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Relativne prečne vibracije valjev tiskarskega stroja, ki pritiskajo drug ob drugega preko gumijaste obloge

The Relative Transversal Vibrations of Printing-Press Cylinders that are Pressed Against Each Other via an Elastic Blanket

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V prispevku predstavljamo rezultate analitične, računalniško podprte raziskave relativnih prečnih vibracij valjev v rotacijskem ofsetnem stroju za obojestransko tiskanje. Predstavljamo postopek izvirne metode, s katero smo izvedli raziskavo in ki temelji na računalniški simulaciji.

Tiskarski stroj sestoji iz naslednjih valjev, ki se, v času delovanja tiskarskega stroja, vrtijo in pritiskajo drug ob drugega prek tanke (približno 2 mm) elastične, gumirane tkanine (gumijasta obloga): dveh valjev za ploščo, na katerih sta pritrjeni tiskarski šabloni, in dveh valjev z gumijasto oblogo, med katerima drsi papirni trak, potreben za tiskanje. V poteku raziskave smo ocenili upogibe valjev, pa tudi elastičnost in dušenje gumijaste obloge ter ležajnih enot valjev. Ugotovili smo, da te vibracije povzročajo spremembe v pritisku med valji, s čimer zmanjšujejo tudi kakovost tiska. Potem ko smo raziskali značilnosti prostih in vsiljenih relativnih vibracij valjev, smo se odločili, da bomo intenzivnost vibracij zmanjšali z uporabo valjev z identično dinamično odzivnostjo. Predstavljamo podatke, pridobljene z ekperimentalnim raziskovanjem, ki kažejo vpliv vibracij pritiska med valji na kakovost tiska.

(Ključne besede: tiskanje, ofset, stroji tiskarski, vibracije)

In this paper we present the results of a computer-aided analytical investigation of the relative transversal vibrations of the cylinders in a web-offset double-sided printing press. An original method for carrying out the investigation, using a computer simulation, is presented.

The printing press consists of the following cylinders that rotate during its operation and are pressed against each other via a thin (about 2 mm) elastic, rubberized cloth (called a blanket): two plate cylinders, with printing forms attached to them, and two blanket cylinders, with a paper tape moving between them for the printing. During the investigation, the deflections of the cylinders as well as the elasticity and damping of the blanket and the cylinders' bearing units were assessed. These vibrations caused changes in the pressure between the cylinders, thus reducing the quality of the prints. After investigating the features of the free and forced relative vibrations of the cylinders, it was decided to reduce the intensity of the vibrations by using cylinders with identical dynamic responses. Data from the experimental investigation that show the impact of the variations of the pressure between the cylinders on the quality of the prints are presented.

(Keywords: printing, offset printing, printing press, vibrations)

0 UVOD

V pričujočem prispevku predstavljamo raziskavo relativnih prečnih vibracij med valjema za ploščo in valjema z gumijasto oblogo v rotacijskem ofsetnem stroju za obojestransko tiskanje, ki uporablja metodo računalniške simulacije za zmanjšanje intenzivnosti teh vibracij. Med postopkom delovanja tiskarskega stroja se odtisi prenesejo s površine valjev, prevlečenih s tanko plastjo (približno 2 mm) gumirane tkanine (gumijasta obloga), na papirni trak, ki se pomika skozi stroj. Odtisi se prenesejo iz

INTRODUCTION

In this paper we present an investigation into the relative transversal vibrations between the plate and blanket cylinders in a web-offset double-sided printing press using a computer-simulation method in order to reduce the intensity of these vibrations. During the operation of the printing press the prints are transferred onto a paper tape, which is moving through the printing press, from the surface of the cylinders that are covered with a thin (approximately 2 mm) rubberized cloth (blanket). The tiskarskih šablon (navlaženih s tiskarskim črnilom), ki sta pritrjeni na valja za ploščo, na gumijasto oblogo. Vsi valji se vrtijo in pritiskajo drug ob drugega po celotni dolžini. Valji so nameščeni tako, da se vsi vrtijo in pritiskajo drug ob drugega prek elastične gumijaste obloge: na sredini tiskarskega stroja sta dva valja z gumijasto oblogo, ki pritiskata drug proti drugemu (med njima drsi trak papirja), medtem pa valja za ploščo pritiskata proti drugi strani valjev z gumijasto oblogo. Ta tip tiskarskega stroja je zelo pogost in v nadaljevanju so navedene podrobnosti njegovega delovanja.

Pri tem načinu tiskanja je treba določiti pritisk med vrtečimi se valji, ki pritiskajo drug ob drugega prek gumijaste obloge ([1] do [3]). Če valji vibrirajo, se spreminja tudi njihov pritisk. Posledica vibracij je poslabšanje kakovosti odtisov in s tem tudi zmanjšanje produktivnosti tiskarskega stroja. To pomeni, da je vibriranje, ki spremlja postopek tiskanja, resen problem; da bi ga razrešili, smo uporabili metodo računalniške simulacije.

Doslej so bile opravljene že mnoge raziskave vibracij rotorjev (gredi, valjev itn.), ki se vrtijo v ležajih [4]; vendar pa te raziskave niso vključevale proučevanja vibracij rotorjev, ki pritiskajo drug ob drugega prek tanke elastične tkanine. Opravljene so bile, na primer, študije valjčne opreme, ki vsebujejo kovinske liste (tu tanek kovinski list drsi med vrtečima se valjema), vendar pa rezulatov analiz teh pojavov ne moremo prenesti na tiskarsko panogo [5].

Pričujoča študija poleg raziskav vibracij valjev prikazuje tudi to, kako lahko spremenjen pritisk med valji učinkuje na kakovost tiskarskih odtisov.

Rezultati naše raziskave vibracij valjev so vsesplošno uporabni. Naše ugotovitve lahko prenesemo tudi na primere valjev rotacijskih ofsetnih tiskarskih strojev, ki se po številu valjev in njihovi namestitvi sicer razlikujejo od primerov, opisanih v pričujoči študiji.

1 VPLIV PRITISKA VALJEV NA KAKOVOST TISKANJA

Ni nam uspelo najti kakršnih koli zanesljivih in podrobnih eksperimentalnih podatkov o vplivu pritiska valjev na kakovost ofsetnega tiskanja, kar je preprečevalo, da bi ocenili vpliv relativnih prečnih pomikov valjev stroja, ki jih povzroča vibriranje, na kakovost tiskanja. Zato smo se odločili izvesti eksperimentalno raziskavo vpliva pritiska na kakovost ofsetnega tiskanja. S strojem Heidelberg Speedmaster 52-2-P [1] smo, pri različnih pritiskih, tiskali dvobarvne slike (rumena in črna), skupaj s stopenjskim nadzorom sive lestvice in usmerjenimi črtami. Pritisk smo spreminjali s sočasnim spreminjanjem razdalje med osema valja za ploščo in valja z gumijasto oblogo ter osema tiskovnega valja in valja z gumijasto oblogo. Ta razdalja, λ, je

prints are transferred onto the blanket from the printing forms (moistened with printing ink) that are attached to the plate cylinders. All the cylinders are in rotation and are pressed against each other along their generatrices. The cylinders are positioned in such a way that all of them rotate and press against each other via an elastic blanket: there are two blanket cylinders pressed against each other in the middle of the press (the paper tape moves between them), and the plate cylinders are pressed against the other sides of the blanket cylinders. This type of printing press is very common, and more details are provided below.

With this type of printing the pressure between the rotating cylinders that are pressed against each other via the blanket must be fixed ([1] to [3]). If the cylinders tend to vibrate, this pressure varies as well. The result of vibration is a deterioration in the quality of the prints and a reduction in the productivity of the printing press. This means that the problem of vibration during printing is a serious one, and so we have used a computer-simulation method in an attempt to solve it.

There are many investigations of the vibrations of rotors (shafts, cylinders, etc.) rotating in bearings [4]; however, the vibrations of rotors that are pressed against each other via a thin elastic cloth were not studied during these investigations. For example, there are some studies on metal-sheet rolling equipment (a thin metal sheet moves between rotating rollers); however, the problems discussed are not related to the printing trade [5].

In this study, in addition to investigating the vibrations of cylinders, we have looked at how varying the pressure between the cylinders can have an effect on the quality of the prints.

The results of our investigation into the vibrations in cylinders can be universally applied. Our findings can be applied to the cylinders of web-offset printing presses where the number of cylinders and their layout differ from those described here.

