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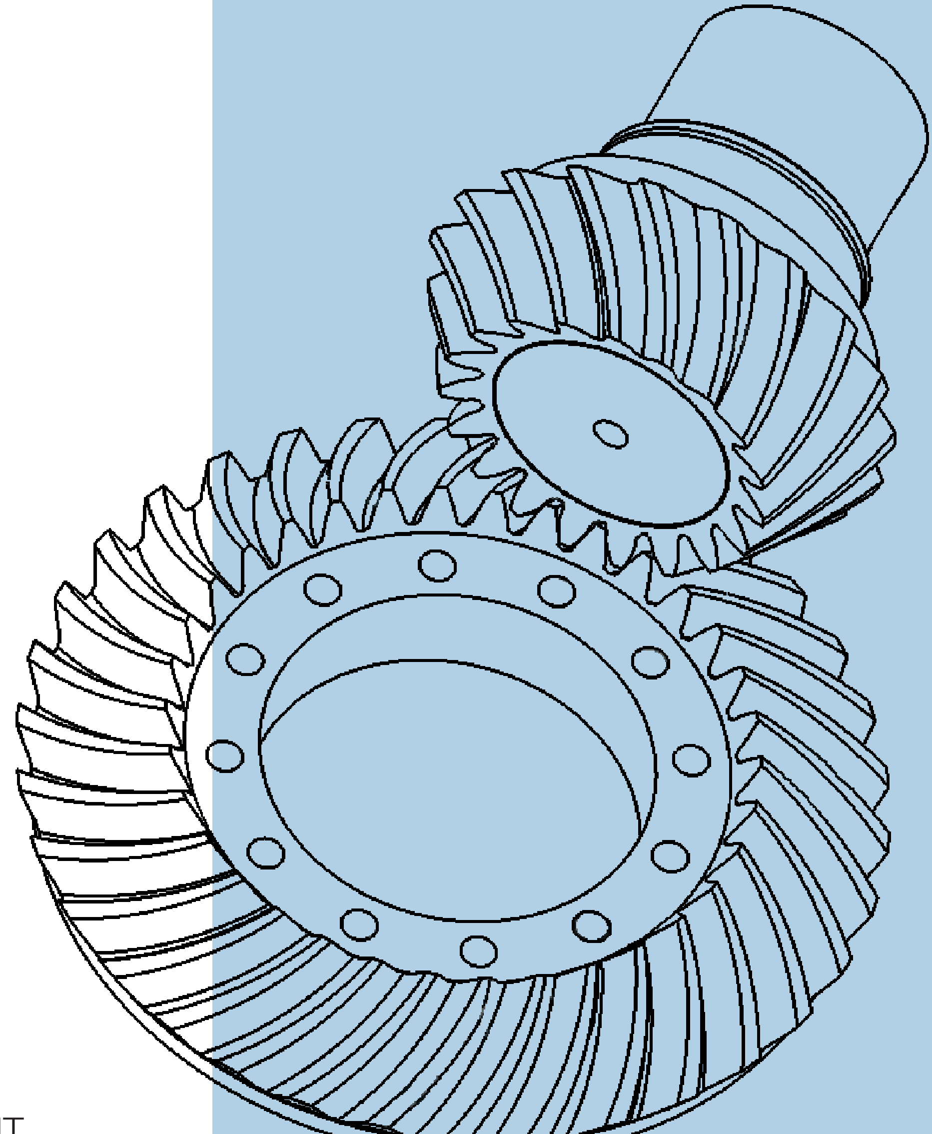

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Uvodnik - Editorial

Uvodnik - Editorial

Boris Černigoj (1915 – 2006)

Pred kratkim nas je zapustil prof. Boris Černigoj, dolgoletni profesor Fakultete za strojništvo Univerze v Ljubljani. Rodil se je v Innsbrucku, srednjo šolo z maturo je končal v Ljubljani, prva dva letnika univerzitetnega študija je opravil v Ljubljani na tedanjem Elektrostrojnem oddelku Tehnične fakultete, nadaljeval študij na zagrebškem vseučilišču, kjer je ob izbruhu druge svetovne vojne diplomiral za strojnega inženirja. Kmalu po diplomi leta 1941 ga je za rednega asistenta nastavil prof. Feliks Lobe, predstojnik tedanjega Zavoda za strojništvo Tehnične fakultete Univerze v Ljubljani. S tem je bila začrtana njegova uspešna pot visokošolskega pedagoga in znanstvenika, ki ji je ostal zvest polnih 39 let do svoje upokojitve leta 1980.

Prof. Černigoj je bil v letih 1941 do 1948 asistent, leta 1948 je postal docent, leta 1957 izredni in leta 1968 redni profesor. Na Fakulteti za strojništvo Univerze v Ljubljani je bil večkrat prodekan in v letih 1971 do 1973 tudi njen dekan. Od 1963 do 1982 je poučeval na Višji pomorski šoli v Piranu, sedanji Fakulteti za pomorstvo in promet.

Prof. Boris Černigoj pripada pionirski generaciji slovenskih visokošolskih pedagogov, ki so vzgajali prve generacije diplomiranih strojnih inženirjev in uspelo jim jih je zelo dobro pripraviti za hiter razvoj slovenske termoenergetike po drugi svetovni vojni. Nalogo je izpolnil vzorno, znal je poklic visokošolskega učitelja v pravi meri povezati s svojim znanstvenim in svojim zelo kakovostnim strokovnim delom. Prof. Černigoj je v letih po končani 2. svetovni vojni projektiral, konstruiral in dal v obratovanje več raznovrstnih strojev in naprav, vendar pa je njegovo zanimanje veljalo predvsem toplotnim pogonskim strojem: v prvih letih še aktualnim parnim batnim strojem, pozneje pa parnim in plinskim turbinam. Njegova ljubezen so bile plinske turbine, in to že tedaj, ko so bile plinske elektrarne na samo pri nas, ampak tudi v svetu še redek pojav. Upravičeno ga lahko imenujemo očeta toplotnih turbinskih strojev v Sloveniji. S svojim bogatim strokovnim znanjem je aktivno sodeloval pri postavitvi prvih plinskih postrojev v Sloveniji, ustvarjalno pa je pomagal graditi prav vse slovenske termoelektrarne.

Kot visokošolski učitelj je napisal vrsto učbenikov in drugih strokovnih ter znanstvenih publikacij. Tu naj bo omenjena knjiga "Parne turbine", ki je izšla pred 50 leti pri Državni založbi Slovenije, članek o plinskih turbinah, ki je izšel leta 1958 v reviji Strojniški vestnik, in knjiga "Osnove plinskih turbin", tiskana leta 1967 pri Univerzitetni založbi. Napisal je skupaj 25 pedagoških knjig, učbenikov in drugih učnih pripomočkov na več ko 3100 tiskanih straneh. To je dosežek, s katerim se tudi v današnjem času računalniške tehnike ne more pohvaliti veliko visokošolskih pedagogov.

Zelo aktivno je bilo tudi njegovo dolgoletno sodelovanje na področju slovenske strokovne terminologije pri Splošnem tehniškem slovarju in pri Slovarju slovenskega knjižnega jezika, predvsem pa pri reviji Strojniški vestnik, pri kateri je bil tudi član prvega uredniškega odbora. Zveza strojnih in elektrotehniških inženirjev in tehnikov tedanje Jugoslavije ga je leta 1956 imenovala za zaslužnega člana, Zveza inženirjev in tehnikov Slovenije pa leta 1972 za svojega častnega člana. Ob upokojitvi je za svoje delo prejel visoko jugoslovansko odličje "Red dela z zlatim vencem". Odlikovanje je prišlo v prave roke, za prof. Černigoja je mogoče napisati, da ga je s svojim vzornim delom in s svojim osebnim zgledom vsekakor zaslužil. Uredništvo Strojniškega vestnika mu je ob 50-letnici izhajanja revije podelilo častno plaketo. Strokovno delaven je bil še v globoki starosti. Napolnil je 85 let, ko je izdal zelo uporaben angleško-slovenski slovar za strojniško stroko.

Prof. Černigoj je bil rojen pedagog širokih pogledov in bogatega strokovnega znanja, osebno pošten in vsestransko razgledan strokovnjak, ki je aktivno obvladal več svetovnih jezikov. Študentom je bil strog, vendar zelo pravičen učitelj, inženirjem v industriji pa vedno dobrodošel strokovni sogovornik in svetovalec. Prav do konca svojega plodnega življenja je ostal skromen in duhovno prožen. Tedensko je prihajal na svojo »almo mater« na klepet ob kavi, ki se je včasih spremenil v pravo strokovno debato. Bil je tudi velik ljubitelj narave in navdušen gornik, ki je poznal veliko lepih in skritih kotičkov ljubih mu slovenskih gora.

Na ljubljanskih Žalah smo se dne 24. aprila poslovili od spoštovanega visokošolskega učitelja, priznanega strokovnjaka in pionirja plinskih in parnih turbin. Za njim žaluje in se ga spominja vsaj 35 generacij univerzitetnih diplomiranih inženirjev strojništva s slovenske industrije in z obeh slovenskih univerz.

prof.dr. Matija Tuma

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Merjenje izvedbe pri prenovi poslovnih tokov

Performance Measurement in Business Process Re-Engineering

Nataša Vujica Herzog - Andrej Polajnar - Petja Pižmoht
(Fakulteta za strojništvo, Maribor)

V prispevku sta podana razvoj in ovrednotenje sistema kazalnikov za merjenje uspešnosti prenove poslovnih tokov. Razvoj kazalnikov temelji na rezultatih anketne raziskave, ki je bila izvedena v 73 srednje velikih in velikih slovenskih podjetjih s področja kovinsko-predelovalne, elektro-strojne industrije in s področja elektronike.

Ker večina literature o prenovi poslovnih tokov temelji na študijih primera, smo pri preučevanju kazalnikov za merjenje uspešnosti prenove poslovnih tokov vzeli anketno raziskavo. Na podlagi pregleda literature smo razpoznali sedem bistvenih meril, ki so pomembna za uspešno vrednotenje prenove poslovnih tokov: stroški, kakovost, čas, prilagodljivost, zanesljivost, zadovoljstvo kupca in človeški viri oz. zadovoljstvo zaposlenih. Z uporabo analitičnih tehnik, ki zagotavljajo veljavnost in zanesljivost merilnega orodja, smo znotraj omenjenih področij razvili niz ustreznih kazalnikov merjenja.
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(Ključne besede: tokovi poslovni, prenova tokov, merjenje izvedbe, raziskave anketne)

In this paper we present the development and validation of performance measurement indicators for a business process re-engineering (BPR) evaluation. The results are based on a survey carried out in 73 medium-sized and large Slovenian manufacturing companies in the mechanical, electro-mechanical and electronic industries.

Since BPR literature is mostly based on case studies, the survey research methodology was assumed for studying performance measurement indicators when addressed to the dimensions of BPR. Based on a literature review, seven crucial areas, important for a successful BPR evaluation, were identified: costs, quality, time, flexibility, dependability, customer satisfaction and human resources with employee satisfaction. New variables were developed within the crucial areas, using reliability and validity analysis.
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(Keywords: business process reengineering, performance measurements, survey research)

0 UVOD

Področje merjena izvedbe v zadnjem času zaposluje številne akademike in menedžerje. To je v glavnem posledica vedno večjih zahtev, ki izhajajo iz konkurenčnega okolja. Neely [1] je razloge, zakaj so postala običajna finančna merila nezadostna, strnil v naslednje vsebinske sklope:

- *Spremembe v naravi dela*. Zaradi velikih vlaganj v napredne proizvodne tehnologije se je delež neposrednih stroškov dela zmanjšal in temu primerno se je zmanjšala ustreznost običajnih računovodskih sistemov.
- *Konkurenčnost na trgu.* Zvečevanje konkurenčnosti terja od podjetij iskanje izvirne strateške lege, ki, za podjetje, temelji na posebnih

0 INTRODUCTION

The subject of performance measurement is encountering increasing interest in academic and managerial circles. Neely [1] combined the following main reasons why traditional financial measures are no longer enough:

- *The changing nature of work;* because of the massive investments that have been made in process automation, the direct labour share was reduced and consequently the suitability of the traditional accounting systems reduced.
- *Increasing competition;* demands that firms search for an original strategic position, based on a firm's particular resources and capabilities. Companies do not compete only with price and costs,

virih in zmožnostih. Podjetja ne tekmujejo samo s ceno in stroški kot posledičnim konkurenčnim merilom, temveč se poskušajo razlikovati na podlagi kakovosti, prožnosti, prilagodljivosti zahtevam kupca, prenove in hitrega odziva.

- *Pojav naprednih proizvodnih osnutkov.* Zamisel vitke proizvodnje, celovito obvladovanje kakovosti, prenova poslovnih tokov, primerjanje s konkurenco, množinska prilagodljivost in sočasno inženirstvo so napredne proizvodne zamisli, ki so pripomogle, da so podjetja hkrati napredovala v smislu različnih konkurenčnih meril. Uspešnosti poslovanja tako ni več mogoče meriti enorazsežno skozi finančna merila.
- *Spremembe vlog v podjetjih.* Največ kritik o neustreznosti meril, s katerimi spremljamo poslovanje, so v osemdesetih in devetdesetih letih izrekli strokovnjaki, ki so se ukvarjali z računovodstvom. Drugo skupino, ki je prevzela dejavnejšo vlogo pri oblikovanju meril in njihovo uporabo, predstavljajo odgovorni za razvoj človeških virov. Merila so se vključila v celoten menedžment človeških virov, ki sestoji iz postavljanja ciljev, merjenja izvedbe, povratnih informacij in nagrajevanja.
- *Zahteve poslovnega okolja.* Porabniki želijo vse več informacij o izdelku ali storitvi in tudi o načinu, kako je izdelek narejen. Še najmanj, ali pa sploh ne, jih zanimajo bilančni in finančni kazalniki. Povečevanje ekološke zavesti je pripeljalo do izraza odgovornost podjetja. Podjetja so pod pritiskom javnosti, ki ji morajo sporočati informacije, s katerimi dokazujejo ekološko neoporečnost svojega poslovanja.
- *Razvoj informacijske tehnologije.* Razvoj informacijske tehnologije (IT) je ključno vplival na možnost uporabe prenovljenih sistemov za merjenje uspešnosti poslovanja, saj omogoča učinkovito zbiranje podatkov iz različnih virov, za več ljudi, ceneje in hitreje. IT ne omogoča zgolj zbiranja podatkov, ampak tudi njihovo analizo in predstavljanje in tako omogočajo boljše poslovne odločitve v podjetjih, kar se nazadnje kaže v obliki boljših poslovnih rezultatov. Kazalniki torej niso samo informacije, ki predstavljajo trenutno stanje, ampak usmerjajo menedžment pri poslovnih odločitvah.
- *Mednarodne nagrade za kakovost.* Kot prva je bila leta 1950 na Japonskem ustanovljena Demingova nagrada za kakovost, v Združenih državah Amerije ima velik pomen Baldrige Award. Evropsko združenje za menedžment

but they try to differentiate in terms of quality, flexibility, adaptability to customer's demands, innovation and quick response.

- *Specific improvement initiatives*; such as lean production, total quality management (TQM), business process reengineering (BPR), benchmarking, mass customisation and concurrent engineering caused companies to simultaneously pursue several competitive criteria. Therefore, business success can no longer be measured only with uni-dimensional cost measures.
- *Changing organisational roles;* many of the loudest critics of traditional performance measurement systems have come from the academic accounting community in the period from 1980 to 1990. Human resources managers and personnel managers are another group of business professionals who are now taking a more active role in business performance measurement. Performance measures integrated into total human resources management consist of goal setting, measurement, feedback and reward.
- *Changing external demands*; customers want more information about the product or service and also about how the product was produced. They are not especially interested in financial indicators. The growing ecological perception leads to the term company responsibility. Companies also depend upon public opinion, and they have to give them information that proves the ecological integrity of their businesses.
- *The power of information technology;* the key driver in the performance measurement revolution is undoubtedly the power of information technology. Not only has this made the gathering and analysis of data easier, but it has also opened up new opportunities for data gathering from different resources, for more people, cheaper and faster. Of course, IT plays a role not only in data gathering, but also in data analysis and presentation, and thus enables better business decision making that causes better business results. Therefore, indicators are not only information, presenting the current state, but they also direct management at business decisions.
- *National and international quality awards*; among the first was the Deming Prize for quality, introduced in Japan in 1950. Numerous other quality awards have since been introduced, such as the Baldrige Award, which is available in the USA, and the European Foundation for Quality Man-

kakovosti podeljuje priznanja za poslovno odličnost. Podjetja, ki se potegujejo za takšne nagrade, morajo opraviti obsežno ocenjevanje lastnega podjetja in sporočati podrobne informacije o lastni organiziranosti, strategijah, virih, toku informacij, odnosu do družbenega okolja, politiki kakovosti in nenazadnje o finančnih rezultatih.

Navedeni razlogi zahtevajo ponovno obravnavo in posodobitev sistemov merjenja, ki se po eni strani nanaša na prenovitev računovodskih sistemov, predvsem stroškov izdelka, ki temeljijo na dejavnosti, in po drugi strani na razširitev področja merjenja t.i. meritev brez stroškovne osnove, ki po naravi niso ekonomsko-finančni, ampak izhajajo iz potreb kupca [2].

V prispevku bo predstavljen razvoj sistema kazalnikov merjenja v podjetjih, ki so v preteklosti izvajala prenovo poslovnih tokov in se pri tem soočala z neustreznostmi sedanjih sistemov merjenja. Prenova poslovnih tokov je v zadnjih desetih letih postala eno izmed najbolj uveljavljenih menedžerskih orodij, ki se je pojavilo predvsem kot odgovor na svetovno konkurenco, nenehne spremembe tržišča in zahteve kupcev.

Za namen oblikovanja kazalnikov smo vzeli metodologijo anketnega raziskovanja, ki omogoča razvoj veljavnega in zanesljivega sistema kazalnikov za merjenje izvedbe v smislu prenove poslovnih tokov.

1 TEORETIČNE OSNOVE IN OBSEG RAZISKAVE

Obseg raziskave

Iz pregleda literature je razvidno, da je treba zamisel prenove poslovnih tokov preučevati v povezavi z logično dopolnjujočima področjema, kakršna sta na eni strani proizvodna strategija in na drugi strani kazalniki izvedbe, namenjeni preverjanju ustreznosti izbrane strategije in preverjanju ustreznosti izvedbe prenove tokov (sl. 1). Primerjava s konkurenco oz. z najboljšim v panogi, je prav tako vključena v okvir kot uspešno orodje, ki lahko sproži veliko projektov prenove poslovnih tokov.

Prenova poslovnih tokov

Prenovo poslovnih tokov sta Davenport in Short [3] leta 1990 opisala kot analizo in oblikovanje delovnih tokov in postopkov znotraj podjetja in med podjetji. Tri leta kasneje sta Hammer in Champy [4]

agement (EFQM) Award in Europe. Each of these awards requires firms to complete a comprehensive self-assessment as part of the application process and they have to submit detailed data on policies, organization, information, strategies, resources, social environment and financial results.

These reasons demand the revision and updating of performance measurement systems, which is on one hand related to innovation in accounting systems, by means of activity-based costing as it concerns, in particular, product costing, and on the other hand, the extension of the measuring of the so-called non-cost performances, by nature not explicitly economic-financial, but demanded by the customers [2].

In this paper the development of performance measurement indicators for BPR evaluation will be presented. It is based on experiences from the companies that performed BPR in the past and were confronted with the unsuitability of the existing performance measures. BPR was brought into force in the last 15 years as one of the best management intervention tools; it appeared as an answer to global competition, continuous market changes and customer demands.

For the purpose of indicators development the survey research methodology was assumed; this enables the development of a valid and reliable performance measurement system, when addressed to the dimensions of BPR.

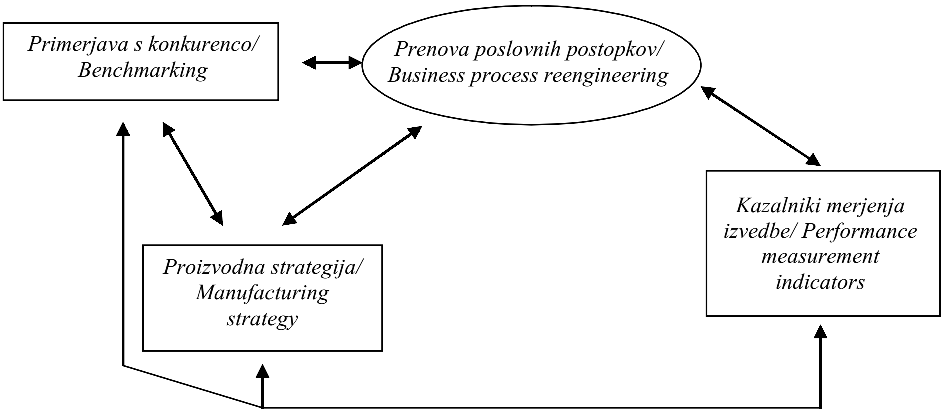
1 THEORETICAL BACKGROUND AND RESEARCH FRAMEWORK

Research framework

With regard to a literature review, the concept of BPR should be studied in connection with logical supplementary areas: manufacturing strategy and, on the other hand, performance indicators, meant for selected strategy and BPR performance verification (Fig. 1). Benchmarking is also added to the framework as a powerful tool for BPR and above all as a trigger for many BPR projects.

Business Process Reengineering

In 1990 Davenport and Short [3] described BPR as the analysis and design of workflows and processes within and between organisations. Three years later, Hammer and Champy [4] promoted BPR



Sl. 1. *Zamisel obsega raziskave*
Fig. 1. *Conceptual framework*

javno predstavila prenovo poslovnih tokov kot 'ponovno preučitev in korenito prenovo poslovnih tokov, z namenom, da dosežemo korenite spremembe s hkratnim merjenjem rezultatov učinka, kakor so stroški, kakovost in hitrost'. Od takrat je mogoče v literaturi zaslediti zelo živahno razpravo o prenovi poslovnih tokov. Akademska skupnost je razvila ogromno metodologij za izvedbo postopka prenove. Postopki prenavljanja so postajali vedno bolj popularni in zanimanje za zamisel prenove je vse do danes ostalo zelo veliko, kljub nekaterim kritičnim opazkam glede same zamisli, ki jih je mogoče zaslediti v literaturi s področja organizacijskih raziskav [5].

Merjenje izvedbe

Kljub temu, da so že Hammer in Champy [4], Davenport in Short [3] v svojih zgodnejših delih opozarjali na pomen merjenja izvedbe pri prenovi poslovnih tokov, se je bistvo oziroma način merjenja v zadnjih desetih letih močno spremenil. Merjenje izvedbe je bilo na področju proizvodnje do nedavnega omejeno predvsem na zastarele sisteme merjenja stroškov in na finančna poročila, kakor jih zahteva zakonodaja ([6] do [8]). Te meritve pa ne upoštevajo potrebe po izpolnjevanju zahtev kupca [9]. Kuwaiti in Kay [10] ugotavljata, da bi moral ustrezen sistem merjenja izvedbe v smislu prenove poslovnih tokov upoštevati dejstvo, da delo poteka skupinsko in da delavci ustvarjajo izdelek, kot končni rezultat proizvodnje, za kupca. V ta namen mora sistem merjenja izvedbe obsegati in ustrezno uravnotežiti številne razsežnosti, ki so potrebne za uspeh prenove tokov. Po pregledu literature smo razpoznali sedem bistvenih meril, ki so pomembna za uspešno vrednotenje prenove poslovnih tokov: stroški, kakovost, čas, prilagodljivost, zanesljivost, zadovoljstvo kupca in človeški viri oz. zadovoljstvo zaposlenih.

as ''the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed''. Since then, there have been considerable discussions in the literature about BPR and the academic community developed a range of methodologies for conducting BPR projects. BPR approaches have become increasingly popular in general and interest in BPR has remained high in spite of the somewhat sceptical stance in relation to the validity of the concept itself, noticed in some organisational studies literature [5].

Performance measurement

Although Hammer and Champy [4], and Davenport and Short [3] in their earlier publications have already emphasized the importance of performance measurement in business process re-engineering, the focus regarding measurements has changed greatly over the past ten years. Performance measurement, particularly in the manufacturing sector, has recently been dominated by outdated costing systems and financial reporting, as required by the legislature and the shareholders ([6] to [8]). These measures do not reflect the need for customer satisfaction [9]. Kuwaiti and Kay [10] ascertained that a relevant performance measurement system in the BPR context takes into account the fact that people work in teams, and actually produce a final output for a customer. For this reason, the PMS has to balance a number of dimensions to enable BPR to succeed. Based on a literature review, seven crucial areas, important for a successful BPR evaluation, were identified: costs, quality, time, flexibility, dependability, customer satisfaction and human resources with employee satisfaction.

Posamične meritve izvedbe

Po ugotovitvah, ki jih navajata De Toni in Tonchia [2], so se običajni sistemi merjenja, osredotočeni predvsem na stroške proizvodnje in produktivnost, na podlagi sprememb, ki izhajajo iz konkurenčnega okolja, preoblikovali v dve vrsti meritev:

- Meritve izvedbe, vezane na stroške, vključno s stroški proizvodnje in produktivnostjo. Za te stroške so značilne jasne povezave, ki jih je mogoče obravnavati v matematični obliki, npr. Goldov model [11], pri čemer dobimo končne rezultate podjetja, kar je čisti prihodek in donosnost.
- Meritve izvedbe brez neposredne stroškovne povezave, ki vedno bolj pridobivajo pomen. Običajno jih merimo z nedenarnimi enotami, zato ni mogoča neposredna povezava z ekonomskimi in finančnimi izkazi.

Meritve izvedbe, vezane na stroške

Johnson ([12] in [13]) je v svojih delih dokumentiral, da večina menedžerskih računovodskih sistemov, ki so še dandanes v uporabi, temelji na predpostavkah izpred šestdesetih let. Garnerjev [14] pregled literature iz računovodstva prav tako kaže na to, da je bila večina t. i. vrhunsko razvitih stroškovno naravnanih računovodskih teorij in praks razvitih okrog leta 1925 (npr. povrnitev vlaganj).

Johnson in Kaplan [15] poudarjata, da, zaradi dramatičnih sprememb poslovnega okolja v zadnjih šestdesetih letih, računovodski sistemi temeljijo na predpostavkah, ki niso več veljavne. Ena od najbolj široko kritiziranih praks je razporeditev neposrednega dela in režijskih stroškov glede na neposredne stroške dela.

Kot rezultat kritik, ki so se nanašale na običajni računovodski menedžment, je Cooper [16] razvil postopek, imenovan na stroških temelječe računovodstvo.

Meritve izvedbe, vezane na kakovost

Običajno je kakovost definirana v smislu prilagajanja podrobnostim in zato so meritve kakovosti v glavnem usmerjene na meritve, kakor so npr. število izmeta in stroški kakovosti [17]. Feigenbaum [18] je prvi ugotavljal, da so dejanski stroški kakovosti odvisnost preprečevanja, ocene in stroškov napak.

Crosbyjeva [19] trditev ''kakovost je zastonj'' temelji na predpostavki, da je za večino podjetij povečanje stroškov preprečevanja več ko le nadomestitev za znižanje stroškov zaradi napak. Crosby opozarja, da je večina podjetij zgrešila pri

Individual performance dimensions and measures

Based on the changes resulting from the competitive environment, traditional performance measures, focused mostly on costs and productivity, transformed into two types of measures [2]:

- Cost measures, including production costs and productivity. Cost performances are distinguished by having a direct link, explainable by mathematical formulae, for example, Gold's model [11], with the final results on the firm that is net income and profitability.
- Non-cost measures, which are increasingly important. The non-cost performances are generally measured by non-monetary units of measure, and cannot be calculated in a precise manner like cost performances.

Performance measures relating to costs

Johnson ([12] and [13]) documented that many management accounting systems used today are based on assumptions that were made 60 years ago. Indeed, Garner's review [14] of the accounting literature indicates that most of the so-called sophisticated cost accounting theories and practice were developed by 1925 (e.g., return of investment – ROI).

