STUDYING THE MOVEMENT OF A HORIZONTAL MOVING BODY TAKING INTO ACCOUNT THE RESISTANCE OF THE ENVIRONMENT AND SOLVING RELATED PROBLEMS

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ANNOTATION

This article examines the laws of motion in the horizontal plane of a ship under the influence of the resistance force of water, as well as the impact of the resistance of air and the friction force of the surface, and issues related to them are worked out.

Keywords: acceleration; the equation of motion; the equation velocity; the equation of motion; force of resistance; to take an integral; limits of integral; resistance of an air.

GORIZONTAL HARAKATLANAYOTGAN JISMNING HARAKATINI MUHITNING QARSHILIGINI E'TIBORGA OLGAN HOLDA O'RGANISH VA UNGA DOIR MASALALAR YECHISH

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Annotatsiya

Ushbu maqolada suvning qarshilik kuchi ta'siridagi kemaning hamda havoning qarshilik va sirtning ishqalanish kuchi ta'siridagi avtomobilning gorizontal tekislikdagi harakat qonunlari o'rganilgan va ularga oid masalalar ishlab ko'rsatilgan.

Калит сўзлар: тезланиши; ҳаракат тенгламаси; тезлик тенгламаси; дифференциал тенглама; қаршлик кучи; интеграллаш; интеграл чегаралари; ҳавонинг қаршилиги.

ИЗУЧЕНИЕ ДВИЖЕНИЯ ГОРИЗОНТАЛЬНО ДВИЖУЩЕГОСЯ ТЕЛА С УЧЕТОМ СОПРОТИВЛЕНИЯ СРЕДЫ И РЕШЕНИЕ СВЯЗАННЫХ ЗАДАЧ.

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АННОТАЦИЯ

В данной статье изучены законы движения судна в горизонтальной плоскости под действием силы сопротивления воды, а также транспортного средства под действием сопротивления воздуха и силы поверхностного трения и разработаны вопросы, связанные с ними.

Ключевые слова: ускорение; уравнение движения; уравнение скорость; дифференциальное уравнение; сила сопротивления; интегрирование; пределы интеграла; сопротивление воздуху.

KIRISH

Ma’lumki, umumta’lim o‘rta maktablarining yuqori sinflari hamda akademik litsey o‘quvchilariga biror sirtda sirpanib harakatlanayotgan jismning harakatini o‘rganish mavzulari juda ham mukammal darajada yoritilgan. Oliy ta’lim muassasalarida ham bu masala chuqurlashtirib differensial va vektor ko‘rinishlarida o‘qitiladi. Aslida, jism harakatlanganda faqat sirtning sirpanish ishqalanishi ta’sir qilmasdan, balki havoning qarshiligi ham ta’sir etadi. Undan tashqari suyuqlikda harakatlanayotgan jismga ham suyuqlik tomonidan qarshilik kuchi ta’sir etadi. Real holatda jismning havo yoki suyuqlik qarshiligi e’tiborga olinadigan holdagi harakati haqiqatga ancha yaqin bo‘lib, bunga esa oliy ta’lim muassasalarida kam e’tibor beriladi. SHuning uchun ham sirtning ishqalanish kuchi va muhitning qarshiligini birgalikda e’tiborga olingan holdagi jismning harakatini o‘rganish talabalarni real vaziyatga ancha yaqinlashtiradi.

Bilamizki, muhitning qarshiligi tezlikning birinchi darajasiga yoki ikkinchi darajasiga to‘g‘ri proporsional bo‘lishi mukin. Masalan, suyuqlik bilan sodir bo‘ladigan hodisalarda (qayiq uoki kemaning harakatini o‘rganishda) qarshilik kuchi tezlikning birinchi darajasiga proporsional bo‘lsa, havo bilan sodir bo‘ladigan hodisalarda (avtomobil harakatini o‘rganishda, aviatsiyada, harbiy texnikada parashyut, o‘q, snaryad va boshqalarni o‘rganishda) qarshilik kuchini tezlikning ikkinchi darajasiga proporsional bo‘ladi. Biz ushbu maqolada suyuqlik sirtida suzayotgan kema yoki qayiqning suvning qarshiligi ta’siridagi harakatini hamda gorizontal sirtda harakatlanayotgan avtomobilning sirtning ishqalanish kuchi va havoning qarshiligining birgalikdagi ta’siri ostidagi harakatini alohida-alohida o‘rganamiz va ularga oid masalalar ishlaymiz.

ADABIYOTLAR TAHLILI VA METODOLOGIYASI

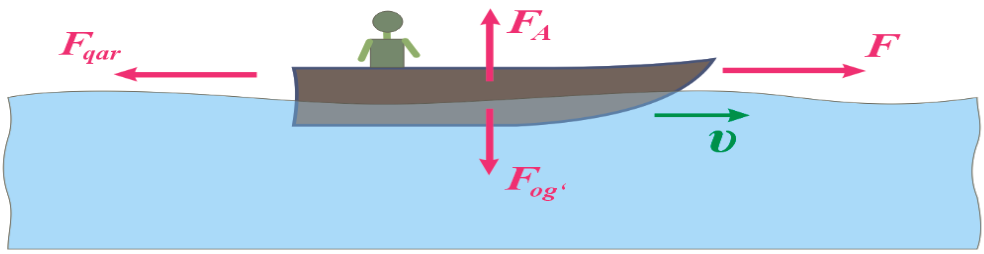
I.

Qayiq yoki kema suyuqlik sirtida suzayotganda unga quyidagi kuchlar ta’sir qiladi (1-rasm):

— $F_{og'} = mg$ – pastga yo‘nalgan og‘irlik kuchi hamda bu kuch bilan kompensatsiyalanuvchi $\vec{F}_A = -\vec{F}_{og'}$ Arximed kuchi;

— $F_{qar} = \alpha\vartheta$ – suyuqlikning qayiq harakatiga ko‘rsatadigan qarshilik kuchi (kichik tezliklarda $F_{qar} \sim \vartheta$ bo‘ladi);

— F – qayiqga ta’sir qiluvchi tezlatuvchi yoki sekinlatuvchi kuchi bo‘lib, u motorining tortish kuchi uchun F>0 ishorali yoki tormozlangandagi tormoz kuchi uchun F<0 ishorali bo‘lishi mumkin.



