# MOYLI KUCH TRANSFORMATOR TEXNIK HOLATI BAKINING VIBROAKUSTIK PARAMETRLARIGA ASOSLANGAN IMITATSION MODELIDAN FOYDALANGAN HOLDA EKSPRESS BAHOLASH

**I.K. Ismoilov**

***Fergana state technical university, Fergana, Uzbekistan***

***E-mail: i.ismoilov@ferpi.uz***

**Annotatsiya.** Moyli kuch transformatorlari elektr tarmog'ida elektr energiyasini taqsimlashning ishonchliligini ta'minlaydigan asosiy qurilmadir. Bu har bir elektr ta'minoti halqalarini bog'lovchi uchun yagona qurilma hisoblanadi. Moyli kuch transformatorlarining uzoq muddatli ishonchli ishlashi energiya tizimiga bevosita ta'sir qiladi va ba'zida baxtsiz hodisalarga olib kelishi mumkin. Moyli kuch transformatorlarining texnik holati uning asosiy qismlariing texnik holatiga bogliq. Ushbu maqolada moyli kuch transformatorining bakida ish ekspluatatsiya jarayonidagi vibroakustik parametrlarining nazariy va imitatsion modelida olingan natijalar tahlil qilinadi. Natijada moyli kuch transformatorlarining texnik holatini ekspress-baholash amalga oshirildi.

**Kalit so‘zlar:** Moyli kuch transformatorlari, vivratsiya, akustika, texnik holatni baholash, imitatsion model, noaniq mantiq, Mamdani usuli (Mamdani fuzzy logic), Matlab Simulink, issiqlik parametrlari, diagnostika va monitoring, aktiv quvvat yo‘qotishlari, Ekspress diagnostika

**Аннотатция.** Силовые масляные трансформаторы являются основными устройствами, обеспечивающими надежность распределения электрической энергии в электросети. Они являются единственными устройствами, связывающими каждый контур электроснабжения. Длительная надежная работа силовых масляных трансформаторов напрямую влияет на энергосистему и иногда может приводить к авариям. Техническое состояние силовых масляных трансформаторов зависит от технического состояния его основных узлов. В данной статье анализируются результаты, полученные в теоретико-имитационной модели виброакустических параметров в баке силового масляного трансформатора в процессе эксплуатации. В результате проведена экспресс-оценка технического состояния силовых масляных трансформаторов.

**Ключевые слова:** Силовые масляные трансформаторы, вибрация, акустика, оценка технического состояния, имитационная модель, нечеткая логика, нечеткая логика Мамдани, Matlab Simulink, тепловые параметры, диагностика и мониторинг, потери активной мощности, экспресс-диагностика

**Abstract**. Power oil transformers are the main devices that ensure the reliability of electric energy distribution in the power grid. They are the only devices that



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connect each power supply circuit. Long-term reliable operation of power oil transformers directly affects the power system and can sometimes lead to accidents. The technical condition of power oil transformers depends on the technical condition of its main units. This article analyzes the results obtained in the theoretical and simulation model of vibroacoustic parameters in the tank of a power oil transformer during operation. As a result, an express assessment of the technical condition of power oil transformers was carried out.

**Keywords:** Power oil transformers, vibration, acoustics, condition assessment, simulation model, fuzzy logic, Mamdani fuzzy logic, Matlab Simulink, thermal parameters, diagnostics and monitoring, active power losses, express diagnostics

