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Analiza vibracij usmernika alternatorja

Vibration Analysis of an Alternator's Rectifier

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Alternator je predvsem zaradi vibracij in načina vpetja na motor izpostavljen velikim dinamičnim obremenitvam, kar bistveno vpliva na njegovo dobo trajanja. Tako se je na obravnavanem tipu alternatorja ta doba skrajšala predvsem zaradi odpovedi usmernikov kot posledica vibracij. Da bi prepoznali vzrok odpovedi, smo na usmerniku izvedli eksperimentalno modalno analizo (EMA). Glavni namen meritev je bil spoznati konstrukcijske dejavnike, ki vplivajo na prezgodnjo odpoved usmernika. Osnova pri vrednotenju dinamičnih lastnosti usmernika so bile izmerjene frekvenčne odzivne funkcije le-tega. Na podlagi rezultatov in analize meritev osnovne izvedbe usmernika in nekaterih njenih sprememb, so bili predlagani ukrepi, ki so izboljšali dinamične lastnosti usmernika in zmanjšali možnosti odpovedi ter podaljšali dobo trajanja izdelka. Pridobljene so bile koristne informacije za konstruiranje naslednjih generacij usmernikov, uporabljene metode pa so uporabne tudi širše, na drugih izdelkih.

(Ključne besede: vibracije, alternatorji, usmerniki, obratovalne oblike, modalne analize)

An alternator is subject to large dynamic loads, mainly because of vibrations in the engine and the fixture type, which affect the alternator's lifetime significantly. A certain type of alternator has had problems with its design, primarily as a result of damaged rectifiers caused by vibrations. To identify the reason for the failure an experimental modal analysis (EMA) was performed on the rectifier. The main purpose of the experimental approach was to identify some of the design factors that shorten the lifetime of rectifiers. The basis of the dynamic analysis was frequency-response functions, measured at the rectifier. Based on the measurement data of the original and modified samples of the rectifier, some corrections were made to improve the dynamic characteristics and to extend the lifetime of the rectifier. Useful information for the development of the next generation of the alternator's rectifier was obtained. The applied methods can also be extended to other products.

(Keywords: vibrations, alternator rectifiers, operational deflection shapes, modal analysis)

0 UVOD

V tehniki se vedno bolj usmerjamo k zmanjšanju hrupa in vibracij na strojih in napravah, s katerimi prihaja v stik človek. Hrup in vibracije povzročajo dinamične obremenitve naprav, katerih posledice znajo biti škodljive tudi za samo napravo. Odločitev o načinu preprečevanja poškodb naprav in zmanjševanja hrupa je odvisna od ravni vibracij in njihovih frekvenčnih karakteristik, zato so meritve vibracij naprav vedno pogostejše.

Podjetje Iskra Avtoelektrika d.d. iz Šempetra pri Gorici je proizvajalec široke izbire izdelkov za avtomobilsko industrijo in svoje izdelke trži na

0 INTRODUCTION

To decrease noise and vibrations is a constant aim in the design of machines, devices and vehicles. Noise and vibrations are caused by the dynamic loading of machines, and can also damage the structure of the machine itself. The choice of the approach for reducing the noise and preventing damage depends on the level of vibration and the frequency characteristics, which is the main reason for the widely used experimental approach.

The company Iskra Avtoelektrika d.d. is a manufacturer of a wide range of products for the automotive industry that are sold on demanding zahtevnih tujih trgih. Pri določenih tipih alternatorjev je bilo pri uporabi zaznati dinamične lome posameznih zvarov priključkov diod (pinov) na usmernikih. Poleg tega je prihajalo tudi do poškodb kondenzatorja pri pritrditvi na zaščitni pokrov.

Raziskati je treba pogoje in vzroke, pri katerih prihaja do odpovedi. Analitično bi bilo to zaradi kompleksnosti usmernika dokaj težavno, zato se bomo problematike lotili eksperimentalno. Prednost takega pristopa je, da ga lahko uporabimo za različne prototipe. Rezultati meritev pokažejo kritična mesta in frekvence, kjer naj bi izvedli izboljšave na usmerniku alternatorja. Poleg tega so lahko rezultati, daljnoročno gledano, osnova za nove zasnove usmernikov alternatorja. Pomanjkljivost omenjene metode je v tem, da je časovno zahtevna, tako glede izvedbe meritev kakor priprave prototipov.

Uporabljen postopek bo omogočil vpogled v obratovalne oblike strukture (OOS - ODS) in lažjo predstavo o tem, kaj se z usmernikom dejansko dogaja. Z meritvami prenosnih funkcij želimo ugotoviti, kateri deli strukture največ prispevajo k poškodbam usmernika. V ta namen bo treba postaviti preizkus in zaradi načina zajema meritev tudi poenostavljen geometrijski model usmernika. Rezultati meritev in analize vibracij nam bodo pokazali, katere izboljšave bi dejansko pripomogle k izboljšanju strukture.

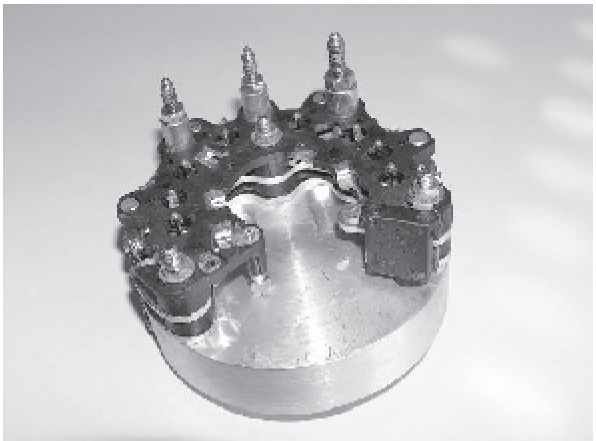
Usmerniki so naprave, ki zagotavljajo potrebno enosmerno napetost za obratovanje naprav (sl. 1). Njihova naloga je, da izmenično napetost usmerijo – spremenijo v enosmerno.

foreign markets. For certain types of alternators some dynamic cracks on the pins of the rectifier's diodes were detected. Furthermore, the capacitor also had some problems at the contact with the housing.