1-rasm

Yuqorida sanab o'tilgan kuchlar ta'sirida harakatlanayotgan qayiq uchun dinamikaning 2-qonuni qo'llaymiz va shu asosda differensial tenglama hosil qilib uni ishlab chiqamiz.

$$ma = F - F_{qar}\,, \quad \rightarrow \quad m\frac{d\vartheta}{dt} = F - \alpha\vartheta, \quad \rightarrow \quad dt = \frac{md\vartheta}{F-\alpha\vartheta} = -\frac{m}{\alpha}\cdot\frac{d\vartheta}{\vartheta - \frac{F}{\alpha}}$$

$$\int_0^t dt = -\frac{m}{\alpha}\cdot\int_{\vartheta_0}^{\vartheta}\frac{d\vartheta}{\vartheta-\frac{F}{\alpha}}, \quad \rightarrow \quad t = -\frac{m}{\alpha}\cdot\ln\left|\vartheta - \frac{F}{\alpha}\right|\Big|_{\vartheta_0}^{\vartheta} = -\frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta-\frac{F}{\alpha}}{\vartheta_0-\frac{F}{\alpha}}\right| =$$

$$= \frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta_0-\frac{F}{\alpha}}{\vartheta-\frac{F}{\alpha}}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 - F}{\alpha\vartheta - F}\right|$$

Demak, differensial tenglamani yechish natijasida gorizontal yo'lda kichik tezlikda harakatalanayotgan avtomobil yoki velosipedning ixtiyoriy ϑ tezlikka erishish vaqti quyidagicha bo'lar ekan:

$$t = \frac{m}{\alpha}\cdot\ln\left|\frac{F-\alpha\vartheta_0}{F-\alpha\vartheta}\right| \qquad \textbf{(I. 1)}$$

Yuqoridagi (I.1) formulada tortish kuchi suyuqlikning qarshilik kuchidan kichik bo'lsa $(F < \alpha\vartheta_0)$, u holda qayiq sekinlanuvchan harakat qiladi va tezlikning miqdori biror ϑ qiymatga erishgach $F = \alpha\vartheta$ bo'ladi va shu erishgan tezlikda harakatni davom ettiradi.

Yuqoridagi (I.1) formulada tortish kuchi suyuqlikning qarshilik kuchidan katta bo'lsa $(F > \alpha\vartheta_0)$, u holda qayiq tezlanuvchan harakat qiladi va tezlikning miqdori biror ϑ qiymatga erishgach $F = \alpha\vartheta$ bo'ladi va shu erishgan tezlikda harakatni davom ettiradi.

Yuqoridagi (I.1) formuladan ϑ tezlikni topib olsak, u holda $\vartheta=\vartheta(t)$ ko'rinishdagi oniy tezlik formulasiga ega bo'lamiz. Shu formulani keltririb chiqarayik.

$$t = -\frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta-\frac{F}{\alpha}}{\vartheta_0-\frac{F}{\alpha}}\right|, \quad \rightarrow \quad \frac{\vartheta-\frac{F}{\alpha}}{\vartheta_0-\frac{F}{\alpha}} = e^{-\frac{\alpha}{m}t}, \quad \rightarrow$$

$$\vartheta - \frac{F}{\alpha} = \left(\vartheta_0 - \frac{F}{\alpha}\right)e^{-\frac{\alpha}{m}t}, \quad \rightarrow \quad \vartheta = \left(\vartheta_0 - \frac{F}{\alpha}\right)e^{-\frac{\alpha}{m}t} + \frac{F}{\alpha}$$

$$\vartheta = \left(\vartheta_0 - \frac{F}{\alpha}\right)e^{-\frac{\alpha}{m}t} + \frac{F}{\alpha} \qquad \textbf{(I.2)}$$

Yuqoridagi (I.2) formulada $t\rightarrow\infty$ bo'lganda bitta had qoladi va avtomobil yoki velosiped erishadigan eng katta tezlikni aniqlash mumkin.

$$\vartheta_{\max} = \frac{F}{\alpha} \qquad \textbf{(I.3)}$$

Yuqoridagi (I.3) formulani dinamikaning asosiy tenglamasidan ham hosil qilish mumkin.

$$ma = F - F_{qar} = 0, \quad \rightarrow \quad F_{qar} = F\,, \quad \rightarrow \quad \alpha\vartheta = F\,, \quad \rightarrow \quad \vartheta_{\max} = \frac{F}{\alpha}$$

Shuni alohida eslatib oʻtish kerakki, (6.23) formula sharti, ya’ni maksimal tezlikka erishish sharti faqat F>fmg boʻlgandagina bajariladi. Chunki, bunda avtomobil yoki velosiped tezlanuvchan harakat qiladi.

Agar (7.3) formulani e’tiborga oladigan boʻlsak, u holda (I.1) va (I.2) formulalarni maksimal tezlik orqali quyidagicha yozishimiz mumkin:

$$t = \frac{m}{\alpha} \cdot \ln\left|\frac{\vartheta_{\max} - \vartheta_0}{\vartheta_{\max} - \vartheta}\right| \qquad \text{(I.1')}$$

$$\vartheta = \vartheta_{\max} - \left(\vartheta_{\max} - \vartheta_0\right) e^{-\frac{\alpha}{m}t} \qquad \text{(I.2')}$$

Endi esa 1-rasmdagi holat uchun yoʻl va tezlik orasidagi bogʻlanishni, ya’ni s=s(ϑ) tenglamani hosil qilaylik. Buning uchun yuqorida keltirib chiqarilgan tenglamalar kabi dinamikaning asosiy tenglamasidan foydalanib differensial tenglama hosil qilamiz va uni yechib chiqamiz.

$$m\frac{d\vartheta}{dt} \cdot \frac{dx}{dx} = F - \alpha\vartheta, \rightarrow\ m\frac{\vartheta d\vartheta}{dx} = F - \alpha\vartheta, \rightarrow\ dx = \frac{m\vartheta d\vartheta}{F - \alpha\vartheta} =$$

$$= -\frac{m}{\alpha} \cdot \frac{\vartheta d\vartheta}{\vartheta - \frac{F}{\alpha}} = -\frac{m}{\alpha} \cdot \left(1 + \frac{\frac{F}{\alpha}}{\vartheta - \frac{F}{\alpha}}\right) d\vartheta.$$

$$s = \int_0^s dx = -\frac{m}{\alpha} \cdot \int_{\vartheta_0}^{\vartheta} \left(1 + \frac{\frac{F}{\alpha}}{\vartheta - \frac{F}{\alpha}}\right) d\vartheta = -\frac{m}{\alpha} \cdot \left[\vartheta + \frac{F}{\alpha} \cdot \ln\left|\vartheta - \frac{F}{\alpha}\right|\right]\Bigg|_{\vartheta_0}^{\vartheta} =$$

$$= -\frac{m}{\alpha} \cdot \left[\vartheta - \vartheta_0 + \frac{F}{\alpha} \cdot \ln\left|\frac{\vartheta - \frac{F}{\alpha}}{\vartheta_0 - \frac{F}{\alpha}}\right|\right] = \frac{m}{\alpha} \cdot \left[\vartheta_0 - \vartheta + \frac{F}{\alpha} \cdot \ln\left|\frac{\alpha\vartheta_0 - F}{\alpha\vartheta - F}\right|\right].$$

$$\text{yoki}\quad s = \frac{m}{\alpha} \cdot \left[\vartheta_0 - \vartheta + \vartheta_{\max} \cdot \ln\left|\frac{\vartheta_{\max} - \vartheta_0}{\vartheta_{\max} - \vartheta}\right|\right]$$

