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3D MODELING AND FEM ANALYSIS ON METAL COIN EMBOSSED EDGE LETTERING DIES

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Abstract: *Generally, the metal coins striking consist in high loads pressing the half-finished metal round blank using negative dies. Mainly introduced as security feature against forgery, the embossed edge inscription was manufactured at mainly coin striking, using also the negative edge die relief. In Romania, the embossed inscription on edge was firstly used in 1881, to strike the former 5 lei silver coin. Due to some varieties given by literature on this device inscription, as letters and character number, the paper purpose is to determine the possible reason for these changes. In present days, modern methods as 3D Modeling and Finite Elements Method, allow to analyze these subjected die edge varieties. The obtained results led to some useful conclusions about the motivation behind this edge lettering changing. On their turn, the conclusions are useful to an improved approach to future numismatic evaluation on the subjected coin varieties.*

Key words: *Metal coin, embossed edge lettering, coin striking, varieties, 3D modeling, FEM analysis.*

1. INTRODUCTION

The metal coin striking consist in pressing at adequate high loads the half-finished blank using hardened steel negative dies, able to form a closed space which is then filled by the coin material [1, 2, 3]. If the engraved model on the each negative die is incused, after the coin striking, the model on coin became embossed.

During the metal coin manufacturing, could appear in some circumstances many amounts of error types. The literature reveals that each kind of error type is depending by the manufacturing step in where it could appear. There are recorded errors caused by the metal alloy or on coin half-finished blank manufacture, on the corresponding striking tools manufacturing and also, on the mainly coin striking [1, 4].

The metal coin to be manufactured includes the coin edge: toothed or smooth, impressed with various text devices and symbols. Some error during the edge inscription manufacturing could appear. These are highly appreciated on the collectors market. An increased spectacular error on coin increases also the value of the subjected piece [4, 5, 6].

The edge lettering was made to ensure the coin security, as embossed or incuse inscription on the smooth edge. Particularly, the embossed edge lettering was manufactured together with the mainly coin striking, so the coin blank material was needed to fill also the negative engraved inscription on the edge die [2, 7].

In Europe, the modern technique of embossed edge lettering has been used since the beginning of the 19th century, but also during the 20th century, by various countries as Great Britain, France, Belgium, Switzerland, on coins made from precious metal, with a high nominal value [8]. In present days, some countries are still producing coins with this embossed edge lettering [9]. In figure 1 is presented the embossed text device impressed on the edge on former French silver coin with nominal value 5 francs, minted in the year 1964.

In Romania, these embossed edge lettering was manufactured on some silver and gold coins, with high nominal value, from 1881 until eventually 1922 [10, 11]. In figure 2, the embossed text device can be observed on the edge of former Romanian 5 lei, silver coin, issued in the year 1884.

Fig.1. The embossed inscription on former French silver coin edge

Fig.2. The embossed inscription on old Romanian silver coin edge

2. PARTICULARITIES OF ROMANIAN COINS EMBOSSED EDGE LETTERING

The Romanian 5 lei silver coins were produced starting 1880. Having 37 millimeters diameter and weighting 25 grams of silver alloy, this coin together with its gold counterparts, was defined by the monetary law from 1867 as etalon of the adopted bimetallism monetary system [12, 13]. Later, in the year 1890, this etalon statute was lost, according to a new monetary law which introduced the gold monometallic monetary system [14, 15, 16].

Following the kingdom's proclamation in 1881, some changes were made on the coin design minted until then at the National Mint. First, on the coin obverse, the title LORD (DOMN in Romanian), was replaced with the title KING (REGE in Romanian) [14]. Also, on coin reverse some changes on the represented country coat of arms were done [15]. On these new 5 lei silver coins, which followed those from 1880 and 1881, the toothed edge was abandoned in favor of the smooth one, embossed inscribed with the motto MY FATHERLAND AND MY RIGHT (PATRIA SI DREPTUL MEU, in Romanian). The words are separated by a star and, at the device end, the separation is realized by a group of five or six stars. This embossed motto was later used in various variants, mostly given by the shape and number of separating stars between device words: on all 5 lei silver coins, from 1881 until 1885, on 20 lei gold coins in 1883 and 1890, respectively on the 100 lei gold coin from the jubilee series with the engraved year 1922, minted in 1927 [10, 11].

The subjected metal coin embossed device was manufactured simultaneously with the properly striking of the sides of the coin, by using three ring sector dies, theoretically equal, according to the schematic representation in figure 3. On their turn, each ring sector die had engraved the negative portion of the related text. Result an important characteristic of this type of embossed coin edge: the fixed position in relation to the sides of the coin and therefore to elements in their model, which makes it possible to read the motto from a clearly determined position of the coin [7]. For the mentioned Romanian coins, the reading of the motto is done from the coin held with the obverse effigy on top, the beginning of the motto always being positioned next to the base of the effigy, as already shown in figure 2. Since small deviations can be attributed to the manufacturing precision, other different positioning may indicate an error or a counterfeit coin.

