3D Modelling and FEM Analysis on Holed Metal Coin Striking Die Mint Error

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Abstract. During last decades, various mints of different countries manufactured a large amount of holed metal coin currency. As main characteristic, these holed metal coins present a central round perforation, which changes some of the initial manufacturing condition, as different coin blank or striking dies model. During the manufacturing process, these coins may encounter some error types which depend by the die dimension, the model flat area size or contour shape. Many pieces wearing these errors were minted and released; in present days these are searched and valuated by collectors. The paper work presents different aspects about the dies damages appeared at the metal holed coin striking process. In the paper beginning part, some particular introductive considerations about the holed metal coins manufactured with cracked dies error are presented; there are presented some examples. Then the simplified blank and the obverse and reverse dies 3D model are introduced, followed by the assembled model which consist in the obverse and reverse negative dies having the coin blank inside them. For these models, the finite element analysis is computed and achieved for different initial inputs. In the last part of the paper work, the analysis results and main conclusions on these are presented.

1. Introduction

Generally the metal coin currency, as industrial manufacturing process, is followed in many of the situations by different amount of failures, known in literature as errors. Each error type depends by the metal coin manufacturing stage where it is possible to appear. In literature [1, 2, 3], there are presented errors which appear on the coin base metal alloy or on the unfinished coin blank manufacture; should be mentioned the failures appeared on the striking tools and, also, during the coin striking. Consequently, the coins perforated with central hole, which present on their surface different mint errors, are desired on the collectors market: for increased and spectacular rarity error, the value is increased for this subjected piece [1, 2].

The holed metal coin are produced by pressing on high loads the previously holed coin blank, using hardened steel negative dies engraved with incused model, which create a closed space between, to be filled by the coin blank alloy. A particular aspect is given by the coin blank having the central hole. During the blank pressing in the closed space between dies, the central hole allows the blank metal to be dislocated also into this free space. As a consequence, according to the literature, the pressing load could slightly decrease [4]. After the properly striking, result the holed metal coin, having the relief model on sides, obverse and reverse. The coin side, which represent the effigy figures or royal symbols is considered the obverse and the side which present the nominal value, the reverse [2, 3].

The negative obverse and reverse dies are obtained each, by pressing with a hardened steel tool, positive die (also known in literature as hub) impressed with the adequate relief model. Each positive die is used to produce a finite number of negative dies, hardened and then used to strike the main mintage of metal coins [5]. If any failure or model change appears on these striking dies, the corresponding coins will wear on faces the same failure or model changes. The properly die crack error occurs when a small crack in the striking die allows blank metal to flow into the damaged area during striking. As a result, a thin and raised rib could be observed at metal coins surface. In most of cases, there is a singular crack rib impressed on the coin face, but multiple cracks rib on the coin face or cracks on both coin faces should be considered as possible. Die cracks error are relatively common on circulation issue coinage and small dimension cracks can fall inside the mint authority accepted tolerances. The cracked dies must be replaced when a large dimension crack appears, in order to avoid other damages [5, 6].

Turning back in time, it has to be mentioned that, different type's holed metal coins were produced, by cast bronze or other metal alloy, in ancient Chinese provinces, somewhere from the 4th century BC until to the early of the 20th century AD [7]. Since the coin shape was round, the inside hole was squared, symbolizing the earth surrounded by the sky. The relief inscription was adapted to fill the resulted space on coin surface. An example of Chinese square holed metal coin (cash denomination) is presented in figure1.

Figure 1. Ancient Chinese squared hole coin

At the beginning of the 20th century, following the occidental influence, the modern techniques on coin manufacturing by pressing a perforated blank on machine struck, the squared hole was replaced by a circular one. On their turn, the occidental countries adopted holed coin as circulating currency in some of their colonies, or properly for their own small value currency [8]. Still today, different holed metal coins are circulating in countries like Denmark, Norway or Japan. In figure 2, a, b and c there is presented some examples of holed coins produced and issued during the 20th century by France, Belgium and Denmark [8].

a) b) c)