**Kirish.**

Moyli kuch transformatorlari elektr energiya tizimlarining eng muhim elementlaridan hisoblanadi [2-7]. Butun sanoat tarmoqlari va aholi hayotiturmush tarzi ularning ishonchli va uzluksiz ishlashiga bog‘liq [1-9]. Vaqt o‘tishi bilan moyli kuch transformatorlarning asosiy elementlari turli omillar (elektr yuklama, ortiqcha qizish, tebranish va boshqalar) ta’sirida texnik holati yomonlashadi. Bu esa moyli kuch transformatorning texnik holati yomonlashishiga va ishdan chiqish xavfining oshishiga olib keladi [2-11]. Elektr energiyasiga bo‘lgan talab ortib borayotgani va elektr ta’minotining ishonchliligi talablarining kuchayishi sharoitida, moyli kuch transformatorlarda nuqsonlarni o‘z vaqtida aniqlash va bartaraf etish yanada muhim ahamiyat kasb etmoqda [8-19]. Shu sababli, hozirgi kunda moyli kuch transformatorlarni texnik diagnostika qilishning yangi, yanada aniq, informativ va tezkor usullari ishlab chiqilmoqda [2-12]. Diagnostikalash moyli kuch transformatorlarning ishonchliligini oshirish va avariyaviy o‘chirishlar xavfini kamaytirish imkonini beradi [2-12]. Diagnostikalash moyli kuch transformatorlarning ishlash sharoitlarini optimallashtirishga yordam beradi, bu esa ularning ekspluatatsiya xarajatlarini kamaytirishga olib keladi [15-23]. Diagnostikalash yordamida moyli kuch transformatorlarning ularni ta’mirlash yoki almashtirishga bo‘lgan ishlar optimallashtiriladi [22-30]. Yuqorida keltirilgan maqolalar moyli kuch transformatorlarini diagnostikalash dolzarbligini tasdiqlaydi [7-30]. Ularda turli diagnostika usullari, ularning afzallik va kamchiliklari, shuningdek, moyli kuch transformatorlardagi turli nuqsonlarni aniqlashdagi qo‘llanilishi yoritilgan [2-11].

O‘z vaqtida diagnostika o‘tkazish va nuqsonlarni aniqlash orqali transformatorlarni avariyaviy o‘chirishlarning oldini olish zarurligini ta’kidlaydi [2, 8-20]. Shuningdek, yangi texnologiya va usullarni qo‘llash orqali diagnostika samaradorligini oshirish masalalari ham ko‘rib chiqilgan [21-30]. Moyli kuch transformatorlarini diagnostika qilish ularni ekspluatatsiya qilishda muhim bosqich



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hisoblanadi [22-30]. Bu esa ushbu muhim energetika ob'ektlarining ishonchliligi, samaradorligi va xizmat muddatini uzaytiradi [8-23].

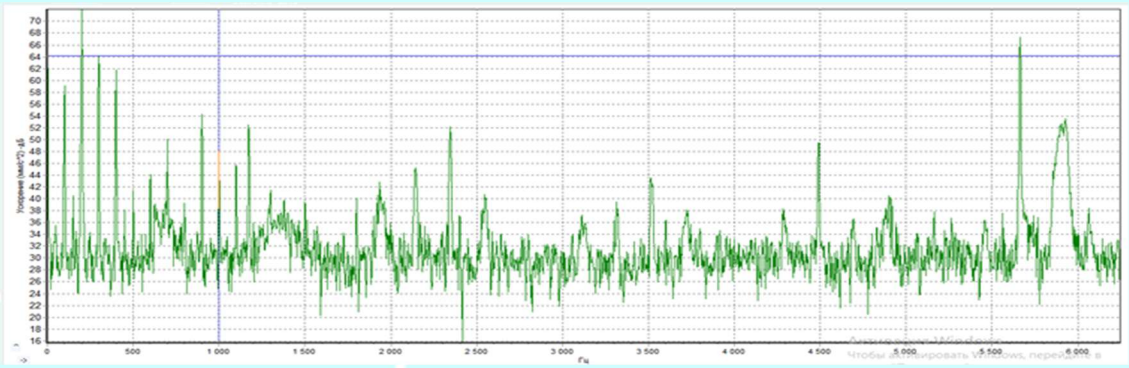
Hozirgi kunda moyli kuch transformatorlarni kompleks diagnostikalash, ya'ni turli diagnostika usullarini birgalikda qo'llash va joriy etishga tobora katta e'tibor qaratilmoqda. Sun'iy intellekt texnologiyalari rivojlanishi moyli kuch transformatorlarni diagnostika qilishda yangi imkoniyatlarni ochib bermoqda. Jumladan, noaniq mantiq (fuzzy logic) yordamida diagnostika natijalarini yanada aniq va samarali talqin qilish mumkin bo'ldi.