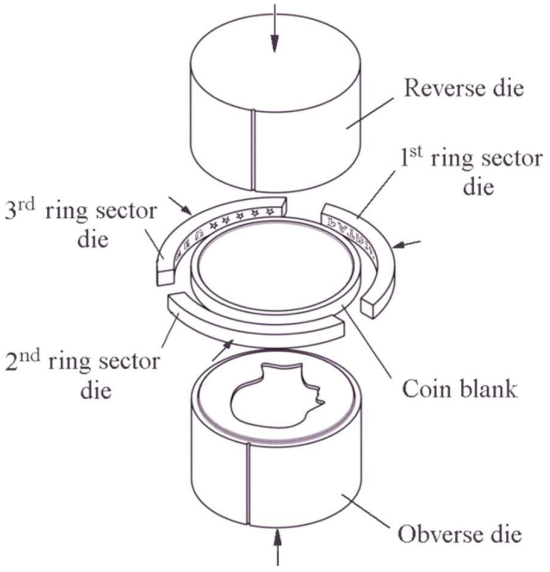


Fig.3. The embossed edge lettering

Due to the ring fragmentation into three portions, to allow the finished piece to exit the dies, the traces of separation surfaces remains visible on the coin edge as dividing lines in relief between the inscription elements. These lines can have a more pronounced or blurred appearance, depending on some working conditions as the dies misalignments, the applied force or the wear of the pressing machine.

In Table 1, there are presented some features of the embossed inscriptions printed in relief on the mentioned 5 lei Romanian coins: the number and type of characters, respectively the division into ring sectors [10]. It can be observed that, when dividing the ring, an equal (in reality approximately equal) distribution of the engraved negative characters, letters or symbols was considered on each sector: 9 characters, letters and stars each, from a total of 27, except for the inscription with 5 stars at the end, where the total character number is 26 so, only 8 characters are present on the 3rd ring sector. The literature [10, 11] reveals that the most known inscription variants are recorded for the 5 lei coin minted in 1881, the beginning year of the embossed edge coin production. These variants are given by the stars type (having five or six corners), by their number or, respectively, by their position – some five corners stars are overturned.

Table 1

Embossed inscription features on the Romanian 5 lei coins edge.

Coin issuing year	Ring sector die		
	1st	2nd	3rd
1881 and 1882	PATRIA ★ SI	★ DREPTUL ★	MEU ★★★★★
Only 1881	PATRIA * SI	★ DREPTUL ★	MEU ★★★★★
From 1881 to 1885	PATRIA ★ SI	★ DREPTUL ★	MEU ★★★★★★
Only 1881	PATRIA ★ SI	★ DREPTUL ★	MEU ★★★★*★
Only 1881	PATRIA ✱ SI	✱ DREPTUL ✱	MEU ✱✱✱✱✱✱

For the coins issued in 1881, the most known are the those having the edge inscription with five or six stars arrangement, each having five corners; the inscription having the overturned five corners stars and, also, the inscription having six stars with six corners are rarely recorded [10]. Then, in next year 1882, the entirely mintage was manufactured with inscriptions having five stars arrangement, each having five corners. Again, starting in 1883, the manufacturing returned to the inscription with six stars arrangement, each having five corners.

The different numbers of characters on edge are influencing their relative position on the coin edge: more characters, less space between them. In figure 4 are comparatively presented some differences on the embossed letters position, for five stars variant (bellow), or six stars variant (above), both belonging to coins issued in 1881, on the 3rd ring sector. The characters relative position is more relevant near the ring sectors separation traces. In figure 4, a, can be observed the character position and separation trace between the 3rd and the 1st ring sector, in figure 4, b, the separation trace between the 1st and 2nd ring sector, and, finally, in figure 4, c, the separation trace between the 2nd and 3rd ring sector.

a. **b.** **c.**

Fig.4. The embossed lettering position

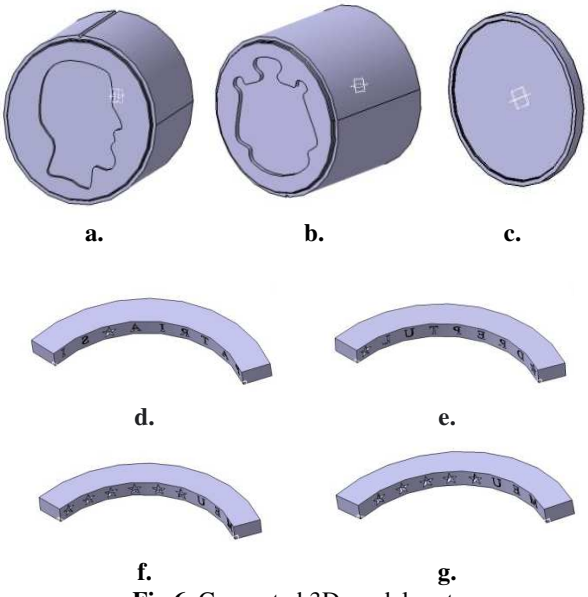
Despite to the well known variants on this type of embossed coin edge lettering, the errors which encountered on manufacturing process are less known or explained by literature. In figure 5, is presented as error example the misaligned position of the characters corresponding to the 3rd ring sector, placed on 5 lei silver coin issued in 1884. The misaligned ring sector led to the coin edge incomplete impression of the motto last letters and stars.