Johnson and Kaplan's [15] thesis is that because the business environment has changed dramatically in the last 60 years, management accounting is based on assumptions that are no longer valid. One of the most criticized practices is the allocation of indirect labour and overhead according to the direct labour costs.

Cooper [16] developed an approach known as activity-based costing, which overcomes many traditional problems of management accounting.

Performance measures relating to quality

Traditionally, quality has been defined in terms of conformance to specification, and hence quality-based measures of performance have focused on issues such as the number of defects produced and the costs of quality [17]. Feigenbaum [18] was the first to suggest that the true cost of quality is a function of prevention, appraisal and failure costs.

Crosby's [19] assertion that 'quality is free' is based on the assumption that, for most firms, an increase in prevention costs will be more than offset by a decrease in failure costs. He says that many integraciji modela stroški kakovosti s postopki upravljanja. To pomeni, da četudi menedžerji ocenjujejo stroške kakovosti, manjkajo ustrezne dejavnosti za njihovo zniževanje.

S pojavom zamisli celovito obvladovanje kakovosti (COK-TQM) se je poudarek iz prilagajanja podrobnostim premaknil v smeri izpolnjevanja zadovoljstva kupca. Posledično se je začelo pojavljati večje število raziskav zadovoljstva kupcev in raziskav tržišča. To kaže tudi pojav Malcolm-Baldridgeve nagrade za kakovost v ZDA in Evropske nagrade za kakovost.

Druge splošno sprejete meritve kakovosti obsegajo statistični nadzor tokov ([20] in [21]) in Motorolina zamisel 6-sigm. Motorola, ki je eden vodilnih svetovnih proizvajalcev in dobaviteljev polprevodnikov, si je leta 1992 za cilj podjetja na področju kakovosti zastavila doseganje sposobnosti 6-sigm (3,4 napak na milijon delov). Zadnji dve vrsti meritev sta za oblikovanje sistema merjenja izvedbe še posebej pomembni, saj sta osredotočeni na postopek in ne na izplen.

Meritve izvedbe, vezane na čas

Čas opisujemo kot vir konkurenčnih prednosti in tudi kot temeljno meritev merjenja izvedbe [22]. Glede na filozofijo proizvodnje s pravočasno dobavo (JIT) so prezgodnja ali prepozna proizvodnja ali dobava prikazane kot izguba. Podobno je eden od ciljev optimalne proizvodne tehnologije skrajšanje pretočnih časov [23]. Galloway in Waldron [24] sta razvila sistem stroškov, ki temelji na času, poznan tudi kot računovodstvo pretoka.

Zanimiv postopek oblikovanja časovno usmerjenih meritev predlagajo Azzone in drugi [25]. Po njihovih ugotovitvah bi morala podjetja, ki želijo uporabljati čas v pomenu konkurenčne prednosti, uporabljati niz meritev, ki se nanašajo na notranji razpored (npr. število sprememb projekta, čas dodane vrednosti kot odstotek celotnega časa, zapletenost postopkov) ali zunanji razpored izmer izvedbe (npr. čas razvoja novega izdelka, čas trajanja postopka, čas izdelave ponudbe).

Meritve izvedbe, vezane na prilagodljivost

Merjenje prilagodljivosti so preučevali že številni avtorji, z različnimi postopki in upoštevajoč različne razsežnosti prilagodljivosti. Definicije prilagodljivosti so običajno splošne ali pa se nanašajo na podjetje oziroma proizvodnjo.

companies fail to integrate the cost of the quality model with their management process. This means that although managers estimate the cost of quality, they fail to take appropriate actions to reduce it.

When total quality management (TQM) appeared, the emphasis shifted away from ‘conformance to specification’ and towards customer satisfaction. As a result, customer opinion surveys and market research appeared frequently. The establishment of the Malcolm Baldrige National Quality Award in the USA and the European Quality Award reflects this trend.

Other common measures of quality include statistical process control ([20] and [21]) and the Motorola six-sigma concept. Motorola, which is one of the world’s leading manufacturers and suppliers of semiconductors, set a corporate quality goal of achieving six-sigma capability (3.4 defects per million parts) by 1992. These last two measures of quality raise an important issue that is relevant to performance measurement system design because they focus on the measurement of the process rather than the output.

Performance measures relating to time

Time has been described as both a source of competitive advantage and the fundamental measure of manufacturing performance [22]. Under the just-in-time (JIT) manufacturing philosophy the production or delivery of goods that is just too early or too late is seen as a waste. Similarly, one of the objectives of optimised production technology is the minimization of throughput times [23]. Galloway and Waldron [24] have developed a time-based costing system known as throughput accounting.

An interesting approach to the design of time-based performance measures is proposed by Azzone et al. [25]. They suggest that companies that seek to employ time as a means of competitive advantage should use a generic set of measures related to internal configuration (e.g., the number of changes in the project, the value-added time as a percentage of total time, the complexity of procedures) and external configuration (e.g., new products development time, cycle time, bid time)

Performance measures relating to flexibility

Manufacturing flexibility has been considered by numerous authors, according to different approaches and considering the various dimensions of flexibility. The definition of flexibility is usually related to the general, company or manufacturing context.

Skinner [26] je preučeval prilagodljivost glede na tri različne razsežnosti, ki se nanašajo na:
1. postopek
2. izdelek
3. obseg proizvodnje.

Buffa [27] je prilagodljivost postopka opredelil v povezavi s časi priprave stroja in prilagodljivost izdelka v povezavi z raznolikostjo izdelka. Beckman [28] je preprosto razlikoval prilagodljivost postopka in prilagodljivost izdelka.

Gerwin [29] je kot prvi omenjal različne vrste prilagodljivosti na način, pri katerem je različne vrste prilagodljivosti povezoval z nedoločenostjo okolja, ki jih povzroča. Ločil je šest osnovnih vrst prilagodljivosti (glede na material, obseg, izdelek, mešano prilagodljivost, ki se nanaša na zmožnost upoštevanja zahtev kupca v pomenu raznolikosti izdelkov, dobavljivih v določenem času, prilagodljivost, ki se nanaša na čas priprave stroja in čas trajanja postopka).

Meritve izvedbe, vezane na zanesljivost, zadovoljstvo kupca in človeške vire

Če smo poprej ugotavljali, da obstajajo določene nejasnosti, ki se nanašajo na merjenje in razumevanje prilagodljivosti, je še veliko težje določiti in meriti zanesljivost, zadovoljstvo kupca in človeške vire.

Človeške zmožnosti oziroma zaposleni so gotovo najpomembnejše sredstvo vsakega podjetja. Pogosto se dogaja, da dve enako veliki podjetji, ki se ukvarjata z enako dejavnostjo in delujeta v enakem okolju, dosegata bistveno drugačne rezultate poslovanja. Razlogi za to so lahko sicer številni, vendar pa je razlika največkrat posledica različnih delovnih zmožnosti zaposlenih oziroma različne kakovosti človeških zmožnosti.

2 RAZISKOVALNA METODOLOGIJA

Za preučevanje predstavljenega problema smo vzeli metodologijo anketnega raziskovanja. Metodologija anketnega raziskovanja, z namenom, da bi preizkusili znane teorije, je dolgotrajen postopek, ki zahteva predhodni obstoj teoretičnega modela ali zamiselnega ogrodja [30]. Vsebuje veliko povezanih podpostopkov, to so: postopek predelave iz teoretičnega področja v izkustveno obliko, postopek oblikovanja vprašalnika in izdelavo predhodne vodilne študije, postopek zbiranja podatkov za testiranje teorije, postopek analize podatkov, postopek razlage podatkov in pisanje poročil.

Skinner [26] considers flexibility according to three dimensions, in relation to the objects of variation:
1. the process,
2. the product,
3. the production volume.

Buffa [27] specifies process flexibility in relation to set-up times, and product flexibility in relation to product variety. Beckman [28] simply distinguish between process flexibilities and product flexibility.

Gerwin [29] was the first to mention various dimensions of flexibility in a specific manner and relate them to the different types of environmental uncertainties that caused them. He distinguishes six basic types of flexibility (regarding materials, volume, products, the mix, defined as the ability to meet the market's requirements in terms of variety of products supplied in a certain time, flexibility relating to the change-over and to the standard cycle or re-routing flexibility).

Performance measures relating to dependability, customer satisfaction and human resources

If we have previously assessed that a certain ambiguity still persists regarding measuring and understanding flexibility it is even more complicated to define and measure dependability, customer satisfaction and human resources.

Human resources are undoubtedly the most important resources of the company. It happens frequently that two equally large companies, engaged in the same activity and working in the same environment, achieve essentially different business results. There can be of course numerous reasons for that, but mostly the difference results from different employee capabilities or from a different quality of human resources.

2 RESEARCH METHODOLOGY

For the proposed problem study survey research was used. Theory testing survey research is a long process that presupposes the pre-existence of a theoretical model or a conceptual framework [30]. It includes a number of related sub-processes: the process of reshaping the theoretical domain into the empirical domain; the design and pilot testing processes; the process of collecting data for theory testing; the data analysis process; and the process of interpreting the results and writing the report.

Pri izvedbi predstavljene raziskave smo upoštevali vse navedene faze. V predhodnem poglavju je predstavljen okvir raziskave, ki je bil izhodišče postopku predelave iz teoretičnega področja v izkustveno obliko z oblikovanjem vprašalnika. Trditve v vprašalniku so bile ovrednotene s pettočkovno Likertovo lestvico, v razponu od 'popolno nesoglašanje' do 'popolno soglašanje'. Kot ciljni vzorec smo izbrali slovenska srednja in velika podjetja iz kovinskopredelovalne in elektro-strojne industrije. Postopek vodilnga testiranja smo izvedli kot kritičen pregled vprašalnika petih akademikov s področja operacijskega menedžmenta z Univerze v Mariboru in Univerze v Vidmu (Italija) in treh višjih menedžerjev iz treh proizvodnih podjetij. Podatke smo zbrali po pošti in kasneje analizirali s pomočjo eno- in več-različnih metod analize podatkov.

Merilo kakovosti meritve

Napake merjenja so v anketnem raziskovanju glavni vir napak [31] in jih je treba obdržati na najnižji mogoči ravni. Ko govorimo o kakovosti meritve, imamo v mislih predvsem kakovost merilnih orodij in postopkov, ki jih uporabljamo pri merjenju [30]. Najpomembnejši vidik merjenja pa se prav gotovo nanaša na merjenje zapletenih, več-razsežnostnih oblik merjenja.

Vrednost meritve se v glavnem ocenjuje na podlagi njene veljavnosti in zanesljivosti. Ko govorimo o zanesljivosti, mislimo predvsem na stabilnost in doslednost meritve, medtem ko nas pri veljavnosti zanima predvsem ustreznost meritve [32].

Zanesljivost meritve

Zanesljivost se ocenjuje po zbiranju podatkov. Štiri največkrat uporabljene metode določanja zanesljivosti so:

- ponovno testiranje z istim testom,
- testiranjem z drugimi oblikami testa,
- cepitvena metoda,
- izračun notranje skladnosti testa.

Kadar določene zveze ali modele razvijamo prvič (kakor v naši raziskavi), se kot edina primerna metoda lahko uporabi metoda notranje skladnosti testa. Najpogostejši postopek za oceno notranje skladnosti testa je Cronbachov koeficient alfa [33]. Nunnally [34] navaja, da lahko novo razvite vrednosti sprejmemo v primeru, ko je $\alpha \geq 0{,}6$, priporočljivo mejo pa pomeni $\alpha \geq 0{,}7$. V primeru da je $\alpha \geq 0{,}8$, imamo zelo zanesljivo meritev.

Regarding the presented research process, all the stated phases were considered. In the previous section the conceptual framework is presented, which was the starting point for reshaping the theoretical domain into the practical domain by designing a questionnaire. The items on the questionnaire were evaluated using the five-point Likert scale, ranging from ´strongly disagree´ to ´strongly agree´. As the target sample medium-sized and large Slovenian companies from mechanical and electro-mechanical branches were selected. The pilot testing process was performed by a critical review of five academics in operations management at the University of Maribor (Slovenia) and at the University of Udine (Italy) and three general managers from three manufacturing firms. The data-collection process was made by mail and later the data were analysed using uni- and multi-variate data analysis.

Assessing the measurement quality

Measurement errors represent the major sources of error in survey research [31] and should be kept at the lowest possible level. When we address the issue of measurement quality, we think of the quality of the survey instruments and the procedures used to measure the constructs of interest [30]. However, the most crucial aspect concerns the measurement of complex constructs by multi-item measures.

The quality of the measures is mainly evaluated in terms of validity and reliability. Validity is concerned with whether we measure the right concept, while reliability is concerned with stability and consistency in measurement [32].

Reliability

Reliability is assessed after data collection. The four most common methods used to estimate reliability are:

- the Test-retest method,
- the Alternative-form method,
- the Split-halves method,
- the Internal consistency method

When developing variables for the first time the only convenient method for measuring reliability is the internal consistency method. The most popular test within the internal consistency method is the Cronbach coefficient alpha [33]. Nunnally [34] states that newly developed measures can be accepted with $\alpha \geq 0.6$, otherwise $\alpha \geq 0.7$ should be the threshold. With $\alpha \geq 0.8$ the measure is very reliable.

Veljavnost

Veljavnost meritve se nanaša na vsebino, merilo in veljavnost izdelka, ki ga merimo [35].

1. Veljavnost vsebine se ne ocenjuje numerično, ampak gre za pristransko oceno raziskovalcev. Ne moremo je določiti statistično, ampak se določa na podlagi kritične presoje raziskovalcev in znane literature. Za preverjanje veljavnosti vsebine je posamezne trditve vprašalnika poprej pregledalo pet akademikov s področja tokovnega vodenja.
2. Veljavnost, ki se nanaša na merilo, imenovana tudi veljavnost, ki jo lahko predvidimo oziroma zunanja veljavnost, se nanaša na obseg, do katerega merilno orodje zagotavlja neodvisnost meritve.
3. Veljavnost izdelka je od vseh različnih lastnosti, ki se nanašajo na meritev, najbolj zapletena in hkrati najbolj kritična za testiranje teorij. Meritev izpolnjuje pogoj veljavnosti izdelka, kadar meri to, kar smo se namenili meriti. Veljavnost izdelka lahko dosežemo tudi z uporabo projekcijskih analitičnih tehnik, kot je npr. projekcija na prvo glavno sestavino (PGS - PCA). Glavni namen projekcije na prvo glavno sestavino je ta, da dobimo čim manjše število linearnih kombinacij iz niza spremenljivk, ki ohranijo čimveč informacij izvirnih spremenljivk. Te linearne kombinacije imajo koeficiente enake lastnim vektorjem korelacijske matrike; lastni vektorji so med seboj pravokotni. Glavne komponente so razvrščene po padajočih vrednostih lastnih vektorjev.

Ugotavljanje veljavnosti in zanesljivosti

Razvoj veljavnih in zanesljivih meritev je postopek, ki je primerljiv s postopkom oblikovanja in preverjanja teorije [30]. Glavni namen postopka ni v tem, da omogoča oblikovanje orodja za testiranje teorije, ampak omogoča oblikovanje orodja, ki bo ponovno uporaben tudi za preverjanje drugih teorij in predvsem za uporabniške namene.

Na sliki 2 je shematično prikazan potek oblikovanja novih spremenljivk. Najprej rezultate vprašalnika, ovrednotene po Likertovi lestvici, vnesemo v enega od statističnih programskih paketov (SPSS, SAS/STAT). Sledi preverjanje kakovosti meritve. Če je koeficient alfa večji od 0,6 je meritev zanesljiva in postopek lahko nadaljujemo z uporabo projekcije na prvo glavno sestavino, za preverjanje veljavnosti. Glavni namen uporabe projekcijskih analitičnih tehnik je zmanjšanje števila spremenljivk ali preučevanje strukture in povezav med spremenljivkami. V našem primeru smo projekcijo na prvo glavno sestavino uporabili z namenom

Validity

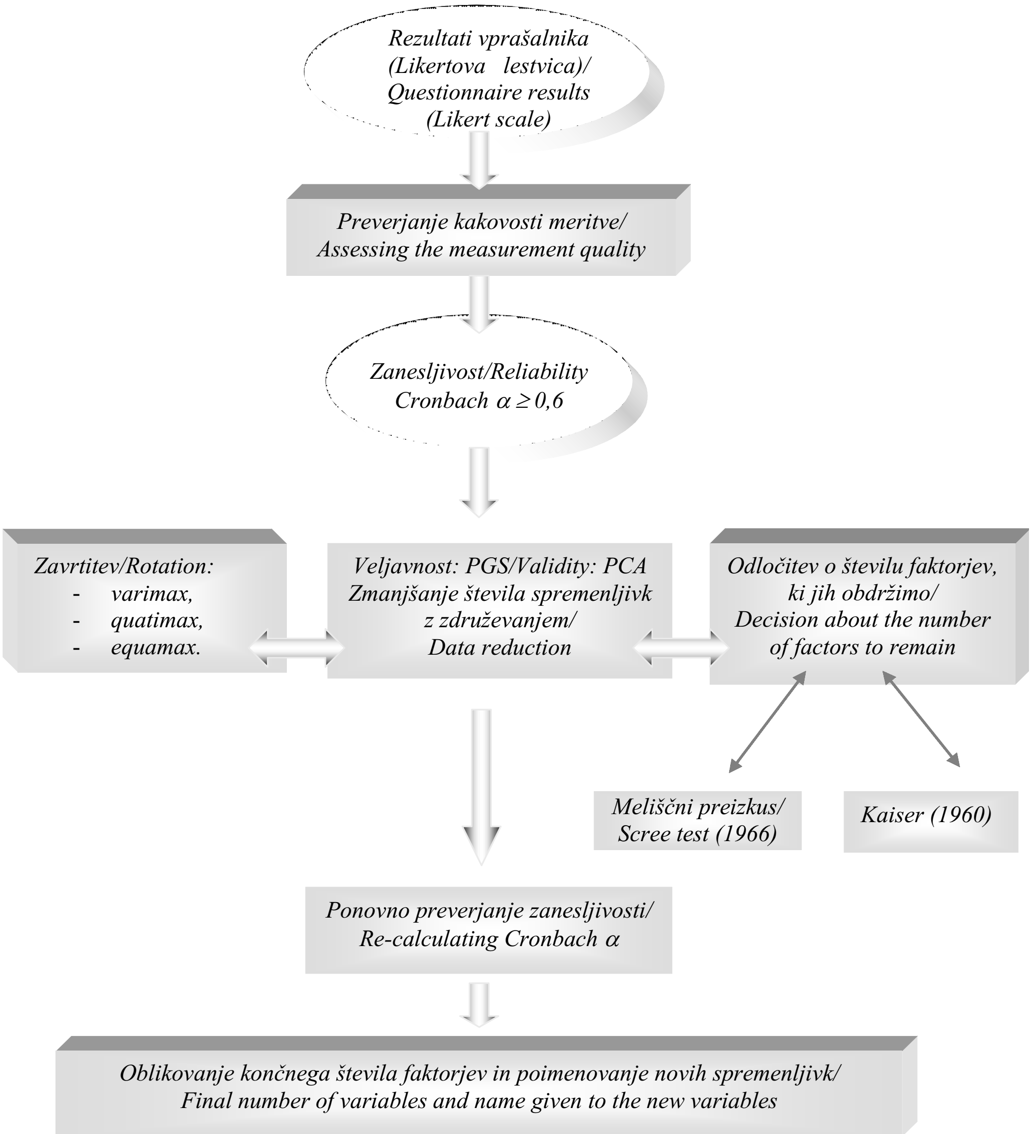
Validity regards content, criterion and construct [35]:

1. Content validity is not evaluated numerically – the researchers subjectively judge it. Content validity cannot be determined statistically but only by experts, and by referring to literature. To establish content validity, the items for each factor were critically reviewed by five academics in operations management.
2. Criterion-related validity, also called predictive validity or external validity, is concerned with the extent to which a measuring instrument is related to an independent measure of the relevant criterion.
3. Construct validity; among the different properties that can be assessed about a measure, construct validity is the most complex and, yet, the most critical to substantive theory testing. A measure has construct validity if it measures the theoretical construct or trait that it was designed to measure. Construct validity can also be established through the use of principal component analysis (PCA). The purpose of PCA is to derive a small number of linear combinations of a set of variables that retain as much of the information in the original variables as possible. These linear combinations have coefficients equal to the eigenvectors of the correlation (covariance) matrix; the eigenvectors are uncorrelated or orthogonal to each other. The principal components are sorted in descending order of the eigenvalues, which are equal to the variances of the components.

Steps in assessing reliability and validity

Developing valid and reliable measures is a process, parallel to that aimed at building and testing the theory [30]. The aim is not only to build an instrument to allow theory testing but also to have an instrument reusable for other theories as well as for application purposes.

Figure 2 presents a schematic review of the new variable construction process. First, the questionnaire results, assessed in terms of the Likert scale, are recorded to a statistics programme package (SPSS, SAS/STAT). Assessing the measurement quality follows. If the reliability coefficient alpha is greater than 0.6, the measure is reliable and the procedure can be proceeded by the PCA for assessing validity. Because the main applications of factor analytic techniques are to reduce the number of variables and to detect structure in the relationships between variables, the PCA was used as a data-reduction method. Various rota-



Sl. 2. *Shematski prikaz poteka oblikovanja novih spremenljivk*
Fig. 2. *Schematic review of the new variable construction process*

zmanjšanja števila spremenljivk. Kot pomoč pri razlagi rezultatov obstajajo različne strategije zavrtitve, to so: varimax, quatimax in equamax. Pri postopku, prikazanem na sliki 2 smo pri izločanju sestavin uporabili zavrtitev varimax. Pri odločitvi o številu dejavnikov, ki jih upoštevamo, smo sledili Kaiserjevemu merilu [36], po katerem lahko upoštevamo samo tiste dejavnike, katerih lastni vektor je večji od 1. Nato smo za vse možne nove spremenljivke še enkrat preverjali zanesljivost, s ponovnim izračunom Cronbachovega koeficienta alfa in v primeru, da je tudi ta večji od 0,6, sprejeli odločitev o končnem številu novih spremenljivk. Novo oblikovane spremenljivke smo na koncu še poimenovali.

tional strategies have been proposed as a support for results interpretation: varimax, quatimax and equamax. In the process presented in Figure 2, varimax rotation was used when extracting principal components. To decide how many factors to extract, the Kaiser [36] criterion was used. According to this criterion we can retain only the factors with eigenvalues greater than 1. After that, for all possible new variables, Cronbach alpha should be re-calculated and if greater than 0.6, the decision about the final number of new variables can be accepted. Finally, an appropriate name should be given to the new variables.

3 REZULTATI IN RAZPRAVA

Glede na priporočljiv potek oblikovanja novih spremenljivk, prikazanem na sliki 2, smo analizo rezultatov pričeli s preverjanjem zanesljivosti meritve. Najprej smo s programskim paketom SPSS izvedli analizo notranje skladnosti testa za postavke vprašalnika znotraj vseh kritičnih izmer merjenja izvedbe, kakor so prikazane v preglednici 1. Iz preglednice je razvidno, da se dobljene vrednosti koeficientov zanesljivosti gibljejo v mejah od 0,6383 do 0,8934. Po priporočilih, ki jih je podal Nunnaly [34], so dobljene meritve vseh kritičnih razsežnosti merjenja izvedbe zelo zanesljive in zato ni potrebno izločanje posameznih spremenljivk (z namenom izboljšanja zanesljivosti meritve).

Ker vse izhodiščne vrednosti izpolnjujejo pogoje zanesljivosti, smo nadaljevali s preverjanjem veljavnosti. Zaradi prostorskih omejitev bo v nadaljevanju predstavljen samo en primer oblikovanja novih spremenljivk. Izbrali smo značilni primer oblikovanja novih spremenljivk za področje merjenja kakovosti, pri katerem izhajamo iz osmih postavk.

Preglednica 2 prikazuje rezultate projekcije na prvo glavno sestavino, z uporabo zavrtitve varimax, izvedeno za kakovost. Program je oblikoval dvofaktorsko rešitev, z dvema lastnima vektorjema, ki sta večja od 1 (Kaiserjeva normalizacija). Lastna vektorja pomenita 56,313% variance prostora, vse preostale nadaljnje rešitve pa pomenijo zelo majhen delež skupne variance prostora. Zavrten vzorec faktorjev vpliva je večinoma zelo jasen, razen za kakovost, predstavljeno z zanesljivostjo dobav,

3 RESULTS AND DISCUSSION

Regarding the steps presented in the new variable development process (Fig. 2), the results analysis started with a reliability verification. First, an internal consistency analysis was performed separately using the SPSS program package for the items of each critical dimension, presented as areas and sub-areas in Table 1. The table shows that the reliability coefficients ranged from 0.6383 to 0.8934. According to the instructions, written by Nunnaly [34], those measurements for all critical dimensions of PM are very reliable and there is no need for an elimination of the defined items (meant for improving the reliability of the measurement).

With regard to all the initial values of the critical dimensions fulfilling the reliability conditions, we continued with validity testing. Because of the space limitations in the continuation only an example of the new variables design will be presented. We selected a representative example of new variables construction for quality, with the eight initial items.

Table 2 shows the results of the PCA with varimax rotation performed for quality. A two-factor solution was generated with an eigenvalue greater than 1.0 (Kaiser Normalization). It explained 56.313% of the variance, while subsequent solutions added just a little to the cumulative variance explained. The rotated factor pattern was very evident for the most part, except for the quality expressed by the delivery reliability, but it is still obvious that the delivery reli-

Preglednica 1. *Rezultati analize notranje skladnosti testa (Cronbach* a*) po posameznih področjih*
Table 1. *Internal consistency analysis results for the critical dimensions of PM*

Kritične razsežnosti merjenja izvedbe ***Critical dimensions of Performance Measurement***	***Izvirne številke postavk Original item numbers***	***Končno število postavk Final number of items***	***Cronbach*** α
stroški / costs	79–85	7	0,6651
kakovost / quality	86–93	8	0,7546
čas / time	94–105	12	0,8934
prilagodljivost / flexibility	106–114	9	0,7579
zanesljivost / dependability	115–118	5	**0,6383**
zadovoljstvo kupca / customer satisfaction	119–124	6	0,7224
človeški viri oz. zadovoljstvo zaposlenih / human resources and employee satisfaction	125–131	7	0,8207
usposobljenost zaposlenih / employee empowerment	143–155	13	0,6763
merjenje stopnje povezovanja zaposlenih / employee integration	156–174	19	0,8658

Preglednica 2. *Kakovost: dvofaktorska rešitev s Kaiserjevo normalizacijo*
Table 2. *Quality: two-factor solution with varimax rotation*

Izvorne spremenljivke za kakovost ***Items on quality***	***1. faktor*** ***1st factor***	***2. faktor*** ***2nd factor***
stopnja izmeta in popravil / scrap level and reworks	**0,732**	0,095
uveljavljanje garancije / warranty claims	**0,749**	– 0,020
stroški izmeta in popravil / cost of scrap and rework	**0,858**	0,159
stroški sistema kakovosti / quality costs	**0,642**	0,241
kakovost dobaviteljev / in bound quality (of suppliers)	– 0,036	**0,866**
zadovoljstvo kupca / customer satisfaction	0,194	**0,722**
negovanje stikov s kupci / customer retention	0,252	**0,711**
zanesljivost dobave / delivery reliability	**0,455**	0,287
lastni vector/ eigenvalue	3,074	1,431
delež variance prostora / proportion of variance explained (%)	38,427	17,885
skupni delež variance prostora / cumulative variance explained (%)	38,427	56,313
ponovno izračunan Cronbach α / re-calculated Cronbach α	0,7483	0,6717
novo oblikovano ime / name given to the new variable	Notranja kakovost Internal quality	Zunanja kakovost External quality

vendar je kljub temu tudi tukaj zelo očitno, da postavka zanesljivost dobav izkazuje večji vpliv na prvi kakor na drugi faktor.

