

3D Modelling and FEM Analysis on Metal Coin Edge Punching Error

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Abstract. Minting metal coin, mean to impress a given relief model on both coin faces and also on the edge. Due to the high striking pressure, the round blank material is forced to fill the inner space between dies. In the past, for less coin value, the coin edge remained cylindrical, without any inscription. Following the increased coin value, it was introduced a security feature against forgery; on the coin edge model could be toothed or inscribed with relief or incuse text logo. Besides the coin edge basic design, a various amount of coin edge error types are released. In the paper there are studied some errors on the metal coin edge impressed with incuse text by punching. First, there are presented some particular examples and general aspects about the coin edge punching are also introduced. Then, the simplified 3D model of the parts is presented. Also, the finite element analysis on this model is realized and is achieved for different initial conditions. In the final part, the analysis results and conclusions are presented.

1. Introduction

As manufacturing process, the metal coin production is followed in most of the situations by a various amount of error types. The each error type depends on the coin manufacturing step where it could appear; there are known errors on the coin metal alloy, coin blank manufacture, at the striking tools manufacturing and, respectively, on the properly coin striking [1, 2]. Since the coins striking include also the edge manufacturing, as toothed or impressed with various text devices and symbols, some error on the edge inscription could appear. The pieces wearing some mint errors are most valuable on the collectors market: for increased spectacular error on coin, the increased value for the subjected piece [1, 3, 4].

Each metal coin is manufactured by pressing at high loads the coin round blank with hardened steel negative dies, which forms a closed space to be filled by coin material [2]. In most cases, the model on the negative die is incused, so after the coin striking, result the relief model on coin.

Introduced as security feature, the coin edge lettering was as relief positive lettering or incuse negative lettering. The relief edge lettering was usually obtained on the properly coin striking, when the coin material had to fill also the negative edge die relief.

To increase productivity and reduce costs, the incuse coin edge lettering was introduced; usually was manufactured before properly coin striking, after forming the coin's blank rim. A straight steel die was used, against which the blanks were pressed with great force and rotated (figure 1). This straight steel die contains the hardened letter punches to be impressed on coin edge [3, 4]. Together with toothed edge, the incuse edge lettering was the most commonly used on circulation coins.

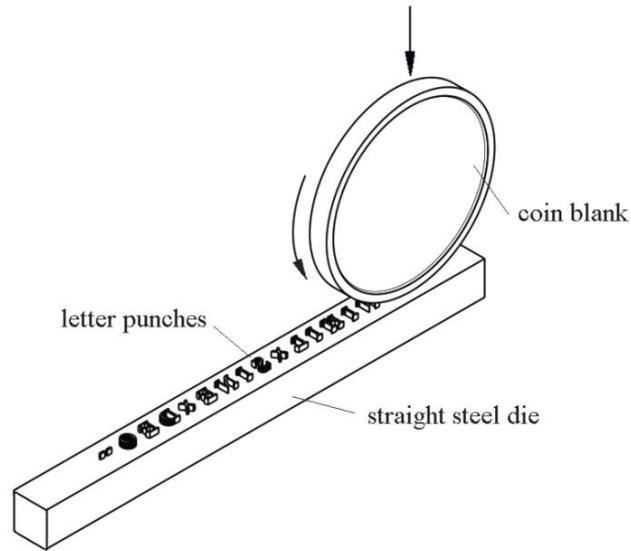


Figure 1. The incuse coin edge lettering

In figure 2, there are presented two examples of coins which bears incuse device on edge: an old Romanian 500 lei silver coin, minted in year 1944, and a former German coin 5 mark, minted in year 1975. In Romania, the incuse device on coin edge was introduced starting 1939. Many devices were used; one of them was “NIHIL SINE DEO”, massively manufactured on different coins edge, from 1941 until 1947 [6, 7]. The mentioned period covers the war and the after war years, in which, due to major inflation, a large amount of metallic coins were minted. Depending by coin value many alloys were used, as nickel plated iron, silver, brass.



