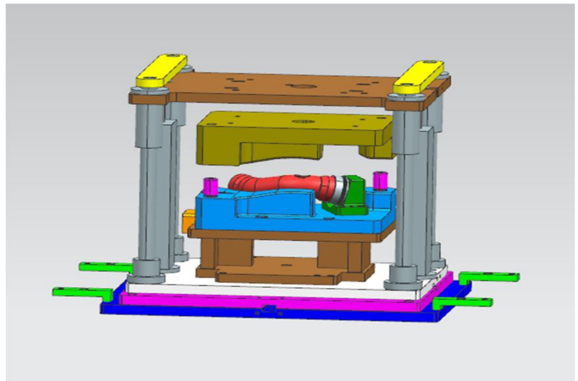

Figure 10

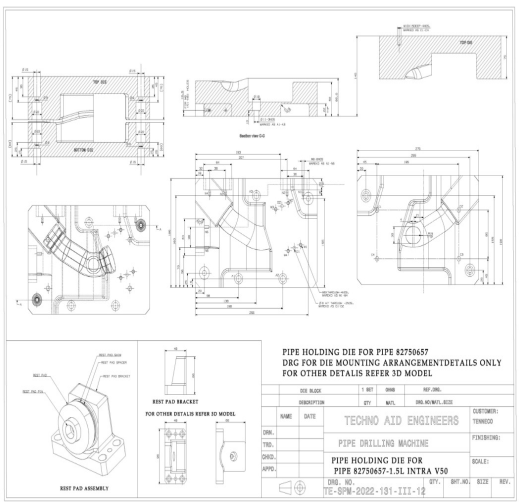


*Figure 11*

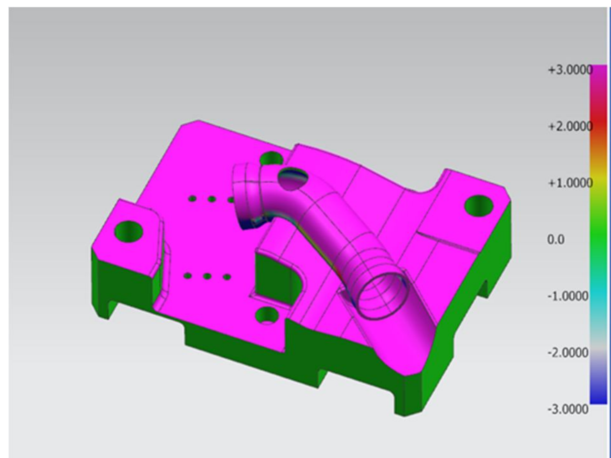


*Figure 12*

*J. Slope Analysis - for Parting Line Development*

In addition to these Considerations / calculations we also need to consider Curvature shape of the Exhaust Pipe / Work piece Component in our Fixture Design Process.

For Easy Loading and Unloading of the curvature shaped Component, we need to develop Parting Line for the Upper and Lower half of the Holding Fixture. For Parting Line Development along the Profile of the Exhaust Pipe we need to take Help of Slope Analysis considering Hole Axis as Z Axis. In this case for ease of loading and Unloading we have carried out Slope Analysis within Fringe width of 03 Degrees on negative side and 03 degrees on Positive side, considering Hole axis as Z Axis.

