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Metoda raziskave nelinearnih upogibov valjev pri rotacijskem ofsetnem tiskarskem stroju

A Method for Investigating the Nonlinear Bends of the Cylinders of a Web Offset Printing Station

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Elastični pomiki valjev s plošč, valjev z gumijasto oblogo in tiskovnih valjev ter še posebej upogibov valjev, ki se pojavijo med vrtenjem valjev, pritiskajo drug ob drugega prek tanke elastične gumirane tkanine, ki pokriva valja z gumijasto oblogo (valji so nameščeni tako, da je v vsakem paru valjev vsaj en valj z gumijasto oblogo), močno vplivajo na delovanje rotacijskega ofsetnega tiskarskega stroja. Valji začnejo pritiskati drug ob drugega zaradi pomikanja njihovih ležajnih sklopov.

Prispevek opisuje metodo raziskovanja upogibov valjev in drugih elastičnih pomikov, pa tudi sprememb tlaka vzdolž valjev, ki pritiskajo drug ob drugega. Med raziskavo smo ocenili nelinearne značilnosti elastičnosti sklopov ležajev, sile teže in lege osi vrtenja valjev glede na njihove medsebojne vplive. Obravnavani problem smo rešili kot zahteven nelinearni statični problem, pri katerem smo na robovih delovnih površin valjev, ki pritiskajo drug ob drugega, poznali potrebne vrednosti tlaka, pri tem pa so bili pomiki sklopov ležajev, ki so potrebni za nastanek omenjenih vrednosti tlaka, na začetku neznani.

Z uporabo metode na specifičnem primeru smo pokazali, da so upogibi valjev bistveno vplivali na porazdelitev tlaka vzdolž dotikalnega predela valjev sodobnega tiskarskega stroja in s tem tudi na kakovost tiska.

(Ključne besede: rotacijsko ofsetno tiskanje, stroji tiskarski, valji, upogibanje, metode raziskovalne)

The elastic shifts of the plate, blanket and impression cylinders and, initially, the bends of the cylinders that appear during the rotation of the cylinders that are pressed against each other via the thin elastic cloth (blanket) that covers the blanket cylinders (the cylinders are located in such way that at least one blanket cylinder exists in each pair of cylinders) have a considerable impact on the operation of web offset printing stations. The cylinders are compressed by shifting their bearing assemblies.

The method of investigating the mentioned bends of the cylinders and other elastic shifts as well as the changes of the pressure along the cylinders that are pressed against each other are described. The nonlinear features of the elasticity of the assemblies of the cylinder bearings, the force of gravity and the location of the axes of the rotation of the cylinders with respect to each other are assessed. The problem under discussion is settled as a complex nonlinear static problem, where the required pressures at the edges of the working surfaces of the cylinders that are pressed against each other are provided and the shifts of the assemblies of the cylinder bearings that are required to ensure the said values of the pressures are unknown at the start.

On the application of the method to the specified example, it was shown that the bends of the cylinders noticeably impact on the distribution of the pressure along the contact zone of the cylinders in a modern printing press and on the quality of the prints.

(Keywords: web offset printing, printing press, cylinders, bending, investigation methods)

0 UVOD

V tiskarski industriji je močno razširjena raba rotacijskih ofsetnih strojev. Najpomembnejši del takšnega stroja je njegova tiskarska enota ([1] in [2]).

0 INTRODUCTION

Web offset printing presses are widely used in the printing industry. The most important part of such a press is its printing station ([1] and [2]).

Najpomembnejše komponente tiskarske enote vključujejo valja s ploščo, valja z gumijasto oblogo in (v nekaterih primerih) tiskovna valja, ki sta vpeta v kotalne ležaje v osrednjem delu stroja. Mehanizma za dovajanje barve in vlaženje sta prav tako pomembna, vendar o njiju tu ne bomo govorili. Površini valjev z gumijasto oblogo sta prevlečeni s posebno tanko elastično tesnilko (oblogo), ki ima gladko zunanjo površino. Vsi valji pritiskajo drug ob drugega po celotni dolžini in so v tiskarski enoti nameščeni tako, da ima v vsakem paru priležnih valjev vsaj en valj gumijasto oblogo. Zato pa valji pritiskajo drug ob drugega v smeri deformacije gumijaste obloge. V manjši meri lahko tlak krmilimo s spreminajnjem razdalje med osmi vrtenja valjev. To dosežemo z vrtenjem valjčnih ležajev, ki so montirani v izsrednih pušah. Med delovanjem tiskarske enote, ko se vsi valji (pritisnjeni drug ob drugega) vrtijo brez drsenja, se odtisi prenesejo iz navlaženih tiskarskih predlog, ki sta pritrjeni na valja za ploščo, na površino gumijaste obloge in od tam na neskončni trak, ki se v primeru obojestranskega tiskanja premika med vrtečima se valjema z gumijasto oblogo (ki pritiskata drug ob drugega), v primeru enostranskega tiskanja pa med valjem z gumijasto oblogo in tiskovnim valjem (ki tudi pritiskata drug ob drugega).

Pritisk valjev drug ob drugega prek elastične obloge povzroča absolutne in relativne elastične pomike valjev (te elastične pomike kasneje imenujemo kar pomiki). Ti pomiki sestojijo iz prečnih premih pomikov sklopov valjčnih ležajev, upogibanja valjev in kotnih pomikov (odstopanj) njihovih prerezov.

Tema tega prispevka je iskanje rešitve problema slabše kakovosti delovanja tiskarskega stroja – razvoj metod za računalniško podprto analitično raziskavo upogibanja obloge, plošče in tiskovnih valjev, ki ga povzroča pritiskanje valjev preko obloge. Ti upogibi imajo negativen učinek na kakovost tiskanja, pa tudi na njegovo izrabo in njegove dinamične značilnosti. Upogibi valjev so povezani z njihovimi pomiki in jih moramo zato raziskovati hkrati. Največ pozornosti smo posvetili relativnim upogibom valjev, ker ti povzročajo spremembe v tlaku med upognjenimi valji, takšne spremembe pa neposredno vplivajo na poslabšanje kakovosti tiskov.

Zdaj bomo namen prispevka opisali bolj podrobno. V strokovni literaturi nismo zasledili rešitev zgoraj opisanega problema, a je vendarle

The most important components of the printing station are the plate cylinders, the blanket cylinders and (in some cases) the impression cylinders, which are mounted in rolling bearings in the body of the equipment. The inking and moistening mechanisms are also important, but they are not discussed here. The surfaces of the blanket cylinders are coated with a special thin elastic gasket (blanket), the external surface of which is even. All the cylinders are pressed against each other along their generatrices and are positioned in the station in such a way that for any pair of adjacent cylinders at least one of them is a blanket cylinder. For this reason, all the cylinders are pressed against each other on a deformation of the blanket. The pressure is regulated in a narrow range by changing the distance between the axes of the cylinders' rotation. This is achieved by rotating the bearings of the cylinders, which are mounted in eccentric hubs. During the operation of the printing press, when all the cylinders (pressed against each other) are rotating without sliding, the prints are transferred from the inked printing forms fixed to the plate cylinders to the surface of the blanket of the blanket cylinders, and from there to the paper web that moves between two rotating blanket cylinders (pressed against each other), in the case of double-side printing, and between the blanket cylinder and the impression cylinder (pressed against it) in the case of printing on one side of the paper.

Pressing the cylinders against each other via the elastic blanket causes absolute and relative elastic shifts of the cylinders (such elastic shifts are subsequently referred to as shifts). These shifts consist of transversal rectilinear shifts of the assemblies of cylinder bearings, the bending of the cylinders, and the angular shifts (deviations) of their cross-sections.

The subject of this paper is the solution of the important problem of the quality of a printing station - the development of methods for a computer-aided analytical investigation of the bending of the blanket, the plate and the impression cylinders caused by their pressing against each other via the blanket. These bends adversely affect the quality of the printing as well as its exploitation and dynamic features. The cylinder bends are linked to their other shifts, so they should be investigated together. The most attention is paid to the relative bends of the cylinders, because they cause changes of pressure between the bent cylinders, and such changes directly reduce the quality of the prints.

The aim of the paper is now described in more detail. There have been no recent solutions to the above-mentioned problem described in any technical nujno najti ustrezne rešitve. Na primer, metode ocenjevanja upogibanja valjev so navedene v virih [3] do [5]. Le-te lahko uporabimo pri razlagi vpliva tovrstnega upogibanja na postopek tiskanja, ne pa tudi pri oceni vpliva upogibanja valjev, ki so v posebnih delih tiskarskega stroja.

Da bi razložili metode raziskave upogibanja valjev, navedenih v tem prispevku, in ocenili pomembnost upogibanja, smo uporabili močno razširjen rotacijski ofsetni tiskarski stroj za obojestransko tiskanje [2]; sestava njegovih valjev in shema njegove postavitve sta prikazani na sliki 1.

Obravnavana tiskarska postaja sestoji iz valjev s ploščo 1, 4 (s pritrjenima tiskarskima predlogama, ki tu nista prikazani), in valjev z gumijasto oblogo 2, 3, ki sta prevlečena z oblogama 5. Premeri valjev so označeni z D_d (kjer je d=1, …, 4 – zaporedna številka valja), njihove dolžine pa kot l_1. Valji imajo lahko odprtine z dolžino l_3 in premerom d_d.

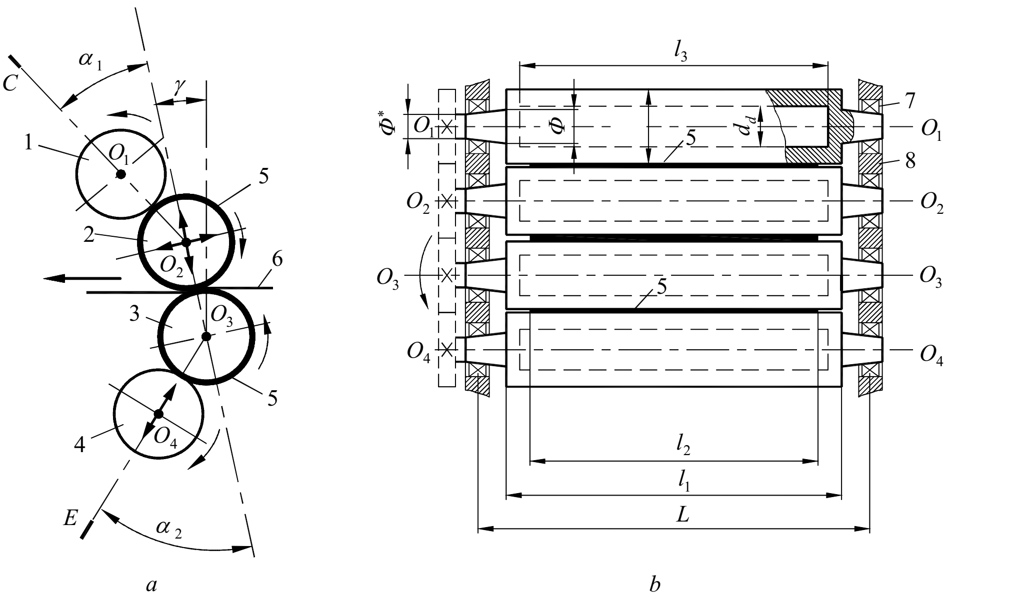
Vsi valji pritiskajo drug ob drugega v smeri deformacije oblog 5 z dolžino l_2; α_1, α_2, γ so koti osi vrtenja valjev. Valji se vrtijo v posebnih ležajih 7 z visoko togostjo in so montirani na stojalo 8 tiskarske enote ter so nameščeni na stožčastih vratovih s premeroma Φ oziroma Φ^*. Stiskanje oblog uravnavamo s

references; however, there is an urgent need to find such solutions. For example, methods of assessing the bending of cylinders are provided in references [3] to [5]. These can be used to explain the impact of such bending on the printing process, but not for assessing the impact of bending cylinders located in specific parts of the printing press on the printing process.