Shunday qilib, s=s(ϑ) tenglamani hosil qildik.

$$s = \frac{m}{\alpha} \cdot \left[\vartheta_0 - \vartheta + \frac{F}{\alpha} \cdot \ln\left|\frac{\alpha\vartheta_0 - F}{\alpha\vartheta - F}\right|\right] \qquad \text{(I.4)}$$

$$s = \frac{m}{\alpha} \cdot \left[\vartheta_0 - \vartheta + \vartheta_{\max} \cdot \ln\left|\frac{\vartheta_{\max} - \vartheta_0}{\vartheta_{\max} - \vartheta}\right|\right] \qquad \text{(I.4')}$$

Yuqoridagi (I.4) va (I.4') formulalar jism ixtiyoriy ϑ tezlikka erishish uchun qanday s masofani bosib oʻtish kerakligini aniqlaydigan formulalardir.

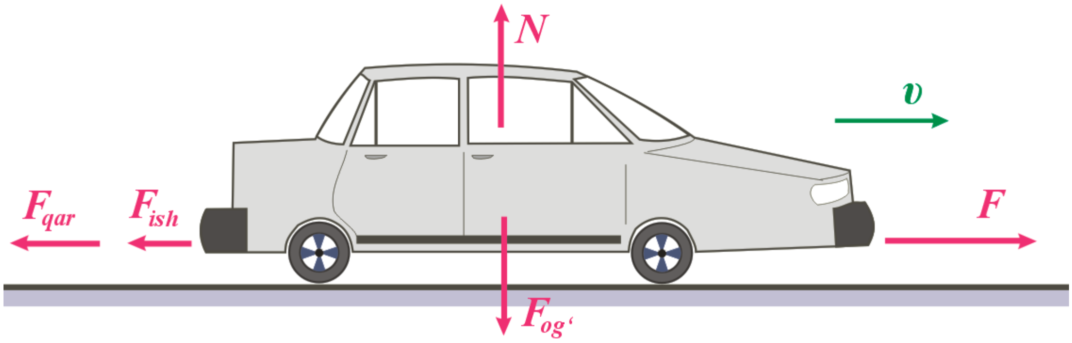
Agar biror boshlangʻich ϑ_0 tezlikka ega boʻlgan qayiqqa F tortish yoki tormoz kuchi ta’sir etmasa, u holda (I.4) formula quyidagi soddaroq koʻrinishga oʻtadi:

$$s = \frac{m}{\alpha} \cdot \left(\vartheta_0 - \vartheta\right) \qquad \text{(I.4a)}$$

Bu keltirib chiqarilgan barcha formulalar velosiped harakati yoki nisbatan kichik tezlikda harakatlanayotgan avtomobil uchun, ya'ni muhitning qarshilik kuchi tezlikning birinchi darajasiga bog'liq bo'lgan hol uchun o'rinlidir.

II. Endi esa gorizontal yo'lda harakatlanayotgan jismning umumiy holdagi harakatini o'rganaylik. Qayiq, kema yoki kater harakatiga nisbatan avtomobillar nisbatan tezroq harakatlangani uchun avtomobillarga tezlikning kvadratiga proporsional bo'lgan havoning qarshilik kuchi ta'sir etasdi deb qaraymiz.

Avtomobil nisbatan tez harakatlanayotgan hol degani bu tezlikning biror kritik qiymatidan kattaroq tezlikda harakatlanish deganidir. Boshqacha aytganda, avtomobil kuzoviga yaqin sohadagi qatlam-qatlam havo oqimlari aralashib girdoblarga aylanadi. Bunda avtomobil havo oqimi tomonidan tezlikning kvadratiga to'g'ri proporsional bo'lgan qarshilik kuchiga uchraydi.



2-rasm

Talabalarga bu mavzuni o'qitishda jismga ta'sir qiladigan kuchlarni to'g'ri joytirishlariga e'tibor qilish kerak. Gorizontal yo'lda harakatlanayotgan avtomobilga quyidagi kuchlar ta'sir qiladi (2-rasm):

— $F_{og'} = mg -$ pastga yo'nalgan og'irlik kuchi hamda bu kuch bilan kompensatsiyalanuvchi $\vec{N} = -\vec{F}_{og'}$ sirtning yuqoriga yo'nalgan reaksiya kuchi;

— $F_{ishq} = \frac{x}{R} mg = fmg -$ dumalashdagi ishqalanish kuchi; x–dumalashdagi ishqalanish koeffitsiyenti; R – avtomobilning g'ildiragi radiusi; $f = \frac{x}{R} -$ dumalashdagi qarshilik koeffitsiyenti, ya'ni avtomobilni joyidan qo'zg'atish uchun kerak bo'lgan kuch avtomobil og'irligining qanday qismini tashkil etishini bildiruvchi koeffitsiyent;

— $F_{qar} = \alpha \vartheta -$ dumalashdagi ishqalanish kuchi (kichik tezliklarda $F_{qar} \sim \vartheta$ bo'ladi);

— F – avtomobilga ta'sir qiluvchi tezlatuvchi yoki sekinlatuvchi kuchi bo'lib, u motorining tortish kuchi uchun F>0 ishorali yoki tormozlangandagi tormoz kuchi uchun F<0 ishorali bo'lishi mumkin.

Rasmda ko'rsatilgani kabi avtomobilga ta'sir qilayotgan kuchlar uchun dinamikaning 2-qonuni qo'llaymiz va shu asosda differensial tenglama hosil qilib uni ishlab chiqamiz.

$$ma = F - F_{ishq} - F_{qar}, \quad \rightarrow \quad m\frac{d\vartheta}{dt} = F - fmg - \beta\vartheta^2, \rightarrow$$

$$dt = \frac{md\vartheta}{F - fmg - \beta\vartheta^2} = -\frac{m}{\beta}\cdot\frac{d\vartheta}{\vartheta^2 - \frac{F - fmg}{\beta}}$$

Demak, bizda

$$dt = -\frac{m}{\beta}\cdot\frac{d\vartheta}{\vartheta^2 - \frac{F - fmg}{\beta}} \qquad (*)$$

ko‘rinishidagi differensial tenglama hosil bo‘ldi. Bu differensial tenglamadagi tenglamani $\frac{F - fmg}{\beta}$ ifodaning musbat yoki manfiy bo‘lishi, ya’ni F>fmg yoki F<fmg bo‘lishiga qarab differensial tenglama yechishning keyingi qadami ikki xil yo‘ldan boradi.