Ponovno preverjanje zanesljivosti z izračunom Cronbachovega koeficienta alfa prav tako potrjuje oblikovanje dveh novih spremenljivk. Tako smo v prvo spremenljivko združili stopnjo izmeta in popravil, uveljavljanje garancije, stroške izmeta in popravil, stroške sistema kakovosti in zanesljivost dobave. Drugo spremenljivko pa predstavljajo kakovost dobaviteljev, zadovoljstvo kupca in negovanje stika s kupci. Glede na vsebino in znano literaturo smo prvi faktor poimenovali notranja kakovost in drugega zunanja kakovost.

Na sliki 3 je podan pregled vseh novo oblikovanih spremenljivk, ki mu lahko rečemo tudi sistem kazalnikov za vrednotenje prenove poslovnih tokov, dobljen iz rezultatov raziskave.

ability item exhibited a much higher loading on the first factor than on the second factor. The development of the two new variables was repeatedly verified using Cronbach alpha for reliability (re-calculated Cronbach alpha for new variables).

The first factor consists of scrap level and reworks, warranty claims, cost of scrap and rework, quality costs and delivery reliability. The second factor consists of in-bound quality, customer satisfaction and customer retention. With regard to the content and existing literature the first factor was named Internal quality and the second factor External quality.

In Figure 3 a review of all the new developed variables, which could also be called performance indicators for the BPR evaluation, are presented, based on the results of the survey research.

4 SKLEP

Iz pregleda in primerjave teoretičnih modelov merjenja izvedbe v znani literaturi smo dobili vpogled v celovitost in obsežnost področja. Eden temeljnih problemov, s katerim se soočimo pri vzpostavljanju uporabnega sistema merjenja izvedbe, je poskus, da bi dosegli ravnovesje med manjšim številom ključnih meritev izvedbe (jasnih in preprostih, ki morda ne kažejo vseh organizacijskih ciljev) na eni strani in večjim številom podrobnih meritev oz. kazalnikov izvedbe (zapletenih in manj primernih za upravljanje, vendar zmožnih prikazati veliko različnih možnosti

4 CONCLUSION

A literature review and a comparison of the existing theoretical models of performance measurement gave us an insight into the integrity and comprehensiveness of the presented problem. One of the problems of devising a useful performance measurement system is trying to achieve some balance between having a few key measures on the one hand (straightforward and simple, but may not reflect the full range of organisational objectives), and, on the other, having many detailed measures (complex and difficult to manage, but capable of conveying many izvedbe) na drugi strani. V splošnem dosežemo poravnavo tako, da zagotovimo jasno povezavo med izbrano strategijo, ključnimi parametri izvedbe, ki kažejo glavne cilje izvedbe, in nizom kazalnikov izvedbe za posamezne ključne parametre [37].

Pri obravnavanju posamičnih meritev izvedbe je najpomembnejše dejstvo, da morajo izhajati iz strategije. Merjenje je lahko "postopek kolikerosti", vendar je njegov glavni namen sprožiti pozitivno delovanje, in kot je izpostavil Mintzberg [38], je strategijo mogoče izpeljati samo s skladnim delovanjem in izvajanjem.

Kot najpomembnejši prispevek raziskave lahko izpostavimo razvoj sistema kazalnikov za vrednotenje prenove poslovnih tokov. Za

nuances of performance). Generally, a compromise is reached by making sure that there is a clear link between the competitive strategy, the key performance indicators that reflect the main performance objectives, and the bundle of detailed measures for key performance indicators [37].

Individual performance measures need to be positioned in a strategic context. Measuring may be the "process of quantification", but its effect is to stimulate action, and as Mintzberg [38] has pointed out, it is only through consistency of action that strategies are realized.

The most important contribution of the presented survey research is the development and validation of new variables when addressed to the di-

Sl. 3. *Sistem kazalnikov za vrednotenje prenove poslovnih postopkov*
Fig. 3. *Performance measurement system for BPR evaluation*

oblikovanje novih spremenljivk smo uporabili metode, ki sicer niso tako pogoste in izhajajo iz znanstvenega področja psihometrike. Pri oblikovanju spremenljivk smo uporabili merilno orodje, ki smo ga temeljito preverili iz vidika zanesljivosti in veljavnosti. Tako lahko z gotovostjo rečemo, da so novo razvite spremenljivke, oblikovane na osnovi izkušenj, zanesljive in veljavne.

Ker so merilne lestvice, ki smo jih pri izvedbi raziskave razvili, zanesljive in veljavne, je drug zelo pomemben prispevek v tem, da je mogoče raziskavo ponoviti – s tem smo zagotovili ponovljivost raziskave.

mensions of BPR. In the study, infrequently used scientific methods were employed; these methods are normally used in the scientific area of psychometrics. For new variables development a measuring instrument that was thoroughly tested for reliability and validity was used. The new variables are, therefore, empirically based and shown to be reliable and valid.

Since a used measuring instrument has been tested for reliability and validity, the second important contribution of the paper is that the results drawn from our research are more likely to be repeatable.

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Naslov avtorjev: dr. Nataša Vujica Herzog
prof.dr. Andrej Polajnar
Petja Pižmoht
Univerza v Mariboru
Fakulteta za strojništvo
Smetanova 17
2000 Maribor
natasa.vujica@uni-mb.si
andrej.polajnar@uni-mb.si
petja.pizmoht@uni-mb.si

Authors' address: Dr. Nataša Vujica Herzog
Prof.Dr. Andrej Polajnar
Petja Pižmoht
University of Maribor
Faculty of Mechanical Eng.
Smetanova 17
2000 Maribor, Slovenia
natasa.vujica@uni-mb.si
andrej.polajnar@uni-mb.si
petja.pizmoht@uni-mb.si

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Dušenje torzijskih vibracij in raziskava učinkovitosti

A Damper of Torsional Vibrations and an Investigation of Its Efficiency

Bronislovas Spruogis - Vytautas Turla
(Vilnius Gediminas Technical University, Vilnius)

V prispevku so prikazani izvirni dušilniki torzijskih vibracij, ki učinkovito delujejo v širokem območju motilnih frekvenc. Raziskali smo tudi nekaj možnih oblikovalskih različic. Osnovni sestavni del dušilnika je rotacijski upogibni obroč. V prispevku raziskujemo gibajoči se sistem na osnovi sistema nelinearnih diferencialnih enačb. Z razdelitvijo gibanja na enakomerno vrtenje in nihanje, razvojem koeficientov enačbe v Taylorjevo potenčno vrsto in izključitvijo ustaljenih delov, dobimo sistem enačb za majhna nihanja. Sistem vsebuje vztrajnostne, upogibne in žiroskopske člene. Izpeljali smo gibalne enačbe in formulirali stabilnostne pogoje za dinamično ravnotežje sistema. Ustrezno pozornost smo namenili tudi drugim možnim nestabilnim oblikam in področjem upogibnega obroča. Analizirali smo lastne frekvence sistema. Oceno učinkovitosti dušilnika glede na različne parametre smo pridobili iz izraza za ekvivalentni vztrajnostni moment in njegovih mejnih vrednosti.
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(Ključne besede: absorberji vibracij, obroči krožni, vibracije, stabilnost, ekvivalent vztrajnostnih momentov)

This paper reviews an original torsional vibration damper retaining its efficiency over a wide disturbing frequency band. Some potential design alternatives are considered. The basic structural element of the damper is a rotary flexible ring. The paper investigates the motion system on the basis of a set of nonlinear differential equations. By separating the motion into uniform rotary and oscillatory, expanding the equation coefficients into a Taylor's power series and excluding the static members, a system of equations for insignificant oscillations is derived. The system contains inertia, flexible and gyroscopic terms. The equations of motion are derived and the stability conditions for the system's dynamic balance are formulated. Proper consideration is given to other possible loss-of-stability forms and regions of the flexible ring. An analysis of the system's natural frequencies is made. The efficiency estimation of the damper versus various parameters is effected as a result of the expression of the equivalent inertia moment and its limit values.
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(Keywords: torsional vibration dampers, rotary flexible rings, vibrations, stability, equivalent inertia moments)

0 INTRODUCTION

New devices, mechanisms, assemblies and machines should be very efficient. High efficiency can be ensured by power- and speed-related properties.

An increase in transmittable powers and speeds of motion is accompanied by an intensification of vibrations in the systems, and such vibrations frequently exceed their dynamic loads. The level of vibrations becomes one of the key criteria of quality and reliability of machines. Because of this, a limitation of the dynamic overloads of machine assemblies is an urgent problem, directly related to an increase of efficiency, reliability, accuracy and longevity of machines, mechanisms, assemblies and devices.

The authors have worked on damping the torsional vibrations of complicated rotating rotor systems for several decades. They explored various methods and measures, for example, the first of them [1] also carried out theoretical and experimental investigations on the development of effective dampers of torsional vibrations.

There is a variety of designs of dampers of torsional vibrations that can be naturally inserted into the structure of a relevant unit. Seeking a natural arrangement is one of the causes of the abovementioned variety of designs; however, successful designs of vibration dampers are rare.

An advantage of the frictional dampers of torsional vibrations is their capability to preserve their efficiency in a certain frequency range. However, seeking for essential efficiency in such a case leads to a non-proportional increase of sizes, weight, etc., the more so that frictional damping of the vibrations is bound with the elimination of heating energy, wear and the use of special materials.

Many works – both theoretical and experimental – have been devoted to investigations of vibration processes in mechanical rotor systems ([2] to [7]).

The well-known pendulous vibration damper has an excellent feature of self-tuning for one harmonic of the torsional vibrations on any change of the speed of rotation of the system. However, it almost does not affect the adjacent harmonics and other torsional vibrations (for example, ones of random character). In addition, a pendulous vibration damper is completely discussed in transitional modes of motion, in particular during the starting period.

The authors set the task to develop such a dynamic damper of torsional vibrations that would be tunable for a wide range of disturbing harmonics (frequencies), remaining a natural element of the rotating system.

It became clear that the set task may be solved to a certain extent by the use of a vibration damper, based on the rotating elastic ring situated on two pendulous rings in the shape of elastic frames. The torsional vibrations of the system generate transversal bending vibrations of the elastic ring. The damping system includes an elastic ring, special masses that can be additionally fixed on it and elastic frames.

1 THE SCHEMES OF CONSTRUCTIONS OF VIBRATION DAMPERS

The design scheme of the simplest damper of torsional vibrations in the shape of a rotating elastic ring [8] is presented in Fig. 1,a. The key element of such a vibration damper is the ring 2 connected to the principal system 1 with two

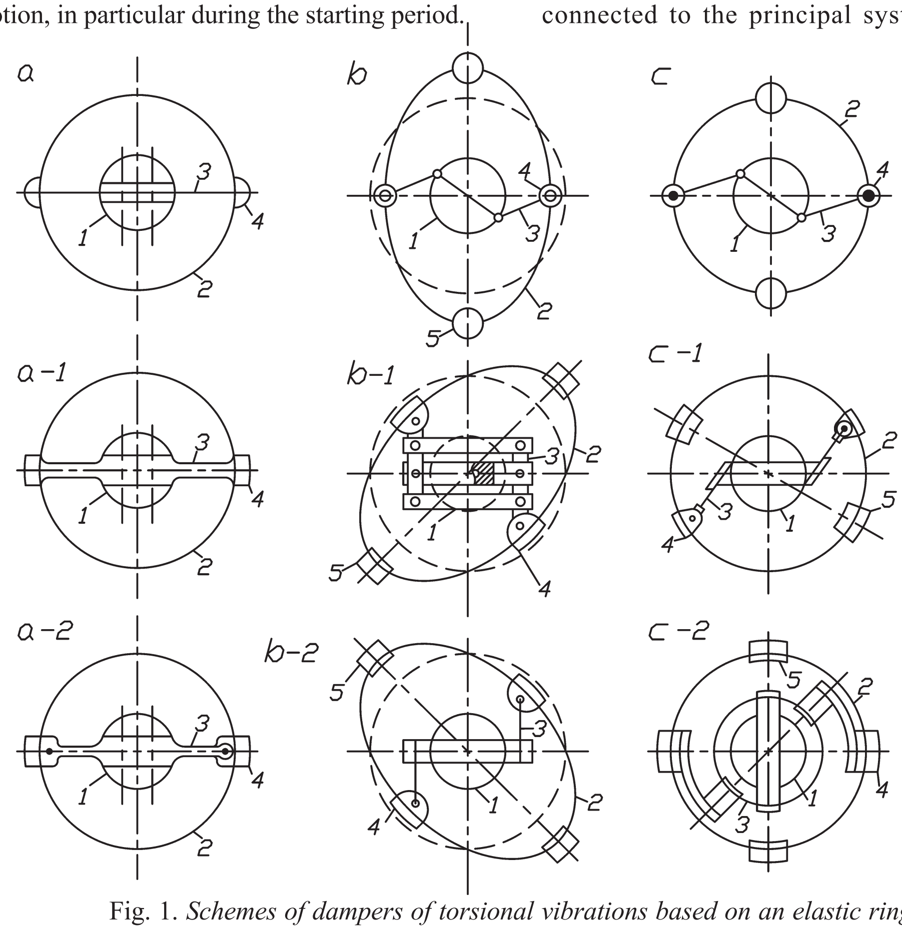

Fig. 1. *Schemes of dampers of torsional vibrations based on an elastic ring*

opposite frames 3. The ring can be equipped with supplemental masses 5 (Fig. 1,b,c), perpendicular to masses 4.

1.1 The principle of operation of a vibration damper on the base of an elastic ring

In the case of the absence of rotation or ideally uniform rotation, the axial line of the ring is an ideal circle in the limits of stability. Torsional vibrations of the principal system cause bending of the elastic frames 3 and periodic compression of the ring 2 in the transversal direction. The ring 2, because of its elasticity and centrifugal mass, can efficiently damp the torsional vibrations of the shaft 1 upon certain parameters across a wide range of harmonics.

The technical realization of the vibration damper according to this scheme is presented in Fig. 1, a-1, a-2. In Fig. 1, a-2, the elastic frames are connected to the ring with swivel clamps.

If two supplemental masses of a particular size are fixed to the ring, symmetrically with the axis of rotation in the plane perpendicular to the plane of the elastic frames (see Fig., 1,b), the ring is extended into an ellipse-shaped body on the rotation. In many cases, such an extended ring exhibits improved vibration-damping properties. The bent centrifugal pendulums 3 can be stabilized by a swivel parallelogram (Fig. 1, b-1) or replaced with symmetric elastic frames 3, tilted by a certain angle with respect to the radius (Fig. 1, b-2).

In many cases the efficiency of the vibration damper can be increased by fixing the elastic ring on two symmetrically tilted pendulums (see Fig. 1, c). The tilted pendulums can be elastic frames (Fig. 1, c-1) or elastically fixed tilted pendulums (Fig. 1, c-2). The vibration damper presented in Fig. 1, c-2 includes one more elastic rings of small diameter 3 in the middle, clamped at two opposite points. The ring is an elastic swivel.

1.2 Investigation of the operation of the vibration damper

Let us start the investigation of the operation of the vibration dampers (see Fig. 1) with a calculation of the potential energy of the deformed ring and the kinetic energy of the system. The potential energy of a half-ring as an elastic body, deformed by the impact of concentrated forces (Fig. 2), can be found from the following expression according to [8]:

$$\Pi_{1/2} = a_B P^2 + b_B PQ + a_B Q^2 \quad (1),$$

where a_B *and* b_B are coefficients, and P and Q are fictitious forces.

Let us find the coefficients a_B and b_B. For this purpose, the shifts of the ring in the direction of the forces P and Q should be found. In accordance with [8]:

$$u_{1\,Q=0} = \frac{\partial \Pi_{1/2}}{\partial P} = 2a_B P + b_B Q = 2a_B P = -\left(\frac{1}{\pi} - \frac{\pi}{8}\right)\frac{PR^3}{EI}$$

$$u_{2\,Q=0} = \frac{\partial \Pi_{1/2}}{\partial Q} = b_B P + 2a_B Q = b_B P = -\left(\frac{1}{\pi} - \frac{1}{4}\right)\frac{PR^3}{EI} \quad (2).$$

Thus:

$$a_B = \frac{1}{4}\left(\frac{\pi}{4} - \frac{2}{\pi}\right)\frac{R^3}{EI}, \quad b_B = -\frac{1}{2}\left(\frac{2}{\pi} - \frac{1}{2}\right)\frac{R^3}{EI} \quad (3).$$

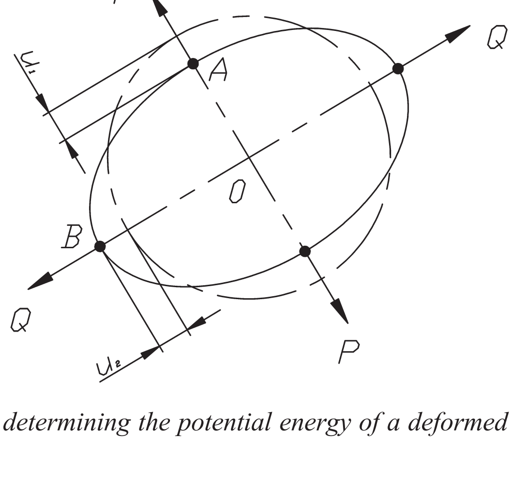

Fig. 2. *For determining the potential energy of a deformed elastic ring*

Let us consider that the shift of point A consists of two components, i.e.:

$$u_1 = u^{\Delta} - ku_0 \quad (4),$$

where u^{Δ} is the shift of point A caused by the force *P*, u_0 is the shift of the point B caused by the force *Q*:

$$k = -\frac{b_B}{2a_B} = \frac{2(4-\pi)}{\pi^2 - 8} \quad (5),$$

correspondingly:

$$u_2 = u_0 - ku^{\Delta} \quad (6).$$

On the basis of Equations (4) and (6), we find u_2:

$$u_2 = u_0\left(1-k^2\right) - ku_1 \quad (7).$$

Let us find the potential energy of the deformed ring as a function of the shifts u_1 and u_2. From the above expressions (2) and (3), the forces *P* and *Q* are expressed as follows:

$$P = \frac{u_1 + ku_0}{2a_B} \quad (8)$$

$$Q = \frac{u_0}{2a_B} \quad (9).$$

After the insertion of the expressions of the forces from (8) and (9) into the expression (1), we find the full potential energy of the elastic ring from the forces *P* and *Q* as follows:

$$\Pi = 2\Pi_{1/2} = \frac{1}{2a_B}u_1^2 + \frac{4a_B^2 - b_B^2}{8a_B^3}u_0^2 = \frac{1}{2}C_{n_1}u_1^2 + \frac{1}{2}C_{n_2}u_0^2 \quad (10),$$

where:

$$C_{n_1} = \frac{1}{a_B} \quad \text{and} \quad C_{n_2} = \frac{4a_B^2 - b_B^2}{4a_B^3} \quad (11).$$

The total potential energy of the system (Π_{Σ}) consists of the potential energy of the elastic ring (Π_k), the potential energy of other deformable elements of the vibration damper (Π_i) and the potential energy of the torsion of the shaft (Π_v), i.e.:

$$\Pi_{\Sigma} = \Pi_k + \Pi_i + \Pi_v \quad (12),$$

where:

$$\Pi_k = f\left(\varphi_1 - \varphi_2, u_0\right), \quad \Pi_i = f\left(\varphi_1 - \varphi_2\right) = \frac{1}{2}C\left(\varphi_1 - \varphi_2\right)^2$$
$$\Pi_v = f\left(\varphi_1\right) \quad (13).$$

In order to calculate the kinetic energy, let us consider the system to be a system with three degrees of freedom. Fig. 3 presents the estimated scheme of the vibration damper, where φ_1 and φ_2 are independent of the angular coordinates, *R* is the initial radius of the elastic ring, *m* is the reduced mass of the part of the ring with the relevant concentrated mass, m_0 is the reduced mass of the part of the ring with the supplemental mass, ρ is the distance of the mass *m* from the axis of rotation, ρ_0 is the distance of the mass m_0 from the axis of rotation, ρ and ρ_0 in the general case are a function of the rotational deformation of the vibration damper. If the radial shift of the mass $m(u_1)$ is a function of (φ_1 - φ_2), the radial shift of the mass m_0 also includes the independent component u_0 that is the third generalized coordinate.

The kinetic energy of the system, taking into account the existence of two couples of masses, is

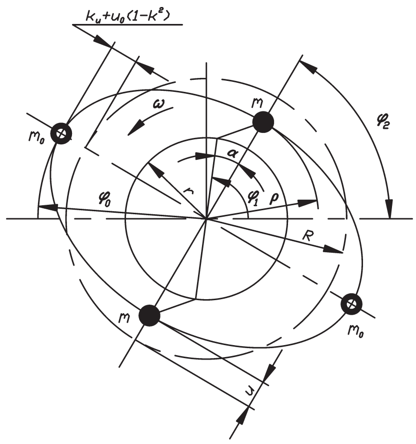

Fig. 3. *The estimation scheme of the vibration damper*

found from the following expression:

$$T = mv^2 + m_0 v_1^2 + \frac{1}{2} I_1 \dot{\varphi}_1^2 \qquad (14),$$

where:

$$v^2 = \rho^2 \dot{\varphi}_2^2 + \left[\frac{d\rho}{d(\varphi_1 - \varphi_2)} \right]^2 (\dot{\varphi}_1 - \dot{\varphi}_2)^2$$

$$v_1^2 = \rho_0^2 \dot{\varphi}_2^2 + \dot{\rho}_0^2$$

I_1 is moment of inertia of the rotated mass; the super point means differentiation with respect to time.

In order to simplify the estimated dependences, we consider that the radius of the string clamping (*r*) equals a half of the radius of the elastic ring (*R*).

Then, the following is concluded from Fig. 3:

$$\begin{aligned} \rho &= R\cos(\varphi_1 - \varphi_2) \\ \rho_0 &= R + 2kr\left[1 - \cos(\varphi_1 - \varphi_2)\right] + u_0\left(1 - k^2\right) \\ \dot{\rho}_0 &= 2kr\sin(\varphi_1 - \varphi_2)(\dot{\varphi}_1 - \dot{\varphi}_2) + \dot{u}_0\left(1 - k^2\right) \end{aligned} \qquad (15).$$

Finally, we find the following expression for the kinetic energy:

$$\begin{aligned} T = &\left\{ \frac{1}{2} I_1 + m\left[\frac{d\rho}{d(\varphi_1 - \varphi_2)} \right]^2 + m_0 \left[\frac{d\rho_0}{d(\varphi_1 - \varphi_2)} \right]^2 \right\} \dot{\varphi}_1^2 - \\ &-2\left\{ m\left[\frac{d\rho}{d(\varphi_1 - \varphi_2)} \right]^2 + m_0 \left[\frac{d\rho_0}{d(\varphi_1 - \varphi_2)} \right]^2 \right\} \dot{\varphi}_1 \dot{\varphi}_2 + \\ &+\left\{ m\left[\left[\frac{d\rho}{d(\varphi_1 - \varphi_2)} \right]^2 + \rho^2 \right] + m_0 \left[\left[\frac{d\rho_0}{d(\varphi_1 - \varphi_2)} \right]^2 + \rho_0^2 \right] \right\} \dot{\varphi}_2^2 \end{aligned} \qquad (16).$$

After relevant transformations, we find the kinetic energy as a homogenous quadratic form of the generalized speeds [8]:

$$\begin{aligned} T = &\frac{1}{2} A_{11} \dot{\varphi}_1^2 + A_{12} \dot{\varphi}_1 \dot{\varphi}_2 + \frac{1}{2} A_{22} \dot{\varphi}_2^2 + \\ &+ \frac{1}{2} A_{33} \dot{u}_0^2 + A_{13} \dot{\varphi}_1 \dot{u}_0 + A_{23} \dot{\varphi}_2 \dot{u}_0 \end{aligned} \qquad (17),$$

where the values of the relevant coefficients are as follows:

$$\begin{aligned} A_{11} &= I_1 + 8mr^2 \sin^2(\varphi_1 - \varphi_2) + 8m_0 k^2 r^2 \sin^2(\varphi_1 - \varphi_2) \\ A_{12} &= -\left[8mr^2 \sin^2(\varphi_1 - \varphi_2) + 8m_0 k^2 r^2 \sin^2(\varphi_1 - \varphi_2) \right] \\ A_{22} &= 8mr^2 + 2m_0 \left\{ R + 2kr\left[1 - \cos(\varphi_1 - \varphi_2)\right] + u_0\left(1 - k^2\right) \right\}^2 + \\ &\quad + 8m_0 k^2 r^2 \sin^2(\varphi_1 - \varphi_2) \\ A_{33} &= 2m_0 \left(1 - k^2\right)^2 \\ A_{13} &= 4m_0 kr \sin(\varphi_1 - \varphi_2)\left(1 - k^2\right) \\ A_{23} &= -4m_0 kr \sin(\varphi_1 - \varphi_2)\left(1 - k^2\right) \end{aligned} \qquad (18).$$

For the formation of differential equations of motion we will use Lagrange equations of the second order [9]:

$$\begin{aligned} \frac{d}{dt}\frac{\partial T}{\partial \dot{\varphi}_i} - \frac{\partial T}{\partial \varphi_i} &= -\frac{\partial \Pi}{\partial \varphi_i} + M_i \quad (i = 1, 2) \\ \frac{d}{dt}\frac{\partial T}{\partial \dot{u}} - \frac{\partial T}{\partial u} &= -\frac{\partial \Pi}{\partial \dot{u}} \end{aligned} \qquad (19),$$

where M_i is the generalized moment of potential forces.

After the differentiation, we find the equations of motion of the system, neglecting the frictional forces:

$$\begin{aligned} &A_{11}\ddot{\varphi}_1 + A_{12}\ddot{\varphi}_2 + A_{13}\ddot{u}_0 + \frac{1}{2}\frac{\partial A_{11}}{\partial(\varphi_1 - \varphi_2)}(\dot{\varphi}_1 - \dot{\varphi}_2)^2 - \\ &-\frac{\partial w_1}{\partial(\varphi_1 - \varphi_2)}\dot{\varphi}_2^2 \left[\frac{\partial A_{13}}{\partial(\varphi_1 - \varphi_2)} + \frac{\partial A_{23}}{\partial(\varphi_1 - \varphi_2)} \right] \dot{\varphi}_2 \dot{u} + \\ &+\frac{\partial \Pi}{\partial(\varphi_1 - \varphi_2)} + \frac{\partial \Pi_v}{\partial \varphi_1} = M_1 \\ &A_{12}\ddot{\varphi}_1 + A_{22}\ddot{\varphi}_2 + A_{23}\ddot{u}_0 - \frac{1}{2}\frac{\partial A_{22}}{\partial(\varphi_1 - \varphi_2)}(\dot{\varphi}_1 - \dot{\varphi}_2)^2 + \\ &+\frac{\partial w_1}{\partial(\varphi_1 - \varphi_2)}\dot{\varphi}_1^2 + \frac{\partial A_{22}}{\partial u_0}\dot{\varphi}_2 \dot{u}_0 + \\ &+\left[\frac{\partial A_{13}}{\partial(\varphi_1 - \varphi_2)} + \frac{\partial A_{23}}{\partial(\varphi_1 - \varphi_2)} \right] \dot{\varphi}_1 \dot{u}_0 - \frac{\partial \Pi}{\partial(\varphi_1 - \varphi_2)} = 0 \\ &A_{13}\ddot{\varphi}_1 + A_{23}\ddot{\varphi}_2 + A_{33}\ddot{u}_0 + \frac{\partial A_{13}}{\partial(\varphi_1 - \varphi_2)}\dot{\varphi}_1^2 - \\ &-\left[\frac{\partial A_{13}}{\partial(\varphi_1 - \varphi_2)} + \frac{\partial A_{23}}{\partial(\varphi_1 - \varphi_2)} \right] \dot{\varphi}_1 \dot{\varphi}_2 - \\ &-\left[\frac{\partial A_{23}}{\partial(\varphi_1 - \varphi_2)} + \frac{1}{2}\frac{\partial A_{22}}{\partial u_0} \right] \dot{\varphi}_2^2 + \frac{\partial \Pi_k}{\partial u_0} = 0 \end{aligned} \qquad (20),$$

here $w_1 = \frac{1}{2} A_{11} + A_{12} + \frac{1}{2} A_{22}$.