For an explanation of the methods of investigating the cylinder bending described here and an assessment of the importance of this bending, a widely used double-sided web offset printing station [2] was used. The structures of the cylinders and a scheme of the arrangement are shown in Fig. 1

The printing station under discussion consists of two plate cylinders 1, 4 (with the printing forms fixed on them and not shown here) and two blanket cylinders 2, 3, coated with blankets 5. The diameters of the cylinders are marked as D_d (where d=1, …, 4 – the consecutive number of a cylinder) and their lengths – as l_1. The cylinders can have l_3 long holes with the diameter d_d.

When all the cylinders are pressed against each other on a deformation of l_2 along the blankets 5, α_1, α_2, γ are the angles of the axes of rotation of the cylinders. The cylinders roll in special and precise high-rigidity bearings 7 that are mounted in the stand 8 of the printing station and put onto the conical necks of the cylinders with diameters Φ and Φ^*, respectively. The compression



Sl. 1. *Shema postavitve valjev s ploščo in valjev z gumijasto oblogo v rotacijskem ofsetnem stroju za obojestransko tiskanje: a – lege osi vrtenja valjev O_1–O_1,..., O_4–O_4; b – postavitev valjev glede na CO_2O_3E*

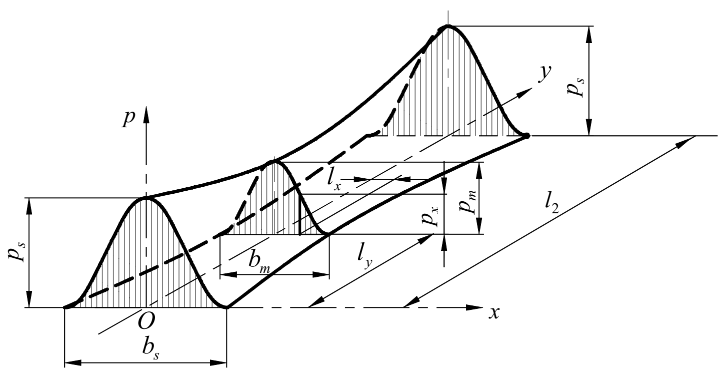
Fig.1. *The scheme of the assembly of the plate and blanket cylinders in the web offset double-side printing station: a – the location of the axes of the rotation of cylinders O_1–O_1,..., O_4–O_4; b – the evolvent of the cylinders according to CO_2O_3E*

premikanjem sklopov ležajev valja 2 v dveh pravokotnih smereh ter premikanjem ležajev valja 4 v eni smeri (na sliki 1 so smeri krmiljenja prikazane s puščicami). Med pritiskanjem se valji (ki jih prek zobnikov obrača električni motor) vrtijo, ne da bi drgnili ob delovne površine, pri tem pa se med valjema z gumijasto oblogo 2 in 3 pomika papirni trak 6. Tiskanje poteka na obeh straneh traku. Delovna površina valja je tisti del površine, ki je prevlečen z oblogo (pri valjih z gumijasto oblogo) in del, ki je v stiku z oblogo (pri valjih za ploščo in tiskovnih valjih).

Ko valji pritiskajo drug ob drugega, se obloga deformira in med valji nastanejo pasovno oblikovani dotikalni predeli. V obravnavanem primeru (slika 1) obstajajo trije dotikalni predeli (j = 3): med valjema 1 in 2, 2 in 3 ter 3 in 4. Na katerikoli točki j-tega stičnega predela je stiskanje obloge Δ_j. Največje stiskanje obloge $\Delta_{m,j}$ vzdolž j-tega dotikalnega predela (j=1, 2, 3) in v prečni smeri nastane približno v sredini omenjenega predela. Opazili smo majhen odmik $\Delta_{m,j}$ od sredine dotikalnega pasu in v smeri, ki je nasprotna smeri premih hitrosti površin vrtečih se valjev, ki pritiskajo drug ob drugega. ([4] in [5]). Tukaj, kakor tudi v primerih [3] do [5], tega odmika nismo upoštevali. Vrednost $\Delta_{m,j}$ se spreminja zaradi upogibanja valjev: vrh $(\Delta_{m,j})_{max} = \Delta_{s,j}$ najdemo na robovih delovnih površin valjev, dol pa v sredini (v primeru, ko se valja upogibata v nasprotnih

of the blankets is regulated by a shifting of the assemblies of the bearings of cylinder 2 in two perpendicular directions and the shifting of cylinder 4 in one direction (Fig. 1, the directions of the regulation are shown by arrows). During compression, the cylinders (rotated by electric engine via tooth gears) are rolling without sliding against their working surfaces and draw the paper tape 6 between the blanket cylinders 2 and 3. The prints are made on both sides of the tape. The working surface of a cylinder is the part of its surface that is coated with a blanket (in blanket cylinders) or the part having contact with it (in the plate and impression cylinders).

When pressing the cylinders against each other, the blanket between them is deformed and band-shaped contact zones appear between them. In the case under discussion (Fig. 1), there are three contact zones (j = 3): between the cylinders 1 and 2, 2 and 3, 3 and 4. At any point of the j-th contact zone the compression of the blanket is Δ_j. The maximum compression $\Delta_{m,j}$ of the blanket along the j–th band of a zone (j=1, 2, 3) in a radial direction is obtained approximately in the middle of the mentioned band. The small deviation $\Delta_{m,j}$ from the middle of the band and in the direction opposite to the one of the linear speeds of the surfaces of rotating cylinders pressed against each other was observed ([4] and [5]). Here, as in [3] to [5], this deviation is not taken into account. The value of $\Delta_{m,j}$ changes because of the bending of the cylinders: the maximum $(\Delta_{m,j})_{max} = \Delta_{s,j}$ is found at the ends of the working surfaces of the cylinders and the minimum is found in the middle (in the case of bending of the cylinders in opposite directions). The pressure p_j between the cylinders depends



Sl. 2. *Porazdelitev tlaka p v j-tem dotikalnem predelu (indeks "j" smo tu opustili);* b_s, p_s *– širina dotikalnega predela in tlak na njegovih robovih;* b_m, p_m *– sta enaka na razdalji* l_y *od začetka dotikalnega predela;* p_x *– tlak na katerikoli točki odseka* b_m *na razdalji* l_x *od točke največjega tlaka* p_m

Fig. 2. *The distribution of the pressure p in the j-th contact zone of the cylinders (the index "j" has been omitted here);* b_s, p_s *– the width of the contact zone and the pressure at its ends;* b_m, p_m *– the same in* l_y *distance from the beginning of the zone;* p_x *– pressure in any point of the section* b_m *in* l_x *distance from the point of maximum pressure* p_m

smereh). Tlak p_j med valji je odvisen od stiskanja obloge Δ_j. Način porazdelitve tlaka p_j po j-tem dotikalnem predelu je prikazan na sliki 2.

Na podlagi izmerjenih podatkov ([5] in [6]) vemo, da med tlakoma p_j, $p_{m,j}$, napetostima σ_j, $\sigma_{m,j}$ v tlačenem delu obloge in njenima stiskoma Δ_j, $\Delta_{m,j}$ obstaja naslednje razmerje:

on the compression of the blanket Δ_j. The character of the distribution of pressure p_j in the j–th contact zone is shown in Fig. 2.

It is known from experimental data ([5] and [6]) that the following interrelation between the pressures p_j, $p_{m,j}$, and the tensions σ_j, $\sigma_{m,j}$ in the compressed part of the blanket and its compressions Δ_j, $\Delta_{m,j}$ exists:

$$p_j = \sigma_j = E\left(\frac{\Delta_j}{c}\right)^{\eta}; \quad p_{m,j} = \sigma_{m,j} = E\left(\frac{\Delta_{m,j}}{c}\right)^{\eta} \tag{1}$$

E in c sta Youngov modul in nedeformirano debelino obloge. Nespremenljivi koeficient η = 1,2 do 1,5 za rotacijsko ofsetno tiskanje ([5] in [6]):

Here, E and c are the Young's modulus and the non-deformed thickness of the blanket. The constant coefficient η=1.2 to 1.5 for offset web printing ([5] and [6]):

$$\Delta_j = \Delta_{m,j}\left(1 - \frac{4\,l_{x,j}^2}{b_j^2}\right) \tag{2}$$

$$\Delta_{m,j} = \frac{b_j^2}{8B_j}; \quad b_j = 2\sqrt{2B_j\Delta_{m,j}} \quad (\mathrm{j} = 1, 2, 3) \tag{3}$$

$$B_1 = \frac{D_1(D+2c)}{2(D_1+D+2c)}; \; B_3 = \frac{D_4(D+2c)}{2(D_4+D+2c)}; \; B_2 = \frac{D+2c}{2}; \; D = D_2 = D_3 \tag{4}$$

Nespremenljivi koeficiet η in običajni Youngov modul obloge E sta uporabljena tako kakor v virih [4] do [6]. Da bi dobili vrhunski tisk, tlak $p_{m,j}$ ne sme prekoračiti največje $(p_{m,j})^*_{\max}$ in najmanjše $(p_{m,j})^*_{\min}$ dovoljene omejitve. Ti dve omejitvi ustrezata razliki med dovoljenima stiskoma obloge.

The constant coefficient η and the conventional Young's modulus of the blanket E are set as in [4] to [6]. In order to obtain high-quality prints, the pressure $p_{m,j}$ should not overstep the maximum $(p_{m,j})^*_{\max}$ and minimum $(p_{m,j})^*_{\min}$ permissible limits. These limits correspond to the difference between the permissible compressions of the blankets

$$\Delta d_m^* = (\Delta_{m,j})^*_{\max} - (\Delta_{m,j})^*_{\min} \tag{5}$$

Vrednosti dovoljenih tlakov in stiskov so odvisne od vrste obloge, pričakovane kakovosti tiska in od drugih dejavnikov. Najpogosteje jih dobimo s preizkusi po določitvi naslednjih odvisnosti: tlak med valji in stisk obloge.

Če uporabimo enačbi po [4] in [5], sta η in E [6]:

The values of the permissible pressures and compressions depend on the type of blanket, the required quality of the prints and other factors. Most frequently, they are found in an experimental way after the formation of the following dependences: the pressure between the cylinders and the compression of the blanket.

