IMK-14 – Istraživanje i razvoj u teškoj mašinogradnji 26(2020)4, SR115-121
UDC 621 ISSN 0354-6829
doi: 10.5937/IMK2004115K

Utvrđivanje uzroka nastanka havarije motora SUS na osnovu retrospektivne funkcije dijagnostike

Vojislav Krstić[1], Nikola Krstić[2], Božidar Krstić[3*]
[1]*Fakultet tehničkih nauka u K. Mitrovici,* [2] Elektronski *fakultet u Nišu,*
[3]*Fakultet inženjerskih nauka u Kragujevcu (Srbija)*

Na pogonskom motoru drumskog vozila došlo je do pojave otkaza. Na njemu su, u servisu sprovedeni postupci održavanja. Nakon izrazito kratkog perioda eksploatacije došlo je ponovo do pojave otkaza motora po istom mehanizmu nastanka. U radu je rasvetlljena problematika nastanka neispravnosti na motoru, ustanovljene uzročno-posledične veze i predložiene mere za otklanjanje uzroka pojave otkaza.

Ključne reči: Motor sa unutrašnjim sagorevanjem, Otkaz, Održavanje

1. UVOD

Na četvorocilindričnom dizel motoru (slika 1) proizvodnje IVECO MOTORS, tipa F1CE0481H*C003, sa serijskim brojem 000507131, radne zapremine 2998 cm^3 i snage 130 kW, a koji je ugrađen u vozilu (slika 2) IVECO, modela 65C18DAILY sa identifikacionom oznakom ZCFC65D0005663135, ukupne mase 6500 kg, godine modela 2006 (slika 2), došlo je do pojave otkaza. Usledio je pokušaj otklanjanju tog otkaza. Po završetku svih sprovedenih postupaka održavanja koji su imali za cilj vraćanje motora u ispravno stanje, došlo je vrlo brzo do ponovne pojave otkaza, i to na isti način.

*Slika 1: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003*

Neke od dilema koje su nastale posle ponovnog otkaza motora su: Šta je prouzrokovalo pojavu prvog otkaza motora; Po kom mehanizmu je nastao prvi otkaz; Šta je prouzrokovalo pojavu drugog otkaza motora; Po kom mehanizmu je nastao drugi otkaz; Da li su napravljene greške tokom eksploatacije vozila u koje je bio ugrađen motor; Da li su napravljene greške tokom održavanja vozila u koje je bio ugrađen; Da li su napravljene greške tokom popravke motora posle pojave prve havarije.

U rasvetljavanju predmetne problematike, i davanju odgovora na nastale dileme, autori rada su se aktivno uključili i došli do odgovora koji će biti prezentovani u radu.

Cilj rada je rasvetliti problematiku nastanka neispravnosti na konkretnom motoru, ustanoviti uzročno-posledične veze i predložiti mere za otklanjanje uzroka pojave otkaza.

Slika 2: Vozilo IVECO, modela 65C18DAILY

2. OBJEKAT ISPITIVANJA

Predmet analize je četvorocilindrični dizel motor (slika 1) proizvodnje IVECO MOTORS, tipa F1CE0481H*C003, sa serijskim brojem 000507131, radne zapremine 2998cm^3 i snage 130 kW, a koji je ugrađen u vozilu (slika 2) IVECO, modela 65C18DAILY sa

*Kontakt adresa autora: Sestre Janjić br.6, Kragujevac (Serbia), email:bkrstic@kg.ac.rs

identifikacionom oznakom ZCFC65D0005663135, ukupne mase 6500 kg, godine modela 2006 (slika 2).

3. TEHNIČKO STANJE VOZILA I NJEGOVOG POGONSKOG MOTORA

Na osnovu uvida u stvarno stanje predmetnog vozila i motora, može se zaključiti sledeće:

1. Predmetno teretno vozilo (marke: IVECO, modela: 65C18DAILY, sa VIN kodom - brojem šasije: ZCFC65D000563, i sa kodom-brojem pogonskog motora: PUS82151500192) je u nezadovoljavajućem tehničkom stanju.
2. Postoji velika razlika u broju pređenih kilometara vozila (koji se vidi na "kilometar satu" (367683km) i broja pređenih kilometara vozila prema "dijagnostici" (koji pokazuje centralna procesorska jedinica u vozilu (647513km).

Razlika u kilometraži koju pokazuje centralna procesorska jedinica i kilometar sat je 279830 km.

Dokaz za ovu tvrdnju je slika 3 i dokumentacija o tehničkom stanju delova predmetnog vozila, dobijena posle dijagnosticiranja, u ovlašćenom servisu IVECO.

3.U rashladnom sistemu je, umesto propisane rashladne tečnosti, nalivena obična voda, što je tehnički neprihvatljivo (slika 4).

Korišćenje obične vode umesto rashladnog sredstva, koje je preporučio proizvođač vozila, i koje je obavezno primenjivati tokom eksploatacije vozila, katastrofalno negativno utiče na rad motora:

- Skraćuje njegov vek motora;
- Pogonske i upotrebne karakteristike motora su u tom slučaju izrazito nepovoljne;
- Proces hlađenja motora se odvija nepravilno, što dovodi do pojave većih temperatura, a samim tim i do mogućnosti pojave deformisanja delova motora;
- Stepen korisnosti motora drastično pada, a samim tim i snaga motora i vučna sila vozila;
- Stvara se efekat stvaranja kamenca unutar rashladnog sistema, što može da ima višestruke negativne efekte na rad motora;
- Usled stvaranja kamenca, stvara se efekat smanjenja protočnog prostora u sistemu za hlađenje, što znači i nemogućnost odvođenja toplote, a što povlači sa sobom i povećanje temperatura u radnom prostoru motora i izazivanja pregrejanosti;
- Stvara se efekat intenzivnog negativnog delovanja procesa korozije.

Opšte je poznata činjenica da korišćenje obične vode u sistemu za hlađenje motora dovodi do brojnih problema tokom eksploatacije vozila, odnosno motora.

Jedan od uzročnika, usled koga je došlo do pojave i prve i druge havarije predmetnog motora u vozilu, je korišćenje obične vode umesto propisane rashladne tečnosti.

4. Ne funkcioniše EGR-ventil (slike 5 i 6).

Kod EGR- ventila na predmetnom motoru došlo je do poremećaja u njegovom radu, porvenstveno usled neadekvatnog održavanja, što dovodi do njegovog negativnog delovanja na rad motora. Uzrok je pojava začepljenja, pre svega usled taloženja čestica čađi

EGR ventil služi da u smešu svežeg vazduha i goriva uvede manju, ili veću količinu izduvnih gasova, pomoću kojih se reguliše sagorevanje. Prevelika količina kiseonika stvara topao plamen i brzo sagorevanje smeše.

Slika 3: Pokazivači u komandnoj kabini vozila IVECO, modela 65C18DAILY

Slika 4: Kontrolom vrste i kvaliteta rashladne tečnosti u motoru, došlo se do zaključka da se u njemu nalazi obična voda

Kao reakcija na povećanje temperature u komori za sagorevanje dolazi do neželjene hemijske reakcije između kiseonika i azota iz usisanog vazduha, kojom prilikom se stvaraju otrovni azot-oksidi.

