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RESEARCH, INNOVATION, RESULTS

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Tashkent state transport university

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Articles are published in Uzbek, Russian, and English, ensuring a wide-reaching audience and fostering cross-cultural academic exchange. As a beacon of academic excellence, the "Journal of Transport" continues to serve as a vital conduit for knowledge dissemination, collaboration, and innovation in the transport sector and related fields.

Developing a mathematical model of the fuel supply system for injection engines

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Abstract: The design and calibration of new types of fuel supply systems for injection engines are based on experimental methods (the trial-and-error method) and on the extensive production and engineering experience of designers. These processes rely not on closed-loop control of mixture formation, but on the use of experimentally compiled data tables at the engine calibration stage and on the task of obtaining mathematical models of injection engines for their subsequent application. The problems of analytical synthesis of control systems therefore represent a relevant and undoubted scientific and practical interest.

Keywords: Injection engine, mathematical modeling, torque, power, fuel consumption, number of revolutions, fuel-air ratio

Injektorlik dvigatellarning ta’minlash tizinmining matematik modelini ishlab chiqish

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Annotatsiya: Injektorli dvigatellari uchun loyihalash, kalibrlash va yangi turdagi yoqilg'i ta’minoti tizimlarini nosozliklarni tuzatish empirik tarzda ("sinov va xato" usuli bilan) amalga oshiriladi va dizaynerlarning boy ishlab chiqarish va muhandislik tajribasiga asoslanadi. Dvigatellar uchun mikroprotsessorli boshqaruv tizimlari, qoida tariqasida, og'ish orqali yopiq tsiklni boshqarish tamoyillariga asoslanmagan,, balki dvigatelni kalibrlash bosqichida eksperimental ravishda tuzilgan ma'lumotlar jadvallaridan foydalanishga asoslanadi hamda boshqaruv tizimlarining analitik sintezi muammolarida keyingi foydalanishga yo'naltirilgan injektorli dvigatellarining matematik modellarini olish muammosi dolzarb va shubhasiz qiziqish uyg'otadi.

Kalit so‘zlar: Injektorli dvigatel, matematik modellashtirish, burovchi moment, quvvat, yoqilg’I sarfi, aylanishlar soni, yonilg’i-havo nisbati

1. Kirish

Bugungi kunda texnik jihatdan rivojlangan mamlakatlarda injektorli dvigatellar (ya'ni, yoqilg'i silindrga majburiy haydash yo'li bilan yetkazib beriladigan dvigatellar) klassik karbyurator ta’minot sxemasini deyarli to'liq almashtirdi. Injektorli dvigatellarning (ID) asosiy afzalliklari quyidagilardan iborat:

1. Dvigatelni elektron boshqarish imkoniyati;
2. Ishchi aralashmani tayyorlashni optimallashtirish ya’ni
   - Yonilg’i sarfini kamaytirish
   - Chiqindi gazlar zararliligini kamaytirish
   - Dvigatelning FIK oshirish
   - Silindrning yeyilishini kamaytirish

3.Yuqori oktanli yoqilg'idan foydalanish imkoniyati.

Biroq, deyarli barcha yirik avtomobil ishlab chiqaruvchilari injektorli dvigatellari bo'lgan keng turdagi avtomobillarni taklif qilishlariga qaramay, ID boshqaruv tizimlarini matematik modellashtirish va analitik sintez qilish bo'yicha ishlar rivojlanishning dastlabki bosqichida. Ko'pgina hollarda, injektorli dvigatellari uchun loyihalash, kalibrlash va yangi turdagi yoqilg'i ta’minoti tizimlarini nosozliklarni tuzatish empirik tarzda ("sinov va xato" usuli bilan) amalga oshiriladi va dizaynerlarning boy ishlab chiqarish va muhandislik tajribasiga asoslanadi.Dvigatellar uchun mikroprotsessorli boshqaruv tizimlari, qoida tariqasida, og'ish orqali yopiq tsiklni boshqarish tamoyillariga asoslanmagan,, balki dvigatelni kalibrlash bosqichida eksperimental ravishda tuzilgan ma'lumotlar jadvallaridan foydalanishga asoslanadi [2,3]. Shu sababli, boshqaruv tizimlarining analitik sintezi muammolarida keyingi foydalanishga yo'naltirilgan injektorli dvigatellarining matematik modellarini olish muammosi dolzarb va shubhasiz qiziqish uyg'otadi.

