© Strojniški vestnik 45(1999)9,321-332 © Journal of Mechanical Engineering 45(1999)9,321-332
ISSN 0039-2480 ISSN 0039-2480
UDK 620.179.1:629.424:629.4.03 UDC 620.179.1:629.424:629.4.03
Objavljeno predavanje na znanstveni konf. (1.08) Scientific conference paper (1.08)

Preskušanje gredi kolesnih dvojic na dizelskih motornih vlakih

Testing of Axles in Wheel and Axle Sets of Diesel-Engine Trains

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V tem prispevku smo prikazali preskušanja gredi kolesnih dvojic na dizelskih motornih vlakih in posvetili pozornost tako teoretičnemu kakor tudi eksperimetnalnemu delu. Na aluminijastem bloku smo najprej izmerili karakteristike ultrazvočnih glav z uporabo elektrodinamičnih sond. Na voljo smo imeli razstavljene in neuporabljene gredi kolesnih dvojic, na katerih smo na posameznih kritičnih mestih simulirali napake različnih globin. Na temelju napak smo nato ugotavljali primernost uporabe različnih ultrazvočnih glav. Tako smo uspešno preskušali z vsako od izbranih štirih ultrazvočnih glav, in sicer na krajši in daljši strani zobnika gonilne gredi z različnih polj ter pri nastavitvi aparata na 1,5 in 2,5 m. Vsako od izbranih različic preskušanja smo nato posneli za kasnejšo analizo rezultatov. Po izbranih postopkih smo v končni fazi za primerjavo rezultatov eksperimentalnega dela izračunali tudi geometrijske oblike znanih tipov zvočnih poti.

(Ključne besede: vlaki motorni (dieselski), preskušanje gredi, preskušanje ultrazvočno, analize poškodb)

The present paper treats the testing of axles in wheel and axle sets of diesel-engined trains; attention is devoted both to theoretical and to practical work. First, the characteristics of ultrasonic probes were measured on an aluminium block by means of electrodynamics probes. To this end we had at our disposal unserviceable axles of wheel and disassembled axle sets, where at individual critical points it was possible to simulate defects at various depths. On the basis of the defects, the applicability of individual ultrasonic probes was assessed. Testing was thus successfully carried out with each of the selected ultrasonic probes at the shorter and longer side of the gear wheel of the driving axle from different fields, and with the apparatus setting at 1.5 and 2.5 m. Each of the variants selected was recorded for subsequent analysis of the results. Finally, based on the procedures selected, the geometries of the known types of ultrasonic paths were calculated for comparison with the results of the experimental work.

(Keywords: diesel engine trains, axle-testing, ultrasonic testing, damage analysis)

0 UVOD

Železniški promet terja varnost in zanesljivost obratovanja vseh tirnih vozil. Vzdrževati je treba ustrezne tehnične sisteme in zanj prirejene metode dela, ki zagotavljajo varnost in urejenost prometa. Vsa vlečna sredstva so zato opremljena z ustreznimi varovalnimi napravami, ki izključujejo subjektivne napake operaterjev. Tako se srečujemo z budnostnimi napravami, katerim se pridružijo še tako imenovane avtostop naprave. O dejanskem stanju na železniški progi poročajo radijske zveze, brez katerih si modernega prometa ne bi mogli zamisliti. Poleg varnega vodenja je treba zagotoviti varno delovanje zavornega sistema in stalni nadzor njegovega delovanja, kar pa je treba razširiti še na odkrivanje napak na najpomembnejših elementih lokomotiv, vagonov in tirnic. Za odkrivanje napak se pogosto uporabljajo predvsem neporušne metode, ki morajo biti dovolj hitre za

0 INTRODUCTION

The railway traffic requires safety and reliability of service of all railway vehicles. Suitable technical systems and appropriately adapted working methods, which meet the requirements on safety and good order of traffic, should be maintained. All driving units are, therefore, equipped with corresponding protective devices, these exclude possible subjective errors by operators by the inclusion of dead - man's handles and auto-stop devices - as well as through radio communications permitting reports on the actual state of the railway line, which are indispensable in modern traffic. In addition to safe work it is indispensable to ensure safe operation of the braking system and continuous supervision of its operation, which also includes detection of defects in vital elements of locomotives, wagons and rails. For detection of defects, non-destructive testing methods - which should be quick, testiranje, pa tudi dovolj zanesljive in poceni. Pregled karakterističnih delov se izvaja po natančno predpisanih internih standardih ali predpisih. Poleg rednih so vključeni še izredni pregledi, ki morajo biti izvedeni po naletih, iztirjenju in oplazitvi železniških vozil.

Med najbolj obremenjene dele železniških vozil uvrščamo gredi kolesnih dvojic, saj njihove poškodbe ali zlomi povzročajo nastanek znatnih materialnih izgub in ogrožajo življenja potnikov in delavcev v železniškem prometu. Zato so že Jugoslovanske železnice izdelale interni standard [1], ki govori o obvezni uporabi ultrazvočnega nadzora gredi kolesnih dvojic, ki jih je nekdanje Železniško gospodarstvo Ljubljana še dopolnilo z navodili [2]. Vzdrževanje tirnih vozil je terminsko predpisano glede na periodične nadzorne preglede, kakor tudi na terminski načrt rednih popravil. Pregledi in popravila so zato predpisana po kriteriju obratovalne dobe, omejene s časom obratovanja lokomotive v prometu ali po kriteriju obratovalne dobe s prevoženo potjo.

reliable and cost-effective - are most often used. Inspection of characteristic parts is carried out periodically in accordance with internal standards or regulations; inspections may be both regular and extraordinary; the latter should be carried out after collisions, derailment or the grazing of railway vehicles.

The most heavily stressed parts of railway vehicles are the axles in the wheel and axle sets. Their damage or breakdown would, in fact, entail considerable material losses and endanger human lives. Consequently, the former Yugoslav Railways had already issued an internal standard [1] which specified the compulsory application of ultrasonic testing to the axles in the wheel and axle sets. This standard was amended by the former Railway Administration Ljubljana which issued the relevant instructions [2]. Maintenance of railway vehicles is scheduled in accordance with periodic inspections and regular repairs. Inspections and repairs are prescribed according to the criteria of operational life, limited by the time of operation of a locomotive in traffic or according to the criteria of operational life including the path travelled.

1 IZBIRA NAČINA PREGLEDA GREDI MOTORNIKA

1.1 Splošno o gredeh motornika

Slovenske železnice imajo garnituro motornih vlakov serije 813/814, ki je bila v prvi fazi izdelana v italijanski tovarni FIAT, kasneje pa v sodelovanju z DO TVT "Boris Kidrič" iz Maribora. Vozilo je terjalo uvajanje sistematičnega pregleda posameznih sklopov in/ali delov. Tako so bile že leta 1976 ugotovljene prve razpoke na gredeh kolesnih dvojic z uporabo neporušnih preiskav. Iz spoznanj, da so gredi kolesnih dvojic med najbolj obremenjenimi deli železniških vozil in da lahko njihova porušitev povzroča veliko materialno škodo, so začeli z zelo sistematičnim pregledovanjem. Iz razpoložljivih podatkov o stanju gredi kolesnih dvojic je bilo ugotovljeno, da so številne napake na mestih prehoda iz roba pesta kolesa proti osi gredi. Poškodbe gredi so se pojavljale na notranjih mestih prehoda pesto/gred (kritični mesti KM 1 in KM 3), kar je prikazano na sliki 1.