Kao posledica toga, pored povećanog zagađenja životne sredine, usled iteracije sa azotom, samoj smeši u motoru ostaje manje kiseonika za sagorevanje goriva, čime se smanjuje snaga i povećava nivo emisije ugljovodonika.

Suština primene i potrebe za pravilnim funkcionisanjem EGR-ventila je u sledećem: Kada pregrejanoj smeši dodate odgovarajuću količinu sagorelih izduvnih gasova, koji ne sadrže kiseonik, dolazi do snižavanja temperature sagorevanja i dovođenja parametara rada motora u normalu.

Kod dizel motora, EGR-ventil doprinosi da se osetno smanji buka detonacije prilikom rada na praznom hodu.

Kod dizel motora, prilikom njegovog rada na minimumu, EGR-ventil je potpuno otvoren i može da obezbedi i do 50 posto prisustva sagorelih gasova u komori za sagorevanje. Prilikom povećanja snage i obrtaja on se u potpunosti zatvara.

EGR-ventil može da ostane potpuno otvoren, potpuno zatvoren, ili može da ima sporu reakciju.

Ako je zaglavljen u otvorenom položaju, kod dizela će izazvati smanjenje snage i crni dim iz auspuha. Ako je EGR ventil ostao zatvoren, izazvaće pojavu povećane buke.

Najčešći uzroci neispravnosti EGR ventila su: Učestale vožnje na kratkom relacijama; Previsoki nivo ulja

u motoru; Pohabane vođice ventila; Neispravnost u sistemu oduška uljnog korita; Neispravan turbopunjač; Neredovna zamena ulja i filtera; Kontaminacija ulja, što znači korišćenje ulja neodgovarajućeg kvaliteta; Pohaban motor (klipno-cilindrični sklop).

Ako je povratni pritisak u izduvnom sistemu previsok, pri većim opterećenjima kod dizel motora EGR ventil se može sam otvoriti. Zbog toga će izgoreti membrana i EGR ventil će se uništiti. Prepoznatljiv znak ove greške je promena boja ventila (poplavi).

Simptomi nepravilnog rada EGR- ventila su: rad motora na praznom hodu nije pravilan, podrhtavanje motora, nedovoljna snaga, izduvni gasovi ulaze u prostor motora, motor ulazi u "safe" ili "limp" - mod i isključuje turbinu kako se ne bi oštetila turbina ili stradao motor.

Predmetno vozilo, sa motorom bez PDf- filtra i nefunkcionalnim EGR-om, ne ispunjava odgovarajući nivo EURO normi i nebi mogao da zadovolji tzv. EKO - test, pri proveri tehničke ispravnosti vozila na liniji tehničkog pregleda, što znači da sa tog aspekta ne bi moglo da se registruje.

5. Ne funkcioniše - fizički ne postoji DPF-FAP filter (slike 7 i 8).

Predmetni motor proizveden je sa DPF – FAP filtrom i tada je zadovoljavavao EURO 4 norme.

Ovaj motor, u trenutku utvrđivanja njegovog tehničkog stanja, ne zadovoljava EURO 4 norme, već radi na nivou EURO 3 norme, pa čak i nižem nivou, prvenstveno zato što je uklonjen DPF – FAP filter (slike 7 i 8), a EGR ventil je zaprljan i nefunkcionalan (slike 5 i 6).

Pošto na predmetnom motoru ne postoji DPF – FAP filter (znači da motor ne funkcioniše sa PDF-filtrom), dolazi do sledećih negativnih efekata:

- Turbo grupa motora, klipovi, dizne, EGR-ventil, klipni prstenovi i ostali delovi motora se oštećuju jer se stvara velika temperatura i pritisak.
- Veći pad u performansama, ogrničava eksploataciju motora do 3000 o/min.

DPF (ili eng: diesel particulate filter) često se serće pod nazivom FAP ili (fra: filtre à particules) je filter čestica čađi i nalazi se u sastavu izduvnog sistema vozila.

Kod analiziranog predmetnog dizel-motora, u kućištu mora da se nalazi DPF-filter.

Svrha ovog filtera je da smanji štetno dejstvo izduvne emisije vozila, tako što čestice čađi zadržava u sebi kada se vozilo koristi posebno na kratkim relacijama.

DPF - filter se sastoji od keramičkog saća koje je napravljeno od silicijum karbida i metalnog kućišta.

Keramičko saće ima veliki broj paralelno smeštenih kanala koji su naizmenično zatvoreni.

Zidovi filtera od silicijum karbida su porozni i oslojeni nosećom smešom za katalizator od aluminijum oksida i ceroksida.

Preko tog nosećeg sloja, kod originalnih DPF filtra, je nanesen tanak film platine, rodijuma i paldijuma koji služe kao katalizator i za sebe vezuju štetne čestice.

Pošto su kanali filtera naizmenično zatvoreni, a zidovi od silicijum karbida porozni kroz njih prolazi gas dok se čestice čađi i ostalih nečistoća zadržavaju.

Kada na motoru postoji PDF-ventil, ali je u otkazu, javljaju se sledeći efekti:

- Vozilo ulazi u "Safe" ili "Limp" - mod i isključuje turbinu kako se ne bi oštetila turbina ili stradao motor.
- Uključuju se lampice upozorenja na instrument tabli (antipollution system fault).

Reprogramiranjem uptravljačke jedinice motora, i fizičkim uklanjanjem DPF-ventila sa izduvnog sistema, dovodi do oštećenja na turbo punjaču, jer nema DPF-ventila koji mu daje podpritisak. U ovim uslovima rada motora, vozilo znatno uvećava potrošnju goriva na većem broju obrtaja i povećava se količina dima pri povećanju dovoda goriva u motor.

Vozilo, bez DPF - filtera nije više EURO 4 (konkretan motor je proizveden po standardu EURO 4), već je na nivou Euro 3, pa čak i nižem.

Korišćenje vozila sa takvim motorom u Evropskoj Uniji nije dozvoljeno.

6. Brizgač na četvrtom cilindru predmetnog motora je sa izuzetno mnogo naslaga kamenca i korozije (slike 9 i 10).

Pod dejstvom rashladne tečnosti (vode), na pogonskom motoru proizvodnje "IVECO " tipa F1CE0481H*C003, došlo je do pojave velikih naslaga kamenca i korozije na injektoru četvrtog cilindra.

Takođe postoji veliko prisustvo kamenca na injektoru.

To govori da dolazi do prodora tečnosti, koja se koristi za hlađenje motora, do injektora na četvrtom cilindru. To je tehnički nedopustivo.

Pošto je tečnost, koja se koristi za hlađenje motora, dolazila do injektora na četvrtom cilindru (kod tehnički ispravnih motora to se ne može dogoditi), ta ista tečnost je oštećivala i druge delove motora i izazivala njegov nepravilan rad.

7. Stanje klipne grupe (klip-klipni prstenovi-cilindar) je izrazito loše. Prisutne su velike naslage smole, korozije i zapeknuća (slike 11, 12).

To govori da eksploatacija predmetnog vozila, ali i njegovo održavanje, nije sprovođeno na način koji je propisao proizvođač. Klipna grupa motora (klip-klipni prstenovi-cilindar) je u izrazito lošem tehničkom stanju (slike 11, 12), između ostalog, i zbog čestih pregrevanja tokom eksploatacije vozila.