After the disintegration of the coefficients of the equations (20) into a Taylor‘s series, we find according to [9]:

$$u_0 = u_0^c + v$$

(u_0^c is the statistic component, v is a small varying value), where each equation is divided into two parts, corresponding to stationary and vibrating motion.

1.3 Investigation of the stability of the dynamic balance

Taking into account a certain identity of two first equations of the system (20), its is described by two equations only:

$$\Pi'' - w''\omega^2 = 0$$
$$\Pi^{xx} - \frac{1}{2}a_{22}^{xx}\omega^2 = 0 \qquad (21).$$

Let us check the stability of the positiveness of the matrix determinant:

$$\Delta = \begin{vmatrix} \Pi'' - w''\omega^2 & \Pi'^x - w'^x\omega^2 \\ \Pi'^x - w'^x\omega^2 & \Pi^{xx} - \frac{1}{2}a_{22}^{xx}\omega^2 \end{vmatrix} \rangle \ 0 \qquad (22),$$

thus:

$$\left(\Pi'' - w''\omega^2\right)\left(\Pi^{xx} - \frac{1}{2}a_{22}\omega^2\right) - \left(\Pi'^x - w'^x\omega^2\right)^2 \rangle \ 0$$

where:

$$w' = \frac{1}{2}a'_{11} + a'_{12} + \frac{1}{2}a'_{22}$$
$$w'' = \frac{1}{2}a''_{11} + a''_{12} + \frac{1}{2}a''_{22}$$
$$' = \frac{d}{d\left(\varphi_1 - \varphi_2\right)}, \quad '' = \frac{d^2}{d\left(\varphi_1 - \varphi_2\right)^2}$$
$$^x = \frac{d}{du_0^c}, \quad ^{xx} = \frac{d^2}{d\left(u_0^c\right)^2}, \quad '^x = \frac{d^2}{d\left(\varphi_1 - \varphi_2\right)du_0^c}$$

The system will be stable if $\Delta > 0$ and

$$\Pi'' - w''\omega^2 \ \langle \ 0 \qquad (23).$$

With an experimental investigation of the various schemes of dynamic vibration dampers on the basis of an elastic ring, some other forms of loss of stability were obtained: 1) because of an excessive increase in the ring‘s radius for its extension, 2) because of a symmetrical deflection of the ring from the axis of rotation, 3) because of non-symmetrical sideways deflections, etc. On the basis of the experimental data, an analytic investigation on the stability of dynamic balances of the elastic ring was carried out at the preset static deformation, and some peculiarities were cleared up.

The criterion of the stability of the dynamic balance shall be considered as the existence of the maximum of kinetic potential in the preset position (point). In such a case, if the kinetic energy itself is equal to the maximum, the stability shall be considered natural and the position of the balance will not depend on the mode of the speed.

If for the point under investigation the kinetic energy is equal to the minimum or at least does not depend on the disturbance under discussion, the forced stability will only be possible at this point, i.e., we will consider that rigid forced stabilization is possible due to elastic elements. In other cases, we will ensure forced stability is possible on a certain shift of the point of dynamic balance. The size of such a shift depends, among other factors, on the mode of the speed. However, such a shift usually is bound with the appearance of a certain instability that is not allowed in a vibration damping system.

Let us discuss various cases:

1. Stability of an ideally symmetric concentric ring in the case of its uniform rotation

Let us suppose that the concentricity of the ring is ensured in any case and no static bending exists. The kinetic energy of the ring is:

$$T = \pi R\gamma_n\omega^2\left(R + \frac{\Delta l}{2\pi}\right)^2 \qquad (24),$$

where R is the initial radius of bending of the elastic ring, γ_n is the mass of the unit of length of the ring, ω is the average rotational frequency of the system, Δl is the absolute elongation of the ring.

The potential energy of the ring is:

$$\Pi = \frac{1}{4}\frac{EF}{\pi R}\left(\Delta l\right)^2 \qquad (25),$$

where F is the area of the cross-section of the elastic ring, E is the module of longitudinal elasticity.

Let us consider that a stable extension of the ring corresponds to the maximum kinetic potential, i.e., the following condition should be satisfied:

$$\frac{\partial\left(T - \Pi\right)}{\partial\left(\Delta l\right)} = 0, \qquad \frac{\partial^2\left(T - \Pi\right)}{\partial\left(\Delta l\right)^2} \ \langle \ 0 \qquad (26).$$

In such a case, the extension of the ring will be as follows:

$$\Delta l = \frac{2\pi R^3\gamma_n\omega^2}{EF - \gamma_n R^2\omega^2} \qquad (27)$$

and the limit value of the angular speed will be:

$$\omega^2 \ \langle \ \frac{EF}{\gamma_n R^2} \qquad (28).$$

The condition (28) identifies the limit of the zone of a stable extension of the ring.

2. Symmetrical longitudinal extension of the ring

As our investigations showed, the maximum efficiency of the vibration damping is achieved when $z > 1$ (in Fig. 3, $z = m_0/m$) and the ring operates as extended. If we consider that the ring is deformed according to the scheme provided in Fig. 3, the element and a more precise investigation provides that the angle $\alpha = 0$, if $z < 1$, and $\alpha > 0$, if $z > 1$, i.e., the deformation, identified with the torsion angle α, when $z > 1$, has a stable fixed value, dependent on the rigidity of the elastic ring and other elements.

It is notable that the bending rigidity of the ring itself does not affect the limits of the zones of stability ($z = 1$), it only defines (together with other parameters) the value of the static deformation.

3. Symmetrical sideways deflection of the ring

The element investigation of stability of the positions of dynamic balance upon the condition of the extremity of the kinetic potential allowed us to make the following conclusions:

a) zero deformation of the ring is possible only on $z < 1/3$ (if the ring is fixed on swivels of pendulum frames);
b) if $z = 1/3$, a certain statistical deformation of the ring is set, depending on the mode of the speeds and the rigidity of the rings;
c) if $z > 1/3$, the ring does not achieve a natural balance, so a symmetric deflection may transform into a non-symmetrical one.

Some other possible disturbances of the ring were discussed, and the conditions of balance were explored as well.

2 INVESTIGATION OF THE EFFICIENCY OF OPERATION OF THE VIBRATION DAMPER

Let us divide the motion along the cyclic coordinates φ_1, φ_2 into a uniform rotational motion and vibrations around it, using the expressions:

$$\begin{aligned} \varphi_1 &= \alpha_1 + \omega t + \beta_1 \\ \varphi_2 &= \alpha_2 + \omega t + \beta_2 \end{aligned} \qquad (29)$$

and introduce the transformation:

$$u = u_0^{\,c} + v \qquad (30),$$

where α_1 and α_2 are the phases of motion of the driving and driven links, respectively, ω is the average frequency of rotation, t is the time, β_1 and β_2 are small deflections of the coordinates φ_1 and φ_2 from the state of uniform rotational motion, u_0^{c} is the static component, and v is a small variable value.

After the disintegration of the coefficients of the non-linear equations of motion into a Taylor's series and the elimination of the static parts of the equations that identify the dynamic balance, the linearized equations of small free vibrations around the position of stationary motion will be as follows:

$$\begin{gathered} a_{11}\ddot{\beta}_1 + a_{12}\ddot{\beta}_2 + a_{13}\ddot{v} - 2w'\omega\dot{\beta}_2 - \omega\left(a'_{13} + a'_{23}\right)\dot{v} - \\ -\left(w''\omega^2 - \Pi'' - \Pi''_v\right)\beta_1 + \left(w''\omega^2 - \Pi''\right)\beta_2 - \frac{1}{2}a'^{x}_{22}\,\omega^2 v = 0 \\ a_{11}\ddot{\beta}_1 + a_{22}\ddot{\beta}_2 + a_{23}\ddot{v} + 2w'\omega\dot{\beta}_1 + \omega\left(a'_{13} + a'_{23} + a^{x}_{22}\right)\dot{v} + \\ +\left(w''\omega^2 - \Pi''\right)\beta_1 - \left(w''\omega^2 - \Pi''\right)\beta_2 + \frac{1}{2}a'^{x}_{22}\,\omega^2 v = 0 \\ a_{13}\ddot{\beta}_1 + a_{22}\ddot{\beta}_2 + a_{33}\ddot{v} + \omega\left(a'_{13} + a'_{23}\right)\dot{\beta}_1 - \omega\left(a'_{13} + a'_{23} + a^{x}_{22}\right)\beta_2 - \\ -\frac{1}{2}a'^{x}_{22}\,\omega^2\beta_2 + \left(\Pi_k^{xx} - \frac{1}{2}a'^{x}_{22}\,\omega^2\right)v = 0 \end{gathered} \qquad (31).$$

The linearized equations of motion (31) include inertial, gyroscopic and quasi-elastic members. Thus, the dynamic link of the vibration damper is a rather complicated link between rotating objects, and in the general case it cannot be reduced to the usual (linear or non-linear) elasticity.

2.1 Solution of the system of equations

The natural frequencies of the system with the vibration damper can be found on the basis of the characteristic determinant:

$$\begin{vmatrix} a_{11}\lambda^2 - w''\omega^2 + \Pi''_v & a_{12}\lambda^2 - 2w'\omega\lambda + w''\omega^2 - \Pi'' & a_{13}\lambda^2 - \frac{1}{2}a'^{x}_{22}\,\omega^2 \\ a_{12}\lambda^2 + 2w'\omega\lambda + w''\omega^2 - \Pi'' & a_{22}\lambda^2 - w''\omega^2 + \Pi'' & a_{23}\lambda^2 + a^{x}_{22}\omega\lambda + \frac{1}{2}a'^{x}_{22}\,\omega^2 \\ a_{13}\lambda^2 - \frac{1}{2}a'^{x}_{22}\,\omega^2 & a_{23}\lambda^2 - a^{x}_{22}\omega\lambda + \frac{1}{2}a'^{x}_{22}\,\omega^2 & a_{33}\lambda^2 + \Pi^{xx} - \frac{1}{2}a^{xx}_{22}\omega^2 \end{vmatrix} = 0 \qquad (32),$$

where $\lambda = i\omega p^{\mathrm{c}}$, p^{c} is one of the natural frequencies. This determinant (32) provides three natural frequencies.

For a determination of the natural frequencies of a vibration damping system only, the below reduced equation (33) can be used; this equation is the condition of frequency tuning for the vibration damper as well:

$$\begin{gathered} \left(a_{22}a_{33} - a_{23}^{\;2}\right)\lambda^4 + \\ +\left[a_{22}\left(\Pi^{xx} - \frac{1}{2}a_{22}^{\;xx}\omega^2\right) - a_{33}\left(w''\omega^2 - \Pi''\right) + \left(a_{22}^{\;\prime x} - a_{22}^{\;\prime x}\,a_{23}\right)\omega^2\right]\lambda^2 - \\ -\left[\left(w''\omega^2 - \Pi''\right)\left(\Pi^{xx} - \frac{1}{2}a^{xx}_{22}\omega^2\right) + \frac{1}{4}a_{22}^{\;\prime x2}\,\omega^4\right] = 0 \end{gathered} \qquad (33).$$

For an assessment of the impact of the vibration damper on the vibration of the system, we find an expression of the equivalent moment of inertia I_{e}, the value of fictitious mass, rigidly connected with the principal system. The vibration damping effect of the mass with respect to the principal system is equivalent to the relevant effect of the supplemental vibration damping unit.

The periodic component of the reactive torsional moment is:

$$M_p = -\left(a_{11} - I_1\right)\ddot{\beta}_1 - a_{12}\ddot{\beta}_2 - a_{13}\ddot{v} + 2w'\omega\dot{\beta}_2 + \omega\left(a_{13}' + a_{23}'\right)\dot{v} - \\ -\left(w''\omega^2 - \Pi''\right)\left(\beta_1 - \beta_2\right) + \frac{1}{2}a_{22}{}'^{x}\omega^2 v \qquad (34)$$

and the equivalent moment of inertia is:

$$I_e = -\frac{M_p}{\ddot{\beta}_1} \qquad (35).$$

After insertion of the values:

$$\beta_i = A_i \sin pt + B_i \cos pt \qquad i=1,2$$
$$v = A_3 \sin pt + B_3 \cos pt$$

as well as their fluxions $\dot{\beta}_i$, $\ddot{\beta}_i$, $\dot{v}$, $\ddot{v}$, and ratios A_2 / A_1, B_2 / B_1 and so on into (35), we find the following expression for the equivalent moment of inertia:

$$I_e = \frac{\left[\left(a_{11}-I_1\right)\left(a_{22}a_{23}-a_{23}{}^2\right)-2a_{12}a_{23}{}^2-a_{22}a_{23}{}^2-a_{12}{}^2a_{33}\right]p^4+}{\left(a_{22}a_{33}-a_{23}{}^2\right)p^4-\left[a_{22}\left(\Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\omega^2\right)-a_{33}\left(w''\omega^2-\Pi'\right)-a_{22}{}'^{x}a_{23}\omega^2+\right]}$$
$$\frac{+\left\{\left(2w-I_1\right)\left[a_{33}\left(w''\alpha\omega^2-\Pi''\right)-a_{13}a_{22}{}'^{x}\omega^2\right]-\left[\left(a_{11}-I_1\right)a_{22}-a_{12}{}^2\right]\right\}}{+a_{22}{}^{x2}\omega^2\ \left.\right]p^2-\left(\Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\omega^2\right)\left(w''\omega^2-\Pi''\right)+\frac{1}{4}a_{22}{}'^{x2}\omega^4}+ \qquad (36).$$
$$+\left[\Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\omega^2\right]+4w'\omega^2\left(a_{13}a_{22}{}^{x}-w'a_{23}\right)-\left(a_{11}-I_1\right)a_{22}{}^{x2}\omega^2p^2+$$
$$+\begin{cases}2w'\omega^2\left[2w'\left(\Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\omega^2\right)+a_{22}{}'^{x}a_{22}{}^{x}\omega^2\right]-\left(w''\omega^2-\Pi''\right)a_{22}{}^{x2}\omega^2-\\-\left(2w-I_1\right)\left(\Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\omega^2\right)\left(w''\omega^2-\Pi''\right)-\left(2w-I_1\right)\frac{1}{4}a_{22}{}'^{x2}\iota\omega^4\end{cases}$$

The limit values of the equivalent moment of inertia for low- frequency disturbances will be found from the following expression:

$$\lim_{p\to 0} I_e = \frac{2w'\omega^2\left[2w'\left(\Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\omega^2\right)+a_{22}{}'^{x}a_{22}{}^{xx}\omega^2\right]-\left(w''\omega^2-\Pi''\right)a_{22}{}^{xx2}\omega^2}{-\left(\Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\varepsilon\omega^2\right)\left(w''\omega^2-\Pi''\right)-\frac{1}{4}a_{22}{}'^{x2}\omega^4} - \qquad (37)$$
$$-\left(2w-I_1\right)\left(\left(\ \Pi^{xx}-\frac{1}{2}a_{22}{}^{xx}\omega^2\ \right)\left(w''\omega^2\right)\left(w''\omega^2-\Pi''\right)-\left(2w-I_1\right)\frac{1}{4}a_{22}{}'^{x}\alpha\omega^4\right)$$

and for high-frequency disturbances:

$$\lim_{p\to\infty} I_e = \frac{\left(a_{11}-I_1\right)\left(a_{22}a_{33}-a_{23}{}^2\right)-2a_{12}a_{23}{}^2-a_{22}a_{23}-a_{12}{}^2a_{33}}{a_{22}a_{33}-a_{23}{}^2} \qquad (38).$$

In our case, the coefficients will be expressed as follows:

$$a_{11} = I_1 + 2mR^2\sin^2\alpha\left(1+zk^2\right)$$
$$a_{12} = -2mR^2\sin^2\alpha\left(1+zk^2\right)$$
$$a_{22} = 2mR^2\left(1+z\right)+4mR^2zk\left(1-\cos\alpha\right)\left(1+k\right)+$$
$$+2mu_0z\left(1-k^2\right)\left\{u_0\left(1-k^2\right)+2R\left[1+k\left(1-\cos\alpha\right)\right]\right\}$$
$$a_{13} = 2mzkR\left(1-k^2\right)\sin\alpha \qquad (39),$$
$$a_{23} = -2mzkR\left(1-k^2\right)\sin\alpha$$
$$a_{33} = 2mz\left(1-k^2\right)^2$$

where $R = 2r$, $m_0 = mz$, α_1 - $\alpha_2 = \alpha$, and z is the ratio of the centrifugal masses m_0 and m. Other coefficients will be expressed as follows:

$$a_{11}' = 2mR^2\sin 2\alpha\left(1+zk^2\right)$$
$$a_{22}' = 4mzkR\left(1+k\right)\sin\alpha\left[R+u_0\left(1-k\right)\right]$$
$$a_{12}' = -2mR^2\sin 2\alpha\left(1+zk^2\right)$$
$$w'' = 2mzkR\left(1+k\right)\cos\alpha\left[R+u_0\left(1-k\right)\right]-2mR^2\cos 2\alpha\left(1+zk^2\right)$$
$$a_{11}'' = 4mR^2\cos 2\alpha\left(1+zk^2\right)$$
$$a_{22}'' = 4mzkR\left(1+k\right)\cos\alpha\left[R+u_0\left(1-k\right)\right]$$
$$a_{12}'' = -4mR^2\cos 2\alpha\left(1+zk^2\right) \qquad (40).$$
$$a_{22}{}'^{x} = 4mzkR\left(1-k^2\right)\sin\alpha$$
$$a_{22}{}^{xx} = 4mz\left(1-k^2\right)^2$$
$$a_{22}{}^{x} = 4mz\left(1-k^2\right)\left\{kR\left(1-\cos\alpha\right)+\left[R+u_0\left(1-k^2\right)\right]\right\}$$
$$\Pi'' = C_{n1}R^2\left(\cos\alpha-\cos 2\alpha\right)$$
$$\Pi^{xx} = C_{n2} = \frac{8\pi^2\left(\pi^3-20\pi+32\right)}{\left(\pi^2-8\right)^3}\frac{EI}{R^3}$$
$$C_{n1} = \frac{16\pi}{\pi^2-8}\frac{EI}{R^3}$$

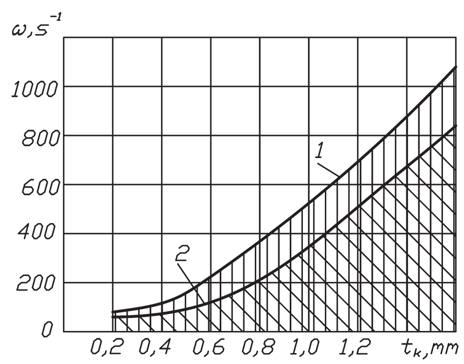

Fig.4. *Dependence of the critical frequency of rotation (ω) of the damper on the thickness of the elastic ring (t_k), when b = 20 mm, z = 2,0, m = 0.03 kg, where the curve 1 corresponds to R = 80 mm and the curve 2 to R = 100 mm (the zones of stability are shaded)*

From the equations of dynamic balance we find the average angle of torsion α_1-α_2 of the vibration damper and u_0^c is the static component of the independent variable u_0:

$$\alpha_1-\alpha_2=\arccos\frac{C_{n1}C_{n2}-2C_{n2}mzk(1+k)\omega^2-2C_{n1}mz\left(1-k^2\right)^2\omega^2}{C_{n1}C_{n2}-2m\omega^2\left[C_{n2}\left(zk^2+1\right)+z\left(1-k^2\right)^2\left(C_{n1}-2m\omega^2\right)\right]} \quad (41)$$

$$u_0^{\,c}=\frac{2mzR\omega^2\left[C_{n1}-2m\omega^2(1+k)\right](1-k)^2}{C_{n1}C_{n2}-2m\omega^2\left[C_{n2}\left(zk^2+1\right)+z\left(1-k^2\right)^2\left(C_{n1}-2m\omega^2\right)\right]} \quad (42).$$

The complete expression of the equivalent moment of inertia (36) of the vibration damper under discussion is not presented here because of its length. The equivalent moment of inertia in the high-frequency zone of disturbances is expressed as follows:

$$\lim_{p\to\infty} I_e=\frac{C_1}{C_2}$$

$$C_1=2mR^2\sin^2\alpha\left\{\begin{array}{l}2Ru_0z\left(1-k_0^{\,2}\right)\left[k(1-\cos\alpha)+1\right]+\\ +R^2\left[\begin{array}{l}\cos^2\alpha+z\left(1-k^2\sin^2\alpha\right)+\\ +2zk(1-\cos\alpha)(1-k)\end{array}\right]+zu_0\left(1-k^2\right)^2\end{array}\right\}$$

$$C_2=-\left\{\begin{array}{l}R^2(1+z)+2R^2zk(1-\cos\alpha)(1+k)+\\ +zu_0\left(1-k^2\right)\left[u_0\left(1-k^2\right)+2R(1+k)(1-\cos\alpha)\right]-zk^2R^2\sin^2\alpha\end{array}\right\} \quad (43).$$

As specific quantitative calculations showed, it is sufficient to describe the deformed ring in many constructions of vibration dampers with only two generalized coordinates, i.e., it can be considered that a transversal compression of the ring is proportional (in some cases equal) to its longitudinal extension.

In such a case, the expression for kinetic energy is reduced to the well-known quadratic trinomial [11], and its coefficients are as follows:

$$\begin{array}{l}A_{11}=I_1+8mr^2\sin^2(\varphi_1-\varphi_2)+8m_0k^2r^2\sin^2(\varphi_1-\varphi_2)\\ A_{12}=-\left[8mr^2\sin^2(\varphi_1-\varphi_2)+8m_0k^2r^2\sin^2(\varphi_1-\varphi_2)\right]\\ A_{22}=8mr^2+2m_0\left\{R+2kr\left[1-\cos(\varphi_1-\varphi_2)\right]\right\}^2+8m_0k^2r^2\sin^2(\varphi_1-\varphi_2)\end{array} \quad (44).$$

Correspondingly, the potential energy will be equal to:

$$\Pi_c=\Pi_k+\Pi_v \quad (45),$$

where $\Pi_k=\frac{1}{2}C_{n1}(2r)^2\left[1-\cos(\varphi_1-\varphi_2)\right]^2$ is the potential energy of the elastic ring; Π_v is the potential energy of the shaft torsion that is a function of φ_1.

Based on the methods described in [12], we find linearized equations for the small torsional vibrations that may be used for an assessment of the stability of dynamic balance and the efficiency of the vibration

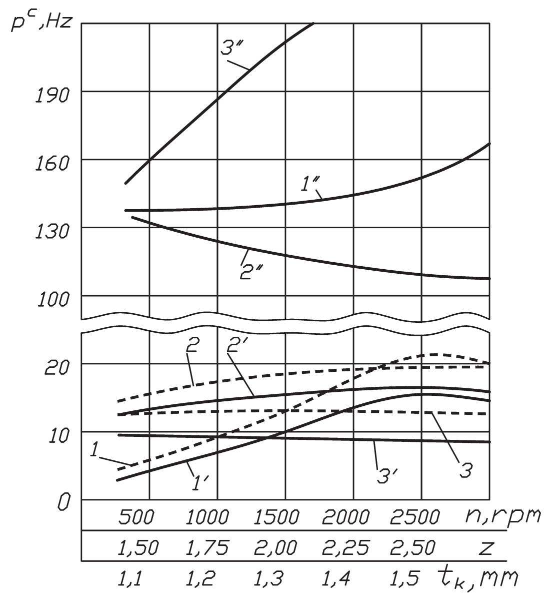

Fig.5. *Dependence of the natural frequencies of vibration damper (p^c) on its structural parameters and the number of revolutions, when the radius of the elastic ring R = 80 mm, m = 0.03 kg, n = 1500 rpm, z = 1.25, t_k = 1.1 mm, b = 20 mm (the solid lines are obtained by using the equations (33) and the dotted ones by using the simplified calculation (48)), where the curves 1, 1′, 1″ – $p^c = f(n)$, 2, 2′, 2″ - $p^c = f(z)$, 3, 3′, 3″ – $p^c = f(t_k)$, the index ′ corresponds to the first frequency and the index " – to the second frequency (in the formula (33))*

damper. To a certain extent, such cases are described in [7] to [9] as well.

In this case, the stable positions of the dynamic balance of the ring are described by one of the following conditions:

a) if $z < 1,\ \alpha_1 - \alpha_2 = 0$,

b) if $z > 1,\ \alpha_1 - \alpha_2 = \arccos \dfrac{C_{n1} - 4zm\omega^2}{C_{n1} - 2(1+z)m^2}$ (46).

For the case b), the minimum cross-section of the ring (its axial moment of inertia) will be found from the following inequality:

$$I \geq \frac{\pi^2 - 8}{16\pi} \frac{(3z+1)m\omega^2}{E} \qquad (47).$$

3 RESULTS

The possible combinations of the parameters are illustrated in Fig.4.

The frequency of resonance tuning of the vibration damper is:

$$p^c = \omega \sqrt{\frac{\frac{C_{n1}}{2m\omega^2}\left(\cos\alpha - \cos 2\alpha - \left[zk(1+k)\cos\alpha - (1+zk^2)\cos 2\alpha\right]\right)}{1+z+2zk(1-\cos\alpha)(1+k)}} \qquad (48).$$

Fig. 5 illustrates some curves of natural frequencies.

The expression for the equivalent moment of inertia will be as follows:

$$I_e = 2mR^2 \frac{(A - B\sin^2\alpha)\left[B\sin^2\alpha\left(\frac{p}{\omega}\right)^2 + C\cos\alpha - B\cos 2\alpha - DE\right] - 4\sin^2\alpha(C - B\cos\alpha)^2}{A\left(\frac{p}{\omega}\right)^2 + C\cos\alpha - B\cos 2\alpha - DE} \qquad (49),$$

where:

$$A = 1 + z + 2zk(1+k)(1-\cos\alpha)$$

$$B = 1 + zk^2$$

$$C = zk(1+k)$$

$$D = \frac{C_{n1}}{2m\omega^2}$$

$$E = \cos\alpha - \cos 2\alpha$$

The dependence of equivalent moment of inertia structural and performance parameters is presented in Fig.6. The limit value I_e in the low-frequency zone:

$$\lim_{p\to 0} I_e = 2mR^2\left[A - B\sin^2\alpha - \frac{8m\sin^2\alpha(C - B\cos\alpha)^2\omega^2}{2m(C\cos\alpha - B\cos 2\alpha)\omega^2 - C_{n1}E}\right] \qquad (50),$$

in the high frequency zone:

$$\lim_{p\to\infty} I_e = 2BmR^2\sin^2\alpha\left(1 - \frac{B\sin^2\alpha}{A}\right) \qquad (51).$$

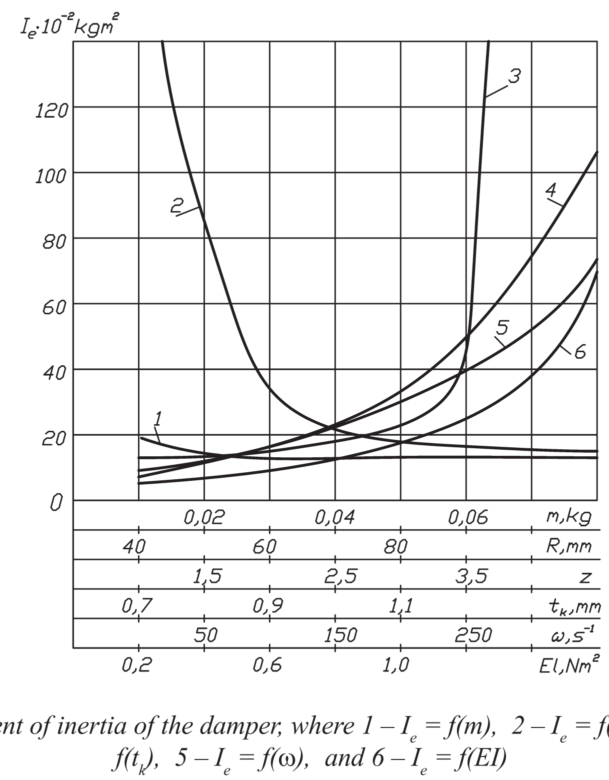

Fig. 6. *Equivalent moment of inertia of the damper, where 1 – $I_e = f(m)$, 2 – $I_e = f(R)$, 3 – $I_e = f(z)$, 4 – $I_e = f(t_k)$, 5 – $I_e = f(\omega)$, and 6 – $I_e = f(EI)$*

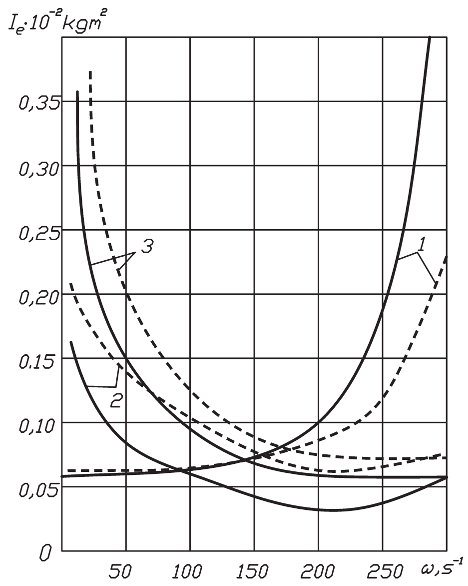

Fig.7. *Comparison of the efficiency of the damper for various estimated models (the dotted lines correspond to the approximate calculation), if R = 80 mm, m = 0.03 kg, z = 2.0,* t_k *= 1.2 mm, b = 20 mm, where 1 -* $\frac{p}{\omega} = 0,1,\ 2 - \frac{p}{\omega} = 1,0,\ 3 - \frac{p}{\omega} = 10.$

The comparison of the values of the equivalent moment of inertia, found from the equation (36) and the simplified calculation (49), is provided in Fig. 7.