Poleg tega pa so se pojavile tudi poškodbe na obeh straneh prehoda zobnik-gred (kritični mesti KM 2 in KM 4).

1.2 Analiza poškodb na gredeh motornika

Vrsta poškodb na 152 gredeh po 10-letni obratovalni dobi kolesnih dvojic je naslednja:

- napake na notranjem robu pesto kolesa - gred 75,6 %,
- napake na mestu pesto zobnika - gred 24,4 %.

1 EXPERIMENTAL PROCEDURE OF RAILCAR AXLES

1.1 General on axles of a railcar

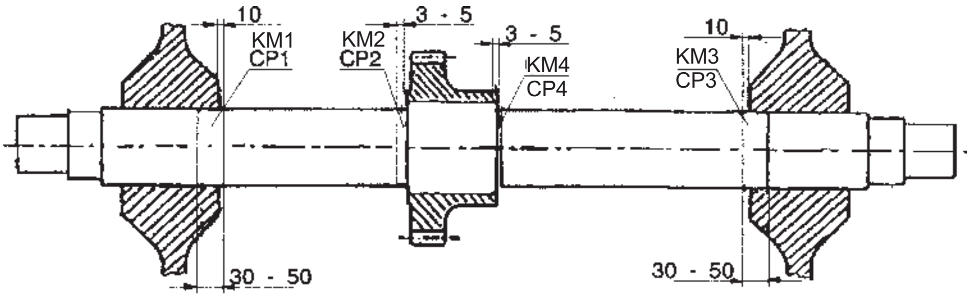
Slovenian Railways have a set of railcars of the series 813/814, which was first manufactured by the Italian firm Fiat, and later in co-operation with DO TVT "Boris Kidrič" from Maribor. The vehicles required the introduction of a systematic inspection of individual assemblies and/or parts. Already in 1976, by means of non-destructive testing the first cracks were found on the axles in the wheel and axle sets. The finding that the axles in the wheel and axle sets belonged to the most heavily stressed parts of railway vehicles led to their systematic inspection. The data available on the state of the axles in the wheel and axle sets indicated that there were numerous defects located at the transition points from wheel hub edge to axle axis. Damages to the axle were found at inner points of the transition from hub to axle (critical points CP 1 and CP 3), as shown in Figure 1.

Damages also appeared on both sides of the transition from gear wheel to axle (critical points CP 2 and CP 4).

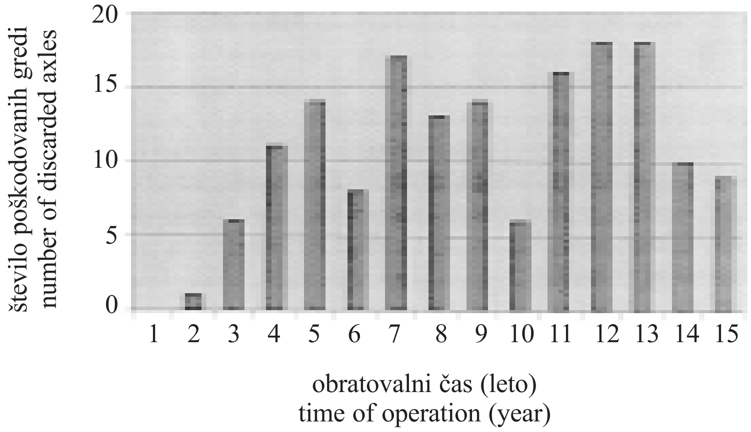
1.2 Analysis of damages to the axles of a railcar

The following kinds of damages have been found on 152 axles after 10 years of service of the wheel and axle sets:

- defects at the inner edge of the transition from wheel hub to axle: 75.6 %,
- defects at the transition from gear wheel to axle: 24.4 %.



Sl. 1. *Pregled kritičnih mest na gredeh gonilnih kolesnih dvojic*
Fig. 1. *Critical points of axles of driving wheel and axle sets*



Sl. 2. *Število izločenih gredi glede na obratovalno dobo*
Fig. 2. *Number of discarded axles with regard to the length of their time of operation*

Poleg relativnega deleža poškodb je treba ugotoviti obratovalno dobo gredi kolesnih dvojic. Izdelovalec gredi kolesnih dvojic zagotavlja nemoteno obratovanje v štiriletnem obdobju. Zato je izredno pomemben podatek o kakovosti gredi tudi prikaz frekvence obratovalne dobe. Na sliki 2 je prikazan histogram o izločenih gredeh iz prometa v odvisnosti od obratovalne dobe. V splošnem lahko ugotovimo, da je povečevanje števila poškodovanih - izločenih gredi v mejah pričakovanja in da so številne gredi zelo kakovostne, saj vzdržijo tudi 2 do 3-kratno predpisano obratovalno dobo. Žal pa lahko ugotovimo, da je treba veliko več pozornosti posvetiti vzrokom, ki so privedli do poškodb - izločitev gredi pred obratovalno dobo štirih let. Predvidevamo, da gre za slabo kakovost materiala, kar pa zahteva tudi izdelavo ustreznih predpisov o kakovosti materiala na vstopu v izdelovalni proces. Zato se pogosto le pri nekaterih izdelovalcih izvajajo preskusi gredi kolesnih dvojic na najneugodnejšo trajno dinamično izmenično obremenitev.

1.3 Izbira postopka preskušanja

Železniški predpis [1] zahteva obvezen pregled kolesnih dvojic v razstavljenem stanju s posebno ultrazvočno glavo z izstopom zvoka pod kotom 37° - AW 37.

In addition to the relevant proportion of damages, the operational life of the axles in the wheel and axle sets also is needs to be established. Consequently, data on axle quality and display of the frequencies of operational life provide very important information. Figure 2 shows a histogram of the discarded axles as a function of the time of operation. Generally, it may be stated that the tendency towards increase in the number of damaged, i.e. discarded, axles is within expectations, and that numerous axles are of high quality since they can last 2 to 3 times the guaranteed operational life. Unfortunately, it has to be stated that much more attention should be paid to causes of damages and discarding of the axles before their operational life of 4 years has elapsed. It is supposed that the material quality is low, which would require elaboration of the relevant regulations on material quality before being released to production; therefore, only some manufacturers perform testing of the axles in the wheel and axle sets with the least favourable cyclic fatigue loading.

1.3 Selection of a testing method

The railway regulation [1] requires a compulsory inspection of the wheel and axle sets in a dismantled state by means of a special ultrasonic probe with the sound exit at an angle of 37°- AW 37.