1 THE INFLUENCE OF PRESSURE ON THE PRINTING QUALITY

We were not able to find any reliable and detailed experimental data on the influence of pressure on the quality of offset printing. This makes it difficult to evaluate the influence of the relative transversal shifts of the cylinders in the press, which are caused by vibration, on the quality of the printing. Therefore, an experimental investigation of the influence of pressure on the offset-printing quality was carried out. Two color images (yellow and black) with a control-step gray scale and narrow lines were printed on a Heidelberg Speedmaster 52-2-P press [1] at various pressures. The pressure was changed by altering the distance between the axles of the plate-and-blanket and the blanket-and-press cylinders simultaneously. This distance, λ, is expressed in μm:

izražena v μm: λ = 0μm in pomeni, da se površine valjev le rahlo dotikajo (med njimi ni pritiska); povečani λ pa označuje povečanje relativnega pritiska. Normalen pritisk tiskanja je dosežen, ko je λ = 35μm. Čeprav ta metoda ne omogoča, da bi določili absolutne vrednosti pritiska, pa omogoča, da razumemo povezavo med prečnimi pomiki valjev in kakovostjo tiskanja.

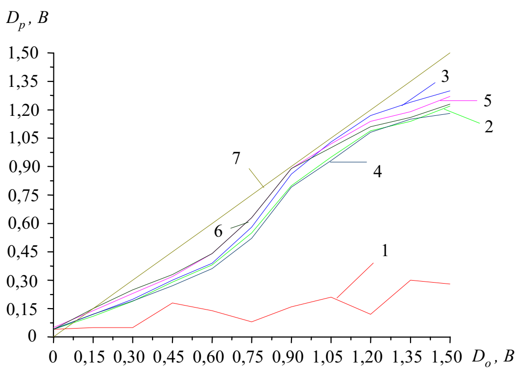
Za določitev kakovosti tiskanja smo uporabili naslednja kriterija: (a) natančnost poltonske reprodukcije (odvisnost optične gostote odtisa D_p od optične gostote izvirnika D_o, izmerjene na stopenjski sivi lestvici; (b) spremembo širine usmerjene črte in velikosti zaslonskih točk. Optično gostoto smo merili z merilnikom gostote Macbeth T-297 (z modrim filtrom za rumeni tisk) z natančnostjo ± 0,02B. Velikost elementov smo izmerili z mikroskopom (povečava: 24^x, točnost: ±0,01 mm).

Rezultati tega preizkusa kažejo na znatne spremembe optične gostote tiska, ki jih povzročijo različne razdalje med valjema v raziskovanem obsegu 8 do 55 μm, in ki posledično vodijo do znatno spremenjenega pritiska. Znatno se spreminjata tudi velikost točk na rastru in širina usmerjene črte. Dobljeni rezultati so prikazani na diagramih 1, 2 in 3.

λ = 0μm means that the cylinders' surfaces are only touching (no pressure); and increasing λ means increasing the relative pressure. The normal printing pressure is achieved when λ = 35μm. Although this method does not allow us to know the absolute values of pressure, it does allow us to relate the transversal shifts of the cylinders to the printing quality.

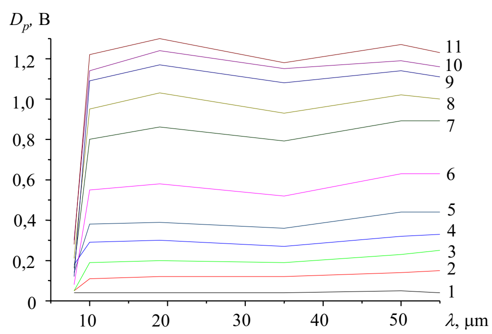
The printing quality was characterized as follows: (a) by the accuracy of the halftone reproduction (the dependence of the optical density of the print D_p on the optical density of the original D_o, measured on the step gray scale; and (b) by the change in the width of the narrow line and the size of the screen dots. The optical density was measured with a Macbeth T-297 densitometer (with a blue filter for the yellow print) with an accuracy of ± 0.02B. The size of the elements was measured using a microscope (magnification: 24^x, accuracy: ±0.01 mm).

The results of the experiment show that the changes in the optical density of a print, which are caused by changes in the distance between cylinders in the investigated range 8 to 55 μm, and consequently changes in the pressure, are considerable. The size of the raster points and the width of a line vary considerably as well. Examples of diagrams showing the obtained results are presented in Figs. 1, 2 and 3.



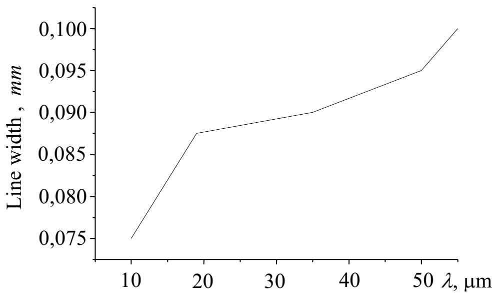
Sl. 1. *Spreminjanje optične gostote rumene nadzorne skale v odnosu do sprememb λ, v razdalji med valjema z gumijasto oblogo in valjema za ploščo: 1- razdalja = 8 μm; 2- razdalja =10 μm; 3- razdalja = 19 μm; 4- razdalja = 35 μm; 5- razdalja = 50 μm; 6- razdalja = 55 μm; 7- idealna reprodukcija poltonov; Do in D_p sta optični gostoti izvirnika in odtisa*

Fig. 1. *The variation of the optical density of the yellow control scale versus changes, λ, in the distance between the blanket and the plate cylinders: 1, distance = 8 μm; 2, distance =10 μm; 3, distance = 19 μm; 4, distance = 35 μm; 5, distance = 50 μm; 6, distance = 55 μm; 7, the ideal reproduction of halftones; Do and D_p are the optical densities of the original and the print*



Sl. 2. *Odvisnost optične gostote (rumena nadzorna skala) od sprememb λ, v razdalji med valjema z gumijasto oblogo in valjema za ploščo: 1 – polje N1 odtisa nadzorne skale (D_o = 0,00); 2 - N2 (0,15); 3 - N3 (0,30); 4 - N4(0,45); 5 - N5(0,60); 6 - N6(0,75); 7 - N7(0,90); 8 - N8(1,05); 9 - N9(1,20); 10 - N10(1,35); 11 -N11(1,50)*

Fig. 2. *The dependence of the optical density (yellow control scale) on the changes, λ, in the distance between the blanket and plate cylinders: 1 – field N1 of the control scale print (D_o = 0.00); 2 - N2 (0.15); 3 - N3 (0.30); 4 - N4(0.45); 5 - N5(0.60); 6 - N6(0.75); 7 - N7(0.90); 8 - N8(1.05); 9 - N9(1.20); 10 - N10(1.35); 11 - N11(1.50)*



Sl. 3. *Odvisnost širine posamezne črte od spremembe λ, v razdalji med valjema z gumijasto oblogo in valjema za ploščo*

Fig. 3. *The dependence of the width of a separate line on the change, λ, in the distance between the blanket and the plate cylinders*

2 PREDMET RAZISKAVE

Raziskovali smo absolutne in relativne prečne vibracije valjev z gumijasto oblogo in valjev za ploščo pri rotacijskem ofsetnem tiskarskem stroju in se pri tem posebej osredotočili na relativne vibracije med valji, z namenom, da bi zmanjšali njihovo intenzivnost. Naše proučevanje je vključevalo naslednje sklope:

- preučevanje prostih prečnih vibracij valjev;
- preučevanje vsiljenih vibracij, sproženih kinematično z netočnostjo krogljičnih ležajev v valjih in z vibracijami okvira tiskarskega stroja ter z netočnostjo delovnih površin valjev (ovalnost itn.);
- preučevanje vibracij, ki jih povzročata zaponki gumijaste obloge na vrtečih se valjih, ki pritiskajo drug ob drugega.

Da bi raziskali ta problem, smo razvili splošno metodo analogno-digitalnega proučevanja prečnih vibracij valjev z gumijasto oblogo in valjev za ploščo pri rotacijskem ofsetnem tiskarskem stroju.

Da bi bili rezultati raziskave čimbolj pomembni, smo preučevanje opravili na pogosto rabljenem ofsetnem tiskarskem stroju za obojestransko tiskanje s štirimi valji, od katerih imata dva valja gumijasto oblogo in med njima drsi papirni trak, druga dva pa sta valja za ploščo (tiskarski stroji s šestimi ali tremi valji se prav tako uporabljajo, čeprav bolj redko; in metoda ter računalniški program, uporabljena v naši raziskavi, se lahko prenašata tudi na te stroje).

Shema tiskarskega stroja je prikazana na sliki 4. Stroj sestoji iz valjev z gumijasto oblogo, (2) in (3), ki po celotni dolžini pritiskata drug ob drugega in imata delovno površino obloženo z plastjo elastičnega gumijastega materiala (6). Papirni trak (5) drsi med dvema valjema z gumijasto oblogo. Valja za ploščo sta prikazana z (1) in (4).

