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DESIGN AND ENGINEERING ANALYSIS OF A ROTATING WELDING TABLE FOR MULTI-SIZE TUBE ASSEMBLIES

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Abstract - This study presents the design and structural analysis of a rotating welding table for tube assemblies with different dimensions and thicknesses. Key features include a robust mainframe, adjustable tube supports, a bearing-based rotation system, a locking ring, and a braking mechanism.

Structural calculations are performed to evaluate bending, deflection, leg stability, and load capacity, ensuring safe operation under typical welding loads. The design also considers ergonomic handling and ease of fabrication. The results demonstrate that the selected tube profiles and support configuration provide sufficient stiffness, stability, and reliability for multi-angle welding operations, offering a practical solution for different manufacturing processes.

Keywords: Design, Welding table, Multi-tube profile assemblies, Welding loads, Design analysis, FEA.

1. Introduction

Welding is a fundamental process in metal fabrication and manufacturing, which requires precision, stability, and accessibility to achieve high-quality joints, assemblies, and products. The quality of a welded assembly or structure depends not only on the skill of the operator but also on the working system and the accessories used during fabrication [1], [2], [3], [4].

In this context, recent engineering studies emphasize the necessity of a systematic approach in the design and analysis of welded structures and auxiliary devices, such as working tables and fixtures, where the relationship between technological parameters and operational performance must be consistently considered [5].

Traditional welding tables, while providing a solid base and functionality, often impose limitations on the accessibility of the workpiece. Operators frequently need to reposition parts manually to reach different faces or orientations, increasing fabrication time, operator fatigue, and the risk of errors when repositioning and moving the assemblies [6], [7].

Despite the widespread use of conventional and rotating welding tables, there remains a lack of optimized design solutions that effectively accommodate multi-size tube assemblies while ensuring structural stability, ergonomic efficiency, and precise rotational control under varying load conditions. This gap highlights a clear research problem related to the integration of adaptability and mechanical performance in a single welding support system.

To address these limitations, rotating welding tables are a versatile solution in modern industrial fabrication and manufacturing. By allowing

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controlled rotation of the working assembly, these tables enable welders to access multiple angles without having to move heavy components manually or reposition the components. This improves workflow efficiency and enhances the safety and ergonomics of welding operations and the manufacturing time. A well-designed rotating table combines structural rigidity with smooth rotational motion, ensuring that the workpiece remains stable throughout the welding process [8], [9], [10].

The design of a rotating welding table involves several key engineering considerations and steps. The frame must be strong enough to support the selected weight of the welding profiles and any additional fixtures while minimizing deflection to maintain precision during operation. The rotation mechanism must allow smooth, controlled movement, with adequate bearing support to carry radial loads. Locking and braking systems are necessary to secure the workpiece in the correct position during welding, preventing accidental rotation and ensuring operator and system safety. Additionally, the choice of structural materials, dimensions, and profiles significantly affects the table’s stiffness, durability, and overall performance. [11],[12].

In parallel, studies on microstructural evolution and mechanical properties demonstrate that structural transformations under intense thermal loading, including welding processes, have a significant impact on the quality and long-term durability of steel structures [13].

The main scientific objective of this research is to design, model, and analyze a rotating welding table capable of supporting multi-size tube assemblies while achieving an optimal balance between structural strength, rotational precision, and ergonomic usability.

The design of the rotating welding table is aimed at achieving a combination of structural stability, functional flexibility, and ergonomic efficiency. The load-bearing frame ensures platform stability, spatial rigidity, and coplanarity of the supporting surface under loading from workpieces and fixtures, achieved through adjustable elements [14], [15], [16].

A key element of the design is the rotation mechanism, which ensures smooth and controlled motion of the platform. For precise positioning, a braking mechanism is implemented, allowing secure fixation of the workpiece in the desired position [17], [18], [19].

Through the integration of a rigid load-bearing frame, an adaptive support system, and a controlled rotation mechanism, an effective solution is achieved for a wide range of welding applications. This configuration serves as a basis for subsequent structural analysis and engineering calculations, confirming its capability to withstand operational loads and to ensure stable and repeatable performance over time [20], [21], [22]. The proposed design improves efficiency and consistency.

The novelty of the proposed approach lies in the integrated design combining structural stiffness, adaptive support configuration, and controlled rotation within a single engineering solution applicable to real manufacturing conditions. This novelty is not based on the development of new theoretical models, but on the systematic integration of established engineering principles into a unified and practically applicable framework.

2. Construction of the Machine

2.1 Main Points

An important phase in the realization of a machine is the design phase. It is in it that the functions and the main technical, economic, operational, and other parameters of the machine are formed. This phase is associated with the analysis and evaluation of a large number of alternative technological solutions and requires finding and justifying the most acceptable of them. Here, the different types of technologies that will be used to manufacture the given product are also determined, and the best and optimal method in this case is chosen, according to the design of the machine and the necessary funds.

The complexity of the analysis and evaluation of the various options under the influence of a large number of factors of different natures requires the use of modern computational methods and information processing tools, which has led in recent years to strong development in the field of automation of structural design.

Main points:

1. The purpose of the part/machine/assembly, its application, working surfaces, and characteristics are clarified.
2. Clarification of the technology that will be implemented on the designed machine. The geometric parameters of the parts to be processed and the machine park for their manufacture are analyzed.
3. Known similar structures are analyzed, comparing them in terms of their geometric, kinematic, power, and other parameters.
4. Trends in the development of technologies, methods of design, calculation, and production are taken into account while searching for an optimal solution.
5. The choice made is justified as the best or acceptable option.
6. The machine assembly is divided into units that are developed constructively or into individual parts.
7. The feasibility of the options for individual solutions (mainly new units) is justified by their development.