The source of these problems was investigated, and because of the complexity of the rectifier's structure, an experimental approach was adopted. The advantage of the experimental approach is its applicability to different prototypes. The measurement results showed us critical points and frequencies, which were taken into account when proposing changes to the structure of the alternator's rectifier. Over the long term, the results and conclusions can be the basis for new concepts relating to alternator rectifiers. The weak point of the experimental method is the time-consuming process of preparing prototypes and making the measurements.

However, the experimental approach gives us an insight into the operational deflection shapes (ODS) and helps us to understand better the response of the rectifier's structure. Measurements of the transfer functions show us the parts of rectifier's structure that contribute most to the damage. With this purpose we set up a measurement, and because of the adopted principle of measuring, a simplified geometrical model of the rectifier's structure also had to be built. The measurement and analysis results showed us which changes actually improved the structure in terms of the vibrations.

A rectifier is an electrical device that converts alternating current to direct current. Rectifiers are used as components in power supplies and as the detectors of radio signals, Figure 1.



Sl. 1. *Usmernik alternatorja na vpenjalu*
Fig. 1. *Alternator rectifier on the testing support*

Usmernik alternatorja je kot del alternatorja izpostavljen zelo različnim zunanjim vplivom, ki so v praksi prispevali k poškodbam delov usmernika. Ker usmernik sam ne izvaja mehanskega dela, lahko sklepamo, da so se vzroki za lome pinov prenesli iz drugih komponent, glede na naravo problema pa lahko sklepamo, da so v ozadju vibracije oz. delovanje zunanjih sil.

Vibracije navadno omenjamo z mislijo na odziv neke strukture na zunanje vzbujanje, zavedati pa se moramo, da je predvsem od materiala in oblike strukture odvisno, kakšen odziv bomo dobili. Pri določitvi vibracij tako govorimo o lastnostih določenega mehanskega sistema, običajno navajamo maso, togost in dušenje. Povezava med temi parametri je pri poenostavljenih modelih matematično popisljiva, zahtevnejše strukture pa težje modeliramo, tako zaradi oblike kakor tudi zaradi nepoznavanja vseh snovnih lastnosti delov strukture.

1 EKSPERIMENTALNI POSTOPEK

Eksperiment, v nasprotju z matematičnim modelom, omogoča vpogled v dejanski dinamični odziv sistema. Frekvenčna odzivna funkcija (FOF - FRF) je eden glavnih načinov prikaza dinamičnih lastnosti neke strukture z meritvami. Opredeljuje vhodno-izhodno razmerje med dvema točkama strukture kot funkcijo frekvence, torej kot razmerje izhodnega odziva in vhodne (vzbujalne) sile, ki je odziv povzročila [1].

Velika prednost takšnih meritev je, da merimo odziv sistema na vloženo silo ter posredno modalne parametre. O masi, dušenju in togosti sistema torej ni treba postavljati nobenih predpostavk, tako se tudi izognemo napačnim približkom. Poskrbeti moramo le, da opravimo zelo dobre meritve, sicer lahko popačimo karakteristike sistema.

Same FOF-je lahko uporabimo za primerjavo različnih usmernikov med seboj, ko pa želimo strukturo dejansko izboljšati, nas zanima, kje in kako lahko to storimo. Uporabne informacije za razumevanje in vrednotenje dinamičnega obnašanja strukture, njenega dela ali celotne strukture dobimo iz obratovalnih oblik strukture. Dobimo jih na dokaj preprost način – z meritvami FOF-jev. Obratovalne oblike običajno definiramo kot nihanje strukture pri določeni frekvenci [2] ali

An alternator’s rectifier is, as a subpart, subjected to different external influences, which in practical applications lead to cracks in parts of the rectifier. Since the rectifier does not perform any mechanical work, we can conclude that the cause of the cracks was transmitted from other alternator components and that the vibrations and external forces caused the damage.

Vibrations are usually described as the response of a structure to an external excitation; however, we must consider the effect of the material and the shape when observing the response of a structure. With the characterization of vibrations we usually think about the properties of a certain mechanical system, which is characterized in terms of mass, stiffness and damping. The relation between these three parameters is mathematically computable for simplified models; however, complex structures are more difficult to model, because of their shape and the possible unknown material properties of certain parts of the structure.

1 EXPERIMENTAL APPROACH

The experiment allows us to observe the real dynamic response of the system. The frequency-response function (FRF) is one of the basic methods used to observe the dynamic properties of a structure through measurement. It defines the input-output relation between two points on the structure as a function of the frequency; it is a quotient between the output response and the input, excitation force causing the response [1].

The advantage of such an approach is the measurement of the response of the system to the input force and the consequent computation of the modal parameters. Using measured modal parameters, incorrect assumptions about the mass, the stiffness and the damping properties of the system can be avoided. The quality of the measurements is very important: low-quality measurements can give the wrong information about a system’s characteristics.

Frequency-response functions can also be used for the comparison of different samples of the rectifier, but when the structure is to be improved, the real question is how and where. With the generation of operational deflection shapes (ODS), important and useful information for understanding and evaluating the dynamic behaviour of a structure (or its part) can be obtained. The ODS are computed from FRF measurements, and are usually defined v nekem časovnem obdobju. Simultano prikazujejo odzive v vseh pomerjenih točkah strukture, tako dobimo vpogled v dejansko nihanje strukture in njenih delov.