4 CONCLUSIONS

The general results of the investigation are provided in the presented schemes of vibration dampers:

- the schemes a, a-1, a-2 (Fig. 1) are distinguished by natural stability, if $z < 1/3$. In such a case, the frames 3 may be designed in the shape of strings that only resist extension,
- if $z > 1/3$, a rigid forced stabilization can be achieved because of the elasticity of the frames 3,
- the vibration dampers, showed in the schemes b and c, can be stabilized by the introduction of a relevant elastic element, resistant to the deflection of the frames 3,
- the remaining schemes are distinguished by rigid stability and preserve their strict symmetry on the relevant rigidity of the elastic elements. The side stabilization of the extended elastic ring can be ensured by a connection of the deflected centrifugal pendulums 3 with the swivel parallelogram (see Fig. 1, b-1) or the replacement of centrifugal pendulums with symmetric elastic frames 3, situated at a certain angle with respect to the radius (see Fig. 1, b-2),
- in many cases the efficiency of a vibration damper may be increased by fixing the elastic ring on two symmetrically deflected centrifugal pendulums (Fig. 1, c). In such a case, the vibration damper is not a stable system; it is inclined to a non-symmetric sideways “deflection”. The stabilization of the ring can be ensured if the deflected pendulums are elastic frames (see Fig. 1, c-1) or elastically fixed pendulums (see Fig. 1, c-2).
- the analytical investigation of the efficiency of the vibration damper, applying special sets of programmes, allows us to state that a vibration damper can be sufficiently precisely presented as a vibrating system with two degrees of freedom for most practically important ranges,
- in many cases the simplified calculation ensures sufficient accuracy,
- with an increase in the radius of the elastic ring, the critical frequencies of rotation of the vibration damper decrease,
- the value of the equivalent moment of inertia is mostly affected by the thickness of the elastic ring,
- the efficiency of a vibration damper increases with an increase in its natural frequencies.

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Authors' Addresses: Prof.Dr. Bronislovas Spruogis
Vilnius Gediminas Technical University
Faculty of Transport Engineering
Lithuania
bs@tti.vtu.lt

Doc.Dr. Vytautas Turla
Vilnius Gediminas Technical University
Mechanical Faculty
Lithuania
vytautas.turla@me.vtu.lt

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Izbira gladilne spremenljivke z optičnimi napetostnimi nanosi

Choice of Smoothing Parameter Using Photo-Elastic Coatings

Violeta Kravčenkiene[1] - Algiment Aleksa[1] - Minvydas Ragulskis[1] - Rimas Maskeliunas[2]
([1] Kaunas University of Technology, Kaunas; [2] Vilnius Gediminas Technical University, Vilnius)

V prispevku je opisana metoda izbire gladilne spremenljivke. Prikazana je na problemu fotoelastične analize upogibnih nihanj plošče. Model končnih elementov sistema temelji na aproksimaciji pomikov vozlišč, medtem ko na postavitev zunanjih robov vpliva polje napetosti v fotoelastičnem nanosu. Vzorci zunanjih robov, ki smo jih ustvarili brez glajenja, se na mejah med elementi vedejo nenaravno. V primeru, da je gladilna spremenljivka prevelika, dobimo preveč zglajeno sliko, ki sicer lahko izgleda sprejemljivo, vendar je daleč od resnične fotoelastične slike. Predstavljen način izbire optimalne gladilne spremenljivke je posplošen za dvorazsežne Lagrangeve končne elemente.
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(Ključne besede: spremenljivke zglajene, izbor spremenljivk, plošče, nihanja upogibna, analize fotoelastične)

A method of choosing a smoothing parameter is described and illustrated for the problem of a photo-elastic analysis of the bending vibrations of a plate. The finite-element model of the system is based on an approximation of the nodal displacements, while the formation of fringes is governed by the stress field in the photo-elastic coating. Without smoothing the reconstructed patterns of the fringes exhibit a non-physical behaviour at inter-element boundaries. When the smoothing parameter is too big, an over-smoothed image is obtained, which may look acceptable but be far from the realistic photo-elastic image. The presented strategy for the selection of the optimum smoothing parameter is generalised for two-dimensional Lagrange finite elements.
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(Keywords: smoothing parameters, parameter choice, plates, bending vibrations, photo-elastic coatings)

0 INTRODUCTION

The problem of the bending vibrations of a plate is a common one in different engineering applications. This problem was analysed by using photo-elastic coatings in [1]. Photo-elastic coating [2] is a classical technique for stress analysis.

The coating has a negligible effect on the vibrations of the plate. First, the eigenmodes are calculated using the usual plate-bending element. The coating is thin and the plane displacements in the coating coincide with the displacements on the surface of the plate, and are the same through the thickness of the coating. The stresses in the coating are calculated assuming conditions of plane stress. The directions of the incident and the reflected light are almost perpendicular to the coating.

The conventional FEM would require unacceptably dense meshing to produce sufficiently smooth photo-elastic patterns. Therefore, there is a need to smooth the generated photo-elastic fringe patterns representing the stress distribution, and which are calculated from the displacement distribution. The choice of the optimum value of the smoothing parameter is an important problem that is addressed in this paper.

1 CHOICE OF THE SMOOTHING PARAMETER

First, the eigenmodes of the plate are calculated by using a displacement formulation common in finite element analysis. Further, x, y and z are used to denote the axes of the orthogonal Cartesian system of coordinates. The plate-bending element with the independent interpolation of the displacement w and the rotations about the appropriate axes θ_x and θ_y is used [3]. It is assumed that the plate performs vibrations according to the eigenmode (the frequency of the excitation is about equal to the eigenfrequency of the corresponding eigenmode). The vibrations of the plate are registered stroboscopically when the structure is in the state of extreme deflections according to the eigenmode.

The nodal variables of the plate-bending element are the deflection of the plate w, the rotation of the plate about the x axis θ_x and the rotation of the plate about the y axis θ_y. It is assumed that in the plate $v = -z\theta_x$ and $u = z\theta_y$, where u and v are the displacements of the plate in the x and y directions, respectively. Thus $u = (h/2)\theta_y$ and $v = -(h/2)\theta_x$ are the displacements on the surface of the plate, and h is the thickness of the plate.

The eigenmodes of the plate are obtained in the usual way, assuming that the coating has no effect on the motion of the plate.
The stresses in the coating are calculated as:

$$\{\sigma\} = [D_c][B]\{\delta\} \qquad (1),$$

where:

$$[B] = \begin{bmatrix} 0 & 0 & \frac{\partial N_1}{\partial x} & \cdots \\ 0 & -\frac{\partial N_1}{\partial y} & 0 & \cdots \\ 0 & -\frac{\partial N_1}{\partial x} & \frac{\partial N_1}{\partial y} & \cdots \end{bmatrix} \qquad (2)$$

$$[D_c] = \frac{h}{2} \begin{bmatrix} \frac{E_c}{1-\nu_c^2} & \frac{E_c \nu_c}{1-\nu_c^2} & 0 \\ \frac{E_c \nu_c}{1-\nu_c^2} & \frac{E_c}{1-\nu_c^2} & 0 \\ 0 & 0 & \frac{E_c}{2(1+\nu_c)} \end{bmatrix} \qquad (3)$$

and $\{\sigma\}$ is the vector of the components of stresses σ_x, σ_y and τ_{xy}, assuming that the coating is in the state of plain stress; N_i is the i-th shape function of the finite element; E_c is the modulus of elasticity of the coating; ν_c is the Poisson's ratio of the coating; and $\{\delta\}$ is the vector of generalised displacements of the eigenmode.

The field of the components of stresses incorporating its smoothing is determined as described in detail in [4]. Furthermore, $\{\delta_x\}$ denotes the vector of the nodal values of σ_x; $\{\delta_y\}$ denotes the vector of nodal values of σ_y; $\{\delta_{xy}\}$ denotes the vector of nodal values of τ_{xy}. The nodal values $\{\delta_x\}$, $\{\delta_y\}$ and $\{\delta_{xy}\}$ are obtained from the following systems of linear algebraic equations:

$$\begin{aligned} &\left(\sum_i \iint_{e_i} \left([N]^T [N] + [B^*]^T \lambda [B^*]\right) dxdy\right) \cdot \{\delta_x\} = \\ &= \sum_i \iint_{e_i} [N]^T \sigma_x dxdy, \\ &\left(\sum_i \iint_{e_i} \left([N]^T [N] + [B^*]^T \lambda [B^*]\right) dxdy\right) \cdot \{\delta_y\} = \\ &= \sum_i \iint_{e_i} [N]^T \sigma_y dxdy, \\ &\left(\sum_i \iint_{e_i} \left([N]^T [N] + [B^*]^T \lambda [B^*]\right) dxdy\right) \cdot \{\delta_{xy}\} = \\ &= \sum_i \iint_{e_i} [N]^T \tau_{xy} dxdy, \end{aligned} \qquad (4)$$

where $[N]$ is the row of the shape functions of the finite element; $[B^*]$ is the matrix of the derivatives of the shape functions (the first row with respect to x; the second row with respect to y); λ is the smoothing parameter; e_i stands for the domain of the i-th finite element; summation denotes the direct stiffness procedure.

When the smoothing parameter is too small the reconstructed images are of unacceptable quality because of the non-physical behaviour of the stress field as a result of its calculation from the displacement formulation. When the parameter is too big an over-smoothed image is obtained, which may look acceptable but be far from the real photo-elastic image.

The problem is to determine the optimum value of the smoothing parameter λ. This can be solved for a one-dimensional problem with linear elements ([5] and [6]). In our problem λ corresponds to Ak in [6] and 1 corresponds to hp in [6]. Thus the condition derived in [6] in our notation takes the form:

$$\frac{\lambda}{l} > \frac{l}{6} \qquad (5),$$

where l is the length of the one-dimensional element.

This gives the optimum value of the smoothing parameter:

$$\lambda \approx \frac{l^2}{6} \qquad (6),$$

or the optimum element size:

$$l \approx \sqrt{6\lambda} \qquad (7).$$

So in order to obtain results which appear acceptable it is necessary to increase the smoothing parameter or to apply a finer finite-element mesh, or both.

For one-dimensional Lagrange elements instead of l the maximum distance between the consecutive nodes is to be used and the optimum value of the smoothing parameter is determined from:

$$\lambda \approx \frac{l^2}{R} \qquad (8),$$

or the optimum element size is determined from:

$$l \approx \sqrt{R\lambda} \qquad (9),$$

where the value of the coefficient R is determined on the basis of numerical experiments for a given element order.

For two-dimensional Lagrange elements instead of l the following value in the equations (8) and (9) is to be used:

$$l = \max\left(l_\xi, l_\eta\right) \qquad (10),$$

where $l\xi$ is the maximum distance between the consecutive nodes in the direction of the local ξ coordinate and $l\eta$ is the maximum distance between the consecutive nodes in the direction of the local η coordinate.

The vector of polarisation is assumed to be given as:

$$\{P\} = \begin{Bmatrix} \cos\alpha \\ \sin\alpha \end{Bmatrix} \qquad (11),$$

where α is the angle of the vector of polarisation with the x axis.

Furthermore, the quadratic Lagrange element is used. In order to calculate the distance between the first pair of consecutive nodes the mapping between the variable $\xi \in [-1, \quad 0]$ and $\tilde{\xi} \in [-1, \quad 1]$ is introduced:

$$\xi = \frac{\tilde{\xi} - 1}{2} \qquad (12).$$

Then:

$$\int ds = \int_{-1}^{0} \frac{ds}{d\xi} d\xi = \int_{-1}^{1} \frac{ds}{d\xi} \frac{1}{2} d\tilde{\xi} \qquad (13),$$

where:

$$\frac{ds}{d\xi} = \sqrt{\left(\frac{dx}{d\xi}\right)^2 + \left(\frac{dy}{d\xi}\right)^2} \qquad (14),$$

and s denotes the length of the curve.

In order to calculate the distance between the next pair of consecutive nodes the mapping between the variable $\xi \in [0, \quad 1]$ and $\tilde{\xi}$ is introduced:

$$\xi = \frac{\tilde{\xi} + 1}{2} \qquad (15).$$

Then:

$$\int ds = \int_{0}^{1} \frac{ds}{d\xi} d\xi = \int_{-1}^{1} \frac{ds}{d\xi} \frac{1}{2} d\tilde{\xi} \qquad (16),$$

where $ds / d\xi$ is given by Equation (14).

The two-dimensional Lagrange element is shown in Fig. 1. Thus, the curve lengths between the consecutive nodes for the one-dimensional quadratic Lagrange element with the nodes 1, 2 and 3: 1 and 2, 2 and 3 are calculated. Then the curve lengths between the consecutive nodes for the one-dimensional quadratic Lagrange element with the nodes 4, 5 and 6: 4 and 5, 5 and 6 are calculated. Then the curve lengths between the consecutive nodes for the one-dimensional quadratic Lagrange element with the nodes 7, 8 and 9: 7 and 8, 8 and 9 are calculated. Then the curve lengths between the consecutive nodes for the one-dimensional quadratic Lagrange element with the nodes 1, 4 and 7: 1 and 4, 4 and 7 are calculated. Then the curve lengths between the consecutive nodes for the one-dimensional quadratic Lagrange element with the nodes 2, 5 and 8: 2 and 5, 5 and 8 are calculated. Then the curve lengths between the consecutive nodes for the one-dimensional quadratic Lagrange element with the nodes 3, 6 and 9: 3 and 6, 6 and 9 are calculated. These calculations are performed as described previously. Then the maximum distance between the consecutive nodes is determined and the smoothing parameter for the element is obtained from Equation (8).

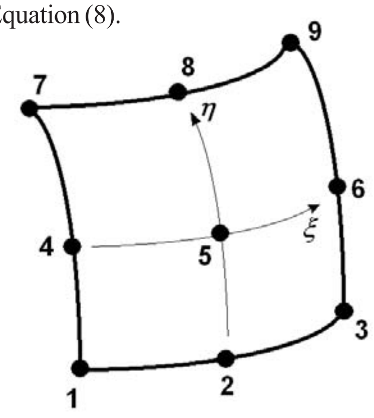


Fig. 1. *Node numbering of the two-dimensional Lagrange quadratic finite element*

2 RESULTS OF ANALYSIS

A circular plate with fixed internal radius performing harmonic vibrations according to the fourth eigenmode is analysed. It is considered that the plate is experiencing resonant vibrations on an eigenmode: the loading is assumed to be harmonic with the frequency of the eigenmode and not orthogonal to it.

The isolines of the absolute value of the difference of the principal stresses are presented in Fig. 2.

The lines of the principal directions of the stresses corresponding to the darkest parts from the images of the isoclinics (composite isoclinic pattern) are shown in Fig. 3. The composite isoclinic pattern is presented for the values of $\alpha = (i-1)\pi/20$, where $i = 1, \ldots, 10$.

In order to investigate the effect of different values of the coefficient *R* the zoomed part of the time averaged photo-elastic images for the plane polariscope with different values of *R* are presented in Fig. 4. It is evident that a smaller value of *R* gives bigger values of the smoothing parameter and thus a more realistic image.

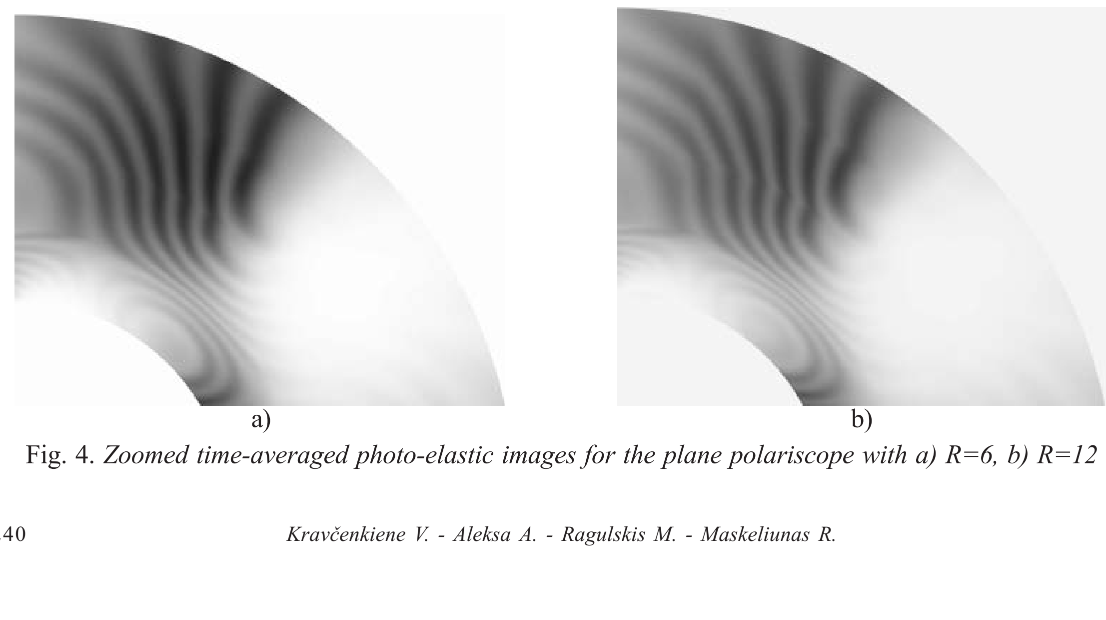
3 CONCLUSIONS

The recommendations for the choice of the smoothing parameter in the smoothing procedure for the analysis of the bending vibrations of a plate by using photo-elastic coatings are presented.

As an illustration of the analysis the isolines of the absolute value of the difference of the principal stresses are obtained and the composite isoclinic pattern is produced. Those two drawings are the basis for the interpretation of the results of photo-elastic analysis.

Fig. 2. *Isolines of the absolute value of the difference of the principal stresses*

Fig. 3. *Composite isoclinic pattern for the values of $\alpha = (i-1)\pi/20$, where i = 1, ..., 10*



a) b)

Fig. 4. *Zoomed time-averaged photo-elastic images for the plane polariscope with a) R=6, b) R=12*

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Authors' Addresses: Violeta Kravčenkiene
Algiment Aleksa
Prof.Dr. Minvydas Ragulskis
Department of Mathematical Research in Systems
Kaunas University of Technology
Studentř str. 50, LT-51368
Kaunas, Lithuania
Minvydas.Ragulskis@ktu.lt

Dr. Rimas Maskeliunas
Department of Printing Machines
Vilnius Gediminas Technical University
J. Basanaviciaus str. 28
LT - 03224 Vilnius, Lithuania
pgmas@me.vtu.lt

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Obvladovanje delovne zastarelosti strojev in opreme: količnik ozdravljivosti delovne zastarelosti kot osnova za odločitve o obnovi ali zamenjavi strojev in opreme

Managing the Functional Obsolescence of Machinery and Equipment: the Quotient of Curability of Functional Obsolescence as a Basis for Decisions Made about the Renovation or Replacement of Machinery and Equipment

Igor Pšunder
(Fakulteta za gradbeništvo, Maribor)

Delovna zastarelost strojev in opreme se velikokrat pojavlja v senci fizične obrabe oziroma gospodarske (ekonomske) zastarelosti. Na teh oblikah poslabšanja, torej v odvisnosti od fizičnega stanja strojev in opreme oziroma v odvisnosti od zunanjih vplivov (npr. spremembe predpisov), temeljijo tudi odločitve o obnovi ali zamenjavi strojev in opreme. Takšne odločitve praviloma niso podprte s študijami ekonomske upravičenosti. Ekonomsko utemeljene obnove ali zamenjave strojev in opreme pa se opirajo predvsem na preučitev njihove delovne zastarelosti.

V tem prsipevku podrobno obravnavamo vlogo delovne zastarelosti v postopku odločanja o obnovi ali zamenjavi strojev in opreme. Posebno pozornost smo namenili merjenju njene ozdravljivosti. V ta namen smo vpeljali tako imenovani količnik ozdravljivosti delovne zastarelosti, ki temelji na razmerju med sedanjo vrednostjo ovrednotenih učinkov delovne zastarelosti ter med vložkom, ki je potreben za njeno odpravo.
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(Ključne besede: zastarelost delovna, količnik ozdravljivosti, stroji, oprema, obnova, zamenjava)

The functional obsolescence of machinery and equipment often appears in the wake of physical deterioration and economic obsolescence. Decisions made about the renovation or replacement of machinery and equipment are mainly based on the last two types of deterioration and are therefore dependent on the physical condition of the machinery and equipment or on external circumstances, e.g., regulation changes. Such decisions are usually not supported by studies of economic feasibility. Economically feasible renovation or replacement of machinery and equipment is usually primarily dependent on functional obsolescence.

The paper is a detailed study of the role of functional obsolescence in the process of making decisions about renovation and the replacement of machinery and equipment. We have given special attention to measuring the curability of this obsolescence. We have, for this reason, introduced the term quotient of curability of functional obsolescence. This quotient is based on the relation between the present value of the quantified effects of functional obsolescence for machinery and equipment, and the investment necessary for its repair.
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(Keywords: functional obsolescence, curability quotient, machinery, equipment, renovation, replacement)

0 UVOD

Delovna zastarelost je v splošnem definirana kot posledica negativnih vplivov na vrednost strojev ali opreme[1], ki izvirajo iz

[1] V nadaljevanju bomo zaradi boljše berljivosti besedila izraza "stroji in oprema" nadomestili z izrazom "stroji".

0 INTRODUCTION

Functional obsolescence is generally defined as a consequence of negative influences on the value of machinery and equipment[1]; influences that originate

[1] In the paper we will replace the term "machinery and equipment" with the term "machinery" to make the text easier to read.

pomanjkljivosti v njihovem ustroju in oslabijo njihovo uporabnost. Vplivi, ki povzročajo delovno zastarelost, so praviloma tehnološke narave, izražajo pa se kot neoptimalen izkoristek predmetnega stroja v primerjavi s sodobnim. Nekateri avtorji delovno zastarelost ločujejo od tehnološke zastarelosti. Svoboda [1] piše, da delovna zastarelost "izvira iz zmogljivostnih razlik med novim in ocenjevanim strojem" tehnološka zastarelost pa "izvira iz razlik v zasnovi in konstrukcijskih materialih, uporabljenih pri sodobnih strojih, v primerjavi s tistimi, ki so bili uporabljeni pri ocenjevanem stroju". Sodobnejši viri razlagajo tehnološko zastarelost kot del delovne zastarelosti. Barreca [2] piše, da "delovna zastarelost izvira iz "hib" v ustrojih, materialih ali zasnovi, ki zmanjšujejo delovanje, koristnost in vrednost naložbe. Izraz "hiba" v tem primeru pomeni kakršnokoli poslabšanje v sredstvu, ki negativno vpliva na zmožnost doseganja želenih učinkov," in nadalje pojasnjuje, da je "tehnološka zastarelost dandanes temeljni povzročitelj delovne zastarelosti". Oba pojma enačijo tudi Mednarodni standardi ocenjevanja vrednosti [3].

Delovna zastarelost se izraža na več načinov, med katerim sta ključna dva:

- kot presežni strošek kapitala, ki izvira iz razlike med reprodukcijskim stroškom analiziranega stroja in t.i. nadomestitvenim stroškom, ki obsega stroške nabave in vgraditve sodobnejšega stroja z enakovredno uporabnostjo, in
- kot povečani ali vsaj razmeroma večji stroški pri delovanju stroja v primerjavi s sodobnim strojem.

Upoštevati velja, da se lahko zaradi bistveno povečanih zmogljivosti sodobnih strojev delovna zastarelost izrazi tudi kot zmanjšan oziroma razmeroma manjši prihodek, ki ga je mogoče pridobiti od delovanja stroja.

V vseh primerih imamo opraviti z neoptimalnimi poslovnimi in finančnimi učinki, ki se po navadi pojavljajo več obdobij (let). Dolžina trajanja delovne zastarelosti je odvisna predvsem od drugih oblik poslabšanja stroja: od fizične obrabe in od gospodarske (ekonomske) zastarelosti, saj je zamenjava stroja praviloma odvisna od teh. Zapisano ponazarjamo na sliki 1.

S slike je razvidno, da dlje ko traja obdobje neoptimalnega izkoristka stroja zaradi delovne

from deficiencies in their structure and weaken their utility. In most cases influences that cause functional obsolescence are of a technological nature and are manifested as a non-optimal yield from a subject machine in comparison with a present-day machine. Some authors distinguish between functional obsolescence and technical obsolescence. Svoboda [1] states that functional obsolescence is obsolescence "resulting from the capability characteristics between a new machine and the appraised machine," while technological obsolescence is an obsolescence "resulting from the difference between design and materials of construction used in present-day machines compared with those used in the machine being appraised". Recent research explains technical obsolescence as a part of functional obsolescence. Barecca [2] states that "functional obsolescence results from the flaws in the structures, materials, or design that diminishes function, utility, and value of an asset. The term 'flaw' in this case means any worsening of the resources which has a negative effect on the ability to achieve the targeted objectives". The author continues with an explanation that "technological obsolescence is the principal cause of functional obsolescence today." Both terms are also treated equally in the International Valuation Standards [3].