8. Development of the design and technological documentation of the entire product, as well as the necessary special devices and tools that will be used for its production.
9. A prototype is manufactured and tested for geometric and kinematic accuracy, stability and noise.
10. After optimizing the design and bringing it into compliance with the permissible standards, acceptance is carried out through a 72-hour test.

2.2 General Design and Dimensions

Figure 1 shows the general design of the welding table. Figure 2 presents the main dimensions of the whole table and the main frame dimensions. The size of the frames and the table are considered for easy manipulation and rotation while working.

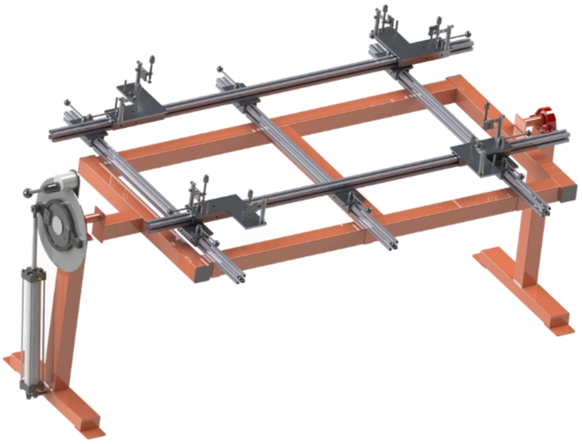

Figure 1: General Design of the Rotating Welding Table

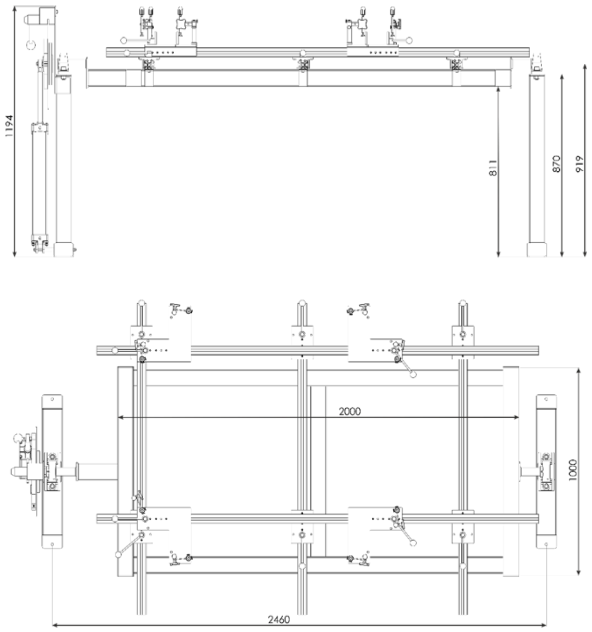

Figure 2: General Dimensions of the Rotating Welding Table

2.3 Main Components of the Machine

1 – Main Frame – The base of the entire structure. It is made of welded profiles. Pipes are used for mounting to the bearings, and plates are mounted to the main profiles to hold the upper structure.

2 – Ring Leg – One of the two support legs of the structure. The bearings that support the frame are mounted to them. The pneumatic hoses are located in this leg.

3 – Bearing Leg – The other of the two support legs of the structure.

4 – UCP 208 bearing – Two encapsulated bearings that are mounted directly to the legs.

5, 6 – Left and right slider – The profiles for welding are placed on them. Here are attached the clamps and pins. They perform movement along the X axis. Two left ones are present and two right ones.

7 – Single slider – A purchased element that performs the movement along the Y axis.

8 – Aluminum profile – Cut to a specific length, the left and right sliders are mounted on it.

9 – Aluminum profile – Cut to a specific length, they are attached to the frame, and the single slider move on them.

Figure 3 highlights the main components.

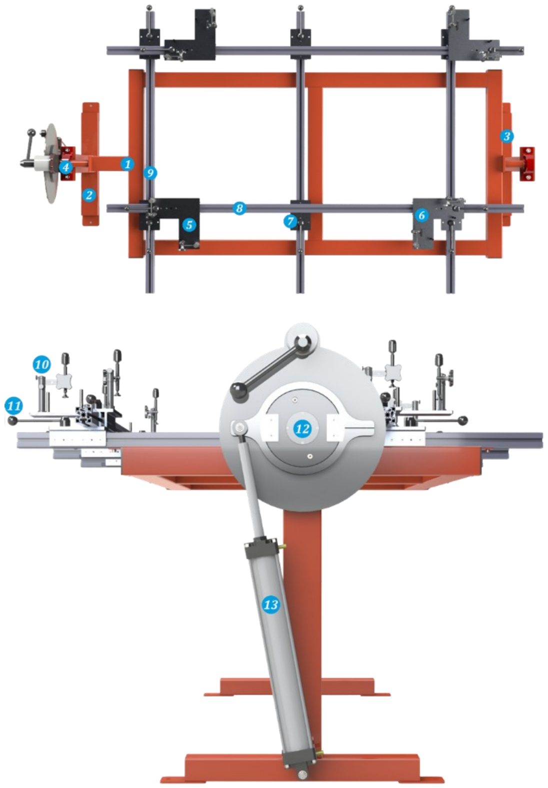

Figure 3: Main components – TOP and SIDE view

10 – Clamp – Used to press the profiles for welding. Ready-made components are used and are attached to the upper sliders. They must provide sufficient pressing force.