Modalne in obratovalne oblike so povezane. Obratovalne oblike merimo z namenom pridobitve modalnih, čeprav so si v več pogledih različne. Obratovalna oblika opisuje nihanje dveh ali več prostostnih stopenj strukture. To pomeni, da obratovalna oblika vsebuje oboje, vsiljene in resonančne komponente nihanja. Modalna oblika pa označuje le resonančno nihanje z dvema ali več prostostnimi stopnjami.

Eksperimentalno-modalna analiza je bula uporabljena za določitev lastnih frekvenc, dušenja, modalnih oblik in mehanskih modalnih parametrov na podlagi odziva omejenega števila izbranih točk na mehanski strukturi.

Modalna analiza je postopek, s katerim opišemo strukturo glede na njene naravne (dinamične) značilnosti – frekvenco, dušenje in lastne oblike. Eksperimentalno-modalna analiza pa na podlagi izmerjenih frekvenčnih odzivov strukture prikaže lastne frekvence, dušenje in modalne oblike. Poznavanje modalnih parametrov pri neki lastni frekvenci je pomembno, saj jo le-ti označijo, tako da vemo kolikšen je vpliv togosti, mase in dušenja na nihanje sestava pri neki frekvenci. [3] V programskem paketu LMS TestLab, kjer smo eksperimentalno-modalno analizo izvajali, je omogočena tudi primerjava med izvedenimi meritvami in izračunanimi krivuljami. Za lažji prikaz obratovalnih oblik in rezultatov smo izvedli poenostavljen geometrijski model usmernika. Na celotno strukturo usmernika smo postavili mrežo točk, na katerih smo opazovali frekvenčne odzivne funkcije. Gostoto mreže in lego točk smo določili tako, da je omogočala prepoznavanje osnovnih oblik nihanja, ki se pojavijo na posameznih komponentah usmernika in na usmerniku kot celoti.

1.1 Meritve

Usmernik alternatorja smo vzbujali s silo preko stresalnika, njegov odziv pa merili z pospeškomerom. Meritev frekvenčne odzivne funkcije zahteva hkratno zajemanje vzbujalne sile, ki povzroča odziv, in pospeškovnega odziva samega.

as the oscillation of a structure at a certain frequency [2] or over a certain period of time. They simultaneously show the response FRFs at all the measured points of a structure, and give a clear picture about the actual behaviour of the structure and its subparts.

The modal shapes and the operational deflection shapes are related. The ODS are measured with the purpose of acquiring the modal shapes, although they differ in some views. The ODS show the oscillation of two or more degrees of freedom of a structure, which means that they contain both forced and resonant components of vibrations. The modal shapes characterize only the resonant vibration of two or more degrees of freedom.

The experimental modal analysis was used to determine the natural frequencies, the damping, the modal shapes and the modal parameters from a limited number of points on the structure.

Modal analysis is a method for describing a structure with respect to its natural (dynamic) characteristics – frequency, damping and mode shapes. On the other hand, experimental modal analysis (EMA) uses the measured frequency responses of the structure to compute the natural frequencies, the damping and the modal shapes. Information about the modal parameters at a certain natural frequency is important for an estimation of how the mass, the stiffness and the damping influence the vibration at that frequency. [3] An experimental modal analysis was made with the software package LMS TestLab, which allows us to compare measured and computed data. The ODS analysis requires a simplified geometrical model of the rectifier's structure for an analysis of the operational shapes. The rectifier's structure was substituted by a mesh of points, which carried information about the measured frequency-response functions. The density of the mesh and the location of the points were defined in such a way that ensured the recognition of the modal shapes on individual parts and on the overall structure of the rectifier.

1.1 Measurements

The alternator's rectifier was excited through the shaker in the form of force, and the response was measured with an accelerometer, Table 1. Measuring the FRF requires the simultaneous acquisition of the excitation force and the acceleration response.

Preglednica 1. *Oprema za vibracijsko analizo*
Table 1. *Vibration analysis equipment*

Oprema / Equipment	Opis / Description
zajem signalov / signal aquisition	LMS SCADAS III
programska oprema / software	LMS Test.Lab 5A
pospeškomer / accelerometer	ENDEVCO 25B, 0.2g
merilnik sile / dynamometer	ENDEVCO 2311-100
stresalnik / shaker	B&K 4824
ojačevalnik / amplifier	B&K 4732

Na merjeno strukturo smo prilepili merilnik sile, ki stresalniku omogoča vzbujanje. Dodana masa merilnika sile bi lahko bila moteča z vidika vpliva na lastne frekvence merjenega sistema, zato smo usmernik pritrdili na namensko izdelano nosilo – vpenjalo iz aluminija, ki oponaša pritrditev usmernika na pokrov alternatorja. Prek nosila lahko z merilnikom sile lažje vzbujamo usmernik alternatorja, saj togost vpenjala močno presega togost usmernika, celotna masa pa je bila dovolj majhna za doseganje zadovoljivih meritev.

Velik pomen pri izbiri merilnih mest je imela njihova dostopnost. Čeprav smo uporabili razmeroma majhne pospeškomere, je bila njihova pritrditev na usmernik dokaj težavna. Odziv strukture smo torej merili le na določenih mestih, programska oprema pa je omogočila spremljanje dinamike vseh točk.

