ANALIZA OŠTEĆENJA KOČIONOG DISKA KOORDINATNOM MJERNOM MAŠINOM I 3D CAD MODELIRANJEM

ANALYSIS OF DISC BRAKE FRACTURE USING COORDINATE MEASURING MACHINE AND 3D CAD MODELING

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REZIME

Kočioni disk je u toku svog radnog vijeka izložen različitim opterećenjima koja uzrokuju trošenje kočione površine, deformaciju, promjenu strukture, pojavu zaostalih napona itd. Cilj ovog rada je mjerenjem ravnosti i potrošenosti kočione površine utvrditi glavni uzrok pojave pukotina na kočionoj povšini, te dati glavne smjernice u cilju produžavanja životnog vijeka kočionog diska i sprečavanja katastrofalnog otkaza. Za mjerenje ravnosti i potrošenosti kočione površine korištena je koordinatna mjerna mašina Zeiss Contura G2, a podaci su dodatno analizirani u 3D CAD softveru Solidworks.

Professional paper

SUMMARY

A brake disc is exposed to various loads during its operational life, which cause braking surface wearing, disc deformation, structural changes, residual stresses etc. The goal of this paper is to find out the main cause of fractures on braking surface, by measuring flatness and wear of braking surface, and to give main guidelines to prolong the operational life and to prevent catastrophic failures. Measurement of flatness and wear was performed on coordinate measuring machine Zeiss Contura G2. Obtained results are then further analyzed using 3D CAD software Solidworks.

1. INTRODUCTION

The main purpose of brake is to decelerate or to stop the moving vehicle. In that process, friction causes vehicle deceleration, but also heats the braking system. Braking systems act as heat accumulators, where kinetic energy is absorbed in braking systems as heat, or transfers to air by convection.

Focus of this paper is to determine the main cause of brake disc fracture using coordinate measuring machine Zeiss Contura G2 and 3D CAD software Solidworks. The analysis was carried out on a brake disc of Mercedes Atego truck, on which two radial cracks were spotted (Figure 1).

Amongst numerous papers that analyzed this topic, the work of scientists H. Abendroth, T. Steffen, W. Falter and R. Heidt should be emphasized. They described in detail the process of cracks creation in presence of braking load and brake disc overheating, and they performed the analysis by both numerical and experimental tests [1].

1. UVOD

Osnovna funkcija kočnice je da uspori ili zaustavi kretanje vozila. Pri tome se javlja trenje, koje usporava automobil, ali i zagrijava kočioni sistem. Kočioni sistemi se ponašaju kao toplotni akumulatori, u kojima se kinetička energija apsorbuje u obliku toplote unutar kočionih sistema ili se konvekcijom prenosi na zrak.

Ovaj rad je usmjeren na otkrivanje glavnog uzroka otkaza kočionih diskova korištenjem koordinatne mjerne mašine Zeiss Contura G2 i 3D CAD softvera Solidworks. Analiza je izvršena na kočionom disku kamiona Mercedes Atego, na kojem su ustanovljene dvije radijalne pukotine (Slika 1.)

Od mnogobrojnih istraživanja koji su analizirali ovaj problem, posebno treba istaći rad naučnika H. Abendroth, T. Steffen, W. Falter i R. Heidt, koji su detaljno opisali proces nastajanja pukotine u prisustvu opterećenja i povišene temperature kočionog diska, a istraživanje su proveli i numeričkim i eksperimentalnim provjerama [1].

a.) b.)

Slika 1. *Pukotine na kočionoj površini diska (a – vanjska površina, b – unutrašnja površina)*
Figure 1. *Cracks on braking surface of the disc (a – inner surface, b – outer surface)*

Convection and conduction heat process inside braking systems were described in details by A.R. Daudi and M. Narrain, who applied CAE and FEM technologies in their work [2].

2. BASIC INFORMATION ABOUT DISC BRAKES

Main characteristics of disc brakes:

- Simple construction,
- Rapid cooling,
- Rapid drying,
- Braking intensity control.

Brake disc fracture occurs commonly, and one could search for a cause in some of the following factors:

- Wear of brake disc,
- Surface inhomogeneities (decorative openings, vents, eccentricity),
- Corrosion.

Brake disc wear is an inevitable phenomenon, as a result of constant friction of brake pads, as well as of multiple machining process to flatten braking surface. Corrosion is a phenomenon which every braking system is faced with. If a vehicle is in permanent use, the braking surface is protected from corrosion by continuous friction wear. In case of vehicles, that are not being used for a longer time, corrosion damages braking surface, and the first use that follows, the damages cause unevenness, rapid wear and additional heating. Vented brake discs are more exposed to corrosion, which penetrates into the structure and can cause fracture.