Za izboljšanje varnosti v železniškem prometu si je služba za defektoskopijo pri Slovenskih železnicah v Ljubljani zadala nalogo, da izboljša zanesljivost preskušanja in zgodnejše napovedovanje napak na gredeh. V ta namen so bila že pred nekaj leti opravljene prve sistematične analize, ki so omogočile izdelavo navodil za ultrazvočni pregled. Omenimo lahko, da je metoda pregleda s čela z normalnimi glavami dokaj nezanesljiva, saj prihaja na prehodih do različnih odbojev in spremembe oblike valovanja. Postavljajo se tri vprašanja:

1. A1i je mogoče odkrivanje napake na vseh kritičnih mestih z ozvočenjem z iste strani gredi?
2. Pri kateri velikosti - globini napake dosežemo pravilno razpoznavanje?
3. Katera izmed normalnih ultrazvočnih glav je primerna za uspešno razpoznavanje napak?

Za preskušanje z ultrazvokom smo izbrali tri gonilne in eno tekalno gred. Na njih smo simulirali različne velikosti napak, izvedenih na umeten način s prečnimi zarezami na valjnem delu gredi. Izbrana mesta z zarezami pomenijo tista značilna mesta, pri katerih se pojavljajo razpoke. Ta mesta smo zato imenovali kritična mesta.

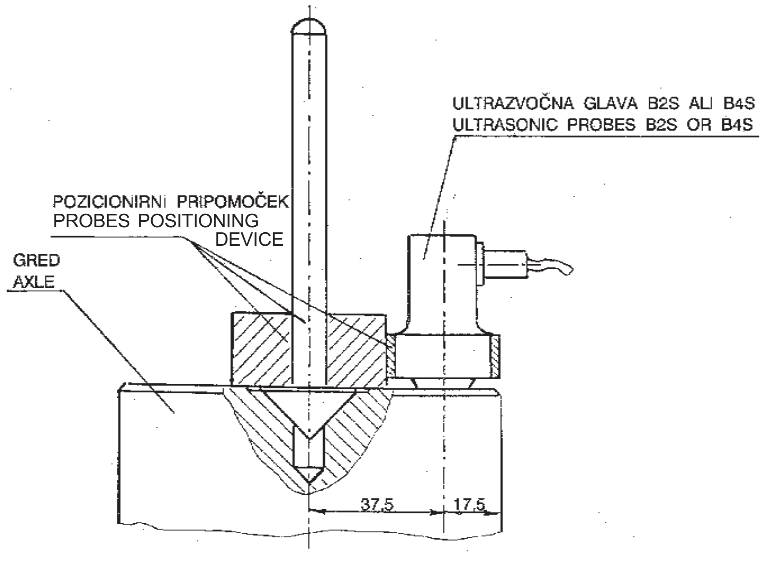
Testiranje smo izvedli z uporabo različnih normalnih ultrazvočnih glav z označbami B2S, MB2S, B4S in MB4S. Identifikacijske postopke smo opravili z obeh čelnih strani posameznih gredi; to je z daljše in krajše strani glede na mesto zobnika, pri čemer je bila nastavitev naprave na 1,5 m in 2,5 m. Za zagotavljanje stalnosti pozicioniranja ultrazvočnih glav na čelni strani gredi smo izdelali ustrezen pripomoček, prirejen za ultrazvočne glave premera 10 mm (sl. 3) in 24 mm (sl.4).

In order to improve safety in railway traffic, the Service for Defectoscopy of Slovenian Railways in Ljubljana has set itself the task of improving the reliability of testing and ensuring earlier detection of defects in the axles. To this end, several years ago, the first systematic analyses were made, which permitted the elaboration of instructions for ultrasonic inspection. It should also be mentioned that the inspection method applied to the front, using normal probes, is rather unreliable since at the transition-points there are various reflections and transformations in the form of wave-motion. Three questions seem to require answers, i.e.:

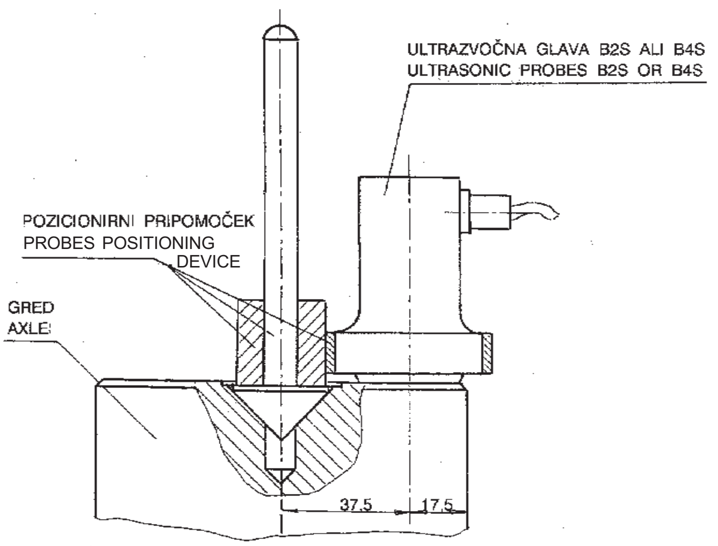
1. Is it possible to detect defects at all critical points by transmission from the same side of the axle?
2. At which size - depth of the defect can appropriate identification be achieved?
3. Which of the normal ultrasonic probes is suitable for efficient identification of defects?

For ultrasonic testing, three driving axles and one running axle were selected. With them three different sizes of artificial defects, which were transverse notches on the cylindrical part of the axles, were simulated. The selected areas with the notches were those characteristic areas where cracks normally appear. These areas were, therefore, called critical areas.

The testing was performed by using different normal ultrasonic probes designated B2S, MB2S, B4S and MB4S. The identification procedure was carried out from both front faces of the individual axles, i.e. from the longer and the shorter face in relation to the gear wheel, while the device used was set at 1.5 and 2.5 m. In order to ensure permanent positioning of the ultrasonic probes at the front face of the axles, a suitable aid was designed and adapted to the ultrasonic probes of 10 mm (Figure 3) and 24 mm (Figure 4) in diameter.



Sl. 3. *Pozicionirna naprava za glavo premera 10 mm*
Fig. 3. *Positioning device for the probe of 10 mm in diameter*



Sl. 4. *Pozicionirna naprava za glavo premera 24 mm*
Fig. 4. *Positioning device for the probe of 24 mm in diameter*

Možnost pregledovanja gredi kolesnih dvojic se je močno skrajšala z nabavo posebne stružnice za obdelavo profila tekalnih koles na gredi motornika. Zato so Slovenske železnice Ljubljana pripravile in sprejele ustrezna navodila za ultrazvočni pregled gredi s čela [2]. Za pregled gredi je treba imeti ustrezne izračune ultrazvočnih poti, ki omogočajo oceniti vse možne signale na zaslonu ultrazvočnega defektoskopa. Vzdolžni val iz normalne ultrazvočne glave se lahko neposredno odbije ali pa se delno odbije po odbojnem zakonu in delno preoblikuje v prečni val pod kotom b_T, ki ima skoraj dvakrat manjšo hitrost. Dobili smo deset tipov zvočnih poti. Dolžine teh zvočnih poti smo izračunali za ozvočenje s krajše strani in daljše strani. Zvočne poti so označene s simboli - velikimi črkami abecede, in sicer tip A, B, C, D, E, F, G, H in K. Za vsak tip zvočnih poti je v prvi vrsti podatek o izračunani zvočni poti, izračunamo pa še število razdelkov na zaslonu naprave, pri katerem se pojavi odboj z umerjanjem naprave na dolžini 1,5 m, oziroma na dolžini 2,5 m ([3] do [6]).

