© Strojniški vestnik 45(1999)11,432-441 © Journal of Mechanical Engineering 45(1999)11,432-441
ISSN 0039-2480 ISSN 0039-2480
UDK 621.63:621.82:62-25 UDC 621.63:621.82:62-25
Izvirni znanstveni članek (1.01) Original scientific paper (1.01)

Študija dinamičnih karakteristik sklopa radialnega rotorja in vležajenja ventilatorja hladilnega sistema borbenih vozil M 84 in T 72

Study of Radial Rotor and Bearing Arrangement Dynamic Properties of the Combat Vehicles M 84 and T 72 Cooling System Fan

Brane Širok - Marko Hočevar - Samo Zupan - Ivan Prebil

Borbena vozila, kakršen je tank M 84, so izpostavljena skrajnim mehanskim obremenitvam pri vožnji in bojevanju, zato so vsi mehanski sklopi konstruirani za mejne obremenitve. Poznavanje teh je vedno povezano s poznavanjem dinamičnih karakteristik obremenitev na opazovanih podsklopih. Na novo razvitem rotorju hladilnega ventilatorja smo na preskušališču simulirali osnovne mehanske obremenitve rotorja z vležajenjem in analizirali dinamične obremenitve. V prispevku predstavljamo potek eksperimentalnega dela in analizo dinamike sklopa rotor - vležajenje. V sklepu smo podali kriterije dopustnih obremenitev ventilatorja in izbrali funkcionalno najugodnejše vležajenje.

(Ključne besede: ventilatorji, uležajenje rotorjev, analize dinamične, karakteristike)

Combat vehicles like the M 84 tank are exposed to extreme mechanical loading when driving and shooting. All the mechanical parts are therefore designed for extreme loading. Loading determination is strongly connected to determination of its dynamic properties in the examined components. With a newly developed rotor for a cooling fan with bearings, mechanical loading was tested and analyzed on a test rig. Experimental work and dynamic analysis are presented in the paper. The most suitable bearing type is selected and criteria of allowed loading of the fan are presented in the conclusion.

(Keywords: fans, bearing arrangements, dynamic analysis, characteristics)

0 UVOD

Povečanje moči pogonskih motorjev z notranjim zgorevanjem zahteva od hladilnega sistema povečano odvajanje toplote v okolico. To povečanje hladilnih zmogljivosti je pri nespremenjenih termodinamičnih karakteristikah hladilnega sistema mogoče le s spremembo hladilnih ventilatorjev. V ta namen smo v Turboinštitutu v Ljubljani razvili nov rotor hladilnega ventilatorja za oklepni vozili M 84 in T 72 [1]. Z novim rotorjem se je pri istih integralnih - geometrijskih in kinematičnih - karakteristikah, pretočna količina povečala. Na sliki 1 je prikazana primerjava med izvirno in modificirano izvedbo rotorja [2] in [3].

Povečano zmogljivost hladilnega ventilatorja smo dosegli s spremenjeno geometrijsko obliko pretočnega dela v rotorju ventilatorja in s spremenjeno tehnologijo izdelave. Profilirane lopatice so nadomestile stare krivljene lopatice, tehnologija litja Al-Mg-litine pa je zamenjala tehnologijo kovičenja. Zaradi povečane aerodinamične obremenitve in

0 INTRODUCTION

Increased demands on the power of the internal combustion engines in combat vehicles require cooling systems with an increased capability for heat dissipation. Such an increase in cooling capabilities can only be achieved with a modification to the cooling fans, provided that the thermodynamic characteristics remain the same. At the Turboinstitute in Ljubljana a new rotor for the cooling fan in the combat vehicles M-84 and T-72 [1] has been developed. While the integral geometric and kinematic properties remain the same, the new rotor causes an increase in the air flow (Fig. 1), [2] and [3].

An increased capacity of the cooling fan was achieved by modifications to the flow duct in the fan rotor and with new method of manufacture. Instead of bending and riveting the fan blades from sheet metal, we used profile shaped blades cast in AlMg. In the new design the aerodynamic loads have increased, the mass distribution changed, and the maxispremenjene porazdelitve mase in vztrajnostnih momentov na novi izvedbi smo morali analizirati vplive, ki so povezani z nastalimi spremembami.

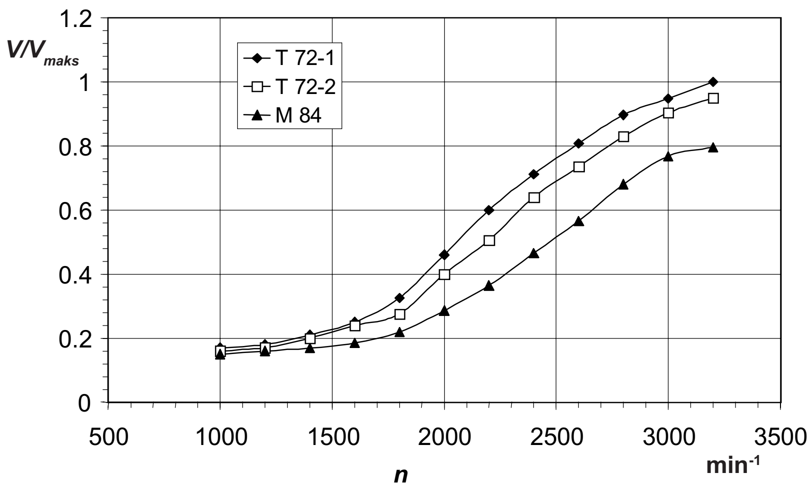
V ta namen smo naredili raziskavo trdnostnih in dinamičnih karakteristik sklopa rotorja ventilatorja s pripadajočim ležajnim okrovom ([4] in [5]). Naredili smo numerično analizo napetostnih stanj v rotorju, pri čemer smo upoštevali dejanske robne pogoje, dobljene na preskusni postaji. Z dinamično eksperimentalno analizo smo ugotavljali obremenitve rotorja ventilatorja in vležajenja. Poskus je tekel v simulirnem ventilatorskem okrovu s prigrajenim sistemom za dinamično vzbujanje, kar naj bi v čim večji meri simuliralo dinamiko dejanskega sistema. Merili smo deformacije vrtečega se rotorja glede na gibajoči se ventilatorski okrov, pri čemer smo naleteli na problem spremljanja deformacij v gibajočem se preskusnem prostoru.

