INŽENJERSKA AKADEMIJA CRNE GORE
SAVEZ INŽENJERA CRNE GORE
DRUŠTVO ODRŽAVALACA SREDSTAVA ZA RAD CRNE GORE
KOOPERATIVNI TRENING CENTAR
MAŠINSKI FAKULTET U PODGORICI

XII MEĐUNARODNA KONFERENCIJA

ODRŽAVANJE I PROIZVODNI INŽENJERING

"KODIP - 2014"

ZBORNIK RADOVA

BUDVA, 18.-21. 06. 2014.

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Dragi učesnici Konferencije,

Nastavljamo sa Konferencijom održavanja i proizvodnog inženjeringa.
Na redu je XII Konferencija KODIP-2014.
I ove godine tema Konferencije će se odnositi na inovacije u organizaciji, tehnici i tehnologiji procesa u oblasti proizvodnog inženjeringa i održavanja.
Ova Konferencija posebno je posvećena tehnologijama oodržavanja i proizvodnog inženjeringa u funkciji ODRŽIVOG RAZVOJA.

Tematske oblasti konferencije su:

- *Proizvodne tehnologije i održavanje u funkciji* ***ODRŽIVOG RAZVOJA***
- *Konvencijalne i nekonvencijalne proizvodne tehnologije*
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- *Savremene tehnike i tehnologije u održavanju*
- *Održavanje - " iz prakse za praksu"*

U Zborniku je 47 radova od preko 70 autora i koautora

Kvalitet radova obuhvata oblasti od primjene u praksi do ozbiljnih naučnih tekstova
Odgovarajući žiri će na kraju Konferencije proglasiti najzapaženije radove istraživačkog karaktera, iz oblasti rješavanja praktičnih problema i najinteresantnije izlaganje.

U ime organizatora Konferencije Inženjerske akademije Crne gore, Saveza inženjera CG, Društva održavalaca sredstava za rad Crne Gore i Kooperativnog trening centra Mašinskog fakulteta u Podgorici izražavam zahvalnost autorima i koautorima radova, učesnicima i gostima, pokrovitelju i suorganizatorima, koji su svojim angažovanjem, prisusutvom i sredstvima, učinili i omogućili da ovaj skup, kao i do sada, bude reprezentativnan i koristan.

Želimo Vam dobrodošlicu, uspješan rad i prijatan boravak na crnogorskom primorju, u divnom ambijentu hotela „Slovenska plaža", ovdje u Budvi.

Predsjednik Organizacionog odbora
Prof. dr Miodrag Bulatović

PREFACE

Dear participants of the Conference

We continue with the Conference of maintenance and production engineering.
On the right is the XII Conference KODIP-2014.
This year the conference theme will relate to innovations in organization, technology and process technology in manufacturing engineering and maintenance.
This conference is specifically dedicated maintenence technology and production engineering for sustainable development

Conference themes include:

- *Production technologies and maintenance of sustainable development*
- *The conventional and unconventional production technology*
- *Tribology*
- *Materials*
- *Industrial Engineering*
- *Software Engineering*
- *Numerical modeling and simulation*
- *construction and design*
- *Production systems and optimization - Implementation of ISO quality standards.*
- *Modern techniques and technologies to maintain*
- *Maintenance - "from practice to practice"*

In Proceedings of the 47 works of over 70 authors and co-authors

Content of work covers the areas of application in practice to serious scientific texts

Responding to the jury at the end of the conference to declare the most notable works of the research character of the area to solve practical problems and interesting presentation.

On behalf of the organizers of the Conference: Engineering Academy of Montenegro, Association of Montenegro, the Company Maintainers funds for the operation of Montenegro and cooperative training center Mechanical Engineering in Podgorica I express gratitude to the authors and co-authors, participants and guests, sponsors and co-organizers, who have their engagement, The presence and resources, and have made it possible to this event, and so far, it reprezentativnan and useful.

We welcome you, successful work and a pleasant stay on the Montenegrin coast, in the beautiful surroundings of the hotel "Slovenska plaza", here in Budva.

President of the Organizing Committee
Prof. Dr. Miodrag Bulatovic

PROGRAM I SADRŽAJ

SRIJEDA, 18.06.2013.