The previous considerations on Romanian coins embossed edge lettering led to the paper purpose, to determine the possible reason for these edge inscription changes made during the year 1881, then in 1882 and again in 1883.

Fig.5. The lettering misaligned position

3. THE VIRTUAL MODEL

Following the metal coin embossed edge inscription manufacturing, simultaneously with the coin faces striking, the negative faces dies, the coin blank and the ring sector dies with negative inscription will be computed for study. To realize the subjected parts 3D model, the CATIA software is used [17, 18]. Since the coin design complex details cannot be entirely reproduced on the parts virtual model, the subjected obverse and reverse striking dies and also the blank simplified models are needed for study, as presented in the figure 6, a, b and c. [1, 5]. All ring sector dies are computed including the incuse negative inscription, as presented in figure 6, d, e, f, and g; because of the character number variants, having five or six stars, the 3rd ring will be computed in both variants. The parts sizes are related with the coin main dimension: the diameter, 37 mm, respectively the width, 3 mm.



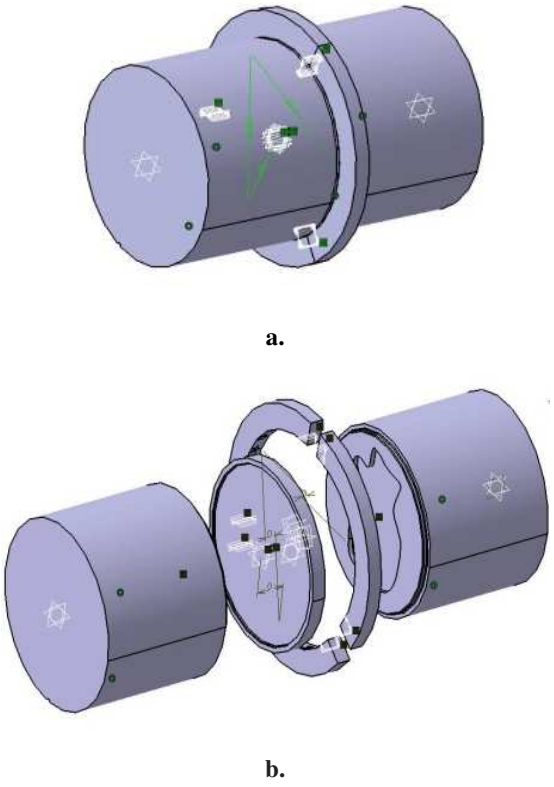
a. **b.** **c.**

d. **e.**

f. **g.**

Fig.6. Computed 3D model part

Then, by using the Assembly Design module, the entire assembly is computed. Considering the first striking contact surfaces, between the negative dies and also the coin blank, the corresponding constraints should be defined. Taking account by the both 3rd ring sector variant, the assembly will be computed also in two variants. For both ensemble computed models, the striking dies are positioned to obtain the real coin faces position, when the obverse-reverse angle is 180^0 [1, 10, 11]. Also, there is respected the fixed position of embossed coin edge in relation to the model sides of the coin, as already presented in figures 2 and 3.



a.

b.

Fig.7. The assembled 3D model

Inside of the assembled model, the defined contact area between dies and blank, respectively blank and sector ring is on the full field common area, considering the presumption when the pressing machine has no misalignments inside [1, 2, 3]. The assembled model view is presented in figure 7, a, and the model expanded view is presented in figure 7 b.

