

Prispevek k obvladovanju neuravnoteženosti krepeljastih polov alternatorjev

A Contribution to the Unbalance Control of Claw Poles for Automotive Alternators

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Krepeljasti poli so še vedno največji in najtežji sestavni del rotorja alternatorjev, ki bo vsaj še nekaj časa ustvarjal električno energijo v motornih vozilih. Zaradi visokih vrtljajev, ki jih alternator med delovanjem doseže, je masna uravnoveženost rotorja bistvenega pomena za dobo trajanja ležajev, majhen hrup in miren tek. Prispevek obravnava izdelavo krepeljastih polov s hladnim preoblikovanjem, pri čemer je poudarek na zmanjšanju njihove neuravnoveženosti, s čimer bi bistveno pripomogli k pospešitvi avtomatskega uravnoveženja rotorjev. V začetku je na kratko orisan problem ter samo načelo uravnoveženja. V nadaljevnju sledi eksperimentalna analiza sedanje proizvodnje, z uporabo metode končnih elementov pa razložimo vzroke za pojav neuravnoveženosti. Poudarek je dan raziskavam v smeri izboljšav sedanjega orodnega sistema za doseganje majhne neuravnoveženosti krepeljastih polov.

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(Ključne besede: rotorji alternatorjev, uravnoveženost mas, sistemi orodni, metode numerične)

The claw pole still represents the largest and the heaviest part of an alternator's rotor; and it is expected that alternators will continue to be used for electric power generation in motor vehicles for at least a decade. Due to the high speeds of the rotor during operation its mass centricity is very important for the service life of the bearings, low noise and smooth running. This paper presents the production of claw poles using cold-forming technology, and a focus on reducing the eccentricity. Achieving this aim will mean a step towards shortening the time needed for automated balancing. We start with the problem of production and principle of balancing, this is followed by an experimental analysis of current production and a FEM analysis, which helps to describe the reasons why unbalance occurs. Emphasis is placed on work towards improving the tooling system for achieving well-balanced claw poles after cold forming.

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(Keywords: alternator rotors, mass centricity, tool systems, numerical methods)

0 UVOD

Geometrijska natančnost polizdelkov je še vedno eden glavnih problemov v tehnologiji hladnega preoblikovanja. Pri tem ima pomembno vlogo preoblikovalno orodje, ki s svojimi značilnostmi prispeva h kakovosti izdelka [1]. Način, s katerim se rešuje problem merske nenatančnosti polizdelkov, je navadno odvisen od geometrijskih značilnosti polizdelka. Zmanjšanja preoblikovalnega odpora z načelom sprostitevni osi na mestih z največjo napetostjo se je lotil že Kondo ([2] do [4]). Podobna metoda je bila uporabljena tudi za hladno kovanje zobnikov ([5] in [6]). V prispevku je prikazan problem natančne izdelave krepeljastega pola s hladnim preoblikovanjem (sl.1) ter podane smernice za ustrezne poprave orodja.

0 INTRODUCTION

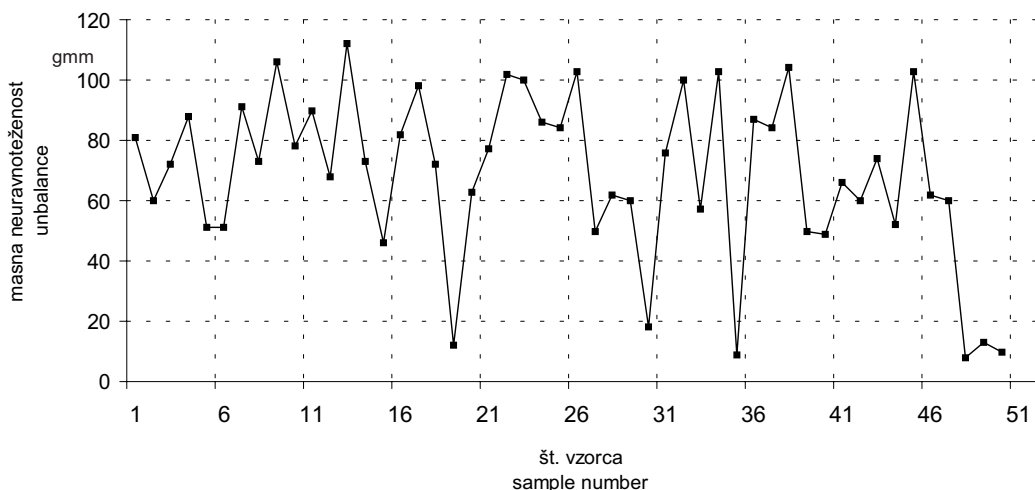
The geometrical accuracy of products is still one of the major problems facing cold-forming technology. The forming tool and its characteristics have an important affect on the quality of the finished part [1]. The principle used for controlling geometrical errors depends mainly on the geometrical properties of the product being produced. Lowering the forming resistance by the principle of relief axis at the points with the highest pressure is one of the methods that has been used already by Kondo ([2] to [4]). A similar method has been used in the cold forming of gears ([5] and [6]). The problem of geometrically accurate production of the claw pole by using cold-forming technology is presented in the paper (Fig. 1), and some advice relating too an improved forming tool is given.



Sl. 1. Platina in izdelani krempljasti pol alternatorja
Fig. 1. Blank and finished claw pole for alternators

Med obratovanjem doseže rotor alternatorja do 18.000 vrtljajev v minuti. Ena bistvenih zahtev, ki jih je treba izpolnjevati, je majhna masna neuravnoteženost celotnega sklopa rotorja. Problem se rešuje z uravnoteženjem rotorja pred vgradnjo v celoten sklop alternatorja. V proizvodnji se to navadno doseže z odvzemanjem materiala v dveh ravninah, kar je lahko v primeru velike neuravnoteženosti zelo zamuden proces. Zaradi slabih sestavnih delov se lahko zgodi, da rotorja ni mogoče primerno uravnotežiti in postane izmet. Na tem mestu se pojavi težnja po čimbolj natančno izdelanih polizdelkih (v prikazanem primeru je to krempljasti pol), ki so sestavni del končnega izdelka.

During operation the rotor of an alternator is moving at high speeds (up to 18,000 rpm), thus one of the important demands is to keep the rotor unbalance as low as possible. Balancing the rotor before its final assembly into the alternator solves the problem. In the production this is normally achieved by drilling holes in two planes, which is often a time-consuming process if the rotor is very unbalanced. In some cases it is impossible to achieve the prescribed tolerance. Thus the need for the cold-formed parts, in this case the claw pole, to be as precise as possible is clear.