A) F>fmg bo‘lganda $\frac{F - fmg}{\beta} > 0$ bo‘ladi va (*) differensial tenglamani yechishda matematikadan $\int\frac{dx}{x^2 - a^2} = \frac{1}{2a}\ln\left|\frac{x-a}{x+a}\right| + C$ integrallash formulasidan foydalanamiz;

B) F<fmg bo‘lganda $\frac{F - fmg}{\beta} < 0$ bo‘ladi va (*) differensial tenglamani yechishda matematikadan $\int\frac{dx}{x^2 + a^2} = \frac{1}{a}arctg\frac{x}{a} + C$ integrallash formulasidan foydalanamiz;

Dastlab biz **A)** shartga bo‘ysungan hol uchun differensial tenglamani yechib t=t(ϑ) bog‘lanishni, ya’ni avtomobilning ixtiyoriy ϑ tezlikka erishadigan vaqt onini topish formulasini keltirib chiqaramiz.

$$\int_0^t dt = -\frac{m}{\beta}\cdot\int_{\vartheta_0}^{\vartheta}\frac{d\vartheta}{\vartheta^2 - \frac{F - fmg}{\beta}}, \quad \rightarrow \quad t = -\frac{m}{\beta}\cdot\frac{\sqrt{\beta}}{2\sqrt{F - fmg}}\cdot\ln\left|\frac{\vartheta - \sqrt{\frac{F - fmg}{\beta}}}{\vartheta + \sqrt{\frac{F - fmg}{\beta}}}\right|\Bigg|_{\vartheta_0}^{\vartheta} =$$

$$= \frac{m}{2\sqrt{\beta(F - fmg)}}\cdot\ln\left|\frac{\vartheta + \sqrt{\frac{F - fmg}{\beta}}}{\vartheta - \sqrt{\frac{F - fmg}{\beta}}}\cdot\frac{\vartheta_0 - \sqrt{\frac{F - fmg}{\beta}}}{\vartheta_0 + \sqrt{\frac{F - fmg}{\beta}}}\right|$$

Demak, (*) differensial tenglamaning **A)** shart bo‘yicha yechish natijasida gorizontal yo‘lda katta tezlikda harakatalanayotgan avtomobilning ixtiyoriy ϑ tezlikka erishish vaqti quyidagicha bo‘lar ekan:

$$t = \frac{m}{2\sqrt{\beta(F - fmg)}}\cdot\ln\left|\frac{\sqrt{\frac{F - fmg}{\beta}} + \vartheta}{\sqrt{\frac{F - fmg}{\beta}} - \vartheta}\cdot\frac{\sqrt{\frac{F - fmg}{\beta}} - \vartheta_0}{\sqrt{\frac{F - fmg}{\beta}} + \vartheta_0}\right| \qquad \textbf{(II.9)}$$

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Bu shartda F>fmg ekanligidan avtomobil faqat tezlanuvchan harakat qilishi kelib chiqadi. Tezlik oshgan sari esa qarshilik kuchi ortib boradi biror maksimal tezlikka erishganda qarshilik va ishqalanish kuchlari tortishish kuchiga teng bo'lib qoladi. Bu maksimal tezlikni dinamikaning 2-qonunidan osongina topish mumkin.

$$ma = F - F_{ishq} - F_{qar} = 0, \quad \to \quad F_{qar} = F - F_{ishq}, \to \beta\vartheta^2 = F - fmg, \to \vartheta_{\max} = \sqrt{\frac{F - fmg}{\beta}}$$

$$\boxed{\vartheta_{\max} = \sqrt{\frac{F - fmg}{\beta}}} \qquad \textbf{(II.10)}$$

(II.10) formulani e'tiborga olsak, (II.9) formulani quyidagicha ifodalshimiz mumkin bo'ladi:

$$\boxed{t = \frac{m}{2\beta\vartheta_{\max}} \cdot \ln\left|\frac{\vartheta_{\max} + \vartheta}{\vartheta_{\max} - \vartheta} \cdot \frac{\vartheta_{\max} - \vartheta_0}{\vartheta_{\max} + \vartheta_0}\right|} \qquad \textbf{(II.9')}$$

Agar avtomobil tinch holatdan harakat boshlagan bo'lsa, u holda (II.9) va (II.9') formulalar quyidagi ko'rinishlarga o'tadi:

$$\boxed{t = \frac{m}{2\sqrt{\beta(F - fmg)}} \cdot \ln\left|\frac{\sqrt{\frac{F - fmg}{\beta}} + \vartheta}{\sqrt{\frac{F - fmg}{\beta}} - \vartheta}\right|} \qquad \textbf{(II.9a)}$$

$$\boxed{t = \frac{m}{2\beta\vartheta_{\max}} \cdot \ln\left|\frac{\vartheta_{\max} + \vartheta}{\vartheta_{\max} - \vartheta}\right|} \qquad \textbf{(II.9'a)}$$

Endi esa biz **B)** shartga bo'ysungan hol uchun differensial tenglamani yechib t=t(ϑ) bog'lanishni, ya'ni avtomobilning ixtiyoriy ϑ tezlikka erishadigan vaqt onini topish formulasini keltirib chiqaramiz.

$$\int_0^t dt = -\frac{m}{\beta} \cdot \int_{\vartheta_0}^{\vartheta} \frac{d\vartheta}{\vartheta^2 - \frac{F - fmg}{\beta}} = -\frac{m}{\beta} \cdot \int_{\vartheta_0}^{\vartheta} \frac{d\vartheta}{\vartheta^2 + \frac{fmg - F}{\beta}}, \quad \to \quad t = -\frac{m}{\beta} \cdot \frac{\sqrt{\beta}}{\sqrt{fmg - F}} \cdot$$

$$\cdot arctg\left(\vartheta\sqrt{\frac{\beta}{fmg - F}}\right)\Bigg|_{\vartheta_0}^{\vartheta} = -\frac{m}{\sqrt{\beta(fmg - F)}} \cdot \left[arctg\left(\vartheta\sqrt{\frac{\beta}{fmg - F}}\right) - arctg\left(\vartheta_0\sqrt{\frac{\beta}{fmg - F}}\right)\right] =$$

$$= \frac{m}{\sqrt{\beta(fmg - F)}} \cdot \left[arctg\left(\vartheta_0\sqrt{\frac{\beta}{fmg - F}}\right) - arctg\left(\vartheta\sqrt{\frac{\beta}{fmg - F}}\right)\right].$$