Premeri delovnih površin vseh valjev so enaki in valji se vrtijo prek zobnikov z enako vrtilno hitrostjo. Valji se vrtijo na krogličnih ležajih (7).

2 OBJECT OF THE INVESTIGATION

The problem we examined was the absolute and relative transversal vibrations of the blanket and plate cylinders of a web printing press, paying particular attention to the relative vibrations between cylinders in order to reduce their intensity. This study included:

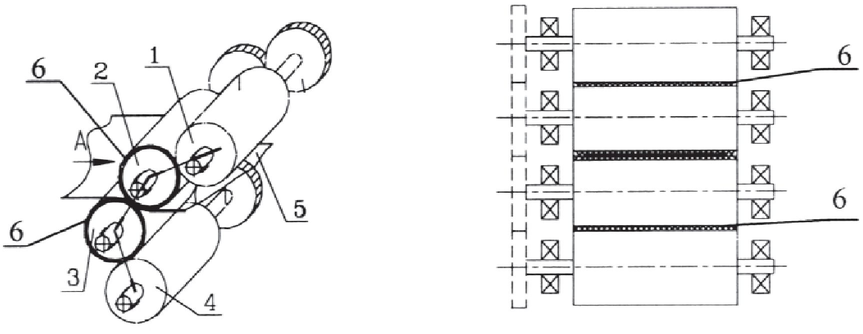
- an examination of the free transversal vibrations of the cylinders;
- an examination of the forced vibrations, excited in a kinematic way by the inaccuracy of the ball bearings in the cylinders as well as the vibrations of the frame of the press, the inaccuracies of the working surfaces of the cylinders (ovality, etc);
- an examination of the vibrations caused by the blanket locks of the blanket cylinders on the rotation of cylinders that are pressed against each other.

In order to investigate the problem a universal method for an analog-digital examination of the transversal vibrations of the blanket and plate cylinders of web printing presses has been developed.

To make the problems under discussion directly relevant, a widely used double-sided offset printing press with four cylinders, consisting of two blanket cylinders with the paper tape running between them, and two plate cylinders, was chosen as the subject (printing presses with six and three cylinders are also used, although more rarely; however, the method and the software used in this work, also apply to them).

A schematic diagram of the printing press is shown in Fig. 4. It consists of the blanket cylinders (2) and (3), pressed against each other, with their working surfaces coated with a layer of elastic rubber-like blanket material (6) along the generatrices of the cylinders. The paper tape (5) runs between the blanket cylinders. The plate cylinders are (1) and (4).

The diameters of the working surfaces of all the cylinders are the same, and the cylinders are rotated with the same rotational speed via gears. The cylinders rotate on ball bearings (7).



a) b)

Sl. 4. *Tiskarski stroj (a - skupina valjev, b - razgrnitev pogleda v smeri A)*
Fig. 4. *The printing press (a - cylinders' group, b - unfolded view in direction A)*

3 DINAMIČNI IN MATEMATIČNI MODEL TISKARSKEGA STROJA

Za potrebe raziskovanja prečnih vibracij valjev smo izdelali dinamični model preučevanega sistema. Shema tega modela je prikazana v diagramu 5. Z uporabo modela lahko ocenimo prečne krivine valjev in odstopanja, ki jih le-te povzročajo, elastičnost krogličnih ležajev v valjih (upoštevajoč dušenje), nenatančnosti ležajev ter elastičnost in dušenje gumijastih oblog. Delovne površine valjev (z napakami ali brez njih) so razdeljene v valjaste končne elemente in mesta, na katerih so montirani ležaji, imajo obliko prisekanega stožca.

Gumijasti oblogi sta simulirani s pomočjo ločenih, elastičnih elementov, skupaj z dušenjem; ti elementi povezujejo zaključke končnih elementov dveh sosednjih valjev. Elastičnost gumijastih oblog je nelinearna. Za to raziskavo vibracij je elastičnost linearizirana v materialih svoje statične deformacije, ob tem ko valji pritiskajo drug ob drugega. Togost in dušenje ločenih elastičnih elementov, ki simulirajo gumijasto oblogo in ležajne enote, sta izračunani na podlagi literature [6] do [9].

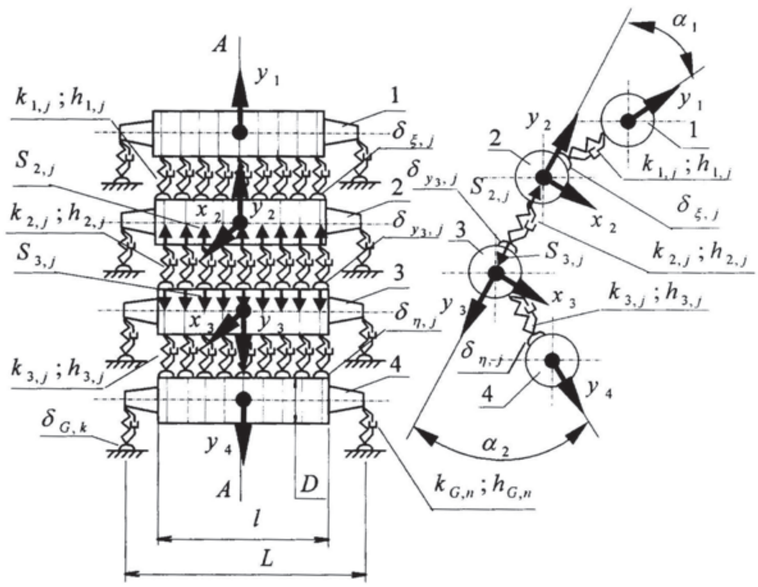
Kroglični ležaji in njihova nenatančnost so simulirani na poenostavljen način, tako da so njihove značilnosti v približku enake značilnostim elastičnih in dušilnih elementov (koeficienta togosti in upora sta k in h z ustreznimima indeksoma). Nenatančnost ležajev je simulirana s kinematično vzbujevanimi elementi (ti so povezani v zaporedje z elastičnimi in dušilnimi elementi); njihova velikost $\delta_{G,k}$ se spreminja glede na vnaprej določeno zakonitost (slika 5). Kinematično vzbujanje sistema prek dna okrova je simulirano enako kakor nenatančnost ležajev. Razlikujejo se le specifične oblike njunega kinematičnega vzbujanja $\delta_{G,k}$. Netočnosti delovnih površin valjev (odstopanja od idealne površine valja) so simulirane s kinematično vzbujevanimi elementi,

3 A DYNAMICAL AND MATHEMATICAL MODEL OF THE PRINTING PRESS

For the investigation of the transversal vibrations of the cylinders a dynamic model of the system under examination was set up. The scheme of the model is presented in Fig. 5. The model evaluates the transversal bends of the cylinders and the deviations caused by them, the elastic shifts of the ball bearings in the cylinders (including damping), the inaccuracies of the bearings, and the elasticity and damping of the blankets. The working surfaces of the cylinders (with or without holes) are divided into cylindrical finite elements, and the places where the bearings are fitted have the shape of a truncated cone.

The blankets are simulated by discrete spring-type elastic elements with damping; these elements connect the ends of the finite elements of two adjacent cylinders. The elasticity of the blankets is non-linear. For this investigation of the vibrations the elasticity is linearized in the media of its static deformation pressing of the cylinders against each other. The stiffness and damping of the discrete elastic elements that simulate the blanket and the bearing units are calculated on the basis of references [6] to [9].

The ball bearings and their inaccuracy are simulated in a simplified way by approximating them with elastic and damping elements (their coefficients of stiffness and resistance are k and h, respectively, with the corresponding indexes). The inaccuracy of the bearings is simulated by kinematic excitation elements (they are connected in series with the elastic and damping elements), and their size $\delta_{G,k}$ varies according to the set regularity (Fig. 5). The kinematic excitation of the system via the foundations is simulated in the same way as the inaccuracy of the bearings. Only the specific expressions of the kinematic excitation $\delta_{G,k}$ differ. The inaccuracies of the working surfaces of the cylinders (the deviations from the ideal surface of a cylinder) are simulated by



Sl. 5. *Shematični prikaz splošnega dinamičnega modela tiskarskega stroja; y_1 do y_4, x_2, x_3 so posplošene koordinate, ki določajo elastične linearne pomike srednjih delov valjev pa tudi smeri vibracij valjev, izbranih za namen raziskave*

Fig.5. *Schematic diagram of the general dynamic model of the printing press; y_1 to y_4, x_2, x_3 are the generalized coordinates defining the elastic linear shifts of the middle parts of the cylinders, which also show the directions of the vibrations of these cylinders, chosen for the research*

spreminjajo se glede na vnaprej določene zakonitosti $\delta_{\xi,j}$, $\delta_{y3,j}$, $\delta_{\eta,j}$.

