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VIENNA, DECEMBER 2009

DIGITALIZATION AND SIMULATION IN COINING

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Abstract: *Coining as metal forming technology is known for its technological complexity and phenomenological problems. Development of 3D scanners and FE codes, have enabled the simulation of coining using verse and obverse medal geometry. This includes simulation of details up to the scale where flow related phenomenon is observable. Modification of coin/medal geometry can be made during any of the phases in die production. This paper is trying to establish a connection between commercial FE code and 3D digitalization in the field of minting. This results in potentially significant savings in tool production, allowing geometry modification, at any moment including the moment of artist creation of coin's obverse and reverse. Paper demonstrates the simulation of coining using digitized medal geometry, within the appropriate FE numerical code that enables the completion of virtual coining.*

Key words: *coining, 3D scan, FEM, metal forming, metal flow*

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This Publication has to be referred as: Skunca, M[arko]; Keran, Z[denka] & Math M[iljenko] (2009). Digitalization and Simulation in Coining, Chapter 20 in DAAAM International Scientific Book 2009, pp. 177-186, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-901509-69-8, ISSN 1726-9687, Vienna, Austria
DOI: 10.2507/daaam.scibook.2009.20

1. Introduction

Coining is very old production technique. The oldest coin in the world is thought to be 1/6 stater made of electrum discovered in Efesos, an ancient Hellenic city and prosperous trading centre on the coast of Asia Minor (Porteous, 1980). The earliest issues, thought to date from the reign of Alyattes (about 610 - 560 BC) i.e. coining technology is more than 2600 years old! During that time many civilizations have left their mark on the verse or the obverse of the coin.

For almost 2000 years coins were completely struck by hand until the Renaissance when both; preparation of coin blanks and striking of coins were supported by machinery. Increase in number of the machines, supporting the coin production have transformed coin making technique into the modern coining technology as we know it today. At the beginning of 21st century there is much new introduced into coining technology. Some of the novels are;

1) Hologram coins representing state of the high tech art (Leech et al., 2004)
2) Computer simulations give promising results regarding the prediction of flow of the material during coining (Buffa et al., 2007)
3) Micro forming is taking an important role in improving the scale of the details on coin vers and revers (Ike, 2005).

Despite the advances in technology, coining is taken to be very traditional technology where innovations are introduced with a great delay. Reason to this is a great effort needed to establish a commercially viable sequence; of manufacturing positive and negative tooling as shown in Fig. 3, resulting in a desired final quality of the coin or medal. Each step is shown in Fig. 3 and includes corrections in order to manufacture final coin of the desired quality. This “makeup” is interwoven with appropriate heat treatment of dies during the manufacture of the final die.

2. Croatian monetary history in brief

The Croats living on the territory of today's Croatia started minting their own money in the late 12th century (Viscevic, 2004). By that time the most used money was Byzantine mone. Greek towns where money was minted were Vis, Stari Grad on island of Hvar, Risan, Lijes and Skadar. Sisak and Sremska Mitrovica were roman towns where minting took place. In the late 12th century, Herceg (Duke) Andrija (1192-1211) minted the silver denar and half-denar according to the standards of the Friesach Pfennings, and hence the name the Croatian Frisatic. For next century and a half heirs of Herceg Andrija minted fine silver *denarius banalis* also known as “banovac”. Minting took place in Zagreb and Pakrac. Croatian Bans (Dukes) continued minting their own coinage. Especially valued are the large Groschen and Talir. In 1848. when Ban Jelačić was appointed Ban, the mint of the Banal Council minted copper Križar and silver Forint. After minting Križar and Forint it took almost 150 years to start massive minting of coinage with clearly visible Croatian symbols. In 1994, kuna has been introduced as the unit of payment in internationally recognized republic of Croatia. Minting of Kuna is still performed at Croatian monetary institute that also contributed to the creation of this paper.

3. Objectives

Aim of this paper is to point to the possibilities of introducing two novel production related technologies to coining:

1) Commercially available FEM codes
2) Digitizing systems based on photogrammetric principles

First goal was accomplished by the use of MSC Marc.Mentat program package that was used in present paper. Second was done by the use of GOM digitizing system named Atos®. Although comparisons between the desired and obtained geometry can be made in this paper digitalization was primarily used in order to create geometry of FE mesh.