XX asrning 70-80-yillari adabiyotlarida keltirilgan ichki yonish dvigatellarining matematik modellari, qoida tariqasida, chiziqli bo'lib, faqat dvigatelning barqaror holatidan kichik og'ishlar uchun o'z kuchini saqlab qoladi [4,5]. Tabiiyki, bunday modellar soddalashtirilgan, chiziqli nazorat qonunlarini ishlab chiqishga qaratilgan edi. Chiziqli bo’lmagan, moslashuvchan va mustahkam boshqaruv

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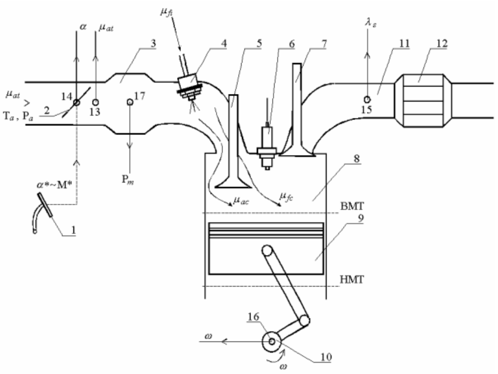
usullarini rivojlantirishning hozirgi darajasi boshqaruv qonunlarini boshqarish ob'ektining nochiziqli xususiyatlarini hisobga olgan holda sintez qilish imkonini beradi, bu esa injektorlarning yanada aniqroq, chiziqli bo'lmagan modellarini yaratish uchun katta hajmdagi ishlarni rag'batlantiradi.

2. Tadqiqot metodologiyasi

XX asrning 70-80-yillari adabiyotlarida keltirilgan ichki yonish dvigatellarining matematik modellari, qoida tariqasida, chiziqli bo'lib, faqat dvigatelning barqaror holatidan kichik og'ishlar uchun o'z kuchini saqlab qoladi [4,5]. Tabiiyki, bunday modellar soddalashtirilgan, chiziqli nazorat qonunlarini ishlab chiqishga qaratilgan edi. Chiziqli bo'lmagan, moslashuvchan va mustahkam boshqaruv usullarini rivojlantirishning hozirgi darajasi boshqaruv qonunlarini boshqarish ob'ektining nochiziqli xususiyatlarini hisobga olgan holda sintez qilish imkonini beradi, bu esa injektorlarning yanada aniqroq, chiziqli bo'lmagan modellarini yaratish uchun katta hajmdagi ishlarni rag'batlantiradi.

Injektorli dvigatel sxemasi



1-rasm. Injektorli dvigatel sxemasi

1-rasmda injektorli dvigatelning sxemasi ko'rsatilgan. Undagi sonlar quydagilarni anglatadi: 1-gaz pedali; 2-drosell zaslonkasi; 3-kiritish kollektori; 4-injektor; 5-kiritish klapani; 6-o't oldirish shami; 7-chiqarish klapani; 8-silindr; 9-porshen; 10-tirsakli val; 11-chiqarish kollektori; 12-katalizator; 13-zaslonkadan o'tayotgan havo miqdorini aniqlaydigan datchik; 14-drosell zaslonkasini holatini aniqlaydigan datchik; 15- kislorod datchiki; 16-tezlik datchiki; 17-kiritish kollektoridagi bosimni ko'rsatuvchi datchik.