Figure 2. The incuse letters on metal coin edges

If some failures or appeared on the straight steel die, the pressed coins resulted with error on edge inscription. The most frequently error is the punch letter crack, witch led to an incomplete incuse letter (named cracked or broken letters) impressed on the coin edge. In the most cases, the literature doesn't reveal exactly the causes of this failure in the coins manufacturing process; moreover, the pieces wearing this error are often unknown or, if known, some of them are considered variants from the basic design [5]. In the following figures there are presented various examples of coins with edge inscription “NIHIL SINE DEO” having broken letters. The studied inscription is composed by twelve letters, included in three words, each separated by ornaments. The letter shape is: open and sharp (for N, I, H, L, E), closed and sharp (D), open and round (S), and, respectively, closed and round (O). The separating ornament shape is usually less complicated.

In figure 3 are presented two Romanian nickel plated iron coins, 100 lei, minted in years 1943 and 1944, with broken letters on the edge inscription. In figure 4, a, the damaged letters are N, I, I from NIHIL, S, N, E, from SINE and D, E, O from DEO. In figure 4, b the damaged letters are I, H, I from NIHIL and I, from SINE.

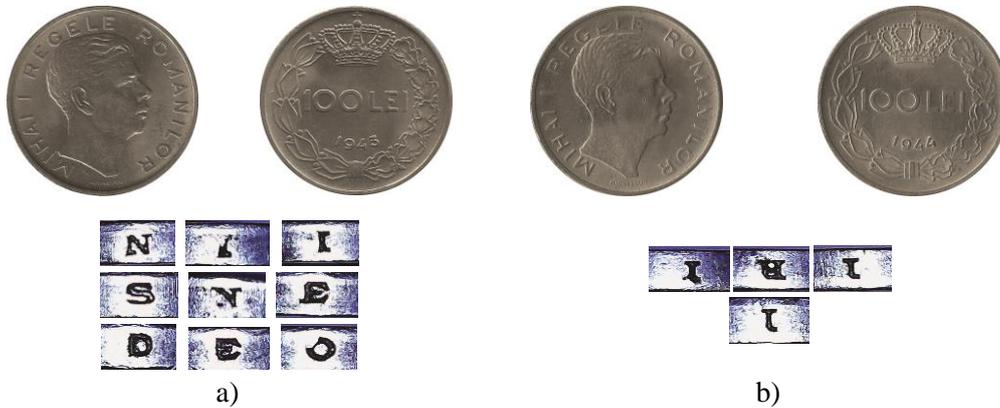


Figure 3. Broken letters impressed on nickel plated iron coin edge

In figure 4 are presented two Romanian silver coins, 25000 lei and 100000 lei, minted in year 1946, with broken letters on the mentioned edge inscription. In figure 4, a, all the inscription damaged letters are I. In figure 4, b the damaged letters are N, I, I from NIHIL.



Figure 4. Broken letters impressed on silver coin edge



Figure 5. Broken letters impressed on brass coin edge

In figure 5 are presented two Romanian brass coins, 2000 lei and 10000 lei, minted in years 1946 and 1947 with broken letters on the edge inscription. In figure 5, a, all the inscription letters and ornaments are damaged, except S from Sine and the final separation ornament. In figure 5, b all letters and ornaments are damaged, except N from NIHIL, E from SINE, D from DEO and the final separation ornament.

Analyzing previous figures, it can be observed that, the most frequently damaged letter or ornament portion on the coin edge are the thin sections (letter serif for sharp letter shape), firstly intersected by the blank during its motion. If the coin blank is rolling without misalignments, the damaged letter portion is on the top and bottom serif, as is presented in figure 6, a. If some misalignments appear, as is presented in figure 6, b, the damages appear on bottom serif on letter. Due to its shape, the letter O has approximately the same intersected portion with coin blank.

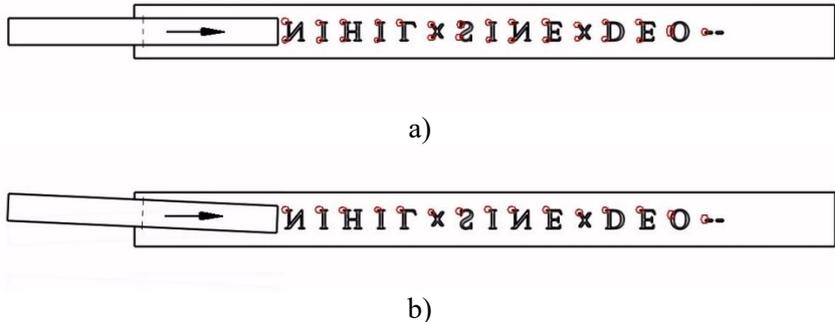


Figure 6. The most damaged letter portion

2. Theoretical aspects

According to the mechanisms theory, the path of a point belonging on a straight line Δ which rolls without slip along the circumference of a circle with radius r is a planar curve named involutes, as presented in figure 7. If the point belongs to a parallel straight line Δ'' , which intersects the circle, it describes elongated involutes path. If the parallel straight line Δ' is outside the circle, the path involutes are shorted [8, 9].