Bu yerda biz matematikadan ma'lum bo'lgan

$$arctgx - arctgy = arctg\frac{x - y}{1 + xy}$$

formulasidan foydalanamiz.

$$t=\frac{m}{\sqrt{\beta\left(fmg-F\right)}}\cdot\left[arctg\left(\vartheta_0\sqrt{\frac{\beta}{fmg-F}}\right)-arctg\left(\vartheta\sqrt{\frac{\beta}{fmg-F}}\right)\right]=$$

$$=\frac{m}{\sqrt{\beta\left(fmg-F\right)}}\cdot arctg\left(\frac{\sqrt{\frac{\beta}{fmg-F}}\cdot\left(\vartheta_0-\vartheta\right)}{1+\frac{\beta}{fmg-F}\cdot\vartheta_0\vartheta}\right)$$

Demak, (*) differensial tenglamaning **B)** shart bo‘yicha yechish natijasida gorizontal yo‘lda katta tezlikda harakatalanayotgan avtomobilning ixtiyoriy ϑ tezlikka erishish vaqti quyidagicha bo‘lar ekan:

$$t=\frac{m}{\sqrt{\beta\left(fmg-F\right)}}\cdot arctg\left(\frac{\sqrt{\frac{\beta}{fmg-F}}\cdot\left(\vartheta_0-\vartheta\right)}{1+\frac{\beta}{fmg-F}\cdot\vartheta_0\vartheta}\right) \qquad \textbf{(II.11)}$$

Bu shartda F<fmg ekanligidan avtomobil faqat sekinlanuvchan harakat qilishi kelib chiqadi. Natijada, qandaydir vaqtdan keyin avtomobil to‘xtaydi (ϑ=0). To‘xtash vaqti quyidagicha bo‘ladi:

$$t_{to'xt}=\frac{m}{\sqrt{\beta\left(fmg-F\right)}}\cdot arctg\left(\vartheta_0\sqrt{\frac{\beta}{fmg-F}}\right) \qquad \textbf{(II.11a)}$$

Endi esa 2-rasmdagi holat uchun yo‘l va tezlik orasidagi bog‘lanishni, ya’ni s=s(ϑ) tenglamani keltirib chiqaraylik. Buning uchun yuqorida keltirib chiqarilgan tenglamalar kabi dinamikaning asosiy tenglamasidan foydalanib differensial tenglama hosil qilamiz va uni yechib chiqamiz.

$$m\frac{d\vartheta}{dt}\cdot\frac{dx}{dx}=F-fmg-\beta\vartheta^2,\ \rightarrow\ m\frac{\vartheta d\vartheta}{dx}=F-fmg-\beta\vartheta^2,\ \rightarrow\ dx=\frac{m\vartheta d\vartheta}{F-fmg-\beta\vartheta^2}=$$

$$=-\frac{m}{\beta}\cdot\frac{\vartheta d\vartheta}{\vartheta^2-\frac{F-fmg}{\beta}}=-\frac{m}{2\beta}\cdot\frac{d\left(\vartheta^2-\frac{F-fmg}{\beta}\right)}{\vartheta^2-\frac{F-fmg}{\beta}},\ \rightarrow\ s=\int_0^s dx=-\frac{m}{2\beta}\cdot\int_{\vartheta_0}^{\vartheta}\frac{d\left(\vartheta^2-\frac{F-fmg}{\beta}\right)}{\vartheta^2-\frac{F-fmg}{\beta}}=$$

$$s=\int_0^s dx=-\frac{m}{2\beta}\cdot\int_{\vartheta_0}^{\vartheta}\frac{d\left(\vartheta^2-\frac{F-fmg}{\beta}\right)}{\vartheta^2-\frac{F-fmg}{\beta}}=-\frac{m}{2\beta}\cdot\ln\left|\vartheta^2-\frac{F-fmg}{\beta}\right|\Bigg|_{\vartheta_0}^{\vartheta}=-\frac{m}{2\beta}\cdot\ln\left|\frac{\vartheta^2-\frac{F-fmg}{\beta}}{\vartheta_0^2-\frac{F-fmg}{\beta}}\right|=$$

$$=\frac{m}{2\beta}\cdot\ln\left|\frac{\frac{F-fmg}{\beta}-\vartheta_0^2}{\frac{F-fmg}{\beta}-\vartheta^2}\right|=\frac{m}{2\beta}\cdot\ln\left|\frac{F-\left(fmg-\beta\vartheta_0^2\right)}{F-\left(fmg+\beta\vartheta^2\right)}\right|$$

Shunday qilib, s=s(ϑ) tenglamani hosil qildik.

$$s=\frac{m}{2\beta}\cdot\ln\left|\frac{\frac{F-fmg}{\beta}-\vartheta_0^2}{\frac{F-fmg}{\beta}-\vartheta^2}\right|=\frac{m}{2\beta}\cdot\ln\left|\frac{F-\left(fmg+\beta\vartheta_0^2\right)}{F-\left(fmg+\beta\vartheta^2\right)}\right| \quad \text{(II.12)}$$

Agar boshlang'ch tezlik nolga teng ($\vartheta_0=0$) bo'lsa, u holda (II.12) formulani quyidagicha ifodalash mumkin bo'ladi:

$$s=\frac{m}{2\beta}\cdot\ln\left|\frac{F-fmg}{F-\left(fmg+\beta\vartheta^2\right)}\right| \quad \text{(II.12a)}$$

Agar F>fmg shart bajarilsa, u holda avtomobil tezlanuvchan harakat qilib, biror maksimal tezlikka erishadi. Bunda (II.10) maksimal tezlik formulasini e'tiborga olsak, u holda (II.12) va (II.12a) formulalarni quyidagicha yozish mumkin:

$$s=\frac{m}{2\beta}\cdot\ln\left|\frac{\vartheta_{\max}^2-\vartheta_0^2}{\vartheta_{\max}^2-\vartheta^2}\right| \quad \text{(II.12')}$$

$$s=\frac{m}{2\beta}\cdot\ln\left|\frac{\vartheta_{\max}^2}{\vartheta_{\max}^2-\vartheta^2}\right| \quad \text{(II.12'a)}$$