S primerjavo rezultatov z vzbujanjem in brez njega smo preučili vpliv zunanjih mehanskih motenj na vrtilno dinamiko sistema. V sklepni fazi raziskav smo rezultate uporabili tudi pri izbiri ustreznega vležajenja rotorja v ventilatorskem okrovu.

mum usable rotational speed has been increased to 3500 min^{-1}. Due to these changes the resulting influences had to be analyzed.

A study of the strength and dynamic properties of the system was performed. First a numerical analysis of the loading and the stress in the rotor was performed ([4] and [5]). Experimentally, the dynamics of the fan rotor motion on its bearings was determined. An experimental fan housing, primarily designed for the measurement of flow parameters, was used for this experiment. An adapted system for dynamic excitation was intended to simulate the basic dynamics of the real system. The deformations of the rotating rotor in relation to the housing movement were measured, a problem of detecting deformations in a moving experimental space.

With the comparison of results obtained, with and without excitation, we have studied the influence of external mechanical disturbances on the rotational dynamics of the system. In the final phase, we used these results for the selection of the suitable rotor bearing arrangement in the fan housing.



Sl. 1. *Relativni prostorninski pretok hladilnega zraka V/V_{maks} v odvisnosti od vrtilne frekvence rotorja n za različne izvedbe ventilatorjev. M 84 - izvedba s kovičenim rotorjem, T 72-1 novi rotor - meritev [2], T 72-2 novi rotor - meritev [3]*

Fig. 1. *Relative volume flow V/V_{max} of cooling air, dependent on rotational speed n for different types of fans, M 84 - riveted rotor, T 72-1 new rotor – measurement [2], T 72-2 new rotor – measurement [3]*

1 VLEŽAJENJE

Pri razvoju novega rotorja ventilatorja se je pojavilo vprašanje o ustreznosti rešitve vležajenja zaradi nepričakovano velikih amplitud nihanj oziroma gibanj celotnega rotorskega sklopa, ki so bile izmerjene na preskuševališču. Nova izvedba naj bi zagotovila predvsem manjše zračnosti in s tem manj izrazite prehodne pojave vibracij pri sunkovitih obremenitvah na okrovu vležajenja, večjo temperaturno stabilnost delovanja v različnih obratovalnih razmerah in povečano statično varnost in dobo trajanja vležajenja.

1 BEARINGS

The question of the suitability of the rotor bearing arrangement arosed during the development, because of unexpectedly large vibration amplitudes and displacements of the entire rotor assembly measured on the test rig. A new arrangement should have reduced play and therefore reduced the transitional effect caused by sudden loads on the casing, increased temperature stability at different operational regimes, and better life expectancy and static safety.

Pri analizi vležajenja je bil izbran obremenitveni profil po vojaških standardih (MIL) in zahtev, ki jih za tovrstno tehniko postavlja vojaška industrija ([4] in [5]). Obremenitve sklopa rotorja izhajajo iz lastne mase (rotor, sklopka in gred), ki znaša skoraj 50 kg, in so določene s pričakovanimi nivoji amplitud vibracij in sunkov za določene režime obratovanja. Kot največjo obremenitev v skladu z MIL-STD-810D smo upoštevali kratkotrajni sunek v radialni in vzdolžni smeri v velikosti 50 g (amplituda sile 25 kN).

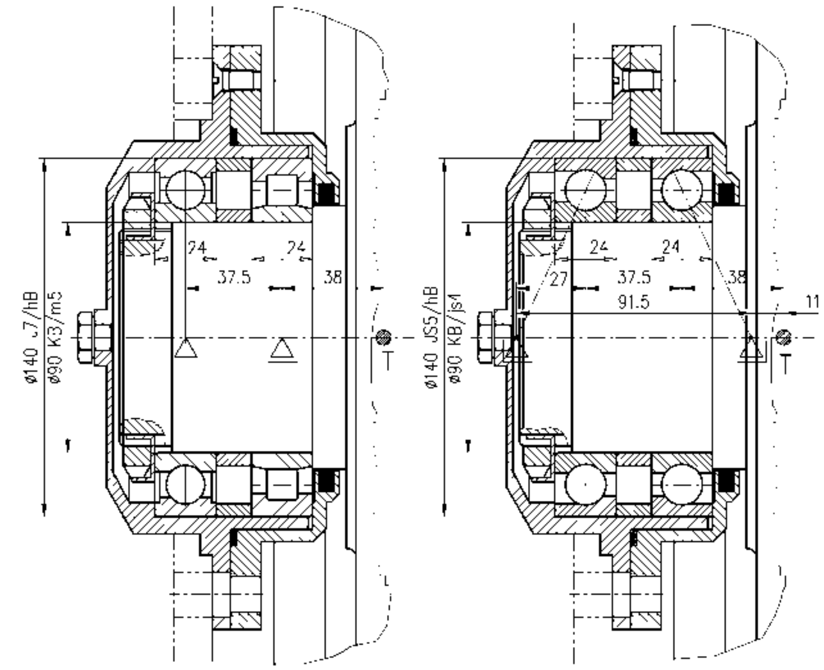
Izvirno vležajenje rotorja pri T 72 in M 84 je standardno z enorednim radialnim krogličnim (6018) in enorednim valjčnim (NU 1018) ležajem in zadošča osnovnim načelom statično določenega vležajenja. Na sliki 2 so prikazane osnovne geometrijske izmere vležajenja in lega težišča sklopa. Takšno vležajenje v določenih obratovalnih razmerah izkazuje nekatere negativne lastnosti, kar kaže tudi izračun statične varnosti in dobe trajanja.

