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Sources of Vibration and Noise of High Voltage Transformer-Reactor Equipment

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Abstract. *The article provides an overview of the sources and nature of vibration and noise in transformer-reactor equipment. During operation at power facilities, transformer-reactor equipment produces noise that adversely affects the environment due to vibration of the active part of the equipment. Vibration affects the mechanical strength of a structure, leading to a reduced service life and increasing the likelihood of internal damage. Consequently, increased and long-term noise exposure is an unfavorable factor in the load on the environment. In this regard, the study of effective measures to reduce the noise and vibration level of transformer-reactor equipment of high and ultra-high voltage class is an urgent task. The reasons for the occurrence of noise and vibration, the main physical processes occurring in the magnetic circuit of transformer-reactor equipment and methods of reducing the noise level are considered.*

Keywords: *transformer-reactor equipment, noise, vibration, noise pollution, magnetostriction, magnetic circuit, electromagnetic force, electrical steel.*

Introduction

The production, transmission and distribution of electricity are fundamental aspects in the life and development of mankind, at the same time, this sector has a negative impact on the environment. In this regard, increasing attention is paid by the international community to the processes to reduce the level of the energy industry's impact on the environment. Measures and developments in this direction are mostly aimed at reducing the level of environmental impact during the production of electricity, but the equipment used in the distribution and transmission of electricity also has a negative impact. One aspect of these effects is noise generated by power equipment.

The impact of noise pollution on the environment and human health leads to the so-called noise diseases and is characterized by the following symptoms: a decrease in the level of auditory sensitivity, impaired digestion due to a decrease in acidity, cardiovascular failure. Personnel working in conditions of prolonged noise exposure experience irritability, headaches, dizziness, memory loss, etc. In addition, noise is a source of changes in the emotional state of a person [1, 2].

At the moment, the average noise level produced by transformers with a reactor power of 110-750 kV ranges from 59 to slightly more than 70 decibels (dB), according to sanitary standards, the permissible noise level that does not harm hearing even with prolonged exposure to the hearing aid is generally considered to be: 55 dB in the daytime and 40 dB at night [3].

Research findings

1. Sources and nature of noise in transformer-reactor equipment.

The main sources of noise in transformer-reactor equipment are vibration of the active part, operation of the cooling system fans, resonance phenomena arising in individual elements – coolers, tank walls, expander, pipelines, etc. (see Table). The magnetic circuit of a loaded transformer in the process of increasing magnetic induction changes its linear dimensions due to deformation of the crystal boundaries of electrical steel, which leads to vibration of the active part. The so-called process of magnetostriction [3, 4].

In magnetic systems of reactors with non-magnetic gaps, magnetic forces of attraction in the gaps can prevail. Magnetostriction is measured in relative units of change in length $\lambda=\Delta l/l$. The magnetostrictive elongation of a steel sheet can reach several tens of microns per meter of length. Together with magnetostrictive forces, magnetic attraction forces are manifested in the butt joints of laminated magnetic systems, flowing from sheet to sheet in air or oil gaps formed due to loose joining of electrical steel sheets, which prevails in reactors. The

Noise characteristics of the three-phase dry-type transformers with cast insulation	
Power (kVA)	Corrected sound power level no more than LPA, dBA
250	65
400	68
630	70
1000	73

resulting vibration occurs at twice the frequency of the mains voltage, since when the magnetic system of the reactors is reversible, the magnetic induction reaches a maximum two times in one period of the alternating current frequency, which corresponds to a two-fold change in the length of the steel sheets of the magnetic circuit.

The sound power levels of transformers are proportional to their weight and size parameters, although in practice this dependence can vary significantly under the influence of various design and technological factors. The vibrational energy generated by the active part is transmitted through the support of the equipment structure, which will lead to resonance of the walls of the expansion tank, stairs, transformer pipelines, increasing the low harmonics of sound. Consequently, the walls of the tank are reinforced with stiffeners.