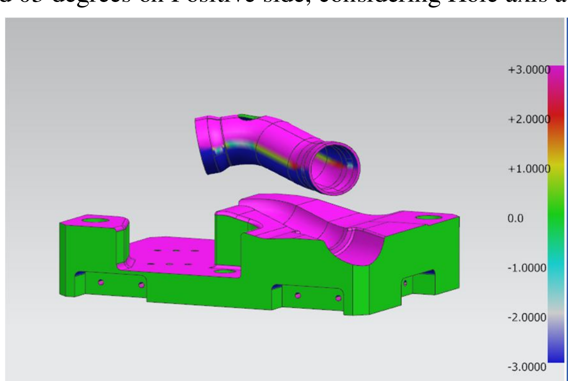


Figure 13

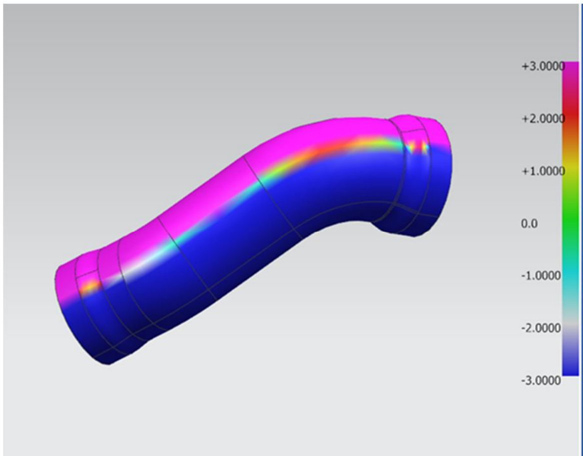

Figure 14

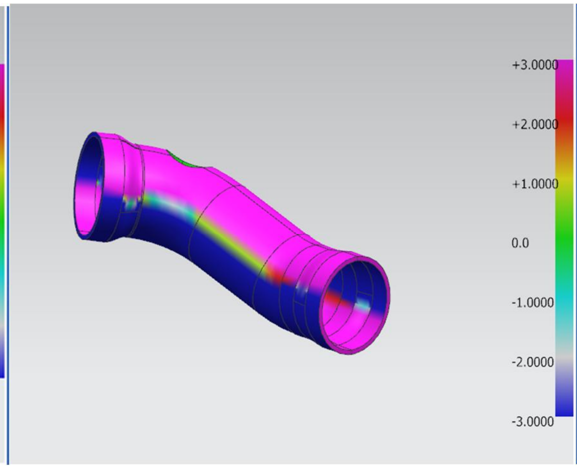

Figure 15

## IV. RESULTS

After successful completion of slope Analysis, we derived a smooth Parting line as the basis for Top and Bottom Fixture Half generation. We have maintained a constant 03 mm gap between Top and Bottom Half mating Faces for positive Clamping.

### *A. Efficiency Analysis: Time and Cost Reduction*

The implementation of the BS6 exhaust muffler outlet bend pipe drilling fixture has resulted in significant efficiency improvements:

1. Time Reduction:
   - The previous manual drilling process required 6–7 minutes per part, including setup and alignment.
   - With the newly developed fixture and CNC automation, the cycle time is reduced to 2 minutes per part, leading to a time savings of nearly 70%.
   - The overall production rate has increased, allowing manufacturers to meet the high demand for BS6 exhaust systems.
2. Cost Reduction:
   - Reduction in Rejection Rate: The initial rejection rate of 25–30% due to misaligned holes is reduced to less than 5%, leading to material savings.
   - Labour Cost Savings: The previous method required skilled operators for manual alignment, whereas the new fixture allows semi-skilled workers to operate the process with minimal supervision.
   - Tool Life Improvement: The optimized drilling parameters and fixture stability extend the tool life by 30–40%, reducing tool replacement costs.
   - Overall, the cost per drilled component is reduced by approximately 40%, making the process highly cost-effective.

## V. CONCLUSION

The development of a BS6 exhaust muffler outlet bend pipe drilling fixture marks a significant advancement in precision manufacturing for the automotive industry. This fixture successfully addresses the challenges of drilling on complex geometries by integrating robust resting, locating, and clamping mechanisms, adhering to the 3-2-1 principle. The detailed calculations of drilling forces, bolt loads, and fixture strength, combined with slope analysis for parting line development, ensure operational reliability and ease of use.

The implementation of this fixture in mass production has demonstrated improved hole-placement accuracy, reduced component rejection rates, and enhanced efficiency. This aligns with the stringent quality and emission standards required in modern automotive systems, supporting the industry's transition toward BS6 compliance. Future work could focus on further optimizing the fixture design for higher automation levels and scalability to accommodate evolving manufacturing demands.