Obremenitev deluje v težišču, ki je na previsnem polju gredi. Ker sta ležaja zelo blizu, je upogibna obremenitev velika in povzroča “neobičajne” obremenitve (porazdelitve po kotalnih elementih) na takih ležajih. Zelo kritično je prevzemanje velikih vzdolžnih sunkov. Ker je vzdolžna zračnost relativno velika, se pri tem kot nošenja močno spremeni (z 0° tudi na 25°). Zaradi tega se lahko na robovih tečin krogličnega ležaja pojavijo odtiski, ki v nadaljevanju povzročajo vibracije in zmanjšujejo dobo trajanja ležaja. Zračnosti vležajenja ni mogoče nadzirati in se z

For the rotor analysis a load spectrum based on military standards (MIL) and requirements, set by the military industry for comparable purposes, was chosen ([4] and [5]). The loads on the rotor assembly originate in its mass (rotor, relief clutch and shaft), amounting to almost 50 kg, and are determined by the expected amplitude levels of vibrations and impulses during various operating conditions. As the largest load, according to MIL-STD-810D, a short-term impulse was considered in the radial and axial directions with a magnitude of 50 g (force amplitude 25 kN).

The original bearing arrangement of the rotor in the T 72 and M 84 is a classic one, with a single row radial ball bearing (6018) and a single row roller bearing (NU 1018), and corresponds to all the basic principles of a statically determined bearing arrangement. Fig. 2 shows the basic layout of the bearing arrangement and the location of the gravity center of the assembly. In certain operational conditions this type of bearing arrangement exhibits, some negative properties, as can be seen from the calculation of static safety and lifetime.

Loading acts on the center of gravity on the overhang field of the shaft. Because the bearings are close, the momentum acting on the bearings is high and causes “unusual” loading (distribution on rolling elements). The most critical is the axial loading. The axial play is relatively high, causing up to a 25^{O} change in the contact angle and possible damage to the ball bearing. The play can not be controlled and increases with wear. The operating play is depen-



Sl. 2. *Shema vležajenja. Levo: stara izvedba T 72 in M 84; desno: spremenjena izvedba z natančnim ramenskim vležajenjem*

Fig. 2. *Bearing arrangements. Left: old version T72 and M 84. Right: modified version with back-to-back arrangement of ball bearings with angular contact*

Preglednica 1. *Konstrukcijske karakteristike vležajenj*
Table 1. *Construction characteristics of bearing arrangements.*

	Vležajenje T 72 in M 84 Bearing arrangement T 72 and M 84		**Izboljšano vležajenje Improved bearing arrangement**
	levi ležaj left bearing	**desni ležaj right bearing**	**levi in desni ležaj left and right bearing**
Tip ležaja Bearing type	enoredni radialni kroglični single row radial ball bearing	enoredni radialni valjčni single row roller bearing	precizna ramenska kroglična - "O" vgradnja precise ball bearings with angular contact - "O" type
oznaka po SKF classification by SKF	6018	NU 1018 MA	7018 ACD/P4A
radialni ohlap v mm radial play in mm	0.012 do/to 0.036	0.050 do/to 0.085	~0
aksialni ohlap v mm axial play in mm	0.158 do/to 0.273	8	~0
dinamična nosilnost C dynamic capacity C	58500 N	80900 N	74100 N
statična nosilnost C0 static capacity C0	50000 N	104000 N	72000 N
standardna življenjska doba L10h standard lifetime L10h	3850 ur/h	4530 ur/h	> 4750 ur/h
popravljena življenjska doba L10ah* corrected lifetime L10ah*	8890 ur/h	10600 ur/h	> 10650 ur/h
statični varnostni faktor S0 static safety factor S0	1.79	2.05	2.75

obrabo povečuje. Delovni ohlap je odvisen od razreda ohlapa ležaja (normalen, C2, C3, itn.), presežka ujema pri montaži ležaja in temperaturne razlike notranjega in zunanjega obroča.

Kot možnega zasuka gredi zaradi zračnosti v ležajih in še posebej premik v vzdolžni smeri sta razmeroma velika, kar deluje negativno na stabilizacijo gibanja ventilatorja po prenehanju dinamičnih in sunkovitih obremenitev.

Pri delovanju vibracij, še posebej pri velikih sunkovitih obremenitvah, je eden od osnovnih načel uspešnega vležajenja čim manjša zračnost oziroma celo prednapetje, kar pri tem vležajenju v osnovi ne more biti izpolnjeno.