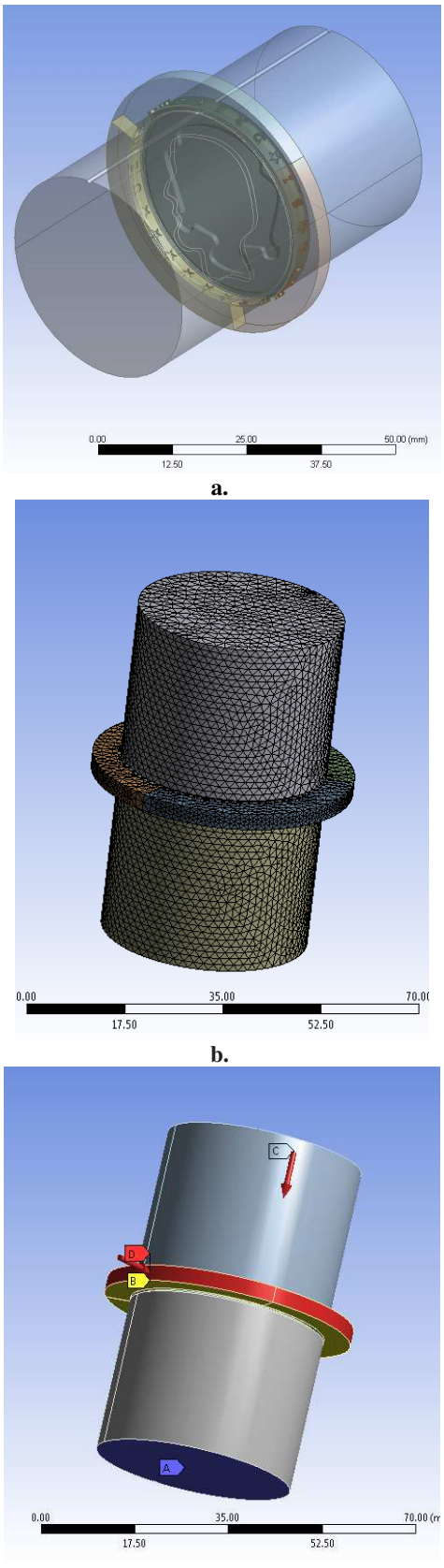
4. THE FINITE ELEMENT ANALYSIS. SIMULATION AND RESULTS

For the following analysis, the ANSYS software is used on both ensembles. The analysis purpose is to determine the pressed ring sector dies on blank behaviour under the subjected load. The previous two virtual assembled models should are used.

The material for ring sectors and dies material is hardened steel, having as mechanical properties: Density 7850 kg/m^3, Tensile Yield Stregth 250 MPa, Tensile Ultimate Strength 460 MPa, Young's Modulus 200000 MPa and, respectively, Poisson's Ratio 0.3 [18, 19, 20]. The coin blank material is silver alloy (Ag 900, Cu 100) having as mechanical properties: Density 10490 kg/m^3, Maximum Yield Stress 6600 MPa and Shear Modulus 29800 MPa [10, 18, 19, 20]. In the mentioned contact area, a smooth mesh having the minimum edge length equal with 0.001 mm is chosen. The applied normal force value is 650KN, required from the pressing machine, to obtain high contact pressures which should exceed the coin blank material allowable stress recommended value, 1600 MPa [2, 7].

In the figure 8, the subjected finite element model, having the total number of finite elements 103023, is presented: as the geometry view, the finite elements mesh and also the applied loads, computed for the studied cases.

The results, which are presented in figures 9 to 20 and table 2, are consisted by the contact pressure maximum values and the maximum values of the penetration in each edge ring sector die material, in both modeling cases, when the 3rd ring sector die has five, respectively six stars arrangement. These obtained values should be considered as relative values, subsequently to be used for comparisons between the different studied situations. Related to obtained results, in table 3 there are presented some useful value measurements about the ring sector dies contact area with the coin blank, for the both studied cases. Also, in table 4 are presented the value measurements about the obverse and reverse dies contact area with the coin blank.



a.

b.

c.