20:00-22:00 REGISTRACIJA UČESNIKA

ČETVRTAK, 19.06.2013.

08:00-10:00 REGISTRACIJA UČESNIKA

10:00-11:00 OTVARANJE KONFERENCIJE - SALA A

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Prof. Dr Ljubomir Pejović, Prof. dr Ljubodrag Tanović, Doc. dr Deda Đelović, Prof. dr Safet Brdarević, Prof. dr Miodrag Bulatović

11:00-12:00 UVODNA IZLAGANJA - A

12:00-13:00 KOKTEL DOBRODOŠLICE

13:00-14:30 Izlaganje radova - A
Predsjedavajući: Prof. dr Radoje Vujadinović, Mirjana Stanić, Prof. dr Krsto Mijanović

PETAK, 20.06.2013.

9:00 - 10:30 Izlaganje radova - A

Predsjedavajući: Prof. dr Milentije Stefanović, Dr Safet Avdić, Mr Milenko Perović

<u>16:00 - 19:00 Izlet brodom</u>

<u>20:30 SVEČANA VEČERA</u>

SUBOTA, 21.06.2013.

<u>09:00 - 11:00 Izlaganje radova - A</u>

Predsjedavajući: Prof. dr Lazo Vujović, Prof. dr Mileta Janjić, Mr Sadžid Nuhodžić

<u>11:30 - 13:30 Izlaganje radova - A</u>

Predsjedavajući: Prof dr Petar Nikšić, Dr Slobodan Radosavljević, Đorđe Lazarević

13:30 - 14:30 ZAVRŠNE DISKUSIJE - ZATVARANJE KODIP 2014 - A

Predsjedavajući: Prof. dr Miodrag Bulatović, Doc. dr Deda Đelović, Prof. dr Mileta Janjić

V. Mandić[1], M. Stefanović[2], Ž, Gavrilović[3]

DEVELOPMENT OF THE FORGING TECHNOLOGY FOR PRODUCING THE ARTIFICIAL HIP STEM THROUGH APPLICATION OF VIRTUAL MANUFACTURING

Abstract

This paper presents the research results of the development of forging technology of artificial hip stem. Technologies of virtual engineering (CAD/CAM/CAE) were applied with special focus on the virtual manufacturing, i.e. numerical simulation of the forging process. In identification of dimensions and shapes of artificial hip stem, technologies of reverse engineering were applied. Based on the results, a CAD model of artificial hip stem was developed, and later of the forging as well. Through a series of numerical simulations, designed tool was verified and optimized, from the aspect of optimal shape in the operation of previous forging that provided quality final forging. Applied technology allows getting quality forging of artificial hip stem in significantly shorter time and with lower expenses than in traditional design. Besides, this can be applied on rapid development of similar implants and their components, customized for the end user.

Key words: *Forging, artificial hip,* CAD/CAM/CAE, virtual manufacturing, reverse engineering

1. INTRODUCTION

In recent years, the development of new materials and technologies for implants production has encouraged the development of various technologies for their production as well. The development of these technologies was followed by application of modern computer tools and techniques such as CAD/CAM/CAE (*Computer-Aided Design, Computer-Aided Manufacturing, Computer-Aided Engineering*), RP (*Rapid Prototyping*), RT (*Rapid Tooling*), RE (*Reverse Engineering*), etc. Combining these technologies with scanning and CT (*Computer Tomography*) allows the development, production and installment of so-called *customized implant* or implant adjusted specifically to the user. Opportunities provided by such implant production that depends on the human anatomy play possibly the most important role in this area.

A lot of researchers have been actively engaged in this problem during the last years and their results are presented in the literature. The demand that emerges in implant

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production relates above all to the material that needs to be bio-compatible and have at the same time required mechanical properties for further exploitation loads and conditions. Additional problems that emerge are related to the geometrical complexity, the ways of attaching it to the bones, size of the touching surface, ways of production, etc.