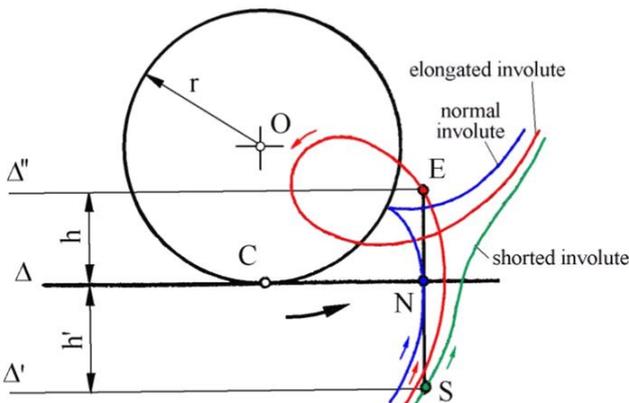


Figure 7. The involute path types between circle and straight line

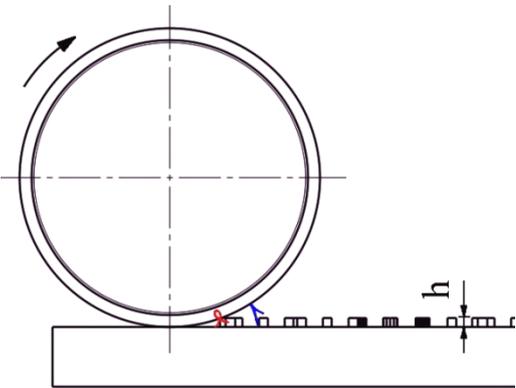


Figure 8. The involute path between coin blank and straight die with punches

When the coin blank is rolling without slip along the straight die, each point on straight die describes involutes path; the letter lower base point on die must be included. Taking account by the punches letter

height h , the letter top points will describe elongated involutes path, as presented in figure 8. Since the letter height is reduced, the elongated involutes amplitude is also reduced.

Usually, the distance between letters on inscription e is constant, but the each letter width s is not (figure 9). This generates a different angular pitch on the blank coin's circumference, corresponding to different letter shape. Due to the reduced letter dimension, it will be considered just the equidistant angular pitch between letters, given by relation

$$\tau = 2\pi/z, \quad (1)$$

where z is total number of the inscription letter and symbols.

For the studied case, the inscription is composed by twelve letters, included in three words, each separated by one ornament. The result is fifteen characters, equiangular disposed on coin edge; taking account by previous relation the angular pitch is $\tau = 24^\circ$.

Also, the relation (1) led to the circular pitch between letters, given by

$$p = 2\pi r/z. \quad (2)$$

From relation (2) result that, for the inscription with same number characters used, the letter punches distance on the corresponding straight die depends by different coins diameter.

On straight die arrangement, the relief negative inscription has a beginning letter or symbol punch and also, an ending one. The studied inscription has, as beginning letter the N from NIHIL and, as ending symbol, the separating ornament which precedes the mentioned word. Before and after the relief negative inscription punches on die, only the straight die surface can be found. So, at coin blank rolling on this surface, its circumference will intersect the first inscription punch letter, as in figure 9.

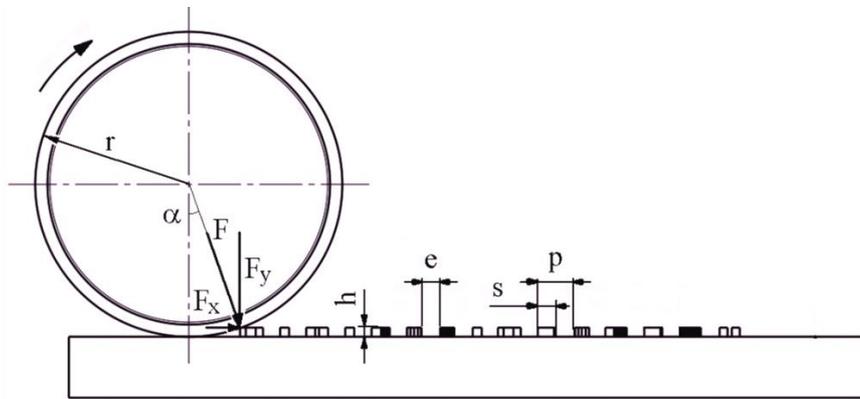


Figure 9. The contact between the rolling blank coin and letter punch

The center angle corresponding to this coin blank position depends by the blank radius and letter punch height and is given by relation