8. Usled korišćenja obične vode, kao sredstva za hlađenje motora došlo je do stvaranja naslaga kamenca u unutrašnjosti glave motora (slike: 13, 14, 15, 16), ali i u celokupnom sistemu za hlađenje predmetnog motora. To je dovelo da su protočni kanali, gde treba da se kreće rashladna tečnost, smanjeni, a samim tim i kapacitet hlađenja (sposobnost odvođenja toplote) smanjen.

*Slika 5: EGR ventil pogonskog motora proizvodnje "IVECO " tipa F1CE0481H*C003 je nefunkcionalan - izrazito zaprljan-pogled 1*

*Slika 6: EGR ventil pogonskog motora proizvodnje "IVECO " tipa F1CE0481H*C003 je nefunkcionalan - izrazito zaprljan-pogled 2*

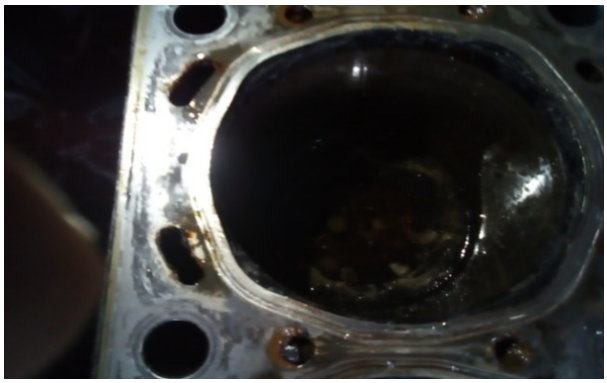
*Slika 7: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - nema PDF ventila-pogled 1*

*Slika 8:Pogonski IVECO motora tipa F1CE0481H*C003 nema PDFventila-pogled 2*

*Slika 9: Izgled brizgača - injektora pogonskog motora proizvodnje "IVECO " tipa F1CE0481H*C003*

*Slika 10: Injektor četvrtog cilindra pogonskog motora "IVECO " tipa F1CE0481H*C003 -*

*Slika 11: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled na kompletan blok motora sa gornje strane, posle demontaže glave motora*



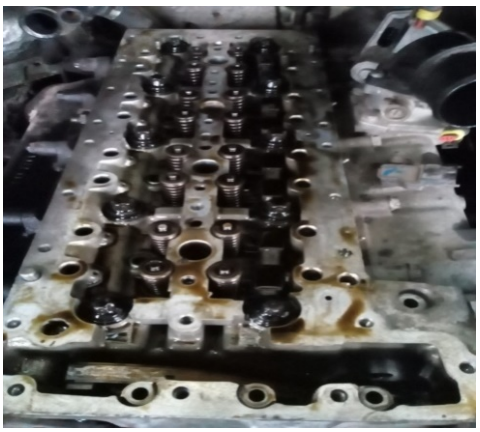
*Slika 12: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled na deo bloka motora - četvrti cilindar i klipa u njemu, posle demontaže glave motora*

Naslage kamenca su izolator, tako da i ta činjenica upućuje na zaključak da oslobođena toplota u radnom prostoru predmetrnog motora nije mogla da se odvodi pravilno, onako kako je to predvideo i realizovao proizvođač predmetrnog motora.

Korišćenjem obične vode, kao sredstva za hlađenje motora, došlo je i do stvaranja naslaga kamenca na brizgaču četvrtog cilindra predmetnog motora.

Korišćenjem obične vode, kao sredstva za hlađenje motora, dovodi do nepravilnosti u radu senzora temperature (tačka ključanja vode je veća od tačke ključanja, propisane od strane proizvođača, rashladne tečnosti, a to znači da senzor ne daje pravu informaciju o stepenu zagrejanosti motora.

To znači da neprekidno dolazi do pregrejanosti motora, a vozač nema pravu informaciju o tome. Ako se ovome doda i nepravilno funkcionisanje EGR-ventila i nepostojanje PDF-ventila, tek onda je sasvim jasno da motor, tokom eksploatacije vozila radi nepravilno (pregrevanje, smanjen stepen iskorišćenja, smanjena snaga, loše ekološke - karakteristike,...). Tehničko stanje predmetnog motora jasno upućuje na zaključak da je ovaj motor konstantno radio sa lošim performansama i upotrebvnim karakteristikama.



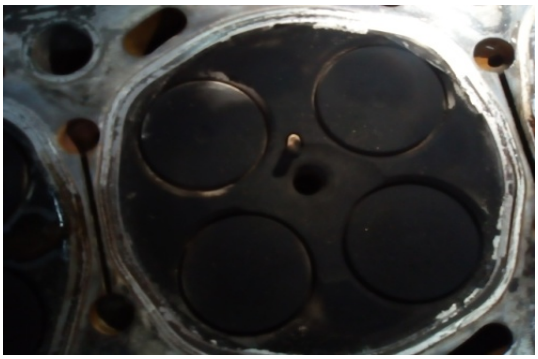
*Slika 13: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled na gornji deo glave motora*

*Slika 14: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled na donji deo glave motora.*

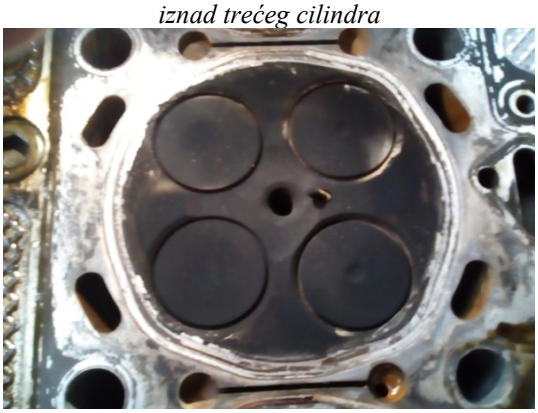
*Slika 15: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled 1 na donji deo glave motora iznad četvrtog cilindra.*

*Slika 16: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled na donji deo glave motora iznad četvrtog cilindra.*

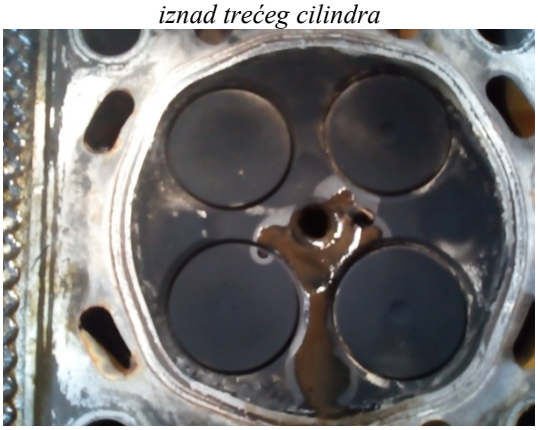
*Slika 17: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled 3 na donji deo glave motora iznad četvrtog cilindra*



*Slika 18: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled na donji deo glave motora iznad trećeg cilindra*

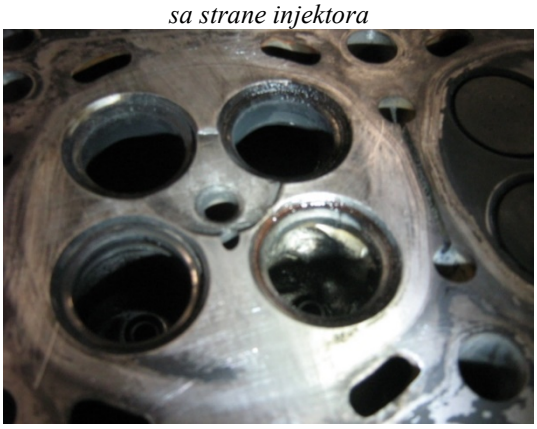


*Slika 19: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled 2 na donji deo glave motora iznad trećeg cilindra*



