Design and Analysis of Drill Jig for Lap Joint Flange (ANSI B16.5)

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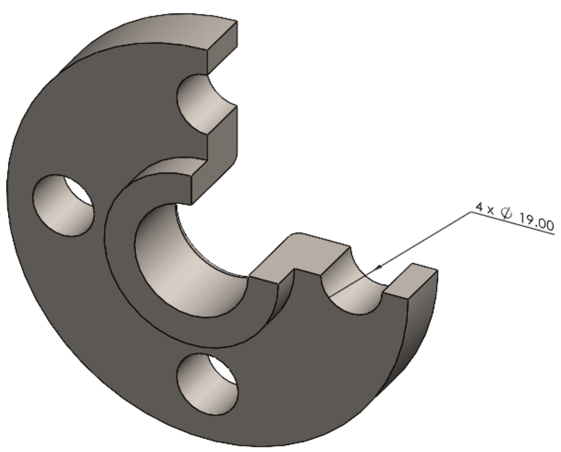
Abstract - *This paper presents the design and analysis of an automatic indexing drill jig for lap joint flanges (ANSI B16.5). The jig enhances efficiency by allowing multiple hole sizes to be drilled on a single setup, reducing part rejections and production time. Designed in SolidWorks and analyzed using ANSYS 2022 R1, the study evaluates the jig's structural performance, focusing on stress and deformation in the clamping system. The results confirm the jig's effectiveness in improving accuracy, minimizing setup changes, and optimizing manufacturing costs.*

***Key Words*: Drill Jig, ANSI B16.5, ASTM A105, Finite Element Analysis, Machining, Structural Analysis**

1.INTRODUCTION

Drilling jigs are essential tool in precision machining operations, ensuring accurate hole placement and reducing setup time. This study focuses on the development and analysis of a drilling jig for Lap Joint Flange (ANSI B16.5) machining ASTM A105 material, commonly found in piping applications. The objective is to assess the jig's performance using FEA and validate its structural integrity.

Figure 1 : 3D-Cad Model of Lap Joint Flange (ANSI B16.5)



2. Materials Used in Analysis

The drilling jig consists of multiple materials selected based on mechanical strength, wear resistance, and machining properties. The following materials were used in the analysis:

Table -1: Mechanical Properties of Materials Used in Jig Analysis

Material	Yield Strength (MPa)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Poisson's Ratio	Density (kg/m³)
ASTM A105	250	485	200	0.3	7850
AISI 1045	310	565	205	0.29	7870
EN-8	280	550	210	0.29	7855
AISI 52100	1520	2410	215	0.28	7810
SAE 1050	440	760	205	0.29	7850
4135-Steel	1034	1158	205	0.29	7850
AISI 4140	415	655	207	0.3	7850
HSS (M2)	2000	4100	225	0.28	8200
Stainless Steel	205	515	193	0.3	7930

3. Cutting and Clamping Force Analysis for Drilling

To determine the cutting force and clamp force for drilling a 19 mm diameter hole in ASTM A105 carbon steel to a depth of 20 mm, the following calculations and assumptions are made:

3.1 Cutting Force Calculation

$F = K \times f \times D$

where:

K is the specific thrust coefficient (600–700 N/mm² for medium carbon steel)

f is the feed rate (0.25 mm/rev, typical for 19 mm drill in steel)

D is the drill diameter (19 mm)

Substituting values:

$F = 600 \times 0.25 \times 19 = 2.85$ kN

$F = 700 \times 0.25 \times 19 = 3.3$ kN

Thus, the cutting force is estimated between 2.85 kN to 3.3 kN.

3.2 Clamp Force Calculation

The clamp force should be three times the cutting force:

$F_{clamp} = 3 \times F$

Using the calculated cutting forces:

$F_{clamp} = 3 \times 2.85 = 8.55$ kN

F_{clamp}=3×3.3=9.9 kN

Thus, the clamp force should be between 9 kN to 10 kN for stability.