**Tadqiqot usuli.** 1974 yilda ishlab chiqarilgan TDTN-40000/110/35.10-U1 rusumli moyli kuch transformatoriga mavjud 110 kVli podstansiyada ekspress diagnostika o'tkazildi. Ekspress diagnostika davomida moyli kuch transformator bakining turli nuqtalarida 50-5000 Hz diapazonda vibroakustik parametrlar o'lchandi.

Moyli kuch transformatorlarining texnik holatini ekspress baholash uchun "agar–unda" (if–then) printsipiga asoslangan noaniq mantiq (fuzzy logic) qoidasi qo'llanildi. Ya'ni, agar magnit o'zak, chulg'am va moy yaxshi holatda bo'lsa, unda moyli kuch transformatori ham yaxshi holatda bo'lishi kerak.

Ushbu holatni ifodalovchi ko'rsatkichlar raqamli qiymatlarda berilib, lingvistik (so'zli) ko'rsatkichlarni raqamli ko'rsatkichlarga o'tkazish uchun bir qator maxsus qoidalar ishlab chiqilgan. Kiruvchi va chiquvchi o'zgaruvchilar o'rtasidagi bog'liqlik "agar–unda" printsipi asosida amalga oshiriladi. Chiqaruvchi va kiruvchi o'zgaruvchilar bahosi o'n xil belgidan biri bilan ifodalanadi: "A+", "A", "A-", "B+", "B", "B-", "C+", "C", "C-", "F", "F-".

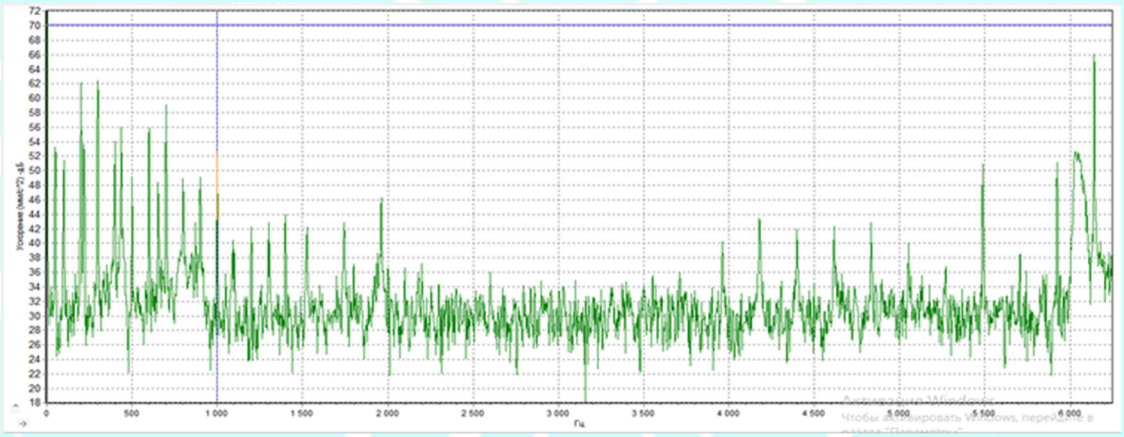
**Natijalar va muhokama.** Vibroakustik xususiyatlar 9 ta nuqtada o'lchab chiqildi. Quyidagi nuqtalarda minimal qiymatdan biroz yuqori tebranish darajasi qayd etildi: bakning pastki qismidagi ikki tomon, yuqori qismi, va bakning o'rta nuqtasining ikki tomoni. 50-1000 Hz chastota diapazonida tebranish darajasi o'rtacha bo'lib, 88 dB me'yoriy chegaradan ancha past ekanligi aniqlandi (1–3-rasmlar).