Tovrstna simulacija netočnosti med valji je prikazana na skliki 5. Vsak kinematično vzbujevan element simulira netočnost površin dveh valjev, ki se na določeni točki dotikata prek gumijaste obloge. Na sliki 5 so prikazane le linearne posplošene koordinate y_1 do y_4, x_2 in x_3, ki določajo pomike osrednjih delov valjev (druge koordinate, ki določajo elastične pomike končnih elementov, niso prikazane). V dinamičnem modelu so koordinate, ki opisujejo absolutne vibracije valjev in so uporabljene v postopku našega izračuna, zamenjane s posplošenimi koordinatami, ki opisujejo relativne vibracije med valji.

Zaradi zahtevnosti dinamičnega modela (dinamični model, prikazan v diagramu 5, ima 168 prostostnih stopenj) je matematični model (enačbe vibracij), ki je nastal na podlagi dinamičnega modela, oblikovan tako, da uporablja poseben algoritem in posebno programsko opremo. Za potrebe poenostavitve in avtomatizacije oblikovanja enačb preučevani sistem vibracij umetno razdelimo na preproste, neodvisne podsisteme in izdelamo pomožne dinamične modele teh podsistemov. To dosežemo z umetno “prekinitvijo” dotika robov elementov, ki simulirajo gumijasto oblogo, z enim od dveh valjev; oba valja sta sicer prek teh elementov vključena v celoten dinamični model. V začetni fazi se enačbe vibracij oblikujejo posebej za vsak posamezen podsistem, kasneje pa se enačbe vibracij, s posebnimi povezovalnimi enačbami, tudi za celoten sistem.

Gumijasto oblogo po vsej dol□ini pritrdimo na ustrezni valj. Za njeno pritrditev uporabljamo

kinematic excitation elements, varying according to the set regularities $\delta_{\xi,j}$, $\delta_{y3,j}$, $\delta_{\eta,j}$.

Such a simulation of the inaccuracies between the cylinders is shown in Fig. 5. Each kinematic excitation element simulates the inaccuracies of the surfaces of both cylinders, contacting via the blanket, at a specific point. In Fig. 5 only the linear generalized coordinates y_1 to y_4, x_2 and x_3, identifying the shifts of the middle parts of the cylinders, are indicated (other coordinates, identifying the elastic shifts of the finite elements, are not shown). In the dynamic model, the coordinates describing the absolute vibrations of the cylinders that are used in the course of the calculation are replaced with generalized coordinates describing the relative vibrations between the cylinders.

Because of the complexity of the dynamic model (the dynamic model shown in Fig. 5 has 168 degrees of freedom), the mathematical model (the equations of the vibrations), which is developed from it, is formed using a special algorithm and software. In order to simplify and computerize the formation of the equations the vibration system under examination is artificially divided into simpler, independent sub-systems, and auxiliary dynamic models of the sub-systems are developed. This is achieved by an artificial “disconnection” of the ends of the blanket-simulating elements from one of two cylinders, which are connected by the elements in the overall dynamic model. Initially, the equations of the vibrations are formed separately for each sub-system, and then, using specially developed link equations, the equations of the vibrations for the overall system are formed.

The blanket is fitted to a blanket cylinder along its generatrix. Special locks in the shape of thin metal posebni zaponki v obliki tankih kovinskih ploščic. Med vrtenjem valjev delovne površine ti zaponki pritiskata druga ob drugo prek gumijaste obloge in povzročata utrip udarcev. Posledica tega je, da valja pričneta vibrirati. Kota vrtenja valjev z gumijasto oblogo, (2) in (3), sta naravnana tako, da se zaponki obeh valjev dotakneta v istem trenutku vrtenja. V tem trenutku pride do udarca, ki povzroča vibracije valjev. V pričujoči študiji izračunavamo le udarec med valjema z gumijasto oblogo (2) in (3), (lahko pa bi izračunali tudi udarca med valji (1) in (2) ali (3) in (4)).

Udarec simuliramo z utripnimi silami $S_{2,k}$ in $S_{3,k}$, ki delujejo vzdolž koordinat $y_{2,i}$ in $y_{3,i}$ (sl. 5). Oblika pulziranj je polsinusoidna (sl. 6), to je $S_{j,k}=A_{j,k}\cdot\sin\nu t$, kadar je $0 \le t \le \pi/\nu_s$ in časovno obdobje π/ν_s kratko.

Oblikovanju dinamičnih modelov posameznih podsistemov sistema, prikazanega na sliki 5, sledi oblikovanje matematičnega modela (enačbe vibracij), ki poteka v dveh fazah. V prvi fazi s programsko opremo in na podlagi dinamičnih modelov posameznih podsistemov oblikujemo enačbe prostih vibracij. Za ta namen uporabimo programsko opremo BEMSK [9], ki je posebej prilagojena izvajanju tovrstnih rešitev. Ta programska oprema je bila zasnovana za vzpodbujanje prostih prečnih vibracij gredi (v tem primeru gre za valja za ploščo in valja z gumijasto oblogo) in uporablja metodo končnih elementov, pri čemer upošteva elastičnost in dušenje njunih ležajev.

Enačba za vsak podsistem, na primer za podsistem k-th, je naslednja:

plates are used for this fitting. During the rotation of the cylinders, the working surfaces are pressed against each other via the blanket, and such locks excite shock pulses. The result is that the cylinders begin to vibrate. The angles of rotation of the blanket cylinders (2) and (3) are adjusted in such a way that the locks of both cylinders come into contact at the same moment during their rotation. At that moment the shock that causes the vibrations of the cylinders appears. In this study only the shock between the blanket cylinders (2) and (3) is evaluated (it could, however, be evaluated between the cylinders (1) and (2), and between (3) and (4)).

The shock is simulated by the force pulses $S_{2,k}$ and $S_{3,k}$, acting along the coordinates $y_{2,i}$ and $y_{3,i}$ (Fig. 5). The shape of the pulses is half-sinusoidal (Fig. 6), i.e., $S_{j,k}=A_{j,k}\cdot\sin\nu t$, when $0 \le t \le \pi/\nu_s$, and the time period π/ν_s is short.

Having obtained the dynamic models of the sub-systems of the system, shown in Fig. 5, the mathematical model (the equations of the vibrations) is formed in two stages. In the first stage a computer-aided formation of the equations of free vibrations according to the dynamic models of separate sub-systems is carried out. In order to do this we used BEMSK software [9], specially modified to solve the above-mentioned problems. The software was designed for the development of the free transversal vibrations of shafts (in this case the plate and blanket cylinders), using the method of finite elements, and taking into account the elasticity and damping of their bearings.

The equations for each sub-system, for example, the k-th sub-system, are as follows:

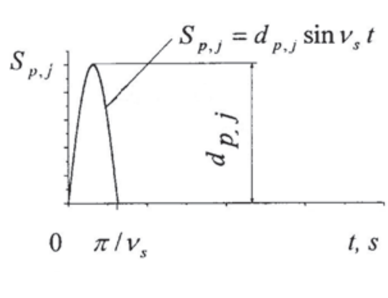
$$[A]_k \left\{\ddot{q}\right\}_k + [B]_k \left\{\dot{q}\right\}_k + [C]_k \left\{q\right\}_k = 0 \quad (k = 1,...,m) \tag{1}$$

kjer so $[A]_k$, $[B]_k$, in $[C]_k$ matrike vztrajnosti, dušenja in togosti k-tega podsistema; $\{q\}_k$ je vektor njegovih posplošenih koordinat, čigar komponente so posplošene koordinate, ki določajo lego k-tega podsistema; m = 6 pa označuje število podsistemov.

V drugi fazi, po opravljenem izračunu zunanjih vzbujevalnih sil, ki delujejo na podsisteme in po kinematičnem vzbujanju ležajev, sestavimo

where $[A]_k$, $[B]_k$, and $[C]_k$ are the matrices of the inertia, the damping and the stiffness of the k-th sub-system; $\{q\}_k$ is the vector of its generalized coordinates, the components of which are the generalized coordinates identifying the position of the k-th system; *and m* = 6, the number of sub-systems.