Sl. 2. Meritve masne neuravnoteženosti krempljastega pola na 50 vzorcih
Fig. 2. Unbalance measurements of the claw pole for 50 samples

Krempljasti pol je najtežji sestavni del rotorja, zato se je primerno posvetiti njegovi izdelavi v smeri majhne neuravnoteženosti. Analiza trenutnega stanja v proizvodnji krempljastih polov pokaže na veliko neuravnoteženost (sl.2), saj merjeni rezultati presegajo dovoljeno mejo 80 gmm (velikost se navadno podaja v gmm, kar pomeni določeno maso materiala na določeni ročici). Zmanjšanje masne neuravnoteženosti krempljastih polov je zato eno ključnih vprašanj.

1 NAMEN URAVNOTEŽENJA

Uravnoteženje delimo na uravnoteženje togih ter prožnih rotorjev ([7] in [8]). Pri prožnih rotorjih

The claw pole is the heaviest part of the rotor so it is worth spending time to reduce its unbalance. An analysis of the current production shows a large degree of unbalance (Fig.2). The measured values exceed the upper limit of 80 gmm, (it is normally measured in gmm which represents a certain amount of material on a given radius). Reducing this unbalance is therefore one of the main tasks.

1 THE PURPOSE OF BALANCING

Balancing is basically divided onto the balancing of rigid and elastic rotors ([7] and [8]).

moramo izvajati modalno uravnoveženje, pri katerem je treba upoštevati upogibne deformacije gredi. S tem se v našem prispevku ne bomo ukvarjali.

Pri uravnoveženju togih rotorjev poznamo uravnoveženje v eni (statično) in več (dinamično) ravninah. Pri uravnoveženju v eni ravnini za počasi tekoče rotorje poskušamo odpraviti njihovo izsrednost oz. uravnovežiti momente mase. Pri balansiranju v dveh ali več ravninah pri hitrotekočih rotorjih pa poskušamo odpraviti masne deviacijske momente glede na par pravokotnih osi, od katerih je ena vedno os vrtenja. Z drugimi besedami, želimo odpraviti momente centrifugalnih sil pri vrtenju.

Uravnoveženje se lahko izvaja terensko, pri čemer se rotor vrti v svojih ležajih, ali pa na uravnovežnih napravah, kjer rotor namestimo na napravo ter ga testno zavrtimo za ugotovitev neuravnoveženosti. Slednja možnost se uporablja tudi pri velikoserijski izdelavi alternatorjev na avtomatiziranih balansirnih napravah

Kupci alternatorjev predpisujejo največjo masno neuravnoveženost, ki jo morajo rotorji dosegati. Pri uravnovežanju z odvzemanjem materiala, ki je v navadi pri množični proizvodnji rotorjev alternatorjev, se pojavijo omejitve pri možni količini odvzetega materiala. Preveliko odvzemanje lahko povzroči celo dodatne neprijetne učinke, npr. pojav magnetne neuravnoveženosti pri uravnoveženju rotorjev elektromotorjev [9].

Ker namen prispevka ni poglobljeno obravnavanje uravnovežnega sistema temveč raziskava možnosti za izboljšanje polizdelkov, bomo v nadaljevanju predstavili tehnološki postopek izdelave krempljastega pola.

2 TEHNOLOŠKI POSTOPEK IZDELAVE

Izhodiščni material za izdelavo krempljastega pola s hladnim preoblikovanjem je debela pločevina, navita na kolute, iz katere se najprej izsekajo platine v obliki zvezd (sl.1). Debelina platin je odvisna od tipa krempljastega pola in se giblje med 10 in 13 mm. Sledi hladno preoblikovanje v sedmih stopnjah na prenosnem orodju, pri čemer se postopoma pride do končne oblike. Po hladnem preoblikovanju sledi še žarjenje za izboljšanje magnetnih lastnosti materiala.

Z vidika masne neuravnoveženosti izdelanega krempljastega pola je zlasti pomembna prva operacija na prenosnem orodju, ko se s tehnologijo finega reza prebije luknja. Centriranje platine v prvi stopnji je prikazano na sliki 3. Funkcionalno je luknja namenjena pritrditvi pola na gred rotorja, med postopkom izdelave v naslednjih šestih stopnjah orodja pa je uporabljena za pozicioniranje platine v orodju.

Centričnost izdelane luknje glede na pozicionirne trne je 0,032 mm, to pomeni, da bi v primeru popolnoma geometrijsko pravilno izdelane platine masna neuravnoveženost izdelanega krempljastega pola nihala za ± 13 gmm. V primerjavi s skupno izsrednostjo

Modal balancing is necessary for elastic rotors, where bending deformations of the shaft need to be taken into account. This topic will not be discussed in the paper.

Single-plane (static) and multiplane (dynamic) balancing are used with rigid rotors. Single-plane balancing is needed for slow-running rotors where gravity moments need to be eliminated. During dynamic balancing the aim is to reduce the mass-deviation moments with regard to two perpendicular axes, one of which is the axis of revolution. In other words, the centrifugal moments during rotating should be removed.

Two different balancing principles are used in practise. The first case is when the rotor is rotating in his own bearings. In the second case, special balancing machinery is used to test and correct the rotor. This latter method is also used in the mass production of alternators.

The highest mass unbalance of the rotors is prescribed by the customer. The balancing principle in mass production normally involves removal of the material by drilling. There are certain limitations relating to the amount of material that can be removed. If too much material has to be removed in order to keep the rotor in the tolerance field some other effects can appear. For example, magnetic unbalance during the balancing of rotors for electric motors [9].

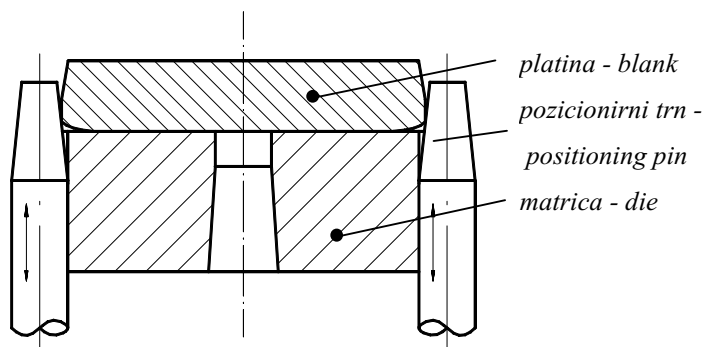
The aim of our paper is not to discuss the theoretical principle of balancing but to improve the mass balance of a cold-formed claw pole. Therefore, the technological process of claw-pole production will be presented in the next section.