*Slika 20. Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled 2 na donji deo glave motora iznad drugog cilindra*

*Slika 21: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled 3 na donji deo glave motora (iznad četvrtog cilindra) gde je došlo do pojave pukotine sa strane injektora*



*Slika 22: Pogonski motor proizvodnje "IVECO " tipa F1CE0481H*C003 - Pogled 2 na donji deo glave motora (iznad četvrtog cilindra) gde je došlo do pojave pukotine sa strane injektora. Na slici je pogled na zavareni deo sa strane ventila.*

9. Zavarena glava motora na četvrtom cilindru sa strane ventila (slike 21,22), gde je glava predmetnog motora imala pukotinu sa strane injektora.
10. Na zaključak da motor nije radio u tehnički ispravnom stanju upućuju sledeće činjenice:

- Stanje klipne grupe predmetnog motora (slike 11,12);
- Stanje brizgača motora (slike: 9,10);
- Stanje EGR-ventila (slike: 5,6);
- Nepostojanje DPF-ventila (slike: 7,8);
- Kvalitet sredstva za hlađenje (slike: 3,4);
- Stanje zaptivanja između glave i bloka motora, kao i stanje ventila (slike: 13,15,16,17,18,19,20).
- Na motoru, u tako lošem tehničkom stanju, u svakom trenutku mogu da se pojave havarije po različitim osnovama.

3. ZAKLJUČAK

Do pojave havarije na vozilu, nakon što ga je popravio tuženi, došlo je zato što su kompletno vozilo, kao i predmetni motor, sveobuhvatno gledano, bili u izrazito lošem tehničkom stanju, te nisu mogli da se otklone svi potencijalni uzroci koji bi mogli da dovedu do nove havarije motora.

Serviseri su, i posle nastanka prve, i posle nastanka druge havarije motora, sproveli adekvatne postupke održavanja, a u skladu sa standardima za nastale havarije.

U radnom nalogu se definšu elementi koji su predmet rada servisa. Vlasnik vozila mogao je da stavi primedbe na te elemente i da zahteva da se u radnom nalogu ubace i drugi elementi koji bi bili predmet rada ovog servisa. Sve ono, što je upisano u radnim nalozima oba servisa, servisi su profesionalno i stručno odradili.

Na osnovu detaljne analize celokupne dokumentacije koja je dostavljena do pred početak utvrdjivanja tehničkog stanja, detaljnom analizom rezultata dijagnosticiranja predmetnog vozila i motora pre rastavljanja predmetnog motora, a potom i detaljnom analizom svih delova tokom demontaže predmetnog motora, može se zaključiti da predmetni motor nije imao inicijalnu naprslinu takve veličine da se mogla identifikovati bilo kojom metodom koja se primenjuje pri realizaciji tzv. hidrotesta glave motora (utvrđivanje postojanja naprslina u glavi motora).

Da je postojala naprslina glave predmetnog motora, bilo bi jako teško izvršiti startovanje-pokretanja ovog motora posle prvog servisiranja.

Ukoliko bi do pokretanja motora, posle prvog servisiranja, i uopšte došlo (uz veliki napor i jako nepovoljno manifestovanje u radu motora), sa takvim motorom ne bi bilo moguće preći kilometražu od 201km, posle koje je došlo do ponovne (druge) havarije predmetnog motora.

Predmetni motor je u jako lošem tehničkom stanju i pojava druge havarije je nastala usled njegove dotrajalosti, neadekvatne njegove eksploatacije i neadekvatnog održavanja.

Neki od uzročnika, usled koga je došlo do pojave i prve i druge havarije predmetnog motora u vozilu su:

- Korišćenje obične vode umesto propisane rashladne tečnosti. Voda je korišćena i pre pojave prve havarije koja je dovela do brojnih nepravilnosti u radu motora. Nalivanje propisane rashladne tečnosti posle otklanjanja prve havarije u sistem za hlađenje doprinelo je da se intenzivira proces razlaganja kamenca u protočnim kanalima sistema za hlđenje, a samim tim i u unutrašnjosti glave motora, što je intenziviralo pojavu inicijalne naprsline koja je najverovatnije postojala sa strane injektora u četvrtom cilindru, ali se nije mogla otkriti tzv. hidrotestom jer je bila, ne samo nepotpuna, već je najverovatnije bila prekrivena kamencem od vode. Pošto je voda, pre pojave prve havarije nalivana prema nahođenju vozača, a motor je stalno bio izrazito nepovoljno termički opterećen, ta voda je i doprinela pojavi inicijalne naprsline.
- Ne funkcioniše - fizički ne postoji DPF - FAP filter (slike 11,12), što takođe dovodi, između ostalog i do pregrevanja motora, ali i do niza drugih nepravilnosti u radu motora o kojima je bilo reči u prethodnom tekstu ovog rada.
- EGR - ventil je zaprljan i nefunkcionalan i on ne samo da ne obavlja propisanu funkciju, nego u velikoj meri uzrokuje nepravilan rad motora, između ostalog, doprinosi i pojavi pregrejanosti motora.

Na motoru svakoga trenutka, zbog njegovog izrazito lošeg tehničkog stanja, mogu da nastanu havarije po različitim osnovama, zbog neprekidnog pregrevanja motora, a koje nastaje prvenstveno zbog nefunkcionalnosti EGR-ventila, nepostojanja DPF-ventila, zbog upotrebe vode kao sredstva za hlađenje, zbog dotrajalosti njegovih delova, ...

Kao dokaz ovoj tvrdnji mogu da posluže sledeće činjenice:

Vozilo, u kome je ugrađen predmetni motor, je u izuzetno lošem tehničkom stanju, i ne ispunjava ni uslove za registraciju po pitanju zadovoljenja postojećih propisa po pitanju izduvne emisije (iako je ugrađeni motor proizveden da zadovoljava EURO 4 norme, on zbog nefunkcionalnosti EGR-a i nepostojanja DPF-ventila, ali i uopšte lošeg celokupnog tehničkog stanja), ne zadovoljava ni EURO 3 norme i kao takav sigurno ne bi zadovoljio EKO - test koji je obavezan na tehničkom pregledu, što znači i da se vozilo sa njim ne bi moglo da registruje.

Problematika potpunog ispravnog funkcionisanja i rada predmetnog motora nije rešena, a nije ni mogla u potpuniosti biti rešena, niti u prvom servisu, niti u drugom servisu, prvenstveno zato što se radi o motoru, ali i vozilu u celini, koje je prošlo ogroman broj pređenih kilometara (647513km), a da pri tome nije pravilno eksploatisano i održavano i zato što se nalazi u izrazito lošem tehničkom stanju.

