MODELING AND SIMULATION OF DEFORMATIONS IN THE FEED SYSTEM FOR ULTRASONICALLY AIDED MICRO-EDM

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ABSTRACT: The paper deals with the study of deformations within the roller screw from the feed system, used in ultrasonically aided micro electrical discharge machining (µEDM+US). The study is focused on the deformation of the roller screw's threads in contact with the three rollers, components of the nut, in two constructive variants. The contact surfaces are determined and isolated on the roller screw, which is then introduced in a numerical simulation module, to calculate its deformation in different positions of the nut. The results pointed out that the load deformations of the roller screw are less than 0.1 µm, so µEDM+US precision would not be affected significantly.
KEYWORDS: EDM, µEDM, µEDM+US, feed system, deformation simulation.

1. INTRODUCTION

Electrical discharge machining (EDM) is defined as the removal of material by electric discharges between two electrodes (workpiece and tool) in a dielectric fluid. The material removal takes place by non-stationary electric discharges (sparks) which are separated from each other both spatially and temporally [1].

The space between the tool and the workpiece is called the spark gap, and its value depends on voltage, amperage, electrode materials and dielectric type. EDM process uses high voltage and amperage for gross material removal. The higher the voltage and the amperage the bigger the working gap becomes.

In order to have a stable EDM process, the spark gap needs to be regularly cleaned of debris by using various flushing techniques [2]. If the gap is not regularly cleaned and the debris is allowed to accumulate, the process enters a short circuit state, which affects the stability of the process and consequently the surface of the tool and workpiece.

Micro electrical discharge machining (µEDM) is a scaled-down EDM process. The electrode tool is much smaller and consequently more fragile, introducing limits to certain flushing techniques, and limits for amperage and voltage in order to prevent excessive wear on the tool [3]. Small amperage and voltage lead to a very small volume of removed material but result in a much higher quality surface [4].

µEDM gained popularity in the industries because of its ability to achieve surface finishing up to micro-levels [5]. However due to low productivity, because of the small work gap, because of frequent short circuits, scientists have sought out solutions to improve its productivity.

Ultrasonically aided micro electrical discharge machining (µEDM+US) is one solution. Aiding the electrode with ultrasonic vibrations solves the problem of work gap flushing. As the electrode moves up and down it creates a pump action in the work gap, effectively forcing the removed material out [6].

To accurately position the electrode and maintain an optimum work gap, a fast response and high precision feed system is required, like the one presented in figure 1, capable of executing a linear movement in increments of 0.2 µm.

This study deals with a numerical simulation of the roller screw's deformations that impacts its precision and ability to maintain a stable µEDM+US process.

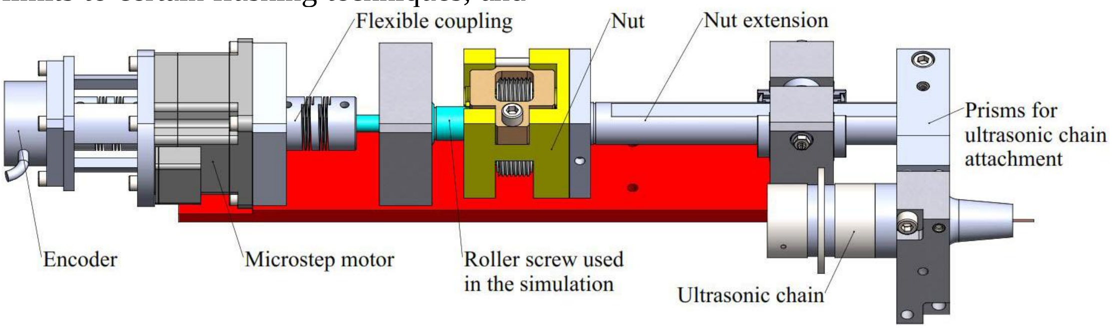

Figure 1. Feed system for ultrasonic aided micro electrical discharge

2. CONTACT SURFACE

To evaluate the deformation of the roller screw, the contact surfaces need to be determined. As seen in figure 2, the nut houses three rollers of M16x2, which are the only parts that maintain contact with the roller screw.