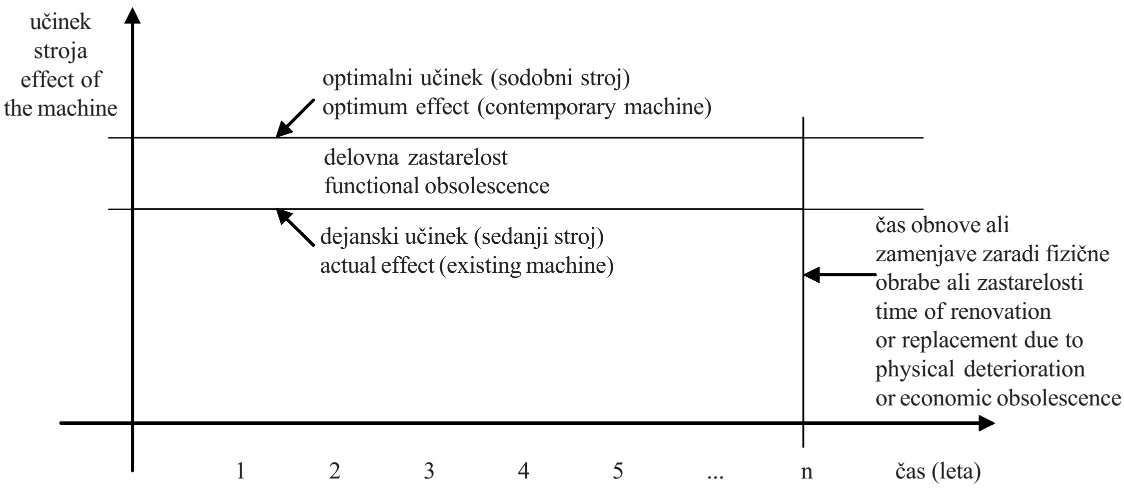
Functional obsolescence is manifested in different ways, among which the following two are of key importance:

- excessive capital cost that results from a difference between the reproduction costs of the analyzed machine and the replacement costs, which include purchasing costs and the costs of implementing a present-day machine with equal utility,
- the increased or relatively higher costs that occur during machine operation in comparison to the present-day machine.

We also need to consider the fact that, owing to the substantially increased capacity of present-day machines, obsolescence may also manifest itself as the reduced or relatively lower profit that can be made from operating the machine.

In all of these examples we are dealing with non-optimized business and financial effects that usually occur over longer periods, i.e., years. The duration of functional obsolescence mostly depends on other forms of machine depreciation: on physical deterioration and economic obsolescence, because machine replacement usually depends on these factors. This can be seen in Figure 1.

Figure 1 shows that as the duration increases the non-optimized yield of the machine, owing to functional



Sl. 1. *Čas trajanja delovne zastarelosti*

Fig. 1. *Duration of functional obsolescence*

zastarelosti, večji je obseg delovne zastarelosti stroja in večja je potreba po preučitvi primernosti obnove ali zamenjave stroja.

1 KVANTIFICIRANJE DELOVNE ZASTARELOSTI

Za vrednotenje delovne zastarelosti je potrebna stvarna ocenitev dveh spremenljivk: (1) časa, v katerem se bo ali se bi delovna zastarelost pojavljala in (2) obsega le-te.

Čas, v katerem se bo ali se bi delovna zastarelost pojavljala, je odvisen od predvidenega časa zamenjave stroja zaradi drugih oblik obrabe ali zastarelosti. Praviloma je odvisen od fizične sestavine poslabšanja, včasih pa njegovo obnovo ali zamenjavo terja gospodarska sestavina, na primer sprememba v predpisih. Z odpravo fizične obrabe, kakor tudi gospodarske zastarelosti, vplivamo na delovno zastarelost stroja, ki jo posredno zmanjšamo ali celo odpravimo.

Obseg delovne zastarelosti ocenimo na podlagi primerjanja prihodkov in odhodkov predmetnega stroja z optimalnim, pri čemer pa ne smemo izpustiti nedenarnih odhodkov (amortizacije), ki bi se z obnovo ali zamenjavo stroja povečali.

1.1 Sedanja vrednost ovrednotene delovne zastarelosti

Zaradi časovnih prednosti ekonomskih osebkov ima denarna enota (npr. 1 EUR) danes večjo

obsolescence, the extent of the functional obsolescence of the machine increases as well as the need to study the feasibility of its renovation or replacement.

1 QUANTIFICATION OF FUNCTIONAL OBSOLESCENCE

To quantify functional obsolescence, an assessment of the existing two variables is needed: (1) the time during which the functional obsolescence occurs, and (2) the extent of the functional obsolescence.

The time during which the functional obsolescence occurs is conditioned by an anticipated time for machine replacement due to other forms of deterioration and obsolescence. It usually depends on the physical component of deterioration; sometimes machine renovation or replacement is required for economic /external/ factors, e.g., changes in regulations. By curing the physical deterioration of the machine or the economic obsolescence, we influence the functional obsolescence of the machine by implicitly decreasing or even curing it.

The extent of the functional obsolescence can be estimated on the basis of comparing the income and expenses of a subject machine with the income and expenses of an optimized machine. When comparing the two machines, we should not omit the non-financial expenses of the machine (depreciation), which would increase if we renovated or replaced the machine.

1.1 Present value of quantified functional obsolescence

Owing to the time preferences of economic subjects a monetary unit (e.g., 1 EUR) has a higher vrednost kakor v prihodnosti, zato se pojavi potreba po ugotavljanju sedanje vrednosti poslovnih in finančnih učinkov, ki se bodo pojavljali v prihodnosti. Ker se delovna zastarelost praviloma izraža v enakomernem obsegu in v ponavljajočih se časovnih obdobjih, se lahko izognemo postopku popustov in lahko uporabimo enačbo za izračun sedanje vrednosti niza denarnih enot, ki se ponavlja več let. Pri tem dobimo količnik sedanje vrednosti letnih plačil (skrajšano *KSV* - *YP*), ki ima naslednjo obliko:

value today than it will in the future, and for this reason the need arises to estimate the present value of business and financial effects that will occur in the future. Because functional obsolescence usually manifests itself regularly and at recurring time periods, we can avoid direct discounting by using an equation to calculate the present value of a series of monetary units occurring over a period of several years. With this equation we acquire a quotient that is known as the "years' purchase single rate" (shortened to *YP*), and which has the following form:

$$YP = \frac{(1+r)^n - 1}{(1+r)^n \cdot r} \qquad (1).$$

V enačbi (1) pomenita r zahtevano donosnost naložbe (v decimalnem zapisu) in n število let oziroma trajanje delovne zastarelosti, če je ne bi odpravili.

Če z izračunanim količnikom *KSV* pomnožimo finančni učinek delovne zastarelosti, ki bi ji bili priča, če je ne bi odpravili (ΔPMT), dobimo enačbo za izračun sedanje vrednosti (*SV* - *PV*) delovne zastarelosti:

Equation 1 presents r; the required rate of return in a decimal record, and n, the number of years or the duration of functional obsolescence, respectively, in the case that the obsolescence is not cured.

If we multiply the acquired quotient *YP* by the financial effect of the functional obsolescence we might face if it were not cured (ΔPMT), we get an equation to calculate the present value (*PV*) of the functional obsolescence:

$$PV = \Delta PMT \cdot YP = \Delta PMT \cdot \frac{(1+r)^n - 1}{(1+r)^n \cdot r} \qquad (2).$$

Delovna zastarelost je lahko ozdravljiva ali neozdravljiva[2]. Kriterij ozdravljivosti povzemamo po Hartman in Shapiro [4]: "Če je (delovna zastarelost) neozdravljiva, je ni mogoče ekonomsko upravičeno popraviti."

Functional obsolescence can be curable or incurable[2]. The criterion for curability is taken from Shapiro and Hartman [4]: "When functional obsolescence is incurable it cannot be corrected in an economically feasible way".

2 PREDMET RAZISKAVE

Kljub navidezni preprostosti kriterija ozdravljivosti delovne zastarelosti ni poznanega modela, s katerim bi lahko enolično ovrednotili upravičenost njenega odpravljanja. Zaradi tega v tem prispevku vpeljujemo model ovrednotenja upravičenosti odpravljanja delovne zastarelosti z upoštevanjem sedanje vrednosti njenih učinkov. Model temelji na izračunu količnika ozdravljivosti delovne zastarelosti ter na podmeni, da izračunani količnik pomeni merilo, na podlagi katerega je mogoče enolično odločati o ozdravljivosti delovne zastarelosti.

2 SUBJECT OF RESEARCH

Despite the apparent simplicity of the criterion for functional obsolescence curability there is no model on which we could invariably quantify the justification for curing functional obsolescence. For this reason this paper introduces a quantification model for the justification of curing functional obsolescence, while acknowledging the present value of its effects. The model is based on a calculation of the quotient of curability of functional obsolescence, and on the hypothesis that the calculated quotient represents a judgment point on which we base our invariable decision about the curability of functional obsolescence.

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[2] Slovenski prevod Mednarodnih standardov ocenjevanja vrednosti [3] uvaja izraza odpravljivost in neodpravljivost namesto izrazov ozdravljivost in neozdravljivost.

[2] The Slovene translation of the International Valuation Standards [3] introduces terms that could be translated as reparability and irreparability instead of the terms curability and incurability.

3 KOLIČNIK OZDRAVLJIVOSTI DELOVNE ZASTARELOSTI

Skoraj vsaka oblika delovne zastarelosti je tehnično popravljiva, vprašanje pa je, ali je popravilo smiselno. "Če sledimo načelu, da bo hotel dober gospodar čimbolj povečati svoje premoženje, bo torej poslabšanje ali zastaranje (katerekoli vrste) upravičeno odpraviti takrat, ko bo njegova odprava stala manj, kakor se bo s tem povečala vrednost…" [5]. Izvesti je torej treba matematično primerjavo med sedanjo vrednostjo poslovnih ali finančnih učinkov, ki bi jih pridobili z odpravo delovne zastarelosti stroja (enačba 2), in med vložkom (I), potrebnim za njeno odpravo. To storimo s količnikom *ozdravljivosti* delovne zastarelosti v enačbi (3):

3 QUOTIENT OF CURABILITY OF FUNCTIONAL OBSOLESCENCE

Almost any form of functional obsolescence is technically correctible, but the question also arises whether all corrections are feasible. "If we follow the principle that a good landlord would want to maximize his/her assets, then curing the deterioration or obsolescence (of any kind) will be reasonable only in cases when its cure costs are lower than the increase of value that would occur…" [5]. Therefore, we need to carry out a mathematical comparison between the present value of the commercial and financial effects that we would gain by curing the functional obsolescence (equation 2), and the investment (I), needed for its cure. We do that by introducing the quotient of curability of functional obsolescence (*curability*) in Equation 3:

$$\text{ozdravljivost / curability} = \frac{\Delta PMT \cdot \frac{(1+r)^n - 1}{(1+r)^n \cdot r}}{I} \quad (3).$$

Če je vpeljani količnik enak ali preseže 1, potem dobimo potrditev smiselnosti zamenjave oziroma obnove analiziranega stroja. Ob upoštevanju več različnih različic prenove oziroma zamenjave stroja pa lahko sodimo tudi o različici, ki je ekonomsko naj učinkovitejša. Nenazadnje lahko iz rezultata razberemo tudi raven učinkovitosti obravnavane različice prenove ali zamenjave stroja. Ker izhajamo iz spremenjenih plačil (ΔPMT) in novih vlaganj (V-I), pomeni, da lahko iz presežka količnika nad 1 razberemo učinkovitost vloženih sredstev.

If the introduced quotient equals or exceeds 1, then there is confirmation of the feasibility of renovation or replacement of the analyzed machine. By taking into consideration the different methods for renovation and replacement of the machine, we can also decide which way is economically the most effective. From the result of the above equation, we can also arrive at the level of efficiency of the projected method for renovating or replacing the machine. Since our calculation is based on modified payments (ΔPMT) and new investments (I), we can also arrive at the efficiency of the invested funds from a quotient that exceeds 1.

4 PREUČITEV PRIMERA

Izhajajoč iz trditve, da mora biti za smiselnost obnove ali zamenjave stroja količnik *ozdravljivosti* večji od 1, lahko zapišemo naslednji neenačbi:

4 CASE STUDY

Acknowledging the fact that for the reasonable renovation or replacement of a machine the *curability* quotient should exceed 1, we can form the following two equations:

$$\frac{\Delta PMT \cdot \frac{(1+r)^n - 1}{(1+r)^n \cdot r}}{I} \geq 1 \quad (4),$$

oziroma / and

$$I \leq \Delta PMT \cdot \frac{(1+r)^n - 1}{(1+r)^n \cdot r} \quad (5).$$

Za boljšo ponazoritev izvedemo hipotetični primer odprave delovne zastarelosti, ki bo trajala še 25 let in bo letno zmanjševala finančni učinek za 1 EUR (v primerjavi z obnovljenim ali zamenjanim

For the purposes of better illustration, we take a hypothetical example of the cure of functional obsolescence that will last for the next 25 years, and will annually decrease the financial effect by 1 EUR strojem, upoštevaje večjo amortizacijo obnovljenega ali zamenjanega stroja). Odprava takšne delovne zastarelosti lahko stane pri zahtevani donosnosti 15 % (r=0,15) 6,46 EUR[3], pri zahtevani donosnosti 10 % (r=0,1) 9,08, pri zahtevani donosnosti 5 % (r=0,05) pa celo 14,09 EUR, kar pomeni, da lahko v slednjem primeru odprava delovne zastarelosti za več ko 14-krat preseže letno zmanjšanje finančnega učinka zaradi delovne zastarelosti.

Na sliki 2 ponazarjamo krivulje največjih mogočih vložkov v obnovo ali zamenjavo strojev zaradi delovne zastarelosti, ki še upravičujejo takšno dejanje. Prikazane so krivulje za tri izbrane zahtevane donosnosti, rezultat pa pove, kolikokrat lahko pri izbrani zahtevani donosnosti in določenem preostalem trajanju delovne zastarelosti (t) investicija v obnovo ali zamenjavo stroja preseže letno zmanjšanje finančnega učinka zaradi delovne zastarelosti.

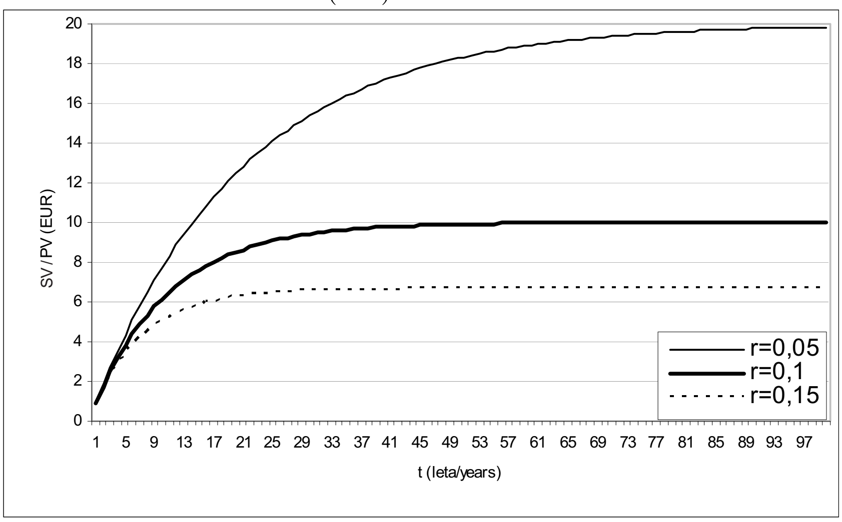
Na podlagi krivulj na sliki 2 je mogoče sklepati, da se krivulje asimptotično približujejo določenim vrednostim, kar je mogoče tudi analitično potrditi. Iz enačbe (5) lahko izračunamo največjo smiselno investicijo za odpravo delovne zastarelosti; enačbo preoblikujemo in dobimo:

(compared to the renovated or replaced machine, and considering the depreciation of the renovated or replaced machine). The cure of such functional obsolescence can cost: at a 15% required rate of return (r=0.15), 6.46 EUR[3], at a 10% required rate of return (r=0.1), 9.08 EUR, and at a 5% required rate of return (r=0.05), as much as 14.09 EUR. This means that in the last case the cure of functional obsolescence exceeds the annual decrease in the financial effect due to functional obsolescence by more than 14 times.

Figure 2 shows the curves of highest possible investment in the renovation or replacement of machinery owing to functional obsolescence that still makes these investments feasible. The curves shown in the diagram represent the three required rates of return, and the results show by how many times the investment in renovation or replacement of a machine exceeds the annual decrease in the financial effect due to functional obsolescence at a chosen required rate of return and for a fixed duration of functional obsolescence.

Based on the curves in Figure 2, we can conclude that the curves are asymptotically approaching certain values, and this process can also be analytically confirmed. Equation 5 gives us the highest feasible investment for the cure of functional obsolescence. We remodel the equation and we get the following result:

$$I \le \Delta PMT \cdot \frac{(1+r)^n - 1}{(1+r)^n \cdot r} = \Delta PMT \cdot \frac{1 - \frac{1}{(1+r)^n}}{r} \qquad (6).$$



Sl. 2. *Najvišji upravičeni vložki v obnovo ali zamenjavo stroja, glede na višino zahtevane donosnosti in pričakovano trajanje delovne zastarelosti*

Fig. 2. *Highest feasible investment in renovation or replacement of a machine according to the required rate of return and the estimated duration of functional obsolescence*

[3] Izračuni so v poglavju 7.

[3] Calculations can be found in chapter 7.

Če n večamo proti neskončnosti, se nagiba člen $1/(1+r)^n$ k vrednosti 0, iz česar lahko ugotovimo, da je najvišja smiselna investicija (V_{maks} - I_{max}) v odpravo delovne zastarelosti, izražena z enačbo:

If we increase n towards infinity, the element $1/(1+r)^n$ in the equation approaches the value of 0. From this we can conclude that the highest feasible investment (I_{max}) in the cure of functional obsolescence, is described by the equation:

$$I_{\max} = \frac{\Delta PMT}{r} \quad (7)$$

oziroma z največjim količnikom KSV_{maks} - YP_{max}:

and the maximum quotient YP_{max}:

$$YP_{\max} = \frac{1}{r} \quad (8).$$

5 SKLEPI

Ugotovimo lahko, da je delovna zastarelost oblika poslabšanja strojev, ki se ne izraža vidno, kakor fizična obraba strojev, temveč se izraža v učinkovitosti stroja, tako rekoč »skrito«. Zaradi tega je potrebno stalno preverjanje obsega delovne zastarelosti kot del trajnega presojanja strojev. Flanagan in Jewel [6] pišeta, da je potrebna “sistematična presoja vseh bistvenih stroškov, prihodkov in učinkov” vseh oblik zastaranja stroja ter da bi moralo trajno presojanje strojev biti integrirano v postopek konstruiranja in uporabe strojev.

Delovno zastarelost lahko razpoznamo šele takrat, ko se je že pojavila. Daljša ko je njena preostala doba trajanja, večja je smiselnost odprave oziroma, zastavljeno drugače: dlje ko (že) traja, manjši so učinki njene odprave. Zaradi tega se pokaže potreba po čim zgodnejšem odkrivanju delovne zastarelosti. Prav to zgodnje odkrivanje ali celo predvidevanje delovne zastarelosti bi lahko bil predmet nadaljnjih raziskav.

Količnik *ozdravljivosti* je mogoče uporabiti kot samostojno orodje za že opisano ocenjevanje (zmanjšanja) učinkovitosti strojev ter kot pomožno orodje za ugotavljanje ozdravljivosti delovne zastarelosti strojev (in opreme) pri ocenjevanju vrednosti podjetij in nepremičnin. Možna je uporaba količnika za celotno postrojenje kakor tudi delno, za analizo dela postrojenja. Pri iskanju variantnih rešitev je količnik *ozdravljivosti* v nasprotju z metodo sedanje čiste vrednosti (SČV - NPV), ki se pogosto uporablja za presojanje investicij, neobčutljiv na obseg investicij, tako da lahko primerjamo tudi delne posege z glavnimi, s čimer se praktična uporabnost količnika *ozdravljivosti* poveča.

5 CONCLUSIONS

We can conclude that functional obsolescence represents a form of machine depreciation that is not visibly manifest, as, for example, in the physical deterioration of machinery, but is manifest in the efficiency of the machine in relatively invisible ways. Therefore, constant checking of the effect of functional obsolescence is needed. This checking has to be a part of a whole-life appraisal (WLA). Flanagan and Jewel [6] state that a ”systematic consideration of all relevant cost, revenues and performance“ of all forms of obsolescence is needed and that the whole-life appraisal of machinery should be integrated into the process of construction and the use of machinery.

Functional obsolescence can only be identified after it has already occurred. The longer the estimated duration of functional obsolescence, the greater the feasibility of a cure or, in other words, the longer the functional obsolescence exists, the smaller are the effects of its cure. Therefore, the need arises to discover functional obsolescence as soon as possible. This early discovery of functional obsolescence or even the anticipation of functional obsolescence could themselves be the subject of future studies.

The *curability* quotient can be used as an independent tool for evaluating the /decreasing/ effectiveness of machinery, and as an additional tool in asserting the curability of the functional obsolescence of machinery (and equipment) in business and real-estate valuation. The quotient can be used for the complete machinery as well as in an analysis of its parts. In the quest for potential solutions, the *curability* quotient differs from the method of net present value (NPV), which is often used for judging investments, in that it is independent of the extent (value) of the investment. This is why we can also compare partial interventions with general interventions, and this further increases the usefulness of the *curability* quotient in practice.

6 SIMBOLI
6 SYMBOLS

sprememba plačil (finančni učinek delovne zastarelosti)	ΔPMT	change in payments (financial effect of functional obsolescence)
investicija	V/I	investment
največja investicija	V_{maks}/I_{max}	maximum investment
število obdobij (let)	n	number of periods (years)
zahtevana donosnost	r	required rate of return
sedanja vrednost (delovne zastarelosti)	SV/PV	present value (of functional obsolescence)
količnik sedanje vrednosti letnih plačil	KSV/YP	years' purchase single rate
največji količnik sedanje vrednosti letnih plačil	KSV_{maks}/YP_{max}	maximum years' purchase single rate

7 IZRAČUNI
7 CALCULATIONS

$$I \le 1 \cdot \frac{(1+0{,}05)^{25}-1}{(1+0{,}05)^{25}\cdot 0{,}05} = 14{,}09\ EUR$$

$$I \le 1 \cdot \frac{(1+0{,}10)^{25}-1}{(1+0{,}10)^{25}\cdot 0{,}10} = 9{,}08\ EUR$$

$$I \le 1 \cdot \frac{(1+0{,}15)^{25}-1}{(1+0{,}15)^{25}\cdot 0{,}15} = 6{,}46\ EUR$$

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Avtorjev naslov: doc.dr. Igor Pšunder
Univerza v Mariboru
Fakulteta za gradbeništvo
Smetanova 17
2000 Maribor
igor.psunder@uni-mb.si

Author's Address: Doc. Dr. Igor Pšunder
University of Maribor
Faculty of Civil Engineering
Smetanova 17
2000 Maribor, Slovenia
igor.psunder@uni-mb.si

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Strokovni članek - Speciality paper (1.04)

Raziskave možnosti uporabe porozne keramike kot podstave ali filtrirne snovi pri čiščenju odpadnih vod

Using Porous Ceramics as a Substrate or Filter Media During the Cleaning of Sewage

Darko Drev - Danijel Vrhovšek - Jože Panjan
(Fakulteta za gradbeništvo in geodezijo, Ljubljana)

Naše preiskave so pokazale, da je lahko porozna keramika ustrezno nosilo biomase (podstava) pri bioloških čistilnih napravah. Lahko se uporablja tudi pri sistemu za vpihovanje zraka ter kot filtrirna snov v membranskem filtru v kombinaciji z biološko čistilno napravo. Posamezni rezultati preskusov so zelo spodbudni, zato smo prepričani, da imajo tovrstne snovi dobre možnosti za uporabo pri bioloških čistilnih napravah.
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(Ključne besede: čiščenje odpadnih voda, naprave čistilne biološke, snovi filtrirne, keramika porozna)

Our research has shown that porous ceramics are good holders of biomass in biological water-treatment plants. They can also be used as an air-blowing system or as the filter media on a membrane filter in combination with a biological water-treatment plant. Individual tests have shown very positive results, and for this reason we are convinced such materials have good possibilities for more frequent use in biological water-treatment plants.
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(Keywords: cleaning sewage, biological water-treatment plants, filter media, porous ceramics)

0 UVOD

Keramične podstave in filtrirne snovi se lahko vgrajujejo v čistilne naprave na različne načine, pri čemer imajo lahko zelo velik vpliv na učinek delovanja in s tem na oblikovanje same čistilne naprave. Pri tem lahko postopke biokemijskega čiščenja samo večajo, ali pa so glavno nosilo čiščenja. Vsi pojavi spodbujanja ali zaviranja biokemijskih postopkov razgradnje nečistoč še niso v celoti raziskani, dokazano pa je, da nekateri materiali omogočajo hitrejše postopke biokemijske razgradnje od drugih.

Postopke čiščenja, pri katerih sodelujejo keramične podstave in filtrirne snovi lahko razdelimo v naslednje skupine:

- biokemijska razgradnja nečistoč z bakterijsko združbo (keramične podstave so nosila biomase),
- fizikalno zadrževanje delcev s filtracijo (membranski filter),
- preostali postopki (adsorpcija, kemične reakcije, prenos informacij itn.).

0 INTRODUCTION

Ceramic substrates and filter media can be built into water-treatment plants in various ways, where they can have a great impact on the effect of the plant's activity and by that on the size of the water-treatment plant. In this way the procedures of biochemical cleaning are intensified or the ceramic substrates and the filter media become the main holders of cleaning. All the processes of stimulation or braking of the biochemical processes of the decomposition of impurities are still not explored well enough, although it has been proven that some materials enable quicker biochemical decomposition than others.

The processes of cleaning during which ceramic substrates and the filter media participate can be divided into the following groups:

- biochemical decomposition of impurities with the help of a bacterial community (ceramic substrates are holders of the biomass)
- physical holding of the particles with filtering (membrane filter)
- other processes (adsorption, chemical reactions, transfer of information, etc.)

Kadar se uporablja keramična snov kot filtrirna snov, katere glavna naloga je zadrževanje delcev (membranski filter), prevladujejo fizikalni postopki čiščenja. V takšnih primerih veljajo enačbe [3].

Za filtracijo velja naslednja enačba spreminjanja koncentracije (masna bilanca):

When one uses ceramic material as filter media, of which the main function is holding of the particles (the membrane filter), then the physical processes of cleaning prevail. In such instances the following equations can be applied [3].

For filtering the next equation for changing the concentration holds (mass balance):

$$\frac{\partial \sigma}{\partial t} + v_f \frac{\partial C}{\partial z} = 0 \qquad (1).$$

Enačba hitrosti filtracije pri čistilnih napravah:

The equation of filtration velocity is:

$$v_f = \frac{Q}{F} = -k_f \frac{d\psi}{ds} \qquad (2).$$

Kinetična enačba pa je:

The kinetic equations are:

$$\frac{\partial C}{\partial z} = \xi C \qquad (3)$$

$$\xi = F\ (dk\ \text{-1 do/to -3}\ ;\ ds\ \text{0 do/to 2}\ ;\ vf\ \text{0,3 do/to -1,56}\ ;\ \Pi^{0,5}\ \text{do/to}\ \Pi^{-2}\ ) \qquad (4)$$

$$\xi = a(\Pi - \sigma) \qquad (5)$$

$$\xi = b - c\frac{\sigma}{v_f.C} \qquad (6)$$

$$\xi = \xi_0 + e.\sigma - f\frac{\sigma}{\Pi - \sigma} \qquad (7).$$

Tu pomenijo:

v_f	filtracijska hitrost [m/s]
Q	pretok vode [m^3/s]
k_f	koeficient pretoka [m/s]
dψ/ds	potencialni padec
F	pretočni prerez [m^2]
s	pot pretoka [m]
σ	upornost filtra (zamašitev filtra)
C	koncentracija snovi, ki jo filtriramo [g/m^3]
z	debelina filtrirne snovi [m]
ξ	filtracijska stalnica
d_s	premer delca v suspenziji [m]
d_k	premer delcev v filtru (velikost odprtin) [m]
Π	poroznost filtrirne snovi
a, b, c	stalnice [-]
e, f	stalnici [-]
ξ_o	stalnica [-]

Pri precejalniku ima podstava glavno vlogo zagotovitve ustrezne površine, na kateri se razvije bakterijska združba. V postopke fizikalnega in kemijskega čiščenje se podstava vključuje v glavnem le posredno. Glavni postopki čiščenja potekajo med odpadno vodo in bakterijsko združbo. Pri rastlinski čistilni napravi s pritrjenim rastlinjem gre v bistvu

Meanings of the symbols:

v_f	velocity of filtering [m/s]
Q	flow rate of water [m^3/s]
k_f	hydraulic conductivity (flow coefficient) [m/s]
dψ/ds	potential drop
F	flow cros-section [m^2]
s	flow path [m]
σ	resistance of the filter
C	concentration of the filtrated material [g/m^3]
z	thickness of the filter media [m]
ξ	filtration constant
d_s	diameter of the particle in suspension [m]
d_k	diameter of the particles in the filter (size of openings) [m]
Π	porosity of the filter media
a b, c	constants [-]
e, f	constants [-]
ξ_o	constant [-]

At the filter the main function of the substrate is to ensure a suitable surface on which the bacterial community develops. In the processes of physical and chemical cleaning the substrate is only indirectly incorporated. The main processes of cleaning occur in the next relation: wastewater - bacterial community. A wetland water-treatment plant with a fixed wetland is, in essence, prav tako za precejalnik, saj prevladujoči postopki čiščenja potekajo med pritrjeno bakterijsko združbo na podstavi in odpadno vodo (Börner T.). V rastlinski čistilni napravi je namreč več ko 90% bakterijske združbe pritrjene na podstavi. Rastline so v glavnim namenjene za dovod kisika do bakterijske združbe ter porabljajo nastalo biomaso za svojo rast.