U prilog ovoj tvrdnji su i sledeće činjenice:

- Serviser, nije utisnuo svoj žig na glavi motora nad kojom je sprovodio određene postupke održavanja (zavarivanja, ravnanja), a samim tim nije dao i garanciju da je ta glava u potpunosti ispravna i da neće otkazati u narednom periodu po nekom osnovu. Ovaj servis je tako postupio imajući u vidu tehničko stanje glave predmetnog motora.
- Posle otklanjanja druge havarije u drugom servisu, došlo je u vrlo kratkom vremenskom periodu (posle petnaest dana) do otkaza senzora broja obrtaja radilice. Taj senzor je sigurno funkcionisao posle otklanjanja druge havarije na motoru u ovom servisu. Da nije funkcionisao, predmetni motor ne bi mogao da se pokrene. Ovo upućuje na zaključak da i ovaj servis nije dao garanciju (a nije ni mogao dati jer je tehničko stanje predmetnog motora neprihvatljivo) da neće doći do otkaza predmetnog motora po nekom osnovu.
- Posle otklanjanja druge havarije u servisu nisu rešena sledeća pitanja (jer je vozilo došlo u servis samo zbog otklanjanja nastale havarije, što je definisano i radnim nalogom na koji tužilac nije imao primedbe): Nepostojanja PDF-ventila (slike 7,8); Nefunkcionalnost EGR-ventila koji ne samo da ne funkcioniše već remeti rad motora (slike 5,6); Ogromne naslage kamenca i korozije na injektoru četvrtog cilindra zbog prodora sredstva za hlađenje (slika 4);
- Neprihvatljivo tehničko stanje klipne grupe (slike11,12,14); Pojava neprekidnog pregrevanja motora koja nastaje ne samo zbog nepostojanja DPF-ventila (slike 7,8) i nefunkcionalnosti EGR-ventila (slike 5,6), već i zbog upotrebe vode kao rashladnog sredstva (slika 4), a za šta je odgovoran vlasnik vozila; Pojave smanjenja stepena kompresije usled "probijanja" na zaptivaču glave i bloka motora iznad četvrtog cilindra (slika 52), što znači da motor, ne samo da je pre pojave prve i druge havarije radio u izrazito nepovoljnim eksploatacionim uslovima, i da je bio termički izrazito nepovoljno opterećen, već i dalje radi u izrazito nepovoljnim eksploatacionim uslovima, i da je i dalje izrazito nepovoljno termički opterećen, što može dovesti do pojave otkaza motora u narednom periodu.

ZAHVALNOST

Istraživanja prikazana u ovom radu podržalo je Ministarstvo nauke Republike Srbije, u okviru projekta TR 35041.

LITERATURA

[1] Krstić, B. (2009), Tehnical serviceability of motor vehicles and engines, University of Mechanical Engineering, Kragujevac (In Serbian)

[2] Krstić, B., et al (2009), Determination of the optimal strategy for preventive maintenance the motor engine using polycriterion optimization, Tractors and power machines, Vol.14, No. 2/3, p.91-98

[3] Krstić, B. (2002), Possibilities of management for vehicle performability in purpose to satisfy exploitation-tehnical characteristics, Tractors and power machines, Vol.7, No. 4, p.95-103

[4] B. Krstić, V. Lazić, V. Krstić (2010),: Some views of future strategies of maintenance of motor vehicles, Tractors and power machines, Vol.15, No.1, p.42-47

[5] B. Krstić, V. Lazić, R. Nikolić, V. Raičević, I. Krstić, V. Krstić (2009),: "Optimal strategy for preventive maintenance of the motor vehicles clutch", Journal of the balkan tribologikal association", Vol.15, No 4, 611-619

[6] Krstić N., Krstić S., Krstić V., Krstić B. (2020),, Availability and reliability of mecatronic systems of motor vehicles, IMCSM 2020 Procedings, ISSN 2620-0597, Volume XVI, Issuise 2, p.121-129, Bor

IMK-14 – Research & Development in Heavy Machinery 26(2020)4, EN115-121
UDC 621 ISSN 0354-6829
doi: 10.5937/IMK2004115K

Determining the Cause of Engine Failure Based on the Retrospective Diagnostic Function

Vojislav Krstić[1], Nikola Krstić[2], Božidar Krstić[3*]
[1]Faculty of Technical Sciences in K. Mitrovica, [2]Faculty of Electronics in Niš, [3]Faculty of Engineering of Kragujevac

The was a failure on the drive engine of the road vehicle. On it, maintenance procedures were carried out in the service. After an extremely short period of operation, engine failure by the same mechanism of occurrence occurred again. The paper sheds light on the problem of engine malfunctions, establishes cause-and-effect relationships and proposes measures to eliminate the causes of failure.

Keywords: Internal combustion engine, Failure, Maintenance

1. INTRODUCTION

On a four-cylinder diesel engine (Fig.1) manufactured by IVECO, type F1CE0481H*C003, with serial number 000507131, displacement 2998 cm^3 and power 130 kW, installed in the vehicle (Fig.2) IVECO, model 65C18DAILI with identification number 000Z66316500 kg, model year 2006 (Fig.2), there was a failure. An attempt was made to eliminate that dismissal. After the completion of all maintenance procedures aimed at restoring the engine to proper condition, the failure occurred very quickly, and in the same way.

*Figure 1: Motor engine manufactured by IVECO type F1CE0481H*C003*

Some of the dilemmas that arose after the engine failure again were: What caused the firest engine failure to occur; By what mechansm did the first dismissal occur; What caused the first engine failure to occur; By what mechanism did the first dismissal occur; What is it caused a second engine failure; By what mechanism did the second dismissal occur; Were any mistakes made during the operation of the vehicle in which the engine was installed; Were any mistakes made during the maintenance of the vehicle in which it was installed; Were any mistakes made during the repairof the engine after the first accident. In clarifying the subject matter, and giving answers to the dilemmas that arose, the authors of the paper were actively involved and came up with answers that will be presented in the paper.

The aim of this paper is to shed light on the problem of malfunctions on a specific engine, to establisch cause - and - efect relationships and to propose measures for eliminating the causes of failures.

Figure 2: Vehicle IVECO 65C18DAILY

2. TEST OBJECT

The subject of the analysis is a four - cylinder diesel engine (Fig.1) manufactured by IVECO, type

*Corresponding author: Sestre Janjić br.6, Kragujevac (Serbia), email:bkrstic@kg.ac.rs

F1CE0481H*C003, with serial number 000507131, displacement 2998 cm^3 and power 130 kW, installed in the vehice (Fig.2) IVECO, model 65C18DAILI with identification number 000Z66316500 kg, model year 2006 (Fig.2).

3. TEHNICAL CONDITION OF THE VEHICLE AND ITS PROPULSION ENGINE

Based on the insight into the actual condition of the vehicle and engine in question, the following can be concluded:

1. The truck in question (brands: IVECO, model: 65C18DAILY, with VIN code - chassis number: ZCFC65D000563, and with drive engine code number: PUS82151500192) is in unsatisfactory technical condition.
2. There is a big difference in the number of kilometres travelled by the vehicle (which is seen on the "hour kilometre" 367683km and the number of kilometres travelled by the vehicle according to the "diagnostics" (shown by the central processing unit in the vehicle (647513km).The difference in mileage shown by the CPU and the mileage is 279830 km. Evidence for this claim is Figure 3 and documentation on the technical condition of the parts of the vehicle in question, obtained after diagnosis, at an authorized IVECO service centre.
3. In the cooling system, instead of the prescribed coolant, ordinary water is poured, which is technically unacceptable (Figure 4). The use of ordinary water instead of coolant, which is recommended by the vehicle manufacturer, and which must be used during the operation of the vehicle, has a catastrophic negative effect on engine performance:

- Shortens its engine life;
- In this case, the drive and operating characteristics of the engine are extremely unfavourable;
- The process of engine cooling takes place irregularly, which leads to the appearance of higher temperatures, and thus to the possibility of deformation of engine parts;
- The degree of usefulness of the engine drops drastically, and thus the engine power and traction of the vehicle;
- A calculus effect is created inside the cooling system, which can have multiple negative effects on engine operation;
- Due to the formation of lime scale, the effect of reducing the flow space in the cooling system is created, which means the impossibility of heat dissipation, which entails an increase in temperatures in the working space of the engine and causing overheating;
- The effect of intense negative action of the corrosion process is created.