11 – Handle, brake – Fixes the position of the sliders on the profiles. It must have sufficient force to prevent free displacement or movement when in the closed position.

12 – Ring – It serves as a frame brake and also to adjust the load using the pneumatic cylinder. It has a more complex design. An additionally mounted ring, the pressing force of which is controlled by a screw, is placed to establish a connection between the module and the frame itself. In the upper part there is a brake that does not allow the brake disc to rotate.

13 – Pneumatic cylinder – to relieve the load on the frame.

2.4 Main Frame Elements

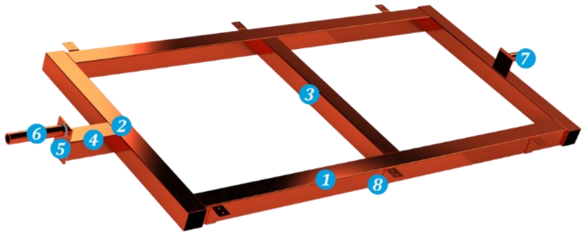

Figure 4: Main frame elements

The main frame assembly – Figure 4 - is created as a single unit. All the elements are prepared and cleaned before welding. After the welding process, every surface is clean, and a coating is applied for protection in different kinds of working environments. The description of the elements is in Table 1.

Table 1. Main frame elements

Position	Description	Thickness [mm]	Length [mm]	Qty.
1	Profile 80x80x2	2	1840	2
2	Profile 80x80x2	2	1000	2
3	Profile 80x80x2	2	820	1
4	Profile 80x80x2	2	200	1
5	Plate	5	-	2
6	Tube 40x5	5	215	1
7	Tube 40x5	5	150	1
8	Plate angular	3	-	6

2.5 Leg Support Elements

The construction has two separate legs – Figure 5. They must provide stability of the whole system. The best solution from a design point of view is to add an additional element between both legs for better stability. In this case an extra element will be in collision with the rotating frame, so it is not possible to add. The feet are anchored to the ground for better working conditions. The legs must sustain the axial forces (in the working process) when the worker is applying the welding process on the frame structure. The description of the elements is in Table 2.

Table 2. Leg support elements

Position	Description	Thickness [mm]	Length [mm]	Qty.
1	Plate feet	5	-	2
2	Plate cover	5	-	2
3	Profile 100x60	2	400	1
4	Profile 80x80x2	2	800	2
5	Plate bearing	5	-	2

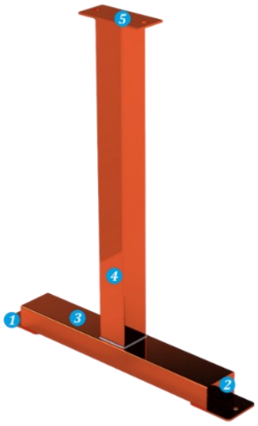

Figure 5: Main frame elements

2.6 Locking Ring

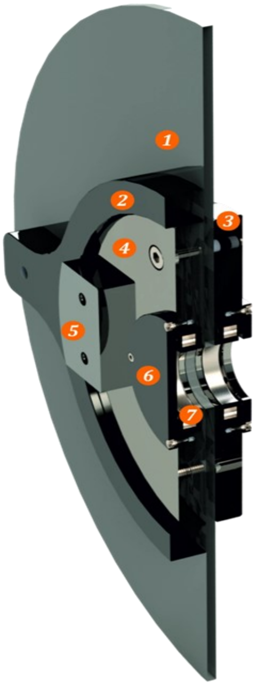

Figure 6: Locking ring

The locking ring is used to adjust the load during the tightening process – Figure 6. Through the pneumatic cylinder, the pressure pushes the piston and changes the position of the adjusting ring. When it is closed, this balances the position of the frame. The brake disc - 1 - stops the movement of the locking ring when necessary. The holder body – 5 – guides the adjusting ring and holds it in position. Roller bearings help the smooth movement of the entire structure. The outer and inner rings play the role of clamps that support the entire mechanism. A full description of the components is stated in Table 3.

Table 3. Locking ring elements

Position	Description	Qty.
1	Brake disk	1
2	Regulating ring	1
3	Inner ring	1
4	Outer ring	2
5	Plate bearing	1
6	Bearing cap	2
7	Roller bearing	2

2.7 Extra Components

In the construction there is an aluminium profile with a standard cross-section of 45x45 mm. They can be cut to any length and at any angle. In this case it is used with profiles with a length of 1500 mm (3 pieces) and 2200 mm (2 pieces).

There are single and double guiders and sliders. They are offered together with the profiles, depending on the length. They have multiple holes that are used to attach to a slider, which in turn is mounted to the profiles themselves. This creates a joint that allows the slider to move along the surface of the profiles. This gives us flexibility and facilitates the construction of similar assemblies, which are otherwise more difficult and require more effort and detail. All the components are described in Table 4.

Table 4. Extra components

Position	Description	Qty.
Aluminium profiles	Holding frame	Different lengths
Guiders	For adjusting the sizes	Different types
Sliders	For adjusting the sizes	Different types
Bearings	UCP 208	2 pieces

2.8 Working Position

The profiles are placed tangentially to the pins 5. The single slider - 1 and the left and right sliders – 2 are used to adjust the size of the frame along both axes. The handles - 3, respectively located at 1 and 2, serve to fix the position of the sliders according to the size of the elements to be welded. With the help of the pair of clamps - 4, the profiles are pressed so that they can be welded without problems. The clamps have a rotating arm (rotation) and movement along the Z axis. With the help of an additional pair of screws, their position can also be additionally fixed. – Figure 7.