$$\alpha = \arccos\left(1 - h/r\right). \quad (3)$$

Considering the relation (1) and (3) the number of letter punches simultaneously intersected by coin blank can be determined

$$n = 2\alpha/\tau, \quad (4)$$

except for first letter, until second letter enters in contact and, also for the last letter after the precedent is out of contact. Taking account by the relation (3) the number of punches simultaneously in contact

depends by letter height h , coin blank radius r and also by the inscription total number of letters and symbols z .

The force F which appears on contact between the blank circumference and the letter punch edge has, as its components

$$F_x = F \sin \alpha \quad (5)$$

and

$$F_y = F \cos \alpha. \quad (6)$$

From relation (3), (5) and (6) result the influence of the center angle, the blank radius and also the letter punch height on the force components.

In the coin edge punching real case, the blank circumference has to maintain contact with the straight die surface, which means that the punch letter needs to dislocate the intersected blank material, in order to obtain the incuse letter on it. In figure 10, the punching steps are presented. Firstly, the coin blank circumference is intersecting the corner point P on the punching letter profile. From this moment, the forces given by relation (5) and (6) start their load to dislocate the coin blank material. The second step can be considered when the letter symmetry axis is coincident with the blank vertical axis. In this position, the most of the coin blank material is dislocated, except some material on top and lateral letter side. The third step is given by the point P last contact position with the coin blank; when all material is already dislocated and the loading force ends their action. The both, first and last contact, between the coin blank and the punching letter profile are given by the same point P , located on the top corner on the letter profile. So, the most loaded letter punch side is given by this point position.

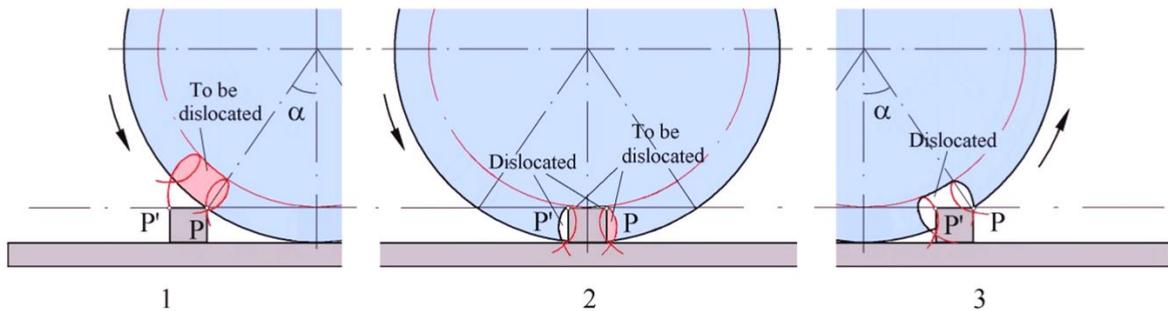


Figure 10. The punching steps between the rolling blank coin and letter punch

3. The virtual model

As was presented, the studied inscription is composed by twelve letters, included in three words, each separated by ornaments. Since on the entire straight die there are multiple complex details, the simplified punches models for each of the mentioned letters will be computed for study. The each punch simplified model consist in a cylinder with relief extruded letter on top, as is presented in figure 11. To elaborate the 3D models, the CATIA software is used [10, 11].

Taking account by punching steps, previously introduced, the most loaded position is the first contact between the coin blank circumference and the punching letter highest profile. From figure 6 results that the letter portion firstly intersected by coin blank is the same for letters N, I, H, L, E, D and consist in the thin portion defined by each letter serifs on left side. From these group of letters, were chosen to be computed the letter N, as the first inscription letter and, also, the letter I, the narrowest in the inscription. Another computed letters are S, where the contact may be on the round lateral portion or on the bottom left serif, and, also the letter O, where any contact with the coin blank is on the round left portion.