It is a well-known fact that the use of ordinary water in the engine cooling system leads to numerous problems during the operation of the vehicle or engine. One of the causes, due to the occurrence of the first and second breakdowns of the engine in question in the vehicle, is the use of ordinary water instead of the prescribed coolant.

4. The EGR valve does not work (Figures 5 and 6). In the case of the EGR valve on the motor in question, there was a disturbance in its operation, primarily due to inadequate maintenance, which leads to its negative effect on the operation of the motor. The cause is the appearance of clogging, primarily due to the deposition of soot particles. EGR valves are used to regulate the combustion of the mixture, in order to increase economy and reduce the amount of nitrogen oxides and hydrocarbons.

Figure 3: Indicators in the vehicle control cabin IVECO, 65C18DAILY

Figure 4: By controlling the type and quality of the coolant in the engine, it was concluded that there is ordinary water in it

The EGR valve serves to introduce a smaller or larger amount of exhaust gases into the mixture of fresh air and fuel, which is used to regulate combustion. Too much oxygen creates a warm flame and a fast-burning mixture.

As a reaction to the increase in temperature in the combustion chamber, an unwanted chemical reaction occurs between oxygen and nitrogen from the intake air, during which toxic nitrogen oxides are formed.

As a result, in addition to increased environmental pollution, due to the iteration with nitrogen, the mixture itself in the engine remains less oxygen to burn fuel, which reduces power and increases the level of hydrocarbon emissions.

The essence of the application and the need for proper functioning of the EGR valve is as follows: When you add the appropriate amount of burnt exhaust gases to the overheated mixture, which do not contain oxygen, the combustion temperature is lowered and the engine operating parameters are brought back to normal.

In diesel engines, the EGR valve helps to significantly reduce detonation noise when idling. With a diesel engine, when it is running at a minimum, the EGR valve is fully open and can provide up to 50 percent of the

presence of combustion gases in the combustion chamber. As the power and speed increase, it closes completely.

The EGR valve may remain fully open, fully closed, or may have a slow response. If stuck in the open position, diesel will cause a reduction in power and black smoke from the exhaust. If the EGR valve remains closed, it will cause increased noise.

The most common causes of EGR valve malfunctions are: Frequent short-distance driving; Engine oil level too high; Worn valve guides; Malfunction in the oil sump vent system; Defective turbocharger; Oil contamination, which means the use no oil of inadequate quality; Worn engine (piston-cylinder assembly).

If the return pressure in the exhaust system is too high, the EGR valve can open on its own at higher loads on diesel engines. As a result, the diaphragm will burn and the EGR valve will be destroyed.

A recognizable sign of this error is a change in the colour of the valve (flood).

Symptoms of EGR valve malfunction are: engine idling, engine shake, insufficient power, exhaust gases enter the engine compartment, the engine enters "safe" or "limp" mode and shuts off the turbine to avoid damaging the turbine to avoid damaging the turbine or a damaged engine.

The vehicle in question, with an engine without a PDF filter and a non-functional EGR, does not meet the appropriate level of Euro norms and could not meet the so-called ECO-test, when checking the technical correctness of the vehicle on the line of technical inspection, which means that from that aspect it would not be possible to register.

5. Does not work-there is no physical DPF-FAP filter (Figures 7 and 8). The engine in question was manufactured with a DPF-FAP filter and then met Euro 4 standards. This engine, at the time of determining its technical condition, does not meet the Euro 4 norm, but works at the level of the Euro 3 norm, and even lower, primarily because the DPF-FAP filter has been removed (Figures 7 and 8), and the EGR valve is dirty and non-functional (Figures 5 and 6). Science there is no DPF-FAP filter on the subject motor (means that the motor does not work with the PDF filter), the following negative effects occur:

- Turbo engine group, pistons, nozzles, EGR valve, piston rings and other engine parts are damaged because high temperature and pressure are created.
- Larger drop in performance, limits engine operation to 3000 rpm.

DPF is often referred to as FAP or is a soot particle filter and is part of the vehicle's exhaust system.

In the case of the diesel engine in question, a DPF filter must be present in the housing.

The purpose of this filter is to reduce the harmful effects of vehicle exhaust emissions by retaining soot particles when the vehicle is used, especially on short distances. The DPF filter consists of a ceramic honeycomb made of silicon carbide and a metal housing. The ceramic honeycomb has a large number of parallel channels that are alternately closed.

The walls of the silicon carbide filter are porous and coated with a carrier mixture for the alumina and peroxide catalyst.

A thin film of platinum, rhodium and palladium is applied over this carrier layer, in the case of the original DPF filters, which serve as a catalyst and bind harmful particles to themselves.

Because the filter channels are ultimately closed and the silicon carbide walls are porous, gas passes through them while soot particles and other impurities are retained. When there is a PDF valve on the engine but it fails, the following effect occur:

- The vehicle enters "Safe" or "Lamp" mode and shuts off the turbine so as not to damage the turbine or damage the engine;
- The warning lights on the instrument panel (antipollution system fault) come on.

By reprograming the engine control units, and physically removing the DPF valve with the exhaust system, the turbocharger is damaged because there is no DPF valve with the exhaust system, the turbocharger is damaged because there is no DPF valve that gives it under pressure. Under these engine operating conditions, the vehicle significantly increases fuel consumption at higher revs and increases fuel consumption at higher revs and increases the amount of smoke as the fuel supply to the engine increases.

The vehicle, without the DPF filter, is no longer Euro 4, but is at the level of Euro 3, and even lower.

The use vehicles with such an engine is not permitted in the European Union.

6. The injector on the fourth cylinder of the subject engine has an extremely large amount of scale and corrosion (Figure 9 and 10). Under the action of the coolant (water), on the propulsion engine produced by Iveco F1CE0481H C03, large deposits of lime scale and corrosion appeared on the injector of the fourth cylinder. There is also a large presence of scale on the injector. This indicates that there is a penetration of the liquid, which is used to cool the engine, to the injector on the fourth cylinder. That is technically unacceptable. Since the fluid used to cool the engine reached the injector on the fourth cylinder (this cannot happen with technically correct engines), that same fluid damaged other parts of the engine and caused it to malfunction.

7. The condition of the piston group (piston-piston rings-cylinder) is extremely poor. Large deposits of resin, corrosion and scorching are present (Figure 11,12). This shows that exploitation of the vehicle in question, but also its maintenance, was not carried out in the manner prescribed by the manufacturer. The piston group of the engine (piston-piston rings-cylinder) is in extremely poor technical condition (Figures 11,12), among other things, due to frequent overheating during vehicle operation.