Agar F<fmg shart bajarilsa, u holda avtomobil sekinlanuvchan harakat qilib, biror masofani o'tib to'xtaydi. (II.12) formuladan to'xtash masofasi quyidagicha bo'ladi:

$$s_{to'xt}=\frac{m}{2\beta}\cdot\ln\left|1+\frac{\beta\vartheta_0^2}{fmg-F}\right| \quad \text{(II.12b)}$$

Yuqoridagi (II.12) formuladan foydalanib tezlikning masofaga bog'lanish $\vartheta=\vartheta(s)$ formulasini aniqlashimiz mumkin.

$$s=-\frac{m}{2\beta}\cdot\ln\left|\frac{\vartheta^2-\frac{F-fmg}{\beta}}{\vartheta_0^2-\frac{F-fmg}{\beta}}\right|,\quad\rightarrow\quad \frac{\vartheta^2-\frac{F-fmg}{\beta}}{\vartheta_0^2-\frac{F-fmg}{\beta}}=e^{-\frac{2\beta}{m}s},\rightarrow$$

$$\vartheta^2-\frac{F-fmg}{\beta}=\left(\vartheta_0^2-\frac{F-fmg}{\beta}\right)\cdot e^{-\frac{2\beta}{m}s},\rightarrow\ \vartheta^2=\left(\vartheta_0^2-\frac{F-fmg}{\beta}\right)\cdot e^{-\frac{2\beta}{m}s}+\frac{F-fmg}{\beta},\ \rightarrow$$

$$\vartheta=\sqrt{\left(\vartheta_0^2-\frac{F-fmg}{\beta}\right)\cdot e^{-\frac{2\beta}{m}s}+\frac{F-fmg}{\beta}}$$

$$\vartheta=\sqrt{\left(\vartheta_0^2-\frac{F-fmg}{\beta}\right)\cdot e^{-\frac{2\beta}{m}s}+\frac{F-fmg}{\beta}} \quad \text{(II.13)}$$

Agar F>fmg shart bajarilsa, (II.10) maksimal tezlik formulasini e'tiborga olsak, u holda (II.13) formulani quyidagicha yozish mumkin:

$$\vartheta=\sqrt{\vartheta_{\max}^2-\left(\vartheta_{\max}^2-\vartheta_0^2\right)\cdot e^{-\frac{2\beta}{m}s}} \quad \text{(II.13')}$$

MUHOKAMA VA NATIJALAR

Yuqorida keltirib chiqarilgan formulalardan yana bir nechta xususiy formulalar keltirib chiqarish mumkin. Masala ishlash davomida ular bilan tanishib chiqamiz.

III. Endi esa yuqorida keltirib chiqarilgan barcha formulalar yuzasidan bir necha masalalar ishlash orqali bilimlarimizni mustahkamlab olamiz.

1-masala: Massasi m ga teng bo'lgan neft tashuvchi tanker kemasiga $F_{кар} = -\alpha\vartheta$ qonunga bo'ysunuvchi suvning qarshilik kuchi ta'sir etadi. Tanker qig'oqqa yaqinlashganda motor o'chiriladi. Bunda kemaning tazligi n marta kamayishi uchun qancha vaqt sarf bo'ladi va qancha yo'l bosib o'tiladi? To'xtaguncha jami qancha yo'l bosib o'tiladi?

Yechish: Masala shartiga ko'ra $F = 0,\ \vartheta = \dfrac{\vartheta_0}{n}$ bo'ladi. Masalani ishlash uchun yuqorida keltirib chiqarilgan (I.1) va (I.4) formulalardan foydalanish etarlidir. (I.1) formulaga ko'ra kema tezligi n marta kamayishi uchun ketgan vaqt

$$t = \frac{m}{\alpha}\cdot\ln\left|\frac{F-\alpha\vartheta_0}{F-\alpha\vartheta}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{0-\alpha\vartheta_0}{0-\alpha\vartheta}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta_0}{\vartheta}\right| = \frac{m}{\alpha}\cdot\ln n$$

bo'ladi. Tezligi n marta kamayguncha kemaning bosib o'tadigan yo'li (I.4) formulaga asosan

$$s = \frac{m}{\alpha}\cdot\left[\vartheta_0 - \vartheta + \frac{F}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 - F}{\alpha\vartheta - F}\right|\right] = \frac{m}{\alpha}\cdot\left[\vartheta_0 - \frac{\vartheta_0}{n} + \frac{0}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 - 0}{\alpha\vartheta - 0}\right|\right] = \frac{n-1}{n}\cdot\frac{m\vartheta_0}{\alpha}$$

bo'ladi. Kema butunlay harakatdan to'xtash uchun esa (I.4) formulaga ko'ra

$$s = \frac{m}{\alpha}\cdot\left[\vartheta_0 - \vartheta + \frac{F}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 - F}{\alpha\vartheta - F}\right|\right] = \frac{m}{\alpha}\cdot\left[\vartheta_0 - 0 + \frac{0}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 - 0}{\alpha\vartheta - 0}\right|\right] = \frac{m\vartheta_0}{\alpha}$$

ga teng yo'lni bosib o'tadi.

2-masala: Massasi m ga teng bo'lgan katerga tezlikning 1-darajasiga proporsional bo'lgan qarshilik kuchi hamda kater motorining o'zgarmas F ga teng tortish kuchi ta'sir etadi. Bunda kema qanday eng katta tezlikka erisha oladi? Maksimal tezlikning 90% iga erishish uchun qancha vaqt sarflanadi va bunda kater qancha masofa bosib o'tadi?

Yechish: Tinch holatdan harakat boshlangani uchun $\vartheta_0 = 0$ bo'ladi. Kater maksimal tezlikka erishganda uning boshqa tezligi oshmaydi, ya'ni tezlanishi nolga aylanadi. Shunga ko'ra maksimal tezlik

$$1)\quad ma = F - \alpha\vartheta = 0, \ \rightarrow\ F = \alpha\vartheta_{\max}, \ \rightarrow\ \vartheta_{\max} = \frac{F}{\alpha}$$

bo'ladi. Masalaning keyingi shartlarida $\vartheta = 0{,}9\vartheta_{\max} = 0{,}9\dfrac{F}{\alpha}$ bo'lguncha qancha vaqt sarflanishi va qancha yo'l bosib o'tilishi so'ralgan. Vaqtni aniqlash uchun (I.1) formuladan foydalanamiz. Unga ko'ra

$$t = \frac{m}{\alpha}\cdot\ln\left|\frac{F-\alpha\vartheta_0}{F-\alpha\vartheta}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{F-\alpha\cdot 0}{F-\alpha\cdot 0{,}9\dfrac{F}{\alpha}}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{F}{F-0{,}9F}\right| = \frac{m}{\alpha}\cdot\ln 10$$

bo'ladi. Masofani aniqlash uchun (I.1) formuladan foydalanamiz. Unga ko'ra

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\frac{F}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0-F}{\alpha\vartheta-F}\right|\right]=\frac{m}{\alpha}\cdot\left[0-0{,}9\frac{F}{\alpha}+\frac{F}{\alpha}\cdot\ln\left|\frac{0-F}{\alpha\cdot0{,}9\frac{F}{\alpha}-F}\right|\right]=$$

$$=\frac{m}{\alpha}\left[-0{,}9\frac{F}{\alpha}+\frac{F}{\alpha}\cdot\ln10\right]=\frac{mF}{\alpha^2}\left[\ln10-0{,}9\right]$$

bo'ladi.