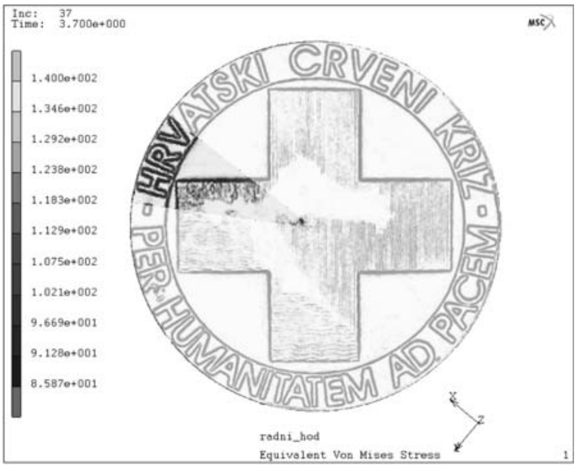
The main problem encountered was to manage large point clouds and stl meshes in FE pre-processor. On occasions some out of 1.2e6 stl surfaces can have had wrong orientation and disabled the creation of FE model. Therefore one must take a great care to have a flawless and acceptable CAD geometry as output from digitizing system. Fortunately this was accomplished by Atos® in the present case.

The problem during simulation also included detection of contact using such a "large mesh". Therefore the right element type has been chosen to successfully model flow of the material.

Other researchers provide very little information, generally, papers on technology like coining or minting are scarce (Ike & Plancak, 1998), (Ike, 2005). Reason to this is highly commercial nature of coining technology. Moreover commemorative medals and coins tend to exhibit increase in price (Ladany, 1981). Therefore monetary institutes keep their technology as secret as possible.

In this paper a numerical model of coining golden medal of diameter Ø 37 mm was created Fig. 1.a.

(a)



(b)

Fig. 1. Red cross medal, (a) Photograph of the obverse, (b) Digitized medal using Atos® with 1/12th marked where FE simulation was performed (Courtesy of Damir Mataušić Academic sculptor & medallier)

Due to the complexity of the detail only 1/12th of the coin obverse was modelled Fig. 1.b. Nevertheless, still 1e5 finite elements had to be used in modelling of the chosen part of the medal. Besides, punch used for forming the geometry consisted of 3e4 surfaces. Creation of such a "large" numerical model for desktop PC, a model that will converge to the solution/coining, required the use of appropriate elements, analysis options, contact detection and many others that will be discussed in this paper.

Result is a successful simulation of coining 1/12th of the coin. Postprocessing of the results points onto the areas of critical stress and strain where problems with cracks are likely to occur, Fig. 2. Visually obtained numerical result, by the use of FE method, is very useful since it can unite artist, production engineer and technician discussing flow related phenomena in front of the computer simulation. It all can take place before any of the tooling has been made. Therefore all the early corrections of the geometry are possible.