8. Due to the use of ordinary water as a means of cooling the engine, lime scale builds up inside the cylinder head (Figures: 13,14,15,16), but also in the entire cooling system of the engine in question. This has led to reduced flow channels, where the coolant is to move, and thus the cooling capacity (heat dissipation capacity) is reduced.

Figure 5: EGR valve of engine IVECO F1CE0481HC003 is non-functional - extremely dirty-view 1

Figure 6: EGR valve of engine F1CE0481HC003 is non-functional - extremely dirty-view 2

Figure 7: Motor engine- does not have PDF valve-view 1

Figure 8: Motor engine - does not have PDF valve-view 2

Figure 9: Engine injectors of engine IVECO F1CE0481HC003

Figure 10: Fourth cylinder engine injectors of engine IVECO F1CE0481HC003

Figure 11: Motor engine IVECO F1CE0481HC003 - view of the complete engine block from top, after disassembling the cylinder head

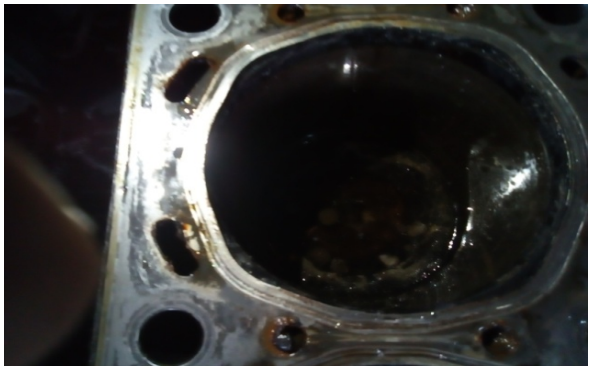


Figure 12: Fourth cylinder engine -view of the engine block part - the fourth cylinder and the piston in it, after dismantling the engine head

Lime scale deposits are an insulator, so that this fact points to the conclusion that the heat released in the working space of the subject engine cold not be removed properly, as predicted and realized by the manufacturer of the subject engine. By using ordinary water as a means of cooling the engine, limescale builds up on the injector of the fourth cylinder of the engine in question.

Using ordinary water as a means of cooling the engine leads to a malfunction of the temperature sensor (the boling point of water is higher than the boiling point prescribed by the manufacturer, the coolant, which means that the sensor does not give true information about the degre of engine heat.

This means that the engine is constanty overheating and the driver does not have the right information, if this is added to the malfunction of the EGR valve and the absence of a PDF valve, it is only clear that the engine is malfunctioning during vehicle operation (overheating, reduced efficiency, reduced power, poor enviromental-characteristics,...).

The technical condition of the engine in question clearly indicates the conclusion that this engine was constantly working with poor performance and performance characteristics.

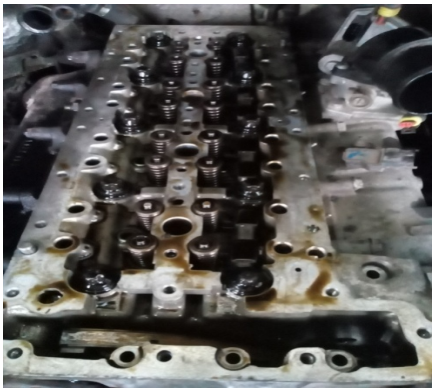


Figure 13: Motor engine IVECO F1CE0481HC003-view of the upper part of the cylinder head

Figure 14: Motor engine IVECO F1CE0481HC003- view of the lower part of the cylinder head

Figure 15: Motor engine IVECO F1CE0481HC003- view 1 of the lower part of the cylinder head above the fourth cylinder.

Figure 16: Motor engine IVECO F1CE0481HC003- View of the lower part of the cylinder head above the fourth cylinder.

Figure 17: Motor engine IVECO F1CE0481HC003- View 3 of the lower part of the cylinder head above the fourth cylinder.

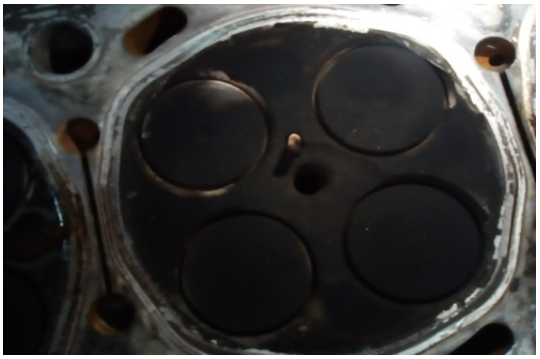


Figure 18: Motor engine IVECO F1CE0481HC003 - view 3 of the lower part of the cylinder head above the third cylinder.

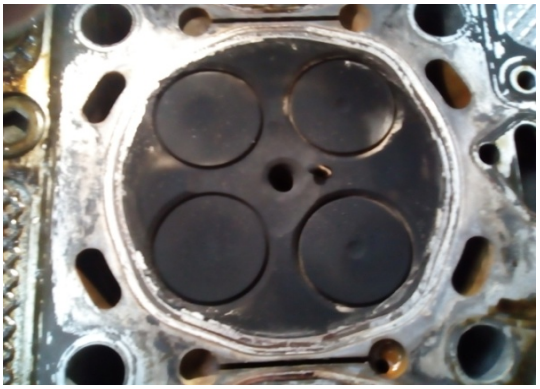


Figure 19: Motor engine IVECO F1CE0481HC003 - view 3 of the lower part of the cylinder head above the third cylinder.

Figure 20: Motor engine IVECO F1CE0481HC003 M - view 2 of the lower part of the cylinder head above the second cylinder.

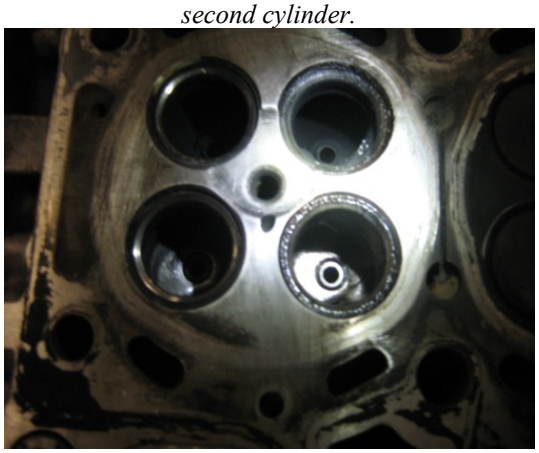


Figure 21: Motor engine IVECO F1CE0481HC003 - view 3 on the lower part of the cylinder head (above the fourth cylinder) where there was a crack on the side of the injector

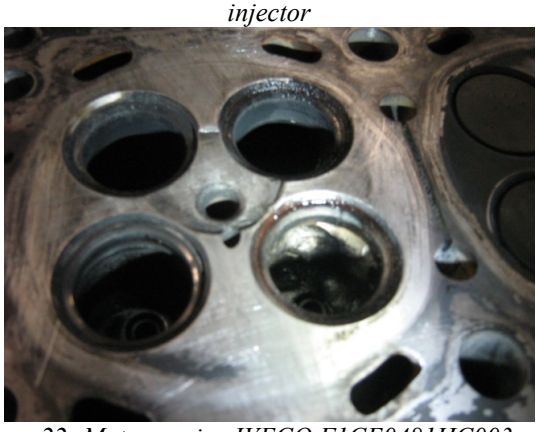


Figure 22: Motor engine IVECO F1CE0481HC003- view 2 on the lower part of the cylinder head (above the fourth cylinder) where a crack appeared on the side of the injector. The picture shows a view of the welded part on the side of the valve.