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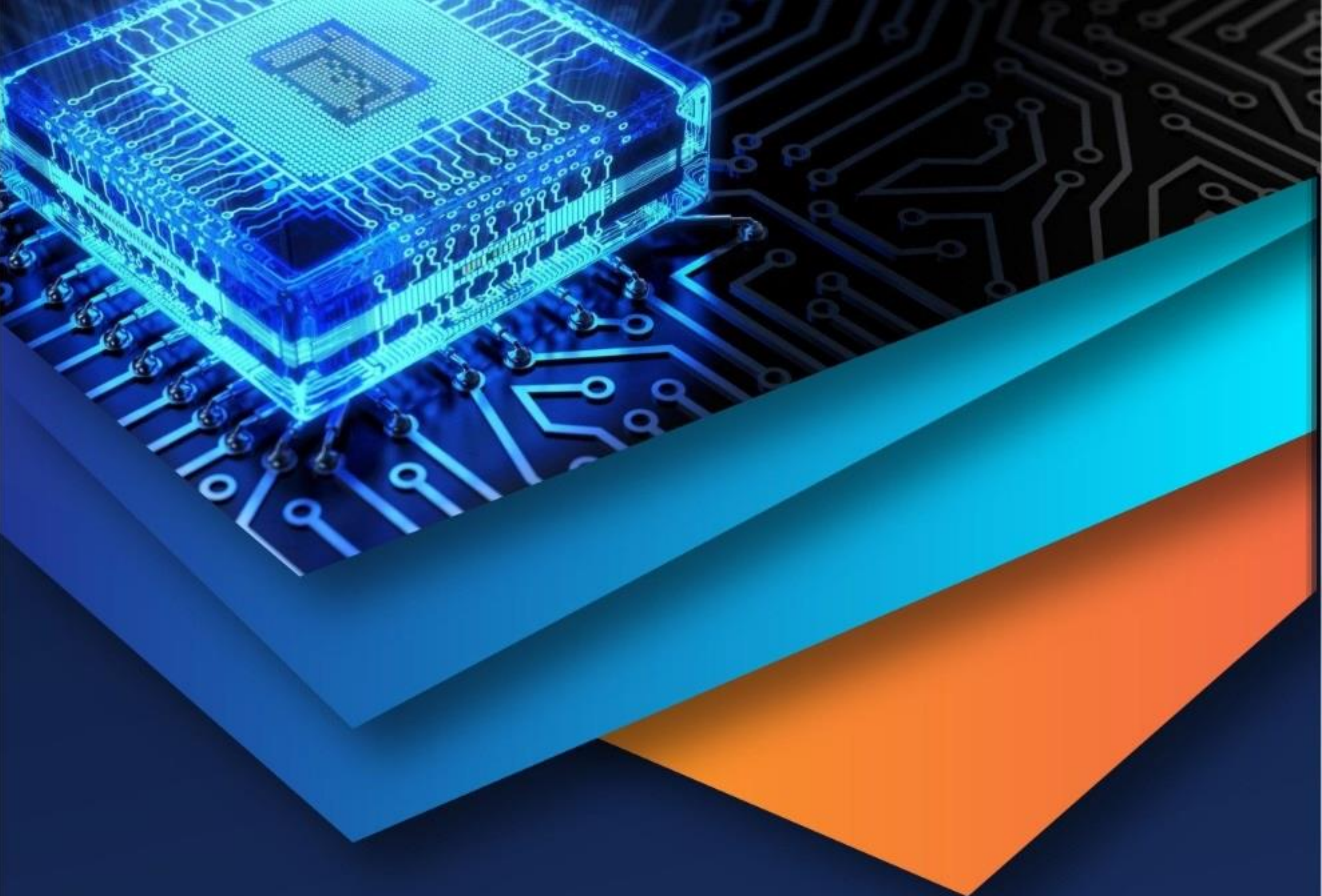


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