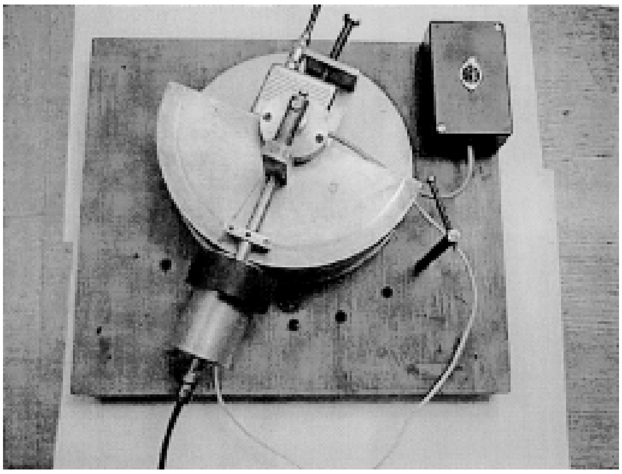
1.4 Pripomoček za merjenje zvočnih pritiskov ultrazvočnih glav

Da bi preverili ustreznost ultrazvočnih glav, smo naredili posebno pripravo - manipulator (sl. 5). Priprava sestoji iz lesenega podstavka, na katerega je vrtljivo nameščena okrogla aluminijasta plošča, ki ima na zgornjem zunanjem robu kotno skalo od 0 do 180°. Na lesenem podstavku je nameščena puščica, ki kaže v osnovni legi 90°. Na to ploščo je pritrjen polkrožni blok premera 100 mm in debeline 43 mm. Na ta blok se v sredino z vijakom pritrdi ultrazvočna glava, ki jo želimo pregledati. Pri tem ne smemo pozabiti na stično sredstvo.

The time required for tests on the axles of the wheel and axle sets was considerably reduced by the purchase of a special lathe for profile treatment of running wheels on the axle of a railcar. Slovenian Railways Ljubljana had, therefore, prepared and adopted relevant instructions for ultrasonic testing of the axles from the front face [2]. For testing of the axles it is necessary to have at one’s disposal appropriate calculations of the sound path, which make it possible to assess all the signals available on the display of an ultrasonic detector. A longitudinal wave from a normal ultrasonic probe may be reflected either directly or partially in accordance with the law of reflection, and may be partially transformed into a transverse wave at an angle b_T, of which the velocity is nearly twice reduced. Ten types of sound paths were obtained. The lengths of these paths were calculated for transmission from both the shorter face and the longer face. The sound paths are designated by symbols, i.e. capitals of the alphabet. So we have types A, B, C, D, E, F, G, H, and K. For each sound-path type, information is available on the calculated sound path in the first line; then, the number of sections on the device display where reflection appears is calculated by calibrating the device at the lengths of 1.5 m and 2.5 m respectively ([3] to [6]).

1.4 Instrument for measurement of the sound pressure of the ultrasonic probes

In order to check the applicability of individual ultrasonic probes a special appliance, i.e. a manipulator, was designed (Figure 5). The appliance consists of a wooden support on which a rotatable round aluminium plate, which has at its upper edge an angle measuring inset circle from 0 to 180°, is mounted. Onto this plate a semicircular block, 100 mm in diameter and 43 mm in thickness, is mounted. In the middle of this block, the ultrasonic probe which is to be controlled is fixed by a screw. The coupling medium should not be forgotten.



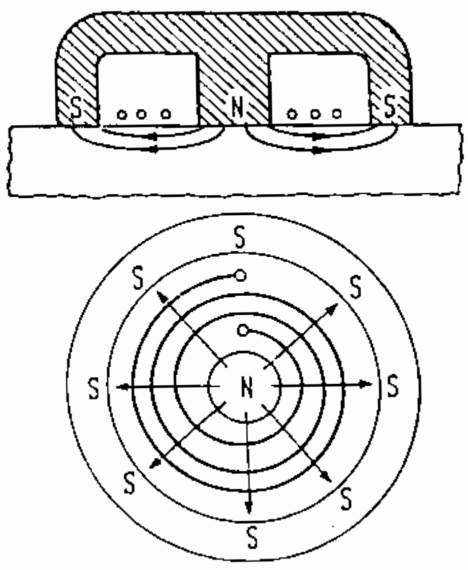
Sl. 5. *Polkrožni aluminijasti blok za merjenje karekteristik ultrazvočnih glav*
Fig. 5. *Semicircular aluminium block for measurement of characteristics of ultrasonic probes*

Na središčni osi je nad polkrožnim blokom nameščena vrtljiva ročica, na katero se nato namesti držalo z elektrodinamično sondo.

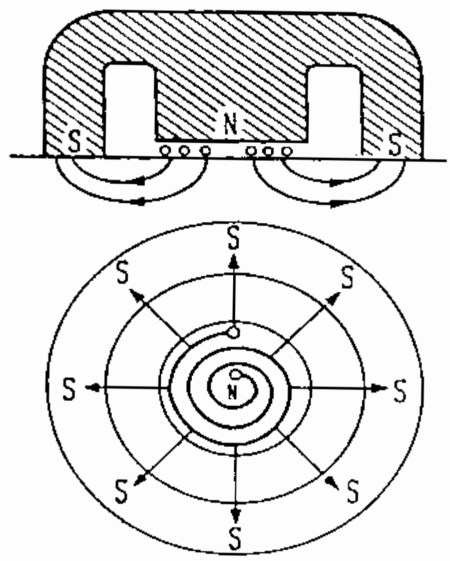
Zaradi zelo nehomogenega barijevega titanata, iz katerega je izdelan oddajnik, nam teoretično izračunane vrednosti za divergenco lahko sliko popačijo. Da bi izmerili dejanske zvočne tlake naših ultrazvočnih glav, smo izdelali elektro-dinamične sonde, s katerimi lahko brez dotika zelo blizu površine merimo zvočne tlake. Za merjenje ultrazvočnih tlakov uporabljamo dva tipa elektrodinamičnih sond, in sicer elektrodinamične sonde za merjenje tlaka vzdolžnega ultrazvočnega valovanja in elektrodinamične sonde za merjenje tlaka prečnega ultrazvočnega valovanja.

There is a rotatable handle in the central axis above the semicircular block on which the holder for the electrodynamic probe is mounted.