Werner A. et al. [1] analyzed the methodology for design and production of user-customized artificial hip implants. Methods of interpretation and identification of anatomic shape of human bones were analyzed based on the data obtained by computer tomography. The methods for implant modeling using CAD systems and parametric modeling techniques were presented. Also, they analyzed the procedures for production of metal prosthesis using CNC machines. This kind of approach helps surgeons to select the right shape and size of the implant for every user as well as in the application of the standard ones.

In their paper [2], the researchers considered the transfer of load and mechanical stability between geometrically less solid implants and bones. In order to solve the problem of geometrical inconsistences of anatomic shape of femoral canal and standard implants, customized implants were developed. A study was elaborated in order to assess the accuracy of the implant adjustment with the thigh bone. Using computer tomography, the contact surface of implant was determined and compared to conventional femoral component.

Mohammad H. Elahinia et al. [3] analyzed the ways of production and processing of implants made of NiTi alloy, also known as Nitinol. The overview of applied manufacturing technologies was given, from casting and powder metallurgy materials to machining. Besides, an overview was given for application of new rapid prototyping of functional implant prototypes from these biocompatible materials using selective laser sintering.

In their paper [4], David Bennett et al. carried out the research on six types of artificial hip stems applying the finite element method on predefined static and dynamic loads which were 6-7 times greater than the weight they were carrying. The target functions for optimization and selection of the best design option are low stress, displacement and wear, at a very high fatigue life.

The aim of the research presented in this paper is to develop the forging technology of the artificial hip stem by applying the modern technologies of virtual engineering. Through application of modern CAD/CAM/CAE computer tools and technology of reverse engineering, the CAD model of artificial hip stem was developed and later of the forging as well. The forging technology and tools are verified and optimized by application of virtual manufacturing, i.e. simulation by the final volume method. For final geometry of the tool cavities, the strategy of CNC milling and NC code was also developed by application of powerful software solutions.

2. DEVELOPMENT OF CAD MODELS OF ARTIFICIAL HIP STEM AND FORGING TECHNOLOGY

Practically, various models of artificial hips are used, both commercial and those developed for the needs of specific client, on the basis of DICOM file of the medical scanner. For the purpose of research presented in this paper, used model of artificial hip is shown in the figure 1.

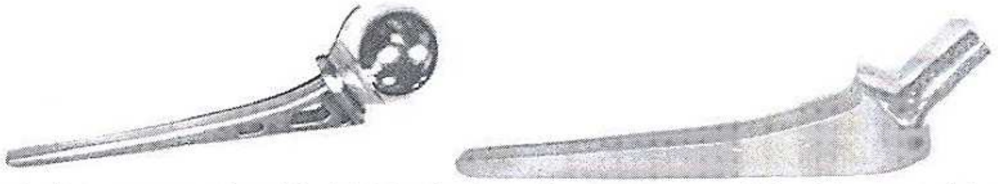

Fig. 1. *Prototype of artificial hip (up) and component of the hip stem (down)*

The artificial hip stem is made by forging technology out of 2CrNiMo18 alloy, in two operations, according to recommended technology for second group forgings, in press forging. The base for forging technology design and optimization by virtual manufacturing technology, i.e. simulation of technology process by application of final volume method, is the CAD model of the stem. With that purpose, the technique of the reverse engineering of the artificial hip model available to the researchers was applied. Numerically operated multisensor coordinate measuring machine WERTH CMM VC-IP250 with three sensor types (optical, laser, *fiber*) was used. In the figure 2, a working table of the machine is presented and figure 3 shows one of the results of optical scanning of artificial hip.

Fig. 2. *Multisensor CMM WERTH VC-IP250 for reverse engineering*

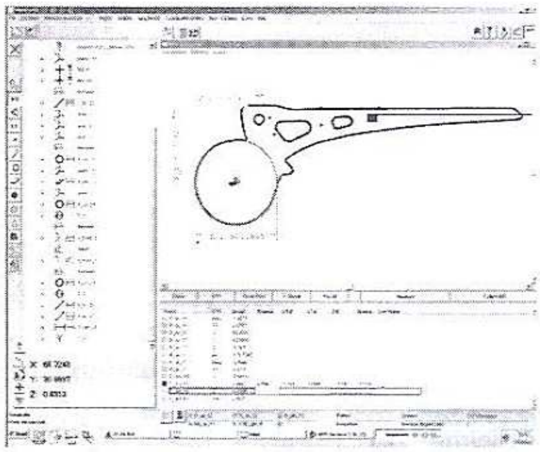

Fig. 3. *The result of optical scanning on CMM*

By identification of geometrical properties of the hip stem on CMM, it was possible to develop its CAD model. Software CATIA v.17 was used as well as modules Generative Shape Design and Part Design. In the figure 4, the CAD model of the artificial hip stem is shown, presenting the starting point for further design of forging technology. The figure 5 presents the drawing in two projections, with referent dimensions.