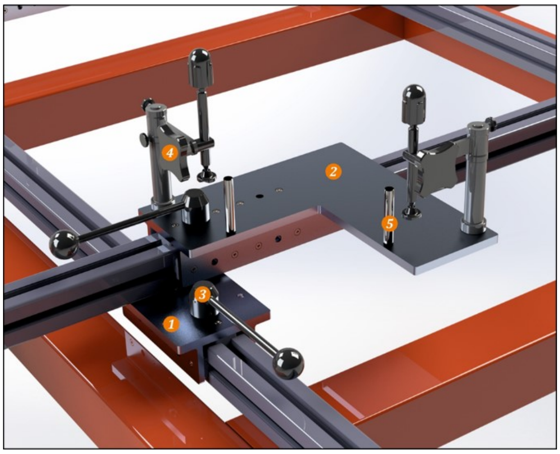

Figure 7: Working area

2.9 Working Steps

In this case, a total of six single sliders are present. It is possible to make the structure with only three, with one profile remaining stationary and fixed plates being mounted to it, not sliders. This somewhat limits the possibilities, and for this reason, in this construction, a pair of regulating profiles is relied on.

A measuring grid with graduated millimeters is placed on the aluminum profiles. In this way, the desired size is set extremely precisely. The size is taken from the center of the profile. It is possible to weld a profile frame with dimensions of 2000x1400 mm (maximum dimensions).

STEP 1: Release the brake, place the entire structure horizontal and fix the brake – Figure 8.

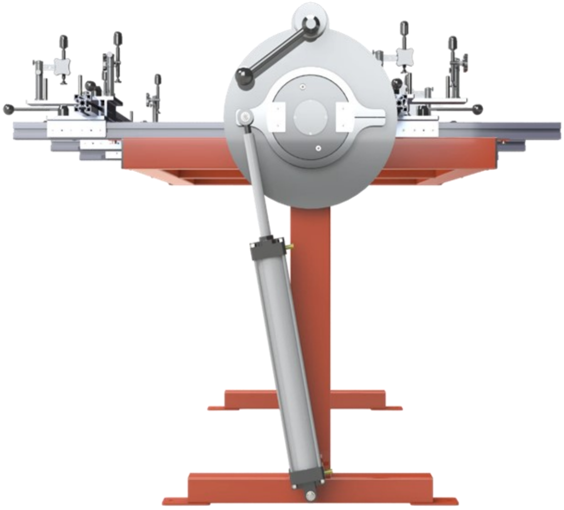

Figure 8: STEP 1

STEP 2: Releasing the handles/fixators and adjusting the width of the frame we are welding – Figure 9.

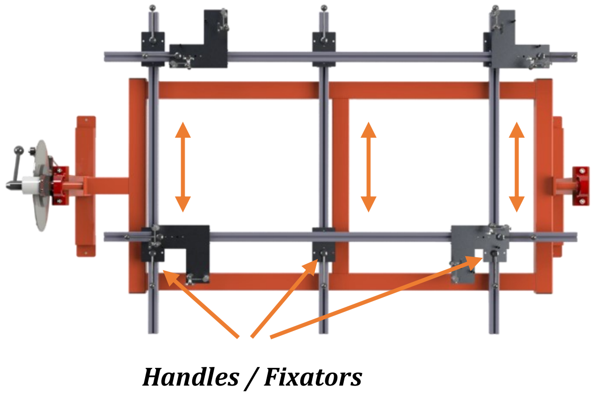

Figure 9: STEP 2

STEP 3: Releasing the handles/locks and adjusting the length of the welding frame – Figure 10.

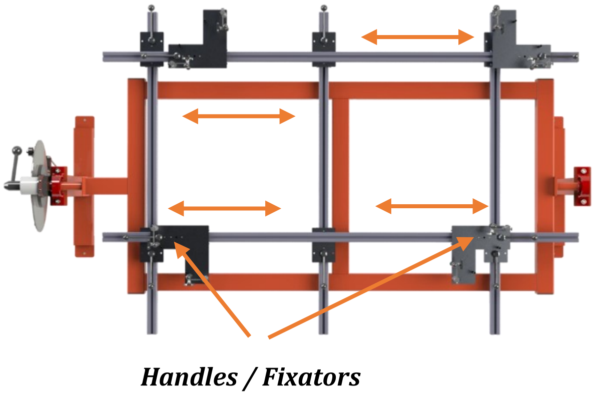

Figure 10: STEP 3

STEP 4: Place the welding profiles and press with the clamps. – Figure 11.