Figure 2. Various european holed metal coin, issued during 20th century

In Romania, the holed coins were introduced, following the occidental influence, in the years 1905 and 1906. The newly series of 5, 10 and 20 bani cupronickel coins were minted. The official reason was to replace the similar previously copper and cupronickel small value coins without hole, to avoid the confusion with the higher valuable silver coins [2, 9].

a) b) c)

Figure 3. Romanian holed metal coin series, issued in 1906

For all nominal values, the mintage was produced during the mentioned years, at the Brussels Mint (in both years, without mintmark, figure 3, c) and Hamburg Mint (only in 1906, having the particular tiny mintmark J on the obverse, figure 3, a, and b) [9]. All nominal values had the same model, on the obverse represented by the royal crown and a scarf with the country name, respectively on the reverse by the nominal value, the minting year and some ornaments. The coin main dimension, as diameters and thickness, are given in table 1.

Table 1. The coin dimensions

Coin type	Exterior diameter, mm	Hole diameter, mm	Thickness, mm
5 bani	19	3.5	1.4
10 bani	22	4	1.7
20 bani	25	4.5	2

In this coin series, was released in circulation a large amount of the 5 bani pieces, wearing as mint error on both, obverse and reverse surface, the die cracks - sometimes accompanied by extrusion strikes [10]; few examples are presented in figure 4. In comparison of this, the 10 and 20 bani pieces with die cracks are quite rarely observed (figure 5, a, respectively 5, b). Most of examples present one crack on the same coin face, figured as straight or curved rib; also, there are examples of multiple cracks on the same coin face and, respectively, cracks on both coin obverse and reverse [3].

Figure 4. Various cracked dies error on 5 bani holed metal coin, issued in 1906

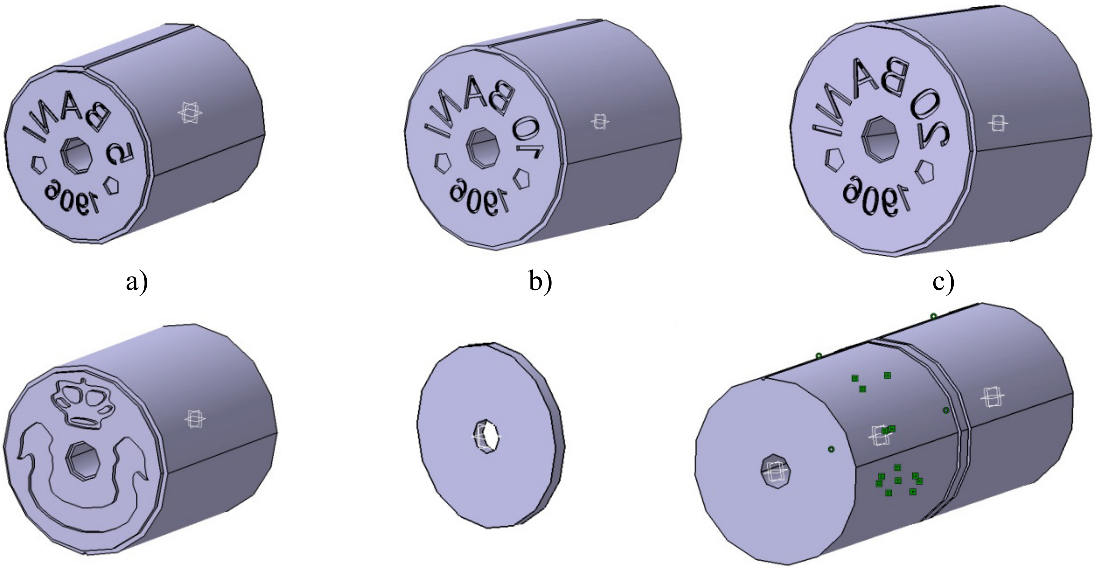
Since the coins were produced in the same mints (to be noticed that all presented error pieces in figures 4 and 5 were manufactured in 1906 at Hamburg Mint), with the same tools, the main question that follows is what caused this disproportioned die crack spreading between the three nominal values pieces. By answering of this, the real proportion of this error can revealed and also, the subjected pieces adequate market value can be estimated.

a) b)

Figure 5. Various cracked dies error on 10 and 20 bani holed metal coin, issued in 1906

2. The virtual model

As it was previously introduced, the three studied coins have almost the same model but some changes should appear on reverse, for changed nominal value and minting year. At a close look, there are multiple complex details which cannot be faithfully reproduced on the virtual model. So, at each studied coin case, for the obverse and reverse striking dies and respectively the blank, simplified models will be computed to be studied. For these, the CATIA software package is used [11].