The occurrence of cracks on brake disc indicates that disc should be replaced. Cracks on the disc cause impacts during braking, uneven heating and rapid wearing of braking surface, and all this finaly causes the cracks to rapidly expand in depth of material. If brake disc with crack is not replaced in a timely manner, the disc often

Proces konvekcije i kondukcije toplote unutar kočionih sistema detaljno su opisali A.R. Daudi i M. Narrain, koji su u svom istraživanju primijenili CAE i MKE tehnologije [2].

2. OSNOVNI PODACI O DISK KOČNICAMA

Osnovne karakteristike disk kočnica:

- Jednostavna konstrukcija,
- Brzo hlađenje,
- Brzo sušenje,
- Kontrola intenziteta kočenja.

Problem pucanja kočionog diska je česta pojava u praksi, a uzrok se može tražiti u nekom od sljedećih faktora:

- Istrošenost kočionog diska,
- Nehomogenost površine (ukrasni i ventilacioni otvori, ekscentričnost),
- Korozija.

Istrošenost kočionog diska je neminovna pojava, a rezultat je stalnog trenja disk pločica, ali i višestruke strojne obrade u cilju poravnavanja kočione površine. Korozija je pojava sa kojom je suočen svaki kočioni sistem. Ukoliko je vozilo u stalnoj upotrebi, kočiona površina je zaštićena od korozije zbog stalnog trošenja trenjem. Kod vozila koja se duže vremena ne koriste, korozija napada kočionu površinu oštećujući je, a tokom prve naredne upotrebe tako nastala oštećenja uzrokuju neravnine, ubrzano trošenje i dodatno zagrijavanje. Kočioni diskovi sa ventilirajućim otvorom su naročito izloženi koroziji, koja ulazi u strukturu i može uzrokovati lom.

Pojava pukotine na disku je pokazatelj da je disk potrebno zamijeniti. Pukotine na disku uzrokuju udare pri kočenju, neravnomjerno zagrijavanje i ubrzano trošenje pločice, a sve to dovodi do ubrzanog širenja pukotine u dubinu materijala. Ukoliko se kočioni disk sa pukotinom na vrijeme ne zamijeni, često se desi da se disk u potpunosti

completely falls apart, which can lead to catastrophic consequences.

3. EXPERIMENTAL DETERMINATION OF DISC BRAKE FAILURE CAUSE

The braking surface flatness was measured by scanning with circular path of measuring tool. The measurement was performed by 8 different radii arranged in the following way:

- The inner surface was measured by circular paths with radii: 250, 270, 310, 330, and 350 mm,
- The outer surface was measured by circular paths with radii: 310, 330, and 350 mm.

Software of the measuring machine allows three-dimensional preview of the results, but in order to obtain real picture of surface curvature, further data processing must be done.

In order to obtain a clearer picture of brake disc surface curvature, and since the surface flatness deviation is not visible by naked eye, measured coordinates are processed with MS Excel, multiplying the difference between the mean of z-axis coordinates and the current values of z-axis coordinates with a certain scaling factor, according to the expression:

$$z_j = z_j + \left|\frac{\sum_1^n z_i}{n} - z_j\right| \cdot k \qquad (1)$$

where:

k – scaling factor,

j - number of the measured point,

n - total number of points,

For this example the scaling factor was k=30.

raspadne, što može uzrokovati katastrofalne posljedice.

3. EKSPERIMENTALNO ODREĐIVANJE UZROKA OTKAZA KOČIONOG DISKA

Ravnost kočione površine izmjerena je kružnom putanjom mjernog alata.

Mjerenje je izvršeno sa ukupno 8 definisanih radijusa raspoređenih na sljedeći način:

- Unutrašnja površina izmjerena je na kružnim putanjama radijusa 250, 270, 290, 310, 330 i 350 mm,
- Vanjska površina je izmjerena po kružnim putanjama radijusa 310, 330 i 350 mm.

Softver mjerne mašine omogućava 3D prikaz rezultata, ali, da bi se dobila stvarna slika površine kočionog diska, potrebno je dodatno obraditi dobivene rezultate.