Dvigatel quyidagicha ishlaydi. Drosell zaslonkasi klapani 2 orqali havo kiritish quvuri 3ga kiradi. Drosell zaslonkasi klapanining orqasida vaqt birligida zaslonka orqali o'tadigan havo oqimini o'lchaydigan datchik 13 mavjud. Drosell zaslonkasi holati datchik 14, uning burilish burchagini o'lchaydi α. Havo bosimi sensori 17 kiritish quvurida joylashgan. Qabul qilish klapanining 5 yonida yoqilg'ini silindr 8 ga yuboradigan injektor 4 mavjud. Kiritish rejimi paytida havo va yoqilg'i silindrga kirish klapani orqali kiradi va aralashadi. Silindagi o't oldirish shami 6 yordamida ish aralashmasi alangalatiladi. Yoqilg'i yoqilgandan so'ng, yonish mahsulotlari silindrdan chiqarish klapan orqali chiqarish klapani 11 ga keladi, bu yerda kislorod sensori 15 joylashgan bo'lib, undan olingan ma'lumotlar silindrdagi havo / yoqilg'i nisbatini hisoblash imkonini beradi. Tezlik sensori 16 tirsakli valning aylanish tezligini o'lchash uchun ishlatiladi. Katalitik konvertor 12, chiqindi gazlardagi uglerod oksidi va uglevodorodlarning parchalanishining kimyoviy reaktsiyasini tezlashtiradigan katalizatorni o'z ichiga oladi. Yuqori burovchi momentni olish uchun silindrdagi optimal havo / yoqilg'i nisbati va bu nisbatga mos keladigan o't oldirish vaqtini doimiy ravishda ushlab turish kerak. Yuqoridagi parametrlardan biri optimal nuqtadan chetga chiqsa, dvigatel quvvati yo'qolishi ishchi aralashmaning to'liq yoki o'z vaqtida yonmasligi tufayli yuzaga keladi. Shuning uchun, injektorli dvigatelini boshqarishdagi eng muhim vazifalar silindrdagi havo/yoqilg'ining optimal nisbatini saqlash va o't oldirish vaqtini zudlik bilan tuzatishdir.

Boshqarish ob'ekti sifatida injektorli dvigateli. Keling, injektorli dvigatelini boshqaruv ob'ekti sifatida tahlil qilaylik, kirish va chiqish (sozlanishi) o'zgaruvchilarni ajratib ko'rsatish, shuningdek, asosiy boshqaruv vazifalarini shakllantirish. Buning uchun inson haydovchisi ishtirokida mashinani boshqarish jarayonini ko'rib chiqing.

Avtomobilni boshqarishda haydovchi avtomobil tezligini o'zgartirish uchun gaz pedalining o'rnini o'zgartiradi. Shunday qilib, haydovchi-avtomobil yopiq tizimining boshqaruv maqsadi avtomobil istalgan tezligini W * barqarorlashtirishdir. Biroq, bu jarayon darhol sodir bo'lmaydi, chunki tezlatgichning (gaz pedali) holatidagi o'zgarish birinchi navbatda dvigatel hosil bo'ladigan burovchi momentning o'zgarishiga olib keladi. O'z navbatida, bu moment va tashqi yuklanish momenti o'rtasidagi farq tezlanishni va natijada avtomobil tezligini aniqlaydi. Shuning uchun biz haydovchini antropogen boshqaruvchi deb taxmin qilishimiz mumkin, u kerakli tezlik W * va haqiqiy tezlik V o'rtasidagi farqga asoslanib, kerakli dvigatel momentini M * belgilaydi. Shunday qilib, tezlatgichning pozitsiyasi M* dvigatel momentining istalgan qiymati sifatida talqin qilinishi mumkin. Shunga asoslanib, dvigatelni boshqarish tizimida quyidagi teskari aloqa halqalarini ajratish mumkin (2-rasm):