Usmernik smo vzbujali v eni točki in spreminjali točko zajema podatkov – pospeškomer smo prestavljali po strukturi. Zaznavalo smo pritrdili z voskom. V preliminarnih testih smo določili primeren način vzbujanja, ustrezno merilno območje in primerno raven napetosti na ojačevalniku stresalnika. Na podlagi teh testov smo določili parametre nastavitve opreme za meritve (preglednica 2).

V podprogramu "Animacije" program po izvedenih meritvah prikaže pomerjene FOF-je na geometrijskem modelu – to so obratovalne oblike. Takšen način prikaza omogoča lažjo predstavo o odzivu vzbujenega usmernika. V podprogramu

The dynamometer, which enables the excitation, was attached to the structure. However, the additional mass of the dynamometer could distort the measured response; therefore, the rectifier was mounted on the special testing support, made of aluminium, which imitates the mounting of the rectifier on the alternator's housing. Using the testing support, the excitation with the dynamometer is improved, as the stiffness of the support exceeds the stiffness of the rectifier. The entire mass is small enough to ensure quality measurement results.

Defining the measurement points on the mesh depended to a large extent on their accessibility. Although very small accelerometers were used, it was difficult to mount them on the rectifier. The response of the structure was measured only at some points, and later the software made it possible to compare all the points of the mesh simultaneously.

The rectifier was excited at one point, but the response was measured at several points on the structure. The accelerometer was fixed with wax. During preliminary measurements, the proper excitation type, frequency range and other parameters for the measurement equipment were determined, Table 2.

The software subsection *"Animation"* used the geometrical model of the structure to demonstrate the measured FRFs as operational shapes. The ODS allows a better understanding of the response of the excited rectifier's structure. In the subsection "Modal Analysis", an experimental

Preglednica 2. *Nastavitve opreme za meritve*
Table 2. Measurement-equipment settings

način vzbujanja / excitation type	burst random
merilno območje / frequency range	0 do/to 2048 Hz
frekvenca vzorčenja / sampling frequency	4096 Hz
frekvenčna ločljivost / frequency resolution	2 Hz
število povprečenj / averaging number	10

"Modal Analysis" smo nato za vsak vzorec izvedli eksperimentalno-modalno analizo z namenom pridobitve modalnih parametrov.

2 PRIMERJALNA ANALIZA USMERNIKOV

Model strukture usmernika je kljub poenostavitvi zgrajen iz mnogih točk, katerih primerjava bi bila zamudna in nepregledna, zato smo se odločili za primerjavo različnih izvedb usmernika po ovojnicah frekvenčnih odzivnih funkcij. V ovojnico so bili zajeti vse FOF-je posameznega usmernika.

Za primerjavo in analizo vibracijskih karaketristik usmernika smo pripravili več različnih izvedb, ki smo jih kasneje na podlagi rezultatov meritev in analize tudi spremenili ali pa smo jim spremenili pogoje vpetja. Dejansko smo razpolagali s sedmimi različicami usmernika.

- ***Stara izvedba*** je vzorec ene zgodnjih izvedb usmernika.
- ***Osnovna izvedba*** je vzorec usmernika, ki se trenutno uporablja in je brez sprememb in dodatnih izboljšav.
- ***Osnovna izvedba brez ALU kovic*** je vzorec osnovne izvedbe usmernika brez aluminijastih kovic med pozitivnim hladilnim telesom in zgornjo plastično ploščo.
- ***Osnovna izvedba brez 1. in 2. vijaka*** je vzorec osnovne izvedbe usmernika brez dveh vijakov na plastični plošči.
- ***Osnovna izvedba s stičnimi vijaki na diodah*** je vzorec osnovne izvedbe usmernika, pri katerem smo v diode privijačili vijak skozi negativno hladilno telo.

Poleg vibracijskih analiz navedenih usmernikov smo usmernike tudi spremenili ali pa jim spremenili način vpetja. Usmernike smo vpenjali na dva načina, brez povezave in s povezavo s statorskimi odcepi. Spremembe, ki smo jih izvedli na usmerniku, so zadevale predvsem vzpostavljanje povezav oz. stikov med posameznimi deli strukture usmernika.

Rezultati so med seboj primerjani v diagramih. Posebej bi omenili enoto amplitude ovojnice FRF, ki je [g/N], kjer g pomeni težnostni pospešek 9,81 m/s^2, N pa enoto za silo Newton.

2.1 Analiza primernosti nadgradnje geometrijskega modela

Zaradi kompleksnosti usmernika smo pri postavitvi modela strukturo sprva močno

modal analysis was performed for each sample of the rectifier with the purpose of acquiring the modal parameters.

2 ANALYSIS OF DIFFERENT RECTIFIERS

The geometrical model of the structure is, despite the reduction, built using many points. A comparison of all the points of the structure would be time and space consuming; therefore, the comparison was carried out between envelopes of the FRFs of the different rectifier samples. A single envelope contained all the FRFs of the individual rectifier sample.

Different samples were prepared for a comparison and an analysis of the dynamic characteristics of the rectifier. Based on the measured results and analyses, some changes in the rectifier's structure were made and additionally tested. The measurements were performed on seven different rectifier samples.

- ***The Previous rectifier*** is a sample of the older type.
- ***The Original rectifier*** is a sample of the rectifier that is currently in use and is without any changes or improvements.
- ***The Original rectifier without ALU rivets*** is a sample of the original rectifier without its aluminium rivets between the positive cooling part and the upper plastic plate.
- ***The Original rectifier without the 1st and 2nd bolt*** is a sample of the original rectifier without two terminal bolts on the upper plastic plate.
- ***The Original rectifier with additional bolts on diodes*** is a sample of the original rectifier with bolts between the diodes and the negative cooling part, with the purpose of additionally exciting the diodes.