Navedene pomanjkljivosti sedanjega obstoječega vležajenja je mogoče odpraviti z "O" vgrajenima krogličnima ležajema s kotnim dotikom (ramenski). Druge rešitve (stožčasti ležaji) so zaradi velikih vrtilnih frekvenc neprimerne. Če ne želimo spreminjati ležajnega okrova ali gredi, je mogoča le uporaba natančnih ramenskih krogličnih ležajev z imenskim kotom nošenja 25° (sl. 2), ki imajo enake vgradne izmere kakor sedanji ležaji. Iz preglednice 1 je razvidno, da se s takim vležajenjem poleg odprave omenjenih pomanjkljivosti standardnega vležajenja izboljša tudi doba trajanja in statična varnost ležajev. Zaradi kota nošenja so vprijemne točke sil na osi gredi bolj razmaknjene in je upogibno delovanje zunanje obremenitve zaradi tega manjše.

Natančne ramenske ležaje je treba naročiti v paru, kar samo po sebi zagotavlja ustrezno minimalno prednapetje (vparjeni obroči po toleranci širine). Če uporabimo distančni puši med notranjima in zunanjima obročema ležajev, morata biti

dent on the class of the bearing (normal, C2, C3, etc.), as well as the matching by mounting and the temperature difference of the inner and outer ring.

The angle of possible turn of the shaft because of the play and axial movement is relatively high, acting negatively on the stability of the rotation of the fan under sudden dynamic loads.

Under vibration, and especially with large shock loads, it is necessary to design a bearing arrangement with the lowest possible play, or even a pre-tensioning, which is inherently impossible with the original arrangement.

We have dealt with these weaknesses by incorporating an "O", i.e. "back-to-back" bearing arrangement of ball bearings with angular contact. Other arrangements (tapered roller bearings) are unsuitable because of the high rotational speed. The only possible solution for designing new bearings in the original casing is by the use of ball bearings with angular contact and a contact angle of 25^{O} (Fig. 2) with the same dimensions as the original bearings. Table 1 reveals that the new type of bearing arrangements, besides overcoming the mentioned weaknesses, also show a higher static safety and life expectancy. The carrying angle causes the force anchor points on the shaft to be further apart, therefore the forces caused by an external bending moment are reduced. With this arrangement it is possible to adjust the play (or pretensioning) during the mounting.

An "O" arrangement requires bearings to be ordered in couples, assuring suitable minimum pre-tensioning (matched angular contact ball bearings). Distance rings between the inner and outer bearing ring must be equal in length (simultaneous popolnoma enako dolgi (hkratna obdelava), ležajni obroči pa v vzdolžni smeri stisnjeni s primerno veliko silo (najmanj 460 N). Na prednapetje oziroma zračnost po potrebi lahko vplivamo s spremembo dolžine distančnih puš.

V raziskavi smo primerjali modificirano ramensko vležajenje z dvema izvirnima izvedbama, ki sta se med seboj razlikovali v zračnosti. Izvedbe smo imenovali izvedbo CEMEK, M 84 in M 84 obnovljeni.

2 PRESKUS

Cilj preskusa je bil določiti dinamične obremenitve na rotorju ventilatorja in poiskati osnovne dinamične karakteristike na sklopu rotor - vležajenje - okrov v odvisnosti od mehanskega vzbujanja sistema. Pri načrtovanju in postavitvi eksperimentalne postaje smo v največji mogoči meri upoštevali dejanske delovne parametre, v katerih ventilator v borbenem vozilu deluje. Posebej smo poudarili simuliranje vzdolžnih in prečnih obremenitev, do katerih pride pri vožnji po razgibanem terenu in streljanju.

Na sliki 3 je shema eksperimentalne postaje, ki jo sestavlja pogonski el. motor z zvezno nastavljivo vrtilno frekvenco v območju 0 do 3600 min^{-1}, največje moči P_{maks}= 35 kW. Pogonski el. motor je prek kardanskega zgiba povezan z razbremenilno sklopko ventilatorja. Rotor je vležajen v izviren ležajni okrov, ki je v geometrijsko enakem spiralnem okrovu ventilatorja kakor v tanku. Na izstopu iz spiralnega okrova so nameščene regulacijske lopute izvirne izvedbe. Za doseganje vzdolžnega in prečnega vzbujanja je spiralni okrov vgrajen v gibljivi tečaj, ki skupaj s kardanskim zgibom dovoljuje kotni zasuk celotnega spiralnega okrova z rotorjem ventilatorja. Prečno vzbujanje okrova je izvedeno s pnevmatskim batom, ki ga sproži krmilni signal iz krmilne enote.

Kot odvisno dinamično spremenljivko smo izbrali relativni vzdolžni pomik zadnje stene rotorja glede na steno spiralnega okrova. V ta namen smo uporabili tri brezstična induktivna zaznavala pomika Turck CK 40. Poleg teh smo za merjenje kota zasuka spiralnega okrova glede na podnožje uporabili induktivno zaznavalo HBM W 50. Kot celostni parameter preskusa smo merili vrtilno frekvenco gredi ventilatorja.

Relativni pomiki zadnje stene rotorja so bili merilo deformacije rotorja ventilatorja v odvisnosti od celovitega obratovalnega parametra – vrtilne frekvence rotorja ventilatorja. Odmik spiralnega okrova glede na podlago eksperimentalne naprave je pomenil dinamično motnjo vzbujanja opazovanega sistema.

S primerjavo različnih konstrukcijskih izvedb uležajenja je omogočena kakovostna in kolikostna ocena vpliva vležajenja na napetostna stanja v rotorju in vpliv na dinamiko celotnega sklopa.

grinding) and bearing rings must be compressed with suitable force in the axial direction (min. 460 N). Play can be adjusted with the selection of distance rings.