Figure 11. The letter punches 3D model

Each punch model (exception on letter O) is loaded in two cases, for aligned rolling coin blank on die, when the force value is equal divided between the top and bottom letter profile and respectively for misaligned rolling coin blank on die, when the force value is entirely applied on the bottom letter profile. For the letter O punch, the entire force is applied on a corresponding portion of the outside round edge. The loading cases are exemplified in figure 12, for letters N and O.

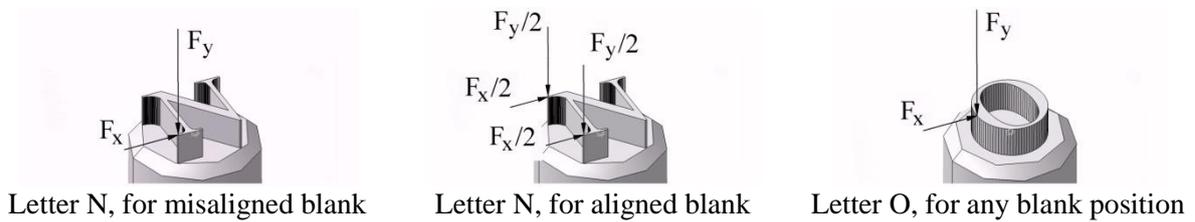


Figure 12. The loading cases on letter punches

4. Finite element analysis, simulation and results.

For the analysis, the ANSYS software is used [12]. The analysis objective is to determine the letter punches behaviour under the load. For the analysis, the previous punches virtual model is used. The letter height is 1.5 mm and the considered blank radius is 25 mm, which led to angle value $\alpha = 20^\circ$. For all the punches models, the considered material is steel; the material properties, as Young modulus, Poisson coefficient, Tensile Yield Strength, Ultimate Strength should be defined [6, 9, 10]. In the contact area it is chosen a smooth mesh with the minimum edge length equal with 0.001 mm.

To dislocate the blank material, the punching force value must exceed the coin blank material allowable stress [2]. The applied normal force F on each punch is equal with 500N, in order to obtain high contact pressures, over the coin blank material allowable stress – 1600 MPa [1, 2, 5]. The results, presented in figures 13 to 19 and also in table 1, consist in the contact pressure maximum values and also the maximum values of the punch material deformation.

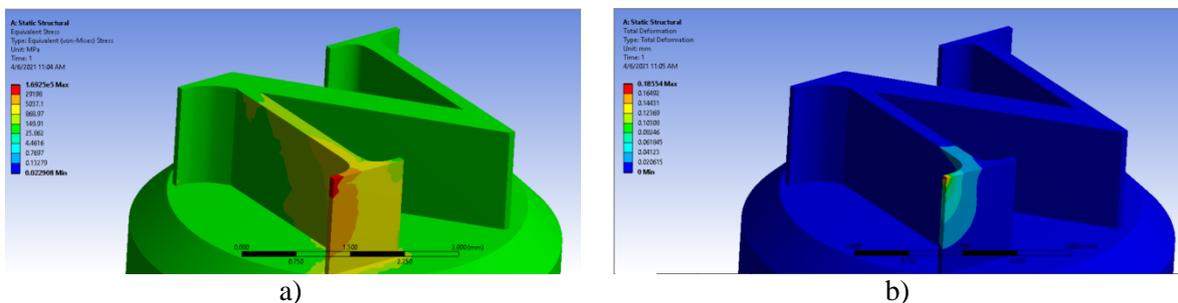
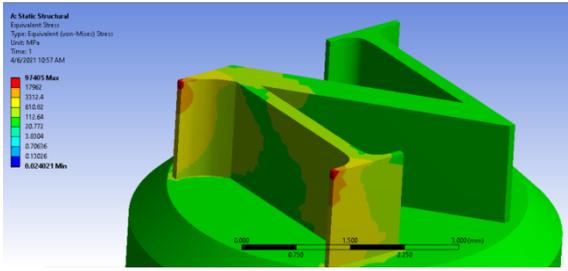
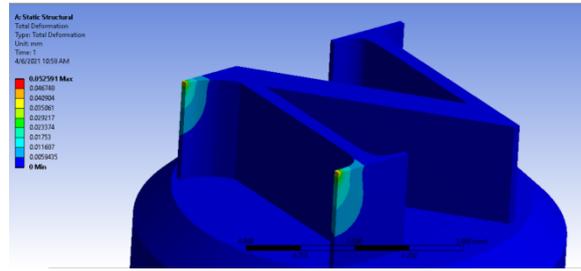