Using equations from [4] and [5], the expressions for η and E [6] can be written as:

$$\eta = \frac{\lg\left[(p_{m,j})^*_{\max} / (p_{m,j})^*_{\min}\right]}{\lg\left\{\left[(\Delta_{m,j})^*_{\min} + \Delta d_m^*\right] / (\Delta_{m,j})^*_{\min}\right\}} \tag{6}$$

$$E = c^{\eta}(p_{m,j})^*_{\max} \Big/ \left[(\lambda_{m,j})^*_{\min} + \Delta d_m^*\right] = c^{\eta}(p_{m,j})^*_{\min} \Big/ (\Delta_{m,j})^*_{\min} \tag{7}$$

Iz enačbe (1) izpeljemo naslednje razmerje med $p_{m,j}$ in $\Delta_{m,j}$:

From (1), the interrelation between $p_{m,j}$ and $\Delta_{m,j}$ is found to be:

$$\Delta_{m,j} = \left(\frac{p_{m,j}}{E}\right)^{1/\eta} c \tag{8}$$

Porazdelitev tlaka p po j-tem dotikalnem predelu je prikazana na sliki 2.

Tlak $p_{m,j}$ je določen kot prvi pogoj. Da bi zagotovili njegovo potrebno vrednost, morajo valji pritiskati drug ob drugega z močjo, ki povzroča potrebno vrednost največjega stiska obloge $\Delta_{m,j}$. Zaželeno bi bilo, da je $p_{m,j}$ = konst, vendar to ni mogoče zaradi upogibanja valjev. Potrebni $p_{m,j}$ (kakor tudi $\Delta_{m,j}$) je lahko povprečna vrednost tlaka $p_{m,j}$ oziroma njegova vrednost na kateremkoli prerezu valjev, na primer, znotraj valja ali na robovih delovnih površin. V tem prispevku predpostavljamo, da sta potrebni največji tlak med valji in ustrezni največji stisk obloge določena na robovih delovnih površin valjev, torej je tlak $p_{s,j}$ stisk obloge $\Delta_{s,j}$.

Stisk obloge povzročajo pomiki sklopov ležajev; ti pomiki se ne ujemajo z $\Delta_{s,j}$, ker med pomikanjem sklopi ležajev in robovi valjev postanejo deformirani. Soodnos med pomiki sklopov ležajev in $\Delta_{s,j}$ za katerokoli dvojico valjev, ki pritiskata drug ob drugega, dobimo z izračunom pomikov vseh valjev tiskarske enote, ko ocenimo nelinearnost odziva elastičnosti obloge.

The distribution of the pressure p in the j-th contact zone is shown in Fig. 2.

The pressure $p_{m,j}$ is set in the requirements. In order to ensure the required value of the pressure, the cylinders are pressed against each other with a force that causes the required value of the maximum compression $\Delta_{m,j}$ of the blanket. It is desirable for $p_{m,j}$ = const, but this is impossible because of the bending of the cylinders. The required $p_{m,j}$ (as well as $\Delta_{m,j}$) can be considered as the average value of the pressure $p_{m,j}$ or its value in any cross-section of the cylinders, for example, inside the cylinders or at the edges of their working surfaces. In this paper, it is considered that the required maximum pressure between the cylinders and the corresponding maximum compression of the blanket are determined at the edges of the working surfaces of the cylinders, i.e., they are the pressures $p_{s,j}$ and the blanket's compressions are $\Delta_{s,j}$.

The compression of the blanket is caused by shifts of the assemblies of cylinder bearings; these shifts do not coincide with $\Delta_{s,j}$, because the assemblies of bearings and the ends of the cylinders are deformed during the shifting. The interrelation between the shifts of the assemblies of bearings and $\Delta_{s,j}$ for any pair of cylinders that are pressed against each other is found by calculating the shifts of all the cylinders of the printing station when the non-linearity of the response of the blanket's elasticity is assessed.

0.1 Cilj raziskave

Cilj prispevka je razvoj analitičnih, računalniško podprtih matematičnih metod, ki jih lahko uporabimo za izračun in raziskavo zakonitosti deformacij valjev s ploščo, valjev z gumijasto oblogo in tiskovnih valjev (pri rotacijskem tiskarskem stroju), ki pritiskajo drug ob drugega prek obloge, pa tudi tlaka na dotikalnih predelih valjev. Omenjene metode prav tako omogočijo določitev vpliva deformacije valjev na analizo postopka tiskanja in določitev vrednosti pomikov sklopov ležajev, ki povzročijo specifične vrednosti stiska obloge $\Delta_{s,j}$ in tlaka $p_{s,j}$.

Rezultate raziskave lahko uporabimo pri oblikovanju in izboljšavi tiskarskih enot in pri oceni kakovosti novih tiskarskih strojev še preden jih začnemo uporabljati.

Razvijanje omenjenih metod je bilo zahtevno, ker je odnos med stiskalnimi silami valjev in stiskom oblog, ki jih povzročijo valji, nelinearen in ker pomiki ležajev, ki omogočijo potrebno stiskanje oblog $\Delta_{s,j}$, niso vnaprej znani. Vendar pa je nujno potrebno, da ugotovimo

0.1 Object of the Paper

The object of the paper is to develop analytical computer-aided calculation methods that are usable for the calculation and investigation of the regularities of deformations of the plate, blanket and impression cylinders (in the web printing press) that are pressed against each other via the blanket as well as the pressure on the contact zones of the cylinders; a determination of the impact of the deformation of the cylinders on an investigation of the printing process; a determination of the values of shifts of the bearings assemblies of such cylinders that cause the set values of blanket compression $\Delta_{s,j}$ and pressure $p_{s,j}$.

The results of the paper may be applied to designing and improving printing stations and an assessment of the quality of the acquired printing presses before starting their exploitation.

The development of the methods was complicated, because the interrelation of the forces of the compression of the cylinders and the compression of the blankets caused by them is non-linear, and the shifts of the assemblies of cylinder bearings that ensure the required compression of the blankets $\Delta_{s,j}$ are not njihove vrednosti, kajti, kakor bomo pokazali v tem prispevku, je prav zaradi tega problema naša raziskava drugačna od običajnih iskanj rešitve sistema nelinearnih enačb.

1 SHEMA IZRAČUNOV

Shema izračunov, ki se nanaša na tiskarsko enoto, predstavljeno na sliki 1, je prikazana na sliki 3. Shema kaže, da so absolutni pomiki valjev izračunani, njihove medsebojne razlike pa lahko uporabimo za določitev relativnih pomikov valjev in s tem vrednosti $\Delta_{m,j}$, $\Delta_{s,j}$, $p_{m,j}$, $p_{s,j}$, ki nas najbolj zanimajo.

V shemi izračunov je bila elastičnost obloge in ležajev ocenjena z uporabo diskretnih elastičnih elementov (njihovi odzivi so opisani z ustreznimi koeficienti togosti) in z uporabo metode končnih elementov, ki izloči pomike valjev. Analogne sheme izračunov smo oblikovali tudi za sklope valjev, ki so drugače razporejeni in so sestavljeni iz drugačnega števila posameznih valjev.

Valji so razstavljeni na ploščate končne elemente, ki so oblikovani kot valji in prisekani stožci (slika 3, c, d). Z uporabo enačb smo ocenili upogibe in druge pomike valjev v ravninah, ki potekajo skozi naslednje teoretične osi vrtenja nedeformiranih valjev (te osi kasneje imenujemo osi vrtenja valjev): valj 1 – ravnina osi vrtenja valja 1 in valja 2 je skladna z osjo koordinat x_1; valj 4 – ravnina osi vrtenja valjev 4 in 3 je skladna z osema koordinat x_2, x_3 in dve ravnini, ki ležita pravokotno na to ravnino – ena gre zkozi os vrtenja valja 2, druga pa skozi os vrtenja valja 3 (prva ravnina ima os koordinat y_2 in druga ima os koordinat y_3).

Tako so absolutni pomiki valja 1, in tudi valja 4 ocenjeni v eni ravnini (pomiki valja 1 v smeri osi koordinat x_1 in pomiki valja 4 v smeri osi x_4), pomiki valjev 2 in 3 pa v dveh pravokotnih ravninah (pomiki valja 2 v smeri osi koordinat x_2, y_2 in pomiki valja 3 v smeri osi koordinat x_3, y_3).

Predpostavljamo, da ima tiskarska enota simetrično ravnino, ki poteka skozi središčne točke valjev (točke O_1,...,O_4) in leži pravokotno na njihove osi vrtenja (sl. 3, b). Zato so vse vrednosti, ki opisujejo valje, njihove pomike in sile, ki delujejo na valje v obeh polovicah valjev, ki jih deli ravnina, enake.

known in advance. It is necessary to find them and this, as we will show here, causes a difference in the problem under discussion from the usual problem of the solution of a system of non-linear equations.

1 THE SCHEME OF CALCULATIONS

The scheme of calculations, corresponding to the printing station, presented in Fig. 1, is shown in Fig. 3. According to this scheme the absolute shifts of the cylinders are calculated and the corresponding differences are used to find the relative shifts of the cylinders and the values $\Delta_{m,j}$, $\Delta_{s,j}$, $p_{m,j}$, $p_{s,j}$ that are our main interest.

In the scheme of the calculations the elasticity of the blanket and the cylinder bearings was assessed by using discrete elastic elements (their responses are described with the corresponding coefficients of stiffness) and by applying the use of a method of finite elements that discretized shifts of the cylinders. Analogous schemes of the calculation are formed for other layouts and numbers of cylinders.

The cylinders are disintegrated to plane finite elements shaped as cylinders and truncated cones (Fig. 3, c, d). Using the equations, the bends and other shifts of the cylinders are assessed in planes, passing through the following theoretical axes of rotation of non-deformed cylinders (these axes are subsequently referred to as the axes of rotation of the cylinders): cylinder 1 – the plane of the axes of rotation of it and cylinder 2 according to the axis of the coordinates x_1; cylinder 4 - the plane of the axes of rotation of cylinders 4 and 3 according to the axes of the coordinates x_2, x_3 and in two planes perpendicular to this plane – one of them goes through the axis of rotation of cylinder 2 and the other - through the axis of rotation of cylinder 3 (the first plane includes the axis of coordinates y_2 and the second plane – the axis of coordinates y_3).

Thus, the absolute shifts of cylinder 1, like that of cylinder 4, are assessed in one plane (the shifts of cylinder 1 in the direction of the axis of coordinates x_1, and the shifts of cylinder 4 in the direction of the axis x_4) and the shifts of cylinders 2 and 3, in two perpendicular planes (the shifts of cylinder 2 in the direction of the axes of coordinates x_2, y_2 and the shifts of cylinder 3 in the direction of the axes of coordinates x_3, y_3).

It is considered that the printing station has a plane of symmetry that passes through the middle points of the cylinders (the points O_1,...,O_4) and is perpendicular to their axes of rotation (Fig. 3, b). Because of this, all the values describing the cylinders, their shifts and the forces impacting on the cylinders in both halves of the cylinders divided by the plane are identical.

Vrednosti stiska oblog $\Delta_{s,j}$ (kadar so znane, so vrednosti tlaka $p_{s,j}$ izračunane z enačbo (1)) dobimo z uporabo nadzornih točk $A_1,...,A_4$ v enotah končnih elementov, ki so na levem robu delovnih površin valjev (sl. 3, b). Spremembe pri razdaljah A_1A_2, A_2A_3, A_3A_4, ki jih dobimo z izračunom, so enake $\Delta_{s,j}$ upoštevaje dovoljeno napako. Zaradi simetrije je dovolj, da ugotovimo navedene spremembe le na eni strani valja.