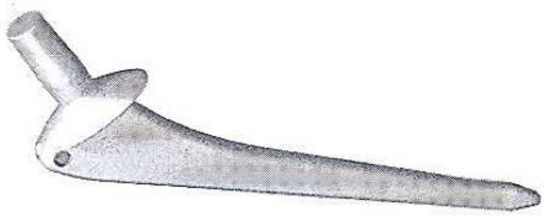

Fig. 4. *CAD model of the artificial hip stem*

The forging of the artificial hip body is performed in the open tools, which means that in the process of forging, extra material is formed in the shape of flash that is additionally removed by the trimming operation. For additional cutting processing, finish allowances of 2mm were planned, and in order to release the forging more easily from the tool cavity, draft angles of 3° were applied. Allowances for material heating and flowing out to the flash are also taken into account. The final form of CAD model of forging is presented in the figure 6.

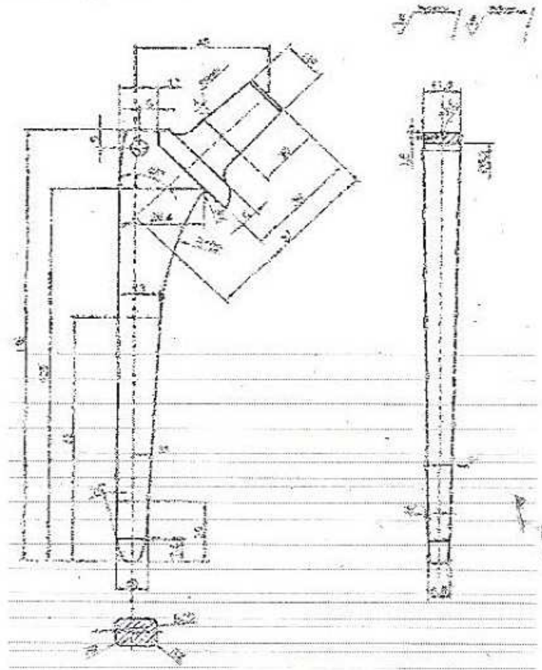

Fig. 5. Drawing of the artificial hip stem

The forging shape of the artificial hip stem belongs to the first group of forgings with elongated axis [5]. Recommended forging technology of this kind of forgings implies the operation of the preform forging. From the condition of equality of final forging volumes, increased by the assessed flash volume and allowances for heating to the forging temperature and calculated forging mass m=444g, a shape of the forging part was obtained in the operation of preform forging, as shown in the figure 7.

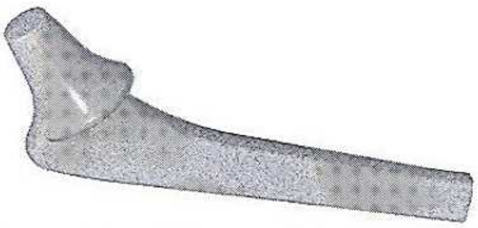

Figure 6. *CAD model of the forging reduced of the artificial hip stem*

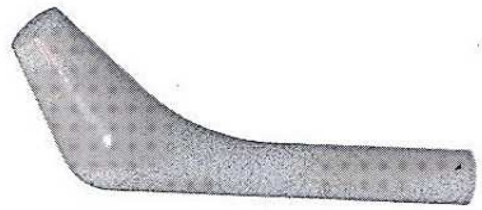

Fig. 7. *CAD model of the preform - forging, for preforming forging operation*

During this process, characteristic cross-sections of final forging were used, and on their basis so-called "reduced forging" was modeled. Its shape allows the complete filling of the tool cavities for final forging with control of material flowing out into the flash and dimensional accuracy. The tools for open-die forging were designed on the basis of previously developed forging. The operation of preform forging was realized on roll forging machines.