1. momentning qayta aloqa davri (asosiy fikr); ushbu sxema uchun boshqaruvning maqsadi - tezlatgichning pozitsiyasi bilan belgilanadigan dvigatel momentining M* istalgan qiymatini barqarorlashtirish (yoki moment o'zgarishining M*(t) istalgan qonunini saqlab turish); bu sxemadagi boshqaruv signali drosell zaslonkasi klapanining burilish burchagi u_2=a;
2. havo/yonilg'i nisbati bo'yicha teskari aloqa halqasi (qulli fikr); ushbu sxema uchun boshqaruvning maqsadi kerakli havo / yoqilg'i nisbatini barqarorlashtirishdir. Benzin uchun 14,7 ga teng stoxiometrik nisbat optimal hisoblanadi. Bu shuni anglatadiki, bir kilogramm benzinni to'liq yoqish uchun 14,7 kg havo kerak bo'ladi. Dvigatelni optimal boshqarish uchun λ koeffitsienti kiritiladi, bu silindrga bosim bilan kiritilgan yoqilg'i massalarining sikl davomida yondirilgan yoqilg'i massasiga nisbatini ko'rsatadi. Bu koeffitsientning kerakli qiymati λ*=1 ga teng. Ushbu sxema uchun boshqaruv signali bosim bilan kiritilgan yoqilg'i miqdori $u_l=\mu_{fi}$;
3. o't oldirish vaqti bo'yicha teskari aloqa davri (teskari aloqani optimallashtirish); ushbu sxema uchun boshqaruvning maqsadi dvigatelning ba'zi xususiyatlarini optimallashtirishdir; bu holda boshqaruv
4. signali - bu yonish vaqti $u_3=\alpha_{ign}$.

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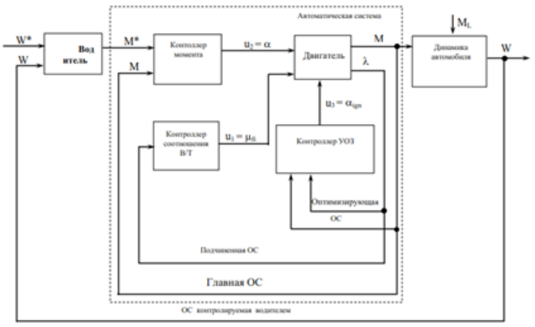
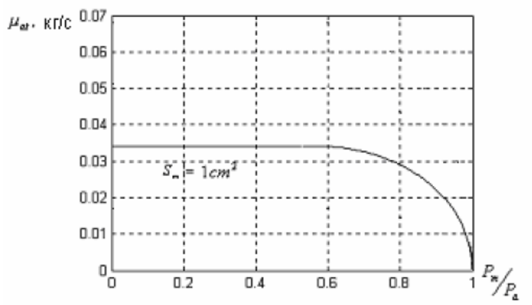


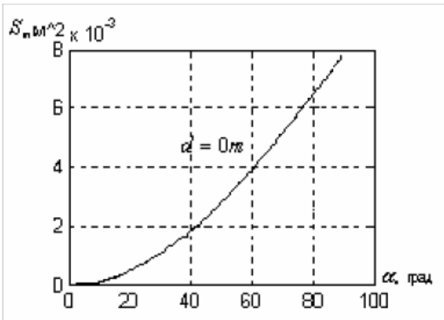
2-rasm. Injektorli dvigatelni avtomatik boshqarish tizimining sxemasi

Injektorli dvigatel modelining tenglamalarini chiqarish. O'rtacha matematik model injektorli dvigatel kirish signallarini (drosell zaslonkasi burilish burchagi α, bosim bilan yuboriladigan yoqilg'i miqdori μ_{fi} va tutash vaqti) boshqariladigan o'zgaruvchilarning o'rtacha qiymatlariga (havo / yoqilg'i nisbati λ va burovchi moment M) o'zgartirish ketma-ketligini tavsiflaydi) dvigatelning har bir aylanishida ushbu qiymatlarning pulsatsiyalarini hisobga olmasdan.

Drosell zaslonkasi orqali o’tuvchi havo oqimi. Ushbu quyi tizimning tenglamalari zaslonka μ_{at} [kg/s] orqali havo oqimining zaslonka burilish burchagi a [rad] va kiritish quvuridagi bosim [Pa] o'rtasidagi munosabatni tavsiflaydi. Bu tushunchani quydagi tenglama orqali ifodalash mumkin: η_{at}-kiritish quvurining samarali to’ldirish koeffisienti (%); $\varphi_1(P_m)$ –drosell zaslonkasi klapanining birlik yuzasidan o'tadigan havo oqimini tavsiflovchi chiziqli bo'lmagan funksiya; $\varphi_2(a)$-zaslonka yuzasi. $\varphi_1(P_m)$ va $\varphi_2(a)$ funksiyalarning tipik shakli 3 va 4-rasmda ko'rsatilgan.