In figure 3, the position of the rollers can be seen, two of them are placed symmetrically at the bottom at an angle of 45º, and one on top, placed at 7º.

The actual contact surface is on the thread of the screw, which is determined by using the command “interference detection” in Solidworks 2016.

The results from figure 4 show eight contact surfaces of approximately 0.02 mm^3 each, for one roller. The measurement unit is mm^3, because the command calculates the common volume of two solid parts (roller screw and roller). The study considers this volume and converts it into surface, meaning that the contact surface is approximately 0.02 mm^2 times seven, for each roller.

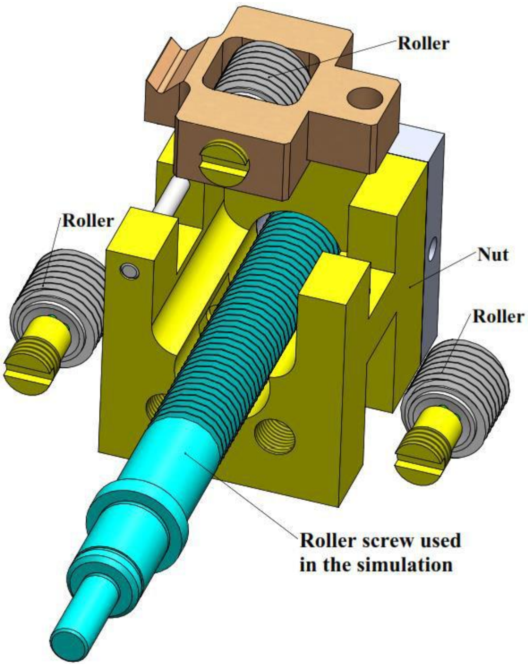

Figure 2. Roller screw and nut assembly

The last thread (figure 4, highlighted in blue) is not always in contact and doesn’t always have the same contact surface as the other 7. Therefore it is excluded from the simulation.

To simulate the deformation of the screw, the contact surfaces need to be isolated. Using Solidworks 2016, three longitudinal planes are created, at the same angle disposal on screw circumference, illustrated in figure 3, to cut the contact surface and isolate it (figure 5).

On every plane created, the sketch in figure 6 is built, using the command “convert entities” on the flanks of the screw. This sketch is created at a distance of 35 mm, which is the start of the usable contact area of the nut (the stroke).