Three types of bearing arrangements were tested, the “O” bearing arrangement and two original arrangements with different play. The arrangements were named CEMEK, M 84 and M 84 renewed.

2 EXPERIMENT

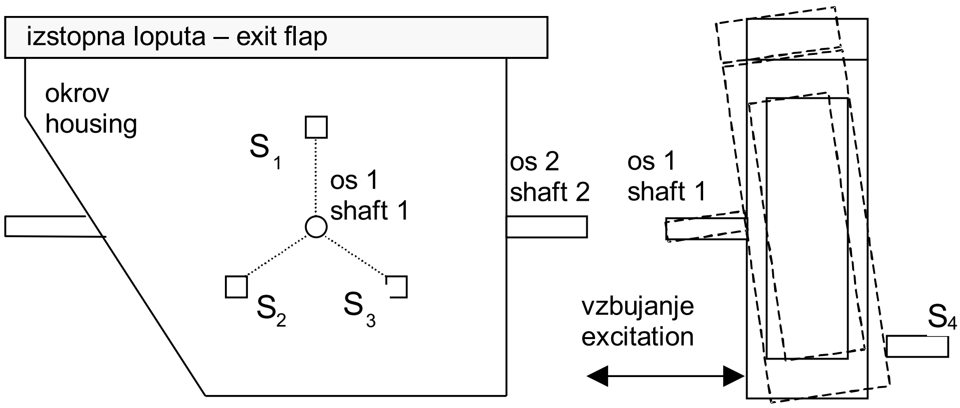
The basic dynamic characteristics of the whole assembly (rotor - bearing arrangement - housing) as a function of the mechanical excitation of the system were investigated. When designing the test rig, the actual operational parameters of the fan were considered as much as possible. The main emphasis was placed on a simulation of axial and transverse loads during driving and shooting.

The test rig (Fig. 3) consists of a main electric motor (P_{max}= 35 kW) with a continuously variable rotational speed from 0 to 3600 min^{-1}. The motor is connected (with a universal joint shaft) to the relief clutch of the fan, located on the front of the rotor. The rotor is mounted in the original bearing housing, which is located in a fan housing geometrically identical to the one used in the tank. For the purpose of axial and transverse excitation, the spiral shaped housing is incorporated into a moving joint, which, in combination with the universal joint shaft, allows angular movement of the fan housing and rotor. A pneumatic cylinder controlled by a signal from the control unit is used for transverse excitation.

Axial movement of the base plate relative to the housing wall has been chosen as a dependent dynamic variable. Three Turck CK 40 inductive transducers were used for this purpose. An HBM W 50 inductive transducer was used to measure the angular movement of the casing relative to the test rig base. Rotational speed was monitored as an integral parameter.

Relative displacements of the fan back plate from the casing were measured for the rotor deformation. The displacements of the spiral shaped housing relative to the base of the test rig were considered as the dynamic disturbance of the excitation of the system.

The comparison of different bearing design arrangements enables a qualitative and quantitative estimation of the influence on the stress field in the rotor and the influence on the dynamics of the whole system.



Sl. 3. *Shema preskusa z legami vgrajenih zaznaval pomika. S_1, S_2 in S_3 so zaznavala pomika ventilatorja glede na okrov, zaznavalo S_4 pa meri pomik okrova. Os 1 je gnana gred rotorja ventilatorja, os 2 je os kotnega vzbujanja okrova.*

Fig. 3. *Test rig with positions of displacement transducers. S_1, S_2 and S_3 are transducers of rotor displacement from the fan housing. S4 is used for housing sensing. Shaft 1 is driven by an electromotor, shaft 2 is the axis of casing rotation.*

3 ANALIZA

Meritev odmikov brez vzbujanja in z vzbujanjem s pnevmatskim batom smo merili časovno neodvisno drugo od druge, zato smo ju pred nadaljnjo obdelavo časovno sinhronizirali. Za referenčne točke smo uporabili ekstreme lokalnih odmikov v zadnji steni rotorja, ki nastanejo zaradi tehnologije obdelave. Signal zaznaval odmika S_1, S_2 in S_3 pri vzbujanju smo premikali v času enega vrtljaja ventilatorja po indeksu *i*, tako da je bil izraz:

$$\sum_{j=1}^{n}\left(\left|d_i - d_j\right|\right) \qquad (1)$$

minimalen. Indeks *j* teče po periodi enega vrtljaja ventilatorja, d_i in d_j pa sta oddaljenosti zadnje stene ventilatorja od okrova v času *i* in *j*. Indeks *i*, pri katerem je zgornji izraz minimalen, označuje čas, za katerega moramo premakniti enega od signalov, da se časovno ujameta. Povprečno razdaljo d zadnje stene rotorja od spiralnega okrova smo izračunali po enačbi:

$$d = \frac{\sum_{i=1}^{n} d_i}{n} \qquad (2),$$

pri čemer je d_i odmik v času *i*, *n* pa je število vseh izmerjenih odmikov izbranega zaznavala.