3-rasm. Drosell zaslonkasi klapan orqali o’tuvchi havo oqimining atmosfera bosimi va kiritish quvuridagi bosimga bog'liqligi



4-rasm. Kiritish quvurining ma’lum bir uchastka maydonining drosell zaslonka klapanining burilish burchagiga bog'liqligi

2. Kiritish kolektoridagi bosim. Kiritish kollektoridagi havo harorati doimiy deb faraz qilgan holda, ideal gaz tenglamasini differensiallash yo'li bilan kiritish kollektoridagi bosim tenglamasi xosil qilamiz:

$$\dot{P}_m + \eta_c \frac{V_d \omega}{4\pi V_m} P_m = \frac{RT_m}{V_m}\mu_{at}(\alpha, P_m), \qquad 0 \le \eta_c \le 1. \qquad (2)$$

2 temlamadagi V_m-kiritish kollektorining hajmi, m^3 ; Tm-kolektordagi harorat, K; η_{at} –drosell zaslonkasi klapanidan o'tadigan havo miqdori, kg/s; η_c –silindrni to’ldirish koeffisienti,%.

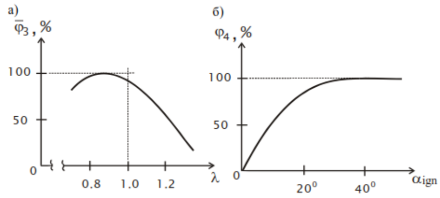
3. Kiritish kollektori devorlarida yonilg’i pardasining hosil bo’lishi. Purkalgan yoqilg'ining bir qismi kiritish kollektori devorlarida plyonka hosil qiladi. Bu plyonka bug'lanish jarayoni natijasida yonilg'ini to'playdi va silindrga yetkazib beradi. Shunday qilib, yoqilg'i silindrga ikkita manbadan kiradi: injektordan va kollektor devorlaridagi yonilg’i plyonkalarining bug'lanishi. Ushbu jarayonni tavsiflovchi aniq analitik model mavjud emas. Biroq, eksperimental ma'lumotlar shuni ko'rsatadiki, uni quyidagi model bilan tavsiflash mumkin:

$$\mu_{fc=}\frac{K}{T_{p+}}\mu_{fi+(1-K)\mu_{fi}}$$

Bu yerda K- purkalgan yoqilg'ining qaysi qismi plyonka hosil qilayotganini hisobga oluvchi koeffitsient (0<K<1); μ_{fi}- injektorda tarqalgan yonilg’i miqdori, kg/s; Tp- Yoqilg'i purkash jarayonining vaqt doimiysi, s.

4. Silindrdagi yonilg’i-havo nisbati. Ushbu quyi tizimni ko'rib chiqishda biz quyidagi ideallashtirilgan taxminni qabul qilamiz.

Silindrga kiradigan barcha yoqilg'i va barcha havo bir siklda yondiriladi va undan butunlay chiqariladi. Shunday qilib, silindrda sikldan-siklga yoqilg'i va havo qolmaydi.



5-rasm. $\varphi_3(\lambda)$ va $\varphi_4(\alpha_{igm})$ funksiyasini tipik funksiyasi

Ushbu fikga asoslanib, havo / yoqilg'i nisbati sifatida hisoblash mumkin:

$$\lambda = \frac{\mu_{ac}}{\mu_{fc}} = \frac{V_d}{4\pi R T_M F_x}\frac{P_m \omega}{\mu_{ff} + (1-K)\mu_{fi}}$$

Bu yerda F_s - stokiometrik nisbat (F_s=14.7).