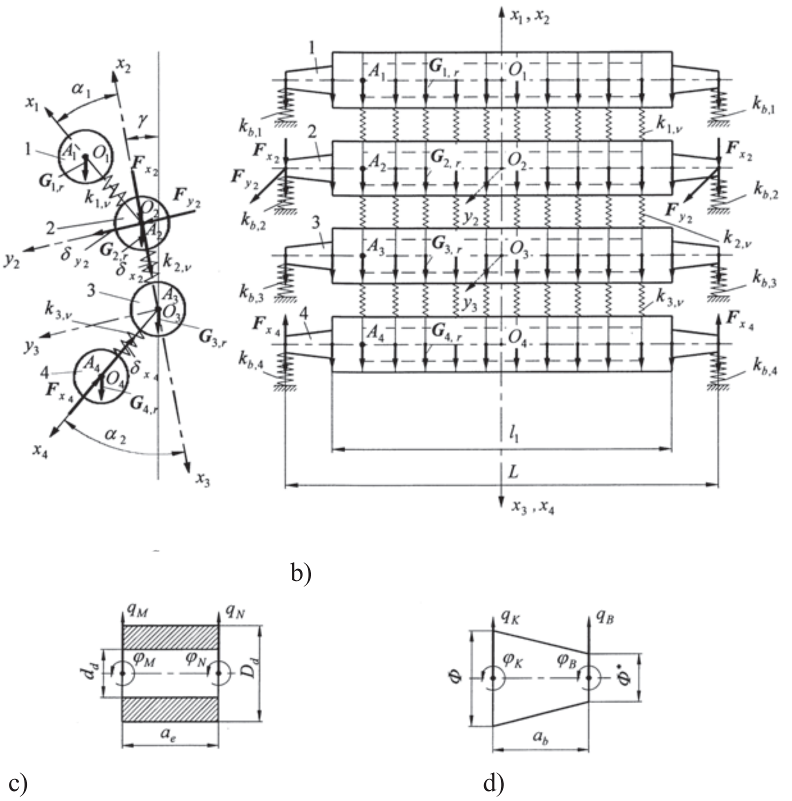
Ležaji valjev so v približku enaki linearnim elastičnim elementom, katerih koeficienti togosti $k_{b,1},...,k_{b,4}$ so izračunani tako kakor v viru [7] (sodobni tiskarski stroji imajo valjaste kotalne ležaje, elastičnost njihovih sklopov pa je v približku premočrtna).

Plast obloge med valjema smo simulirali z diskretnimi nelinearnimi elastičnimi elementi, ki povezujejo delovne površine dvojice valjev, ki pritiskajo drug ob drugega ob dotikališčih končnih

The values of the compression of the blankets $\Delta_{s,j}$ (when they are known, the values of the pressure $p_{s,j}$ are found according to Formula (1)) are found using the control points $A_1,...,A_4$ in the units of the finite elements, situated at the left-hand edge of the working surfaces of the cylinders (Fig. 3, b). Changes of the distances A_1A_2, A_2A_3, A_3A_4, found in the calculation, are equal to $\Delta_{s,j}$, with a permissible error. Because of the symmetry, it is sufficient to find these changes at only one end of the cylinders.

The bearings of the cylinders are approximated with linear elastic elements whose coefficients of stiffness $k_{b,1},...,k_{b,4}$ are calculated according to [7] (in modern printing stations, cylindrical rolling bearings are used, and the elasticity of their assemblies is approximately rectilinear).

The layer of blanket between the cylinders is simulated with discrete non-linear elastic elements that connect the working surfaces of pairs of cylinders that are pressed against each other at the junctions of the finite



Sl. 3. *Shema izračunov za tiskarski stroj, prikazan na sliki 1: a – pogled s strani; b – postavitev glede na osi vrtenja valjev; c, d – tipi končnih elementov, ki simulirajo valje;* $q_M...,q_B$, $\varphi_M...,\varphi_B$ *– linearne in kotne koordinate, ki določajo lege sklopov končnih elementov*

Fig. 3. *The scheme of calculations of the printing station shown in Fig. 1: a – the view from the end; b – the cylinders;* $q_M...,q_B$, $\varphi_M...,\varphi_B$ *– the linear and angular coordinates that define the positions of the assembles of the finite elements*

elementov (sl. 3, b). Te elemente definiramo s koeficienti togosti $k_{j,\nu} = k_{1,\nu}$; $k_{2,\nu}$; $k_{3,\nu}$, ki so odvisni od največjih vrednosti stiskanja obloge (ν - zaporedno število dotikališč končnih elementov na oblogi (v primeru s sl. 3: ν = 1, 2,..., 10) v j-tem dotikalnem pasu). Vsak od njih določi togost z_ν, dolgega valjastega izreza obloge. Vrednosti z_ν so odvisne od dolžin a_e končnih elementov na oblogi (sl. 3, b, c).

Po enačbah (1) do (4) in (8) pa tudi virih ([4] do [6]) smo izpeljali naslednje izraze za koeficiente togosti elastičnih elementov, ki simulirajo oblogo:

elements (Fig. 3, b). These elements are defined by the coefficients of stiffness, $k_{j,\nu} = k_{1,\nu}$; $k_{2,\nu}$; $k_{3,\nu}$, that depend on the maximum values of the compression of the blanket (ν - the consecutive number of junctions of the finite elements covered by the blanket (in this case shown in Fig. 3: ν= 1, 2,..., 10) in the j-th contact band). Each of them determines the stiffness of z_ν, the long cylindrical cut of the blanket. The values of z_ν depend on the lengths a_e of the finite elements covered with the blanket (Fig. 3, b, c).

On the basis of the Formulas (1) to (4) and (8) as well as the references ([4] to [6]) we found the following expressions of the coefficients of stiffness of the elastic elements that simulate the blanket to be:

$$k_{j,\nu} \cong \alpha_j \sqrt{8B_j}\; E z_\nu \psi c^{-\eta} \left(\Delta_{m,j}\right)_\nu^{\eta-0,5} \qquad (\mathrm{j} = 1, 2, 3) \qquad (9).$$

Koeficient $\alpha_1 = \alpha_3 = 1$ ($j = 1, 3$) in $\alpha_2 = 0{,}5$ ($j = 2$). Glede na [4] in [5] dobimo naslednji izraz:

The coefficient $\alpha_1 = \alpha_3 = 1$ ($j = 1, 3$) and $\alpha_2 = 0.5$ ($j = 2$). According to [4] and [5]:

$$\psi \cong \frac{1}{12}\left(1 + 2\cdot 0{,}75^{\eta} + 4\cdot 0{,}9375^{\eta} + 4\cdot 0{,}4375^{\eta}\right) \qquad (10).$$

Torej so vsi koeficienti togosti $k_{j,\nu}$ funkcije vrednosti stiskanja obloge $(\Delta_{m,j})_\nu$.

Papirni trak 6 se pomika med valjema z gumijasto oblogo 2 in 3 (sl. 1). Lahko bi dokazali, da ima elastičnost stisnjenega papirja zanemarljiv učinek, zato je tu ne upoštevamo. Po potrebi bi elastičnost papirja lahko ocenili z ustreznim zmanjšanjem koeficientov togosti obloge med valjema 2 in 3.

Masa valjev lahko doseže nekaj sto kilogramov, zato jo moramo upoštevati. V shemi izračunov (sl. 3, a, b) je masa valjev v približku enaka silam mase $G_{d,r}$ (r = 1, 2, … – zaporedne številke dotikališč končnih elementov), ki delujejo na stikališča končnih elementov.

Pri obravnavanem tiskarskem stroju se oblogi napneta zaradi pomikov sklopov ležajev drugega valja za razdalji (-δ_{x2}), δ_{y2} in zaradi pomikov sklopov ležajev četrtega valja za razdaljo (-δ_{x4}) (sl. 3, a; vrednosti δ_{x2} in δ_{x4} sta negativni, ker pomikanje poteka v smereh, ki sta nasprotni smerem pozitivnih smeri osi koordinat x_2 in x_4). To dogajanje ustvarja naslednje sile pomikanja valjev 2 in 4, ki učinkujejo na priključke ležajev valjev (sl. 3, a, b):

Therefore, all the coefficients of stiffness $k_{j,\nu}$ are functions of the values of the compression of the blanket $(\Delta_{m,j})_\nu$.

The paper tape 6 moves between the blanket cylinders 2 and 3 (Fig. 1). It can be shown that the elasticity of its compression has a negligible impact, so it is not taken into account here. If necessary, the elasticity of the paper can be assessed by the corresponding reduction of the coefficients of stiffness of the blanket between the cylinders 2 and 3.

The weight of the cylinders can reach some hundreds of kilograms, so it should be taken into account. In the scheme of the calculations (Fig. 3, a, b), the weight of the cylinders is approximated with the forces of gravity $G_{d,r}$ (r = 1, 2, … - the consecutive numbers of junctions of the finite elements) acting at the junctions of the finite elements.

In the printing station under discussion the blankets are stretched by shifting the assemblies of bearings of the second cylinder distances (-δ_{x2}), δ_{y2} and the assemblies of the bearings of the fourth cylinder a distance (-δ_{x4}) (Fig. 3, a; the values δ_{x2} and δ_{x4} are negative, because the shifting is performed in directions opposite to the set positive directions of the axes of coordinates x_2 and x_4). This generates the following forces of the shifting of cylinders 2 and 4 that affect the cylinders in the fittings of their bearings (Fig. 3, a, b):

$$F_{x_2} = k_{b,2}\,\delta_{x_2};\;\; F_{y_2} = k_{b,2}\,\delta_{y_2};\;\; F_{x_4} = k_{b,4}\,\delta_{x_4} \qquad (11).$$

Vrednosti pomikov δ_{x2}, δ_{y2}, δ_{x4} in tudi sil F_{x2}, F_{y2}, F_{x4} so funkcije elastičnih pomikov valjev.

The values of the shifts δ_{x2}, δ_{y2}, δ_{x4} as well as of the forces F_{x2}, F_{y2}, F_{x4} are functions of the elastic shifts of the cylinders.

2 ALGORITEM IZRAČUNOV

2.1 Glavne značilnosti algoritma

Na kratko bomo opisali zaporedje izračunov. Najprej smo ugotovili absolutne pomike valjev v smereh osi koordinat $x_1,...,x_4$, ki so prikazani na sl. 3, a, b. Te pomike opišemo s posplošenimi Lagrangevimi koordinatami (v nadaljevanju jih imenujemo kar koordinate) $q_1,q_2,...,q_n$ (skupaj sestavljajo vektor q). Nato, z uporabo ustreznih razlik med omenjenimi koordinatami, relativne pomike med valji najdemo na ravninah, ki potekajo skozi osi vrtenja valjev 1 in 2, 3 in 4 (pomiki valjev 2 in 3 se preslikajo na te ravnine), ter skozi osi vrtenja valjev 2 in 3.

Vrednosti koordinat q lahko najdemo v rešitvi enačb oblikovanih na njihovi osnovi. Če so vrednosti pomikov sklopov ležajev δ_{x2}, δ_{y2}, δ_{x4} znane, lahko omenjene koordinate dobimo z naslednjim nelinearnim sistemom algebraičnih enačb:

2 THE ALGORITHM OF THE CALCULATIONS

2.1 The Principal Features of the Algorithm

The sequence of the calculations will be briefly described. First of all, the absolute shifts of the cylinders in the directions of the axes of coordinates $x_1,...,x_4$ shown in Fig. 3, a, b were found. These shifts are described by using the generalized Lagrange coordinates (subsequently, the coordinates) $q_1,q_2,...,q_n$ (altogether they form the vector q). Then, by using the corresponding differences of the said coordinates, the relative shifts between the cylinders are found in the planes that pass through the axes of the rotation of cylinders 1 and 2, 3 and 4 (the shifts of cylinders 2 and 3 are projected onto these planes), and through the axes of rotation of cylinders 2 and 3.