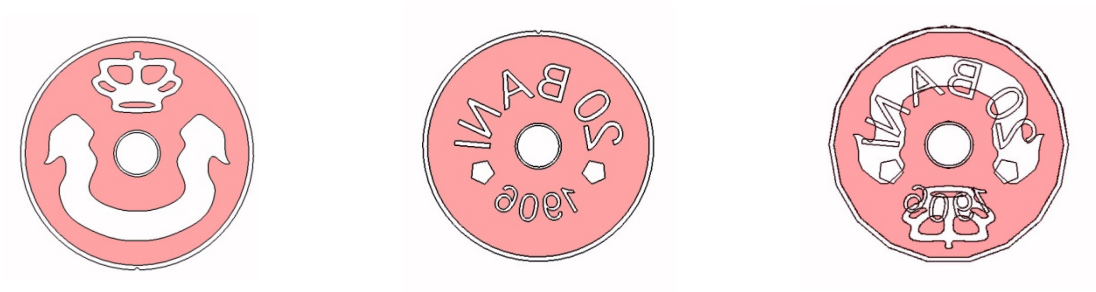
a) b) c)

d) e) f)

Figure 6. The 3D model

The obverse and reverse die model is composed by a cylinder having engraved the negative contours of the coin model (figure 6, a, b, c, and d); between the dies the perforated blank is introduced (figure 6, e, f). For each pair of dies and corresponding blank model is necessary to change the dimensions and, on the reverse, also the corresponding model for each nominal value. Part sketching is followed by the virtual model computing, using the adequate Part Design module.

Then, in the Assembly Design module, the device assembly is realised. Taking account by the real first striking contact surface between the dies and coin blank (as presented in fig. 7 a, and b), the ensemble corresponding constraints are defined. For all three ensemble models, the dies are positioned in the model to obtain the real piece faces rotation, where the obverse-reverse angle is positioned at 180^0, as represented in figure 7, c. The defined contact area, on the full common field between dies and blank, correspond to the presumption for no misalignments inside of the striking machine and, also, for a plane face field [5, 9, 12].



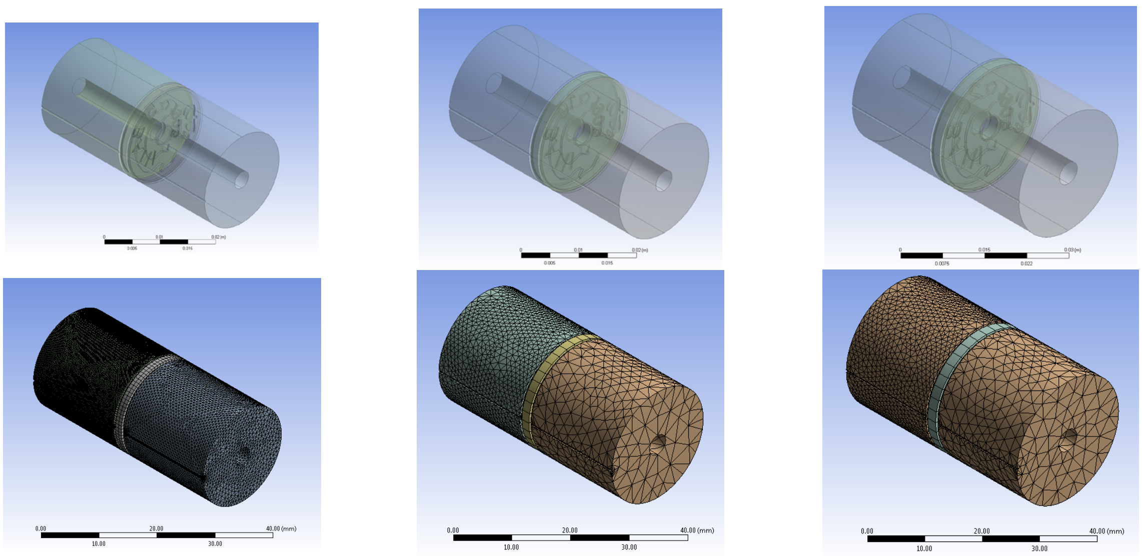
a) b) c)