Figure 13. The letter punch N loaded for misaligned coin blank on die

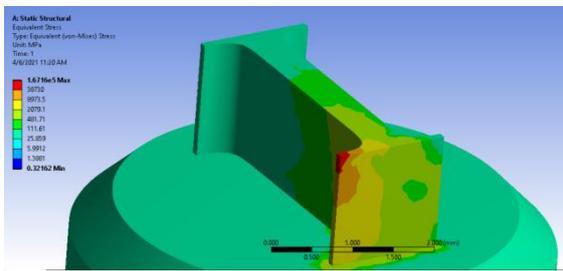


a)

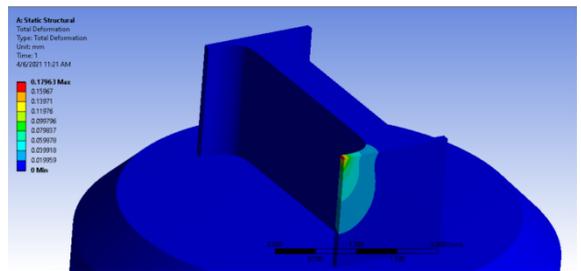


b)

Figure 14. The letter punch N loaded for aligned coin blank on die

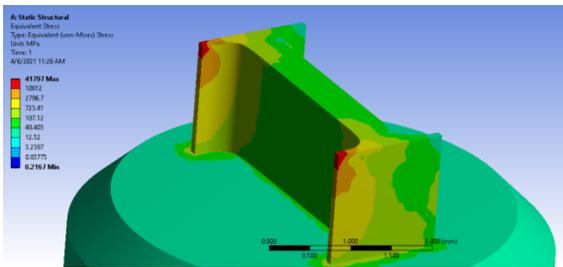


a)

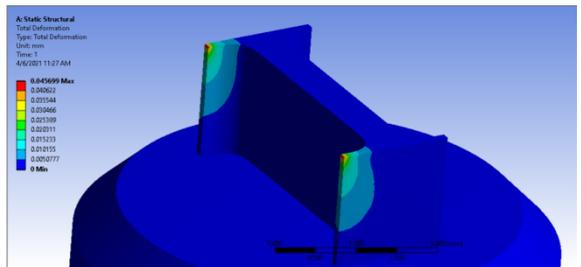


b)

Figure 15. The letter punch I for misaligned coin blank on die

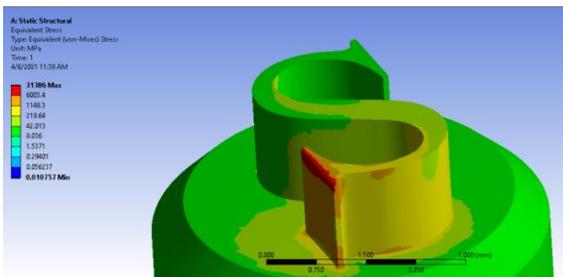


a)

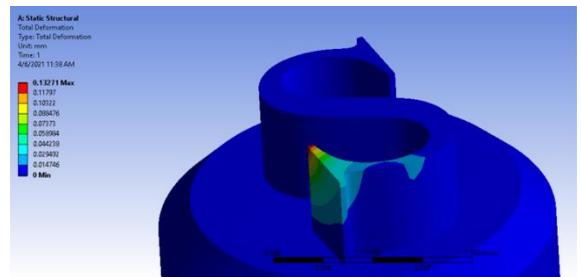


b)

Figure 16. The letter punch I loaded for aligned coin blank on die



a)



b)