Fig.8. The studied finite element model

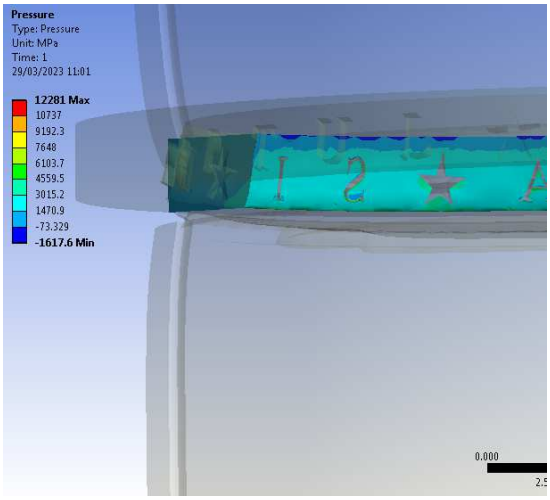


Fig.9. The contact pressure on 1st ring sector die, for 6 stars edge lettering

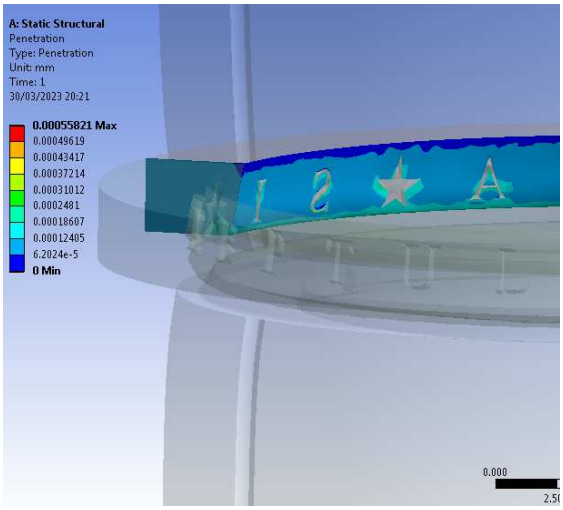


Fig.12. The penetration on 1st ring sector die, for 5 stars edge lettering

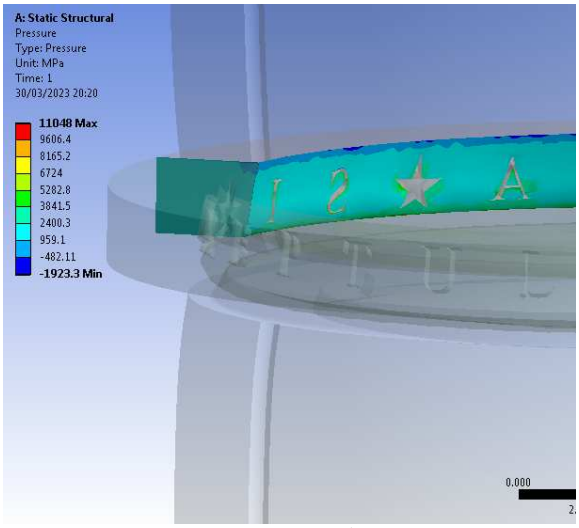


Fig.10. The contact pressure on 1st ring sector die, for 5 stars edge lettering

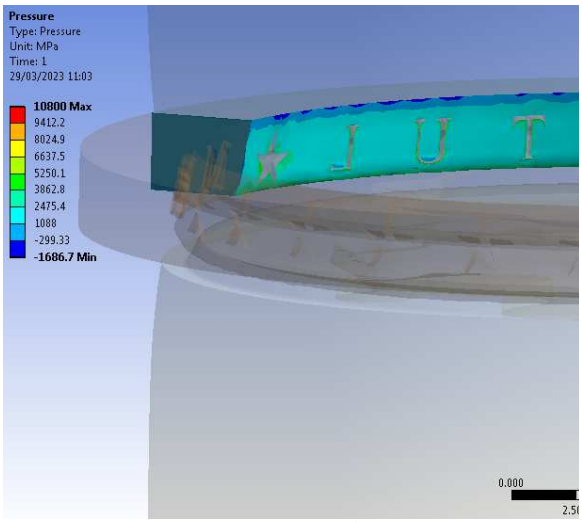


Fig.13. The contact pressure on 2nd ring sector die, for 6 stars edge lettering

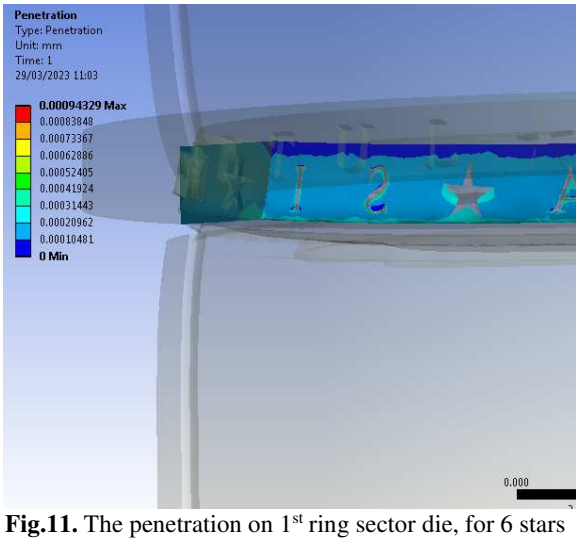


Fig.11. The penetration on 1st ring sector die, for 6 stars edge lettering

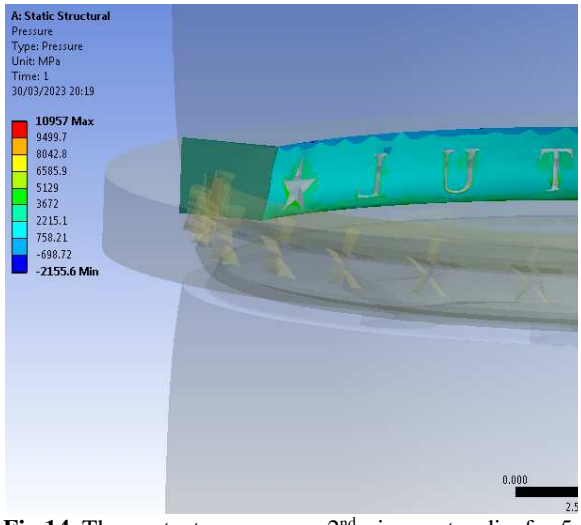


Fig.14. The contact pressure on 2nd ring sector die, for 5 stars edge lettering

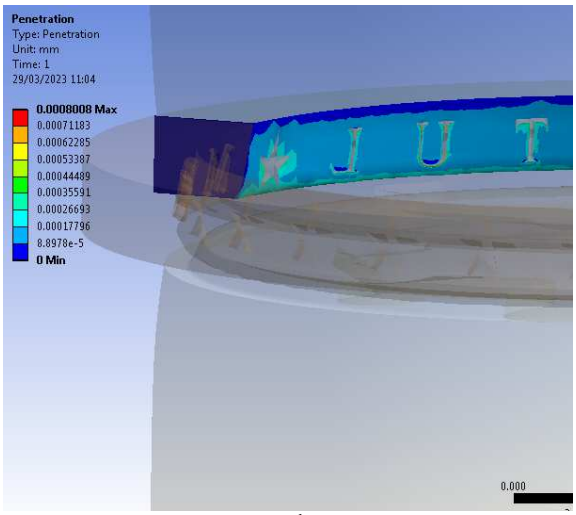