Da bi se dobila jasnija slika zakrivljenosti kočione površine diska i s obzirom da odstupanje ravnosti površine nije vidljivo golim okom, izmjerene koordinate su pomoću MS Excel prerađene množenjem razlike srednje vrijednosti z-koordinate i trenutne vrijednosti z-koordinate određenim faktorom uvećanja, prema izrazu:

$$z_j = z_j + \left|\frac{\sum_1^n z_i}{n} - z_j\right| \cdot k \qquad (1)$$

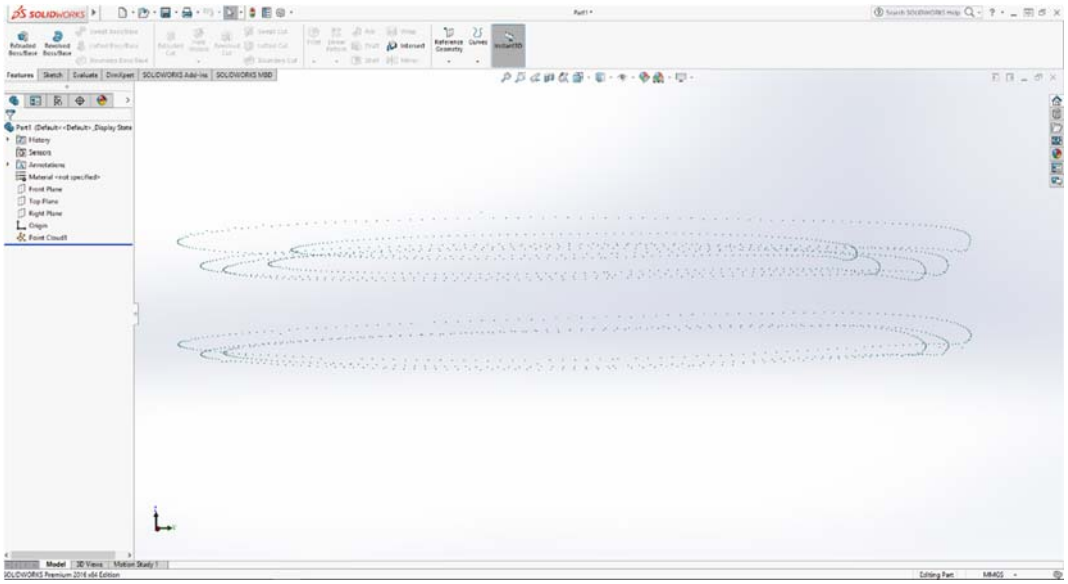
gdje je:

k - faktor uvećanja,

j - redni broj izmjerene tačke,

n - ukupan broj tačaka,

Za ovaj primjer faktor povećanja je k=30.



Slika 2. *Izmjerene tačke na kočionoj površini diska učitane u softver Solidworks*

Figure 2. *Measured points on braking surface loaded in Solidworks software*

The coordinates of measured points are imported into Solidworks 3D model using "Scan to 3D" from the "Add-ins" menu. In this example, all measured points are loaded together, for better visualisation of surface curvature (Figure 2).

In order to further improve the surface model created, loaded points were connected into curves, and a curved surface which closely reflects the actual state of the curvature of the brake disk surface was created. The curved surface could be created in several ways, but for this example, function "Surface Loft" from the menu "Insert Surface" was used.

However, creating surface in this way requires all points measured with the same measurement radius to be connected with a curve. Even this is quite a tedious job, the surface created in this way precisely describes the curvature of the original disc surface.