2 TECHNOLOGICAL PROCESS

The material used for claw-pole production in cold-forming technology is thick sheet metal bound in coils. Blanks are made first by free blanking. The thickness depends on the type of claw pole and ranges between 10 and 13 mm. Next, the blanks are formed to their final shape on a mechanical press using a seven-step transfer die. Finally, the claw poles are annealed to improve their magnetic properties.

Flow piercing of the hole (first transfer die) is a forming step that has a major affect on the final claw-pole unbalance. Positioning of the blank in the first transfer die is shown in Fig.3. The hole is used for mounting the claw pole onto the rotor shaft. It is also used for positioning the blank during forming in subsequent operations.

The manufacturing tolerance field of the piercing punch with regard to the positioning pins is 0.032 mm. If the blanks were produced in a geometrically precise way, the maximum theoretical unbalance would be 13 gmm. This is a negligible



Sl. 3. Pozicioniranje platine pri prebijanju luknje
Fig. 3. Centering of the blank during piercing

izdelanega krempljastega pola je to zanemarljivo, saj se ta giblje pri vrednosti 80 gmm. Iz povedanega smemo za neuravnotežje izdelanih krempljastih polov sumiti prvo tehnološko operacijo (prosto rezanje), pri kateri ne izdelamo geometrijsko pravilne oblike platine. Ta nepravilna oblika je bistvena za vnos neuravnotežja v polizdelek, ki se nato prenese v končni izdelek.

amount compared to the total claw-pole unbalance, which is around 80 gmm. Therefore, we can conclude that the first operation, the free blanking of the blanks, is essential for the accuracy of the finished product, where a geometrically imperfect blank is made. This nonsymmetrical geometry of the blank is essential for the unbalance of the finished product.

3 VZROKI ZA NASTANEK NEURAVNOTEŽJA PRI PROSTEM REZANJU

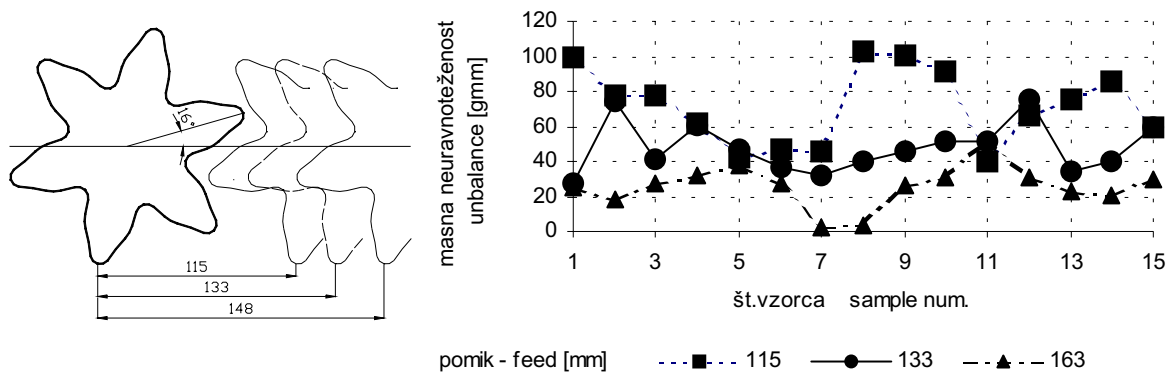
3 REASONS FOR NONSYMMETRICAL FREE BLANKING

Želja po čim boljšem izkoristku materiala narekuje čim gostejšo postavitev platin na trak. Izkazalo se je, da je le to ključnega pomena za nastanek masne neuravnoteženosti. Z namenom, da bi ugotovili vpliv velikosti mostička med dvema platinama, smo dva pestiča vzeli iz orodja in povečevali razmik izrezanih platin.

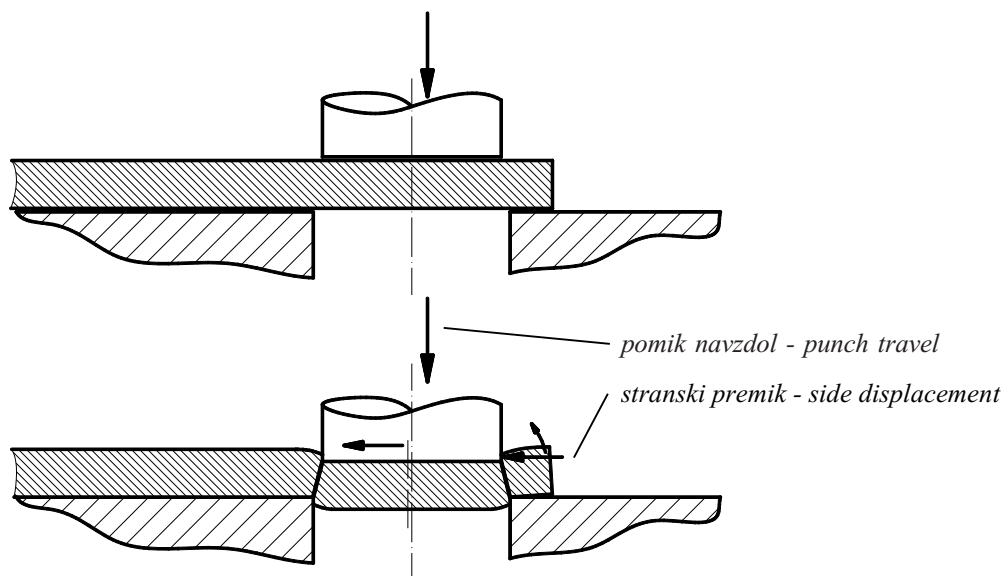
In order to save on the material costs it is necessary to arrange the blanks to be as close together as possible. However, many problems occur for this reason, a fact that was experimentally verified. In order to determine the influence of the web width, two punches were taken out of the tool and the feed was increased.

Rezultati so prikazani na sliki 4, kjer se vidi, da se je ob večanju razmika med platinama masna neuravnoteženost izdelanega krempljastega pola zmanjšala. Glavni vzrok za izsrednost izdelanega krempljastega pola je izsredena obremenitev stiskalnice in nesimetričen rez, ki je posledica neenakomerne porazdelitve materiala okrog rezilnega pestiča. Pri gibu orodja navzdol nastanejo poleg glavne rezalne sile v smeri giba orodja še stranske rezalne sile, ki pa med seboj niso v ravnotežju (sl.8).