9. Welded cylinder head on the fourth cylinder on the valve side (Figure 21,22), where the cylinder head in question had a crack on the injector side.

10. The conclusion that the engine did not work a technically correct condition is indicated by the following facts:

- Condition of the piston group of the subject engine (Figures 11,12);
- Engine injector condition (Figures 9,10);
- EGR valve condition (Figures 5,6);
- Lack of DPF valve (Figures 7,8);
- Coolant quality (Figures 3,4);
- Sealing condition between cylinder head and engine block, as well as valve condition (Figures 13,15,17,18,19, 20);

3. CONCLUSION

The accident on the vehicle, after it was repaired by the defendant, occurred because the entire vehicle, as well as the engine in question, overall, were in extremely poor technical condition, and it was not possible to eliminate all potential causes that could lead to a new engine failure.

After the occurrence of the first and the occurrence of the second engine failure, the service technicians carried out adequate maintenance procedures, in accordance with the standards for the occurrence of accidents.

The work order defines the elements that are subject of the service. The owner of the vehicle could make objections to these elements and request that other elements that would be the subject of the work of this service be included in the work order. Everything that is written in the work orders of both services, the services did professionally and expertly.

Based on a detailed analysis of the entire documentation submitted before the start of determining the technical condition, a detailed analysis of the results of diagnosing the vehicle and engine before disassembling the engine, and then a detailed analysis of all parts during disassembly of the engine, it can be concluded that the engine did not have initial a crack of such a size that it could be identified by any method used in the implementation of the so called cylinder head hydro test (determination of the presence of cracks in the cylinder head).

If there was a crack in the head of the engine in question, it would be very difficult to start-start this engine after the first servicing. If the engine started, after the first servicing, and occurred at all (with great effort and very unfavourable manifestation in the operation of the engine), with such an engine it would not be possible to exceed the mileage of 201 km, after which there was a second engine failure.

The engine question is in very pot technical condition and the occurrence of the second accident occurred due to its dilapidation, inadequate exploitation and in adequate maintenance.

Some of the causes, due to which the first and second breakdowns of the subject engine in the vehicle occurred, are:

- Use plain water instead of the prescribed coolant. The water was used even before the appearance of the first accident, which led to numerous irregularities in the operation of the engine.
- Pouring the prescribed coolant after removing the first accident into the cooling system contributed to the intensification of the process of decomposition of scale in the flow channels of the cooling system, and thus inside the cylinder head, which intensified the initial crack that most likely existed on the injector side in the fourth

cylinder, but could not detect the so-called hydro test because it was not only incomplete, but most likely covered with lime scale. Since the water was poured at the discretion of the driver before the first accident occurred, and the engine was constantly extremely unfavourably thermally loaded, that water also contributed to the appearance of the initial crack. It does not work-there is no physical DPF-FAP filter (Figures 11,12), which also leads, among other things, to engine overheating, but also to a number of other engine malfunctions discussed in the previous text of this paper.

- EGR - the valve is dirty and non-functional and it not only does not perform the prescribed function, but largely causes improper engine operation, among other things, contributes to the occurrence of engine overheating. On the engine at any time, due to its extremely poor technical condition, accidents can occur on various grounds, due to continuous engine overheating, which occurs primarily due to non-functionality of the EGR valve, lack of DPF valve, due to the use of water as coolant, due to wear and tear of its parts.

The following facts can serve as proof of this claim: The vehicle, in which the engine in question is installed, is in extremely poor technical condition, and does not meet the requirements for registration in terms of meeting the existing regulations in terms of exhaust emissions (although the installed engine is manufactured to meet Euro 4 standards, it is due to EGR dysfunction and the non-existence of DPF valves, but also poor overall technical condition), does not meet the Euro 3 norms and as such would certainly not meet the ECO-a test that is mandatory at the technical inspection, which means that the vehicle could not be registers.

The problem of completely correct functioning and operation of the engine in question has not been solved, and could not be completely solved, neither in the first service, nor in the second service, primarily because it is the engine, but also the vehicle as a whole, which passed a huge number of passed kilometres (647513km), without being properly exploited and maintained and because it is in extremely poor technical condition.

The following facts support this claim:

- The service technician did not imprint his stamp on the engine head over which he performed certain maintenance procedures (welding, straightening,), and thus did not give a guarantee that the head is completely correct and that it will not fail in the future basis. This service did so having in mind the technical condition of the head of the subject engine.
- After the elimination of the second accident in the second service, there was a failure of the crankshaft speed sensor in a very short period of time (after fifteen days). That sensor certainly worked after eliminating another engine failure in this service. If it did not work, the engine in question would not be able to start. This points to the conclusion that this service did not give a guarantee that the engine in question will not fail on some grounds.
- After the elimination of the second accident, the following issues were not resolved in the service: Lack of PDF valve (Figure 7,8); EGR valve dysfunction that not only does not work but disrupts engine operation (Figure 5,6); Huge deposits of lime scale and corrosion on the fourth cylinder injector due to coolant penetration (Figure 4); Unacceptable technical conditions of the piston group (Figures 11,12,14); Occurrence of continuous engine overheating caused not only by the absence of a DPV valve (Figure 7,8) and the non-functionality of the EGR valve (Figure 5,6), but also by the use of water as a coolant (Figure 4), for which the owner is responsible vehicles;
- Occurrence of reduction of compression due to "puncture" on the seal of the head and engine block above the fourth cylinder (Figure 12), which means that the engine, not only before the first and second accidents, worked in extremely unfavourable operating conditions, and was thermally unfavourably loaded, but still works in extremely unfavourable operating conditions, and that it is still extremely unfavourably thermally loaded, which can lead to engine failure in the coming period.

ACKNOWLEDGMENTS

The research presented in this paper was supported by the Ministry of Science of the Republic of Serbia, within the project TR 35041.

REFERNCES

[1] Krstić, B. (2009), Tehnical serviceability of motor vehicles and engines, University of Mechanical Engineering, Kragujevac (In Serbian)

[2] Krstić, B., et al (2009), Determination of the optimal strategy for preventive maintenance the motor engine using polycriterion optimization, Tractors and power machines, Vol.14, No. 2/3, p.91-98

[3] Krstić, B. (2002), Possibilities of management for vehicle performability in purpose to satisfy exploitation-tehnical characteristics, Tractors and power machines, Vol.7, No. 4, p.95-103

[4] B. Krstić, V. Lazić, V. Krstić (2010),: Some views of future strategies of maintenance of motor vehicles, Tractors and power machines, Vol.15, No.1, p.42-47

[5] B. Krstić, V. Lazić, R. Nikolić, V. Raičević, I. Krstić, V. Krstić (2009),: "Optimal strategy for preventive maintenance of the motor vehicles clutch", Journal of the balkan tribologikal association", Vol.15, No 4, 611-619

[6] Krstić N., Krstić S., Krstić V., Krstić B. (2020),, Availability and reliability of mecatronic systems of motor vehicles, IMCSM 2020 Procedings, ISSN 2620-0597, Volume XVI, Issuise 2, p.121-129, Bor