In the second stage, after an evaluation of the external excitation forces affecting the sub-systems, and



Sl. 6. *Približek spreminjanja sil $S_{p,j}(t)$, ki se pojavi kot posledica udarca zaponk*

Fig. 6. *The approximation of the variation of the forces $S_{p,j}(t)$, appearing as a result of the shock caused by the locks*

pomožen sistem enačb vibracij, pri katerem povezave med podsistemi še niso ocenjene:

the kinematic excitation of the bearing, an auxiliary system of the equations of vibrations is formed where the links between the sub-systems are not yet evaluated.

$$[A]_0\left\{\ddot{q}\right\}_0+[B]_0\left\{\dot{q}\right\}_0+[C]_0\{q\}_0=\{P(t)\}_0 \qquad (2),$$

kjer je matrika $[A]_o$ sestavljena iz matrik $[A]_k$, ki so na njeni diagonali; matriki $[B]_0$ in $[C]_0$ sta sestavljeni iz analogno nameščenih matrik $[B]_k$ in $[C]_k$; $\{q\}_0$ – je vektor, čigar komponente so posplošene koordinate, ki so vključene v vse enačbe (1); $\{P(t)\}_0$ – je vektor posplošenih zunanjih sil, iz katerih se sestavijo od nič različne komponente posplošenih sil, ki vplivajo na posamezne podsisteme:

where the matrix $[A]_o$ is composed of the matrices $[A]_k$ located on its diagonal, the matrices $[B]_0$, $[C]_0$ – of the analogously situated matrices $[B]_k$ or $[C]_k$; $\{q\}_0$– the vector with which the components are the generalized coordinates included into all the equations (1); $\{P(t)\}_0$ – the vector of the generalized external forces with which non-zero components are formed of the generalized forces affecting separate sub-systems:

$$\{P(t)\}_0=\{F(t)\}_0+\{F_B(t)\}_0 \qquad (3),$$

kjer je $\{F(t)\}_0$ vektor, pri katerem so od nič različne kompnente posplošene sile udarcev zaponk $S_{j,k}$; $\{F_B(t)\}_0$ je vektor, s katerim se sestavijo od nič različne koordinate elementov nenatančnosti ležajev pri kinematičnem vzbujanju prek dna okrova in netočnosti delovnih površin valjev.

S pomožnim sistemom enačb vibracij (2) in povezovalnih enačb ter ob uporabi posebnega algoritma in programske opreme DJOINX [9], ki sta prilagojena za naše potrebe, lahko ustvarimo splošni sistem enačb, ki opisujejo vibracije celotnega sistema:

where $\{F(t)\}_0$ is the vector with which non-zero coordinates are the generalized forces $S_{j,k}$ of the blows of the locks; $\{F_B(t)\}_0$ is the vector with which non-zero coordinates are formed of the elements of the inaccuracy of bearings on a kinematic excitation via the foundation and the inaccuracies of the working surfaces of the cylinders.

Having the auxiliary system of the equation of vibrations (2) and the link equations, and using a special algorithm and the software DJOINX [9], modified for this case, the general system of equations describing the vibrations of the total system is obtained:

$$[A]\left\{\ddot{q}\right\}+[B]\left\{\dot{q}\right\}+[C]\{q\}=\{P(t)\} \qquad (4),$$

kjer je $\{q\}$ vektor posplošenih koordinat, ki enoznačno določi lego tiskarskega stroja pri vibriranju; $[A]$, $[B]$, $[C]$ – kvadratne matrike vztrajnosti, dušenja in togosti sistema pri redu n; $\{P(t)\}$ je vektor posplošenih sil, ki ga določimo z uporabo vektorja $\{P(t)\}_0$.

where $\{q\}$ is the vector of the generalized coordinates, monosemantically identifying the position of the printing press on vibrations; $[A]$, $[B]$, $[C]$ – the square matrices of inertia, damping and stiffness of the system of the n-th order; $\{P(t)\}$ is the vector of the generalized forces, found using the vector $\{P(t)\}_0$.

4 REŠITVE ENAČB

Za nadaljnjo računalniško analizo prostih in vsiljenih vibracij tiskarskega stroja uporabljamo sistem enačb (4), čigar rešitve dobimo z uporabo modalne metode, temelječe na uporabi normaliziranih koordinat Bulgakova (NBK) ([9] in [10]). Uporabljamo posebne algoritme in programsko opremo DDINCHAR, ki je razvita na njihovi podlagi in prirejena potrebam naših raziskovanj. Potek rešitve je naslednji:

Sprva določimo korene karakteristične enačbe in lastnih vektorjev sistema (4), ki predstavljajo tudi oblike lastnih nihajnih načinov valjev ob upoštevanju dušenja. Nato, na podlagi normaliziranih koordinat Bulgakova, sestavimo enačbe (4). V primeru naše raziskave vsak kompleksni skupni koren $\varepsilon_h \pm i\omega_h$ ustreza dvema diferencialnima enačbama prvega reda v normaliziranih koordinatah

4 SOLUTIONS OF THE EQUATIONS

For a further computer analysis of the free and forced vibrations of the printing press the system of equations (4) is used, with which solutions are found using the modal method based on an application of the normalized Bulgakov's coordinates (NBK) ([9] and [10]). Special algorithms and the software DDINCHAR, developed on their basis and modified to solve the problems under discussion, were used. The course of the solution is the following.

The roots of the characteristic equation and the eigenvectors of the system (4), which are also the shapes of the eigenvibrations of the cylinders, taking into account the damping, are found. Next, equations (4) are formed in normalized Bulgakov's coordinates. In the case under examination each complex joint root $\varepsilon_h \pm i\omega_h$ corresponds to two differential equations of the first order in the normalized Bulgakov's coordinates

Bulgakova, ζ_h in ζ_{n+h}, ki ju ne omejujejo druge enačbe:

ζ_h and ζ_{n+h}, not bound with other equations:

$$\begin{cases} \dot{\zeta}_h - \varepsilon_h \zeta_h - \omega_h \zeta_{n+h} = \Phi_h(t); \\ \dot{\zeta}_{n+h} + \omega_h \zeta_h - \varepsilon_h \zeta_{n+h} = \Phi_{n+h}(t); \end{cases} \qquad (5),$$

kjer sta Φ_h(t) in Φ_{n+h}(t) komponenti 2n-razse nega vektorja $\{\Phi(t)\}$, ki ga dobimo pri določeni premeni vektorja $\{P(t)\}$.

where: Φ_h(t), Φ_{n+h}(t) are the components of the 2n-dimensional vector $\{\Phi(t)\}$, found on a certain transformation of the vector $\{P(t)\}$.

Rešitve enačb (5) zlahka dobimo na analitičen način; algoritme njihovih rešitev pa zlahka programiramo. Ko pridobimo vrednosti koordinat ζ_h in ζ_{n+h}, lahko določimo tudi vrednosti koordinat $\{q\}$.

The solutions of equations (5) are easily found in an analytical way; the algorithms of their solutions are easily programmed. Having obtained the values of the coordinates ζ_h and ζ_{n+h}, the values of the coordinates $\{q\}$ can be found as well.

Iz opisanih enačb smo razvili programsko opremo, s katero lahko raziščemo vibracije valjev za ploščo in valjev z gumijasto oblogo, ki so povezani prek gumijaste obloge. Poglavitna prednost te metode je razčlenjenost zahtevnega sistema (4) v veliko bolj preproste, neodvisne podsisteme, ki omogočijo oceniti linearno dušenje sistema, in za katere praktično ne vpeljemo nobenih omejitev.

On the basis of the above-described equations the software was developed to investigate the vibrations of the plate and the blanket cylinders connected via the blanket. The main advantage of this method is a division of the complicated system (4) into much simpler, independent sub-systems to evaluate the linear damping of the system, to which practically no restrictions are applied.

Z uporabo iste metode lahko pridobimo tudi podatke za dušene proste vibracije sistema.

In addition, the data for damped free vibrations of the system can be found using the same method.

5 PREČNE VIBRACIJE VALJEV

5 TRANSVERSAL VIBRATIONS OF THE CYLINDERS

Raziskali smo absolutne in relativne vibracije valjev. Posebno pozornost smo posvetili relativnim prostim in vsiljenim vibracijam valjev vzdolž naslednjih koordinat (sl. 5):

Absolute and relative vibrations of the cylinders were examined. A particular attention was paid to the relative free and forced vibrations of the cylinders along the following coordinates (Fig. 5):

$$\begin{aligned} \gamma_{1,2} &= y_1 - y_2 \cos\alpha_1 - x_2 \sin\alpha_1; \\ \gamma_{3,4} &= y_4 - y_3 \cos\alpha_2 - x_3 \sin\alpha_2; \\ \gamma_{2,3} &= y_2 + y_3;\ \gamma_x = x_2 - x_3. \end{aligned} \qquad (6).$$

Po spremembi posplošenih koordinat (razlike) $\gamma_{1,2}$, $\gamma_{2,3}$ in $\gamma_{3,4}$ pride do spremembe pritiska med valji, ki pritiskajo drug ob drugega prek gumijaste obloge in kakovost tiska se poslabša. Vibracije vzdolž γ_x tudi niso zaželene.

After changing the generalized coordinates (differences) $\gamma_{1,2}$, $\gamma_{2,3}$, $\gamma_{3,4}$ a change in the pressure between the cylinders that are pressed against each other via the blanket takes place, and the quality of the prints deteriorates. Vibrations along γ_x are also not desirable.