4 REZULTATI

Osnovni rezultati časovnega odziva vrtečega se rotorja na mehansko vzbujanje spiralnega okrova za izbrane izvedbe vležajenja so predstavljeni na slikah 4 do 6. Krivulja "zasuka okrova" pomeni potek relativnega premika spiralnega okrova glede na podlago eksperimentalne naprave in je posledica kotnega vzbujanja. Krivulja "brez vzbujanja"

3 ANALYSIS

Measurements with and without excitation are independent in time, and hence they were synchronized before further processing. The extremes of local displacements in the rotor back plane, caused by the method of manufacture served as reference points. The signals of transducers S_1, S_2, S_3 were, according to index *i*, shifted in time over one revolution to minimize the expression:

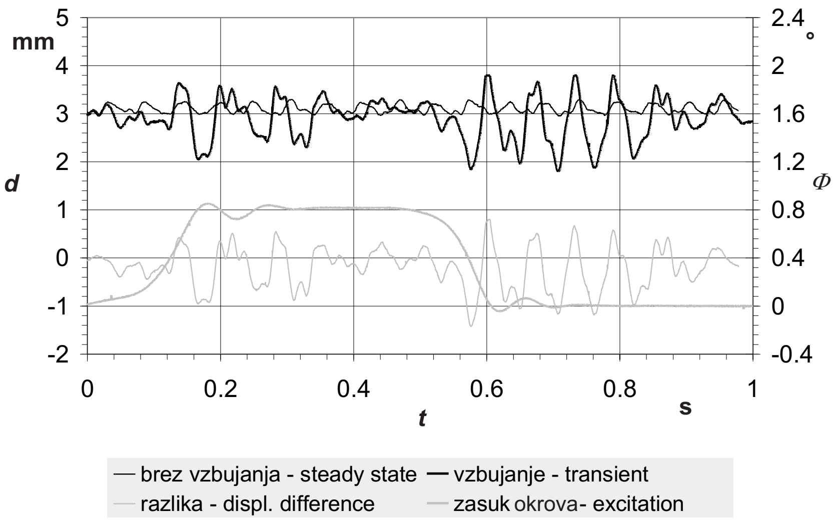
here *j* is the index, running over a period of one revolution, d_j and d_i are displacements of the back plate of the rotor from the casing at the time *i* and *j*. The index *i*, where the expression above reaches its minimum, corresponds to the time shift of one signal to the another. The average displacement of the rotor back plate to the casing was calculated according to the expression below

where d_i is the displacement at time *i* and *n* is the number of samples.

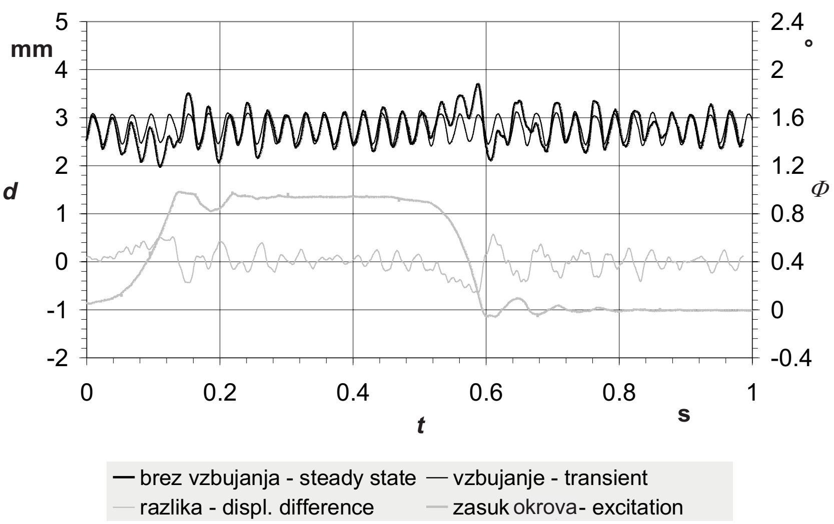
4 RESULTS

Results of the time dependent response of the rotor are shown in Figs. 4-6. The curve "excitation" represents the relative movement of the housing with respect to the base of the test rig. This movement is caused by the pulse excitation. The "steady-state" curve is a quasi-periodic signal of rotor movement away from the back wall of the housing during predstavlja navidez periodični signal odmika rotorja od zadnje stene v režimu ustaljenega delovanja. Periodično osciliranje odmika zadnje stene glede na zaznavalo je posledica neravnosti zadnje stene rotorja in odstopanja osi vležajenja od normale na ravnino zadnje stene spiralnega okrova. To potrjuje tudi značilna frekvenca periodičnega signala, ki je enaka pripadajoči vrtilni frekvenci rotorja. Iznos amplitude signala brez vzbujanja ne vpliva na končni rezultat analize. Krivulja "vzbujanja" pomeni simultani signal odmika rotorja od zadnje stene v prehodnem režimu vzbujanja spiralnega okrova. Krivulja "razlike" pomeni razliko med krivuljama z vzbujanjem in brez vzbujanja ter na ta način omogoča količinjenje dejanske – vzdolžne dinamike rotorja zaradi vzbujanja sistema. Vrednost časovnega poteka krivulje razlike je sorazmerna z relativnim odmikom rotorja od zadnje stene spiralnega okrova in je posledica deformacije rotorja in vležajenja v opazovani delovni točki.