The results are presented in Fig.4. We can conclude that when the web width is increased the unbalance of the finished claw pole becomes proportionally lower. The major reason for the unbalance of the finished claw pole is a non-symmetrical blanking, which is the reason for the non-uniform distribution of the material surrounding the blanking punch. Apart from the major blanking force there are side forces that emerge when the tool closes (Fig.8). These side forces are not symmetrical due to



Sl. 4. Vpliv razmika platin na izsrednost
Fig. 4. Influence of the blank scatter on the eccentricity



Sl. 5. Vodoravni premik rezilnega pestiča proti matrici
Fig. 5. Horizontal shift of the punch relative to the die

Zaradi zračnosti v vodilih orodja in stiskalnice povzročajo stranski premik pestiča v primerjavi z matrico (sl.5).

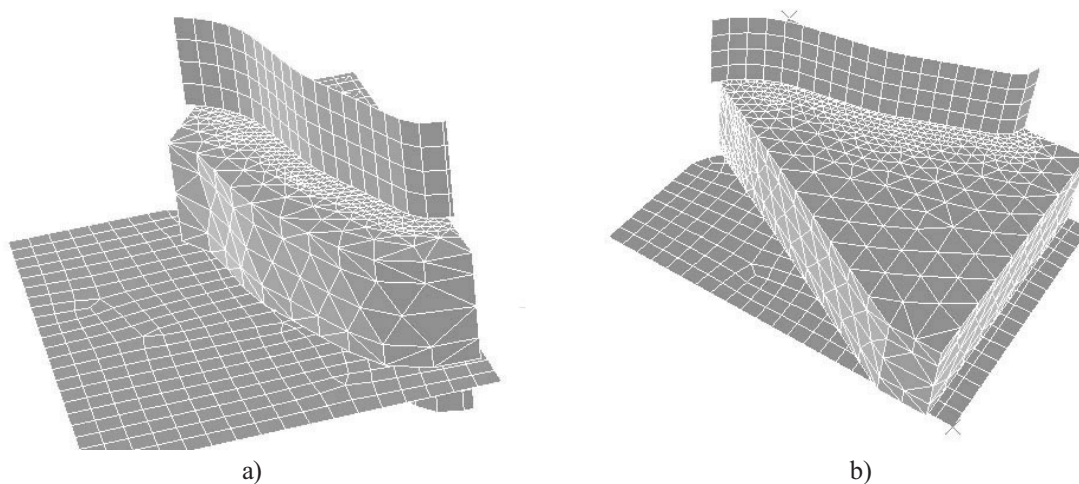
Za potrditev domneve o pojavu nesimetričnih stranskih sil na pestič med postopkom rezanja je bilo narejeno numerično simuliranje začetne faze rezanja. Skušali smo napovedati dogajanje po obodu enega zoba pestiča. Problem je v tem, da je zaradi poprej izrezane platine na eni strani zoba pestiča bistveno več materiala kakor na drugi strani (sl. 8). Posledica tega je razvoj bočnih sil na zob pestiča, ki nista v medsebojnem ravnovesju in povzročata vodoravni premik pestiča.

Z dvema numeričnima simuliranjima začetne faze rezanja, pri čemer je bilo v prvem primeru okoli pestiča manj materiala v drugem pa več, smo domnevo potrdili (sl. 6 in 7). Primerjava deformacij platine v obeh primerih pokaže, da ima v primeru, ko je na zunanji

the different size of the web. Because of the clearing in the tool and press guiding system these side forces cause a punch shift relative to the die (Fig. 5).

In order to confirm our assumption about the development of side forces on the punch we made a numerical simulation of the beginning of the cutting process. The circumstances on one side of the blanking teeth were predicted. The problem is a nonuniform distribution of the material surrounding the punch, due to the blank cut in the previous step (Fig. 8). A consequence is the development of side forces on the punch, which causes a horizontal shift of the punch.

The assumption was confirmed by performing two numerical simulations of the initial cutting phase. In the first case less material was used surrounding the punch, in the second case more material was used (Fig. 6 and 7). Comparing the deformation in the first



Sl. 6. Model zoba pri rezanju platine a) manj materiala b) več materiala
Fig. 6. FE Model during blanking a) less material b) more material

strani pestiča manj materiala, le-ta veliko večjo težnjo po gibanju navzgor in s tem proti pestiču. Deformacija zgornjega dela platine je v prvem primeru 0,045mm v drugem pa 0,01mm. Prav tako je potrjena domneva o neenakomernem razvoju prečnih sil na pestič, kar ima za posledico pritiskanje zoba pestiča v stran.

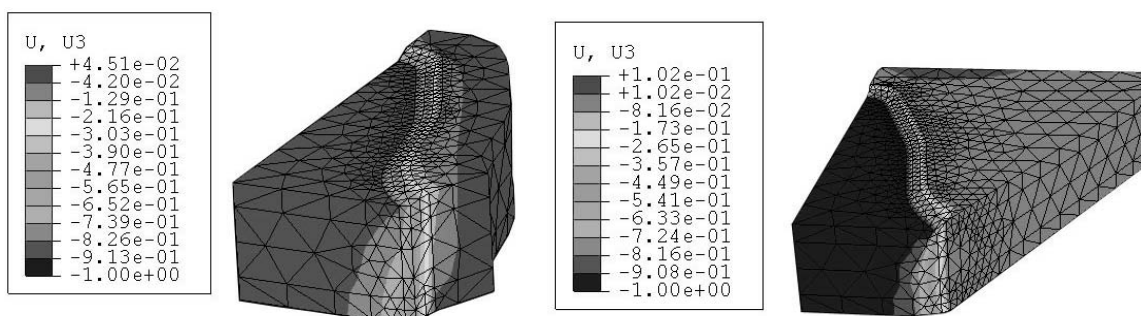
Potek sil v ravnini pestiča je prikazan na sliki 8. V primeru večje količine materiala na zunanji strani pestiča je bočna pritiska sila manjša. Komponenta sile v smeri zoba zaradi deformacije ni problematična, ker je po obodu celotnega pestiča nameščenih šest zob, katerih sile se med seboj izničijo. Problematična je rezultanta sile prečno na zob, katere velikost je glede na rezultate simuliranja približno 1,5 % celotne preoblikovalne sile. Z upoštevanjem dejstva, da je potrebna sila za rezanje ene platine 2000 kN, pomeni to 27 kN bočne sile na zobe, ki povzročajo torzijo pestiča in s tem neenakomeren potek kota lomne cone na platini.