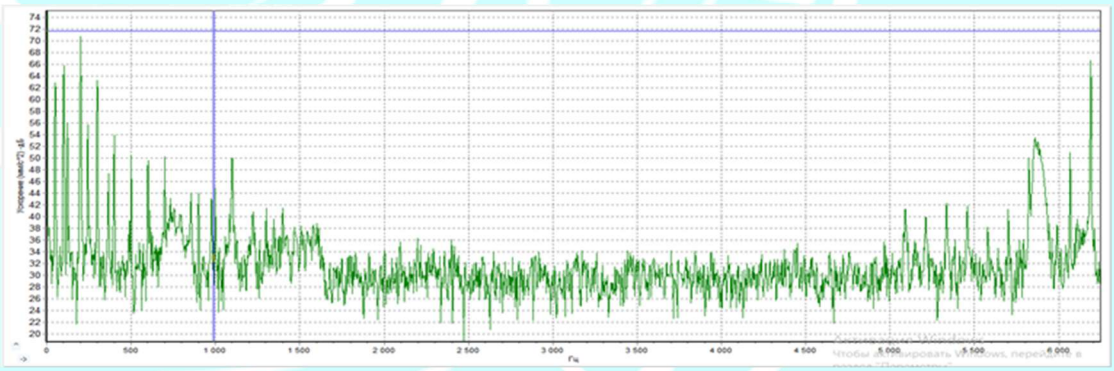
**1-rasm. Bakning yuqori tomoni (A faza), pastki qismining vibroakustik xarakteristikasi (TDTN-40 000/110/35/10)**



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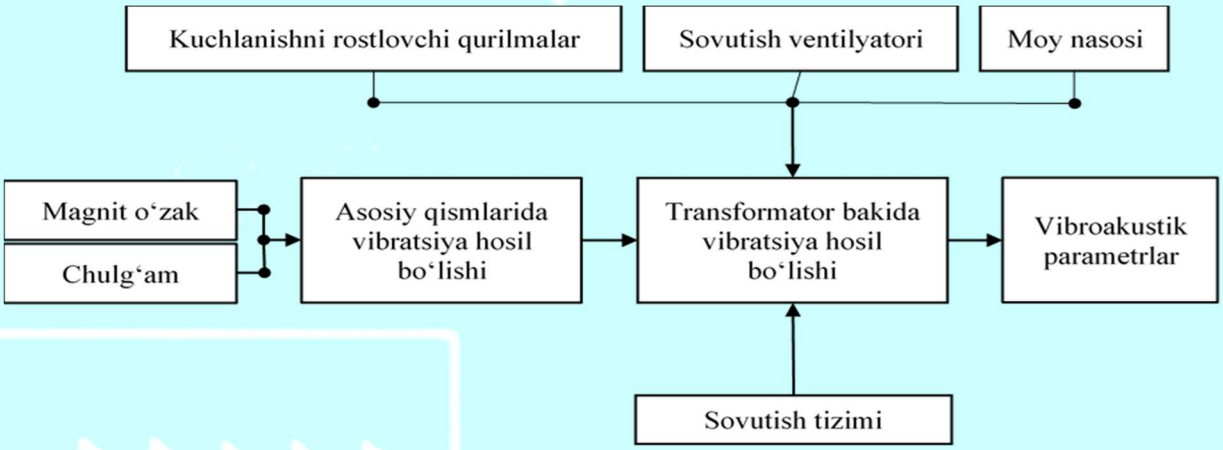
**2-rasm. Bakning yuqori tomonidagi pastki qismining (B faza) vibroakustik xarakteristika (TDTN-40 000/110/35/10)**



**3-rasm. Bakning yuqori tomonidagi pastki qismining (C faza) vibroakustik xarakteristika (TDTN-40 000/110/35/10)**

Natijalar 1000 Gts gacha bo‘lgan diapazonda tahlil qilinadi. 7 ta maksimum nuqta kuzatildi. Har bir maksimumda tegishli chastota va tovush tezlanishi mavjud. Masalan, 1-rasmda 100 Gts da 72 dB, 2-rasmda 450 Gts da 56 dB, 3-rasmda 600 Gts da 49 dB va boshqa maksimumlar uchun ham shu tarzda qiymatlar aniqlangan. Ushbu qiymatlar noaniq mantiq asosida tahlil qilinadi. Har safar chulg‘amdagi tezlanish moyli kuch transformatorining asosiy qismlaridan biriga mos keladi.