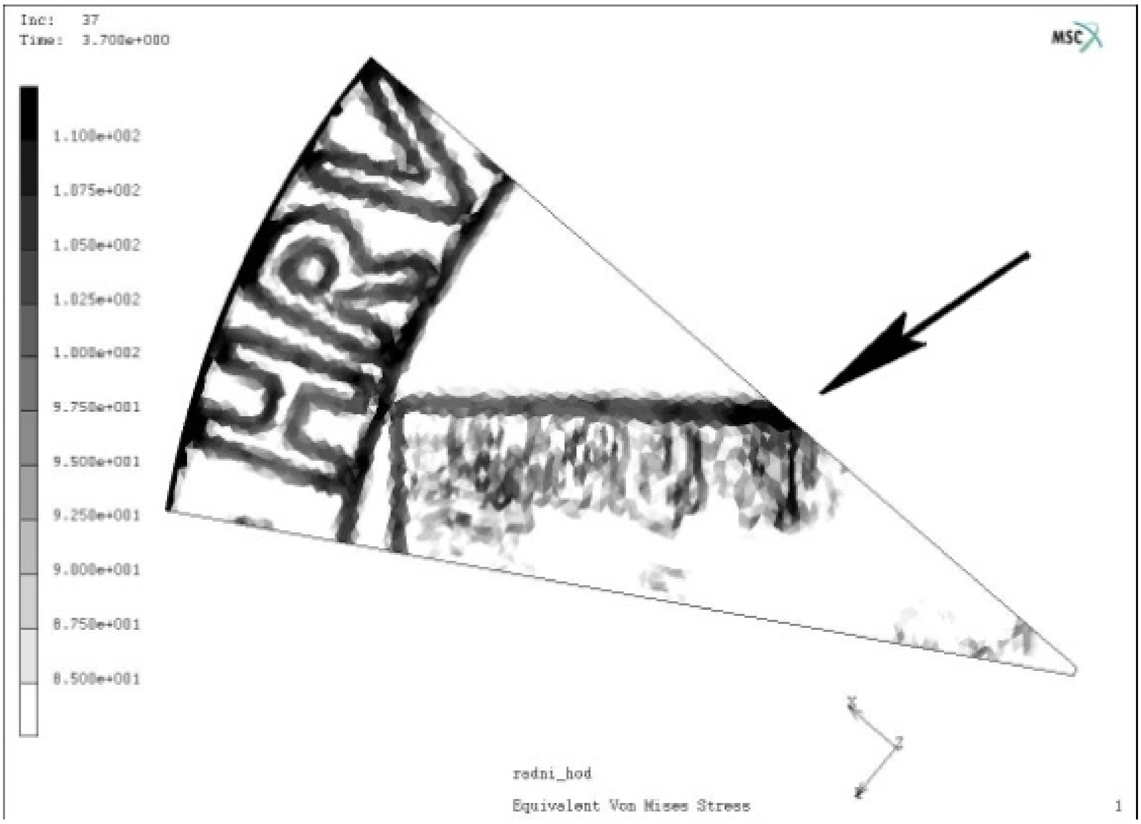


Fig. 2. Stress distribution along 1/12th of the medal, darker colour shows highly stressed areas where cracks and flow related problems are likely to occur

Due to the size of the model and limitations to the FE modelling of the whole medal, one can move the area of interest to the highly stressed areas. Stepwise simulation can be preformed and information on flow related phenomenon obtained for any part of the medal itself. Experience of the mint workers can point to the area where to start this fractional numerical modelling.

Further research should include repetition of the present modelling using some other geometry. In addition stress-strain curve for gold should be recorded, in order to precisely model golden medal production. An adequate method should be chosen for the acquisition of true stress-strain curve applicable to coining as a process characterized by low volume-surface ratio in state of compressive stress.

4. Implementation of digitalization

Steps from artists idea to minting of the coin/medal are shown in Fig. 1.. In each of these steps digitalization can be introduced in order to follow creation of particular positive/negative geometry. In present case only finally produced coin was digitized for the creation of FE geometry and simulation. In order to make a greater use of FE modelling, digitalization should take place at early step of Gypsum positive creation by an artist. Even direct, CAD supported creation of artist creation is theoretically possible, but in praxis technology includes such a details that cannot be absolved by the use of any computer CAx. The latest accomplishments in rapid manufacturing are trying to overcome this gap, but as a traditional technology coining will resist any of novel improvements since the product goes to the an *eye exam* by the commission to be classified as;

1) proof
2) uncirculated
3) extremely fine
4) very fine
5) fine
6) very good
7) good

Satisfying the existing aesthetical/personal aspect, coins and medals are not likely going to initiate some new expensive technological advancement. Mints are likely to stick to their well known processes until the laws of the market change the strategy and force non technical leading staff to allow some technical changes.

Use of digitalization systems like Atos® could give an additional and much more universal criterion to perform the quality check on the coin or medal. But technology aims towards optimal target, and at the moment this target it is primarily satisfaction of the current numismatic criterion. Practical experience of acceptable and unacceptable is the most important asset in judgement of the quality. Since there is no practical experience with digitizing systems it will take some time for any digitalization systems to be employed. Since coining technology and supporting technologies are kept as secret as possible, novel things that appear on mint director conferences minimally five or more years after their successful implementation.

4.1 Digitalization in the present case

Digitalization of coin geometry was performed at Faculty of Mechanical Engineering Zagreb, using ATOS Standard 3D digitizer manufactured by GOM mbh (http://www.gom.com). ATOS measuring head consisted of two CCIR-50Hz cameras 0,8 MPixel each, with retro reflective illumination.