Odpravljati vzroke premika rezalnih pestičev na orodju in stiskalnici bi bilo ekonomsko neupravičeno, saj bi pomenilo bistvene posege v stroj in orodje. Povečanje

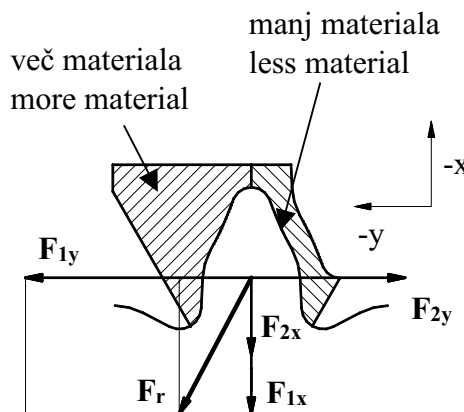
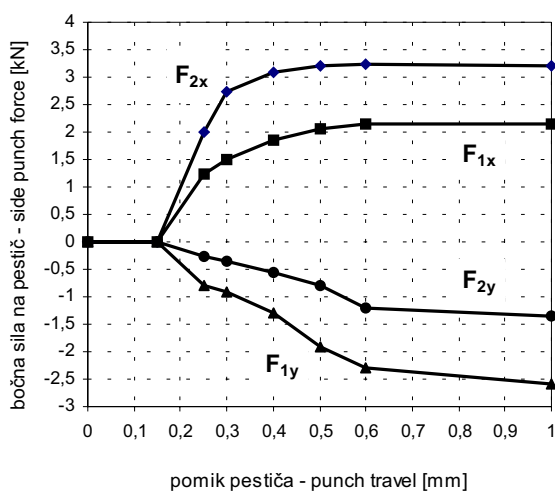
and second case shows that when there is less material near the punch it has a much higher tendency to move upwards and towards the punch. Vertical deformation of the blank in the first case is 0.045 mm, and in the second case it is 0.01 mm. The assumption of the nonsymmetrical side forces was confirmed as well, these forces cause a sideways movement of the punch.

The forces acting on the punch are presented in Fig. 8. In the case when we have more material outside the punch the side force is lower than with less material. The force component acting parallel to the punch tooth is not problematic since there are six teeth arranged circumferentially and the forces disappear. The most problematic component acts perpendicularly to the tooth. Its magnitude is 1.5% of the total blanking force, according to the simulation. Taking the 2000 kN that is needed for one blank into account, it means 27 kN of side force. These forces are the reason for the torsional punch displacement, which causes a nonuniform distribution of the angle of the fracture zone.

Solving the problem of the horizontal punch displacement would mean large investments in the tool and press, which may not be the correct economic decision. Increasing the web width between the blanks



Sl. 7. Deformacija platine v prvem in drugem primeru
Fig. 7. Blank deformation in the first and second cases



Sl. 8. Komponenti rezalne sile na pestič v ravnini platine
Fig. 8. Blanking force components in the blank plane

razmika med pestiči pa bi hkrati pomenilo tudi manjši izkoristek materiala ter povsem novo orodje za rezanje. Zaradi povedanega se bomo osredotočili na prvo operacijo v prenosnem orodju - fino rezanje luknje.

4 TEORETIČEN IZRAČUN NEURAVNOTEŽENOSTI

Da bi potrdili domnevo o glavnem vplivu nesimetričnega odreza platine na masno neuravnoteženost izdelanega krempljastega pola, je bila masna neuravnoteženost tudi teoretično izračunana na podlagi meritev premika pestiča pri rezanju platin.

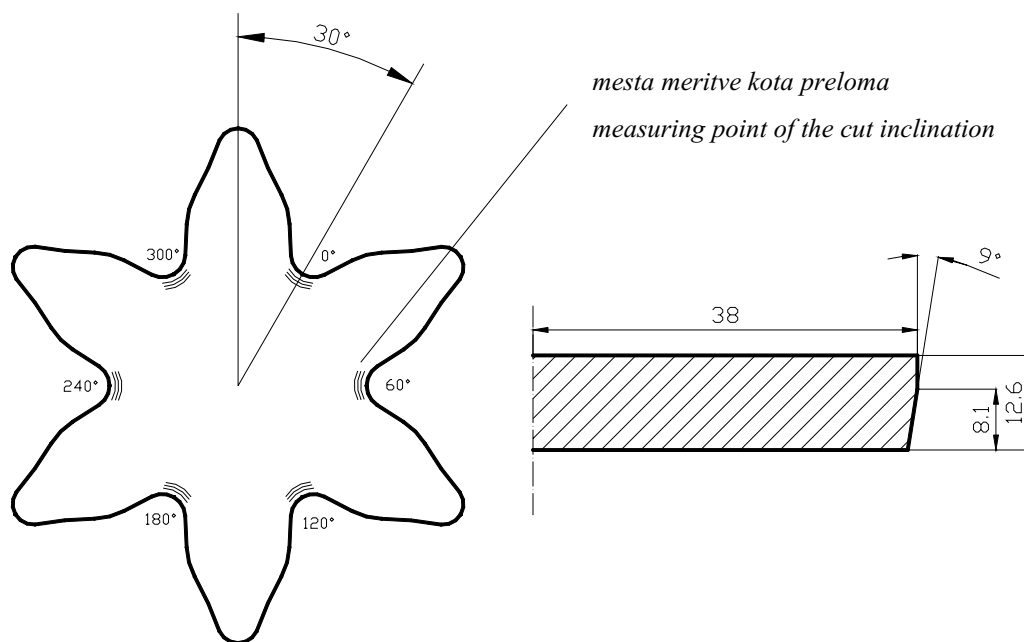
V primeru morebitnega ujemanja izračunanih rezultatov ter rezultatov meritev neuravnotežja izdelanega krempljastega pola, je jasno, da preoblikovanje na prenosnem orodju ne vpliva bistveno na končno neuravnoteženost izdelka. V ta namen je bilo iz serije vzetih 25 platin, na katerih smo merili kot preloma materiala med rezanjem (sl. 9).

would mean higher material costs, which is again not a profitable solution. Apart from that, a completely new blanking tool will be required. Because of this, further discussion will be focused on the flow piercing of the hole, which is the first operation in the transfer die.

4 THEORETICAL CALCULATION OF THE ECCENTRICITY

In order to confirm the assumption about the major affect of the blanking tool on the claw-pole unbalance we made a theoretical calculation of the unbalance. It was based on the punch shift during blanking, which was measured by examining the blanks.

When the results obtained theoretically by inspecting the blanks are identical to those measured on the finished claw poles we can conclude that the forming on the transfer tool does not have any affect on the overall unbalance. In order to perform this calculation, 25 blanks were taken from production. The angle of the fracture zone was measured at six positions on the blank (Fig.9).