Relativne prečne vibracije valjev v smeri posplošenih koordinat $\gamma_{1,2}$, $\gamma_{2,3}$ in $\gamma_{3,4}$ so v nadaljnjem besedilu imenovane *relativne vibracije v smereh pritiska valjev;* relativne vibracije valjev z gumijasto oblogo, ki potekajo v smeri pravokotno na prej omenjene vibracije in vzdolž posplošene koordinate γ_x pa so imenovane *relativne obodne vibracije valjev z gumijasto oblogo*.

The relative transversal vibrations of the cylinders in the directions of the generalized coordinates $\gamma_{1,2}$, $\gamma_{2,3}$, $\gamma_{3,4}$ are referred to in the remainder of the text as the *relative vibrations in the pressing directions of the cylinders;* and the relative vibrations of the blanket cylinders in the direction perpendicular to these vibrations, along the generalized coordinate γ_x, are referred to as the *relative tangential vibrations of the blanket cylinders*

Oblike vsiljenih resonančnih harmoničnih vibracij se rahlo razlikujejo od značilnih oblik lastnega nihajnega načina. Resonančne frekvence so v približku najpogosteje enake naravnim frekvencam. Poleg tega so prehodne frekvence vibracij valjev, ki jih povzročajo udarci zaponk gumijaste obloge, frekvence prostih vibracij. Določitev naravnih frekvenc sistema omogoča vpogled v dragocene podatke o vsiljenih vibracijah. Večino naše pozornosti namenimo raziskavi

The shapes of the forced resonance harmonic vibrations differ slightly from the eigenshapes of the eigenvibrations, and the resonance frequencies most frequently approximately coincide with the natural frequencies. In addition, the frequencies of the vibrations of the cylinders on the transients, which are caused by the shocks of the blanket locks, are the frequencies of the free vibrations. Determining the natural frequencies of the system provides valuable information about the forced vibrations. Most attention relativnih vibracij v smereh pritiska valjev. Preiskujemo pa tudi odvisnost relativnh obodnih vibracij valjev z gumijasto oblogo od relativnih vibracij.

5.1 Proste vibracije

Proučevali smo korene karakteristične enačbe preučevanega sistema, naravne frekvence (imaginarni deli korenov) in oblike lastnih nihajnih načinov $\{V\}_h$, pri čemer smo upoštevali tudi dušenje sistema. Izkazalo se je, da kadar so vsi parametri (izmere, masa, togost in dušenje) in dinamične karakteristike vseh valjev enaki, lahko ugotovimo specifične značilnosti prostih vibracij stroja (takšen stroj odslej imenujemo stroj z enakimi valji).

Če je izpolnjen omenjeni pogoj, potem so tri najnižje naravne frekvence tiskarskega stroja enake isti ponovljeni naravni frekvenci: $\omega^*=\omega_1=\omega_2=\omega_3$. Ponovijo se tudi koreni karakteristične enačbe: $\gamma_{1,2}$, $\gamma_{2,3}$ in $\gamma_{3,4}$. Frekvenca ω^*, ki je enaka najnižji naravni frekvenci kateregakoli valja z elastično oporo, ustreza trem različnim oblikam lastnih nihajnih načinov $\{V\}_1$, $\{V\}_2$, $\{V\}_3$. V smereh pritiska valjev ni nobenih modalnih relativnih vibracij s frekvenco ω^*.

Slika 7a prikazuje dejanske dele oblik relativnih lastnih nihajnih načinov tiskarskega stroja z različnimi valji. Valja z gumijasto oblogo (2 in 3) sta votla in njune dinamične karakteristike se razlikujejo od karakteristik valjev za ploščo (1 in 4) glede na najnižjo naravno frekvenco ω_1. (Imaginarni deli niso prikazani, ker so v našem primeru zelo majhni.)

Na osi x je razdalja l med oporama valjev nespremenljiva. Krivulja 1 ustreza obliki relativnih vibracij vzdolž posplošene koordinate $\gamma_{1,2}$, krivulja 2 ustreza koordinati $\gamma_{2,3}$, krivulja 3 ustreza koordinati $\gamma_{3,4}$ in krivulja 4 ustreza koordinati γ_x. Obliki relativnih lastnih nihajnih načinov, ki ustrezata naravnim frekvencam ω_2 in ω_3, sta enaki. To pomeni, da so

is paid to investigating the relative vibrations in the pressing directions of the cylinders. The dependence of the relative tangential vibrations of the blanket cylinders on these vibrations is examined as well.

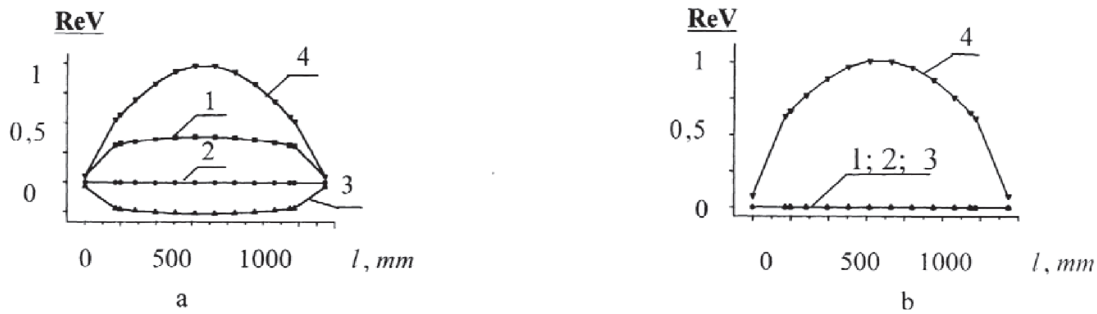
5.1 Free vibrations

The roots of the characteristic equation of the system under discussion, the natural frequencies (the imaginary parts of the roots), the shapes of the eigenvibrations $\{V\}_h$ were examined, taking into account the damping in the system. It was shown that if all the parameters (such as dimensions, mass, stiffness, and damping) and the dynamic characteristics of all the cylinders are the same, the specific features of the free vibrations of the equipment (such equipment hereinafter is referred to as equipment with the same cylinders) are obtained.

If the above-mentioned condition is satisfied, the three lowest natural frequencies of the printing press become equal to the same repeated natural frequency $\omega^*=\omega_1=\omega_2=\omega_3$. The roots $\gamma_{1,2}$, $\gamma_{2,3}$, $\gamma_{3,4}$ of the characteristic equation are repeated as well. The frequency ω^*, equal to the lowest natural frequency of any of the cylinders with elastic supports, corresponds to three different shapes of eigenvibrations $\{V\}_1$, $\{V\}_2$, $\{V\}_3$. No modal relative vibrations with the frequency ω^* in the pressing directions of the cylinders remain.

Fig. 7a shows the real parts of the shapes of the relative eigenvibrations of a printing press with different cylinders. The blanket cylinders (2 and 3) are hollow and their dynamic characteristics differ from those of the plate cylinders (1 and 4) in terms of the lowest natural frequency ω_1. (The imaginary parts are not shown, because in this case they are very small.)

On the x axis the distance l between the supports of the cylinders is fixed. The curve 1 corresponds to the shape of the relative vibrations along the generalized coordinate $\gamma_{1,2}$, the curve 2 corresponds to $\gamma_{2,3}$, the curve 3 corresponds to $\gamma_{3,4}$ and the curve 4 corresponds to γ_x. The shapes of the relative eigenvibrations corresponding to the natural frequencies ω_2 and ω_3 are the analogous. This



Sl. 7. *Značilne oblike relativnih prečnih vibracij valjev, ki ustrezajo trem najnižjim naravnim frekvencam (prikazani so le realni deli, imaginarni so premajhni): a – za sistem z različnimi valji; b – za sistem z enakimi valji*

Fig. 7. *The eigenshapes of the relative transversal vibrations of the cylinders, corresponding to the three lowest natural frequencies (only the real parts, the imaginary parts are small): a – a system with different cylinders; b – a system with the same cylinders*

proste vibracije valjev s frekvencami ω_1, ω_2 in ω_3, kakor tudi vsiljene harmonične resonančne vibracije v razponu teh frekvenc, zadovoljivo določene s posplošenimi koordinatami y_1 do y_4, x_2 in x_3, ki so prikazane v diagramu 5. (Vibracije drugih delov valjev, ki ustrezajo isti frekvenci, se razlikujejo le po velikosti).