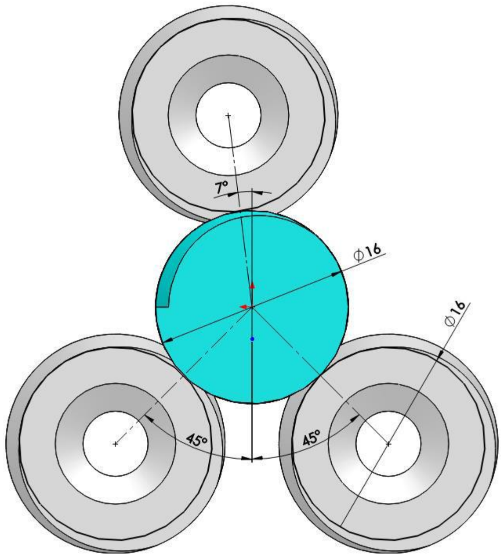

Figure 3. Roller position to screw

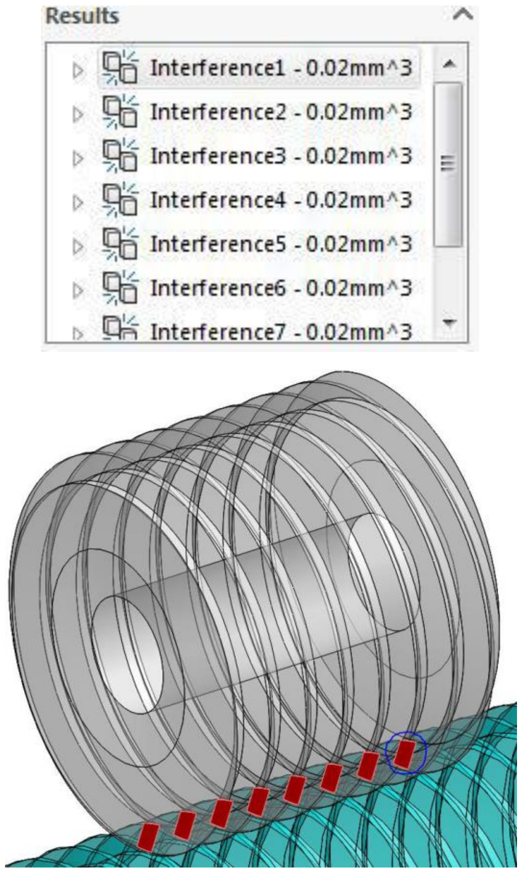

Figure 4. Interference detection and representation

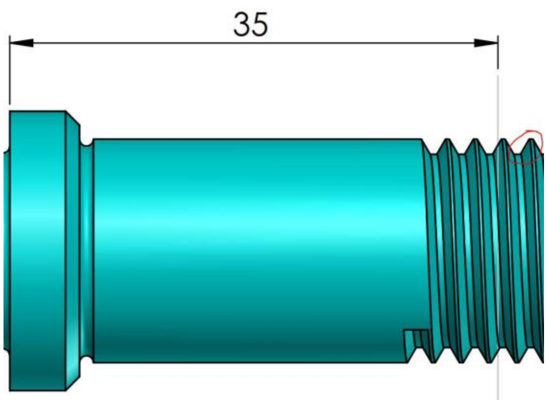

Figure 5. Sketch location

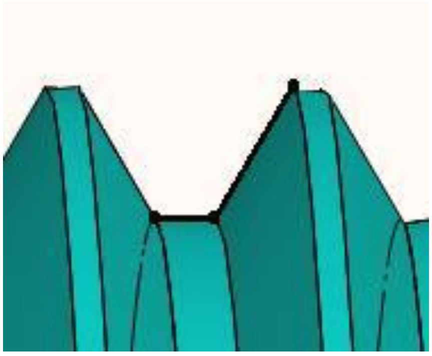

Figure 6. Sketch construction

Using the sketch from figure 6, a perpendicular plane to the flank of the thread was created through the highlighted line in figure 7.

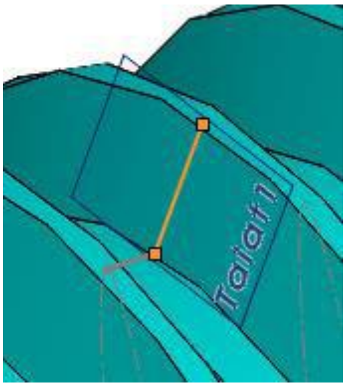

Figure 7. Perpendicular plane created on the surface thread

On the newly created plane, a sketch is drawn with the dimensions presented in figure 8.

These dimensions were determined by always comparing the isolated surface with the surface indicated by the command "interference detection".

Through iterative modifications of the dimensions of the isolated surface, presented in figure 8, the difference is narrowed down to 0.00164 mm^2, as shown in figure 9.