2. Calculation of the sound power level.

Magnetic systems of transformers are characterized by a dense spectrum of natural frequencies in the range of 1-3 kHz, due to individual plates of electrical steel. In the thickness of the magnetic system, there are voids determined by the filling factor of the steel (not less than 0.97 in accordance with GOST 21427.2-83), which leads to high-frequency resonant vibrations of the plates and their sections. Also, the sound power level of transformers depends on the electrical power, and may vary depending on the complexity of the design and materials, induction or mass, while maintaining other characteristics [5].

The sound power level of the transformer is in direct proportion to the length of the rod of the magnetic system and is determined by the following formula:

$$L_p = L_V + 20\lg I + 10\lg S_O,\ [\text{dB}]$$

where I – longest rod length, m;

S_O – cross-sectional area of the rod, m^2;

L_V – vibration velocity, dB (with induction $B=1.6$ T, $L_V=70$ dB; a decrease in induction by 0.5 T provides a decrease in vibration velocity by 10 dB). The L_V value depends on the properties of the electrical steel.

3. Review of experimental work on the occurrence of vibration and noise by the method of finite element analysis.

High-frequency interference, the frequency of the mains supply in which various semiconductor devices operate, definitely affects the sound and vibration level of the transformer. Electric transformers operating in the intermittent arc melt mode have increased vibration activity. The oversaturation of the magnetic circuit as a result of remanent magnetization increases the sound level by 20-30 dB, and this is due to the resonances of individual plates of the magnetic system. In the work of Hyun-Mo An and other authors [6], using the finite element analysis (FEA) method, electromagnetic forces were experimentally tested and predicted in the short circuit mode of a dry transformer with a capacity of 50 kVA. The windings of the high voltage (20 sections) and low voltage (22 sections) transformer have been simulated. Using the KEA method, the directions of the electromagnetic forces (Figure 1), acting on each section of the windings of a dry transformer, the potentials of the magnetic vectors, and the magnetic flux density under short circuit conditions were calculated. The electromagnetic forces in the radial and axial directions (Figure 2, 3) depend on both the short-circuit current and the leakage flux density. These results were used to accurately predict the resulting mechanical forces based on structural characteristics such as stress distribution or deformation of the windings.

To calculate the electromagnetic forces, first of all, it is necessary to obtain the magnetic flux density by solving the vector equations of the electromagnetic potential [7, 8]:

$$\nabla^2 A = \begin{cases} -\mu_0 J\,(in\ windings) \\ 0\,(otherwize) \end{cases}$$

where $A=Az$ – the vector of the magnetic potential in the core window, J – current density, μ_0 – magnetic permeability, and then:

$$B = \nabla \times A = \vec{i}B_x + \vec{j}B_y,$$

where B – magnetic flux density (T) and, therefore

$$F = I(-\vec{i}B_y + \vec{j}B_x) = \vec{i}F_x + \vec{j}F_y.$$

The above formulas make it possible to calculate the magnetic field and magnetic forces in the transformer winding by the KEA method in the Ansys software package [9]. According to the results of calculations, the axial flux density gradually decreases from the middle to the ends of the windings, while the radial