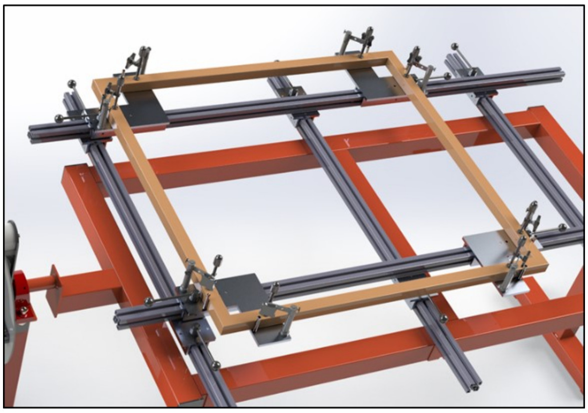

Figure 11: STEP 4

Each of the profiles is guided along the pins. Then, using the clamps, it is pressed to remain in a fixed position. Then the adjacent profile to be welded is placed. When there are only two profiles on the frame, they are aligned and pressed with the clamps. The next step is to release the opposite sliders and place the other two profiles, fixing their position according to the desired size.

After the profiles are closer, the sliders are adjusted to the correct position with the clamps, and then the two profiles are pressed. This is done because of the different sizes, and the frame adjusts itself according to the size being made.

STEP 5: Adjusting the frame load. – Figure 12, Figure 13 and Figure 14.

First, we loosen the set screw, then turn the adjusting ring to the lowest position on the cylinder, release the brake, and turn the frame to the upper position. Tighten the brake and place the cylinder back in the vertical position, but 180 degrees from the previous one.

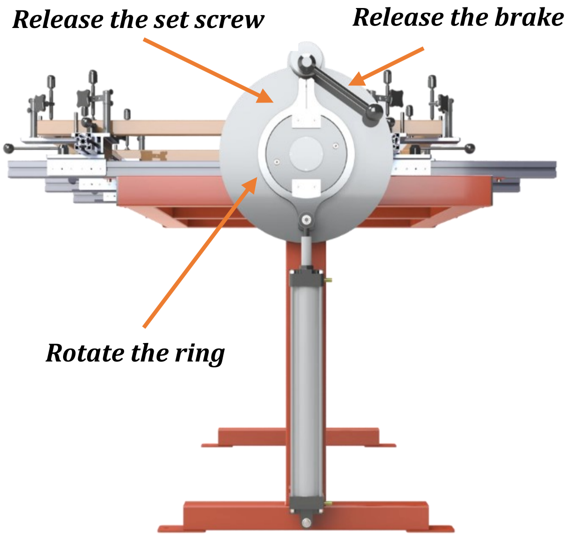

Figure 12: STEP 5

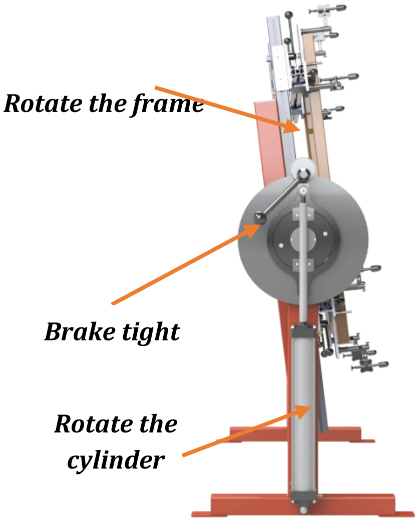

Figure 12: STEP 5 movement

The set screw is tightened, and the brake is released and turned in the opposite direction. An air valve is placed through the support leg of the frame, and an air hose is passed to the cylinder (not shown on the model). The weight of the frame is adjusted using the pressure created.

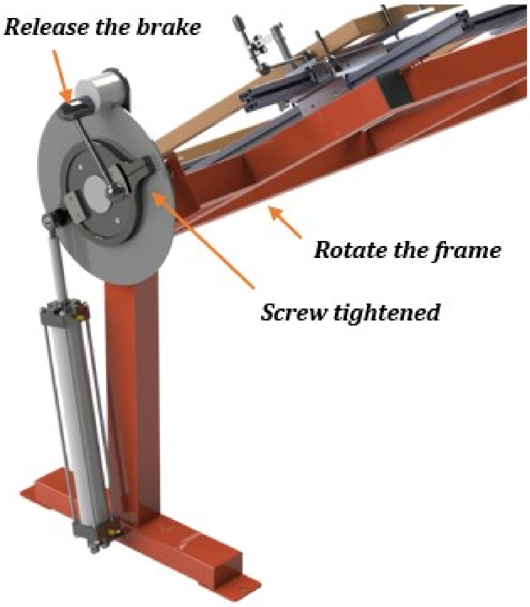

Figure 14: STEP 5 adjustment

STEP 6: Positioning and welding. – Figure 15.

Once the load is balanced, the frame is positioned, locked, welded on both sides, and the finished assembly is removed.

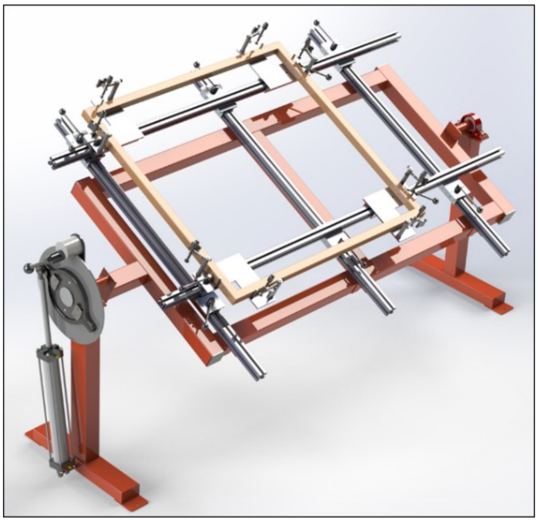

Figure 15: STEP 6 - Welding

3. Structural and Functional Assessment

The structural assessment is based on structural steel AISI 1020 (σ_y = 350 MPa, E = 210 GPa), with a total load F[N] composed of the self-weight (m_1 =110 kg) and the maximum operational load (m_2 = 300 kg). A safety factor of K = 2 is applied.

$$m = m_1 + m_2 = 410kg \tag{1}$$

$$F = m.g = 4022N \tag{2}$$

$$[\sigma] = \frac{\sigma_y}{K} = 175MPa \tag{3}$$

The maximum bending moment for the main frame is (SHS 80 × 80 × 2 mm):

$$M_{max} = \frac{F.L}{4} = 2011\ Nm \tag{6}$$

where: L – Main frame length (Figure 2) – 2000 mm.