Parting line was defined in such way that approximately the same material volumes were forged in upper and lower cavity. Forging cavities were proportionally increased by 2.4% taking into consideration thermal expansion of metal because the forging processes were carried out at increased temperatures. Also, the flash for flowing out of material excess and for ensuring the filling of the whole tool was modeled around the forging edges. The figure 8 presents the tools for final forging.

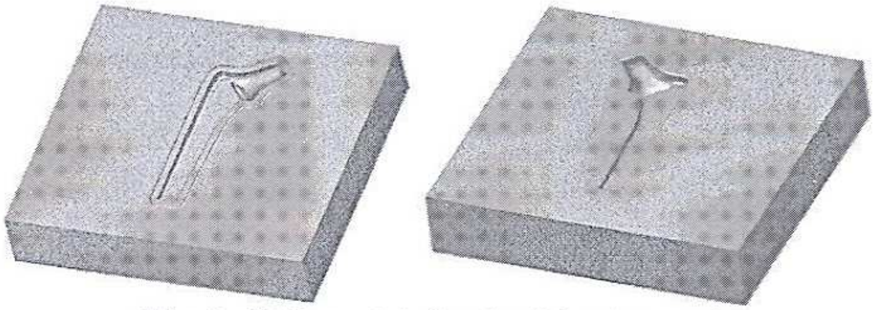

Fig. 8. *CAD models for final forging tools*

3. VIRTUAL MANUFACTURING OF THE FINAL FORGING OPERATION

For numerical simulation of forging process and testing the designed technology, as well as the forging tools shapes and cavities, the commercial software *Simufact.forming [6, 7]* was used. The final volume method was applied having in mind that the process was simulated in hot state so the plastic flow of material was described by flow formulation, similar to fluid dynamics. CAD models of tools and preform were imported into the software as STL formats.

The hydraulic press with forming speed of 250 mm/s was defined and tools were "virtually mounted" on it. From the software *Simufact.material* and its data base, the material of preform was selected in accordance with DIN standard 1.430. In this process, this material had behavior very similar to that of 2CrNiMo18.143. The initial preform temperature of 1000°C was defined. The preform mass in the first simulation was m=0.444kg. The selected material for upper and lower tool was H13 that matches the real material Č4751 and tool heating temperature of 250°C was assigned. The contact friction conditions during the simulation were defined by the constant friction law and the value of friction factor of m=0.6. In this way all inputs for "virtual manufacturing" process were defined for forging of the artificial hip stem in final operation.

The results of virtual manufacturing in this case were material flow presentation, testing of filling the tools cavities, as well as strain, stress and temperature fields. In order to test the tool filling, a contrast display of virtual forging at the end of simulation was used, where the zones outside the contact with tools were presented by red color. The figure 9 presents the virtual forging in contrast display, where the zones of tool with incomplete filling can be identified, as well as the inaccuracy of the forging.

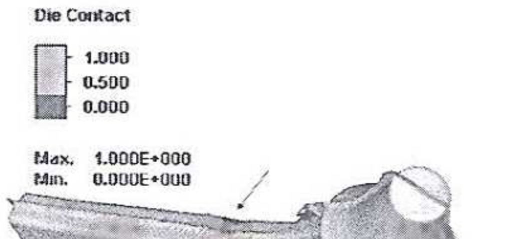

Fig. 9. *Virtual forging in contrast display of the tool cavity filling after the first simulation*

Additionally, the flash zone was also minimal, which led to conclusion that there was insufficient material volume of the preform for filling in the tool cavities in the final forging operation.
By analyzing the problem and identified defects, the forging volume was increased by 20% and new simulation was performed with the same input parameters as in previous case. The preform mass in this case was m=0.533kg.
The figure 10 presents the filling of the tool cavity with material during the second simulation in different stages of the process (20%, 40%, 60% and 80%, respectively).