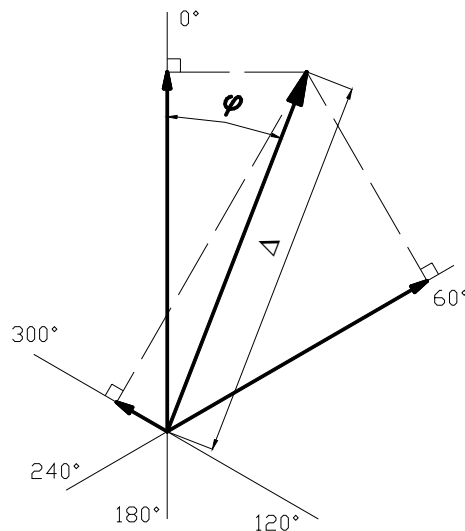


Sl. 9. Meritev kota preloma materiala na platini
Fig. 9. Measuring the cutting angle on the blank

Iz šestih meritev kota preloma materiala sta bili ocenjeni smer ter velikost premika pestiča proti matrici, iz tega pa izračunana masna neuravnoteženost platine:

The direction and amplitude of the punch shift were calculated based on six measurements of the angle, the theoretical unbalance was also calculated:

$$\begin{aligned} \Delta_0 &= t \cdot \left[\tan \left(\frac{\varphi_0 + \varphi_{180}}{2} \right) - \tan \varphi_0 \right] \\ \Delta_{60} &= t \cdot \left[\tan \left(\frac{\varphi_{60} + \varphi_{240}}{2} \right) - \tan \varphi_{60} \right] \\ \Delta_{120} &= t \cdot \left[\tan \left(\frac{\varphi_{120} + \varphi_{300}}{2} \right) - \tan \varphi_{120} \right] \end{aligned} \quad (1).$$



Sl. 10. Izračun premika pestiča proti matrici
Fig. 10. Calculation of the punch shift

Oznake v enačbah so glede na sliko 9:

- φ - kot preloma pri kotu i v vodoravni ravnini v °,
- t - debelina lomne cone v mm,
- Δ_i - velikost premika pestiča v smeri i v vodoravni ravnini v mm.

Zaradi napak pri merjenju pa je rezultanto premika primerno določiti po metodi najmanjših kvadratov.

In Fig.9 the following notation is used:

- φ - fracture angle at an angle in the horizontal plane,
- t - fracture-zone thickness,
- Δ_i - punch shift in the i -th direction in the horizontal plane [mm].

Because of the measurement errors the punch shift calculation was based on three measurements using the least-square method.

$$G = [\Delta \cdot \cos \varphi - \Delta_0]^2 + [\Delta \cdot \cos(\varphi - 60^\circ) - \Delta_{60}]^2 + [\Delta \cdot \cos(\varphi - 120^\circ) - \Delta_{120}]^2 \quad (2).$$

Pri čemer je Δ absolutna vrednost premika pestiča, φ pa smer, v kateri se premakne (sl.10). Z minimiziranjem funkcije G pridemo do končnega rezultata. V ta namen parcialno odvajamo po Δ in φ :

Where Δ is an absolute punch displacement, φ is the displacement direction (fig.10). By minimizing the function G a final result is obtained by partial differentiation in Δ and φ :

$$\frac{\partial G}{\partial \varphi} = 0 \quad \frac{\partial G}{\partial \Delta} = 0 \quad (3),$$

$$\tan \varphi = \frac{\sqrt{3}(\Delta_{60} + \Delta_{120})}{2 \cdot \Delta_0 + \Delta_{60} - \Delta_{120}} \quad (4),$$

$$\Delta = \frac{\sqrt{3}}{3}(\Delta_{60} + \Delta_{120}) \cdot \sin \varphi + \frac{1}{3}(2 \cdot \Delta_0 + \Delta_{60} - \Delta_{120}) \cdot \cos \varphi \quad (5).$$

Dobljeni sta smer in velikost premaknitve pestiča, iz česar se nato po enačbi (6) izračuna še teoretična neuravnoteženost platine:

Based on the direction and the amplitude of the punch shift, a theoretical unbalance of the claw pole is finally calculated according to:

$$U = \left| \frac{\Delta}{2} \cdot \frac{t}{s} \cdot m \right| \quad (6).$$

Posamezne oznake so:

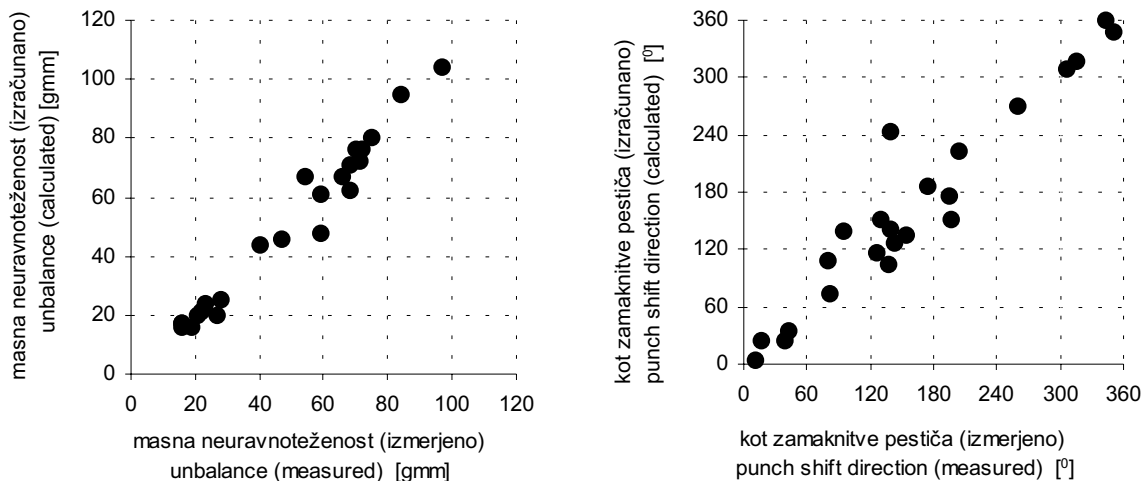
- U - masna neuravnoteženost v gmm,
- D - premika pestiča v mm,
- s - debelina materiala v mm,
- m - masa platine v g

Na vzorčnih platinah je bila označena izračunana smer premika pestiča proti matrici, nato pa so bile prenesene v prenosno orodje, kjer je bila

Notation:

- U - eccentricity [gmm],
- Δ - punch shift [mm],
- s - material thickness [mm],
- m - blank mass [g]

The calculated direction of the eccentricity of the blanks was marked before being put into the transfer die. A sample charge of claw poles was



Sl. 11. Primerjava izračunov in meritev
 Fig. 11. Comparison between calculated and measured values

izdelana končna oblika kreppljastega pola. Po končani izdelavi kreppljastih polov je bila na njih izmerjena končna masna neuravnoteženost ter smer, v kateri neuravnoteženost leži.