Slika 7b prikazuje realne komponente ene izmed značilnih oblik vibracij enoličnih (trdnih) valjev v smereh njihovih pritiskov, ki ustrezajo ponovljeni naravni frekvenci ω*. Krivulje 1, 2, 3, prikazane v diagramu 7a, ležijo na isti ravni črti in kažejo, da so preostale zgolj relativne obodne proste vibracije valjev z gumijasto oblogo (krivulja 4, diagram 7b). Na enak način lahko določimo dve drugi značilni obliki prostih vibracij (le-ti tu nista prikazani), ki ustrezata frekvenci ω*.

5.2 Vsiljene vibracije

Relativne periodične vibracije v smereh pritiska valjev, ki jih vzbudimo na kinematični način, smo raziskovali z uporabo amplitudno-frekvenčnih odzivov tiskarskega stroja z enakimi in tudi z različnimi valji. Kinematično harmonično vzbujanje, ki povzroča vibracije valjev, za katere smo izmerili amplitudne in frekvenčne odzive, je v približku enako harmoničnim funkcijam $\delta_k(vt)$. Le-te simulirajo nenatančnosti valjčnih ležajev oziroma vibracij dna okrova tiskarskega stroja.

6 REZULATATI IN OBRAVNAVA

Za frekvence do 500 Hz smo pridobili naslednje rezultate:

a) Intenzivnost harmoničnih vibracij pri tiskarskem stroju z enoličnimi valji kakor tudi intenzivnost periodičnih relativnih vibracij v smereh pritiska valjev je v vseh primerih manjša kakor pri tiskarskem stroju z različnimi valji. Intenzivnost relativnih obodnih vibracij ima v obeh primerih enak red.

b) V primeru tiskarskega stroja z različnimi valji smo najbolj intenzivne vibracije v smereh pritiska valjev opazovali v resonančnih področjih, ki ustrezajo najnižjim naravnim frekvencam, ω_1 do ω_4,tiskarskega stroja. V primeru enakih valjev ne pride do resonančnih vibracij v razponu ponovljene naravne frekvence ω*: intenzivnost vibracije določajo zgolj resonančna področja, ki ustrezajo višjim naravnim frekvencam.

c) Intenzivnost vsiljenih harmoničnih vibracij v smereh pritiska valjev v frekvenčnem razponu do 500Hz se znatno spreminja v odvisnosti od narave vzbujanja $\delta_k(vt)$ (vrednosti amplitud, lege njihovega delovanja in fazni pomiki med posameznimi vzbujanji). Takšni učinki so še posebej opazni pri tiskarskem stroju z enakimi valji.

means that the free vibrations of the cylinders with the frequencies ω_1, ω_2 and ω_3, as well as the forced harmonic resonance vibrations in the media of these frequencies, are sufficiently well identified by the generalized coordinates y_1 to y_4, x_2 and x_3 shown in Fig. 5. (The vibrations of the other parts of the cylinders corresponding to the same frequency differ only in terms of scale).

Fig. 7b shows the real components of one eigenshape of the vibrations of uniform (solid) cylinders in the directions of their pressing, corresponding to the repeated natural frequency ω*. The curves 1, 2, 3, shown in Fig. 7a, lie on the same straight line, showing that only the relative tangential free vibrations of the blanket cylinders (curve 4, Fig. 7b) remained. In the same way, two other eigenshapes of the free vibrations (not shown here), corresponding to the frequency ω*, are found.

5.2 Forced vibrations

Relative periodic vibrations in the pressing directions of the cylinders, excited in a kinematic way, were explored by an application of the frequency response method to a printing press with the same, and with different, cylinders. The kinematic harmonic excitation causing the vibrations of the cylinders, for which the amplitude and frequency responses were measured, is approximated with the harmonic functions $\delta_k(vt)$. They simulate the inaccuracies of the cylinders' bearings or the vibrations of the foundation of the press.

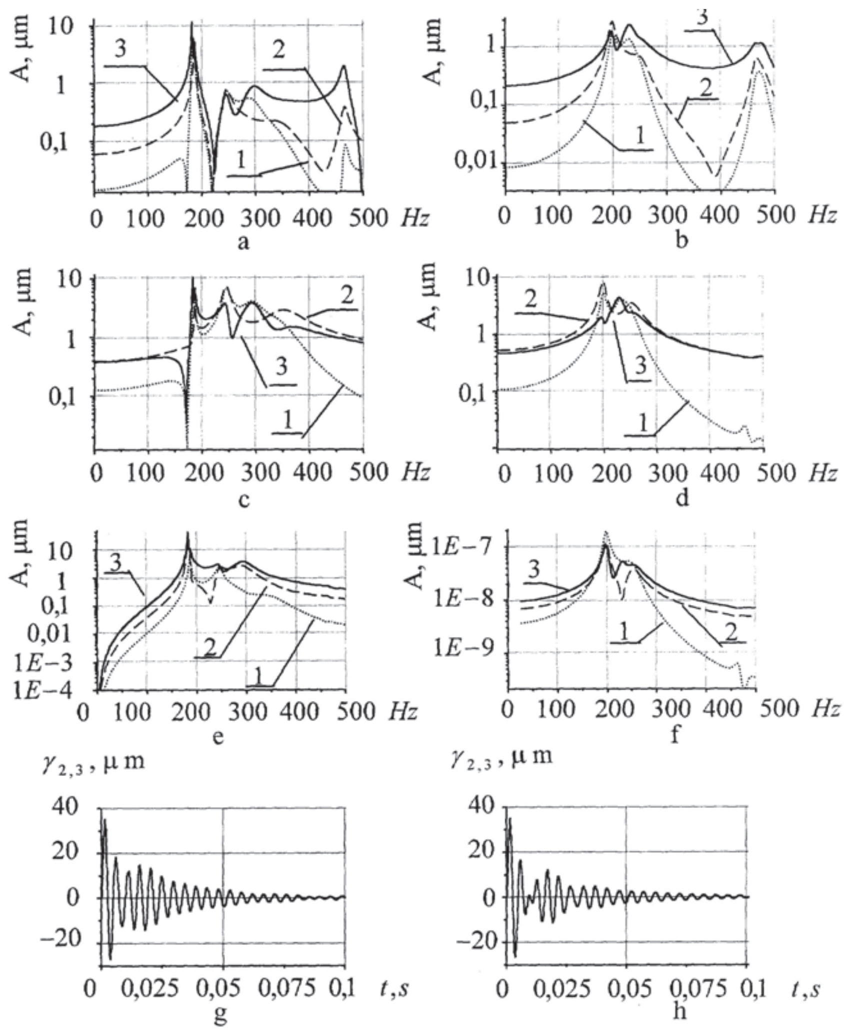
6 RESULTS AND DISCUSSION

For frequencies up to 500 Hz the following results were obtained.

a) For a printing press with uniform cylinders the intensity of the harmonic vibrations, as well as the periodic relative vibrations in the pressing directions of the cylinders, is in all cases less than in a printing press with different cylinders. The intensity of the relative tangential vibrations is of the same order in both cases.

b) For a printing press with different cylinders the most intense vibrations in the pressing directions of the cylinders are observed in the resonance zones that correspond to the lowest natural frequencies,ω_1 to ω_4, of the press. If the cylinders are the same, there are no resonance vibrations in the media of the repeated natural frequency ω*: the intensity of the vibration is defined only by the resonance zones corresponding to higher natural frequencies.

c) The intensities of the forced harmonic vibrations in the pressing directions of the cylinders in the frequency range up to 500Hz vary considerably, depending on the character of the excitations $\delta_k(vt)$ (the values of their amplitudes, their locations of action and the phase shifts between separate excitations). Such an effect is particularly noticeable in a printing press with the same cylinders.