5. Dvigatelning burovchi momenti. Dvigatelning burovchi momenti silindrdagi yonilg’I miqdori, yonilg’I-havo aralashmasi nisbati va o’t oldirish burchagiga bog’liq. Birinchi taxminiy xulosa sifatida biz hozircha quyidagi ifodani yozishimiz mumkin:

$$M = C_M \mu_{ac} \varphi_3(\lambda) \varphi_4(\alpha_{igm})$$

Bu yerda C_M –moment koeffisienti, N*m*c/kg; a_{ign}-o’t oldirish burchagi,rad;

$\varphi_3(\lambda)$ va $\varphi_4(\alpha_{igm})$ funksiyasini tipik funksiyasi 5-rasmda tasvirlangan.

6. Dvigatel harakati tenglamasi. Dvigatelning mexanik sxemasi quydagi tenglama bilan tavsiflanadi

$$J^*\omega = M - M_L - M_\omega$$

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Bu yerda J-dvigatel inertsiyaning momentini kamaytirish, kg/m^2; M_L -tashqi yuklamada momentning kamayishi,N*m; M_ω- ishqalanish orqali momentning kamayishi, N*m;

Avtomobilda bo'lmagan holdagi dvigatel modeli. Yuqorida keltirilgan tenglamalarga asoslanib, biz dvigatel Avtomobilda bo'lmagan holdagi modelini yozamiz:

$$
\begin{aligned}
\dot{x}_1 &= -a_1 x_1 + b_{11} x_1 x_3 \varphi_3(x_1, x_2, x_3, u_1)\varphi_4(u_3) - b_{12}\delta_1(t),\\
\dot{x}_2 &= -a_2 x_2 + b_2 u_1,\\
\dot{x}_3 &= -a_3 x_1 x_3 + b_3 \varphi_1(x_3)\varphi_2(u_2),\\
y_1 &= \frac{1}{x_1 x_3}(c_1 x_2 + d_1 u_1),\\
y_2 &= c_2 x_1 x_3 \varphi_3(x_1, x_2, x_3, u_1)\varphi_4(u_3),
\end{aligned}
$$

Bu yerda x_1=ω-chiqarish valdagi aylanishlar tezligi, ayl/min; x_3=P_m-kiritish kollektoridagi bosim, Pa; y_1=λ-yonilg'i-havo nisbati; y_2=M-burovchi moment, N*m; δ_1=M_L-tashqi yuklama momenti,N*m; u_1=μ_{fi}-silindrga kiritilayotgan yonilg'i miqdori, kg; u_2=a-drossell zaslonkasi burilish burchagi, rad; u_3=a_{ing}-o't oldirish burchagi.

Shunday qilib, injektorli dvigatelining matematik modeli uchinchi tartibli chiziqli bo'lmagan differentsial tenglamalar tizimi (7) - (8) bilan ifodalanishi mumkin, ularning holat koordinatalari: tirsakli valning aylanishlar chastotasi, tiritish kollektori devorlarida yonilg'i plyonkasi og'irligi va undagi havo bosimi. Ushbu modelning ba'zi parametrlarini oldindan aniq hisoblash yoki eksperimental ravishda aniqlash mumkin emas (masalan, kiritish kollektori devorlarida plyonka hosil qilgan yoqilg'ining massasi). Shuning uchun, injektorli dvigatel modeli parametrik noaniq bo'lib, bu moslashuvchan yoki mustahkam boshqaruv usullarini qo'llash zaruratini keltirib chiqaradi.

3. Xulosa

Modelni yanada takomillashtirish silindrni to'ldirish koeffitsienti va kiritish kollektori to'ldirish samaradorligi koeffitsientining dvigatel holati o'zgaruvchilariga – kiritish kollektoridagi bosimi va tirsakli valning aylanish tezligiga bog'liqligini aniqlashdan iborat. Dvigatelning asosiy parametrlarining sovutish suyuqligi haroratiga bog'liqligini aniqlash alohida qiziqish uyg'otadi. Matematik modellashtirish ishlarini amalga oshirish iqtisodiy va vaqt sarfini kamaytiradi.

Foydalangan adabiyotlar / References

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