Because of the strong inhomogenity of barium titanate, of which the transmitter is made, the theoretical values for divergence may deform the picture. In order to measure the actual sound pressures of our ultrasonic probes, electrodynamic probes were designed; these permit measurement of the sound pressures in close vicinity to the surface. Two types of electrodynamic probes are used for measurement of the sound pressures, i.e. electrodynamic probes for pressure measurement of longitudinal ultrasound wave-motion, and those for pressure measurement of transverse ultrasound wave-motion.



Sl. 6. *Elektrodinamična sonda za merjenje vzdolžnih valovanj*
Fig. 6. *Electrodynamic probe for measurement of longitudinal wave-motions*



Sl. 7. *Elektrodinamična sonda za merjenje prečnih valovanj*
Fig. 7. *Electrodynamic probe for measurement of transverse wave-motions*

Načelo nastajanja in sprejemanja ultrazvočnih valov z elektrodinamično sondo temelji na Lorentzovih zakonih. Na sliki 6 in 7 sta prikazani sondi za merjenje vzdolžne (levo) in prečne (desno) komponente ultrazvočnih valov. Razlika je v načinu navitja. Občutljivost elektrodinamične sonde je približno za 60 dB manjša od piezoelektrične. Njena prednost je v tem, da dela brez dotika in brez stičnega posrednika. Preprosto lahko ločimo vzdolžni od prečnega vala.

1.5 Postopek merjenja in cena izmerjenih karakteristik

V središče odrezane ploskve polkrožnega bloka z vijakom pritrdimo želeno ultrazvočno glavo z naoljeno stično površino. Priklopimo jo na oddajni priključek ultrazvočne naprave. Na gibljivo ročico namestimo držalo z ustrezno elektrodinamično sondo in jo priključimo na koordinatni risalnik ali pa na ultrazvočno napravo kot sprejemnik.

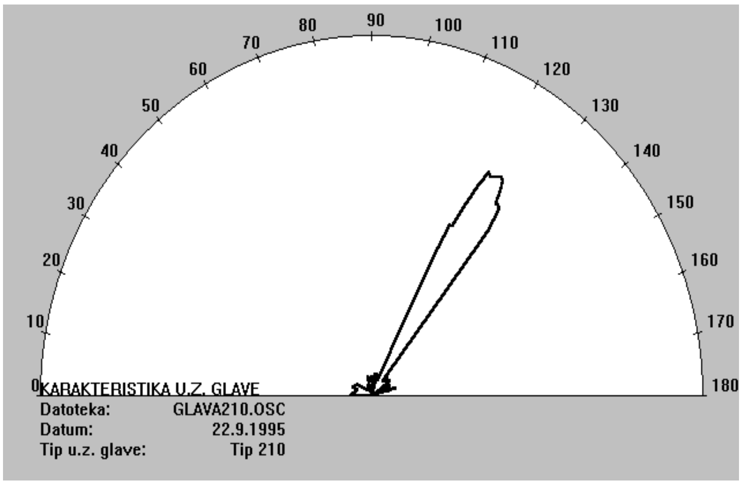
S premikom ročice z elektrodinamično sondo levo-desno iščemo maksimalni zvočni tlak in to že pove, koliko stopinjska je ultrazvočna glava. Ročico nato v tej legi utrdimo. Če imamo na voljo koordinatni risalnik, potem je vezana spodnja plošča s stopinjsko lestvico na linearni potencimeter, ki zarisuje kotne stopinje na abscisni osi. Elektrodinamično sondo priklopimo na ordinatno os in zarisuje zvočni tlak v odvisnosti od kotnih stopinj v polarnem koordinatnem sistemu (sl. 8).

The principle of generation and reception of ultrasonic waves by an electrodynamic probe is based on the Lorentz laws. Figures 6 and 7 show the probes for measurement of longitudinal (left) and transverse (right) components of ultrasonic waves. The difference between them consists in the type of winding. The sensitivity of the electrodynamic probe is approximately 60 dB weaker than that of the piezo-electrical one. Its advantage is that it works without any contact and without a coupling medium. The longitudinal and transverse waves are easy to distinguish.

1.5 Measurement procedure assessment of the characteristics measured

In the centre of the surface cut off from the semicircular block, the required ultrasonic probe, which has on oiled contact surface, is fixed by a screw. It is then connected to the output of the ultrasonic detector. The holder with a suitable electrodynamic probe is mounted on the movable handle, which is then connected to a co-ordinate system plotter or to an ultrasonic apparatus as a receiver.

By moving the handle, the electrodynamic probe searches - to left and right - for the maximum sound pressure. This indicates the degrees characteristic of the probe. The handle is then fixed in this position. If the co-ordinate system plotter is available, then the lower plate with a scale of degrees is connected to a linear potentiometer which plots the angle degrees on the abscissa. The electrodynamic probe is, meanwhile, connected to the ordinate, and plots the sound pressure in a polar co-ordinate system as a function of the angle degrees (Figure 8).



Sl. 8. *Računalniški izris karakteristike ultrazvočne glave*
Fig. 8. *Computer plot of the characteristics of an ultrasonic probe*

Če primerjamo v diagramih normalnih ultrazvočnih glav karakteristike z mejnimi stopinjami izračunane divergence, vidimo, da se v večini primerov pojavlja na meji še vedno blizu 50% največjega zvočnega tlaka. Na trosenje zvočnega tlaka najbolj vplivata premer vibratorja in frekvenca ultrazvočnega valovanja.

If, in the diagrams of normal ultrasonic probes, the characteristics are compared with the limiting degrees of the divergence calculated, it may be noticed that still as much as 50 % of the maximum sound pressure appears at the boundary. The scatter of the sound pressure is most strongly affected by the vibrator diameter and the frequency of sound wave-motion.

2 EKSPERIMENTALNI REZULTATI IN ANALIZA

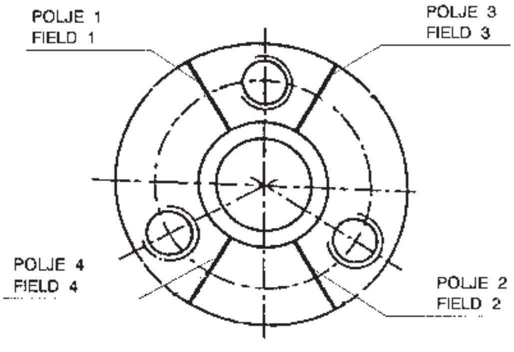
2.1 Priprava in označbe motornih gredi

Za eksperimentalno delo smo uporabili dve motorni gredi kolesnih dvojic. Ker je ob snemanju koles prišlo do deformacije čelnih ploskev gredi, smo na stružnici izvedli njeno poravnavo. Gredi so bile nato nameščene na posebna jeklena stojala. Proste površine so med izvrtinami na čelni ploskvi označili s številkami, in sicer: gredi 1 in 2 imata štiri polja, ki so označena s številkami od 1 do 4. Pri zelo razgibanih oblikah čelne ploskve smo morali zagotoviti enotne razmere preskušanja. Da bi zadostili pogojem, smo morali izdelati ustrezne pripomočke, med katere sodijo tudi pripomočki za pozicioniranje (sl. 9).