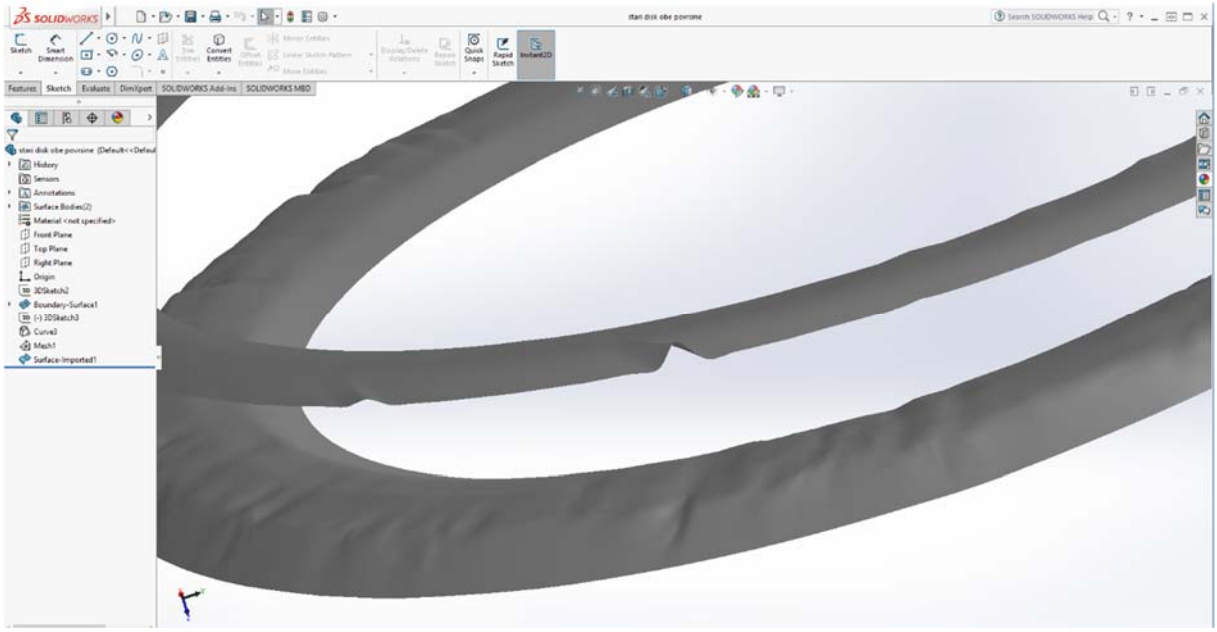
The final appearance of the surface reveals many minor variations that are present across the entire surface. However, the most important thing to note is the curvature of the brake disc surface in the radial (Figure 3) and polar direction (Figure 4), which are present on both sides of the disc.

Koordinate tačaka se u 3D Solidworks model unose naredbom "Scan to 3D" iz menija "Add-ins". U ovom primjeru su radi jasnijeg prikaza ravnosti učitane istovremeno koordinate svih tačaka obje površine (Slika 2).

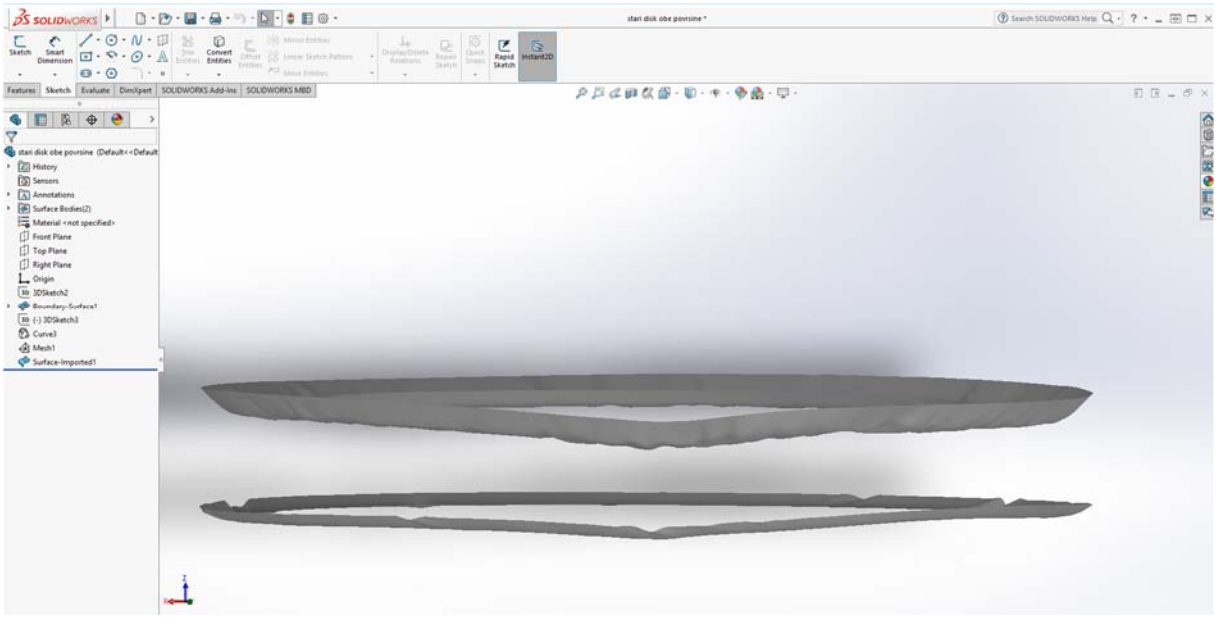
S ciljem daljeg unapređenja jasnoće prikaza učitane tačke su povezane krivuljama i kreirana je zakrivljena površina koja približno prikazuje stvarno stanje zakrivljenosti kočione površine diska. Povezivanje tačaka u zakrivljenu površinu moguće je izvršiti na više načina, a za ovaj primjer korištena je funkcija "Surface Loft" iz menija "Insert Surface".