Moyli kuch transformatorlarida vibroakustik parametrlarni aniqlash jarayoni quyidagi blok-sxema yordamida bayon qilamiz (4-rasm).




**4-rasm. Moyli kuch transformatorida yuzaga keladigan vibroakustik parametrlari shakllanish jarayonini ifodalovchi blok-sxemsi**



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Moyli kuch transformatorlaridagi tebranish manbalari asosan uning aktiv qismlarida hosil bo‘ladi. Moyli kuch transformatorlarining magnit o‘zagi va chulg‘amlari asosiy tebranish manbasi hisoblanadi va ular ushbu tebranishlarni o‘zining asosiy qismlari orqali moyli kuch transformator bakiga uzatadi. Moyli kuch transformatori moyi esa bakka uzatilayotgan tebranish parametrlari o‘zgarishini ta’minlovchi asosiy muhit hisoblanadi. Moyli kuch transformatorning uzoq muddat ishlashi davomida, unda qisman razryadlar natijasida hosil bo‘ladigan mexanik cho‘kindilar va pufakchalar konsentratsiyasi oshishi natijasida moyning fizik-kimyoviy xossalari o‘zgaradi va bu bevosita uzatiladigan tebranish parametrlariga ta’sir qiladi. Shuning uchun, transformator moyining texnik holatini vibroakustik parametrlar spektri orqali baholash mumkin.

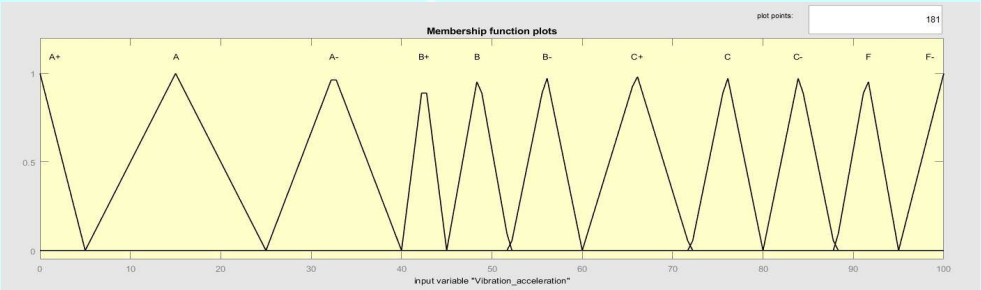
Moyli kuch transformator elementlari o‘zaro ta’sirlashayotgan kuchlar natijasida, ularning bir-biriga nisbatan fazoviy siljishi oqibatida yo‘qotishlar yuzaga keladi. Bu jarayonni quyidagicha bayon qilish mumkin.

$$\sum_i (F_i - m_i a_i) \cdot \delta r_i = 0 \qquad (1)$$

Bu yerda, i – moyli kuch transformatori elementlarining soni; $\delta r_i$ — transformator elementi fazoviy siljishi; $F_i$ — transformator tizimida hosil bo‘ladigan kuchlarning geometrik yig‘indisi. Ushbu formula D’Alembert prinsipi asosida uzluksiz tuzilmaning diskretlashtirilgan ko‘rinishida ifodalanadi. Natijada, transformator elementi uchun massa, qattiqlik va tebranish (dempferlik) xarakteristikasini o‘z ichiga olgan tenglama quyidagi ko‘rinishda yoziladi:

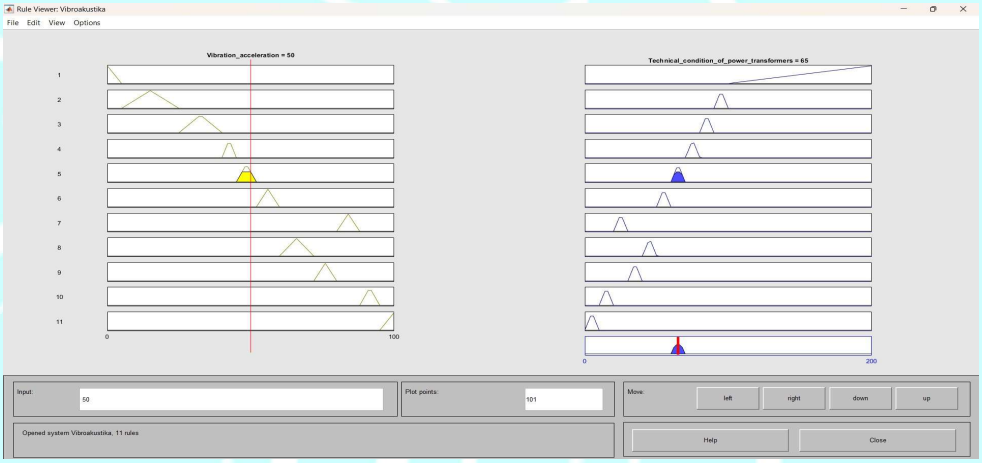
$$\{F(t)\} = [M] \cdot \{\ddot{u}\} + [C] \cdot \{\dot{u}\} + [K] \cdot \{u\} \qquad (2)$$

Bu yerda, $[M]$ - elementning konstruktiv massa matritsasi; $[C]$ - elementning viskoz so‘nish (dempferlik) matritsasi; [K] - moyli kuch transformator moyining qattiqlik (yoki elastiklik) matritsasi; $\{\ddot{u}\}$ - tugunlarning tezlanish vektori; $\{\dot{u}\}$ - tugunlarning tezlik vektori; {u} - tugunlarning siljish vektori; {F(t)} - kuchning vaqt bo‘yicha o‘zgarish funksiyasi. Ushbu ifoda transformator tizimining o‘tkinchi (transient), modalli (model) va garmonik (harmonik) xususiyatlarini ifodalaydi.

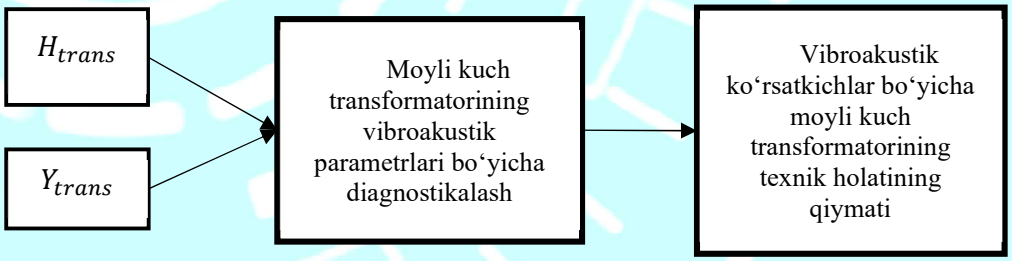



**5-rasm. Kirish o‘zgaruvchisi parametrlarning a‘zolik funksiyasidir**


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**6-rasm. Noaniq mantiqning Mamdani usulidan foydalangan holda “Moyli quvvat transformatori”ning texnik holatini ekspress diagnostikasining chiqish qiymatilari interfeysi**




**7-rasm. Moyli kuch transformatorining texnik holatini vibroakustik parametrlarga asoslanib aniqlashning tuzilma sxemasi**

Kirish va chiqish o‘zgaruvchilari uchun mos ravishda mansublik funksiyalari ishlab chiqilgan. Noaniq mantiq yordamida texnik holatni baholashda kirish va chiqish o‘zgaruvchilari uchun T, L, γ — sinflar bo‘yicha a’zolik funksiyalari aniqlanadi. Kirish va chiqish o‘zgaruvchilari o‘rtasida bog‘liqlik qoidalari o‘rnatilgan. Chiqish o‘zgaruvchisidagi har bir noaniq to‘plam uchun umumiy masublik funksiyasi aniqlandi. Chiqish natijasini olish jarayonida sentroid (markazlashtirish) metodi qo‘llanildi va quyidagicha ifodalandi:

$$\text{1-qoida: } W_{(V)1} = \min\left(\mu_{A+}(V_1), 1\right) \rightarrow \mu_{A+}(y_{trans(1)})$$

$$\text{2-qoida: } W_{(V)2} = \min\left(\mu_{A}(V_2), 1\right) \rightarrow \mu_{A}(y_{trans(2)})$$

$$\text{11-qoida: } W_{(V)11} = \min\left(\mu_{F-}(V_{11}), 1\right) \rightarrow \mu_{F-}(y_{trans(11)})$$