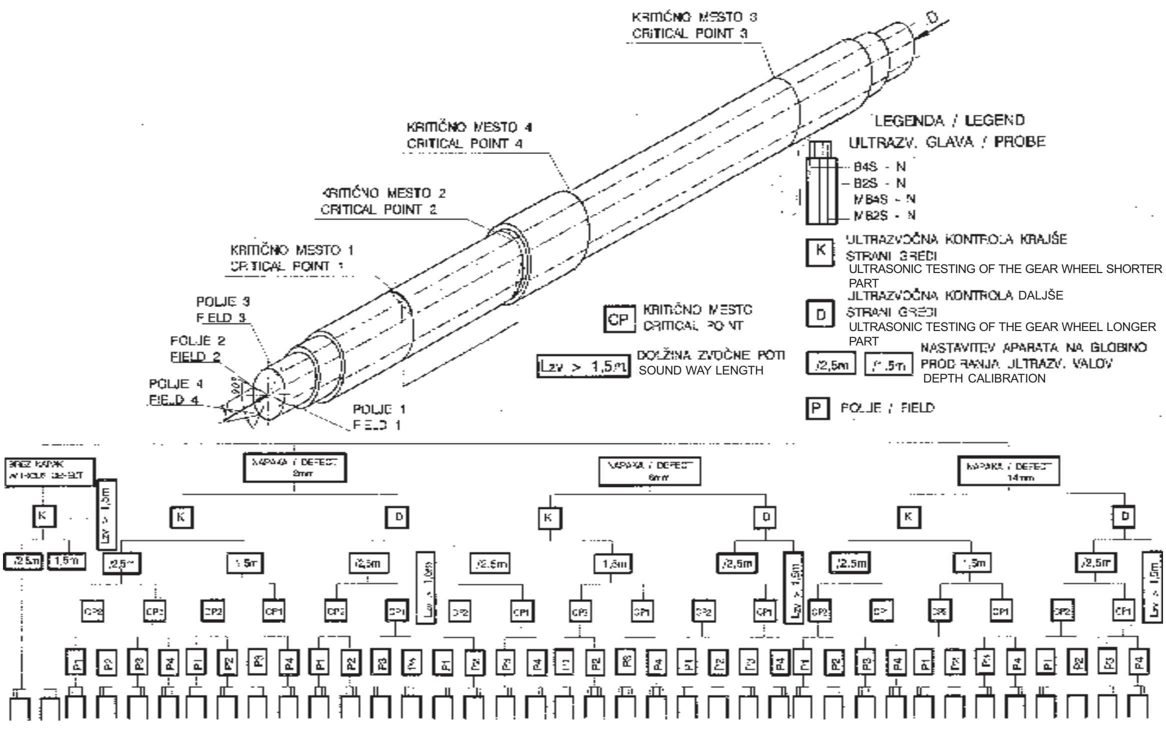
2 EXPERIMENTAL RESULTS AND ANALYSIS

2.1 General on axles of a railcar

For the experimental work two motor axles of the wheel and axle sets were used. However, when the wheels were being removed, deformation of the front faces occurred. The axles were then straightened on a lathe, and placed on special steel stands. The unoccupied surfaces found between the borings at the front face were designated by numbers, as follows: axles 1 and 2 have four fields (marked: 1 to 4). With very agitated shapes of the front face, uniform testing conditions had to be provided. In order to meet these requirements, suitable accessories, including positioning devices, were designed, (Figure 9).



Sl. 9. *Razdelitev prostih površin na polja med izvrtinami na čelni ploskvi gredi*
Fig. 9. *Division of unoccupied surfaces between borings at the front face of the axle into the fields*



Sl. 10. *Shematičen prikaz preskušanja na kritičnih mestih 1 in 2*
Fig. 10. *Schematic representation of tests performed at critical points 1 and 2*

Na posameznih kritičnih mestih, označenih z 1 do 4 smo naredili zareze, ki smo jih med preskušanjem postopno povečevali. Kritično mesto 3 smo preverjali do globin 8 mm z ultrazvočno glavo M82S-N, napako globine 12 mm pa z ultrazvočnimi glavami B4S-N, B2S-N, MB4S-N in MB2S-N. Rezultate smo potem uredili v preglednice.

Na sliki 10 je prikazana shema gonilne gredi kolesne dvojice z označbo št. 1. To gred smo namenili za simuliranje napak na kritičnih mestih 1 in 2; gred, označeno s št. 2 pa smo namenili za simuliranje napak na kritičnih mestih 3 in 4. Strani gredi smo označili z naslednjimi označbami:

- K - pomeni ozvočenje s krajše strani zobnika,
- D - pomeni ozvočenje z daljše strani zobnika.

Čela gredi med izvrtinami smo označili s posameznimi polji. Na posameznih kritičnih mestih (1 do 4) smo zarezali umetne razpoke. Med preskušanjem smo jih postopoma povečevali. Napako na kritičnem mestu 3 smo preskušali na polju 3 in 1, medtem ko je bila napaka na kritičnem mestu 4 preizkušana na polju 2 in 1, kakor je prikazano na sliki.

Razlika je tudi v tem, da nismo simulirali napak na obeh kritičnih mestih hkrati, ampak najprej na kritičnem mestu št. 3 in nato na kritičnem mestu št. 4. Potrebno je bilo stopnjevanje napak po določenem zaporedju glede na kritične točke:

- kritično mesto 3 – napako smo stopnjevali v zaporedju 1, 2, 4, 8 in 12 mm,
- kritično mesto 4 – napako smo stopnjevali v zaporedju 2, 5, in 12 mm.

Zgoraj omenjene kritične točke na gredi 2 smo pregledovali z naslednjimi ultrazvočnimi glavami:

- kritično mesto 3 smo pregledovali do napake globine 8 mm samo z ultrazvočno glavo MB2S-N, napako globine 12 mm pa smo pregledovali z ultrazvočnimi glavami B4S-N, B2S-N, MB4S in MB2S-N;
- kritično mesto 4 smo pregledovali za napake vseh globin z ultrazvočnimi glavami B4S-N, B2S-N, MB4S-N in MB2S-N.

At individual critical points - marked by 1 to 4 - notches were made. These were gradually increased during testing. The critical point 3 was inspected to a depth of 8 mm by the ultrasonic probe M82S-N, and a defect at a depth of 12 mm by the ultrasonic probes B4S-N, B2S-N, MB4S-N and MB2S-N. The results obtained were then arranged in Tables.

Figure 10 schematically shows the testing of a driving axle in the wheel and axle set marked No. 1. This axle was intended for simulation of defects at the critical points 1 and 2; the axle marked No. 2 however, was, intended for simulation of defects at the critical points 3 and 4. The front faces of the axles were then marked as follows:

- K - transmission from the shorter side of the gear wheel,
- D - transmission from the longer side of the gear wheel.