Primerjava med izmerjenimi vrednostmi neuravnoteženosti kreppljastega pola in izračunanimi vrednostmi neuravnoteženosti platin je prikazana na sliki 11. Izmerjene in izračunane vrednosti so praktično enake, kar pomeni, da je neuravnoteženost vnesena že v prvi preoblikovalni operaciji (rezanje platin). Izboljšanje rezilnega orodja je težko izvedljivo, zato bo v nadaljnjem prikazana mogoča sprememba prve stopnje prenosnega orodja (fino rezanje luknje), s čimer bi bistveno zmanjšali končno neuravnoteženost izdelka.

produced. Afterwards a final mass unbalance and its direction was measured and compared to the theoretically obtained values.

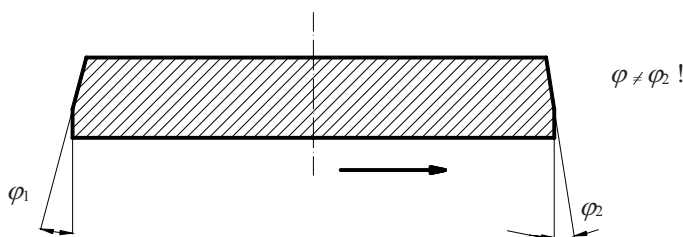
The comparison between the calculated values of the blank unbalance and the measured values of the claw-pole eccentricity is presented in Fig. 11. Practically, there is no difference between the measured and the calculated values. It confirms the assumption that the eccentricity is already input at the first forming stage (blanking). Improving of the blanking tool is connected with large investments; therefore, the modification of the flow-piercing tool in the first step of the transfer die will be discussed. Much could be done in order to lower the final eccentricity.

5 PREDLOG REŠITVE

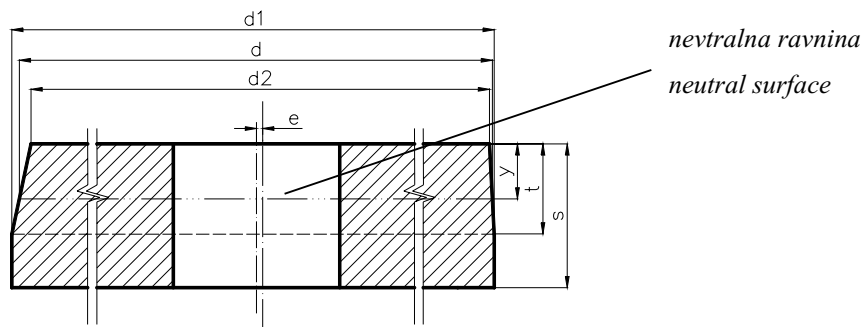
Trenutno je centriranje platine v prvi stopnji prenosnega orodja izvedeno s tremi vzmetenimi pozicionirnimi trni, medsebojno premaknjenimi za kot 120°. Prerez je prikazan na sliki 3. Problem takšne izvedbe je v tem, da je masno središče platine, kjer bi moralo biti središče luknje, premaknjeno za določeno vrednost (sl. 12). Vzrok za to je središčenje platine po spodnji površini, katere središče zaradi nesimetričnega reza ne leži v masnem središču platine. Prednost uporabljenega načela pozicioniranja na spodnjo površino platine je v tem, da je preprosto izvedljiv.

5 SOLUTION PROPOSAL

Currently, the positioning of the blank during flow piercing is made by using three positioning pins aligned in a 120° scatter. A cross-section is presented in fig.3. The problem of this centering principle is that the mass center where the fine blanked hole should lie in order to have the minimum eccentricity is not positioned in the center of the hole (Fig.12). The reason for this is the centering of the blank on its bottom surface, whose center does not lie in the blank mass center. The advantage of this centering principle using the lower blank surface is that it is relatively simple to perform.



Sl. 12. Premaknitev masnega središča platine
 Fig. 12. Shift of the mass center of the blank



Sl. 13. Položaj nevtralne ravnine
Fig. 13. Position of the neutral surface

V primeru centriranja na zgornjo površino platine bi prišlo do enakega pojava, saj tudi središče te površine zaradi nesimetričnega reza ne leži v masnem središču platine. Da bi izločili vpliv nesimetričnega reza na neuravnoteženost pola, bi morali pozicionirati v tisti ravnini, ki v svojem središču vsebuje tudi masno središče, ta pa leži nekje med zgornjo in spodnjo površino (sl. 13).

Glede na parametre platine (sl.13), ki so približno nespremenljivi, lahko lego centrirne ravnine izračunamo po enačbi (7). V enačbi se pojavljajo le stalni parametri in je torej tudi lega ravnine približno nespremenljiva. Globina prodora je predvsem odvisna od stanja orodja in je v praksi relativno nespremenljiva za vse platine ($s - t \sim 4,5$ mm).

The same problem occurs in the case of centering on the top surface of the blank. Due to the nonsymmetrical cut, the center of this surface does not lie in the blank mass center. In order to eliminate the nonsymmetrical blanking, positioning should take place in the plane, which is symmetrical to the mass center of the blank. This plane lies somewhere between the upper and lower surface of the blank.

According to the blank parameters (Fig.13), which are almost constant, the position of the centering plane can be calculated according to eq.7. The equation is based on constant parameters only; therefore, the position of the surface is constant. Punch penetration is relatively constant for all the blanks and basically depends on the tooling conditions ($s - t \sim 4.5$ mm).

$$y = t^2 \cdot \left(\frac{d_1 + d_2}{d_1 \cdot (2 \cdot s - t) + d_2 \cdot t} \right) \quad (7).$$

Oznake:

d_1 - premer platine na spodnji površini v mm,
 d_2 - premer platine na zgornji površini v mm,
 s - debelina platine v mm,
 t - debelina lomne cone platine v mm,
 y - oddaljenost središčne ravnine od zgornje površine platine v mm
 Za konkretne geometrijske parametre platine:
 $d_1 = 74,9$ mm,
 $d_2 = 72,3$ mm,
 $s = 12,6$ mm,
 $t = 8,1$ mm

je lega nevtralne ravnine $y = 5,17$ mm.

To pomeni, da leži v središču ploskve, ki je prerez platine in ravnine 5,17 mm pod zgornjo površino, tudi masno središče platine. Lega te ravnine je neodvisna od trenutnega premika pestiča proti matrici, kar pomeni, da jo je primerno uporabiti za usreditevno ravnino.