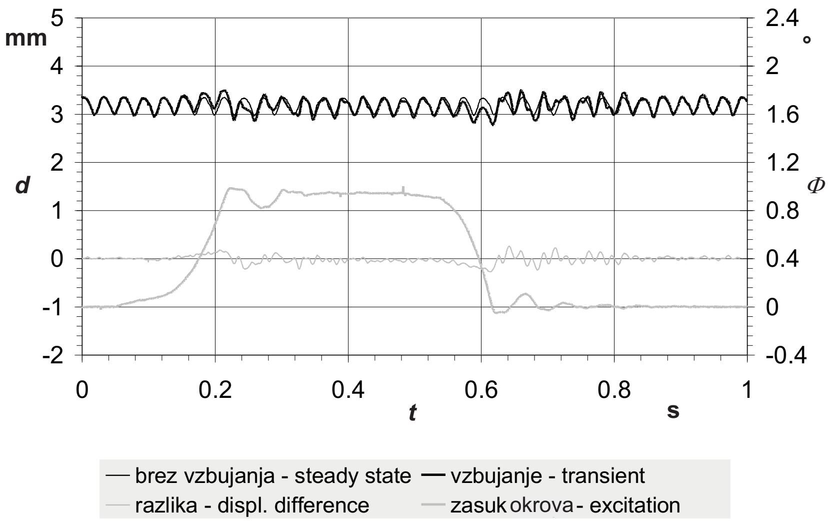
the steady operation. The periodic oscillation of the rotor base plate relative to the transducer is caused by the uneven surface of the base plate of the fan, deviation of the bearing axis from normal to the housing back wall plane, as well as by bearing play. The typical frequency of the periodic signal equals the corresponding rotational frequency of the rotor. The amplitude of the signal is irrelevant for the final result of the analysis. The curve "transient" represents the signal of the rotor movement away from the back wall of the housing during housing excitation. The curve "displ. difference" is the difference between the curves with and without excitation and indicates the transient, enabling quantification of the real axial dynamics of the rotor, caused by the excitation. The displacement difference is proportional to the relative displacement of the rotor from the rotor spiral casing and is a consequence of deformation of the rotor and bearing arrangement at the selected operational point.



Sl. 4. *Odziv zaznavala S_1, vležajenje M 84, n=1155 min^{-1}*
Fig. 4. *Transducer S_1 response, bearing type M 84, n=1155 min^{-1}*



Sl. 5. *Odziv zaznavala S_1, vležajenje M 84-obnovljeno, 2160 min^{-1}*
Fig. 5. *Transducer S_1 response, bearing type M 84-renewed, n=2160 min^{-1}*



Sl. 6. *Odziv zaznavala, vležajenje CEMEK, n=2020 min^{-1}*
Fig. 6. *Transducer S_1 response, bearing type CEMEK, n=2020 min^{-1}*

S časovnim povprečenjem deformacij signala razlike na vseh mernih zaznavalih pri različni vrtilni frekvenci rotorjev in različnih tipih vležajenja lahko določimo časovno povprečeno deformacijo rotorjev na obodu rotorja. Pri tem je treba poudariti, da na rezultat, poleg dejanske deformacije zadnje stene rotorja, vpliva tudi deformacija v ležajnem okrovu. Ta povečuje dejansko deformacijo, tako da jo lahko v primeru nedoseganja kritične deformacije uporabimo za merilo dopustne deformacije pri dejanskem eksperimentalnem testiranju v serijski proizvodnji hladilnih ventilatorjev.

Na slikah 7 do 9 so predstavljene deformacije zadnje stene rotorja za opazovana vležajenja. Krivulje na diagramih pomenijo časovno povprečene odmike po enačbi (2) – deformacije na zaznavalih S_1, S_2 in S_3 v odvisnosti od vrtilne frekvence rotorja. Iz diagramov je razvidno, da so opazne pomembne razlike v deformacijah pri različnih vležajenjih. Povzamemo lahko, da je deformacija sklopa močno odvisna od izbire tipa vležajenja in da je delež deformacije, povezan z napetostnim stanjem v rotorju, razmeroma neizrazit. V primeru vležajenja CEMEK se te deformacije pojavljajo šele v področju vrtilne frekvence, večje od 2500 min^{-1}.

By calculating the mean - by - time of the measured deformations on all transducers at various rotational frequencies of the rotor and with various types of bearing arrangement we can determine the characteristic mean deformation of the rotors, i.e. the axial displacement on the perimeter of the base plate of the fan. A very important influence on the result is the deformation of the bearing housing, enlarging the actual deformation. It can be used as a measure for the allowed deformation under real experimental testing in the serial production of fans.

Figures 7 to 9 show deformations of the rotor back plate for the tested bearing types. Curves represent time-averaged displacements according to eq. (2) – deformations on the transducers S_1, S_2 and S_3. The graphs show that the movement of the assembly depends on the choice of the bearing arrangement, and that the part of the displacement that can be traced to the stress state in the rotor is small. In the case of the new bearing arrangement, important deformations appear only when the rotational frequency exceeds 2500 min^{-1}.

5 SKLEP

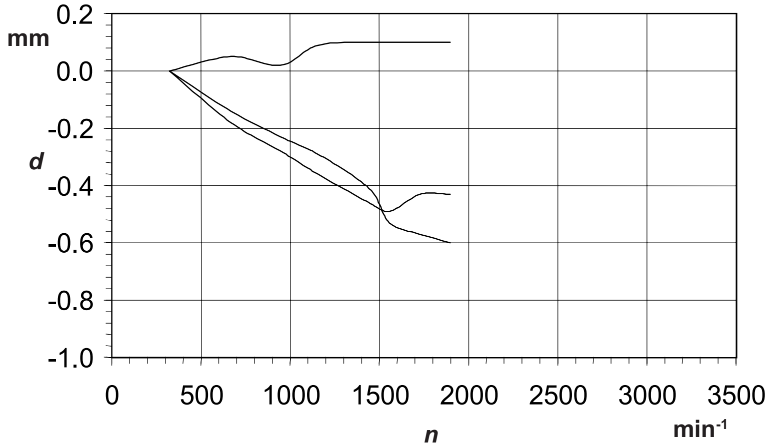
V prispevku smo predstavili analizo sklopa ventilator – vležajenje na način, ki omogoča vrednotenje mejnih mehanskih obremenitev sklopa. S to metodo smo potrdili pravilen izbor vležajenja CEMEK. Pri tem želimo poudariti, da v sklopu naloge nismo analizirali temperaturne obremenitve vležajenja in njegovega obnašanja ob dolgotrajnih dinamičnih obremenitvah.

