Design of a high precision mechanical linear system for the study of the variables involved in the gas metal arc welding process

J L Lázaro Plata¹, C S Sánchez Rincón¹, and F J Regino Ubarnes¹
¹ Grupo de Investigación en Ingenierías Aplicadas para la Innovación, Gestión y Desarrollo, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia

E-mail: jllazarop@ufpso.edu.co, cssanchezri@ufpso.edu.co

Abstract. The gas metal arc welding process is studied because of its high productivity and low cost. One of the drawbacks of this process is achieving repeatability of the welding seams. This article shows the design of a linear mechanical system that provided a high precision in the trajectory of the base platform. Three important factors were investigated such as platform speed, the main stresses present and the manufacturing material. A descriptive type methodology was used which consisted of conducting the study as a discrete particle system. The optimum conditions for the efficiency of its operation were a linear velocity of 1.44 mm/s, maximum shear stress in the power screw of 283.57 kPa, which was calculated by means of static analysis to determine as the material of medium carbon steel of type AISI 1040, which due to its ductility, facilitated the machining of the power screw. This provided a mechanical efficiency of 30.9%. The kinematic calculations of the system were made with standardized elements found on the market.

1. Introduction
Gas metal arc welding (GMAW) is a very complex process that uses many scientific and engineering disciplines to study techniques that can lead to the best possible mechanical properties of the resulting part. The GMAW process is widely used because of its low cost and productivity, and other processes. Despite these advantages, the quality obtained by human work in a repetitive and prolonged process tends to suffer variations [1], which requires a high precision inspection to achieve the desired physical and mechanical properties. Today, the use of automated welding, as is the case with industrial robots, is one of the main signs of contemporary welding [2].

A truly mechanical welding frame should have three main parts: sensors, which identify the status of the welding procedure; a process model, which provides the relationship between the welding factors and the geometry of the weld seam; a control frame, which evaluates the sensor information and changes the welding procedure factors using the relationship in the process model [3-6].

The GMAW process is influenced by some variables, such as: welding current, arc voltage, welding speed, electrode extension (stick-out), welding torch inclination, joint type, electrode diameter, gas protection and wire feed speed, [7]. It is important to emphasize that knowledge and control of these variables are essential to obtain satisfactory quality welds. These variables are not completely independent and changes in one of them require changes in one or more of the others to produce the desired results [8]. One of the elementary components for the development of such processes is the
power screw, which is used to provide a smooth and uniform linear movement. It mainly contains a worm and screw gear assembly, a pinion and bevel gear, a bronze screw and nut and a drive motor [9].

In the same way, physics and mathematics play an important role in development because of the complexity of the problems, since their intervention in the engineering discipline is fundamental [10]. So, the physical principles that developed the equations to perform the static and dynamic analysis present in the power screw are used. Therefore, the objective of this research is to design a high production precision machine using the equations that associated the physical principles to perform the kinematic and static stress analysis in the power screw.

2. Methodology
The type of research is descriptive and aims to define the design of a linear mechanical system for the study of the mechanical properties of the joints welded by the GMAW welding process, which can obtain control of the geometry of the weld seam with precision and repeatability.

The deposition of a weld bead is defined by the process and by a mechanical component that allows for straight-line displacement. This displacement is carried out by means of a power screw. This article takes as a reference the analysis of the loads and stresses acting on the screw, being one of the main working elements in the development of the research. Therefore, it is studied as a discrete system of particles, which relates to physical principles such as Newton's second law, with the development of the equations to perform the static and dynamic analyses present in the power screw. The kinematic calculations of the system are with standardized elements found in the market. In addition, this process was developed in the environment of computer aided design (CAD) programs.