Fig.15. The penetration on 2nd ring sector die, for 6 stars edge lettering

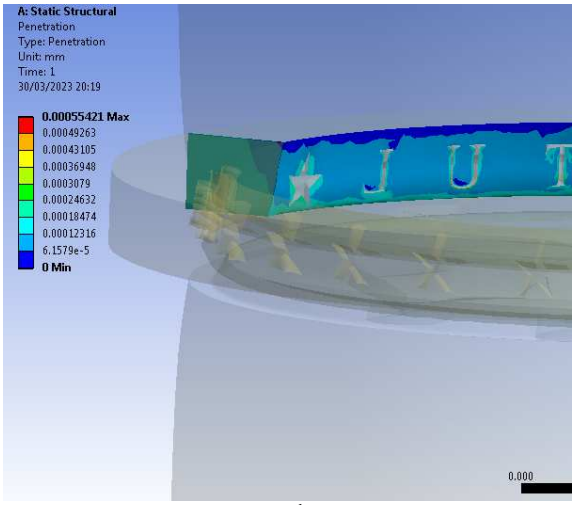


Fig. 16. The penetration on 2nd ring sector die, for 5 stars edge lettering

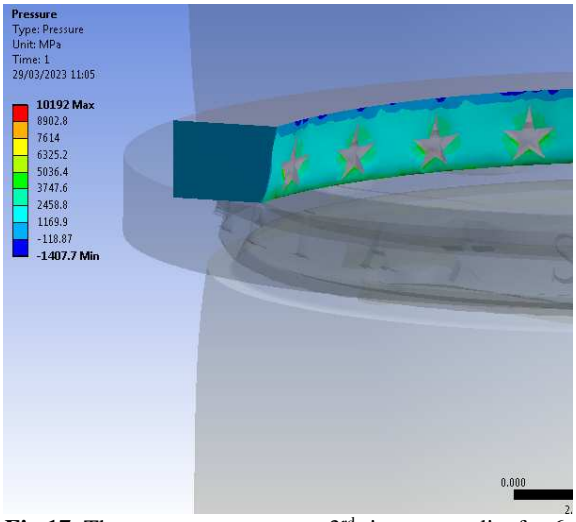


Fig.17. The contact pressure on 3rd ring sector die, for 6 stars edge lettering

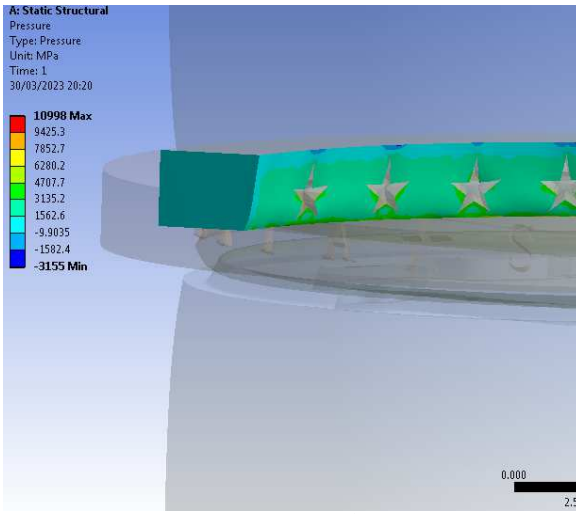


Fig.18. The contact pressure on 3rd ring sector die, for 5 stars edge lettering

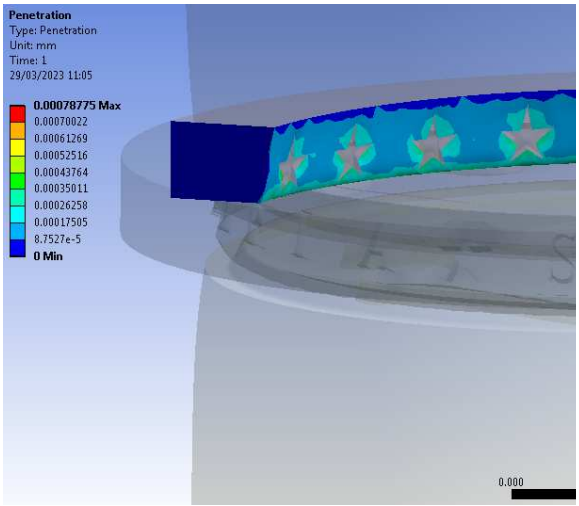


Fig.19. The penetration on 3rd ring sector die, for 6 stars edge lettering

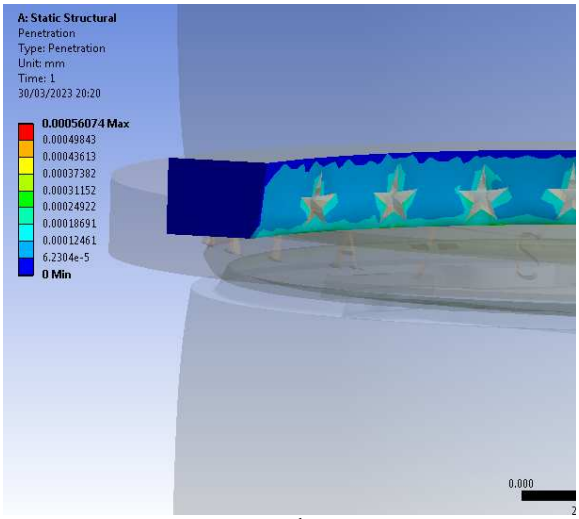


Fig.20. The penetration on 3rd ring sector die, for 5 stars edge lettering

Table 2

The contact pressure and the penetration on edge ring sector die, as maximum values