Sl. 8. *Amplitudno-frekvenčni odzivi relativnih prečnih vibracij valjev tiskarskega stroja (a, c, e – za stroje z različnimi valji; b, d, f – za stroje z enakimi valji; krivulja 1 – amplitudno-frekvenčni odzivi za $\gamma_{1,2}$, krivulja 2 – amplitudno-frekvenčni odzivi za $\gamma_{2,3}$, krivulja 3 – amplitudno-frekvenčni odzivi za $\gamma_{3,4}$) in relativne vibracije valjev z gumijasto oblogo, ki jih povzročajo udarci zaponk gumijastih oblog (g – različni valji, h – enaki valji)*

Fig. 8. *The amplitude and frequency responses of the relative transversal vibrations of the cylinders of a printing press (a, c, e – for presses with the different cylinders; b, d, f – for presses with uniform cylinders; the curves 1 – the amplitude and frequency responses according to $\gamma_{1,2}$, the curves 2 – the amplitude and frequency responses according to $\gamma_{2,3}$, the curves 3 – the amplitude and frequency responses according to $\gamma_{3,4}$) and the relative vibrations of the blanket cylinders caused by the shocks of the blanket locks (g – the different cylinders, h – the same cylinders)*

d) Amplitudno-frekvenčni odziv relativnih obodnih vibracij valjev z gumijasto oblogo pri tiskarskem stroju z enakimi valji ima le en resonančni vrh v razponu najnižje naravne frekvence katerega koli posameznega valja. Kadar pa so valji različni, pride do več manjših resonančnih vrhov. Primeri pridobljenih amplitudno-frekvenčnih odzivov so prikazani v diagramih 8a do 8f. Diagrama 8a, 8b prikazujeta amplitudno-frekvenčne odzive za vibracije, ki jih vzbudi netočnost levega ležaja valja za ploščo (4). Diagrama 8c, 8d prikazujeta vibracije, ki jih vzbudi enaka netočnost ležajev obeh valjev z gumijasto oblogo (3). V prvem primeru

d) In the amplitude and frequency response of the relative tangential vibrations of the blanket cylinders in a printing press with the same cylinders there is only a single resonance peak in the media of the lowest natural frequency of any separate cylinder. When the cylinders are different, several smaller resonance peaks appear. Examples of the obtained amplitude and frequency responses are presented in Fig. 8a–f. In Fig. 8a, b the amplitude and frequency responses for vibrations excited by an inaccuracy in the left-hand bearing of the plate cylinder (4) are shown. Fig. 8c, d shows the vibrations excited by the same inaccuracy of the bearings of both blanket cylinders (3). In the (a, b) je bila raven vibracij pri tiskarskem stroju z enakimi valji zmanjšana za približno desetkrat; tudi v drugem primeru (c, d) je bila raven vibracij zmanjšana, a v manjšem obsegu. Bistveno zmanjšanje vibracij istih valjev pa dosežemo v primeru navpičnega vzbujanja vibracij, ki ga povzroča vibriranje dna okrova tiskarskega stroja (Diag. 8e, 8f). Raziskovali smo tudi relativne vibracije v smereh pritiska valjev, ki jih povzročajo udarci zaponk gumijastih oblog. Vsak udarec povzroči prehodne pojave, ki so sestavljeni iz dušenih prostih vibracij. Pridobili smo naslednje rezultate.

e) Frekvence prehodnih pojavov približno ustrezajo dvem ali trem najnižjim naravnim frekvencam tiskarskega stroja.
f) V prehodnih pojavih, vzbujenih pri tiskarskem stroju z enakimi valji, ni komponent s ponovljeno naravno frekvenco ω^*.
g) Opazili smo povečanje relativnih pomikov med valji v obdobju vibriranja prvega prehodnega pojava, ko delujejo sile $S_{p,j}$ (prva amplituda relativnih vibracij prehodnega pojava je znatno višja od kasnejših amplitud).

Sliki 8g in 8h prikazujeta relativne vibracije med valjema z gumijasto oblogo (vzdolž posplošene koordinate $g_{2,3}$) v smereh pritiska valjev, ki jih povzročajo udarci zaponk gumijaste obloge. Za prikazana primera velja, da sta raven in trajanje vibracij v stroju z enakimi valji in v stroju z različnimi valji približno enaka, čeprav ne vsebujeta komponente, ki bi ustrezala ponovljeni naravni frekvenci ω^* prehodnega pojava, prikazanega na diagramih 10, h. Vzrok za to stanje je v dejstvu, da se v preučevanem primeru naravni frekvenci f_4, f_5 tiskarskega stroja z enakimi valji zgolj malenkostno razlikujeta od najnižjih frekvenc f_1, f_2 tiskarskega stroja z različnimi valji.

6.1 Vibracije, ki jih povzročajo nenatančnosti delovnih površin valjev

Predpostavljali smo, da so netočnosti na delovnih površinah valjev periodične. V času vrtenja valjev smo tovrstne netočnosti simulirali kot periodično kinematično vzbujanje. Dobljene učinke smo ocenili s pomočjo amplitudno-frekvenčnih odzivov. Pri tiskarskem stroju z enakimi valji smo opazili rahlo znižanje ravni vibracij.

7 ZANESLJIVOST REZULTATOV

Glede na dejanski sistem, ki je bil predmet naše raziskave, kakovost programske opreme in metode raziskave, obstajata dva poglavitna dejavnika, ki določata primernost dinamičnega in matematičnega modela. Primernost dinamičnega modela (računalniška

first case (a, b) the level of vibrations in the printing press with the same cylinders was reduced by about 10 times, and in the second case (c, d) it also was reduced, but not to such an extent. A very significant reduction in the vibrations of the same cylinders is obtained for the vertical excitation of vibrations via the vibrating foundation of the press (Fig. 8e, f). Relative vibrations, caused by the shocks of the blankets locks, in the pressing directions of the cylinders were explored as well. Each shock generates transients, consisting of damped free vibrations. The following results were obtained.

e) The frequencies of the transients are about the two or three lowest natural frequencies of the printing press.
f) There are no components with the repeated natural frequency ω^* in the transients excited in a printing press with the same cylinders.
g) An increase in the relative shifts between cylinders within the period of the vibration of the first transient, when the forces $S_{p,j}$ act, was observed (the first amplitude of the relative vibrations of the transient is considerably higher than the subsequent ones)

In Fig. 8g and 8h the relative vibrations between blanket cylinders (along the generalized coordinate $\gamma_{2,3}$) in the pressing directions of the cylinders, caused by the shocks of the blanket locks, are shown. For the shown cases, the level and duration of the vibrations in a printing press with the same cylinders and a printing press with different cylinders are approximately the same, although there is no component corresponding to the repeated natural frequency ω^* in the transient shown in Fig. 10h. This is caused by the fact that in the example under discussion the natural frequencies f_4, f_5 of the printing press with the same cylinders differ insignificantly from the lowest frequencies f_1, f_2, of the printing press with different cylinders.

6.1 Vibrations caused by an inaccuracy in the working surfaces of the cylinders

We have considered that the inaccuracies in the working surfaces of the cylinders may be periodic in character. During the rotation of the cylinders, such inaccuracies are simulated as a periodic kinematic excitation. There effects are also evaluated, using amplitude and frequency responses. A slight reduction in the level of vibrations was found in a printing press with the same cylinders.

7 THE RELIABILITY OF THE RESULTS

Two main factors determine the appropriateness of the dynamic and mathematical models in terms of the real system under investigation and the quality of the software and the method of investigation. The appropriateness of the dynamic model (the shema) temelji na dejstvu, da je le-ta zadovoljivo podroben in sestavljen iz elementov, ki simulirajo deformacijo valjev, pa tudi elastičnost ter dušenje gumijaste obloge in ležajev, saj uporablja metode omenjene v literaturi in dokazane s preizkusi ([2], [3], [6] do [8]). Za potrebe oblikovanja in izvedbe matematičnega modela (enačbe vibracij) smo uporabili metode in programsko opremo, ki so bili prevejeni v praksi [9]. Zaradi navedenega menimo, da so dobljeni rezultati dovolj zanesljivi.

8 SKLEPI

1. Predstavljena metoda računalniške simulacije prostih in vsiljenih prečnih vibracij valjev za ploščo in valjev z gumijasto oblogo rotacijskega ofsetnega stroja za obojestransko tiskanje je primerna za ocenitev delovanja stroja.
2. Pokazali smo, da se v primeru, ko so dinamični modeli in parametri vseh valjev enaki, tri najnižje naravne frekvence valjev, ki so med seboj povezani, ponovijo in da med valji ni več modalnih relativnih vibracij, ki bi jim ustrezale. S tem je zmanjšana intenzivnost prostih in vsiljenih relativnih vibracij.
3. Pokazali smo, da spreminjanje razdalje in s tem pritiska med valji, ki ga povzroči vibriranje valjev, lahko znatno spremeni kakovost tiskanja.

scheme of computing) is based on the fact that it is sufficiently detailed and is formed of elements that simulate the deformation of the cylinders as well as the elasticity and damping of the blanket and the bearings using methods mentioned in the references and proved in experiments ([2], [3], [6] do [8]). For the formation and solution of the mathematical model (equations of vibrations), the methods and software tested in practice were applied [9]. For this reason, it is considered that the reliability of the obtained results is sufficient.

8 THE CONCLUSIONS

1. The developed computer-simulation method for the free and forced transversal vibrations of the plate and blanket cylinders of the printing press of a double-sided web-offset printing press is appropriate for assessing the performance of the press.
2. It was shown that if the dynamic models and the parameters of all the cylinders are the same, the three lowest natural frequencies of the cylinders connected with each other are repeated, and no modal relative vibrations corresponding to them remain between the cylinders. This reduces the intensity of the free and forced relative vibrations
3. It was shown that varying the distance and, consequently, the pressure between the cylinders caused by the vibration of cylinders can result in a significant change to the printing quality.

9 LITERATURA
9 REFERENCES

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