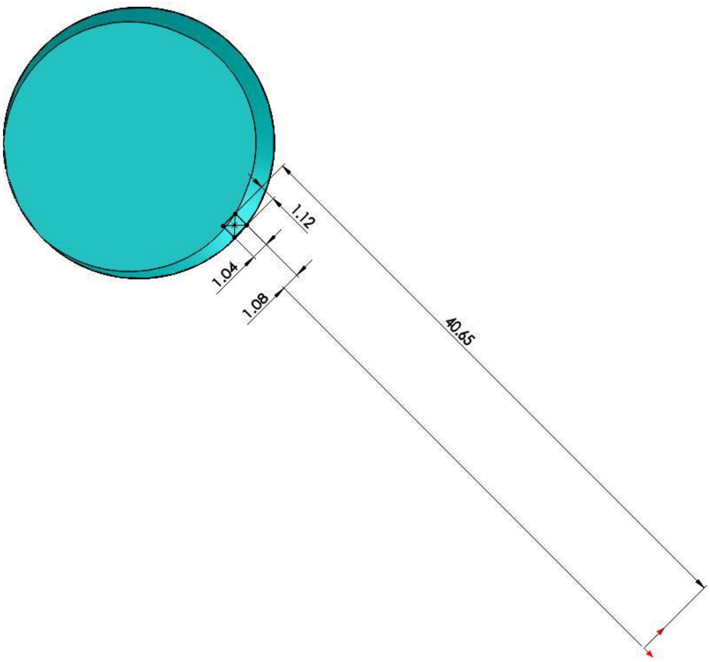

Figure 8. Sketch dimensions for surface location

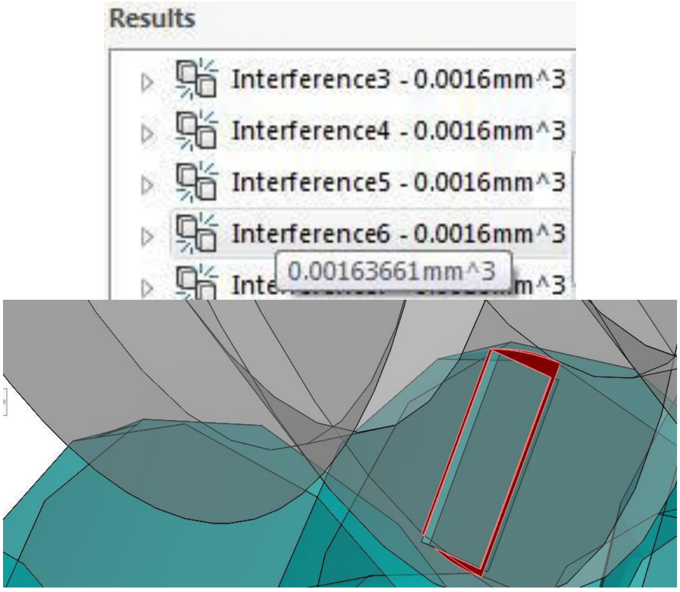

Figure 9. Isolated surface compared to interference detection

After the surface for one roller is isolated (figure 9, highlighted), a circle is drawn on the roller screw that goes through the middle of the highlighted center of the rectangle previously created in figure 8.

Now using this circle and the dimensions from figure 8 (1.12 and 1.04 mm), the dimensions from the origin (screw center) from figure 8 (40.65 mm and 1.08 mm) are modified such that the middle point of the rectangle to be situated on the previously drawn circle, as seen in figure 10. The isolated surface is always compared to the surface indicated by the command interference detection.

After one of each roller surface is isolated, the command "LPattern" is used on each surface to copy them onto the next 6 flanks, at a 2 mm distance (the pitch of the screw), as seen in figure 11.

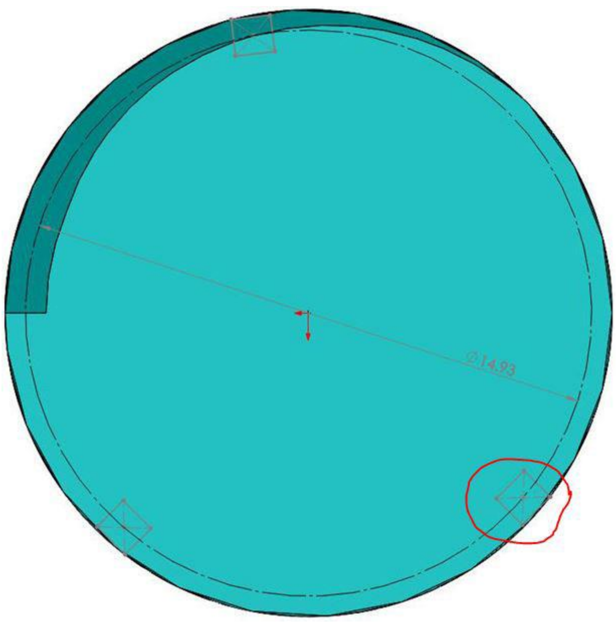

Figure 10. Sketch distribution of the isolated surfaces

To simulate the roller screw in different positions of the nut, two more sets of contact surfaces are added, as shown in figure 13. The command "LPattern" is used and the isolated surfaces previously built are selected, in order to create position 2 and position 3. The distances at which they are created are as follows: 40 mm for position 2 and 70 mm for position 3.