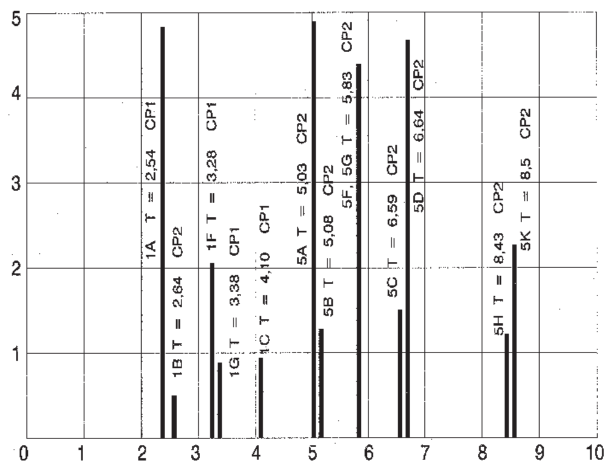
The front axles are marked by the designations of the individual fields. At the individual critical points (1 to 4) notches were made. During testing they were gradually enlarged. The defect at the critical point 3 was tested in fields 3 and 1, while the defect at the critical point 4 was tested in fields 2 and 1 as shown in the figure.

The difference consists in the simulation of the defect which was not performed at both critical points simultaneously, but first at critical point 3 and then at critical point 4. It was also necessary to graduate the defects in a certain succession with regard to the critical points, i.e.:

- critical point 3 - graduation of defect/notch 1, 2, 4, 8 and 12 mm,
- critical point 4 - graduation of the defect/notch 2, 5 and 12 mm.

The above-mentioned critical points of axle 2 were inspected by the following ultrasonic probes:

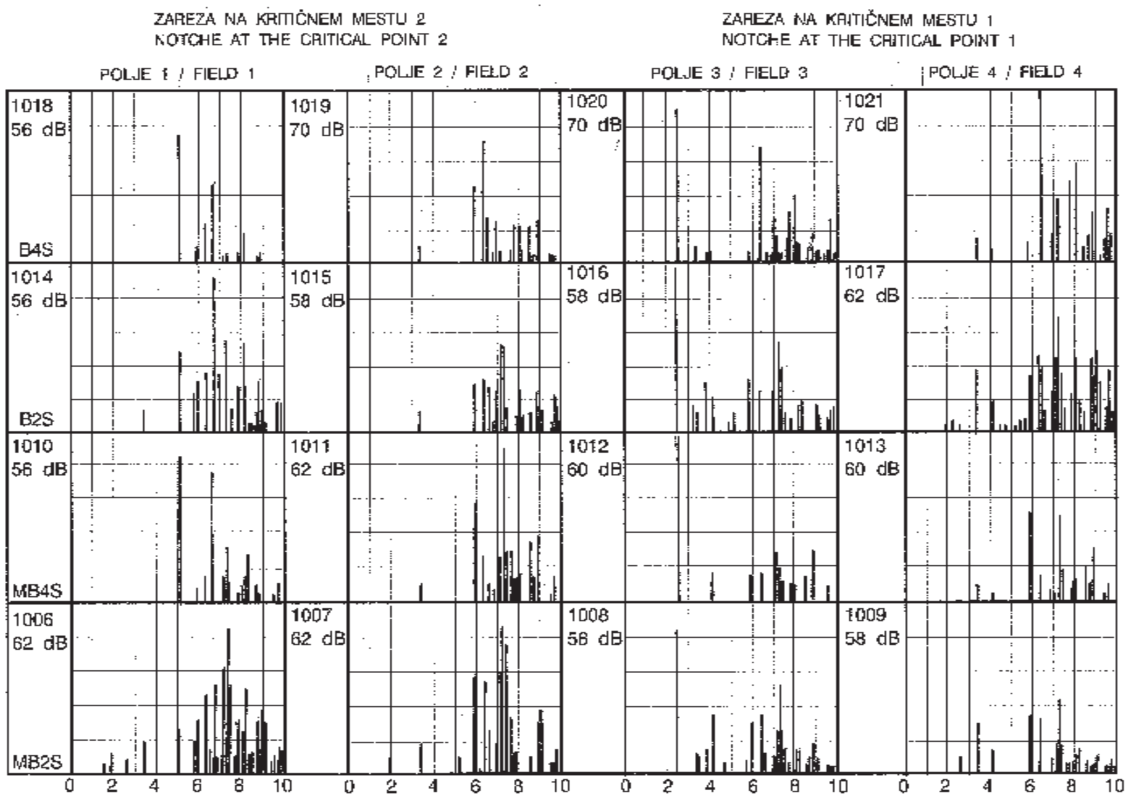
- critical point 3 was inspected to a depth of 8 mm with the ultrasonic probe MB2S-N, while the defect in a depth of 12 mm was inspected with the ultrasonic probes B4S-N, B2S-N, MB4S and MB2S-N;
- critical point 4 was inspected at all the depths selected with the ultrasonic probes B4S-N, B2S-N, MB4S-N and MB2S-N.



Sl. 11. *Ehograf kritičnih točk po preskušanju s krajše strani zobnika*
Fig. 11. *Echograph of critical points after testing the driving axle from the shorter side of the gear wheel*

Slika 11 na prikazuje enega od številnih posnetih ehografov za kritični mesti 1 in 2, ko smo preskušali gred brez napak. Preskušanje smo izvedli s krajše strani zobnika pri umeritvi ultrazvočne naprave na zvočno pot 1,5 m.

Figure 11 shows one of the numerous echographs for the critical points 1 and 2 for the case without any defects. Testing was carried out from the shorter side of the gear wheel after setting the device on the sound path length at 1.5 m.



Sl. 12. *Prikaz slik ultrazvočnih signalov v gredi s krajše strani pri napaki globine 2 mm, na polju 1 in 3 in pri nastavitvi naprave na zvočno pot 1,5 m (na kritičnih točkah 1 in 2)*

Fig. 12. *A case of sound transmission through the axle from the shorter side, at a notch depth of 2 mm, in fields 1 and 3, and with a setting at 1.5 m (selected critical points 1 and 2)*

Slika 12 prikazuje zvočne odboje v gredi s krajše strani namestitve zobnika. Pregled je bil izveden pri napaki z globino 2 mm na kritičnem mestu 1 in 2. Kritična mesta smo preskušali s štirimi že zgoraj omenjenimi ultrazvočnimi glavami še na polju 1 in 3 in z umeritvijo naprave na razdaljo 1,5 m.

Podoben postopek smo lahko opazovali na ehografu pri preskušanju gredi s krajše strani, vendar pri globini napake 6 mm (sl.13). Na podlagi več preskušanj je mogoče najti najustreznejšo metodo in dovolj zanesljivo, da omogoči oceno velikosti napake.

Figure 12 shows a case of sound transmission through the axle from the shorter side. Testing was carried out with notches at a depth of 2 mm at the critical points 1 and 2. The critical point was tested by the four above-mentioned ultrasonic probes in fields 1 and 3, and with a setting at 1.5 m.