Međutim, da bi se na ovaj način kreirala površina, potrebno je prethodno sve tačke jedne kružnice spojiti jednom krivuljom. Iako je to dosta zahtjevan zadatak, površina kreirana na ovaj način precizno opisuje zakrivljenost površine.

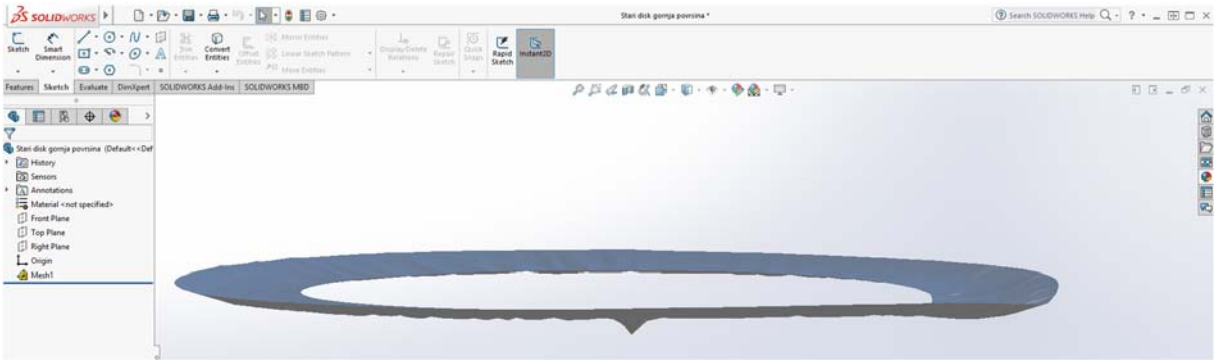
Konačan izgled površine pokazuje mnogo manjih neravnina koje su prisutne duž cijele površine. Međutim, najznačajnije je primijetiti savijenost površine kočionog diska u radijalnom pravcu (Slika 3) i u polarnom pravcu (Slika 4) koje su prisutne na obje strane diska.



Slika 2. *Zakrivljenost kočione površine u radijalnom pravcu*
Figure 3. *Curvature of braking surface in radial direction*



Slika 3. *Zakrivljenost kočione površine u polarnom pravcu*
Figure 4. *Curvature of braking surface in polar direction*



Slika 4. *Pozicija pukotine na unutrašnjoj površini diska*
Figure 5. *Crack position on the inner side of the disc*

4. CONCLUSION

The appearance of radial cracks could be directly related to curvature in radial direction, because of which uneven pressure of braking pads on disc surface causes additional bending stresses (Figure 3). Curvature in polar direction (Figure 4) causes impacts and vibrations, which have additional negative influence on braking disc stress state. Impacts cause dynamic load, which causes cracks even with normal load intensity, and it also causes faster propagation of cracks.

Overheating, as a main cause of braking surface deflection, could be prevented by regular cleaning and corrosion protection of venting opening whenever brake pads are replaced. Installation of sensors that would signal overheating of brake disc would almost completely eliminate the problem of overheating. Bimetal switches which would trigger the alert sound, or turn on signal light in

4. ZAKLJUČAK

Izgled radijalnih pukotina može se direktno povezati sa savijenošću u radijalnom pravcu usljed koje neravnomjeran pritisak kočione pločice uzrokuje dodatne savojne napone (Slika 3). Neravnost u polarnom pravcu (Slika 4) je uzročnik udara i vibracija koje dodatno negativno utiču na naponsko stanje diska. Udari uzrokuju dinamičko opterećenje koje dovodi do pojave pukotina čak i pri normalnom opterećenju, a dodatno pospješuje i propagaciju pukotina.

Pregrijavanje kao osnovni uzrok pojave neravnina na kočionom disku može se spriječiti redovnim čišćenjem i zaštitom od korozije ventilirajućeg otvora pri svakoj izmjeni kočionih pločica. Ugradnja senzora koji bi signalizirali pregrijanost kočionog diska bi skoro u potpunosti eliminisala problem pregrijavanja. Kao senzori mogle bi se koristiti i bimetalne

case of overheating, could also be used as sensors. In case of modern car models with central coumputer, brake disc overheating could be signalised on central display.

sklopke, koje bi u slučaju pregrijavanja proizvodile upozoravajući zvuk ili bi upalile signalnu lampicu na instrument tabli vozila. Kod modernijih modela automobila sa centralnim kompjuterom, pregrijavanje kočnice bi se moglo signalizirati na centralnom ekranu.

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