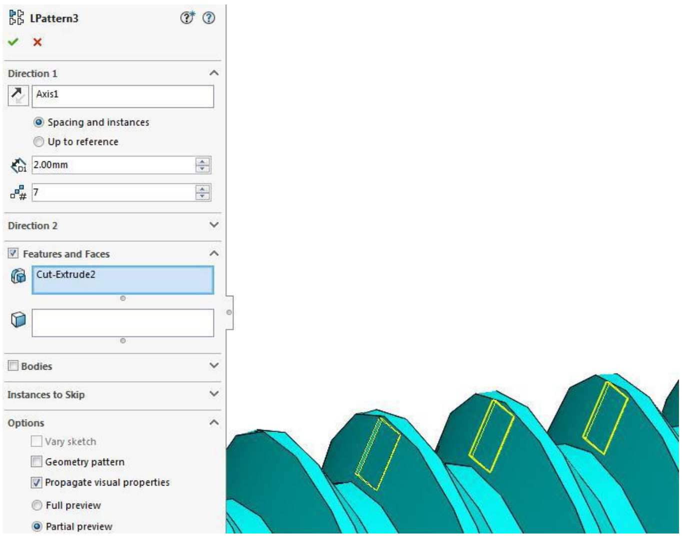

Figure 11. Multiplying the isolated surfaces

3. SIMULATION

The roller screw, with the isolated surfaces, was exported from Solidworks 2016 into Inventor 2020, where the analysis was performed (figure 15).

Afterward, the material of the roller screw is added in Inventor's material library (figure 12), 50CrMo4 – recommended by SKF [7], with the characteristics presented in table 1.

Table 1. Material characteristics for 50CrMo4 [8]

Code	50CrMo4
Young's modulus [GPa]	210
Poisson's ratio [-]	0.3
Shear Modulus [MPa]	80 000
Density [g/cm^3]	7 800
Yield Strength [MPa]	1 100
Tensile Strength [MPa]	1 300

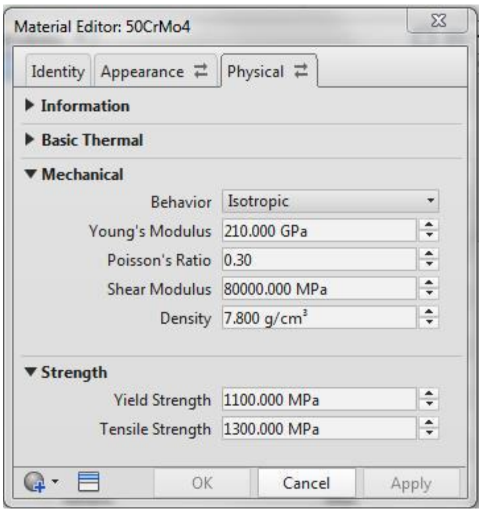

Figure 12. Adding 50CrMo4 to the material library and assigning it to the roller screw

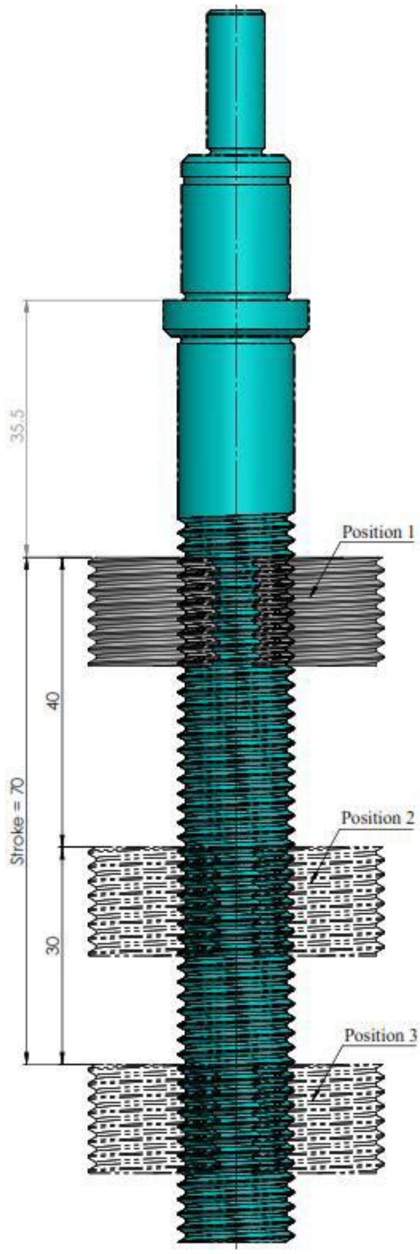

Figure 13. Multiple positions for testing purposes

The settings used for meshing are by default, as seen in figure 14. Meshing consists of splitting the geometry of the roller screw into a finite number of elements.