Besides the mentioned samples, some modified rectifiers with different mountings were also tested. The mounting was realized both with and without the wire connections to the stator. The modifications to the rectifier mostly affected the connections or the contacts between particular parts of the rectifier's structure.

An analysis of the results is presented in Figures 3, 4 and 5. The unit of the FRF envelope is [g/N], where g is the gravitational constant, 9.81 m/s^2, and N is the force unit Newton.

2.1 Rationality of geometric model upgrades analysis

Due to the complexity of the rectifier's structure the model was simplified at the beginning;

poenostavili, vendar se je med meritvami izkazalo, da delni geometrijski model sestava ni ustrezen, zato smo ga nadgradili z dodatnimi komponentami (sl. 2).

Tako delni model predstavljajo komponente: pini diod (PIN), pozitivno hladilno telo (POZht) in negativno hladilno telo (NEGht); celotni model pa poleg omenjenih treh še: zgornja plastična plošča (PLOpl), terminalski vijaki (TERvi) in kondenzator (KON).

Na sliki 3 je prikazana ovojnica FRF-jev osnovne izvedbe usmernika, in sicer z upoštevanimi različnimi geometrijskimi oblikami. Vidimo lahko, da se krivulji delnega modela in celotnega modela brez dodanih novih komponent popolnoma prekrivata, kar kaže na dobro ponovljivost eksperimenta. V nasprotju z omenjenima krivuljama pa krivulja odzivov celotne geometrijske oblike z upoštevanimi novimi komponentami (črtkana črta) močno odstopa. Iz tega lahko sklepamo, da imajo predhodno izpuščene komponente (PLOpl, TERvi, KON) bistven vpliv na odziv sistema in jih ne smemo zanemariti.

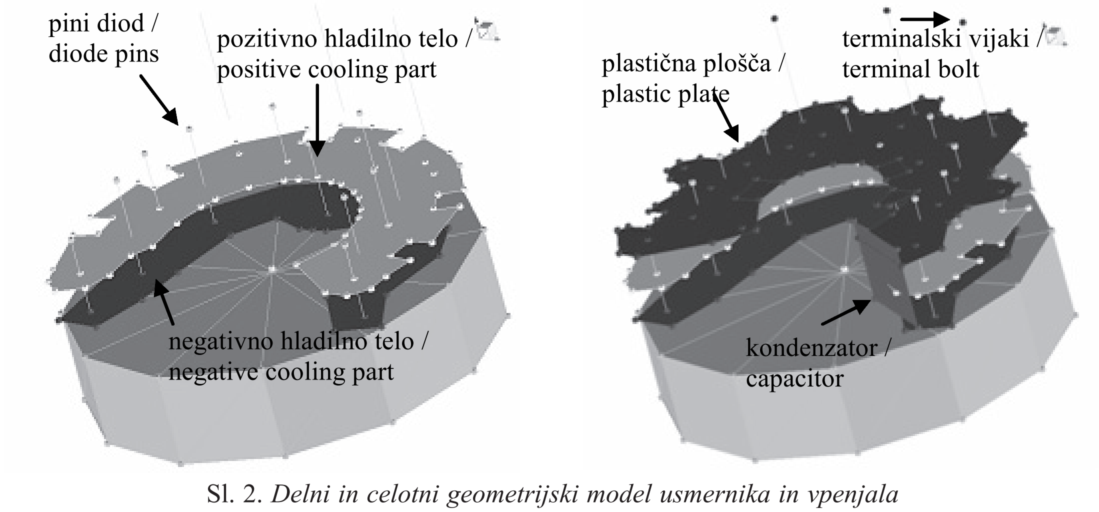
Prispevki posameznih omenjenih komponent strukture h končni sliki – odzivu celotnega usmernika so prikazani na sliki 4. S slike je razvidno, koliko in kako posamezna komponenta prispeva h končnemu odzivu. Pri nižjih frekvencah (1200 Hz) je bistven vpliv kondenzatorja. Spremembo odziva v okolici frekvence 1750 Hz prispevajo prav na novo upoštevane komponente, saj opazimo, da je lastna frekvenca pri modelu brez dodanih komponent kar 100 Hz nižje, pri 1650 Hz (sl. 3).

however, during measurements, as it has turned out, the reduced geometrical model was not appropriate and so it was upgraded with several rectifier parts, Figure 2.

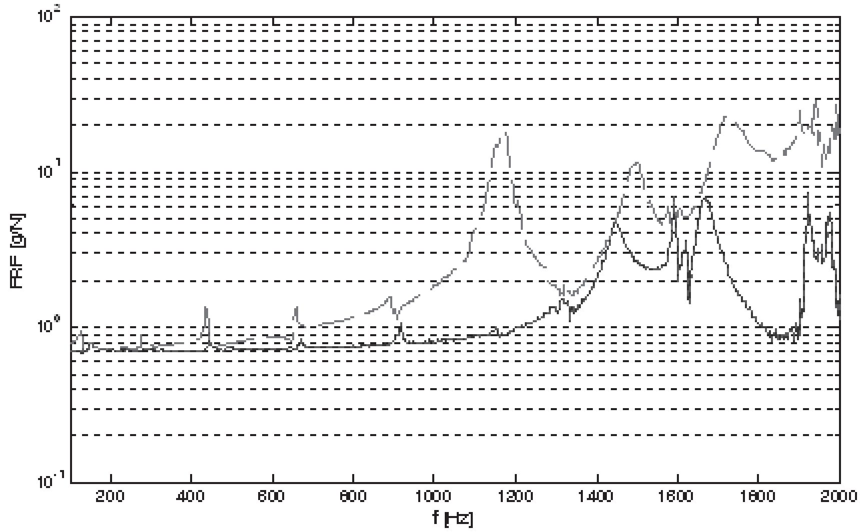
The reduced model was built with the following components: diode pins (PIN), the positive cooling part (POZht) and the negative cooling part (NEGht). The upgraded, complete model also contains the upper plastic plate (PLOpl), the terminal bolts (TERvi) and the capacitor (KON).