The bending stress is calculated as:

$$\sigma = \frac{M_{max}}{z} = 127.3MPa \tag{7}$$

where:

- z = 1.58×10^4 mm^3 - section modulus.

$$\sigma < [\sigma] \quad 127.3 < 175\ MPa \tag{8}$$

Therefore, the selected profile (SHS 80×80×2 mm) satisfies the strength requirement.

The maximum deflection is:

$$\delta_{max} = \frac{5.F.L^3}{384.E.I} 3.15\ mm \tag{9}$$

This value is small compared to the frame length (2000 mm) and is acceptable for the intended welding operations.

The load on one supporting leg is:

$$F_1 = \frac{F}{2} = 2011N \tag{10}$$

$$\sigma_C = \frac{F_1}{A} = 3.2MPa \tag{11}$$

$$\sigma_C \ll \sigma_y \tag{12}$$

where:

- F_1 – force on one leg [N];
- A – cross section area [m^2];
- σ_C - compressive stress [MPa].

The compressive stress σ_C [MPa] is significantly lower than the yield strength of the material.

Critical load F_C [N]:

$$F_C = \frac{(\pi^2.E.I)}{{H_L}^2} = 1.51x10^6 N \tag{13}$$

where:

H_L – Leg height [m].

The buckling verification gives F_1 / Fc = 0.13%, indicating a very large safety margin against instability.

The defined loading model and the obtained results confirm that the structure satisfies the strength, stiffness, and stability requirements for practical welding conditions.

4. Finite Element Analysis

4.1 Central load

The rotating welding table is designed to be operated manually, resulting in relatively low rotational speeds. Consequently, dynamic effects such as centrifugal forces and inertial loading are considered negligible and are not included in the present analysis. Under these conditions, the structural behavior of the system can be accurately evaluated using a static approach.

A finite element analysis (FEA) was therefore conducted to assess the structural integrity of the main frame under representative worst-case loading scenarios. The model incorporates both the self-weight of the structure and the maximum payload associated with the heaviest tube assembly configuration.

To ensure a conservative assessment, the loading conditions include not only a centrally applied load but also consider potential eccentric loading cases, which may occur during manual positioning of the workpiece. This approach reflects realistic operating conditions, where perfect load symmetry cannot always be guaranteed.

Boundary conditions were defined to replicate the actual support configuration of the welding table, including constraints at the mounting points and rotational supports. A linear static analysis was performed to evaluate stress distribution and deformation characteristics.

The results of the analysis provide insight into the structural performance of the system and confirm whether the design satisfies the required safety and stiffness criteria under practical operating conditions.

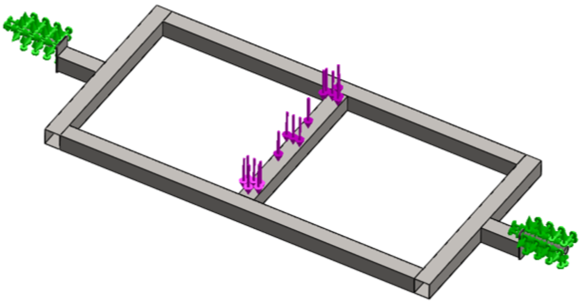

Figure 16: FEA setup – simplified model

Figure 16 shows the initial setup for the central load analysis. We have two fixtures on the side, where the bearings are connected to the frame and the rotation occurs.

Here we simplified the load case with a force – 4100 N (4022 N), applying on the single beam of the frame in the middle (frame weight + extra weight from welding frames). This may amplify the results, but they have to be similar to the one we have in the calculations.

The mesh is shown in Figure 17.

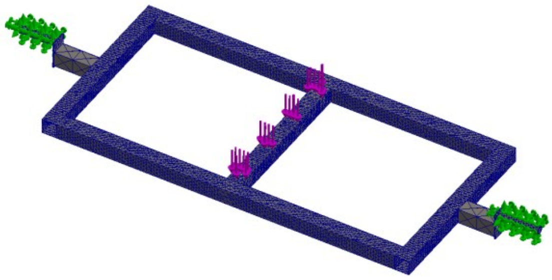

Figure 17: FEA mesh

After running the study, we get the stress analysis and the displacement in Figure 18 and Figure 19. It is shown that the stress correlates with the previous calculations.

The displacement has a difference in the middle of the frame, due to the fact that the load is not subjected to the whole frame, but just to the middle beam.