3-masala: Massasi m=1340 kg ga teng bo'lgan NEKSIYA avtomobili 4-uzatmada $F=420\,N$ tortish kuchi ta'sirida maksimal ϑ_{max}=126 km/soat tezlik bilan harakatlana oladi. Yo'lning qarshilik koeffitsienti $f=0{,}025$ ga teng bo'lsa, havoning qarshilik koeffitsienti β nimaga teng? Erkin tushish tezlanishini $g=9{,}8\,m/s^2$ deb oling. Bunda tortish kuchining qanday qismi havoning qarshiligini engishga sarf qilinadi?

Yechish: Eng avvalo tezlikning qiymatini XBS sistemasida

$$\vartheta_{\max}=126\,\frac{км}{соат}=35\frac{м}{с}$$

deb olamiz. Bu masalani yechish uchun yuqoridagi (II.10) formuladan foydalanib β koeffitsient formulasinihosil qilamiz.

$$\vartheta_{\max}=\sqrt{\frac{F-fmg}{\beta}},\ \rightarrow\ \beta\vartheta_{\max}^2=F-fmg,\ \rightarrow\ \beta=\frac{F-fmg}{\vartheta_{\max}^2}$$

Endi hisob-kitob ishlarini bajaramiz.

$$\beta=\frac{F-fmg}{\vartheta_{\max}^2}=\frac{420\,Н-0{,}025\cdot1340кг\cdot9{,}8\frac{м}{с^2}}{\left(35\frac{м}{с}\right)^2}=\frac{92\ кг\frac{м}{с^2}}{1225\frac{м^2}{с^2}}\approx0{,}075\ \frac{кг}{м}$$

Avtomobil harakatiga havoning qarshilik kuchini aniqlaymiz.

$$F_{карш}=\beta\,\vartheta_{\max}^2=0{,}075\ \frac{кг}{м}\cdot\left(35\ \frac{м}{с}\right)^2=92\,Н$$

Bu kuch umumiy kuchning

$$\frac{F_{карш}}{F}=\frac{92\,Н}{420\,Н}=0{,}219=21{,}9\ \%$$

qismini tashkil etadi.

4-masala: Spark avtomobilining haydovchi bilan birigalikdagi massasi m=950 kg ga teng. Dumalashdagi qarshilik koeffitsienti $f=0{,}02$ ga teng bo'lgan yo'lning gorizontal qismida harakatlanayotgan bu avtomobil motorning F=380 N doimiy tortish kuchi ta'sirida tezlanuvchan harakat qilmoqda. Havoning qarshilik koeffitsienti $\beta=0{,}14\,\frac{kg}{m}$ ga teng. Erishish mumkin bo'lgan maksimal tezlikning 80% qiymatiga erishish uchun qancha vaqt sarflanadi? Bunda avtomobil qancha masofa bosib o'tadi? Erkin tushish tezlanishini $g=9{,}8\,m/s^2$ deb oling.

Yechish: Masalani ishlash uchun avvalo maksimal tezlikning qiymatini ainqlaymiz.

$$\vartheta_{max}=\sqrt{\frac{F-fmg}{\beta}}=\sqrt{\frac{380\,N-0,02\cdot 950\,kg\cdot 9,8\frac{m}{s^2}}{0,14\,\frac{kg}{m}}}=37,2\,\frac{m}{s}.$$

So‘ralgan vaqtni yuqoridagi (II.9') formuladan foydalanib topamiz.

$$t=\frac{m}{2\beta\vartheta_{max}}\cdot\ln\left|\frac{\vartheta_{max}+\vartheta}{\vartheta_{max}-\vartheta}\cdot\frac{\vartheta_{max}-\vartheta_0}{\vartheta_{max}+\vartheta_0}\right|=\frac{m}{2\beta\vartheta_{max}}\cdot\ln\left|\frac{\vartheta_{max}+0,8\vartheta_{max}}{\vartheta_{max}-0,8\vartheta_{max}}\right|=$$

$$=\frac{m}{2\beta\vartheta_{max}}\cdot\ln 9=\frac{950\,kg}{2\cdot 0,14\frac{kg}{m}\cdot 37,2\frac{m}{s}}=91,2\;s\cdot 2,2=200\;s=3\min 20\,s.$$

Endi esa so‘ralgan masofa uzunligini ainqlash uchun (II.12') formuladan foydalanib topamiz.

$$s=\frac{m}{2\beta}\cdot\ln\left|\frac{\vartheta_{max}^2-\vartheta_0^2}{\vartheta_{max}^2-\vartheta^2}\right|=\frac{m}{2\beta}\cdot\ln\left|\frac{\vartheta_{max}^2-0^2}{\vartheta_{max}^2-\left(0,8\vartheta_{max}\right)^2}\right|=\frac{950\,кг}{2\cdot 0,14\frac{кг}{м}}\cdot\ln 2,778=3466\,м$$

5-masala: Massasi m ga teng bo‘lgan engil avtomobilning biror ondagi tezligi $\vartheta_0=40\,\frac{m}{s}$ ga teng. Agar shu onda avtomobil bakidagi yoqilg‘isi tugab qolsa, avtomobil sekinlanuvchan harakat qila boshlaydi. Bunda avtomobilning $\vartheta_1=0,5\vartheta_0$ tezlikka erishish uchun ketadigan vaqt t_1 hamda bosib o‘tadigan yo'l s_1 nimaga teng? Umumiy to‘xtash vaqti $t_{to‘xt}$ hamda masofasi $s_{to‘xt}$ nimaga teng? Avtomobil massasi $m=1200\,кг$ ga, yo‘lning harakatga qarshilik koeffitsientini $\mu=0,015$ga, havoning qarshilik koeffitsientini esa $\beta=0,1\,\frac{kg}{m}$ ga teng. Erkin tushish tezlanishini $g=9,8\;m/s^2$ deb oling.