Figure 3 shows the envelope of the FRFs of the original rectifier, each graph with different parts of the geometry taken into account. The graphs of the reduced and the complete model without any new, additional components coincide completely, which proves the good repeatability of the measurements. On the other hand, the graph of the response of the complete geometry (with new components) differs significantly. We can conclude that the previously neglected components contribute significantly to the response of the whole structure, and as such cannot be ignored.

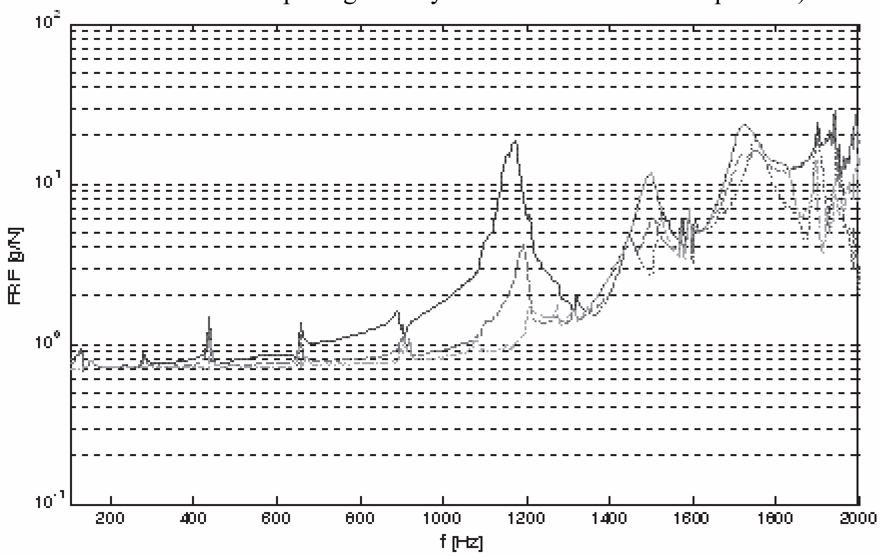
The measure and the manner of how each new component contributes to the final response is shown in Figure 4. At lower frequencies (1200 Hz) the capacitor has a large influence on the response of the system. A noticeable change in the response function around 1750 Hz can be mainly attributed to newly added components. As in the reduced model the natural frequency occurs at 100 Hz lower (at 1650 Hz) than in the complete (upgraded) model, Figure 3.



Sl. 2. *Delni in celotni geometrijski model usmernika in vpenjala*
Fig. 2. *Rectifier and testing support geometric model, reduced and complete*



Sl. 3. *Primerjava ovojnic FOF-ij posameznih geometrijskih modelov usmernika*
(——— Delna geometrijska oblika modela usmernika; -------- Celotna geometrijska oblika modela usmernika; ········ Celotna geometrijska oblika modela usmernika brez novih komponent)
Fig. 3. *Comparison of the FRF envelopes for the reduced and complete geometrical models*
(——— Rectifier reduced geometry model; -------- Rectifier complete geometry model; ········ Rectifier complete geometry model without new components)



Sl. 4. *Primerjava ovojnic FOF-ij različnih geometrijskih modelov usmernika*
(——— Geometrijska oblika modela usmernika z vsemi komponentami; -------- Geometrijska oblika modela usmernika s plastično ploščo; ········ Geometrijska oblika modela usmernika s kondenzatorjem; ·-·-·-·-·- Geometrijska oblika modela usmernika s terminalskimi vijaki)
Fig. 4. *Comparison of the FRF envelopes for the different geometrical models of the rectifier*
(——— Rectifier geometry model with all components; -------- Rectifier geometry model with plastic plate; ········ Rectifier geometry model with the capacitor; ·-·-·-·-·- Rectifier geometry model with terminal bolts)

2.2 Analiza vpliva dosedanjih izboljšav na odziv strukture

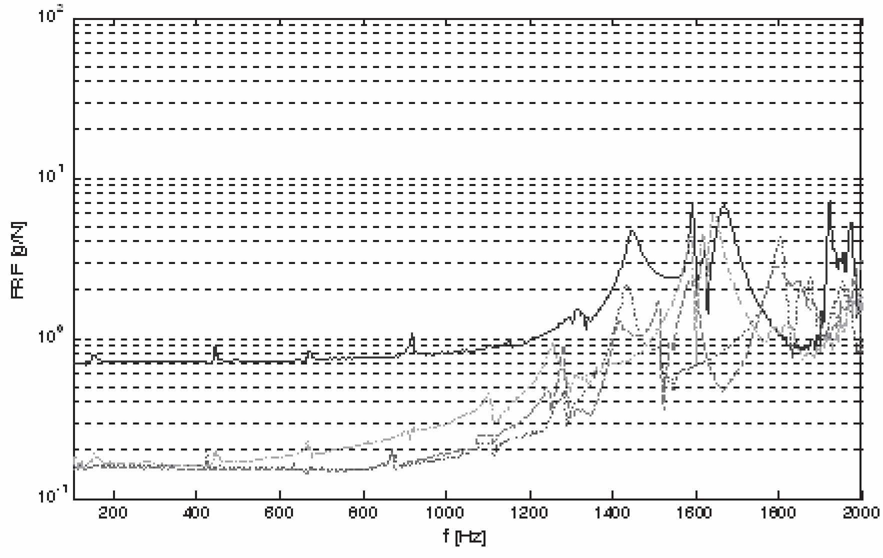
Osnovno izvedbo usmernika, vzeto iz sedanje proizvodnje, smo analizirali glede vpliva dosedanjih izboljšav na odziv usmernika. V ta namen smo več usmernikov spremenili, tako da smo jim odstranili posamezne dele, ki so bili rezultat dotedanjih izboljšav.