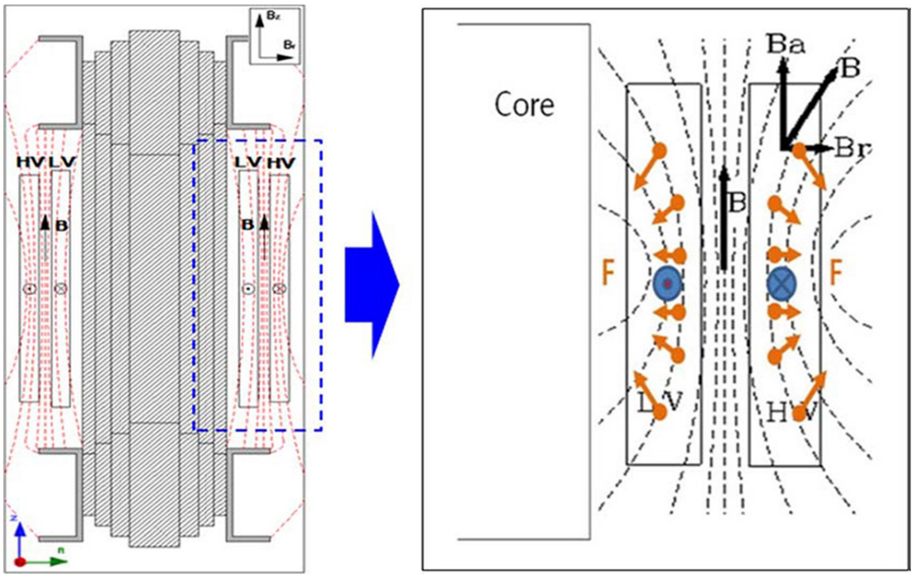

Figure 1 – Electromagnetic force, current and leakage flux in a transformer

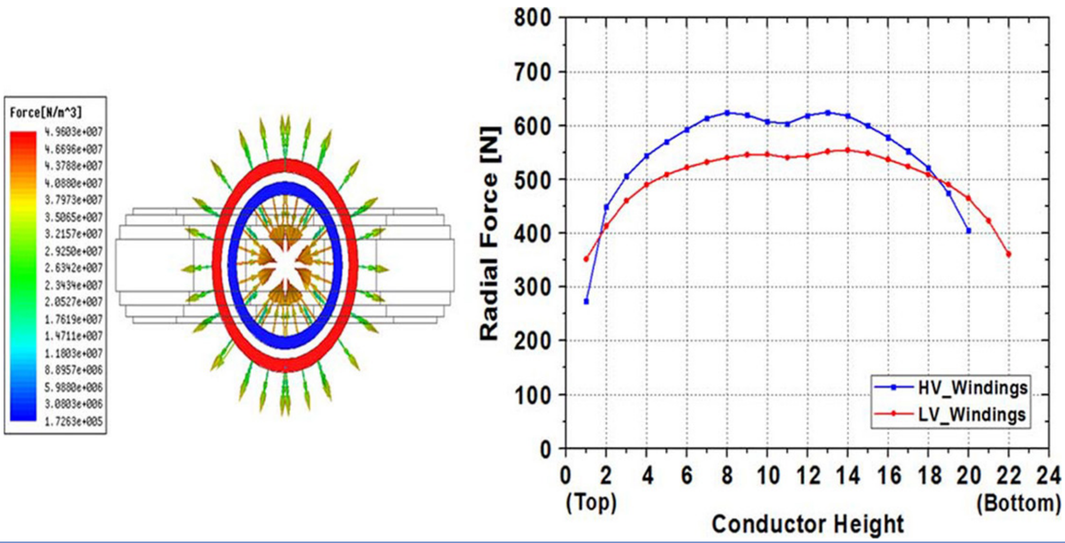

Figure 2 – Radial force of each section

flux density is lower in the middle of the windings, and much higher at the ends of the windings. The radial and axial components of the magnetic forces have a distribution pattern similar to the axial and radial magnetic flux density, respectively, whereas the axial force at the ends of the windings is opposite in direction and much higher than in the middle of the windings. Work accurately simulates the force to analyze the mechanical strength of the windings.

Reducing the noise of transformers is associated with solving problems in the field of acoustics, vibration, dynamics, mechanics, materials science and electrical engineering. The development of an action plan to reduce the noise of transformer-reactor equipment should be preceded by a vibroacoustic survey of the electrical installation room, workplaces and directly sources of increased noise. Work to reduce noise should begin with the elimination of resonant vibrations of the tank structure and coolers. Further, it is envisaged to eliminate vibration and noise of the internal parts of the transformer, which can be carried out, for example, during scheduled preventive or major repairs.

Also, the vibration of the transformer is transmitted through the foundation on the structure of the building in which it is installed, as a result of which it begins to emit its own low-frequency noise. Therefore, the foundation for the transformer should not have any connection to the building structures. Reducing the impact of vibration of the transformer on the environment is achieved by a multiple increase in the mass of the foundation for the transformer, it