Yechish: Masaladagi so‘ralgan vaqt va masofalarni hisoblash uchun (II.11) va (II.12) formulalardan foydalanib topamiz. Dastlab t_1 hamda s_1 kattaliklarni hisoblaylik. Bunda avtomobil motori o‘chgani uchun F=0 deb olamiz.

$$t_1=\frac{m}{\sqrt{\beta\left(fmg-F\right)}}\cdot arctg\left(\frac{\sqrt{\frac{\beta}{fmg-F}}\cdot\left(\vartheta_0-\vartheta\right)}{1+\frac{\beta}{fmg-F}\cdot\vartheta_0\vartheta}\right)=\sqrt{\frac{m}{\beta fg}}\cdot arctg\left(\frac{\sqrt{\beta fmg}\cdot\left(\vartheta_0-\vartheta\right)}{fmg+\beta\vartheta_0\vartheta}\right)=$$

$$=\sqrt{\frac{1200\,kg}{0,1\,\frac{kg}{m}\cdot 0,015\cdot 9,8\frac{m}{s^2}}}\cdot arctg\left(\frac{\sqrt{0,1\,\frac{kg}{m}\cdot 0,015\cdot 1200\,kg\cdot 9,8\frac{m}{s^2}}\cdot\left(40\frac{m}{s}-20\frac{m}{s}\right)}{0,015\cdot 1200\,kg\cdot 9,8\frac{m}{s^2}+0,1\,\frac{kg}{m}\cdot 40\frac{m}{s}\cdot 20\frac{m}{s}}\right)=$$

$$=745\,s\cdot arctg\left(\frac{84}{256,4}\right)=235\;s=3\min 55\,s.$$

$$s_1 = \frac{m}{2\beta}\cdot\ln\left|\frac{F-\left(fmg+\beta\vartheta_0^2\right)}{F-\left(fmg+\beta\vartheta^2\right)}\right| = \frac{m}{2\beta}\cdot\ln\left|\frac{\beta\vartheta_0^2+fmg}{\beta\vartheta^2+fmg}\right| = \frac{1200\,кг}{2\cdot 0{,}1\frac{кг}{м}}\cdot$$

$$\cdot\ln\left|\frac{0{,}1\frac{кг}{м}\cdot\left(40\frac{м}{с}\right)^2+0{,}015\cdot1200\,кг\cdot9{,}8\frac{м}{с^2}}{0{,}1\frac{кг}{м}\cdot\left(20\frac{м}{с}\right)^2+0{,}015\cdot1200\,кг\cdot9{,}8\frac{м}{с^2}}\right| = 6000\,м\cdot\ln\left|\frac{336{,}4}{216{,}4}\right| = 2647\,м.$$

Endi esa umumiy to‘xtash vaqti $t_{to'xt}$ hamda to‘xtash masofasi $s_{to'xt}$ ni aniqlaymiz. Bunda avtomobil motori o‘chgani uchun F=0 deb hamda avtomobil yurib borib to‘xtagani uchun $\vartheta=0$ deb olamiz.

$$t_{to'xt} = \frac{m}{\sqrt{\beta\left(fmg-F\right)}}\cdot arctg\left(\frac{\sqrt{\frac{\beta}{fmg-F}}\cdot(\vartheta_0-\vartheta)}{1+\frac{\beta}{fmg-F}\cdot\vartheta_0\vartheta}\right) = \sqrt{\frac{m}{\beta fg}}\cdot arctg\left(\sqrt{\frac{\beta}{fmg}}\cdot\vartheta_0\right) =$$

$$= \sqrt{\frac{1200\,kg}{0{,}1\frac{kg}{m}\cdot0{,}015\cdot9{,}8\frac{m}{s^2}}}\cdot arctg\left(\sqrt{\frac{0{,}1\frac{kg}{m}}{0{,}015\cdot1200\,kg\cdot9{,}8\frac{m}{s^2}}}\cdot40\frac{m}{s}\right) =$$

$$= 745\,s\cdot arctg\left(0{,}9524\right) = 567\ s = 9\min 27\,s.$$

$$s_{to'xt} = \frac{m}{2\beta}\cdot\ln\left|\frac{F-\left(fmg+\beta\vartheta_0^2\right)}{F-\left(fmg+\beta\vartheta^2\right)}\right| = \frac{m}{2\beta}\cdot\ln\left|1+\frac{\beta\vartheta_0^2}{fmg}\right| = \frac{1200\,kg}{2\cdot0{,}1\frac{kg}{m}}\cdot$$

$$\cdot\ln\left|1+\frac{0{,}1\frac{kg}{m}\cdot\left(40\frac{m}{s}\right)^2}{0{,}015\cdot1200\,kg\cdot9{,}8\frac{m}{s^2}}\right| = 6000\,m\cdot\ln\left|1{,}907\right| = 3873\ m.$$

XULOSA

Biz ushbu maqolada talabalarga umumiy tushunchalar berish maqsadida gorizontal tekislikda harakatlanayotgan jismga qarshilikli muhitning ta’sirini va bundagi harakat va tezlik tenglamalarini o‘rgandik. Lekin, hayotda bundanda murakkabroq holatlar uchraydi. Masalan, qiya tekislik bo‘ylab tepalikka ko‘tarilayotgan yoki pastga tushayotgan avtomobilning ishqalanish va havo qarshiligi ta’siridagi harakatini o‘rganish birmuncha murakkabdir. Undan tashqari havoning avtomobil harakatiga qarshilik kuchini ham tezlikning ikkinchi darajasi uchun (nisbatan yuqoriroq tezliklar uchun) o‘rganduk. Haqiqatda esa real sharoitda avtomobil tezligi oshib borib biror kritik tezlikdan oshganda qarshilik kuchi $F_{qar}\sim\vartheta$ bog‘lanishdan birdaniga $F_{qar}\sim\vartheta^2$ bog‘lanishga o‘tadi, shuningdek harakat va tezlik tenglamalari ham o‘zgaradi. Bularni birgalikda yechilishini o‘rganish talabalar uchun biroz murakkablik qiladi.

Qarshilikli muhitda jismning harakatini oʻrganishda, biz jismdagi qarshilik kuchini va shuning uchun jismning tezlik oʻzgarishini uning tezligining biror funksiyasi deb hisoblaymiz. Bunday qarshilik kuchlari odatda konservativ emas va kinetik energiya odatda issiqlik sifatida ajraladi. Bunday mavzuni oʻrganish hamda ularga oid masalalar yechish talabalarni ob'ektiv reallikka yaqinlashtiradi hamda tasavvur qila olish qobiliyatini oʻstiradi, shuningdek differensial va intgeral hisob-kitob ishlariga koʻnikma hosil qilishda yordam beradi.

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