Rezultati so za vse vzorce prikazani na sliki 5, kjer smo osnovno izvedbo usmernika primerjali z že omenjenimi vzorci. Uporabljena je bila delna geometrijska oblika modela usmernika. Kovice naj bi usmerniku zagotavljale povezavo med pozitivnim hladilnim telesom in zgornjo plastično ploščo, vendar se je izkazalo, da je odziv brez kovic v nižjih frekvencah ugodnejši. To bi lahko pripisali vplivu kovic glede na večji prenos vibracij iz pozitivnega hladilnega telesa. Pri višjih frekvencah brez kovic pride do povečanih odzivov glede na osnovno izvedbo. Vijaka za pritrditev zaščitnega pokrova predstavljata na usmerniku dodatno maso. Vzorec brez teh vijakov je imel povečane odzive pri 1450 Hz in 1800 Hz. Dodatni vijaki na diodah so prenašali vibracije na diode zaradi povezave

2.2 Previous improvements influence analysis

The original rectifier was analyzed in terms of the influence of previous improvements on the rectifier's response. For this purpose, some rectifiers were modified so that a particular previous improvement, a result of the former analysis, was removed.

The original rectifier sample was compared to the modified samples, Figure 5. The reduced-geometry model was used. The rivets should ensure the connection between the positive cooling part and the upper plastic plate, but the response at lower frequencies is better without them. The rivets, therefore, cause the transmission of vibration from the positive cooling part. However, at higher frequencies the absence of rivets causes a greater response with regard to the original rectifier. The rectifier is mounted on the alternator's housing with terminal bolts that are an additional mass on the rectifier. The rectifier sample without bolts had a higher response at 1450Hz and 1800Hz. The additional bolts on the diodes allow a more intense vibration transmission



Sl. 5. *Primerjava ovojnic FOF-ij različnih spremenjenih osnovnih izvedb usmernika*
(——— Osnovna izvedba usmernika; -------- Vzorec usmernika brez ALU kovic; ········ Vzorec usmernika brez 1. in 2. terminalskega vijaka; -·-·-·-·- Vzorec usmernika z dodanimi vijaki za vzbujanje diod)

Fig. 5. *Comparison of the FRF envelopes for different modified samples of the original rectifier*
(——— Original rectifier sample; -------- Sample of rectifier without ALU rivet; ········ Sample of rectifier without 1st and 2nd terminal bolt; -·-·-·-·- Sample of rectifier with bolts to additionally excite the diodes)

pozitivnega z negativnim hladilnim telesom. Izkaže se, da se odziv usmernika spremeni glede na povečane amplitude in premika večine vrhov proti frekvenci 1600 Hz.

2.3 Analiza vpliva vpetja in podprtja usmernika

Poleg vpliva geometrijske oblike in snovnih lastnosti na vibracije strukture so seveda bistveni tudi robni pogoji – pogoji vpetja usmernika in povezave posameznih delov usmernika. V ta namen smo primerjali osnovno izvedbo usmernika, ki je bila "normalno" pritrjena na vpenjalo, in izvedbo, vpeto tudi preko statorskih odcepov na obodu strukture. Primerjava je prikazana na sliki 6. Iz primerjave ugotovimo, da pritrditev statorskih odcepov celotno strukturo usmernika utrdi, kar se kaže v nižjih vrednostih frekvenčnih odzivov in višjih lastnih frekvencah.

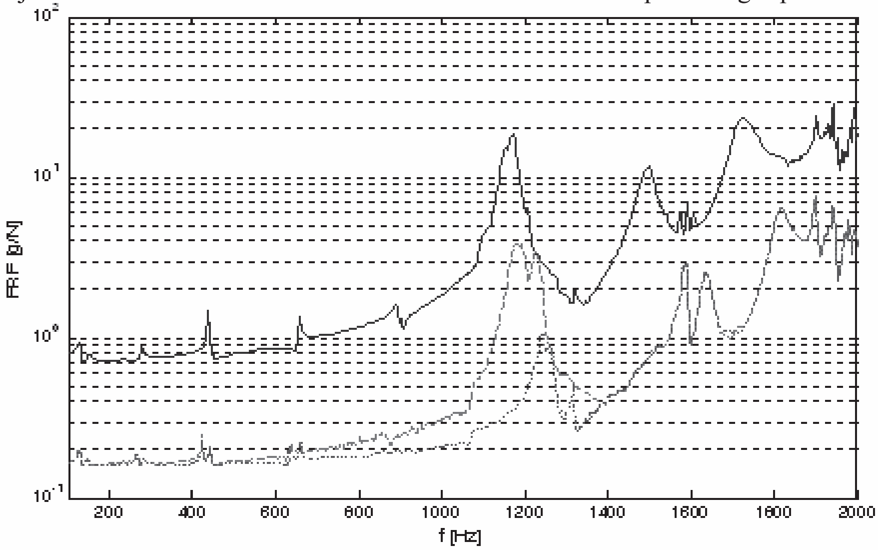
Strukturo smo skušali izboljšati na različne načine, tukaj pokažimo le primer z dodatnim podprtjem kondenzatorja (omejili smo gibanje v ravnini pravokotni na alternator). Na sliki 6 vidimo, da smo s takšno izboljšavo zelo znižali odziv pri lastni frekvenci v okolici 1200 Hz, kar je pomemben dosežek z vidika preprečitve lomov kondenzatorja.

inside the structure due to the connection between the positive and negative cooling parts. This rectifier's response is higher and most peaks move towards a frequency of 1600Hz.