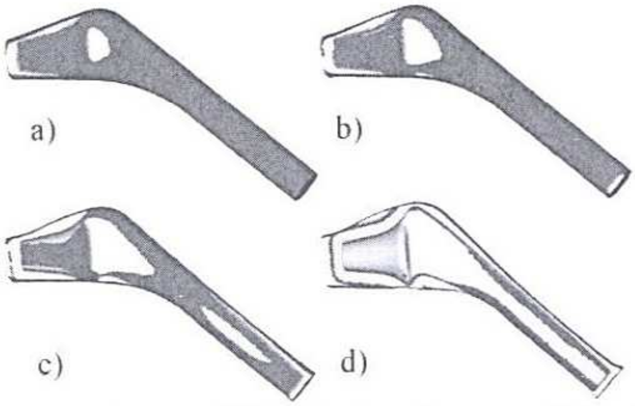

Fig. 10. *Presentation of the tool cavity filling during the second simulation a) 20%, b) 40%, c) 60% and d) 80%*

The shape of the virtual forging with the flash at the end of the final forging operation is presented in the figure 11. After realized corrections, the second simulation gave satisfying results, tool filling and desired forging shape and accuracy.

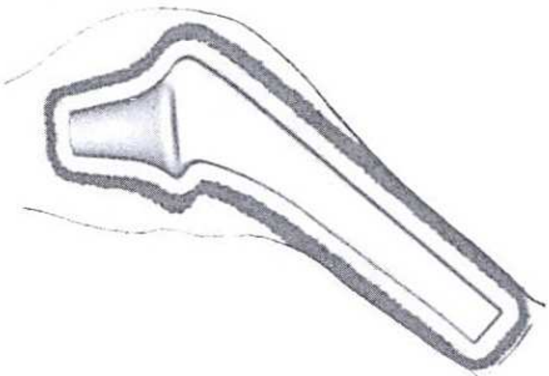

Fig. 11. *Virtual forging with the flash at the end of the final forging operation*

In post-processing, the other results of process simulation were reviewed, such as temperature distribution in the forging at the end of the process (figure 12), distribution of contact pressures between the forging and the tool (figure 13), tool temperatures at the end of the process (figure 14), distribution of the effective plastic strain (figure 15) as well as effective stress in the forging (figure 16). All presented results suggest well designed technology and tools, which leads to obtaining the good forging, dimensionally and qualitatively.

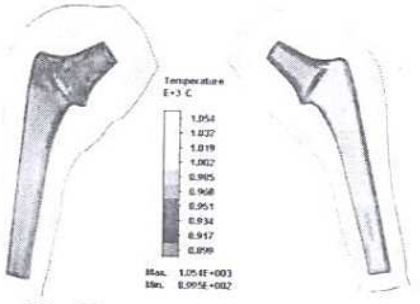

Fig. 12. *Temperatures at the end of the forging*

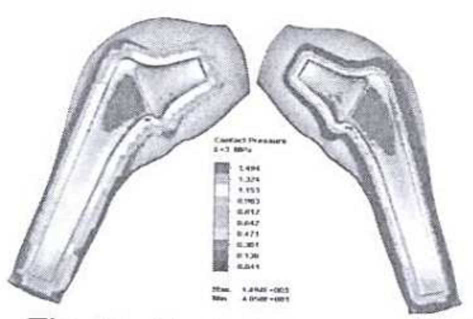

Fig. 13. *Contact pressures in the forging*

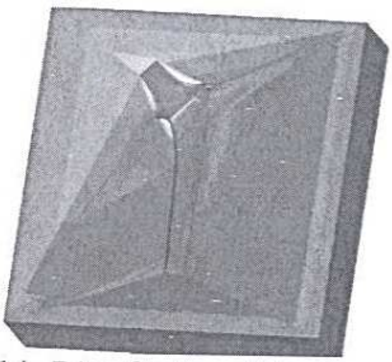

Fig. 14. *Distribution of the temperatures in lower tool at the end of the forging process*