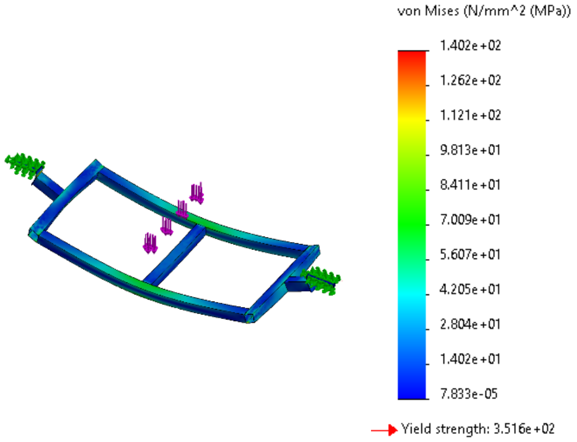

Figure 18: FEA – stress results

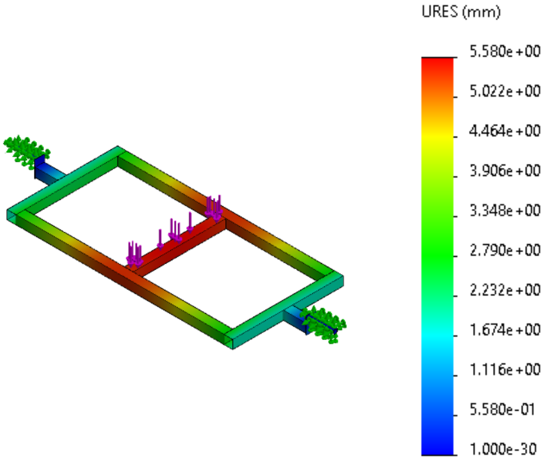

Figure 19: FEA – displacement results

Figure 20 clearly shows that there is practically no displacement at the location of the bearing, which show that there is no additional load or stress during the working steps.

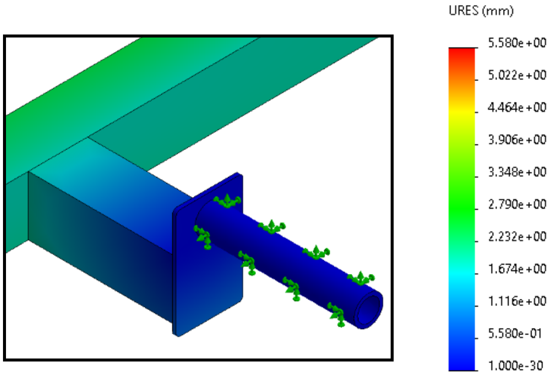

Figure 20: FEA – local displacement results

4.2 Eccentric Load

In addition to the centrally applied load, an eccentric loading condition was introduced to account for potential asymmetrical positioning of the workpiece during operation. Although the welding table is designed with a nominally symmetric geometry, practical usage conditions may result in uneven load distribution due to variations in tube size, fixture positioning, and manual handling.

To simulate this scenario, the maximum payload was applied with a lateral offset relative to the geometric center of the frame, corresponding to a realistic worst-case position on one side of the welding table. This configuration introduces combined bending and torsional effects in the structure, which are not captured under purely symmetric loading conditions.

The inclusion of this load case enables a more comprehensive evaluation of the structural response, particularly in identifying critical stress regions and deformation patterns that may arise under non-ideal operating conditions. The results obtained from the eccentric load scenario are compared with those from the central loaded case to assess the robustness and reliability of the frame design – Figure 21.