2.3 Mounting and support analysis

The geometry and the material properties influence the structural vibration, but the boundary conditions are also fundamental – the conditions of the mounting and the connections between the parts inside the rectifier's structure. A comparison of the original rectifier's sample, mounted on the testing support, and of the original rectifier's sample, mounted as previously and additionally connected with wire connections to the stator, was made, Figure 6. From the figure we can see that the connection to the stator reinforces the whole structure, which appears as lower responses and higher natural frequencies.

The rectifier's structure was modified in many different ways to achieve the response improvement. Here, we only present the alternative case of the capacitor support. The capacitor's motion was restrained in the plane perpendicular to the alternator. With this modification, the response was lower, especially around the natural frequency of 1200Hz, which is an important achievement in preventing capacitor breaks.



Sl. 6. *Primerjava ovojnic FOF-ij različnih vpetih in podprtih osnovnih izvedb usmernika*
(——— Osnovna izvedba usmernika brez statorskih odcepov; -------- Osnovna izvedba usmernika s statorskimi odcepi; ········ Osnovna izvedba usmernika s statorskimi odcepi in podprtim kondenzatorjem)

Fig. 6. *Comparison of the FRF envelopes for different support types of the original rectifier*
(——— Original rectifier sample without wire connections to the stator; -------- Original rectifier sample with wire connections to the stator; ········ Original rectifier sample with wire connections to the stator and with a modified capacitor mounting)

3 SKLEP

Glede na rezultate vibracijske analize osnovne izvedbe usmernika alternatorja in nekaterih njenih sprememb so bili predlagani nekateri ukrepi, s katerimi bi lahko še izboljšali značaj vibracijskega odziva usmernika alternatorja in tako zmanjšali možnost za prezgodnjo odpoved usmernika in posledično alternatorja.

V prispevku je obravnavan drugačen postopek reševanja vibracijskih težav z usmernikom alternatorja, ki so se do sedaj reševale z bolj konstrukterskega vidika. Posvetili smo se vibracijskim vplivom na strukturo usmernika alternatorja in raziskali pogoje in vzroke, pri katerih prihaja do odpovedi usmernika v praksi. Tematika je še vedno pomembna, pojavljajo pa se tudi novi problemi s strukturo usmernika, zato je pomemben prispevek tega dela glede na pripravo podlage za nadaljnje izboljšanje strukture sedanjega usmernika in za testiranje usmernikov v razvoju.

Ključna sprememba, ki naj bi pripomogla k podaljšanju dobe trajanja oz. bi odpravila vzrok za lom pinov (zvarjeni priključki diode), je bila uvedba distančnikov, ki bi vzpostavljali stik med plastično ploščo in pozitivnim hladilnim telesom v bližini priključnih odcepov za diode. Tako smo omejili gibanje plastične plošče proti pinom diod in posledično zmanjšali sile, ki obremenjujejo pine. Kot drugi ukrep lahko vpeljemo še dodatne kovice v območje prvega in tretjega priključnega vijaka z namenom utrditve in povezave plastične plošče s pozitivnim hladilnim telesom. Predvidevamo, da bi s tem zmanjšali prenos vztrajnostnih sil kot posledice mase terminalskih vijakov. Bistvena sprememba je podprtje kondenzatorja in s tem omejitev njegovega gibanja v vzdolžni in prečni smeri ter morebiten lom.

Uporabljena zasnova meritev je uporabna tudi za druge tipe usmernikov, le nastavek zanje mora biti posebej izdelan. V odzivu smo analizirali lastne frekvence in oblike in si ogledali obratovalne oblike, ki veliko povedo o obnašanju sistema v izbranem frekvenčnem območju. Odzive usmernikov smo zaradi obsega podatkov primerjali med seboj na podlagi ovojnic FOF-ij posameznega usmernika. Odzive smo primerjali grafično, lepši vpogled v dogajanje pa dobimo s pregledom obratovalnih oblik in animacij.

3 CONCLUSION

The results of the vibration analysis of the original alternators rectifier and its modified samples were the basis for the proposed modifications for the improvement of the vibration response of the rectifier that would reduce the possibility of a premature failure.

In this paper a different approach to solving the problems with the vibration of the alternator’s rectifier is discussed. More attention was focused on the influence of the vibration on the structure of the alternator’s rectifier, and the conditions and the sources for the rectifier’s failure were investigated. The problem is still present and there are new problems with the rectifier’s structure; therefore, the contribution of this paper will be the basis for further improvements to the existing structure and for the development of new rectifiers.

The main modification that would contribute to a longer lifetime and a lower probability for the failure of the diodes was the introduction of additional pins between the plastic plate and the positive cooling part near the connectors of the diodes. The motion of the plastic plate was restrained to lower the forces on the diodes’ pins. Another modification was additional rivets positioned near the terminal bolts to reinforce the structure and to connect the upper plastic plate to the positive cooling part. We expected to limit the transmission of inertial forces caused by the terminal bolts’ mass. Another important modification was the alternative capacitor support, which should prevent any possible damage.

The proposed method is also applicable to other types of rectifiers; however, the measuring support needs to be adjusted before. The response was analyzed in terms of the natural frequencies and the shapes, and the operational shapes were observed to investigate the motion of the structure and its parts in the particular frequency range. The responses were compared to the diagrams as FRF envelopes, mainly due to the quantity of the data being measured. The operational deflection shapes and the animations offer an even better overview of the rectifier’s dynamics.

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