2.1. Weld bead deposition
As a pre-welding test, the technical indices are set as a basis for making a productivity comparison between the different welding processes [11]. One of these factors is: The deposited material $M_D$ is a key factor for the calculation of welding costs and is defined as the quantity of filler material required to complete a given joint. A $D_R$ of 108 Kg/h, a $t_{arc}$ of 0.39 minutes was considered, the deposited material was calculated from Equation (1).

$$M_D = \frac{D_R \cdot t_{arc}}{60}.$$

Where, $M_D$ is the material deposited (Kg), $D_R$ is the deposition rate (Kg/h), $t_{arc}$ is welding time (minutes). This rectilinear displacement is transferred to a welding working deck by GMAW deposition. For greater accuracy with the load data that the shaft will support, the weight of the weld deposition was calculated taking into account the ER70S-6 welding feed material for a linear bead of 15 cm, and a welding speed of 1.44 mm/s. In addition, the weight of the plates was added to the calculations. The physical properties are shown in Table 1.

On the other hand, to avoid damage to the linear table, either by current leakage or by excessive heating during the welding process, a Bakelite plate was necessary, a copper plate to facilitate rapid heat distribution and return of welding current, this allows electrical and thermal insulation, the parts are shown in Figure 1.

### Table 1. Physical properties of materials.

| Material      | Dim (b-h-l) (cm) | V (cm³) | $\rho$ (g/cm³) | Mass (g) | Weight (N) |
|---------------|------------------|---------|----------------|----------|------------|
| Weld bead ER70S-6 | x:x:15          | x       | 7.83           | 12.27    | 0.12       |
| Plate AISI 1020    | 5:0.635:20       | 63.50   | 7.87           | 500.00   | 4.90       |
| Plate Cu           | 30:0.5:25        | 375.00  | 8.96           | 3360.00  | 32.96      |
| Plate bakelite     | 30:0.5:25        | 375.00  | 1.30           | 487.50   | 4.78       |
| Plate Al           | 30:0.5:25        | 375.00  | 2.71           | 1012.50  | 9.93       |
2.2. Power screw force and torque analysis

Power screws are mechanical devices that change a rotation or angular displacement in a straight line, transmitting force and mechanical power. In practice, power screws are provided by specialized suppliers that offer technical literature that includes all the data necessary for their selection. Two common types of thread are shown in Figure 2. Screwed joints can only transmit limited alternating stresses due to the notch stresses resulting from the functional design of a screw [12].

The square chord shown in Figure 2(a) provides the highest efficiencies and strengths; it also eliminates the radial force components between the bolt and nut. However, Acme chord is a common selection for power screws that must carry loads in both directions. The Acme chord, shown in Figure 2(b), has an included angle of 29°, which makes it easier to fabricate and also allows the use of a split nut that is tightened radially against the bolt to reduce wear. Most bolts are manufactured with only one chord (1 boot) [13].

2.2.1. Coefficient of friction. The coefficient of friction must be greater than the tangent of the feed angle. For a static coefficient of friction on the screw flank of 0.15, the maximum corresponding feed angle should be 8.8°. In this case the coefficient of friction was maintained, and the feed angle was calculated [14]. When choosing one of the steps used commercially by the Acme threads, it is verified that it met the previous condition. The pitch diameter Dp of the thread is obtained from Table 2, being a single strand, the feed L is equal to the pitch p.

| p, in | 1/14 | 1/12 | 1/10 | 1/8  | 1/6  | 1/5  |
|-------|------|------|------|------|------|------|
| Dp, in| 5/16 | 3/8  | 1/2  | 5/8  | 3/4  | 7/8  | 1    |

Figure 1. Loads on the power screw.

Figure 2. Power screw with (a) square thread and (b) Acme thread.
2.2.2. **Torque.** The movement of the platform is defined by the angular movement of the power screw, which in turn requires the action of a torque. The motor to be used on the table can be step-by-step, which is capable of directly controlling the axis by a pulse train and can be configured from 200 pulses per turn to 10000 pulses. The torque is applied to move the load on the power screw and is calculated with Equation (2).

\[
T = \frac{F \cdot D_p \left( \cos\phi \cdot \tan \lambda + \mu \right)}{2 \left( \cos\phi - \mu \tan \lambda \right)}.
\] (2)

Where, \(T\) is the torque required to move the screw, \(F\) is the resulting force due to the torque, \(D_p\) is the pitch diameter of the thread, \(\lambda\) is the forward angle, \(\mu\) is the coefficient of static friction on the screw flank, \(\phi\) is the angle of thread.