Stars number on 3rd ring sector	Ring sector	Contact pressure, MPa	Penetration in the material, mm
5	1st	11048	0.00055821
	2nd	10957	0.00055421
	3rd	10998	0.00056074
6	1st	12281	0.00094329
	2nd	10800	0.00080080
	3rd	10192	0.00078775

Table 3

The ring sector dies contact area with coin blank

Stars number on 3rd ring sector	Ring sector	Contact area with coin blank, mm²	Contact area amount on entire ring, mm²
5	1st	107.828	317.375
	2nd	105.266	
	3rd	**104.821**	
6	1st	107.828	315.662
	2nd	105.266	
	3rd	**103.108**	

Table 4

The obverse and reverse dies contact area with coin blank

Die type	Contact area with coin blank, mm²
Obverse	532.129
Reverse	464.791

5. CONCLUSION

The applied load, 650 KN, is given by a usual pressing machine used for different coin types striking. Taking account by technological and also economical reasons, the pressing force adjustment, depending by the coin material or dimension, was not always possible; so, during the time, a given pressing machine was used to strike different types of coins [21]. Also, it has to be mentioned that, the embossed edge lettering was manufactured simultaneously with the coin faces, having different contact area conditions with their corresponding dies, as presented in tables 3 and 4. For the studied case these situation led to the maximum contact pressure values from table 2. Since the values are exceeding the coin blank allowable stress recommended value, result that the coin material was deformed to fill the dies cavities. But, in the same time, these increased values worse the ring sector dies condition, which led to some premature damage of them and needed to be replaced.

When the embossed star arrangement on the motto is changed from five stars to six, the only change is represented by the decreasing of the involved contact area, between the 3rd ring sector die and coin blank. Following this, on the applied load direction, the stiffness increases with the subjected contact area increasing. If the mentioned contact area decreases, an increased contact pressure allows the coin blank material to fill easier the cavities inside the faces dies and, respectively, the ring sector dies.

From table 2, it can be observed that, the change of stars arrangement on the 3rd ring sector die is also influencing the contact pressure and the penetration values on other two rings. For the 1st ring sector die, the contact pressure decreases with the increasing of contact area, on the 3rd ring sector die. Also, the penetration decreases together with the contact area increasing.

For the 2nd and 3rd ring sector dies, the contact pressure increases with the subjected contact area increasing, respectively, the penetration decreases together with the contact pressure increasing. The contact pressure and penetration variations have a different behavior for the 1st ring sector die, on one side and, also for the 2nd and 3rd ring sector dies, on the other side, due to the coin blank different stiffness along the applied load direction on ring sector dies. This different stiffness is caused by the irregularly obverse and reverse dies incuse design: the effigy and coat of arms contours or some other inscription.

For the five star arrangements on 3rd ring sector die, the contact pressures and penetration values are close to equal on all three ring sector dies; for the six star arrangements, only the penetration values has some tendency to maintain this trend.

Turning back in time, the replacing of the embossed edge device having five star arrangements with the six star arrangements, increased the inscription total number of

character from 26 to 27 and apparently equilibrated the character number on each ring sector die, 9. But, following the present day study, it can be concluded that, adding or removing the sixth star on coin edge inscription, the parts stiffener and also the striking condition were differently changed. From this point of view, the results are useful to an improved approach to future numismatic evaluation on the subjected coin varieties.

Generally, the choosing of a coin edge embossed motto must fulfill some initial condition, as: the symbols or letter number need to be divided equally on the each ring sector; the size, shape or displacement of them must improve the dies condition and, respectively, the applied load must be adjusted to the coin material and dimension.

6. REFERENCES

[1] Gavrilă, C. C., Lateş, M. T. *3D Modelling and FEM Analysis on Die Clash Mint Error,* IOP Conf. Ser.: Mater. Sci. Eng. 898 012040, 2020.

[2] Iliescu, C., Tureac, O., *Cold Pressing Technology (Tehnologia presării la rece),* Editura Universităţii din Braşov, Braşov, 1987 (in romanian).

[3] Hilbert, H., *Punching Technique, Part I (Stanzereitechnik, Band I),* Carl Hanser Verlag, Munchen, 1938 (in german).

[4] Gavrilă, C. C., *Few Error Types on Romanian Modern and Contemporan Coins* (*Câteva tipuri de erori identificate la monedele româneşti moderne şi contemporane),* Oltenia. Studii şi comunicări. Arheologie-istorie XXVI, Muzeul Olteniei, ISSN 1454-6892, Craiova, 2019 (in romanian).

[5] Gavrilă, C. C., Lateş, M. T., *Metal Coin Error Study Using 3D Modelling and FEM Analysis*, IOP Conf. Ser.: Mater. Sci. Eng. 568 012002, 2019.