Postopke čiščenja, ki potekajo na precejalniku, lahko obravnavamo tudi kot podaljšano vzdolžno disperzijo, pri čemer na ni pomembno, kakšni postopki v čistilni napravi potekajo, temveč le učinki čiščenja [5]:

also a filter, because the dominant processes of cleaning are performed in the next relation: fixed bacterial culture on substrate - sewage (Börner, 1992). In a wetland water-treatment plant more than 90% of the bacterial communities are fixed on the substrate. The vegetation serves as an oxygen supplier for the bacterial community and it uses the formed biomass for its own growth.

The processes of cleaning that occur on the filter may be viewed as a prolonged longitudinal dispersion, where only the cleaning effects, not the processes occurring in the water-treatment plant, are important [5]:

$$D\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \quad (8).$$

Rešitev zgornje enačbe pri spremljanju koncentracije katerekoli snovi v precejalniku ali rastlinski čistilni napravi pri začetnih pogojih t = 0, C(0,t) = C_o, se glasi:

The solution of the above equation during the monitoring of the concentration of any material in a filter or in a wetland water-treatment plant for the initial conditions t = 0, C(0,t) = Co is the following:

$$C(x,t) = \frac{1}{2}C_0 e^{t\gamma}\left\{ e^{\frac{x(V-\xi)}{2D}} \cdot erfc \cdot \left(\frac{x-\xi.t}{2\sqrt{Dt}}\right) + e^{\frac{x(V+\xi)}{2D}} \cdot erfc\left(\frac{x+\xi.t}{2\sqrt{Dt}}\right)\right\} \quad (9)$$

$$\xi = \sqrt{V^2 + 4D\gamma} \quad (10)$$

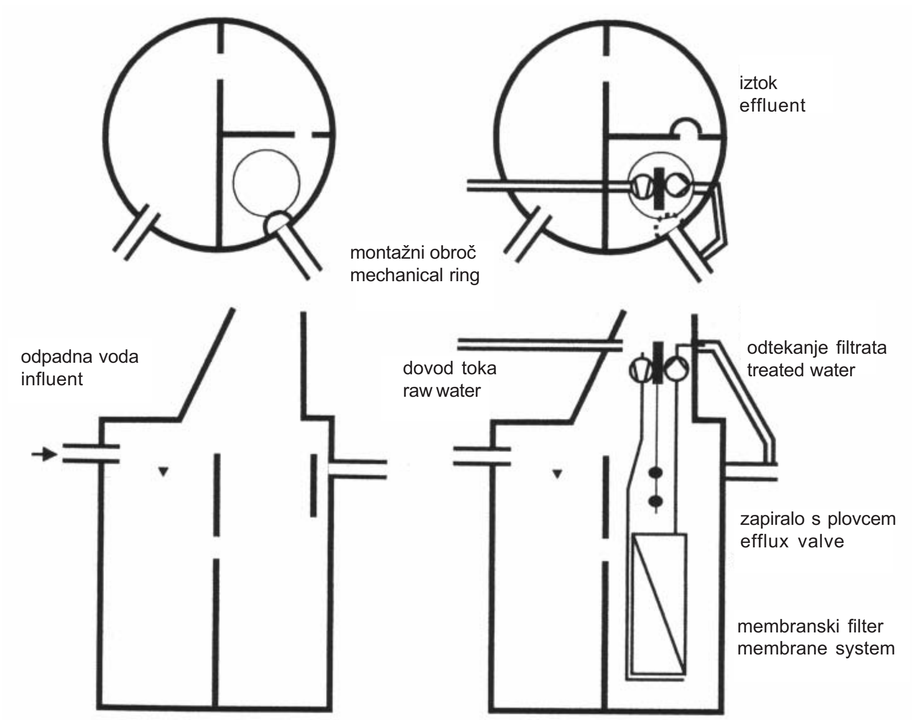
$$erfc\ y = 1 - erf\ y = 1 - \phi.(y) = 1 - \frac{2}{\sqrt{\pi}}.\int_0^y e^{-Z^2} dz \quad (11).$$

Tu pomenijo:
- D vzdolžni disperzijski koeficient [m^2/s]
- C koncentracija raztopine v tekočini [g/m^3]
- V povprečna hitrost toka [m/s]
- X koordinata vzporedna s tokom tekočine [x]
- t čas [s]
- ξ filtracijska stalnica

Porozna keramika se lahko uporablja kot nosilo biomase (podstava) ali pa kot membranska filtrirna snov. V zadnjem času se uporabljajo membranski filtri v kombinaciji z biološkimi čistilnimi napravami. Kot filtrirna snov v teh membranskih filtrih se uporabljajo najpogosteje polimerne in kompozitne membrane, porozna keramika, porozno steklo, porozne kovine pa redkeje. Razlog za to je verjetno v slabšem poznavanju tehnologije izdelave drugih membranskih naprav. Najbolj razvite so tehnologije izdelave polimernih in kompozitnih membran, zato so takšne naprave postale lahko dostopne in razmeroma poceni. Mnenja smo, da je mogoče iz porozne keramike izdelati tudi ustrezne membranske filtrirne naprave, ki se lahko vgrajujejo v membranske filtre in niso bistveno slabši od polimernih. Pri nekaterih značilnostih imajo lahko tudi določene prednosti, ki jih je mogoče koristno izrabiti.

Meanings of the symbols:
- D longitudinal dispersion coefficient [m^2/s]
- C solution concentration in the liquid [g/m^3]
- V mean flow velocity [m/s]
- X coordinate parallel to the liquid current [m]
- t time [s]
- ξ filtration constant

Porous ceramics can be used as a holder of biomass (substrate) or as membrane filter media. Lately, the membrane filters have been used in combination with biological water-treatment plants. As the filter media in these membrane polymeric filters and composite membranes are often used, while porous ceramics, porous glass and porous metals are used only rarely. The main reason for that is probably the somewhat poorer knowledge of the technology of making of other membrane modules. The most developed is the technology of making polymeric and composite membranes, which is nowadays accessible and relatively cheap. Our opinion is that from a porous ceramics membrane filter modules can also be made. They can then be built into the membrane filters, and are as effective as the polymeric ones. In the case of some characteristics they can also have important advantages that can be usefully employed.



Sl. 1. *Primer male čistilne naprave brez membranskega filtra in z vgrajenim membranskim filtrom [2]*
Fig. 1. *Example of a small-sized water-treatment plant without a membrane filter and with a built-in membrane filter [2]*

Primer vgradnje membranskega filtra v majhno komunalno čistilno napravo je prikazan na sliki 1. Avtor Gründer B. [2] ne navaja vrste membran, ki so vgrajene v filtru, ker to ni pomembno. Pomembno je, da takšna membranska naprava ustrezno deluje.

Porozne keramične snovi (podstave, filtrirne snovi) lahko izdelamo na več načinov, odvisno od lastnosti, ki jih pričakujemo. Pri sintranju keramične snovi lahko dosežemo popolno zlitje delcev, ali pa ostane del strukture še odprt. Pri izdelavi grobih keramičnih membran se lahko v keramično maso vmeša gorljiv organski material, ki omogoča nastanek razmeroma velike odprte površine. Kot najbolj grobi dodatek za dosego odprtosti strukture se lahko uporablja zelo drobna žagovina, še drobnejše pore pa omogoča dodatek škroba. Najdrobnejšo strukturo keramičnih membran dosežemo s slojem aluminijevega hidroksida.

V keramične snovi in steklo je mogoče vgrajevati tudi različne informacije, ki lahko spodbujajo postopke biokemijske razgradnje. Opravili smo nekaj tovrstnih preizkusov in ugotovili določene pozitivne učinke. Rezultati preiskav še tečejo, zato jih ne navajamo. Pri tem gre v veliki

An example of the implantation of a membrane filter in a small communal water-treatment plant is shown in Figure 1. The author of this figure (Gründer, 2000) does not state the type of membranes that are being used because it is not important. What is important is that such a membrane module works properly.

Porous ceramic materials (substrate, filter media) can be made in various ways. This depends on the characteristics we want them to have. During the sintering of ceramic material we can either achieve the perfect fusion of particles or a part of structure remains opened. When creating rough ceramic membranes we can add combustible organic materials, which enables the creation of a large open surface. As the roughest additive for achieving the openness of the structure one can use very refined sawdust, whereas more refined pores can be achieved by adding starch. We can achieve the most refined ceramic-membrane structure with the help of a layer of aluminium hydroxide.

In ceramic materials and glasses it is possible to build-in "information", which can stimulate the processes of biochemical decomposition. We have conducted several such experiments that show some positive effects. The results of our research are currently being investigated in a more thorough manner, and meri tudi za postopke, ki še niso v celoti znanstveno razjasnjeni.

that is why we do not mention them in this paper. Most of the processes are still not scientifically cleared up.

1 SNOVI IN METODE

Pri pilotnih preizkusih izdelave keramičnih membran smo se zadovoljili s simetrično strukturo, zato je postopek izdelave obsegal le tri faze: priprava keramične mase, oblikovanje profila in sintranje. Izbrali smo dve različni keramični snovi: FSZ/F–Fuchssche Tongruben GmbH & Co. KG in S 3–Keramika Liboje

Snov FSZ/F je deklarirana kot snov z razmeroma majhno poroznostjo, medtem ko ima S – snov 2 do 3 krat večjo poroznost. Za ugotavljanje filtracijske zmožnosti porozne keramike smo merili: zmožnost vpijanja vode, prepustnost zraka, prepustnost vode ter zmožnost zadrževanja delcev TiO_2 z znano porazdelitvijo delcev.

Preizkuse uporabe različnih podstav smo izvajali na poskusni čistilni napravi, izdelani iz poliakrilnega stekla, ki je podana na sliki 2. V prekate smo dajali podstave (rečni prod, zeolit, keramika, steklo, šota, vermikulit itn.) in odpadno vodo spuščali prek naprave na različne načine.

V velikih prekatih P1, P2 in P3 smo imeli rečni prod, v prekate 1, 2, 3 in 4 pa smo dodajali posebne podstave. Pred dodajanjem posebnih podstav smo spuščali prek čistilne naprave samo greznično odpadno vodo, da se je na pesku kot podstavi oblikovala ustrezna bakterijska združba. Nato smo dodajali posebne podstave. Dejavnost mikrobne biomase smo merili z metodo spremembe INT (jodo-nitro-tetrazonijevega klorida) v formazan. V epruvete smo dodali okoli 20 g peska ali druge podstave z bakterijskim filmom, dodali 5 ml 0,85% NaCl, 0,5 ml 0,5% Na – acetata in 0,2 ml

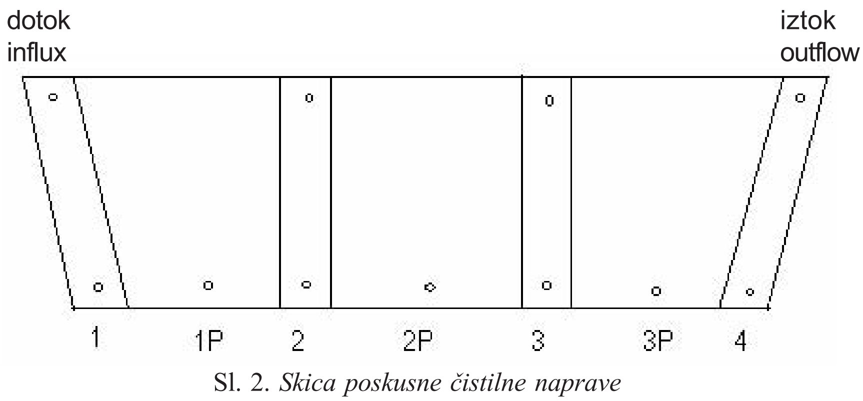
1 MATERIALS AND METHODS

The ceramic membranes used in the pilot experiments were made with only a symmetrical structure, and that is why the manufacturing procedure included only three phases: preparing the ceramic mass, forming of the profile, and sintering. Two different ceramic masses were chosen: FSZ/F- Fuchssche Tongruben GmbH & Co. KG and S 3 - Ceramics Liboje.

The mass FSZ/F is declared as the one with the relatively low porosity, while the porosity of the S3 mass is two to three times greater. To establish the filtration ability of the porous ceramics we measured the following: ability to absorb water, permeability to air, permeability to water, and the ability of to hold TiO_2 particles with a known distribution.

The use of different substrates was carried out on a pilot water-treatment plant made from Plexiglas, which is shown in Figure 2. We placed the substrates in ventricles (river gravel, zeolite, ceramics, glass, peat, Vermikulit, etc.) and dropped sewage over the device in different ways.

River gravel was placed in the large chambers P1, P2 and P3, and in chambers 1, 2, 3 and 4 special substrates were added. Before adding the special substrates we dropped only plain sewage over the water-treatment plant to enable the bacterial community to form on the substrate (sand). Next, special substrates were added. The activity of the microbial biomass was measured with the INT conversion method (iodo-nytro-tetrasonium chloride to formazan). In the test tube we added approximately 20 g of sand or other substrate with a bacterial film and added 5 ml of 0.85% NaCl, 0.5 ml of 0.5% Na - acetate and 0.2 ml of 0.25%



Sl. 2. *Skica poskusne čistilne naprave*
Fig. 2. *Pilot-plant scheme*

0,25% INT. Vzorce smo inkubirali pri sobni temperaturi in po 24 urah izločili formazan s 3 ali 5 ml izobutanola. Količino nastalega formazana smo določili spektrafotometrično pri valovni dolžini 490 nm. Izračun smo izvedli po naslednjem obrazcu:

INT. The samples were incubated at room temperature and after 24th hours we extracted formazan with the help of 3 or 5 ml of iso-butanol. The amount of formed formazan was established with the spectrophotometric method at a 490-nm wavelength. The calculations were carried out with the following equation:

$$\text{dejavnost mikrobnega ETS/activity microbs ETS } (\mu l\ O_2 S^{-1} h^{-1}) = \frac{Abs^{490nm}.V_r}{S.t.1,42.V_t} \qquad (12).$$

Tu pomenijo:
- $Abs^{490\ nm}$ absorpcija izobutanolne frakcije [-],
- V_r končna prostornina reakcijske zmesi (5,7 ali 11,4) [ml],
- S velikost vzorca (podstave) [g],
- t čas inkubacije (24 ur) [h],
- 1,42 faktor premene količine formazana v prostornino kisika [-].

Meanings of the symbols:
- $Abs^{490\ nm}$ absorption of isobutanol fraction [-],
- V_r final volume of the reaction mixture (5.7 or 11.4) [ml],
- S size of sample (substrate) [g],
- t time of incubation (24 hours) [h],
- 1.42 conversion factor (amount of formazan to the volume of oxygen) [-].

2 EKSPERIMENTALNI DEL

2.1 Izdelava keramičnih filtrirnih snovi

Iz izbranih keramičnih mas z deležem vlage 19% (FSZ/F– Fuchssche Tongruben GmbH & Co. KG in S 3– Keramika Liboje) smo izdelali ploščati filtrirni snovi s postopkom struženja. Po sušenju smo sintrali izdelka v električni peči pri različnih temperaturah. S sintranjem se zagotovi ustrezna mehanska trdnost ter delno zmanjša poroznost. Najprej smo izmerili velikost in porazdelitev delcev v keramičnih snoveh. Ta porazdelitev je zelo pomembna, saj po sintranju zagotavljajo poroznost prav prazni prostori med delci. S temperaturo in časom sintranja se prazni prostori postopno zmanjšujejo in v končni fazi pride do popolnega zlitja. Na sliki 3 sta prikazani porazdelitveni krivulji za obe uporabljeni keramični snovi. Velikost in porazdelitev delcev pri obeh keramičnih snoveh sta približno enaka. Zato je bila tudi velikost odprtin med delci v obeh primerih približno enaka. Ker sta bila tudi čas in temperatura sintranja za obe gradivi enaki, je bila poroznost odvisna le od vrste snovi.

S slike 4 je razvidno, da je prepustnost zraka zelo odvisna od temperature sintranja ter vrste keramične snovi. Pri keramični snovi FSZ/F je pri temperaturi 1000 °C že prišlo do tako majhne prepustnosti zraka, da z razpoložljivo metodo ni bila več merljiva.

Tudi vpojnost vode je odvisna od temperature sintranja in vrste snovi. Keramična

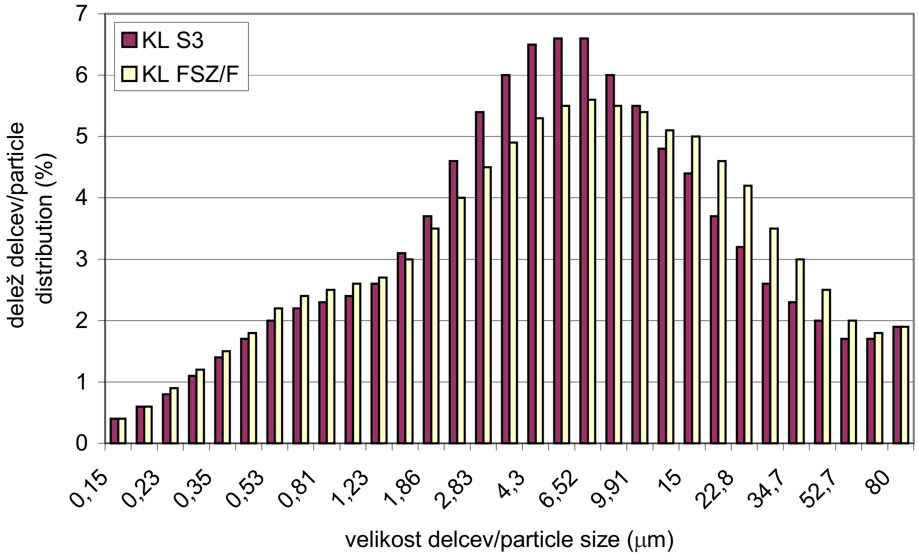
2 EXPERIMENTAL

2.1 Making the ceramic filter media

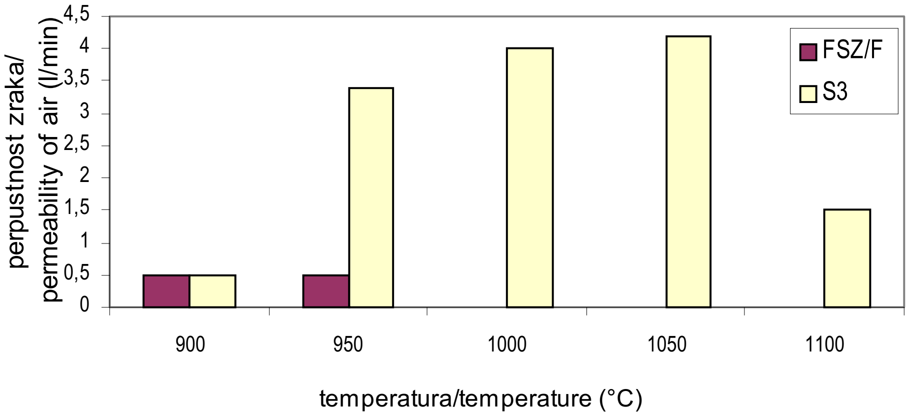
From selected ceramic masses with a 19% moisture content (FSZ/F- Fuchssche Tongruben GmbH & Co. KG and S3- Ceramics Liboje) we created flat filter media using lathe-tooling methods. After the products were dried they were sintered in electric furnaces at different temperatures. The sintering ensures a suitable mechanical strength and partly reduces the porosity. First we measured the size and distribution of particles in the ceramic masses. This distribution is very important because after sintering the empty places between the particles ensure the porosity. The exposure time and the sintering temperature slowly reduce the size of the empty places until it comes to a perfect fusion. Figure 3 shows the distribution curve for both the ceramic masses used. The size and the distribution of the particles in both the ceramic masses are approximately equal. Therefore, the size of the openings between the particles in both cases was approximately equal. Because the exposure time and the sintering temperature were the same for both materials, we can conclude that the porosity depends only on the type of material.

From Figure 4 it can be seen that the permeability of the air is very dependent on the temperature of the sintering and on the ceramic mass type. In the case of the FSZ/F ceramic mass the permeability of the air at 1000°C was so small that we were not able to measure it.

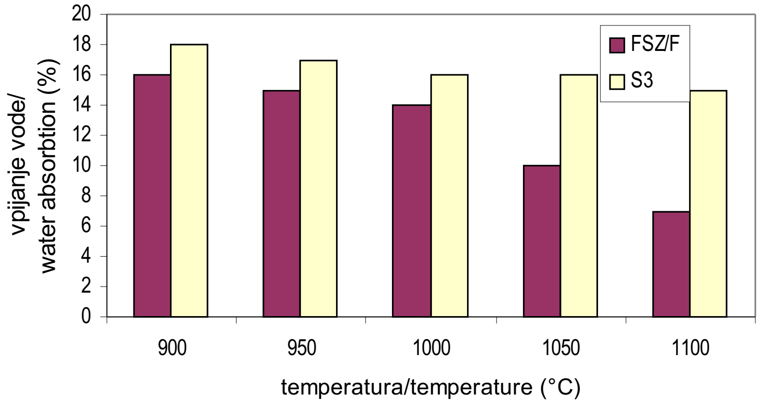
The water absorbency is also dependent on the sintering temperature and on the type of mate-



Sl. 3. *Porazdelitvene krivulje delcev v keramičnih snoveh FSZ/F in S 3*
Fig. 3. *Particle distribution curve for ceramic masses FSZ/F and S3*



Sl. 4. *Odvisnost prepustnosti zraka od temperature sintranja*
Fig. 4. *Permeability of air versus the sintering temperature*



Sl. 5. *Odvisnost prepustnosti zraka od temperature sintranja (l/min), ΔP = 400 Pa*
Fig. 5. *Permeability of air versus the sintering temperature (l/min), ΔP = 400 Pa*

snov S3 je imela pri 900 °C nekoliko večjo vpojnost vode kakor FSZ/F. S povečanjem temperature sintranja do 1100 °C pa se ji je vpojnost vode le nekoliko zmanjšala, medtem ko se je pri snovi FSZ/F zmanjšala za več ko 60 odstotkov.

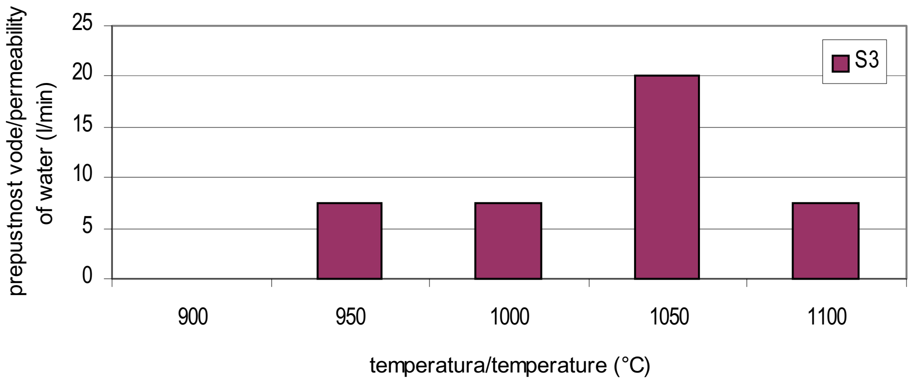
Pri napravi, izdelani iz keramične snovi S, ki se je pokazala kot primernejša, smo izmerili tudi odvisnost prepustnosti vode od temperature sintranja. S slike 6 je razvidno, da je bila dosežena največja prepustnost vode pri temperaturi sintranja 1050 °C.

Pri porozni keramiki, ki je bila izdelana iz keramične snovi S 3 in sintrana pri 1050 °C, smo merili tudi zmožnost zadrževanja delcev iz vodne suspenzije delcev $Ti O_2$ s porazdelitvijo, ki smo jo predhodno izmerili in je podana na sliki 7. Ker v filtratu nismo

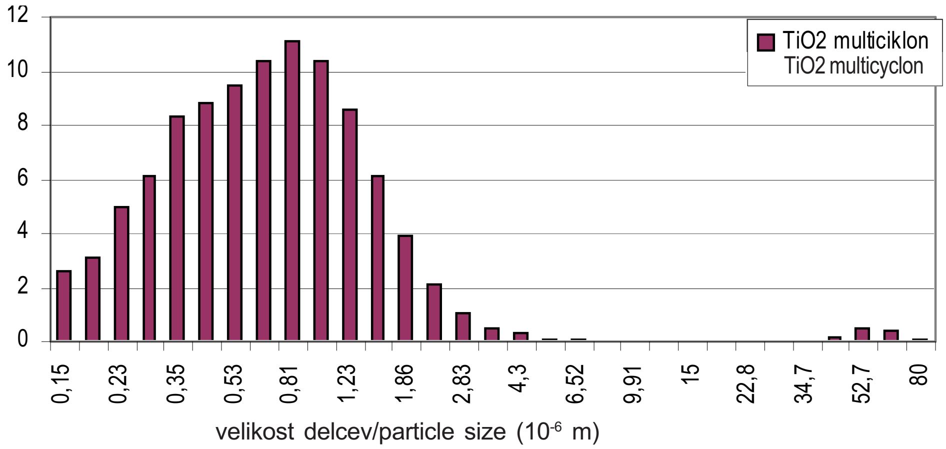
rial. At 900°C the S3 ceramic mass had a slightly larger water absorbency than the FSZ/F. By increasing the sintering temperature to 1100°C the water absorbency of the S3 reduced slightly, while for the FSZ/F it fell by more than 60%.

In the case of the module made from ceramic mass S3, which proved to be more suitable, the dependence of the water permeability on the sintering temperature was also measured. From Figure 6 it is clear that the greatest permeability of water was achieved for a sintering temperature of 1050°C.

In the case of the porous ceramic that was made from ceramic mass S3 and sintered at 1050°C we also measured the ability to hold particles of TiO_2 particle water suspension with a distribution that was preliminarily measured and is shown in Figure 7. Because we could not establish the presence of the TiO_2



Sl. 6. *Odvisnost prepustnosti vode od temperature sintranja (l/min), ΔP = 100 Pa*
Fig. 6. *Permeability of water versus the sintering temperature (l/min), ΔP = 100 Pa*



Sl. 7. *Porazdelitvena krivulja delcev TiO_2, ki smo jih uporabili za testiranje porozne keramike*
Fig. 7. *Distribution curve of TiO_2 particles that were used for testing the porous ceramics*

opazili delcev Ti O_2, smo mnenja, da so pore manjše od velikosti najdrobnejših delcev.