The values of the coordinates of q can be found in the solution of the equations formed on their basis. If the values of the shifts δ_{x2}, δ_{y2}, δ_{x4} of the assemblies of the cylinder bearings are known, the said coordinates can be found from the following non-linear system of algebraic equations:

$$\left[\mathbf{K}(q_1,\ldots,q_n)\right]\boldsymbol{q} = \boldsymbol{F}\left(\delta_{x_2},\delta_{y_2},\delta_{x_4}\right)+\boldsymbol{F}_G \qquad (12).$$

Tu del elementov matrike togosti [**K**] vsebuje koeficiente tromosti gumijaste obloge $k_{j,v}$, ki so funkcije vrednosti stiskanja obloge $\Delta_{m,j}$ pa tudi koordinat q.

Kljub temu pa je oblikovanje in reševanje enačb tipa (12) zapleteno, ker so vrednosti stiska oblog $\Delta_{s,j} = \Delta_{s,j}(q_1,...,q_n)$, ki so odvisne od vrednosti pomikov δ_{x2}, δ_{y2}, δ_{x4}, sicer znane, ne poznamo pa tudi vrednosti samih δ_{x2}, δ_{y2}, δ_{x4}; prav tako je neznan analitični medsebojni odnos med temi vrednostmi. Zato so neznani tudi ustrezni izrazi komponent vektorja $\boldsymbol{F}$.

Algoritem, ki je predstavljen spodaj, predlagamo kot mogočo rešitev sistema enačb tipa (12) z uporabo iterativne metode izračuna, ki smo ga razvili prav za ta namen: z njegovo izpeljavo so linearizirani sistemi enačb rešeni ob vsaki ponovitvi in oblikovanje nelinearnega sistema enačb (12) sploh ni potrebno.

Izračun poteka v več stopnjah. Na vsaki stopnji smo preučili naslednji linearni sistem algebraičnih enačb, pridobljenih z lineariziranjem sistema (12) (metode lineariziranja so opisane v odstavku 2.2):

Here, a part of the elements of the matrix of stiffness [**K**] includes the coefficients of stiffness of the blanket $k_{j,v}$ that are functions of the values of the compression $\Delta_{m,j}$ of the blanket as well as of the coordinates of q.

However, the formation and solution of the equations of type (12) is complicated, because the values of the compression of the blankets $\Delta_{s,j} = \Delta_{s,j}(q_1,...,q_n)$ that depend on the values of the shifts δ_{x2}, δ_{y2}, δ_{x4} are known, but not the values of δ_{x2}, δ_{y2}, δ_{x4} themselves, and the analytical interrelation between these values is also unknown. So, the specific expressions of the components of the vector $\boldsymbol{F}$ are unknown as well.

The algorithm described below is proposed as a solution of the systems of (12)-type equations by using the iterative method of calculation that was developed for this purpose: on its realization, the linearized systems of equations are solved on each iteration and the formation of a non-linear system of Equations (12) is not required.

The calculation is performed in several stages. At each stage, the following rectilinear system of algebraic equations obtained on the linearization of the system (12) was examined (the methods of linearization are described in paragraph 2.2):

$$\left[\mathbf{K}^{(i)}\right]\boldsymbol{q}^{(i)} = \boldsymbol{F}^{(i)}\left(\delta^{(i)}_{x_2},\delta^{(i)}_{y_2},\delta^{(i)}_{x_4}\right)+\boldsymbol{F}_G \qquad (13).$$

Tu so elementi matrike togosti [$\mathbf{K}^{(i)}$] koeficienti togosti gumijaste obloge $k_{j,\nu}^{(i)}$ (njihov izračun je opisan v odstavku 2.2), pa tudi koeficienti togosti sklopov ležajev valjev, ki kažejo deformacije valjev. Vsi elementi matrike [$\mathbf{K}^{(i)}$] so nespremenljive.

Vektor sil $\boldsymbol{F}^{(i)}$, ki pomikajo valje v i-tem približku, je funkcija približne vrednosti pomikov sklopov ležajev $\delta_{x_2}^{(i)}, \delta_{y_2}^{(i)}, \delta_{x_4}^{(i)}$, ki smo jo dobili med izračunom. Vsebuje le tri nespremenljive neničelne dvojice komponent (dve enaki komponenti za vsak pomik):

Here, the elements of the matrix of stiffness [$\mathbf{K}^{(i)}$] are the coefficients of the stiffness of the blanket $k_{j,\nu}^{(i)}$ (their calculation is described in paragraph 2.2) as well as the coefficients of the stiffness of the assemblies of bearings and the cylinders that reflect the deformations of the latter. All the elements of the matrix [$\mathbf{K}^{(i)}$] are constants.

The vector $\boldsymbol{F}^{(i)}$ of the forces shifting the cylinders in the i-th approximation is a function of the approximate values of shifts of the assemblies of bearings $\delta_{x_2}^{(i)}, \delta_{y_2}^{(i)}, \delta_{x_4}^{(i)}$ found in the course of the calculation. It includes only three constant non-zero pairs of components (the same two components for each shift):

$$F_{x_2}^{(i)} = k_{b,2} \cdot \left(-\delta_{x_2}^{(i)}\right); \quad F_{y_2}^{(i)} = k_{b,2}\delta_{y_2}^{(i)}; \quad F_{x_4}^{(i)} = k_{b,4} \cdot \left(-\delta_{x_4}^{(i)}\right) \qquad (14).$$

Tudi komponente vektorja sil težnosti $\boldsymbol{F}_G$ so nespremenljive.

Z uporabo računalniško podprte metode, ki sledi shemi izračunov, smo oblikovali sistem enačb (13), ki je prikazan na sliki 3. Za njegovo oblikovanje lahko uporabimo različne algoritme, vendar pa priporočamo naslednji algoritem, ki smo ga razvili. Najprej za posamezne valje oblikujemo enačbe podsistema našega sistema (ne celotnega sistema); oblikujemo tudi elastične elemente, ki simulirajo gumijasto oblogo in so umetno ločeni od enega valja. Tako v obravnavanem primeru sestavimo naslednje ločene sisteme enačb šestih podsistemov: enačbe valja 1 z elastičnimi elementi, ki simulirajo gumijasto oblogo in so ločeni od valja 2 (njihovi koeficienti togosti so $k_{1,\nu}^{(i)}$)) – te enačbe opišejo pomike valja v smeri x_1; enačbe valja 2, ki opišejo pomike valja v smeri x_2, z elastičnimi elementi, ločenimi od valja 3 (njihovi koeficienti togosti so $k_{2,\nu}^{(i)}$); enačbe valja 2 brez elastičnih elementov, ki opišejo pomike valja v smeri y_2; dva analogna sistema enačb brez elastičnih elementov, ki posamično opišeta pomike valja 3 v smereh x_3 in y_3; enačbe valja 4, ki opišejo pomike valja v smeri x_4 z elastičnimi elementi, ločenimi od valja 3 (njihovi koeficienti togosti so v). Poleg tega oblikujemo tudi linearne algebraične povezovalne enačbe, ki opišejo povezave prostih koncev elastičnih elementov; ti simulirajo gumijasto oblogo, pri čemer so valji umetno ločeni od elastičnih elementov.

Potem ko razvijemo vseh šest sistemov enačb podsistemov ter povezovalne enačbe, jih združimo v enoten sistem (13) z uporabo računalniško podprte metode. Takšna metoda oblikovanja enačb, ki

The components of the vector $\boldsymbol{F}_G$ of the forces of gravity are constants as well.

The system of Equations (13) was formed by using a computer-aided method following the scheme of calculations and is provided in Fig. 3. Various algorithms can be used for its formation; however, we recommend the following algorithm that was developed by us. First, equations of the subsystems of the system (not of the whole system) are formed for separate cylinders, as are the elastic elements simulating the blanket that are artificially separated from one of the cylinders. In such a way, in the example under discussion, the following separate systems of equations of the six subsystems are formed: the equations of cylinder 1 with the elastic elements simulating the blanket that are separated from cylinder 2 (their coefficients of stiffness are $k_{1,\nu}^{(i)}$) – these equations describe its shifts in the direction x_1; the equations of cylinder 2 that describe its shifts in the direction x_2 with elastic elements separated from cylinder 3 (their coefficients of stiffness are $k_{2,\nu}^{(i)}$); the equations of cylinder 2 without elastic elements that describe its shifts in the direction y_2; two analogous systems of equations without elastic elements that separately describe the shifts of cylinder 3 in the directions x_3 and y_3; the equations of cylinder 4 that describe its shifts in the direction x_4 with the elastic elements separated from cylinder 3 (their coefficients of stiffness are $k_{3,\nu}^{(i)}$). In addition, linear algebraic link equations are formed; they describe the links of the free ends of the elastic elements simulating the blanket with the cylinders artificially separated from them.

After the development of all six systems of the equations of subsystems and the link equations, they are united into a single system (13) using the computer-aided method. Such a method for the formation of the uporablja posamezne podsisteme valjev, je koristna, ker z njo lahko na podlagi poznanih enačb podsistemov valjev, preprosto oblikovanih povezovalnih enačb in mnogih drugih zapletenih enačb, ustvarimo celoten sistem na način, ki lahko vključuje različna števila valjev in njihove medsebojne lege. Ta metoda razvoja enačb je podrobno opisana v virih [8] in [9].

Sedaj predpostavimo, da so vrednosti pomikov sklopov ležajev, kakor tudi komponente vektorja $\boldsymbol{F}^{(i)}\left(\delta_{x_2}^{(i)},\delta_{y_2}^{(i)},\delta_{x_4}^{(i)}\right)$, znane. Ko rešimo sistem nelinearnih algebraičnih enačb (13), ugotovimo, da potekajo absolutni pomiki v nadzornih točkah $A_1,...,A_4$ v smereh osi koordinat $x_1^{(i)},...,x_4^{(i)},y_2^{(i)},y_3^{(i)}$ v i-tem približku. Zdaj lahko ugotovimo, da so spremembe razdalj A_1A_2, A_2A_3, A_3A_4, tj. spremembe stiskov obloge med nadzornimi točkami v i-tem približku naslednje:

equations by using separate subsystems of the cylinders is useful, because on the basis of known equations of the subsystems of cylinders and the easily formed link equations and many more complicated equations the whole system can be formed in a way that involves various numbers of cylinders and their locations with respect to each other. This method of the development of the equations is described in detail in [8] and [9].