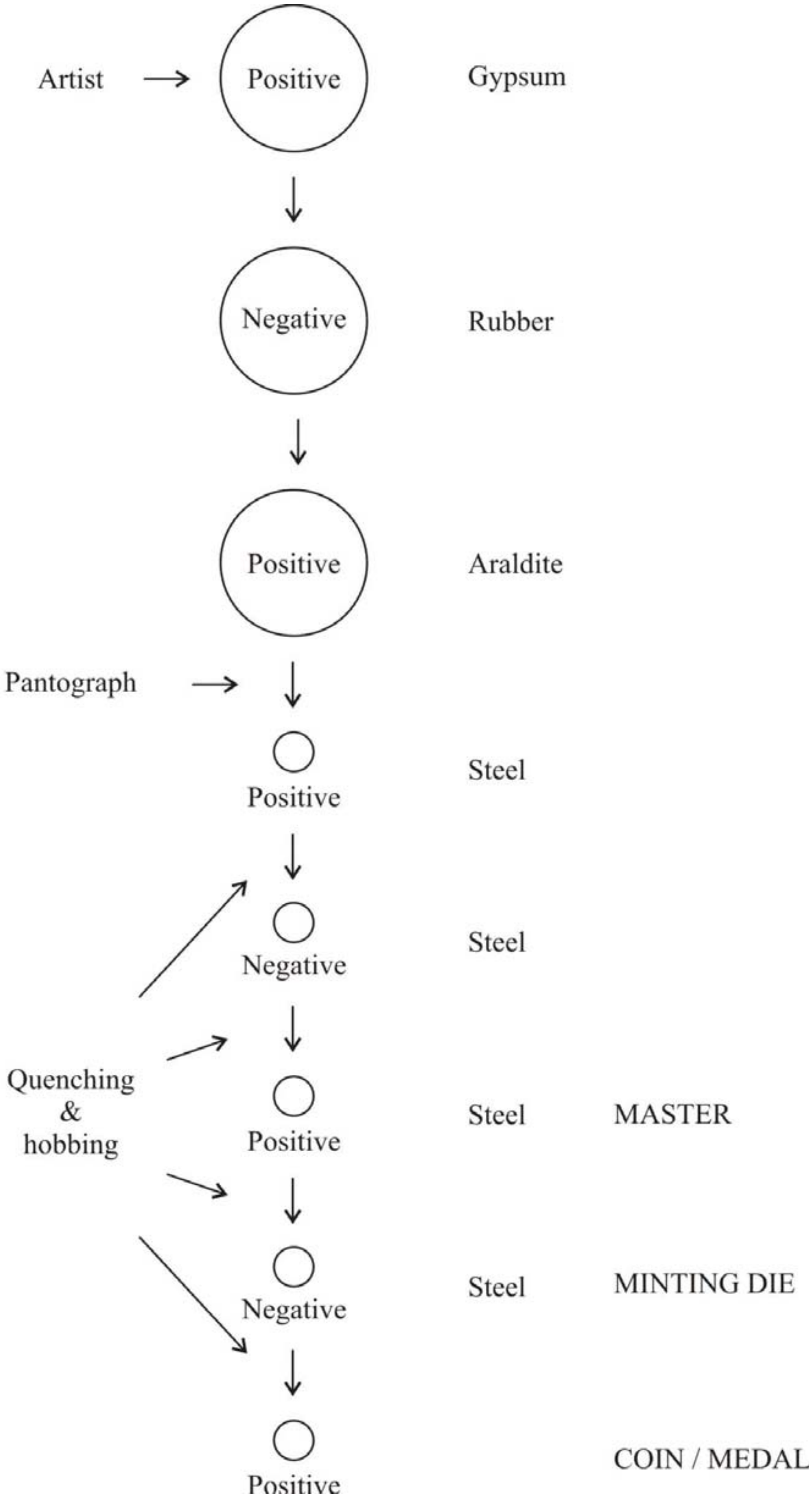


Fig. 3. Die manufacturing steps, necessary sequence of phases in minting die production

Medal of 37 mm diameter was digitized using available measuring volume of 50 x 40 mm (one set of lenses: 35 mm projector lens, 50 mm camera lenses, calibration object 50x40 mm). Implemented photogrametric triangulation technique resulted in high detail scan. Basic steps of digitalisation were as follows; After fixture on base plate, medal was sprayed with penetrant in order to neutralise surface reflection. Calibration and digitalisation were performed in short time. Once point cloud was recorded, ATOS software was used to digitize, process, visualize and export the measured data in stl format to Mentat for preprocessing and FE model geometry creation. Fortunately no bigger problems with surface orientation and definition were encountered.

Digitalization, in this paper performed only on final positive medal obverse, can take place at many stages during die production, shown in Fig. 3. Therefore it represents appealing alternative to be introduced to today´s coining technology.