Figure 17. The letter punch S loaded for misaligned coin blank on die

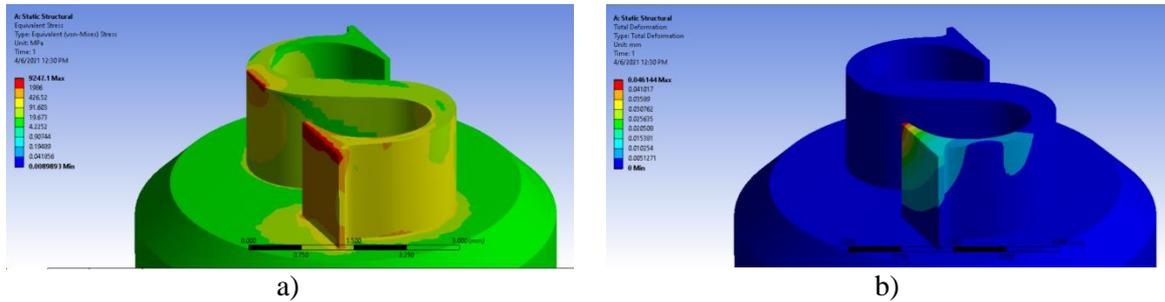


Figure 18. The letter punch S loaded for aligned coin blank on die

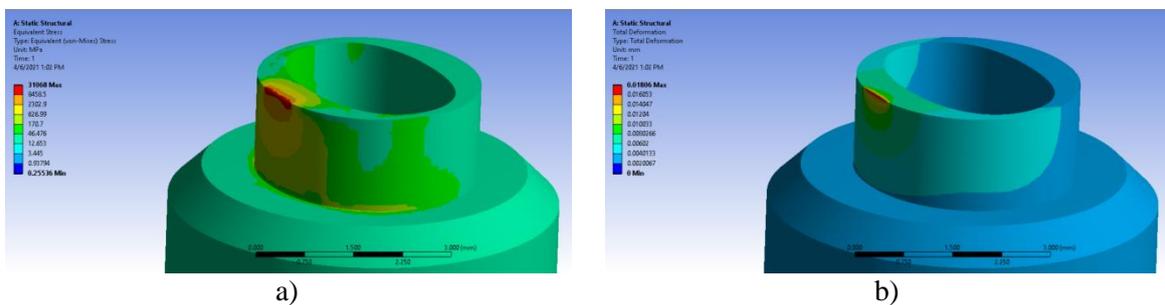


Figure 19. The letter punch O loaded for both misaligned and aligned coin blank on die

5. Conclusions

The most frequently damaged letter or ornament portion on the coin edge are the thin sections of the punch letter (letter serif for sharp letter shape), firstly intersected by the coin blank during its motion. If the coin blank is rolling without misalignments, the damaged letter portion is on the top and bottom serif. If some misalignments appear, the damages appear on bottom serif on letter. Due to its shape, the letter O has approximately the same intersected portion with coin blank in both situations.

When the coin blank is rolling without slip along the straight die, each point on straight die describes involutes path; the letter lower base point on die describes an involutes path and, respectively, the letter top point describes an elongated involutes path. The elongated involutes trace gives the incuse letter cavity shape inside the coin blank edge.

Depending by the letter angular pitch and center angle, the presented punching steps led to different combinations on simultaneously letter punches in action, to obtain the corresponding loading cases for various coin edge inscriptions. Some characteristics, as the loading case, blank radius, letter punch height and shape and also the misalignments inside the pressing machine, have a direct influence on the force components and on the contact area. To impress the incuse letter on coin blank, the punching force value must exceed the blank material allowable stress but also, to be less than the punches material allowable stress. Instead of this, the increased loads led to worse the punch letter profile behaviour, so the coin edge result impressed with broken letter having a missing part.

The obtained values presented in table 1 should be considered as relative values, to be used to compare the different studied cases. Due to the dramatically reduced contact area between the studied letter punch and coin blank, the contact pressure and the material deformation are highly increased; the thin details of the punch letter are exposed to be damaged. For the same loading force, the round letters S and O have better behaviour (less contact pressure and less deformations) than the sharp letters N and I. For all studied letters, the loading case without rolling misalignments led also to a better behaviour on each punch letter.

Table 1. The contact pressure and the deformation, maximum values

The letter punch	Loading case	Contact pressure, MPa	Deformation, mm
N	For misaligned coin blank on die	169250	0.18554
N	For aligned coin blank on die	97405	0.052591
I	For misaligned coin blank on die	167160	0.17963
I	For aligned coin blank on die	41797	0.045699
S	For misaligned coin blank on die	31386	0.13271
S	For aligned coin blank on die	9247.1	0.046144
O	For misaligned coin blank on die	31607	0.01806

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