Figure 7. The striking dies contact surface with coin blank

3. Finite element analysis, simulation and results.

To realize the analysis, the ANSYS software package is used. This analysis main objective is to determine the behaviour under the load of the dies pressed on blank ensemble. In the analysis, the previous virtual assembled models are used. In following figure, there are presented the obtained finite element model view and geometry, computed for all three studied cases (figure 8, a for 5 bani model, figure 8, b for 10 bani model and, respectively, figure 8, c for 20 bani model).

Some material properties inputs for dies (hardened steel) and coin blank (cupronickel alloy), as Young modulus, the Poisson coefficient, the Tensile Yield Strength, and Ultimate Strength are needed to be defined [13, 14]. In the corresponding contact area should be chosen a smooth mesh having the minimum edge length, equal with 0.001 mm. The loading normal force is equal with 650KN, in order to result the needed high contact pressures, over the coin blank material allowable recommended stress, 1600 MPa [4, 9].



a) b) c)

Figure 8. The finite element model

The analysis results are presented in figures 9 to 14 and, also, in table 2. The results consist in the contact pressure maximum values and the maximum values of the penetration in the each striking die material. The obtained values presented must be considered such as relative values, useful to make comparisons between different studied situations.

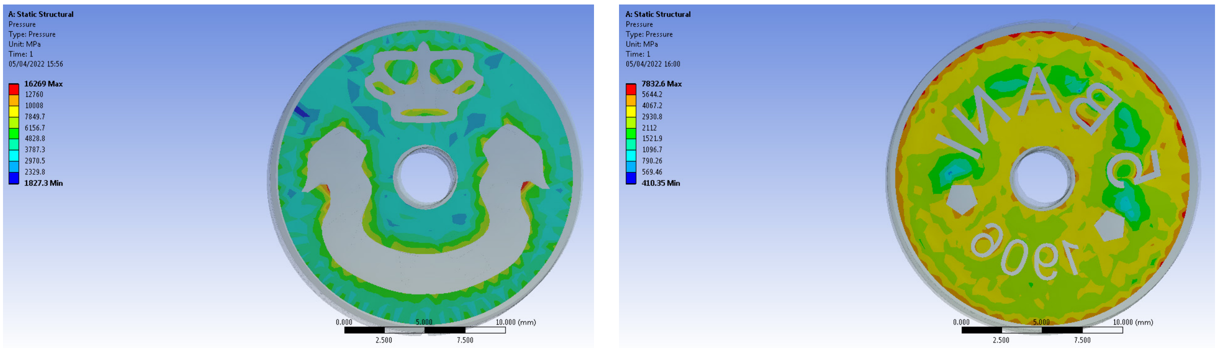


Figure 9. The contact pressure on the 5 bani striking dies model

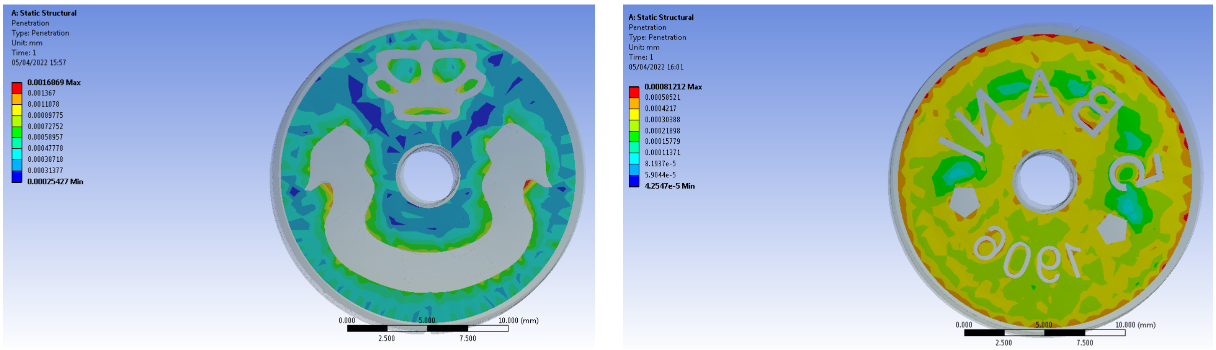


Figure 10. The penetration on the 5 bani striking dies model

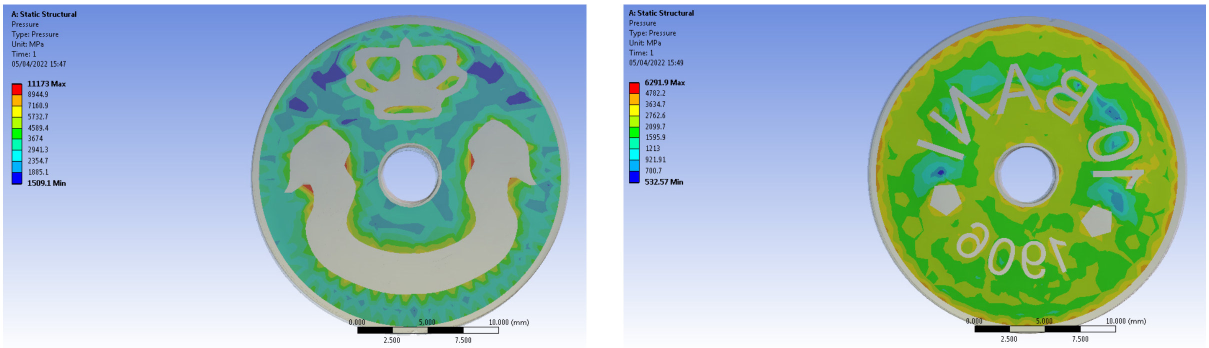


Figure 11. The contact pressure on the 10 bani striking dies model

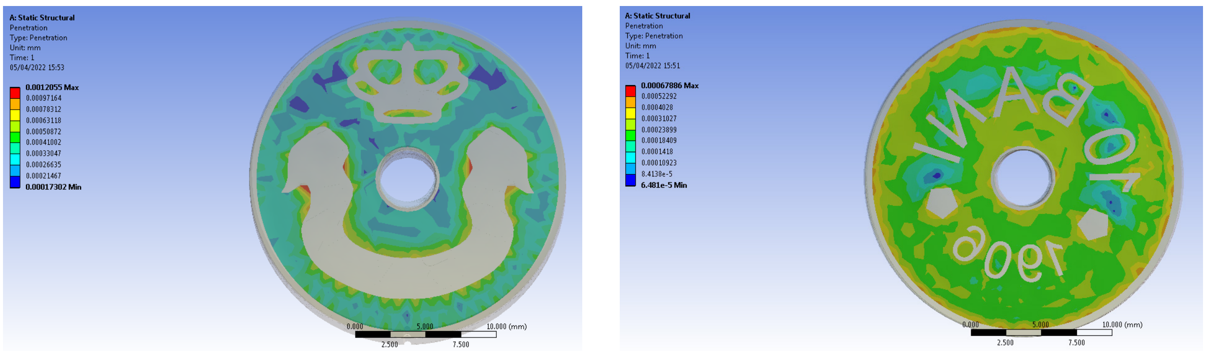


Figure 12. The penetration on the 10 bani striking dies model

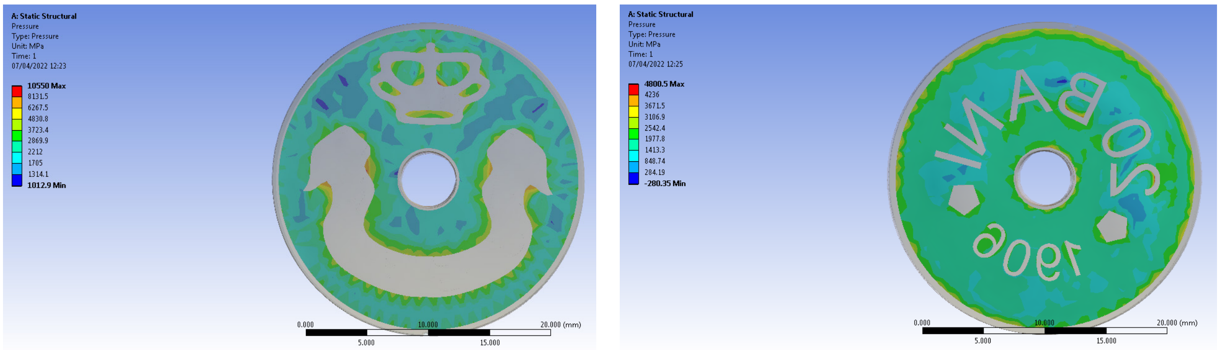


Figure 13. The contact pressure on the 20 bani striking dies model

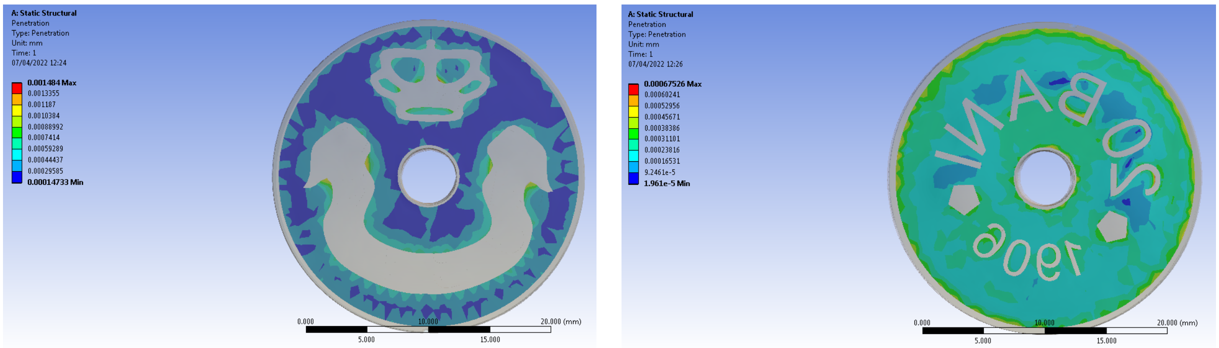


Figure 14. The penetration on the 20 bani striking dies model

4. Conclusions

For both, obverse and reverse dies, the first contact area with coin blank appears on the surface defined by the outer rim circle, incuse contour of the represented image shape and inner hole circle. If letters or symbols have inner closed contours, these should be added to the main surface.

For a given coin and hole diameter, the increasing of the represented image dimension led to a decreased area: from figures above, it can be observed that the contact pressure medium values for each coin, corresponding obverse and reverse dies having same size, the obverse has worst condition.

For the studied situations, the penetration maximum values are extremely reduced; anyway, the penetration increases with the contact surface decreasing.

Comparing all three studied models, the medium values of the contact pressure on surface are increased for the reduced coin diameter and slightly decreased for increased coin diameter. The maximum contact pressure values presented in table 2 maintain the same trend. Due to the blank metal tendency to fill the striking die model incuse empty spaces, on each model these maximum values appear on the stress concentrators defined by images contour and, also, near outside rim diameter and hole edges. Minimum values are noticed to appear on the surface portion where both, obverse and reverse incuse image contours overlay and the blank metal is allowed to fill more empty space (as represented in figure 7, c).

The reduced contact area between parts, combined with the real striking conditions as misalignments, repeated shocks or inadequate loads adjustments, led to the risk of die damage as cracks or extrusion strikes. The worse condition appears to the model corresponding to 5 bani coin, situation which explains the increased number of minted coins wearing errors. The increased number of this released error pieces led to a decreased collector market value.

Table 2. Contact pressure and penetration on striking die, maximum values

The dies corresponding coin	Contact pressure, MPa		Penetration in the material, mm	
	Obverse die	Reverse die	Obverse die	Reverse die
5 bani	16269	7832.6	0.0016869	0.00081212
10 bani	11173	6291.9	0.0012055	0.00067886
20 bani	10550	4800.5	0.0014840	0.00067526

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