5. Preprocessing

5.1 Geometry

Digitally obtained stl triangles were converted to the geometry of 7e5 surfaces, modelling. From this number, 3e4 surfaces was chosen to model one twelvth of the coin obverse, shown shadowed in Fig. 2.b. Minimum surface sizes of 0.05 mm were taken as satisfactory modelling of the surface geometry.

One twelfth of the rigid punch was modelled using 3e4 surfaces. Beneath the punch FE mesh was generated as 1/12th of the cylinder of radius 18.3 mm and height 0.68 mm. Divided into mesh of 0.17 mm element size, cylinder is made of 1e5 finite elements. Tip of the cylinder near axis of symmetry was cut off in order to avoid (well known bug) of node penetration trough wedge formed by two intersecting surfaces.

Two wedge plains were used to impose boundary conditions upon 1/12 of the coin. Using more complex boundary condition consumes much more processor time extending the simulation time.

Flow of the material at the outer edge was restricted by the cylinder surface intersecting wedge planes. Definition of all boundary conditions using restricting surfaces is rather simple and requires minimal prerequisites.

Base plane was modelled as a flat plane, in order to keep the model as small as possible. Only one twelve of the obverse was modelled, making present model as simple as possible on behalf of maximization of mesh and surface resolution.

In every case of defining rigid surfaces, analytical definition of surfaces using non-uniform rational B-splines was avoided. Analytical surface definition disable the completion of coining simulation.

5.2 Material

Rigid plastic formulation of material was used in order to make model numerically as simple as possible. Stress-strain curve for gold was assigned to material after an internal data sheet not intended for publishing.

5.3 Contact bodies

As previously mentioned, besides deforming FE billet, there are six contact bodies in numerical simulation; punch, lower plate, two wedge planes and outer cylinder. FE billet, punch and lower plate are main contact bodies, while two wedge planes and outer cylinder were used to impose boundary conditions. As mentioned before no analytical definition of the surfaces was used.

5.4 Boundary conditions

Posed by the use of the symmetric wedge planes enabled the simulation to run to its completion. Boundary conditions imposed in this manner enable the use of remeshing techniques. Although not used in current work they represent an optio for the future investigations of coining FE models.

5.5 Loadcases

Only one, static, time independent loadcase was considered. Basic constant time step loading procedure was used for the same reason of simplicity. Regarding global stiffness matrix positive definiteness was required. Number of recycles was increased to ensure completion of the simulation. Convergence criterion was set using relative residual force.

5.6 Job

Job was set upon one and single loadcase using linear tetrahedral elements written for the updated Lagrangian framework.

6. Processing

Numerical simulation lasted for 60 hours on average desktop PC of the year 2004. It was performed in MSC Marc via input text file created in MSC Mentat. (Buffa et al., 2007) used DEFORM-3DTM, but no FE simulation processing time was given.

7. Postprocessing

MSC Mentat was use to perform postprocessing. Sueccesful simulation was obtained using the simplest allowable element type and avoiding B-spline surface description. FE simulation has pointed to critical stress areas, Fig. 2. Qualitatively these areas coincide with the critical points identified by a engineers involved in technology. Although not included in simulation, part of the geometry that caused the most problems during coining is identified by highly stressed area denoted by the arrow, Fig. 2. Indeed this area is a bit to the right at the right angled tip.

Force stroke diagram shows adequate calibration steep force rise at punch displacement of 0.22 mm. The order of magnitude is appropriate to the force used in a workshop to mint a medal. Still future work should include precise acquisition of force-stroke diagram on medal production press.

8. Conclusion

As shown in this paper it is possible to create and perform 3D FE medal minting simulation using digitized medal geometry. The main difficulty was to enable FE program package to simulate detailed geometry using fine mesh. This limitation pointed out the necessity of simulating only technologically important parts of the medal where one is to expect flow related problems.

Besides the primarily qualitative accordance of numerical and simulation data, one has to be aware of the limits of the simulation. Capturing the fine details emerging in minting operation, requires extremely large number of finite elements. Therefore only critical areas should be modelled, i.e. ‘virtual reality’ should be only applied to model fragments of the object of interest.