4. Selection of Drill Bush & Calculation

The drill bush was selected based on ISO 4247 (BS 1098 PT. 2 1977 / DIN 172A) standards to ensure precision and durability in repeated drilling operations. A Headed Type, Press Fit Bush (PH30H Series) was chosen for its accurate drill alignment, firm press-fit into the jig body to prevent displacement, and head support for stable positioning and easy replacement. The bore size and length were selected to match the required drill diameter for machining Lap Joint Flanges (ANSI B16.5), following ISO standard increments to ensure compatibility with drills and reamers.

Figure 2: 3D-Cad Model of Drill Bush (PH30H Series)

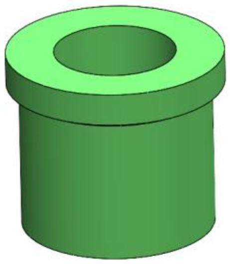


Figure 3: Standard Data Sheet of Drill Bush

A Dia. F7 Limits (Drills) * Limits(Reamers)		B Dia. n6 Limits	Length C and Bush Reference						D Dia. h13 Limits	E Length
			Short		Long		Extra Long			
From	Up to		C	Ref.	C	Ref.	C	Ref.		
-	1	3	6	PH3A	9	PH3C	-	-	6	2
1.05	1.8	4	6	PH4A	9	PH4C	-	-	7	
1.85	2.6	5	6	PH5A	9	PH5C	-	-	8	
2.65	3.3	6	8	PH6B	12	PH6E	16	PH6F	9	2.5
3.4	4	7	8	PH7B	12	PH7E	16	PH7F	10	
4.1	5	8	8	PH8B	12	PH8E	16	PH8F	11	
5.1	6	10	10	PH10D	16	PH10F	20	PH10H	13	3
6.1	8	12	10	PH12D	16	PH12F	20	PH12H	15	
8.1	10	15	12	PH15E	20	PH15H	25	PH15J	18	
10.1	12	18	12	PH18E	20	PH18H	25	PH18J	22	4
12.1	15	22	16	PH22F	28	PH22K	36	PH22N	26	
15.25	18	26	16	PH26F	28	PH26K	36	PH26N	30	
18.25	22	30	20	PH30H	36	PH30N	45	PH30R	34	

5. Finite Element Analysis Results and Discussion

The Finite Element Analysis (FEA) was conducted to evaluate the structural integrity of the drill jig under operational loads. The analysis helps determine the stress distribution, deformation, and overall safety of the design. The total deformation analysis, as shown in Figure 2, reveals a maximum deformation of 0.088 mm, which is minimal and does not affect the precision of the drilling process. This confirms that the jig maintains its alignment throughout multiple drilling operations. Additionally, the Equivalent (Von-Mises) stress distribution, depicted in Figure 3, shows that the maximum stress recorded is 288 MPa, primarily concentrated at critical regions such as the drill bush interface and clamping areas. Since this stress value remains well below the yield strength of the material, the jig operates within safe limits.

The key FEA results are summarized in Table 2:

Table 2: Summary of Finite Element Analysis (FEA) Results

Parameter	Value
Maximum Stress	288 (MPa)
Maximum Deformation	0.088 (mm)

To further assess the structural safety of the jig, the Factor of Safety (FoS) was calculated using the relation:

FoS= Maximum Applied Stress/Material Yield Strength
FoS= 1034 /288 =3.59

With an FoS of 3.59, the jig operates well within safety limits, ensuring structural integrity, durability, and reliability under machining conditions. The plunger effectively locks the indexing plate, maintaining precise rotational positioning for accurate hole placement. Additionally, the hook clamps securely hold the workpiece, preventing vibration and misalignment during drilling. The uniform load distribution and controlled clamping pressure minimize stress concentrations and prevent localized wear at critical contact points. These factors collectively enhance the jig's performance, longevity, and machining accuracy, making it a robust and efficient solution for precision drilling applications.