The reason is that the solution can be more easily found in small simple elements, rather than big and complex ones. The higher the meshing quality, the more precise the simulation becomes.

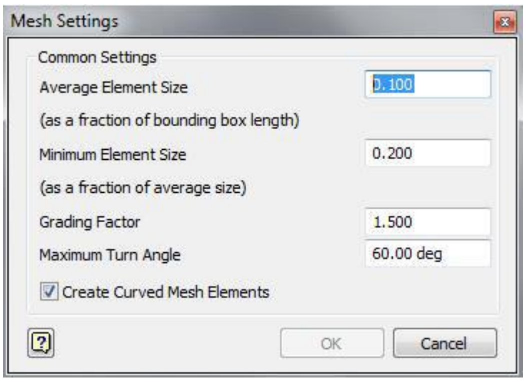

Figure 14. Mesh settings

Figure 15. Roller screw imported in Inventor with highlighted contact surfaces

After the meshing and the material allocation, a fixed constraint is put in place on the highlighted surface – where a bearing is assembled, as shown in figure 16.

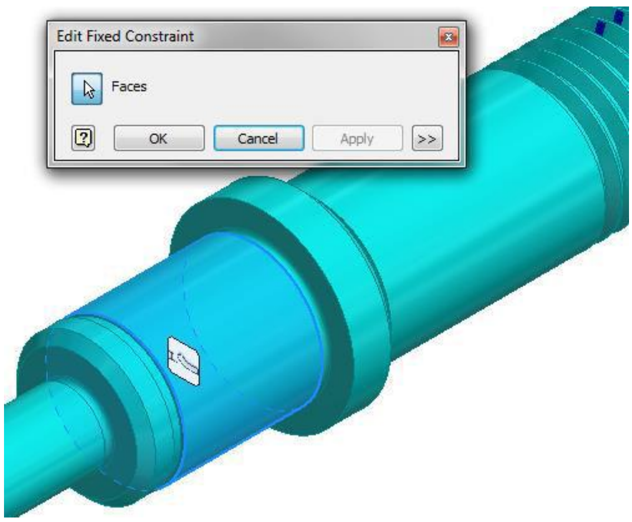

Figure 16. Adding a fix constraint to the highlighted surface

The force is added to every isolated surface in the first position, as seen in figure 17.

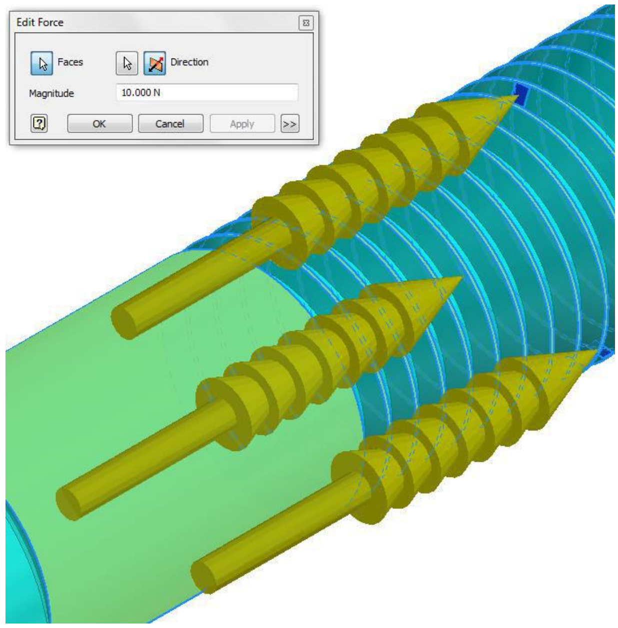

Figure 17. Adding a force of 10 N to the isolated surfaces

The weight of the nut and all parts, belonging to the ultrasonic chain, is estimated at 1 Kg. Multiplying the weight to the value of gravitational acceleration, 9.81 m/s^2, results in a force of 9.81 N. Which is then approximated to a fair value of F = 10 N and used in the simulation. The direction of the force is along the X axis, as shown by the arrows in figure 17.