Chiqish o‘zgaruvchisidagi har bir noaniq (fuzzy) to‘plam uchun umumiy masublik funksiyasini aniqlash:

$$\mu^*_{A+}(y_{trans(1)}) = \max\left(W_{(V)1}, 0\right)$$

$$\mu^*_{A}(y_{trans(2)}) = \max\left(W_{(V)2}, 0\right)$$

$$\mu^*_{F-}(y_{trans(11)}) = \max\left(W_{(V)11}, 0\right)$$

Vibratsion tezlanish qiymati orqali moyli kuch transformatorining texnik holatini aniqlash jarayonida markazlashtirish (sentroid) metodi quyidagicha qo‘llaniladi:


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$$Y_{Trans} = \frac{\sum_{i=1}^{11} W_{(V)i} * \mu_i^*(y_{trans\,(i)})}{\sum_{i=1}^{11} \mu_i^*(y_{trans\,(i)})}$$

Tajriba asosida aniqlangan vibroakustik parametrlarga ko‘ra, moyli kuch transformatorining magnit o‘zagining texnik holati belgilangan tartib asosida, chulg‘am va moydagi shikastlanish belgilari bilan bog‘liq holda baholanadi.




**8-rasm. Moyli kuch transformatorining texnik holatini ekspress baholashning Simulink modeli**

8-rasmda keltirilgan simulyatsiya modeliga muvofiq, moyli kuch transformatorining texnik holati vibroakustik parametrlar asosida baholandi. Matematik model kiruvchi o‘zgaruvchilar qiymatiga qarab yutish (so‘nish) koeffitsiyentlari va transformatorning umumiy texnik holatini hisoblab chiqildi. Masalan, 1-rasmda -100 Gts da 72 dB maksimum; 2-rasmda - 450 Gts da 56 dB; 3-rasmda - 620 Gts da 49 dB va boshqa maksimumlar uchun ham shunga o‘xshash qiymatlar aniqlandi. Dastur natijalari bo‘yicha, 100 Gts da 72 dB maksimum har doim kuzatiladi va bu pik magnit o‘zakda magnitostriksiya natijasida hosil bo‘ladigan elektromagnit kuchlar hamda chulg‘amda elektrodinamik jarayonlar ta’sirida yuzaga keladi, va u tarmoq chastotasining ikki barobariga teng bo‘ldi. 450 Gts da 56 dB normal hisoblanadi, agar 60 dB dan oshsa, bu chulg‘amda axial siljish (o‘qi bo‘ylab siljish) mavjudligini ko‘rsatadi va 600 Gts da 49 dB - normal holat. Agar 60 dB dan oshsa, bu transformator magnit o‘zakining to‘yinganligi (saturatsiya) natijasida spektrda uchinchi va beshinchi garmoniklarning ikki barobar ko‘rinishini bildiradi. Agar magnit o‘zak yaxshi siqilgan (presslangan) bo‘lsa, qolgan garmoniklar deyarli kuzatilmaydi. Mexanik shikastlanishlar esa spektrda 400, 500, 600 Gts diapazonlarda harmonik maksimumlarning oshishiga olib keladi.

Xulosa. Moyli kuch transformatorlarining texnik holatini baholash uchun diagnostik parametrlar asosida ishlovchi imitatsion model ishlab chiqildi. Ushbu model transformatorning umumiy texnik holatini aniqlash va baholash imkonini beradi. Tashkillashtirilgan eksperimental tadqiqot natijalari asosida, model yordamida transformatorning muayyan qismi nosozlikka uchrashi ehtimoli va xavf zonalari oldindan prognoz qilinadi. Bu esa, ekspluatatsiyada ishonchlilikni oshirish va avariyaviy holatlarning oldini olishga xizmat qiladi.


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