Figure 4 : Total Deformation Analysis

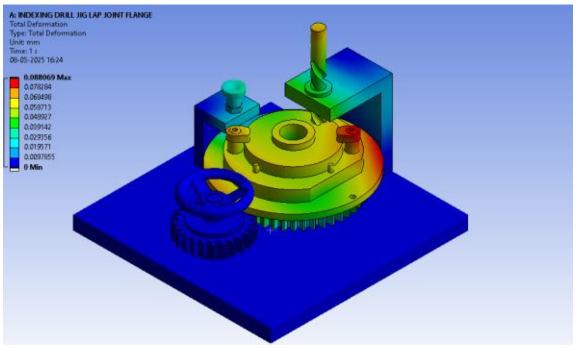
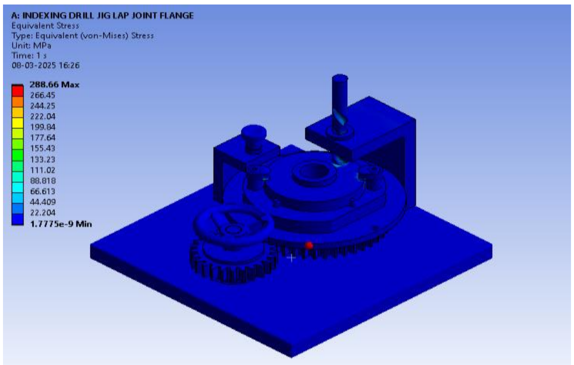


Figure 5: Equivalent (Von-Mises)Stress



6. Assembly and Implementation

The indexing jig, developed in SolidWorks and shown in Figure 4 and Figure 5, enables precise machining of ASTM A105 components. It consists of a base plate, a gear-driven rotary system for controlled positioning, a drill bushing holder for accuracy, a plunger for secure locking, and a hook clamp for firm workpiece holding. The plunger ensures positional accuracy, while the hook clamp minimizes vibration. A hand wheel allows manual indexing for uniform hole spacing, enhancing efficiency. High-strength fasteners improve stability, making this jig a reliable solution for precise hole placement in manufacturing.

Figure 6: 3D model of the Indexing Jig

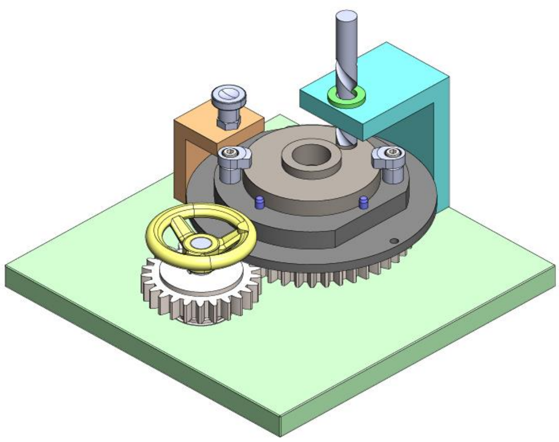
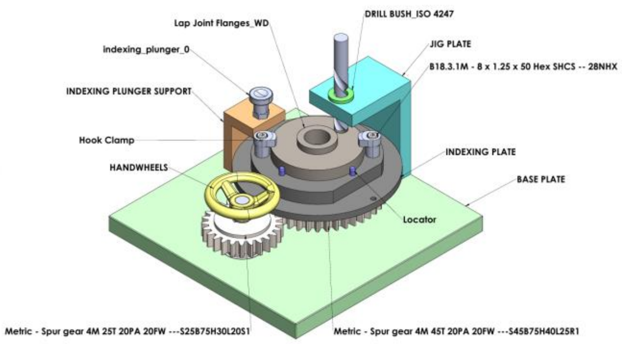


Figure 7: Assembled Indexing Jig with key components Labeled



7. CONCLUSIONS

The Finite Element Analysis (FEA) results validate the structural integrity and efficiency of the designed drill jig for lap joint flanges. The maximum stress recorded (288 MPa) remains well within the material's yield strength, ensuring safe and reliable operation. Minimal deformation of 0.088 mm confirms the jig's precision in maintaining alignment, while a Factor of Safety (FoS) of 3.59 guarantees its ability to withstand operational loads without failure. Additionally, the uniform load distribution and optimized clamping mechanism reduce localized wear, enhancing long-term durability. These design features collectively improve machining accuracy, minimize setup time, and ensure consistent performance in precision drilling applications. This study establishes the drill jig as a robust and effective solution for machining ASTM A105 components. Future enhancements could explore automation and material optimizations to further improve efficiency and reduce manufacturing costs.

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