Let us suppose that the values of the shifts of the assemblies of bearings are known and the components of the vector $\boldsymbol{F}^{(i)}\left(\delta_{x_2}^{(i)},\delta_{y_2}^{(i)},\delta_{x_4}^{(i)}\right)$ are known as well. Then, after having a solution of the system of non-linear algebraic Equations (13), we find that the absolute shifts of the control points are $A_1,...,A_4$ in the directions of the axes of coordinates $x_1^{(i)},...,x_4^{(i)},y_2^{(i)},y_3^{(i)}$ in the i-th approximation. Then, the changes of the distances A_1A_2, A_2A_3, A_3A_4, i.e., the compressions of the blanket between the control points in the i-th approximation are found to be:

$$\begin{aligned}
\Delta_{s,A_1A_2}^{(i)} &= q_{A_1,x_1}^{(i)} - \left(q_{A_2,x_2}^{(i)}\cos\alpha_1 + q_{A_2,y_2}^{(i)}\sin\alpha_1\right)\\
\Delta_{s,A_2A_3}^{(i)} &= q_{A_2,x_2}^{(i)} + q_{A_3,x_3}^{(i)}\\
\Delta_{s,A_3A_4}^{(i)} &= q_{A_3,x_3}^{(i)}\cos\alpha_2 + q_{A_3,y_3}^{(i)}\sin\alpha_2 - q_{A_4,x_4}^{(i)}
\end{aligned} \qquad (15).$$

Absolutne linearne pomike $q_{A_1,x_1}^{(i)},...,q_{A_4,x_4}^{(i)}$ v točkah $A_1,...,A_4$ in v smereh ustreznih osi koordinat smo dobili v postopku rešitve sistema (13). Namesto enačb (15) lahko zapišemo naslednje:

Where the absolute rectilinear shifts $q_{A_1,x_1}^{(i)},...,q_{A_4,x_4}^{(i)}$ of the points $A_1,...,A_4$ in the directions of the relevant axes of the coordinates are found during the solution of the system (13). Instead of Equations (15) we can write the following:

$$\begin{aligned}
\Delta_{s,A_1A_2}^{(i)} &= \gamma_{A_1A_2,x_2}^{(i)}\cdot\left(-\delta_{x_2}^{(i)}\right) + \gamma_{A_1A_2,y_2}^{(i)}\cdot\delta_{y_2}^{(i)} + \gamma_{A_1A_2,x_4}^{(i)}\cdot\left(-\delta_{x_4}^{(i)}\right) + x_{A_1A_2,G}^{(i)}\\
\Delta_{s,A_2A_3}^{(i)} &= \gamma_{A_2A_3,x_2}^{(i)}\cdot\left(-\delta_{x_2}^{(i)}\right) + \gamma_{A_2A_3,y_2}^{(i)}\cdot\delta_{y_2}^{(i)} + \gamma_{A_2A_3,x_4}^{(i)}\cdot\left(-\delta_{x_4}^{(i)}\right) + x_{A_2A_3,G}^{(i)}\\
\Delta_{s,A_3A_4}^{(i)} &= \gamma_{A_3A_4,x_2}^{(i)}\cdot\left(-\delta_{x_2}^{(i)}\right) + \gamma_{A_3A_4,y_2}^{(i)}\cdot\delta_{y_2}^{(i)} + \gamma_{A_3A_4,x_4}^{(i)}\cdot\left(-\delta_{x_4}^{(i)}\right) + x_{A_3A_4,G}^{(i)}
\end{aligned} \qquad (16).$$

Enačbe (13) so linearne in pri njihovih rešitvah moramo upoštevati načelo nalaganja. Zato so enačbe (16), ki smo jih dobili z rešitvijo enačb (13), veljavne in koeficienti $\gamma^{(i)}$ z ustreznimi indeksi bodo ostali nespremenjeni za vse končne vrednosti $\delta_{x_2}^{(i)}$, $\delta_{y_2}^{(i)}$, $\delta_{x_4}^{(i)}$, $x_{A_1A_2,G}^{(i)},...,x_{A_3A_4,G}^{(i)}$ (vključno z ničelnimi vrednostmi). To značilnost enačb (16) lahko uporabimo pri izračunu koeficientov $\gamma^{(i)}$ in komponent $x_{A_1A_2,G}^{(i)},...,x_{A_3A_4,G}^{(i)}$, kakor tudi pri izračunu pomikov ležajev v i-tem približku. To bo izvedeno takole.

The equations (13) are linear and the principle of superposition is valid for their solution. Because of this, the equalities (16), found from the solution of the equations (13), are valid and the coefficients $\gamma^{(i)}$ with the relevant indices will not change on any finite values of $\delta_{x_2}^{(i)}$, $\delta_{y_2}^{(i)}$, $\delta_{x_4}^{(i)}$, $x_{A_1A_2,G}^{(i)},...,x_{A_3A_4,G}^{(i)}$ (including zero values). This feature of the equations (16) is applied to a calculation of the coefficients $\gamma^{(i)}$ and the components $x_{A_1A_2,G}^{(i)},...,x_{A_3A_4,G}^{(i)}$ and then to a calculation of the shifts of the bearings in the i-th approximation. This will be carried out as follows.

1. Izračun koeficientov $\gamma^{(i)}$ (predpostavljamo, da je $F_G = 0$):

Koeficiente $\gamma_{A_1A_2,x_2}^{(i)},\gamma_{A_2A_3,x_2}^{(i)},\gamma_{A_3A_4,x_2}^{(i)}$ izračunamo po rešitvi sistema (13) in enačb (16), ki so oblikovane na predpostavki, da je $\delta_{y_2}^{(i)} = \delta_{x_4}^{(i)} = 0$;

1. Calculation of the coefficients $\gamma^{(i)}$ (it is considered that $F_G = 0$):

The coefficients $\gamma_{A_1A_2,x_2}^{(i)},\gamma_{A_2A_3,x_2}^{(i)},\gamma_{A_3A_4,x_2}^{(i)}$ are calculated on the basis of solutions of system (13) and the equations (16) obtained on the consideration

$\delta_{x_2}^{(i)}=1$. V tem primeru je sistem deformiran z dvema enakima posplošenima silama $F_{x2} = k_{b,2}$, ki vplivata na robove valja 2 in sta edini neničelni komponenti vektorja $F^{(i)}$. Koeficienti, ki jih moramo določiti, kar je razvidno iz enačb (16), za omenjene razmere, bodo enaki vrednostim $\Delta_{s,A_1A_2}^{(i)}, \Delta_{s,A_2A_3}^{(i)}$ in $\Delta_{s,A_3A_4}^{(i)}$.

Koeficiente $\gamma_{A_1A_2,y_2}^{(i)}, \gamma_{A_2A_3,y_2}^{(i)}, \gamma_{A_3A_4,y_2}^{(i)}$ izračunamo na način, ki je analogen sistemu (13), $\delta_{x_2}^{(i)}=\delta_{x_4}^{(i)}=0$ in $\delta_{y_2}^{(i)}=1$ (na sistem vplivata dve posplošeni sili $F_{y2} = k_{b,2}$), koeficiente $\gamma_{A_1A_2,x_4}^{(i)}, \gamma_{A_2A_3,x_4}^{(i)}, \gamma_{A_3A_4,x_4}^{(i)}$ pa dobimo s predpostavko, da je $\delta_{x_2}^{(i)}=\delta_{y_2}^{(i)}=0$ in $\delta_{x_4}^{(i)}=1$ (na sistem vplivata dve posplošeni sili $F_{x4} = k_{b,4}$).

2. Komponente $x_{A_1A_2,G}^{(i)}, x_{A_2A_3,G}^{(i)}, x_{A_3A_4,G}^{(i)}$, ki se pojavijo zaradi sile teže, ki delujejo na valje, dobimo iz enačb (13) in (16), če upoštevamo, da je $\delta_{x_2}^{(i)}=\delta_{y_2}^{(i)}=\delta_{x_4}^{(i)}=0$ in $F_G \neq 0$. Po izračunu, dobljenem na tej osnovi, bodo komponente enake vrednostim $\Delta_{s,A_1A_2}^{(i)},...,\Delta_{s,A_3A_4}^{(i)}$.

3. Ko dobimo koeficiente $\gamma_{A_1A_2,x_2}^{(i)},...,\gamma_{A_3A_4,x_4}^{(i)}$ in komponente, ki se pojavijo zaradi sile teže, enačbe (16) uporabimo za določitev približnih pomikov sklopov ležajev valjev. Za ta namen približne vrednosti stiskanja gumijastih oblog $\Delta_{s,A_1A_2}^{(i)},...,\Delta_{s,A_3A_4}^{(i)}$ na levi strani enačb (16) nadomestimo z natančnimi potrebnimi vrednostmi stiskanja gumijastih oblog $\Delta_{s,A1\,A2}$, $\Delta_{s,A2\,A3}$, $\Delta_{s,A3\,A4}$. Približne vrednosti pomikov sklopov ležajev nato dobimo iz naslednjega sistema enačb:

that $\delta_{y_2}^{(i)}=\delta_{x_4}^{(i)}=0$; $\delta_{x_2}^{(i)}=1$. In such a case, the system is deformed by two equal generalized forces $F_{x2} = k_{b,2}$ affecting the ends of cylinder 2, which are the only non-zero components of the vector $F^{(i)}$, and the coefficients to be found, as can be seen from the equations (16), on the said conditions, will be equal to the values of $\Delta_{s,A_1A_2}^{(i)}, \Delta_{s,A_2A_3}^{(i)}$ and $\Delta_{s,A_3A_4}^{(i)}$.

The coefficients $\gamma_{A_1A_2,y_2}^{(i)}, \gamma_{A_2A_3,y_2}^{(i)}, \gamma_{A_3A_4,y_2}^{(i)}$ are calculated in a analogous way to that in System (13), $\delta_{x_2}^{(i)}=\delta_{x_4}^{(i)}=0$ and $\delta_{y_2}^{(i)}=1$ (the system is affected by two generalized forces $F_{y2} = k_{b,2}$) and the coefficients $\gamma_{A_1A_2,x_4}^{(i)}, \gamma_{A_2A_3,x_4}^{(i)}, \gamma_{A_3A_4,x_4}^{(i)}$ – on the consideration that $\delta_{x_2}^{(i)}=\delta_{y_2}^{(i)}=0$ and $\delta_{x_4}^{(i)}=1$ (the system is affected by two generalized forces $F_{x4} = k_{b,4}$).

2. The components $x_{A_1A_2,G}^{(i)}, x_{A_2A_3,G}^{(i)}, x_{A_3A_4,G}^{(i)}$ caused by the force of gravity acting on the cylinders are found from the equations (13) and the equalities (16), taking into account that $\delta_{x_2}^{(i)}=\delta_{y_2}^{(i)}=\delta_{x_4}^{(i)}=0$ and $F_G \neq 0$. Based on the mentioned conditions, they will be equal to the values of $\Delta_{s,A_1A_2}^{(i)},...,\Delta_{s,A_3A_4}^{(i)}$.