Predstavljena metoda ponuja možnost testiranja sklopov rotor - vležajenje pred vgraditvijo v vozilo, s čimer lahko povečamo zanesljivost delovanja.

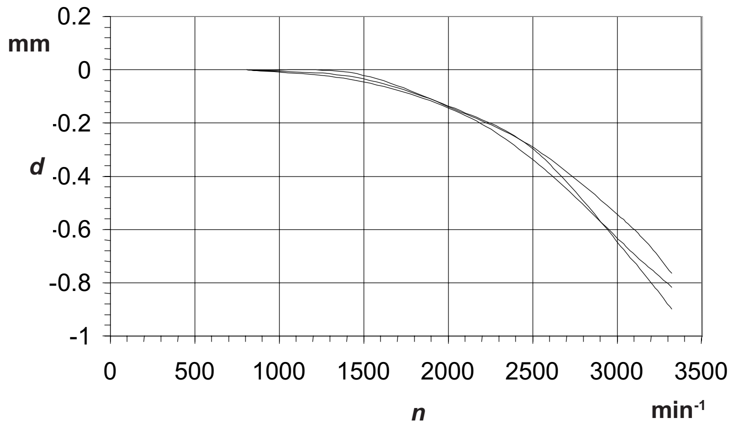
5 CONCLUSION

In this paper a theoretical and experimental analysis of the fan-bearing assembly was shown, in a way that enables an evaluation of the limiting mechanical loads of the assembly. With the presented method the need for, and the choice of, a new bearing arrangement for the rotor was confirmed. During the performed analysis temperature loading and long term thermodynamic load was not analyzed.

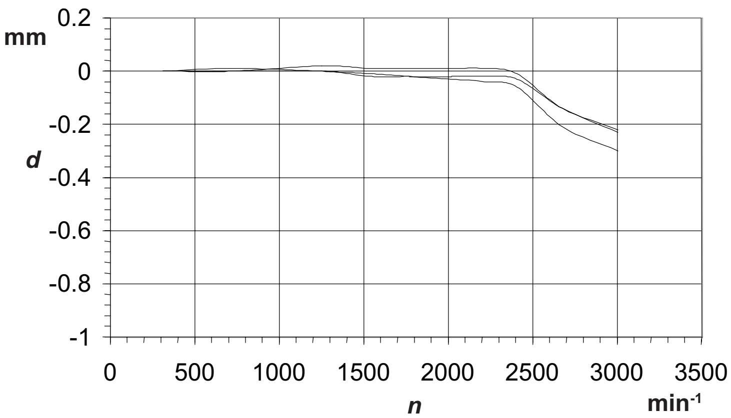
The presented method facilitates the testing of rotor-bearing assemblies their prior to being to be mounted in a vehicle and hence the operation reliability was improved.



Sl. 7. *Deformacija rotorja ventilatorja za vležajenje M 84*
Fig. 7. *Axial displacement of the rotor wall (mean), bearing type M 84*



Sl. 8. *Deformacija rotorja ventilatorja za vležajenje M 84-obnovljeno*
Fig. 8. *Axial displacement of the rotor wall (mean), bearing type M 84 - renewed*



Sl. 9. *Deformacija rotorja ventilatorja za vležajenje CEMEK*
Fig. 9. *Axial displacement of the rotor wall (mean), bearing type CEMEK*

6 LITERATURA
6 REFERENCES

[1] Širok, B., M. Hočevar (1997) Ventilator for the tank T 72. *Report Turboinštitut.* No. 3151.

[2] Paleš, P. (1997) T 100 A, 1000 HP driving modular system for Zuzana 155 mm/ T 72 SPG and T 72 modernization. *report, Kerametal-Transmisie*.

[3] Nagaratnam, N.S. (1996) Cooling system T 72 specifications. *Report, Madras.*

[4] Zupan, S., Kunc, R., I. Prebil (1998) Analiza vležajenja in trdnostna analiza ventilatorja tanka M 84 : Tehnično poročilo. *Ljubljana, Fakulteta za strojništvo, CEMEK,* 20 str., [22] str. pril. [COBISS-ID 2551835].

[5] Kunc, R., Prebil, I., Hočevar, M., B. Širok (1999) Trdnostno in aerodinamično optimiranje ventilatorja. *IAT99,* Nova Gorica.

Naslova avtorjev: doc.dr. Brane Širok
mag. Samo Zupan
prof.dr. Ivan Prebil
Fakulteta za strojništvo
Univerze v Ljubljani
Aškerčeva 6
1000 Ljubljana

Marko Hočevar
Turboinštitut
Rovšnikova 7
1000 Ljubljana

Authors' Addresses: Doc.Dr. Brane Širok
Mag. Samo Zupan
Prof.Dr. Ivan Prebil
Faculty of Mechanical Engineering
University of Ljubljana
Aškerčeva 6
1000 Ljubljana,Slovenia

Marko Hočevar
Turboinstitute
Rovšnikova 7
1000 Ljubljana, Slovenia

Prejeto:
Received: 19.10.1999

Sprejeto:
Accepted: 3.12.1999