4. RESULTS AND DISCUSSION

In figure 18, the displacement along the X axis is shown. The maximum displacement is 2.261e-05 mm, which equals 0.02261 µm.

However the three rollers on the screw are not stationary, so for the study to be relevant, the other two positions (see figure 13) were simulated.

The results are presented in table 2 and figure 18.

Table 2. Maximum deformation along the X axis

Position	Maximum value [mm]	Maximum value [µm]
1	2.261e-05	0.02261
2	4.261e-05	0.04261
3	5.743e-05	0.05743

The maximum deformation is in position 3, at the end of the feed range, with a value of 0.057 µm.

In the case of µEDM+US, the usual working gap is 5 µm, with an amplitude of 1 – 2 µm modifying it. The minimum frontal gap is considered 1 µm, taking account of discharge parameters and particle filtration of less than 1 µm of dielectric liquid.

The feed system's accuracy is 0.2 µm. However, since, during the µEDM+US process, the position of the tool-electrode varies between two points of elongation (amplitude of around 2 µm), due to ultrasonic vibrations, the deformation of the screw will have a minimal impact on accuracy.

For comparison purposes, a second roller screw is simulated, but with the rollers being set at equidistant angles of 120° on the circumference of the roller screw.

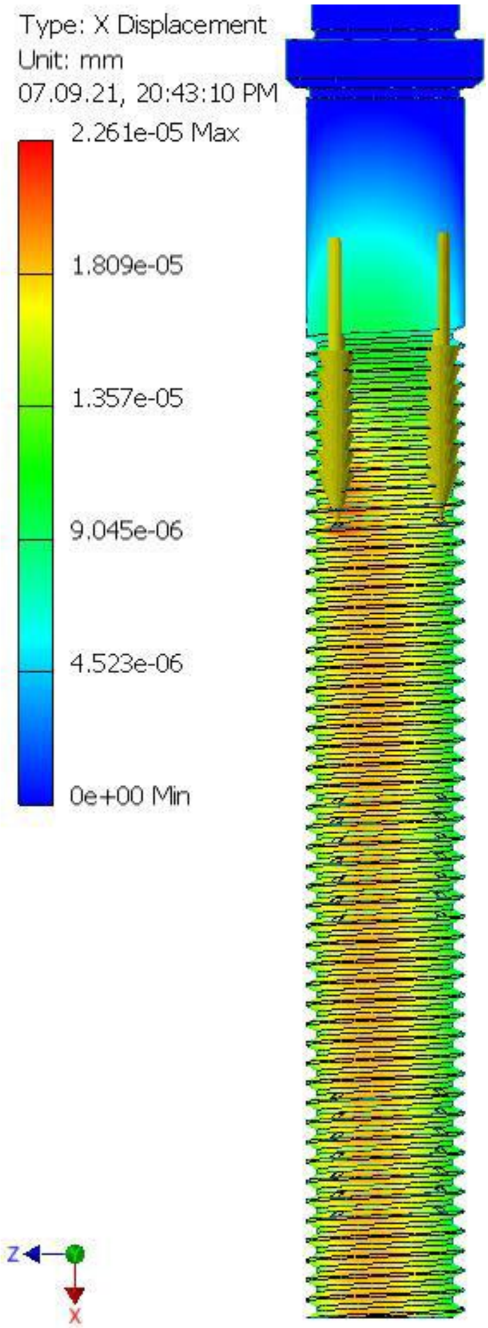

Figure 18. Displacement along the X axis

For the second roller screw (equidistant) the deformation values are presented in table 3 and its displacement along the X axis in figure 19.