Pri primerjavi našega vzorca porozne keramike z drugimi filtrirnimi snovmi se vidi velika razlika med PTFE in keramičnimi membranami. Membrana PTFE je znana kot filter z najbolj odprto strukturo. Pri membrani, ki je podana v preglednici, je 93-odstotna odprtost strukture. Keramične membrane imajo bistveno bolj zaprto strukturo. Tega parametra nismo merili, temveč smo merili prepustnost zraka in vode. Z dodajanjem škroba ali kakšnih drugih gorljivih snovi pa lahko povečamo poroznost. Pri tem moramo upoštevati, da z dodatki povečamo tudi velikost por, kar pa negativno vpliva na zmožnost zadrževanja delcev. Zato je najboljša rešitev izdelava asimetrične strukture porozne keramike. Tanek dejavni sloj ima zelo majhne pore, debelejši nosilni sloj pa večje pore, ki ne pomenijo velikega upora pri filtraciji.

Pri primerjavi našega vzorca porozne keramike z drugimi filtrirnimi snovmi lahko ugotovimo, da smo izdelali razmeroma dobro keramično filtrirno snov. Morda bi lahko z njo zadrževali celo bakterije, saj je njihova velikost večja od 0,2 µm.

Naša keramična filtrirna snov je imela veliko večjo prepustnost vode od tržnega izdelka. Pri tem pa ni bila bistvena razlika v velikosti por. Pri našem vzorcu smo ugotovili, da je filter zadržal tudi vse delce velikosti 0,15 µm. Meritev zadrževanja delcev velikosti 0,13 µm pa žal nismo mogli izvesti.

particles in the filtrate we concluded that the pores were smaller than the most refined particles.

A comparison of our sample of porous ceramic with other filter media shows a great difference between the PTFE and the ceramic membranes. The PTFE membrane is known as the filter with the most open structure. In the case of the membrane in the table there is a 93% openness of the structure. The ceramic membranes have much more closed structures. These parameters were not measured, but the permeability of the air and the water were. By adding starch or another combustible material an increased porosity could be achieved. But we must consider that by using additives the pore size increases, which has a negative effect on the ability to hold the particles. That is why the best solution is to make porous ceramics with an asymmetric structure. The thin active layer has very small pores and the fatter carrier layer has bigger pores, which consequently results in a smaller resistance during filtering.

From a comparison of our porous ceramic samples with other filter media we can establish that we created a relatively well-functioning ceramic filter media. Perhaps it could even filter bacteria, because their size is greater than 0.2 µm.

Our ceramic filter media had a significantly greater water permeability than the market product. However, there was essentially no difference in the pore size. In the case of our sample we have also established that the filter even withheld particles of 0.15 µm. Unfortunately it was not possible to measure the filtering of particles of 0.13 µm.

2.2 Testiranje porozne keramike kot podstave v bioloških čistilnih napravah

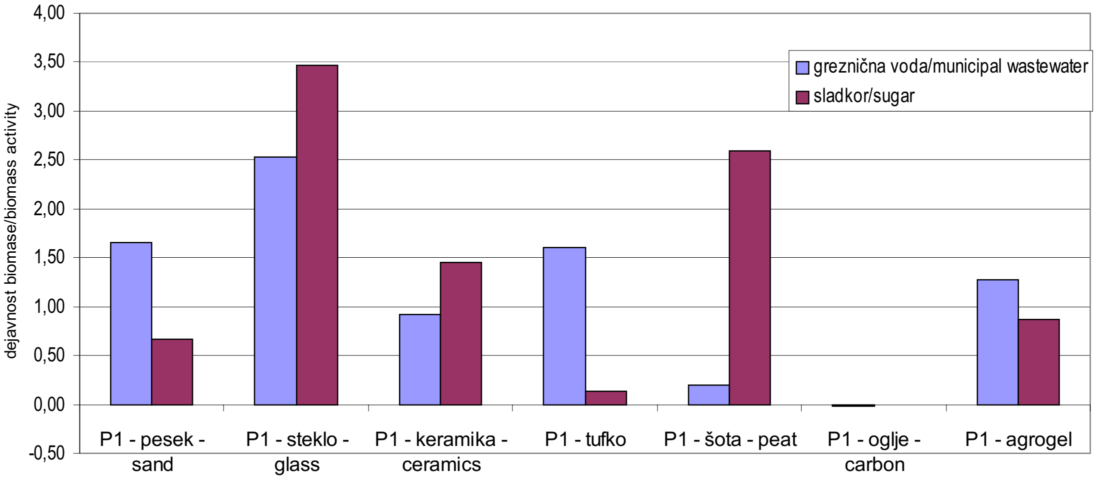
Začetne preizkuse smo izvajali na poskusni čistilni napravi, izdelani iz poliakrilnega stekla z izmerami, ki so podane na sliki 2 po opisani metodi. Rezultati so podani na slikah 8 do 12.

2.2 Testing of porous ceramics as a substrate in biological treatment plants

Pilot experiments were carried out on a pilot water-treatment plant made from Plexiglas, with the dimensions shown in Figure 2. The results are shown in Figures 8 to 12.

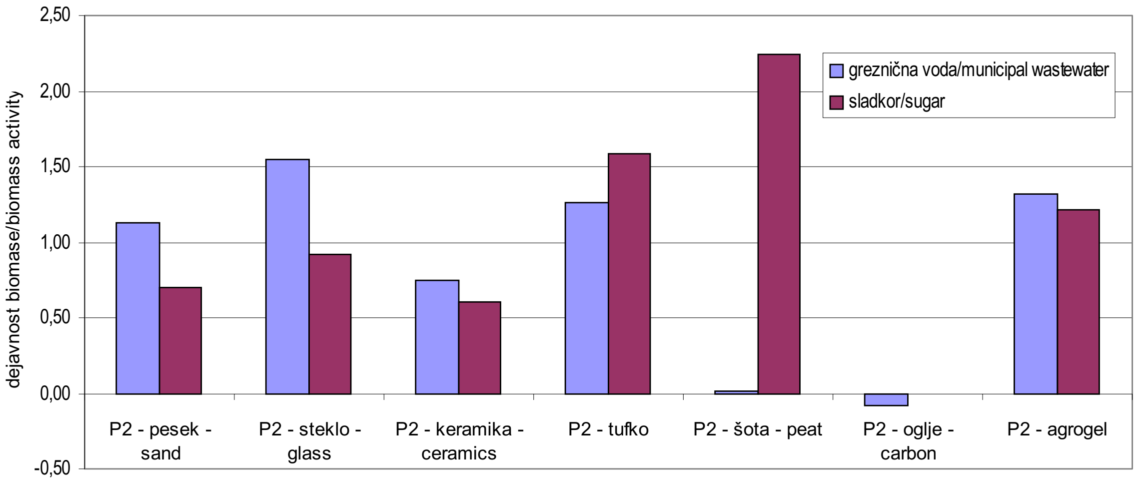
Preglednica 1. *Primerjava izdelanega vzorca porozne keramike z nekaterimi drugimi filtrirnimi snovmi*
Table 1. *Comparison of our porous ceramic sample with some other filter media*

Filtrirana snov Filter media	Velikost por size of pore (µm)	Prepustnost zraka permeability of air (m^3/m^2 h), Δ *P* = 400 Pa	Prepustnost vode permeability of water (l/m^2 min), Δ *P*
naš vzorec S 3 our sample S 3	0,2	126	0,75, 33 (Δ *P* = 100 Pa, 2 bar)
PTFE membrana PTFE membrane (W.L. GORE)	0,2	420	2 (Δ *P* = 100 Pa)
keramična membrana ceramic membrane Hoogovens Industrial Ceram. memb.	0,13	-	6 (Δ *P* = 200 kPa)



Sl. 8. Dejavnost *mikrobne biomase v 1.10^{-9} O$_2$ ml/(g.h) na različnih podstavah s hranivom greznično vodo in sladkorjem v prekatu P1*

Fig. 8. A*ctivity of microbial biomass in 1.10^{-9} O$_2$ ml/(g.h) on different substrates with added nutrition, municipal wastewater and sugar in the area P1*



Sl. 9. *Dejavnost mikrobne biomase v 1.10^{-9} O$_2$ ml/(g.h) na različnih podstavah s hranivom greznično vodo in sladkorjem v prekatu P2*

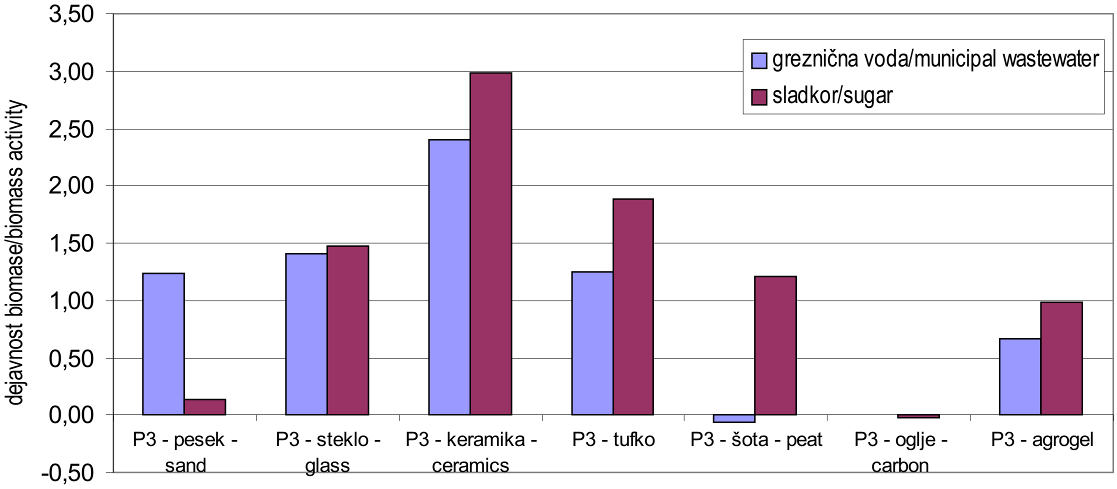
Fig. 9. *Activity of microbial biomass in 1.10^{-9} O$_2$ ml/(g.h) on different substrates with added nutrition, municipal wastewater and sugar in the area P2*

Raziskave so pokazale, da se na posameznih podstavah razvije bistveno več bakterijske združbe kakor na drugih. Ekspandirano steklo se je pokazalo kot najbolj ugodna podlaga za razvoj mikroorganizmov. Tudi rečni prod in porozna keramika sta dala dobre rezultate.

Vseh vplivov podstav ni mogoče natančno ovrednotiti, saj ne poznamo vseh mehanizmov delovanja posamezne snovi na postopek biokemijske razgradnje. Posebno poglavje so "informirane" podstave, ki dodatno pospešujejo postopke biokemijske razgradnje. Takšne

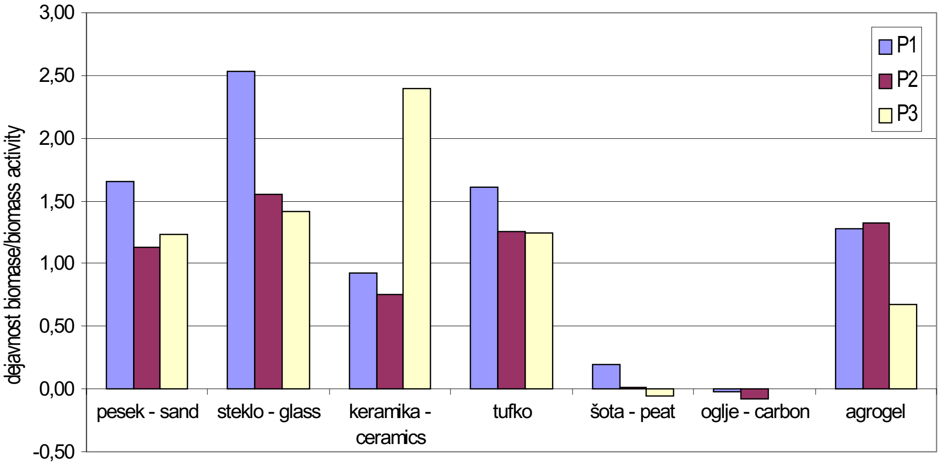
Our research has shown that on individual substrates significantly more bacterial communities develop than on others. Expansion glass has shown itself to be the most favourable base for the development of micro-organisms. Also, river gravel and porous ceramics have provided good results.

The effects of all of the possible substrates cannot be quantified because we do not know all the effects of the activity of individual materials on the processes of biochemical decomposition. "Informed" substrates are a chapter for themselves, because they can additionally accelerate the processes of biochemi-



Sl. 10. *Dejavnost mikrobne biomase v 1.10^{-9} O_2 ml/(g.h) na različnih podstavah s hranivom grezično vodo in sladkorjem v prekatu P3*

Fig. 10. *Activity of microbial biomass in 1.10^{-9} O_2 ml/(g.h) on different substrates with added nutrition, municipal wastewater and sugar in the area P3*



Sl. 11. *Dejavnost mikrobne biomase v 1.10^{-9} O_2 ml/(g.h) na različnih podstavah s hranivom grezično vodo*

Fig. 11. *Activity of microbial biomass in 1.10^{-9} O_2 ml/(g.h) in areas where the municipal wastewater is used as a nutrition*

"informacije" je mogoče vgrajevati v keramične in steklene snovi.

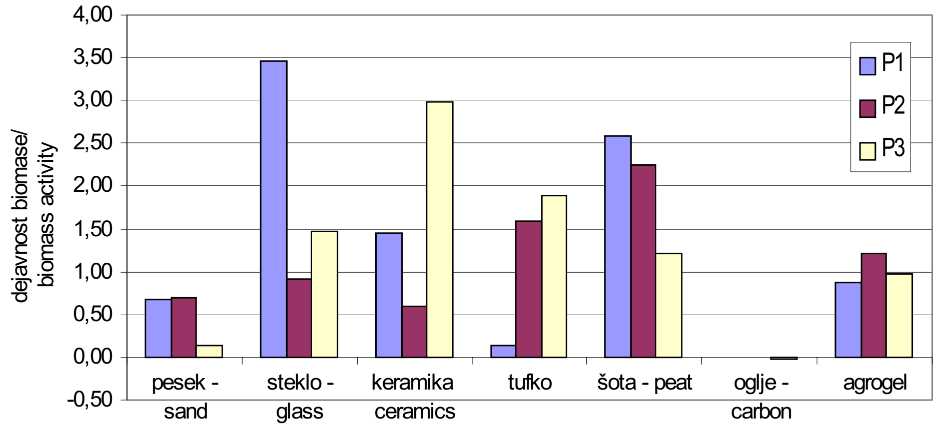
3 REZULTATI IN OBRAVNAVA

Pri čistilnih napravah s pritrjeno biomaso na pritrjeni nosilni podlagi ima izbira podstave velik vpliv na določanje čistilne naprave. Dejavnost mikrobne biomase je namreč zelo odvisna od vrste podstave. S poskusi smo ugotovili, da je lahko keramična podstava ena izmed najprimernejših nosil mikrobne biomase. Pri testiranju smo sicer dobili še

cal decomposition. It is possible to build-in such "information" into glass and ceramic materials.

3 RESULTS AND DISCUSSION

In water-treatment plants with fixed biomass on a fixed carrying base the choice of substrate has an enormous impact on the dimensions of the water-treatment plant. The activity of microbial biomass is very much dependent on the type of substrate. With the help of experiments we can conclude that a ceramic substrate is one the most suitable holders of microbial



Sl. 12. *Dejavnost mikrobne biomase v 1.10^{-9} O_2 ml/(g.h) na različnih podstavah s hranivom greznično vodo in sladkorjem*

Fig. 12. *Activity of microbial biomass in 1.10^{-9} O_2 ml/(g.h) in areas where the sugar is used as a nutrition*

Preglednica 2. *Preglednica razvrstitve od največje do najmanjše dejavnosti biomase na posamezni podstavi glede na dejavnost v vseh prekatih*

Table 2. A*rrangement of biomass activity on different substrates with regard to activity in all ventricles*

Podstava Substrate	1.mesto 1st place	2.mesto 2nd place	3.mesto 3rd place	4.mesto 4th place	5 mesto 5th place	6. mesto 6th place	7.mesto 7th place
steklo glass	3 x	2 x		1 x			
pesek sand		1 x		3 x	2 x		
tufko		2 x	3 x			1 x	
agrogel		1 x	1 x	2 x	2 x		
keramika ceramics	2 x		1 x		2 x	1 x	
šota peat	1 x	1 x		1 x		3 x	
oglje charcoal							6 x

nekoliko ugodnejše rezultate z ekspandiranim steklom, takoj za tem pa je bil vzorec keramične snovi. Steklo in keramika se po kemični sestavi bistveno ne razlikujeta, mnenja smo, da gre v bistvu za enako skupino snovi. Mnenja smo, da je mogoče razviti takšno keramično snov, ki bo zagotavljala še ugodnejše razmere za razvoj mikrobne biomase. V stekleno in keramično snov je mogoče vnesti tudi določene informacije, ki lahko pospešujejo postopke biokemijske razgradnje nečistoč. Izvedli smo več tovrstnih preizkusov, vendar pa raziskave niso končane in tudi rezultati niso dovolj natančni, zato jih ne navajamo v tem prispevku.

Keramična snov se lahko uporablja tudi kot mikroporozno filtrirno snov v membranskih filtrih.

biomass. Tests provided slightly better results when using expanded glass, but the ceramic materials were second best. The glass and ceramics do not differ much in terms of chemical composition, and that is why we think that this is basically the same group of materials. Our opinion is that it is possible to develop such ceramic materials, which will give even more advantageous conditions for the development of microbial biomass. In the case of glass and ceramic materials it is also possible to build-in some “information” that can accelerate the processes of the biochemical decomposition of impurities. We have conducted several such experiments; however, the results are not exact enough for them to be included in this paper.

Ceramic materials can also be used as microporous filter media in membrane filters. The sam-

Vzorec porozne keramike, ki smo ga izdelali, bi morda že lahko uporabljali v membranskem filtru. V odvisnosti od konstrukcije membranskega filtra bi morali zagotoviti dovolj velik pretok vode in zmožnost zadrževanja delcev. Za zadrževanje koloidnih delcev ne bi bilo posebno težko izdelati ustreznih mikroporoznih keramičnih naprav. Zadrževanje raztopljenih snovi v vodi pa je stvar obrnjene osmoze, kar pa ni predmet naših preiskav. Po našem mnenju bi lahko postala mikroporozna keramika ena izmed pogosto uporabljenih snovi za izdelavo membranskih filtrov. Takšne membrane bi bile zmožne zadrževati tudi bakterije, zato bi jih lahko uporabljali za sterilizacijo očiščene vode pred iztokom v vodotok. Pri našem vzorcu je bila velikost por manjša od 0,2m, kar pomeni, da bi ga lahko uporabljali za zadrževanje bakterij. V primeru izločanja blata iz čistilne naprave (koloidnih in grobih delcev), kar je prikazano v uvodnem delu, je treba zagotoviti sprotno odstranjevanje nastale pogače. Posamezni proizvajalci čistilnih naprav so to rešili z zrakom, po našem mnenju pa bi bilo mogoče tudi z vodnim curkom. Zaradi kemične in toplotne stabilnosti bi jih lahko temeljito čistili na bistveno preprostejši način kot občutljive polimerne membrane.

ple of porous ceramics we made could perhaps be used in membrane filters. Depending on the membrane filter construction, a sufficient influx of water and a sufficient ability to hold the particles would have to be ensured. For holding colloidal particles, however, it would not be particularly difficult to make suitable micro-porous ceramic modules. The holding of dissolved materials in water is covered by the field of reverse osmosis and is not the subject of our research. In our opinion, micro-porous ceramics could become one of the more frequently used materials for making membrane filters. Such membranes would also be capable of holding bacteria, and that is why we could use them for the sterilization of cleaned water before the outflow to the water course. In our sample the size of the pores was smaller than 0.2m, which means that it could be used for holding bacteria. In the case of mud excretion from the water-treatment plant (colloidal and rough particles), as was shown in the initial part of the paper, it is necessary to ensure the continuous removal of the formed cake. Individual producers of water-treatment plants have solved this problem by using air, but in our opinion this could also be done by using a water jet. Because of its chemical and thermal stability we could clean these membranes in a simpler manner than the more sensitive polymeric membranes.

4 LITERATURA
4 LITERATURE

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Naslov avtorjev: dr. Darko Drev
prof.dr. Danijel Vrhovšek
prof.dr. Jože Panjan
Univerza v Ljubljani
Fakulteta za gradbeništvo in geodezijo
Jamova 2
1000 Ljubljana
darko@limnos.si
joze.panjan@fgg.uni-lj.si

Authors' Address: Dr. Darko Drev
Prof.Dr. Danijel Vrhovšek
Prof.Dr. Jože Panjan
University in Ljubljana
Faculty for Civil Engineering and Geodesy
Jamova 2
1000 Ljubljana, Slovenia
darko@limnos.si
joze.panjan@fgg.uni-lj.si

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Osebne vesti - Personal Events

Doktorati, magisteriji in diplome - Doctor's, Master's and Diploma Degrees

DOKTORATI

Na Fakulteti za strojništvo Univerze v Ljubljani sta z uspehom zagovarjala svoji doktorski disertaciji:

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dne *16. marca 2006*: **mag. Marko Jakomin**, z naslovom: "Določanje mehanskih in stabilnostnih karakteristik plitkih dvoslojnih osnosimetričnih lupin v homogenem temperaturnem polju".

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dne *24. marca 2006*: **Silva Čepin**, z naslovom: "Primerjava elektrokemijske aktivacije (ECA) in ultrazvoka pri obdelavi biocidnih odpadnih vod";

dne *24. marca 2006*: **Darja Firm**, z naslovom: "Čiščenje tekstilnih odpadnih voda onesnaženih s kislimi barvili z ozoniranjem in adsorpcijo na aktivno oglje".

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- seznam literature in
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Strojniški vestnik izhaja od leta 1992 v dveh jezikih, tj. v slovenščini in angleščini, zato je obvezen prevod v angleščino. Obe besedili morata biti strokovno in jezikovno med seboj usklajeni. Članki naj bodo kratki in naj obsegajo približno 8 strani. Izjemoma so strokovni članki, na željo avtorja, lahko tudi samo v slovenščini, vsebovati pa morajo angleški povzetek.

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Since 1992, the Journal of Mechanical Engineering has been published bilingually, in Slovenian and English. The two texts must be compatible both in terms of technical content and language. Papers should be as short as possible and should on average comprise 8 pages. In exceptional cases, at the request of the authors, speciality papers may be written only in Slovene, but must include an English abstract.

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- Conclusions, which should present one or more conclusions that have been drawn from the results and subsequent discussion.
- References, which must be numbered consecutively in the text using square brackets [1] and collected together in a reference list at the end of the paper. Any footnotes should be indicated by the use of a superscript[1].

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Texts should be written in Microsoft Word format. Paper must be submitted in electronic version.

Do not use a LaTeX text editor, since this is not compatible with the publishing procedure of the Journal of Mechanical Engineering.

Equations should be on a separate line in the main body of the text and marked on the right-hand side of the page with numbers in round brackets.

Enote in okrajšave

V besedilu, preglednicah in slikah uporabljajte le standardne označbe in okrajšave SI. Simbole fizikalnih veličin v besedilu pišite poševno (kurzivno), (npr. *v, T, n* itn.). Simbole enot, ki sestojijo iz črk, pa pokončno (npr. ms^{-1}, K, min, mm itn.).

Vse okrajšave naj bodo, ko se prvič pojavijo, napisane v celoti v **slovenskem jeziku**, npr. časovno spremenljiva geometrija (ČSG).

Slike

Slike morajo biti zaporedno oštevilčene in označene, v besedilu in podnaslovu, kot sl. 1, sl. 2 itn. Posnete naj bodo v ločljivosti, primerni za tisk, v kateremkoli od razširjenih formatov, npr. BMP, JPG, GIF. Diagrami in risbe morajo biti pripravljeni v vektorskem formatu.

Pri označevanju osi v diagramih, kadar je le mogoče, uporabite označbe veličin (npr. *t, v, m* itn.), da ni potrebno dvojezično označevanje. V diagramih z več krivuljami, mora biti vsaka krivulja označena. Pomen oznake mora biti pojasnjen v podnapisu slike.

Vse označbe na slikah morajo biti dvojezične.

Preglednice

Preglednice morajo biti zaporedno oštevilčene in označene, v besedilu in podnaslovu, kot preglednica 1, preglednica 2 itn. V preglednicah ne uporabljajte izpisanih imen veličin, ampak samo ustrezne simbole, da se izognemo dvojezični podvojitvi imen. K fizikalnim veličinam, npr. *t* (pisano poševno), pripišite enote (pisano pokončno) v novo vrsto brez oklepajev.

Vsi podnaslovi preglednic morajo biti dvojezični.

Seznam literature

Vsa literatura mora biti navedena v seznamu na koncu članka v prikazani obliki po vrsti za revije, zbornike in knjige:

[1] A. Wagner, I. Bajsić, M. Fajdiga (2004) Measurement of the surface-temperature field in a fog lamp using resistance-based temperature detectors, *Stroj. vestn.* 2(2004), pp. 72-79.
[2] Vesenjak, M., Ren Z. (2003) Dinamična simulacija deformiranja cestne varnostne ograje pri naletu vozila. *Kuhljevi dnevi '03*, Zreče, 25.-26. september 2003.
[3] Muhs, D. et al. (2003) Roloff/Matek Maschinenelemente – Tabellen, 16. Auflage. *Vieweg Verlag*, Wiesbaden.

Podatki o avtorjih

Članku priložite tudi podatke o avtorjih: imena, nazive, popolne poštne naslove in naslove elektronske pošte.

SPREJEM ČLANKOV IN AVTORSKE PRAVICE

Uredništvo Strojniškega vestnika si pridržuje pravico do odločanja o sprejemu članka za objavo, strokovno oceno recenzentov in morebitnem predlogu za krajšanje ali izpopolnitev ter terminološke in jezikovne korekture.

Avtor mora predložiti pisno izjavo, da je besedilo njegovo izvirno delo in ni bilo v dani obliki še nikjer objavljeno. Z objavo preidejo avtorske pravice na Strojniški vestnik. Pri morebitnih kasnejših objavah mora biti SV naveden kot vir.

Units and abbreviations

Only standard SI symbols and abbreviations should be used in the text, tables and figures. Symbols for physical quantities in the text should be written in italics (e.g. *v, T, n,* etc.). Symbols for units that consist of letters should be in plain text (e.g. ms^{-1}, K, min, mm, etc.).

All abbreviations should be spelt out in full on first appearance, e.g., variable time geometry (VTG).

Figures

Figures must be cited in consecutive numerical order in the text and referred to in both the text and the caption as Fig. 1, Fig. 2, etc. Pictures may be saved in resolution good enough for printing in any common format, e.g. BMP, GIF, JPG. However, graphs and line drawings sholud be prepared as vector images.

When labelling axes, physical quantities, e.g. *t, v, m,* etc. should be used whenever possible to minimise the need to label the axes in two languages. Multi-curve graphs should have individual curves marked with a symbol, the meaning of the symbol should be explained in the figure caption.

All figure captions must be bilingual.

Tables

Tables must be cited in consecutive numerical order in the text and referred to in both the text and the caption as Table 1, Table 2, etc. The use of names for quantities in tables should be avoided if possible: corresponding symbols are preferred to minimise the need to use both Slovenian and English names. In addition to the physical quantity, e.g. *t* (in italics), units (normal text), should be added in new line without brackets.

All table captions must be bilingual.

The list of references

References should be collected at the end of the paper in the following styles for journals, proceedings and books, respectively:

[1] A. Wagner, I. Bajsić, M. Fajdiga (2004) Measurement of the surface-temperature field in a fog lamp using resistance-based temperature detectors, *Stroj. vestn.* 2(2004), pp. 72-79.
[2] Vesenjak, M., Ren Z. (2003) Dinamična simulacija deformiranja cestne varnostne ograje pri naletu vozila. *Kuhljevi dnevi '03*, Zreče, 25.-26. september 2003.
[3] Muhs, D. et al. (2003) Roloff/Matek Maschinenelemente – Tabellen, 16. Auflage. *Vieweg Verlag*, Wiesbaden.

Author information

The information about the authors should be enclosed with the paper: names, complete postal and e-mail addresses.

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