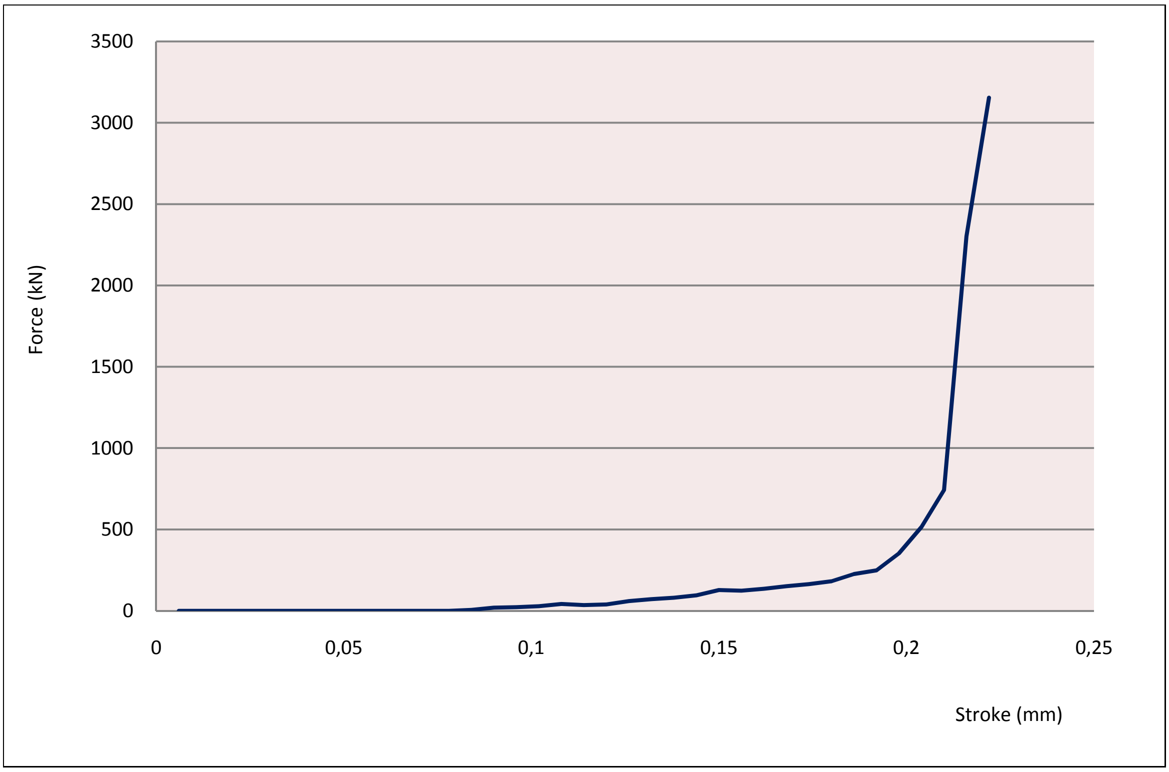


Fig. 4. Force-stroke diagram of medal minting

More quantitative interconnections between experiment and simulation should be established. Force-stroke diagram should be recorded, surface hardness or even grain texture via MLI (mean linear intercept) should be introduced. Aim of all mentioned work is to integrate simulation and production, necessary for any serious technological advancement.

Moreover, when considering large/detailed models, simple numerical methods regarding element types, surface representation and integration models should be used.

In die manufacturing steps shown in Fig. 3, digitalization can take place in each of the phases, and therefore is very appealing to the minting technology. Effort taken in this paper considers geometry of medal and its transfer to FE code trough digitalization. Future work should try to establish same connection between artist made gypsum positive and FE model of medal minting.

Although 1.2e6 stl surfaces used in modelling the medal, if exact golden medal is to be made from digitized model, this medal would be worse than good grade, and visual exam would reveal stl facets making up a medal obverse. Therefore it means that coining technology standards, although visually established, greatly surpass the possibilities of both used novel production technologies.

Therefore partial numerical simulation of the coining should take place, primarily on the areas where flow related problems are likely to occur. In this areas, certain “zoom in” can be preformed to capture the details of the flow and dimension of modelling element can be made as small as possible. The guidelines, to choose location and dimension of areas for FE simulation, should be taken from the past experience because only its combination with new technology can lead to any serious improvement.

Future plans are to find the most appropriate step in minting die production and minting itself, to use digitalization and FE simulation. Since there is a large number of steps involved and minting technology is “traditional” technology, accomplishment of all mentioned will need a great effort from both engineers and technicians.

9. Acknowledgment

The present work has been supported by The Ministry of Science, Education and Sports of Republic of Croatia. Medal was provided by Croatian Monetary Institute.

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