Table 3. Maximum deformation along the X axis for equidistant rollers

Position	Maximum value [mm]	Maximum value [µm]
1	1.848e-05	0.01848
2	3.116-05	0.03116
3	4.08e-05	0.0408

In figure 18, it can be observed that the deformation isn't evenly distributed on the roller screw. This is because the rollers are not disposed at equidistant angles, so the deformation is more present to the left, where the 7° roller is, hence the brighter red color.

In comparison, figure 19, the deformation is evenly distributed, the green color is more prominent on the roller screw. Also for the deformation value, the equidistant roller stands out, 0.018 µm vs 0.023 µm, with less deformation. Which makes this variant ideal for mitigating the effects of deformation upon the feed system's precision.

However, the reason why the equidistant rollers are not used is that the roller placed at 7° acts as a lever and brings all rollers into contact with the roller screw with a greater closing force.

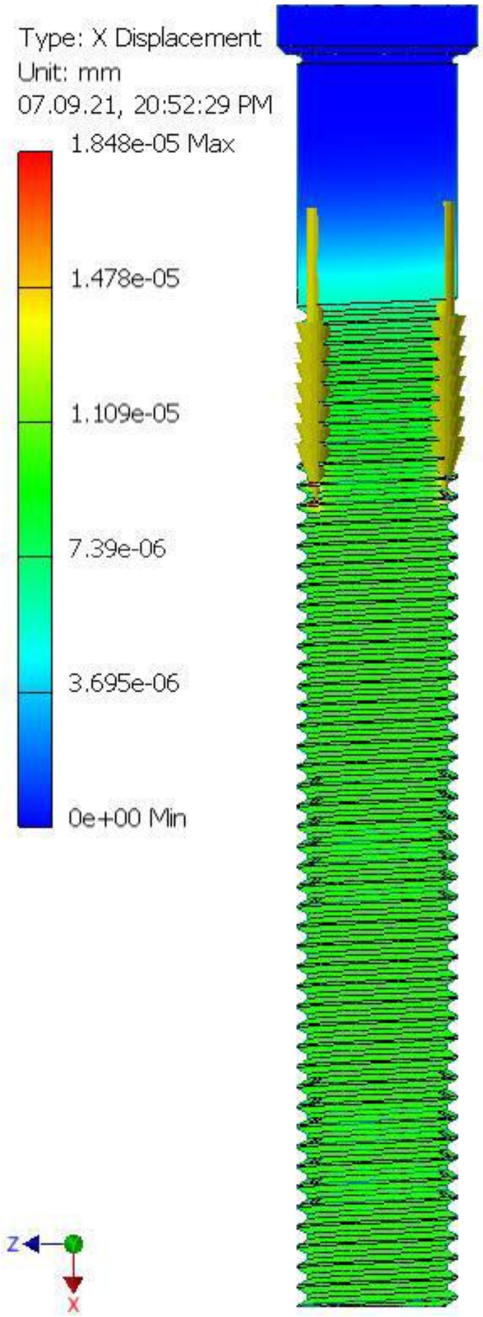

Figure 19. Displacement along the X axis for equidistant placement of the rollers

5. CONCLUSION

For both constructive variants of the roller screw, the greatest deformation was determined in position 3, at the end of the longitudinal stroke, measuring 0.057 µm for the asymmetric disposal of the rollers, and 0.041 µm for the equidistant disposal, on screw circumference. Although the second variant has a lower deformation value and a more uniform variation along the roller screw, the initial roller screw with a 7° asymmetric roller disposal is preferred. This is because of its possibility to be used as a lever to bring all the rollers in contact with a greater closing force on the roller screw.

The screw deformations, relative to the linear incremental movements of 0.2 µm of the feed system, and within around 5 µm frontal working gap, that varies with about 2 µm, due to US oscillation amplitude, are low and should not have a significant influence on the precision and stability of the process in any of the tested positions.

Further research will be done on the physical feed system, in a variety of different positions, to validate the results of the finite element analysis, using appropriate measuring instruments like laser interferometry.

6. ACKNOWLEDGMENTS

This work was supported by a grant from the Ministry of Research, Innovation and Digitization, CNCS/CCCDI – UEFISCDI, project number PN-III-P2-2.2-PED-2019-0367, within PNCDI III.

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