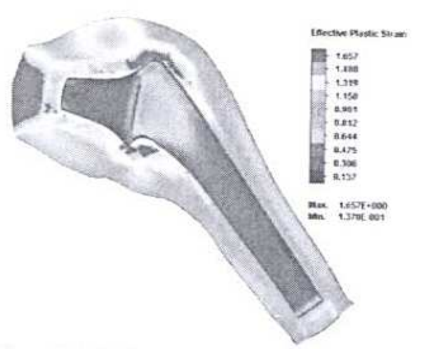

Fig. 15. Distribution of *effective plastic strain in the forging*

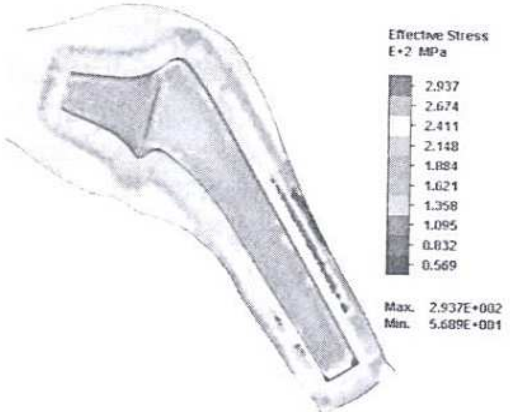

Fig. 16. *Distribution of the effective stress*

4. DEVELOPMENT OF THE FORGING TOOLS PROCESSING ON CNC MILLING MACHINE

In order to create optimum processing strategy for CNC milling of tool cavities, the software DELCAM PowerMill was used. The software allows the processing simulation, its optimization and finally the automatic generation of the NC code.

After the import of designed tool model in STEP format, definition of the coordinate system position and dimensions of the preform, strategies were selected for rough and fine milling processing. The software has the tool base as well as recommendations for regimes of processing and plunge strategies for fine and rough machining. For CNC milling of the upper tool cavity, following strategies were used:

- RasterAreaClear Model (rough machining of the surface outside the cavity)
- Offset AreaClear model (rough machining of the cavity)
- Offset Flat Finishing (fine machining of the surface outside the cavity)
- 3D Offset Finishing (fine machining of the cavity)

• Corner MultiPencil Finishing (machining of the transitional radiuses R2)
The figure 17 presents the tool path in arbitrary time period.

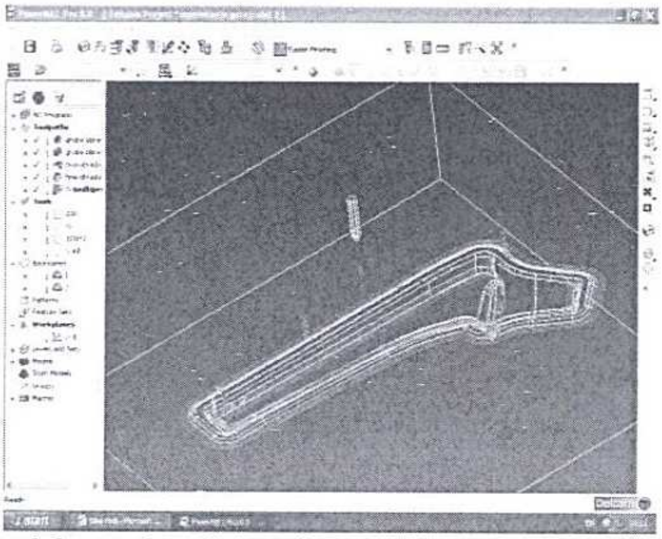

Fig. 17. *View of the tool path in arbitrary time of CNC milling simulation*

5. CONCLUSION

By using CAD/CAM/CAE technologies, reverse engineering, virtual manufacturing and powerful software solutions for simulation of technology and forming process, production processes and technologies can be successfully developed, tested and optimized. For development of forging technology for artificial hip stem, all abovementioned technologies of virtual engineering were applied, which resulted in complete analysis of designed technologies, design of the tool and strategy of their production. In this way, it was possible to have the higher quality of production and analysis of all important parameters that influence the material processing in shorter period time and with lower expenses in comparison to traditional "*trial and error*" design approach. Application of virtual manufacturing leads to significant reduction of development time, decrease of expenses and increase of the forgings quality. For the development of implants that have components obtained through the forging process, presented technology development procedure can be successfully applied in order to the test the filling of the tool, as well as to define the strategy of CNC machining of its cavities.

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