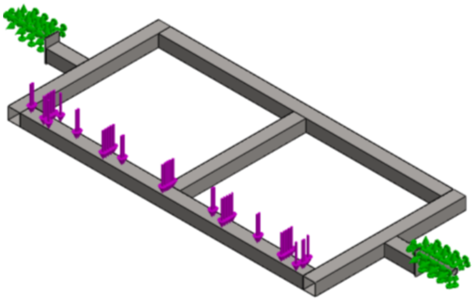

Figure 21: FEA setup – simplified model

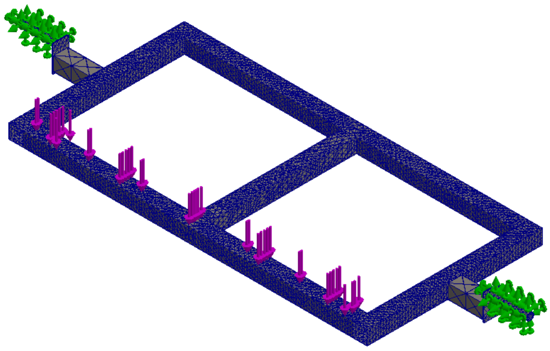

Figure 22: FEA mesh – eccentric load

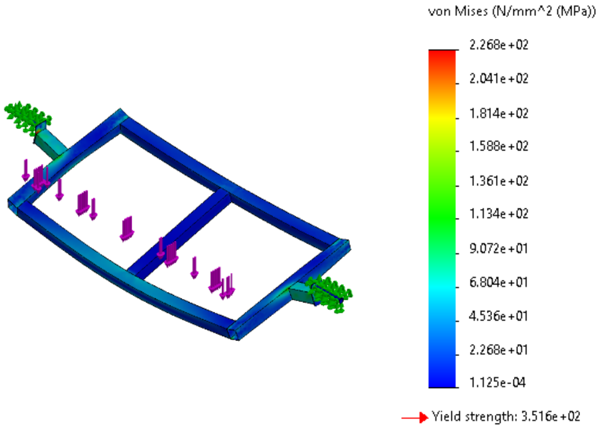

Figure 23: FEA – stress results eccentric

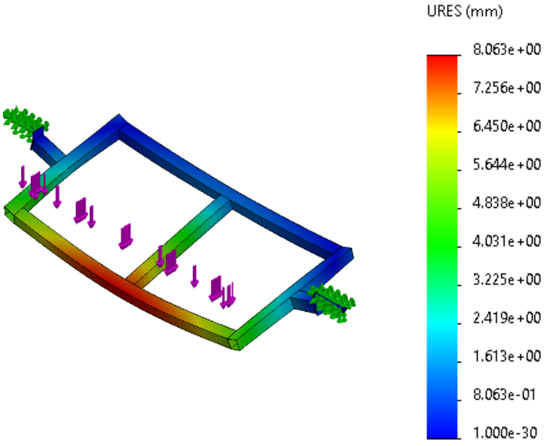

Figure 24: FEA – displacement results eccentric

Figure 22 shows the mesh, figure 23 the new stress analysis result, using the eccentric load. This shows similar results as the one in Figure 18. The only difference is the higher local stress in the plate, connected to the tube, which connects to the bearing, but again they are not above the permissible values – Figure 25.

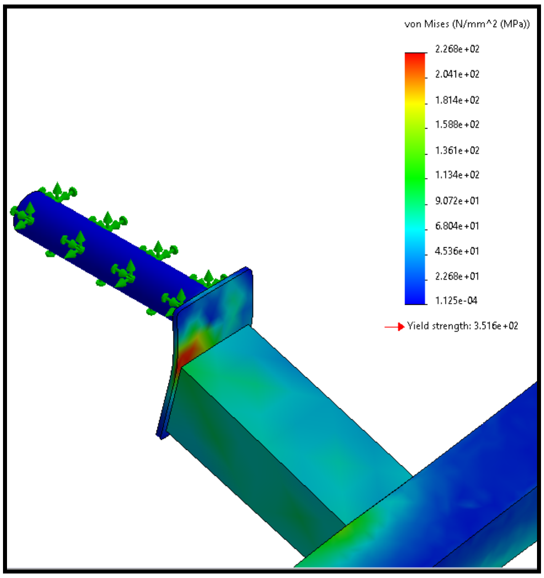

Figure 25: Local stress maximum

The displacement – Figure 24 is higher because of the distance from the center of gravity of the frame. Again, the displacement at the bearing connection is negligible.

5. Design Validation

To ensure the structural integrity and operational reliability of the proposed rotating welding table, a qualitative engineering validation approach was adopted. The presented validation approach is supported by the analytical calculations outlined in Section 3, which confirm the structural adequacy of the proposed design. The load-bearing frame was designed to withstand static and dynamic loads generated by tubular assemblies during welding operations, while maintaining minimal deformation and ensuring positional stability. Particular attention was given to the distribution of stresses across the supporting structure and the rotation mechanism, as these are critical for preventing misalignment and ensuring consistent weld quality.

The rotation system, including bearings and supporting elements, was dimensioned to accommodate radial and axial loads under typical working conditions. Locking and braking mechanisms were incorporated to eliminate unintended motion during welding, thereby enhancing operational safety and precision. Additionally, the selection of structural materials and cross-sectional profiles was guided by the requirement to achieve an optimal balance between stiffness, durability, and manufacturability.

From a functional perspective, the design enables improved accessibility to the welded components, reducing the need for manual repositioning and minimizing operator-induced variability. This contributes to enhanced process repeatability and reduced fabrication time. Overall, the proposed solution demonstrates adequate mechanical robustness and ergonomic efficiency, supporting its applicability in practical welding environments.

The proposed design is based on established technological solutions, while its novelty lies in their targeted integration and adaptation to specific operating conditions. This leads to the development of a structure that distinguishes itself from existing solutions through improved functional performance, enhanced structural stability, and better ergonomic efficiency. In this context, the developed solution represents a practically applicable engineering approach for the optimization of welding operations.

Furthermore, the structural behavior of the system was evaluated under representative loading scenarios, considering both central and eccentric load application. The results indicate that the induced stresses remain within allowable limits for the selected material, while the overall deformation is sufficiently low to ensure stable positioning and consistent welding accuracy.

The validation results are consistent with expected engineering performance and confirm the practical applicability of the proposed design under real operating conditions.

6. Conclusions

The present study introduced the design and engineering assessment of a rotating welding table intended for multi-size tubular assemblies. The proposed solution integrates a welded steel frame with a controlled rotation mechanism, resulting in improved accessibility, ergonomics, and operational safety during welding processes.

The structural evaluation confirmed that the selected profiles ensure sufficient strength and stiffness under typical and maximum loading conditions, with stresses and deflections remaining within acceptable limits. Stability analyses demonstrated adequate safety margins against buckling and overturning, while the bearing-supported rotation system provides smooth operation and reliable positional locking.

The implementation of a modular support system significantly enhances the adaptability of the welding table, enabling efficient handling of assemblies with varying geometries and dimensions. In combination with the rotation and locking mechanisms, this contributes to improved positioning accuracy, operational flexibility, and process reliability.

Overall, the proposed design demonstrates a balanced integration of structural robustness, functional adaptability, and ergonomic efficiency, making it suitable for practical industrial applications.

However, the novelty of the proposed approach does not lie in the development of new theoretical models, but in the systematic integration of structural analysis, adaptive support configuration, and controlled rotation into a unified engineering framework applicable under real manufacturing conditions.

Future work may focus on the integration of motorized rotation systems, advanced locking mechanisms, and numerical simulations using finite element analysis to further optimize the structural performance and extend the applicability of the design.

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