3. After finding the coefficients $\gamma_{A_1A_2,x_2}^{(i)},...,\gamma_{A_3A_4,x_4}^{(i)}$ and the components caused by the forces of gravity, the equalities (16) are used to determine the approximate shifts of the assemblies of bearings of the cylinders. For this purpose, the approximate values of the compressions of the blankets $\Delta_{s,A_1A_2}^{(i)},...,\Delta_{s,A_3A_4}^{(i)}$ on the left-hand side of the equalities (16) are replaced with the exact required values of the compression of the blankets $\Delta_{s,A1\,A2}$, $\Delta_{s,A2\,A3}$, $\Delta_{s,A3\,A4}$. Then the approximate values of the shifts of the assemblies of the bearings are found from the following system of equations:

$$\begin{cases} -\gamma_{A_1A_2,x_2}^{(i)}\delta_{x_2}^{(i)}+\gamma_{A_1A_2,y_2}^{(i)}\delta_{y_2}^{(i)}-\gamma_{A_1A_2,x_4}^{(i)}\delta_{x_4}^{(i)}=\Delta_{s,A_1A_2}-x_{A_1A_2,G}^{(i)} \\ -\gamma_{A_2A_3,x_2}^{(i)}\delta_{x_2}^{(i)}+\gamma_{A_2A_3,y_2}^{(i)}\delta_{y_2}^{(i)}-\gamma_{A_2A_3,x_4}^{(i)}\delta_{x_4}^{(i)}=\Delta_{s,A_2A_3}-x_{A_2A_3,G}^{(i)} \\ -\gamma_{A_3A_4,x_2}^{(i)}\delta_{x_2}^{(i)}+\gamma_{A_3A_4,y_2}^{(i)}\delta_{y_2}^{(i)}-\gamma_{A_3A_4,x_4}^{(i)}\delta_{x_4}^{(i)}=\Delta_{s,A_3A_4}-x_{A_3A_4,G}^{(i)} \end{cases} \quad (17).$$

2.2 Stopnje izračuna

Na podlagi ugotovitev iz poglavja 2.1, pomike valjev izračunamo v naslednjih stopnjah.

1. stopnja (ničti približek, $i = 0$)

a) Predpostavimo, da so valji absolutno togi. Če so potrebne vrednosti stiskanja gumijastih oblog $\Delta_{s,A1\,A2}$, $\Delta_{s,A2\,A3}$, $\Delta_{s,A3\,A4}$ znane in jih vnesemo v enačbo (8) namesto $\Delta_{m,j}$, bomo dobili ničti približek koeficientov togosti elastičnih elementov obloge $k_{1,\nu}^{(0)}, k_{2,\nu}^{(0)}, k_{3,\nu}^{(0)}$.

2.2 The stages of calculation

Following the statements provided in subparagraph 3.1, the shifts of the cylinders will be calculated in the following stages.

The Stage 1 (the zero approximation, $i = 0$)

a) The cylinders are considered absolutely stiff. If the required values of the compression of the blankets $\Delta_{s,A1\,A2}$, $\Delta_{s,A2\,A3}$, $\Delta_{s,A3\,A4}$ are known and they are written into formula (8) instead of $\Delta_{m,j}$, the coefficients of stiffness $k_{1,\nu}^{(0)}, k_{2,\nu}^{(0)}, k_{3,\nu}^{(0)}$ of the elastic elements of the blanket are found in the zero approximation.

b) Potem ko izračunamo navedene koeficiente togosti, z uporabo teh koeficientov in drugih znanih parametrov obravnavanega sistema sestavimo matriko koeficientov togosti [K$^{(0)}$] v ničtem približku.
c) Nato izračunamo koeficiente $\gamma^{(0)}_{A_1A_2,x_2},...,\gamma^{(0)}_{A_3A_4,x_4}$ iz enačbe (16) in komponente $x^{(0)}_{A_1A_2,G}$, $x^{(0)}_{A_2A_3,G},x^{(0)}_{A_3A_4,G}$, ki se pojavijo zaradi sile teže, ki deluje na valje.
d) Iz enačb (17) dobimo vrednosti $\delta^{(0)}_{x_2},\delta^{(0)}_{y_2},\delta^{(0)}_{x_4}$, nato pa sestavimo vektor $\boldsymbol{F}^{(0)}\left(\delta^{(0)}_{x_2},\delta^{(0)}_{y_2},\delta^{(0)}_{x_4}\right)$ z neničelnimi komponentami (14).
e) Rešimo sistem ničtega približka (13), pri katerem upogibe in druge pomike valjev ocenimo v ničtem približku:

b) After the calculation of the said coefficients of stiffness is completed, the matrix of the coefficients of stiffness [K$^{(0)}$] in the zero approximation is formed by using that coefficient and other known parameters of the system under discussion.
c) Then the coefficients $\gamma^{(0)}_{A_1A_2,x_2},...,\gamma^{(0)}_{A_3A_4,x_4}$ from the equality (16) and the components $x^{(0)}_{A_1A_2,G},x^{(0)}_{A_2A_3,G},x^{(0)}_{A_3A_4,G}$ caused by the force of gravity acting on the cylinders are calculated.
d) The values of $\delta^{(0)}_{x_2},\delta^{(0)}_{y_2},\delta^{(0)}_{x_4}$ are found from the equations (17) and then the vector $\boldsymbol{F}^{(0)}\left(\delta^{(0)}_{x_2},\delta^{(0)}_{y_2},\delta^{(0)}_{x_4}\right)$ with non-zero components (14) is formed.
e) The system of zero approximation (13), where bends and other shifts of the cylinders are assessed in the zero approximation, is solved:

$$\left[\mathbf{K}^{(0)}\right]\boldsymbol{q}^{(0)}=\boldsymbol{F}^{(0)}\left(\delta^{(0)}_{x_2},\delta^{(0)}_{y_2},\delta^{(0)}_{x_4}\right)+\boldsymbol{F}_G \tag{18}$$

in dobimo ničte približke vrednosti koordinat $q^{(0)}$.

and the values of the coordinates $q^{(0)}$ in the zero approximation are found.

2. stopnja (prvi približek, *i*=1)

a) Ko poznamo vrednosti koordinat $q^{(0)}$, tj. ko ocenimo ničte približke pomikov valjev, vključno z upogibi, lahko z enačbo (9) bolj natančno določimo koeficiente togosti elastičnih elementov gumijaste obloge, nato pa tudi bolj natančno definiramo matriko koeficientov togosti [K$^{(1)}$].
b) Zdaj izračunamo bolj natančno definirane koeficiente $\gamma^{(1)}_{A_1A_2,x_2},\dots,\gamma^{(1)}_{A_3A_4,x_4}$ iz enačb (16) pa tudi komponente $x^{(1)}_{A_1A_2,G},x^{(1)}_{A_2A_3,G},x^{(1)}_{A_3A_4,G}$.
c) Iz enačb (17) dobimo približne vrednosti pomikov sklopov ležajev $\delta^{(1)}_{x_2},\delta^{(1)}_{y_2},\delta^{(1)}_{x_4}$, nato pa sestavimo vektor $\boldsymbol{F}^{(1)}\left(\delta^{(1)}_{x_2},\delta^{(1)}_{y_2},\delta^{(1)}_{x_4}\right)$ z neničelnimi komponentami (14).
d) Sestavimo naslednji sistem enačb:

The Stage 2 (the first approximation, *i*=1)

a) When the values of the coordinates $q^{(0)}$ are known, i.e., after an assessment of the shifts of the cylinders in the zero approximation, including the bends, the coefficients of the stiffness of the elastic elements of the blanket are more closely defined by using formula (9) and then the more closely defined matrix of the coefficients of stiffness [K$^{(1)}$] is formed.
b) The more closely defined coefficients $\gamma^{(1)}_{A_1A_2,x_2}$, $\dots,\gamma^{(1)}_{A_3A_4,x_4}$ included into the equalities (16) as well as the components $x^{(1)}_{A_1A_2,G},x^{(1)}_{A_2A_3,G},x^{(1)}_{A_3A_4,G}$ are then calculated.
c) The approximate values of the shifts of the assemblies of bearings $\delta^{(1)}_{x_2},\delta^{(1)}_{y_2},\delta^{(1)}_{x_4}$ are found from Equations (17), and the vector $\boldsymbol{F}^{(1)}\left(\delta^{(1)}_{x_2},\delta^{(1)}_{y_2},\delta^{(1)}_{x_4}\right)$ with non-zero components (14) is then formed.
d) The following system of equations is formed:

$$\left[\mathbf{K}^{(1)}\right]\boldsymbol{q}^{(1)}=\boldsymbol{F}^{(1)}\left(\delta^{(1)}_{x_2},\delta^{(1)}_{y_2},\delta^{(1)}_{x_4}\right)+\boldsymbol{F}_G \tag{19}.$$

Ko ga rešimo, dobimo vrednosti prvega približka koordinat $q^{(1)}$.

After its solution, the values of the coordinates $q^{(1)}$ in the first approximation are found.

Naslednje stopnje (i=2, 3, ...)

S približnimi vrednostmi koordinat $q^{(i-1)}$, dobljenih na predhodni stopnji, bolj natančno definiramo koeficiente togosti gumijaste obloge in sestavimo matriko [$\mathbf{K}^{(i)}$]. Nato dobimo koeficiente $\gamma^{(i)}_{A_1A_2,x_2},...,\gamma^{(i)}_{A_3A_4,x_4}$ iz enačb (16) in komponente $x^{(i)}_{A_1A_2,G},x^{(i)}_{A_2A_3,G},x^{(i)}_{A_3A_4,G}$, iz enačb (17) pa dobimo

Further stages (i=2, 3, ...)

By using the approximate values of the coordinates $q^{(i-1)}$ found at the previous stage, the coefficients of the stiffness of the blanket are more closely defined and the matrix [$\mathbf{K}^{(i)}$] is formed. Then, the coefficients $\gamma^{(i)}_{A_1A_2,x_2},...,\gamma^{(i)}_{A_3A_4,x_4}$ included in the equalities (16), and the components $x^{(i)}_{A_1A_2,G},x^{(i)}_{A_2A_3,G},x^{(i)}_{A_3A_4,G}$ are vrednosti pomikov $\delta^{(i)}_{x_2}, \delta^{(i)}_{y_2}, \delta^{(i)}_{x_4}$. Po oblikovanju vektorja $\boldsymbol{F}^{(i)}\left(\delta^{(i)}_{x_2}, \delta^{(i)}_{y_2}, \delta^{(i)}_{x_4}\right)$, dobimo sisteme enačb, kjer je i = 2, 3, 4 itn. V postopku iskanja rešitve vsakega od sistemov bolj natančno definiramo vrednosti koordinat $q^{(i)}$.

Na teh stopnjah z izračunom nadaljujemo, dokler razlike med koordinatama $q^{(i)}$ in $q^{(i-1)}$, komponentami vektorjev, pomiki sklopov ležajev valjev in drugimi vrednostmi, ki smo jih dobili med potekom zadnjih dveh stopenj, ne postanejo manjše od 1%. Ko se to zgodi, prenehamo z izračunavanjem.

Iz dobljenih rezultatov dobimo potrebne vrednosti pomikov ležajev valjev pa tudi zakonitost razporeditve deformacij valjev ter tlaka med valjema, ki pritiskata drug ob drugega preko gumijaste obloge.

Z uporabo teh metod v praksi smo ugotovili, da dosežemo zadostno natančnost rezultatov (ko napaka znaša manj kot 1%), ko je i = 4,5.

3 PRIMER

Z uporabo tu opisane metode smo raziskali upogibe valjev tiskarskega stroja "Compacta 213", izdelanega v Nemčiji, in razporeditev tlaka vzdolž njihovih delovnih površin. Obdelali smo pomike polnih valjev in cevastih valjev. Parametri valjev so bili naslednji (isti za vse valje) L =1,384 m; l_1 =1,04m; l_2 =1,00m; l_3 =0,96m; D_d =0,2m; $k_{b,1} = k_{b,2} = k_{b,3} = k_{b,4}$ =1,7·10^{6}N/m; E =500MPa; η =1,5; α_1 = 30°; α_2 = 50°; γ = 35°; spreminjali smo premer odprtin valjev d_d, vsak valj pa smo razdelili na 13 končnih elementov (sl. 3).