2.2.3. **Mechanical efficiency.** The efficiency in a screw is the same as in any system: the work entering the system, due to the applied torque (servomotor), is equal to the work leaving, plus the work of the friction losses on the screw flanks. As the power screw is an Acme thread, the value of the angle between the flanks is 14.5°. If the friction on the rope is reduced, the efficiency would increase significantly [15].

2.2.4. **Shear force.** This effort is what will sustain the mechanism due to the stresses parallel to the cross section. To calculate the shear stress produced by the torque, it is assumed that the area of the core is equal to that of a circle with a diameter equal to that of the interior of the screw, so the maximum shear stress occurs at the periphery of the section and is given by Equation (3).

\[
\tau = \frac{16T}{\pi d_r^2}.
\] (3)

Where, \(\tau\) is the shear force, \(T\) is the torque, \(d_r\) is the minor diameter.

2.3. **Material**

When a structural element or machine component made of brittle material is under uniaxial tension, the value of the normal stress that causes it to fail is equal to the ultimate strength of the material [16]. A ductile material, medium carbon steel of type AISI 1040, was considered for this selection. Therefore, a failure theory, involving the factor of safety and the maximum stress, is applied for the determination of the \(Sy\). It is calculated with the Equation (4).

\[
\tau_{\text{max}} = \frac{Sy}{2n}
\] (4)

Where, \(\tau_{\text{max}}\) is the maximum shear, \(Sy\) is the yield strength, \(n\) is the safety factor.

2.4. **Modeling in computer aided design software**

The parts are sized according to the conditions of the machine. The vertical structure of 250 mm, with a space for the welding gun that rests on a base connected to the pair of shafts, and the location of the motor that will give the torque to the power screw. Figure 3 shows a preview of the design using SolidWorks software.
3. Results

3.1. Design calculations
In the application of the stress equations, the selected values, and the use of the commercial tables of the materials, allowed finding and calculating the following factors exposed in Table 3.

3.2. Material determined
In accordance with the results of subsection 3.1, the maximum stress on the power screw is 283.57 kPa. To ensure that the material to be chosen will support the stresses already calculated, the failure theories were applied, where a safety factor of 1.5 was considered, in order to have a result closer to reality, providing a considerable service life. When calculating yield stress, based on tables illustrating the types of materials and the stress resistance they support, the ideal material for the construction of the power screw was AISI 1040 steel, as it provides sufficient ductility for easy machining, and thus ensures the accuracy of the thread.

| Design factors                        | Value          |
|---------------------------------------|----------------|
| Angle of travel (λ)                   | 4.04°          |
| Torque (T)                            | 0.08 Nm        |
| Mechanical efficiency (e)             | 30.90%         |
| Stress under axial load (τ_a)         | 370.27 kPa     |
| Shear stress (τ)                      | 214.86 kPa     |
| Maximum shear stress (τ_max)          | 283.57 kPa     |
| Yield strength (Sy)                   | 850.72 Pa      |

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3.4. Computer aided design modelling
In the design of the pieces that form part of the mechanism and the modelling of the existing ones, the optimization of the materials that carry the quality line was considered, in addition it was stipulated as a biaxial system, emphasizing the automation of the welding speed. Consequently, the system is...
composed horizontally of a base containing a power screw coupled to a servomotor and a pair of sliders with their respective blocks, supported on a table; vertically, as shown in Figure 4, it consists of a worm adapted to the base that holds the welding gun and two additional sliding shafts that provide manually adjustable freedom of movement.

4. Conclusions
The study focused on the calculation of the main stresses of the power screw since it is the piece most exposed to alterations in its movement with loads. The equations used were deduced through the physical principles of the second law of newton, focusing on the forces present and the kinematics of torque. In this way, the results of the stress analysis corroborate the hypothesis that the forces involved in the movement of the power screw will not alter the speed of the process. Furthermore, the material selected for processing can withstand the stress and move a 53 N load in both directions, from 0 mm to 150 mm at a speed of 1.44 mm/s. Finally, the modeling of the machine determined that the dimensions were appropriate for this type of application, which provided a preview of its construction.

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