Predlog nove izvedbe orodja je prikazan na sliki 14. Nad sedanji pozicionirni trn se namesti še drug glavni pozicionirni trn, ki bi ležal na premeru d (sl.13), kakor ga določa nevtralna ravnina:

$$d = d_2 + \frac{y}{t} (d_1 - d_2) = 73,9 \text{ mm} \quad (8).$$

Notation:

d_1 - blank diameter on bottom surface [mm],
 d_2 - blank diameter on top surface [mm],
 s - blank thickness [mm],
 t - fracture-zone thickness [mm],
 y - centering plane distance [mm].

For real blank parameters:

$d_1 = 74.9$ mm,
 $d_2 = 72.3$ mm,
 $s = 12.6$ mm,
 $t = 8.1$ mm

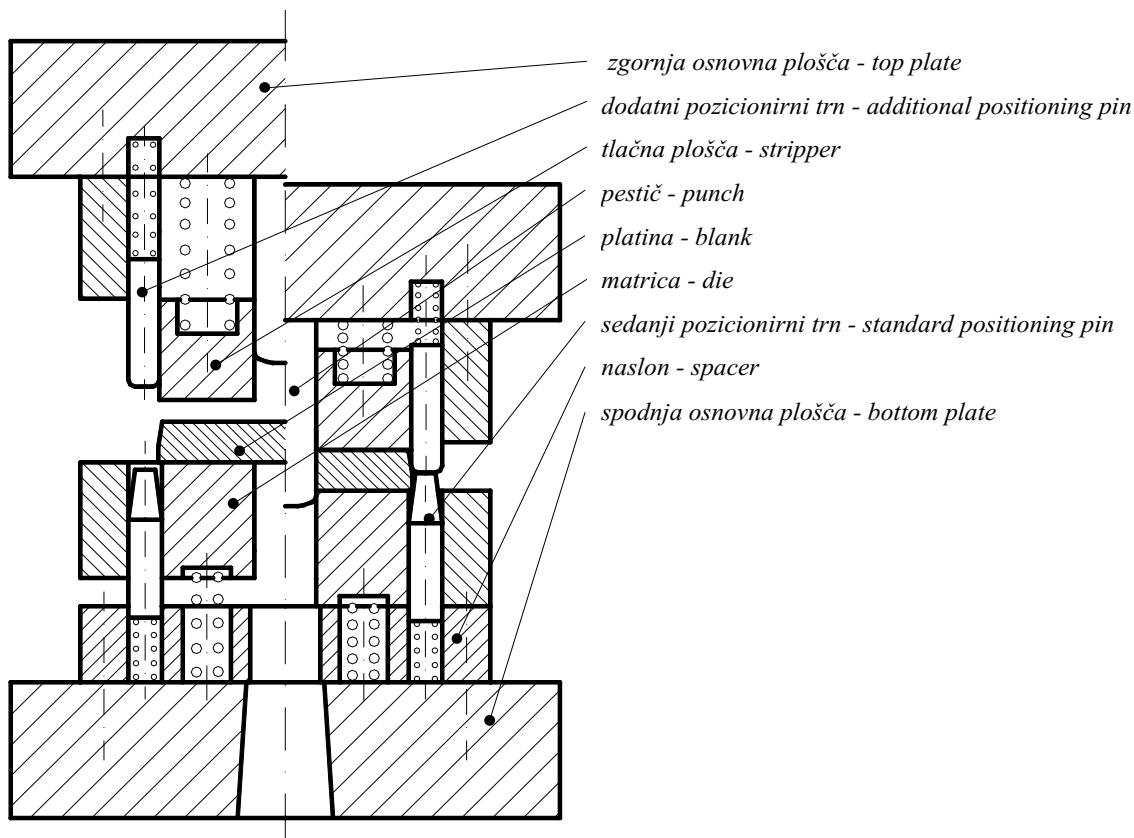
the position of the neutral surface is $y = 5.17$ mm.

This means that the mass center of the blank lies in the center of the surface, which is 5.17 mm below the top surface of the blank. The most important thing is that the position of this plane is independent of the punch shift during blanking. It means that this plane could be used for better centering of the blank during flow piercing.

The tool scheme of the new centering principle is presented in Fig.14. Above the current positioning pin another one (major) is mounted. The position of this pin will be determined by the diameter d (Fig.13) of the neutral plane:

Med zapiranjem orodja pritiska glavni pozicionirni trn na sedanji pozicionirni trn, ki je namenjen samo za pozicioniranje v prvi stopnji, ga odmakne in s tem sprosti platino, ki se nato pozicionira glede na nov pozicionirni trn. Ta se platine dotika v prej izračunani razdalji od zgornje ravnine, ki v svojem središču vsebuje masno središče. Podlaga za takšno izvedbo pozicionirnega sistema je predvsem v tem, da je izmera matrice in pestiča med preoblikovanjem konstantna, kar je tudi praktično povsem pravilno, saj je elastična deformacija matrice in pestiča v primerjavi z deformacijo platine minimalna. Prav tako je nespremenljiva debelina materiala ter približno nespremenljiva debelina lomne cone.

During the tool closing the new positioning pin acts on the current positioning pin, which is now used only for centering in the first step. It is pushed down and the blank is released for a moment and allows the upper positioning pin to position the blank in the calculated surface. It touches the blank in the previously calculated distance from the top blank surface. The basic fact for such a tool design is in first case the assumption that there is no elastic deformation of the punch and die during blanking. This is found to be correct in practice. The elastic deformation of the punch compared to the deformation of the blank can be neglected. Material thickness and the height of the punch penetration are held almost constant as well.



Sl. 14. Načelna shema orodja
Fig. 14. Tool scheme

6 SKLEP

V prispevku je prikazano sistematično reševanje problema manjšanja masne neuravnoteženosti pri izdelavi krempljastega pola alternatorja. Eksperimentalno delo in teoretična izhodišča so uspešno kombinirana in podprta z numeričnimi metodami. Poudarjen je sistematičen postopek reševanja konkretnih industrijskih problemov na področju občutljivosti in stabilnosti proizvodnih postopkov v velikoserijski proizvodnji, ki so problem tako z vidika stalnosti parametrov postopka kakor primernosti orodij [10]. Na koncu so podane še smernice za ustrezne konstrukcijske spremembe preoblikovalnega orodja, ki bi omogočal bistveno bolj stabilen tehnološki proces.

6 CONCLUSION

A systematic approach to lowering the eccentricity of the claw poles for alternators is presented in the paper. Experimental work and theoretical aspects are combined successfully and supported with modern numerical methods. A systematic approach to solving the real industrial sensitivity and stability problems in the mass series production processes is discussed. They are problematic from the point of view of process parameters and tools [10]. Some solution proposals of constructional tool modifications for more stable and reliable production process are discussed at the end.

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