Po opravljeni raziskavi smo ugotovili, da relativni upogibi valjev z gumijasto oblogo in valjev s ploščo, ki pritiskajo drug ob drugega, lahko znašajo do 24 mm in povzročijo 14 do 31 odstotkov sprememb v tlaku vzdolž delovnih površin valjev. To lahko vidno poslabša kakovost tiska. Pokazali smo, da ni praktično uporabljati cevaste valje s tankimi stenami (valji tiskarskega stroja "Compacta 213" so polni).

Da bi poenotili razporeditev tlaka, lako uporabljamo valje, ki imajo izbočene ali vbočene delovne površine, ne pa valjastih površin. Za ta namen smo, z uporabo posebnega programa, spremembe v premeru valjev določili tako, da smo zagotovili premo dotikalno površino valjev. V takšnem primeru je tlak vzdolž dotikalnih pasov valjev nespremenljiv.

found, and the values of the shifts $\delta^{(i)}_{x_2}, \delta^{(i)}_{y_2}, \delta^{(i)}_{x_4}$ are calculated from the equations (17). Then, after the formation of the vector $\boldsymbol{F}^{(i)}\left(\delta^{(i)}_{x_2}, \delta^{(i)}_{y_2}, \delta^{(i)}_{x_4}\right)$, systems of equations, where i = 2, 3, 4 and so on, are formed. In the course of finding a solution to each of these systems, the values of the coordinates $q^{(i)}$ are more closely defined.

The calculation at these stages is continued until the differences between the coordinates $q^{(i)}$ and $q^{(i-1)}$, the components of the vectors, the shifts of the assemblies of cylinder bearings and other values found during the two last stages become less than 1%. In such a case the calculation is then stopped.

From the obtained results the necessary values of the shifts of the cylinder bearings as well as the regularities of the distribution of deformations of the cylinders and the pressure between the cylinders that are pressed against each other via blankets are found.

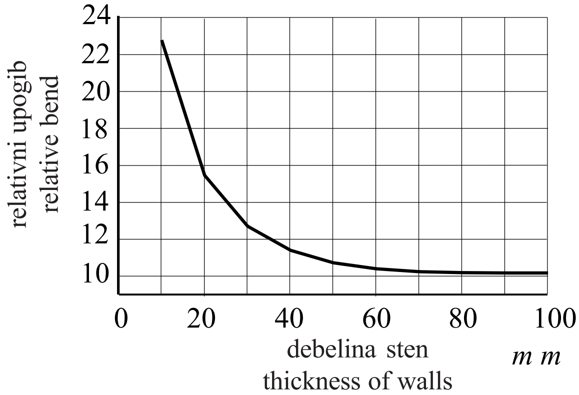
By using these methods in practice we found that sufficient accuracy (when the error is less than 1%) is achieved when i = 4.5.

3 THE EXAMPLE

By using the method described herein, the bends of the cylinders of the "Compacta 213" printing station, made in Germany, and the distribution of the pressure along their working surfaces were investigated. The shifts of the solid and the pipe-type cylinders were investigated. The parameters of the cylinders were as follows (the same for all cylinders): L =1.384 m; l_1 =1.04m; l_2 =1.00m; l_3 =0.96m; D_d =0.2m; $k_{b,1} = k_{b,2} = k_{b,3} = k_{b,4}$ =1.7·10^{6}N/m; E =500MPa; η =1.5; α_1 = 30°; α_2 = 50°; γ = 35°; the diameter d_d of cylinder holes was varied, and each cylinder was divided into 13 finite elements (see Fig. 3).

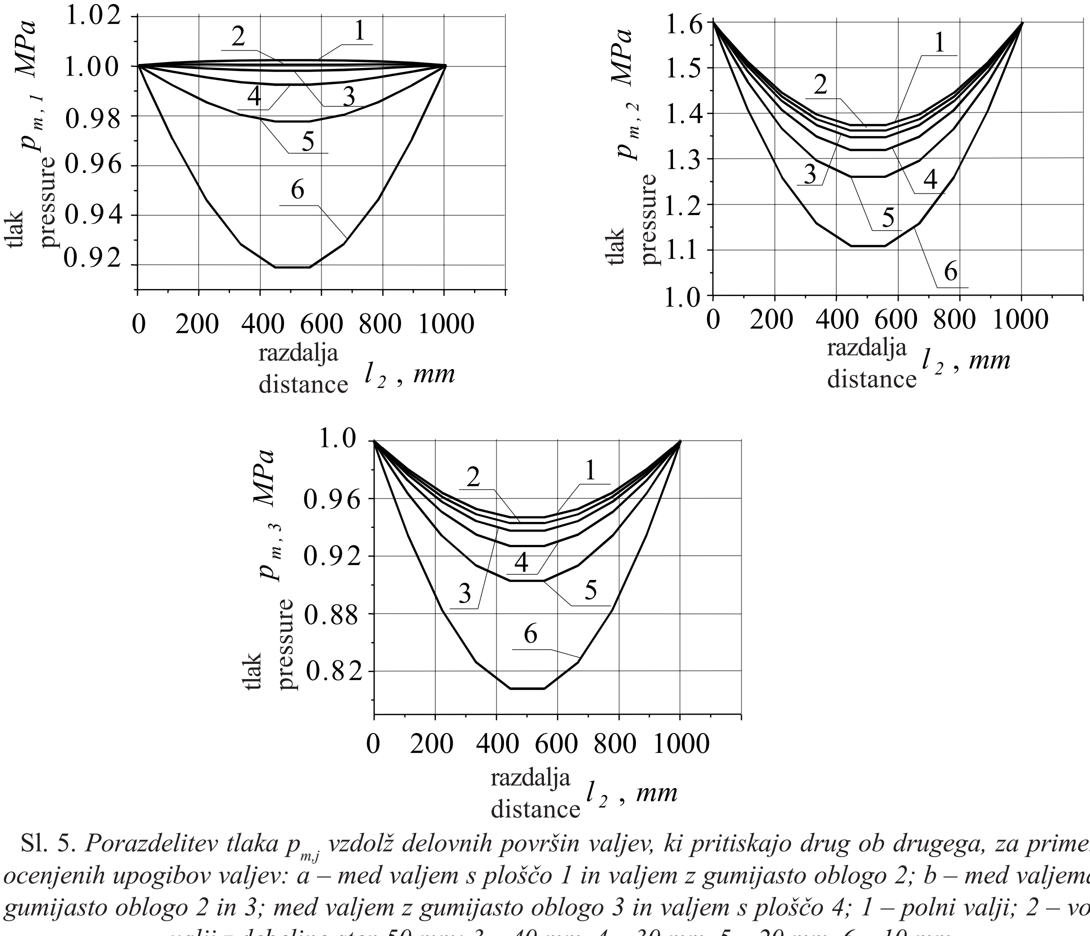
After the completion of the investigation it was found that the relative bends of the blanket and the plate cylinders that were pressed against each other can be up to 24 μm and cause 14–31% changes in the pressure along the working surfaces of the cylinders. This may noticeably deteriorate the quality of the prints. It was shown that it is not useful to use pipe-type cylinders with thin walls (the cylinders of the "Compacta 213" printing press are solid).

In order to equalize the distribution of the pressure, the working surfaces of the cylinders can be made convex or concave, but not cylindrical. For this purpose, by using the special programme, changes of the diameters of the cylinders are chosen in such way so as to ensure a rectilinear surface of the contact of the cylinders. In such a case, the pressure along the contact bands of the cylinders remains constant.



Sl. 4. *Največji relativni upogib med delovnima površinama valjev z gumijasto oblogo 2, 3 pri različnih debelinah sten votlih valjev 1, 2, 3, 4 (so enake za vse štiri valje)*

Fig. 4. *The maximum relative bend between the working surfaces of the blanket cylinders 2, 3 on the various widths of the walls of the hollow cylinders 1, 2, 3, 4 (the same for all four cylinders)*



Sl. 5. *Porazdelitev tlaka $p_{m,j}$ vzdolž delovnih površin valjev, ki pritiskajo drug ob drugega, za primer ocenjenih upogibov valjev: a – med valjem s ploščo 1 in valjem z gumijasto oblogo 2; b – med valjema z gumijasto oblogo 2 in 3; med valjem z gumijasto oblogo 3 in valjem s ploščo 4; 1 – polni valji; 2 – votli valji z debelino sten 50 mm; 3 – 40 mm, 4 – 30 mm, 5 – 20 mm, 6 – 10 mm*

Fig. 5. *The distribution of the pressure $p_{m,j}$ along the working surfaces of cylinders that are pressed against each other on an assessment of the bends of the cylinders: a – between the plate cylinder 1 and the blanket cylinder 2; b – between the blanket cylinders 2 and 3; between the blanket cylinder 3 and the plate cylinder 4; 1 – solid cylinders; 2 – hollow cylinders with the width of the walls 50 mm; 3 – 40 mm, 4 – 30 mm, 5 – 20 mm, 6 – 10 mm*

Primeri rezultatov izračunov so prikazani na slikah 4 in 5.

Examples of the results of the calculation are shown in Fig. 4 and 5.

4 SKLEPI

1. Predlagali smo metodo raziskave upogibov in drugih elastičnih pomikov valjev s ploščo, valjev z gumijasto oblogo in tiskovnih valjev rotacijskega ofsetnega tiskarskega stroja, ki pritiskajo drug ob drugega prek gumijaste obloge, pa tudi spremembe v tlaku vzdolž valjev. Obravnavani problem smo razrešili kot zahteven nelinearni statični problem, pri katerem imamo na začetku potreben tlak na robovih delovnih površin valjev, ki pritiskajo drug ob drugega, medtem pa so pomiki sklopov ležajev, ki omogočijo potrebne vrednosti tlaka, neznane.
2. S predlagano metodo smo ocenili nelinearne značilnosti elastičnosti obloge, upogibe valjev, elastičnost sklopov ležajev, silo teže in lege osi vrtenja valjev glede na njihove medsebojne lege.
3. Z uporabo metode na specifičnem primeru smo pokazali, da upogibi valjev bistveno vplivajo na porazdelitev tlaka vzdolž dotikalnega predela valjev v tiskarskem stroju in na kakovost tiska.

4 CONCLUSIONS

1. A method of investigating the bends and other elastic shifts of the plate, blanket and impression cylinders of the web offset printing press that are pressed against each other via blankets as well as the changes of the pressure along the cylinders was proposed. The problem under discussion was settled as a complex nonlinear static problem, where in the beginning the required pressures at the edges of the working surfaces of the cylinders that are pressed against each other are provided, and the shifts of the assemblies of the cylinder bearings required to ensure the said values of the pressures are unknown.
2. In the proposed method, the nonlinear features of the elasticity of the blanket's material, the bends of the cylinders, the elasticity of the assemblies of their bearings, the force of gravity and the location of the axes of the rotation of the cylinders with respect to each other are assessed.
3. With the application of the method to the specified example, it was shown that the bends of the cylinders noticeably impacted on the distribution of pressure along the contact zone of the cylinders in the printing press and on the quality of the prints.

5 VIRI
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