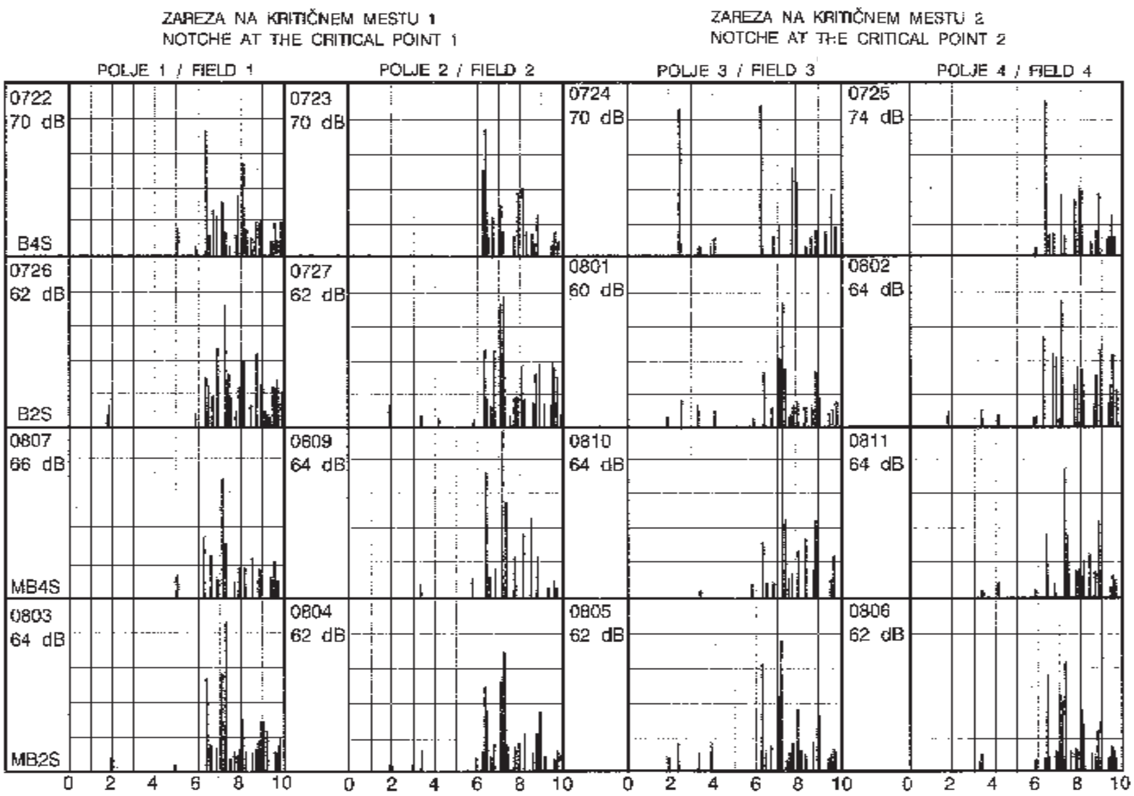
A similar procedure can be observed in the echograph of testing the axle from the shorter side, but with a notch at a depth of 6 mm (Figure 13). On the basis of numerous tests it is possible to find the testing method most suitable for a given point and a given size of defect.

3 SKLEP

V tem članku smo prikazali preskušanje osi kolesnih dvojic v podstavnih vozičkih dizelskih motornih vlakov, kjer smo se z največjo pozornostjo posvetili teoretičnemu pa tudi praktičnemu delu. Na voljo smo imeli izdelane neuporabne gredi kolesnih dvojic, na katerih smo na kritičnih mestih simulirali

3 CONCLUSION

In this paper presented on the testing of axles in the wheel and axle sets of diesel-engined trains, the greatest attention was paid both to the theoretical and to the practical work. Unserviceable axles dismantled were at our disposal for testing. At individual critical points, defects at various depths were simulated. By



Sl. 13. *Prikaz slik ultrazvočnih signalov v gredi s krajše strani pri napaki globine 6 mm, na polju 1 in 3 in pri nastavitvi naprave na zvočno pot 1,5 m (na kritičnih točkah 1 in 2)*

Fig. 13. *A case of sound transmission through the axle from the shorter side, at a notch depth of 6 mm, in fields 1 and 3, and with sa etting at 1.5 m (selected critical points 1 and 2)*

napake različnih globin. Na temelju teh napak smo nato ugotavljali primernost uporabe različnih ultrazvočnih glav. Z vsako od štirih ultrazvočnih glav smo pregledovali napake s krajše in daljše strani zobnika gonilne gredi z različnih polj in pri nastavitvi ultrazvočne naprave na razdaljo 1,5 in 2,5 m. Vsako od teh različic smo posneli za kasnejšo analizo rezultatov. Na koncu preskušanja smo na podlagi izbranih metod izračunali geometrijske oblike znanih tipov ultrazvočnih poti za primerjavo z rezultati, ki smo jih dobili z eksperimentalnim delom.

Iz navedenega lahko povzamemo, da smo dobili pri pregledu gredi s čela dokaj zanesljive rezultate, za to pa je bilo potrebno zelo dolgotrajno in potrpežljivo preskušanje. Za dejansko uporabo predlaganega načina preskušanja gredi bi bilo treba izvesti še dodatne preiskave in morebitne teoretične izračune v primeru, ko imamo nameščene gredi v sklopu.

means of the simulated defects the applicability of individual ultrasonic probes was then established. Thus testing was carried out efficiently with each of the selected four ultrasonic probes at the shorter and the longer sides of the gear wheel of the driving axle from various fields, and with settings of the apparatus at 1.5 and 2.5 m. Each of the selected testing variants was then recorded on film for subsequent analysis of the results. Finally, on the basis of the selected testing methods, the geometries of the known types of sound paths were also calculated for comparison with the results of the experimental work.

It may be stated that reasonably reliable results were obtained in the testing of axles from the front face; to achieve this, however, time-consuming and patient testing was indispensable. For a practical application of the proposed testing method for the axles, additional studies and eventual theoretical calculations should be made when the axles are mounted in the set.

4 LITERATURA
4 REFERENCES

[1] Interni standard JŽS V3.006

[2] Službena obvestila Železniškega gospodarstva Ljubljana (1979) št. 19

[3] Krautkrämer, J., H. Krautkrämer (1983) Ultrasonic Testing of Materials, Third Edition, *Springer Verlag*, Berlin, Heidelberg, New New York

[4] Šipek, M. (1992) Priručnik za ultrazvočne materiale, *Metalbiro*. Zagreb

[5] Jemec, V., J. Poljak (1995) Automation of control the vitalization elements of railway locomotive, *International conference KBR'95 NDT "Inservice Inspection"*, Pula, 67-78

[6] Jemec, V., J. Grum, J. Petrišič, J., idr. (1994) Uporaba neporušnih metod pri preizkušanju podvozij železniških vozil, Raziskovalno-razvojni projekt Ministrstva za znanost in tehnologijo št. B 42-0477-0361, Ljubljana

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Prejeto:
Received: 7.1.1999

Sprejeto:
Accepted: 15.9.1999