[6] **** Euro 4, Coins and Banknotes (Euro 4, Monnaies et Billets),* Edition Les Chevau-Lègers, Paris, 2007 (in french).

[7] Gavrilă, C. C., Lateş, M. T., *3D Modelling and FEM Analysis on Metal Coin Edge Punching Error,* IOP Conf. Ser.: Mater. Sci. Eng. 1169 012006, 2021.

[8] Schön, G., Schön, G., *Small German Coin Catalogue (Kleiner Deutscher Münz-katalog)*, Battenberg, ISBN 3-89441-514-2, München, 2002 (in german).

[9] Krause, C., Mishler, C., *Standard Catalog of World Coins* Krause Publications, ISBN 0-87341-884-0, Iola, 2001.

[10] Buzdugan, G., Luchian, O., Oprescu, C. C., *Romanian Coins and Banknotes (Monede şi bancnote româneşti),* Editura Sport Turism, Bucureşti, 1977 (in romanian).

[11] **** Finance Ministry, *National Mint, Ten Years of Activity (*Ministerul Finanţelor, *Monetăria naţională. Zece ani de activitate),* Monitorul oficial şi Imprimeriile statului, Bucureşti, 1945 (in romanian).

[12] Hamangiu, G. *The General Code of Romania, Vol. II: Customary Laws, 1860 – 1903* (*Codul general al României, Vol. II: Legi uzuale, 1860 – 1903)*, Editura librăriei Leon Alcalay, Bucureşti, 1903, (in romanian).

[13] Dumitrescu, Şt. I., *The coin. Exchange, technique and monetary thinking, (Moneta. Schimbul, technica şi gândirea monetară)*, Institutul de arte grafice "Tirajul", Bucureşti, 1944, (in romanian).

[14] Gavrilă, C. C., *Obverse Changes to the 5 Lei Coin From 1881, On the Occasion Of the Kingdom Proclamation (Modificări ale aversului monedei de 5 lei din anul1881, cu prilejul proclamării Regatului),* Colecţii şi colecţionari din Sălaj. Anuarul Asociaţiei Colecţionarilor din Sălaj, XI, ISSN 2537-3404, Zalău, 2022 (in romanian).

[15] Gavrilă, C. C., *Millesim Changes to the 5 Lei Coins From 1881 (Modificări ale milesimului la monedele de 5 lei din anul 1881),* Colecţii şi colecţionari din Sălaj. Anuarul Asociaţiei Colecţionarilor din Sălaj, XI, ISSN 2537-3404, Zalău, 2022 (in romanian).

[16] Angelescu, N. C. *Monetary policy (Politica monetară)*, Enciclopedia României, vol. IV, Bucureşti, 1943 (in romanian).

[17] Ghionea, I. G., CATIA v5. *Parametric Design and Programming Applications (Aplicaţii de proiectare parametrică şi programare),* Editura Printech, ISBN 978-

606-23-1264-0, Bucureşti, 2021 (in romanian).
[18] Geru, N., Chircă, D., Bane, M., Ripoşan, I., Marin, M., Coşmeleaţă, G., Biolaru, T., *Metallic Materials. Structure, Properties, Uses (Materiale metalice. Structură, proprietăţi, utilizări),* Editura Tehnică, Bucureşti, 1985 (in romanian).
[19] Lateş, M. T., *Finite Elements Method. Applications (Metoda elementelor finite. Aplicaţii),* Editura Universităţii Transilvania din Braşov, Braşov, 2008 (in romanian).
[20] Lee, H. H., *Finite Element Simulations with ANSYS Workbench 14. Theory, Applications, Case Studies,* Schroff Development Corporation, Kansas, 2012.
[21] Gavrilă, C. C., Lateş, M. T. *3D Modelling and FEM Analysis on Holed Metal Coin Striking Die Mint Error*, IOP Conf. Ser.: Mater. Sci. Eng. 1256 012001, 2022.

Modelarea 3D și analiza MEF a matrițelor destinate inscripționării în relief a cantului unei monede metalice

În general, fabricarea monedei metalice constă în presarea cu forțe mari a rondelei între cele două matrițe negativ, corespunzătoare pentru avers și revers. În principal, introdus ca element de siguranță împotriva falsificării, cantul inscripționat în relief a fost obținut odată cu presarea propriu zisă a monedei, utilizând o matriță negativ adecvată de formă inelară. În România, tehnica imprimării în relief a cantului a fost pentru prima dată utilizată în 1881, la baterea vechilor monede de 5 lei din argint. Datorită variantelor de inscripționare apărute și identificate de literatură, precum numărul caracterelor utilizate în inscripție, lucrarea își propune determinarea posibilelor cauze care au dus la apariția acestora. Metode moderne ca modelarea 3D sau metoda elementelor finite, permit analiza variantelor de matrițe utilizate la inscripționarea în relief a cantului. Rezultatele analizei efectuate duc la o serie de concluzii asupra posibilelor motive ce au dus la modificările inscripției. Nu în ultimul rând, concluziile formulate sunt utile unei mai bune evaluări, din punct de vedere numismatic, a variantelor existente ale acestor monede.

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