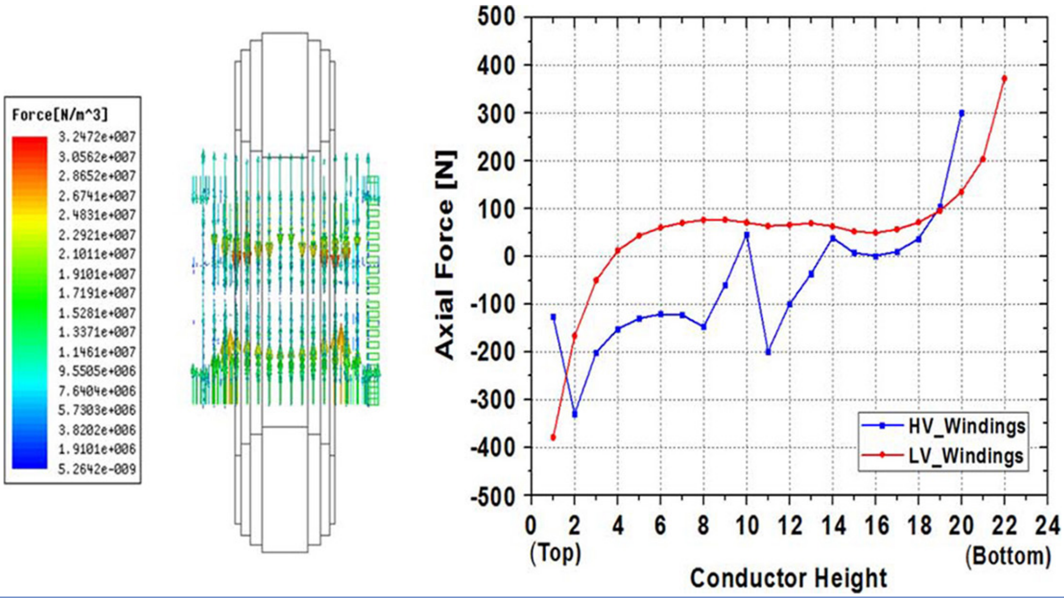

Figure 3 – Axial directional force of each section

should exceed the mass of the transformer at least by a factor of 10 [10].

Mechanical impact on electrical steel increases its magnetostriction and, consequently, the noise of the transformer; such impact should be avoided when working on the active part. The same effect on steel is exerted by its compression in the direction of rolling. Therefore, the press-in of the magnetic system and windings must comply with the factory recommendations. Inadequate pressing can create preconditions for resonances of both the entire active part and its elements, up to a separate plate of electrical steel. Therefore, it is advisable to control its frequency of free vibrations when carrying out work on the active part.

Conclusion

To date, special attention is paid to the issue of the influence of vibration of reactor equipment in order to increase the service life. In this connection, the article provides an overview of works on the study of the occurrence of the nature of vibration and noise in transformer-reactor equipment of high voltage. Over the entire period of operation, due to vibration of the active part, first of all, the wear of the insulating parts occurs, which in turn will lead to frequent overhauls and the unusability of the insulating parts. Also, long-term noise exposure is an unfavorable load factor on the environment, accompanied by symptoms of noise sickness of electrical personnel.

In Kazakhstan, work on the study of noise and vibration of transformer-reactor equipment in order to increase the life cycle and reduce harmful noise impact on the environment is carried out at the production base of the Asia Trafo plant. The plant is part of the Alageum Electric group of companies. The company's specialists with years of experience in the production of transformers and reactors are working on the creation of a reactor with improved vibration and noise characteristics, using electrical steel with low specific losses of 0.95 W/kg. The new design is aimed for a longer service life than older counterparts and lower noise levels.

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Жоғары кернеулі трансформаторлы-реакторлық қондырғылардағы діріл мен шу көздері

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***Аңдатпа.** Мақалада трансформаторлы-реакторлық қондырғылардағы діріл мен шуылдың көздері мен сипаты туралы шолу берілген. Энергетикалық нысандарды пайдалану кезінде трансформаторлы-реакторлық қондырғылардың белсенді бөлігінде болатын дірілге байланысты қоршаған ортаға теріс әсер ететін шу шығарады. Діріл қондырғы құрылымының механикалық беріктігіне әсер етуі нәтижесінде қызмет мерзімі қысқарады және ішкі зақымдану ықтималдығы артады. Демек, шудың жоғарылауы және ұзақ мерзімді әсері қоршаған ортаға қолайсыз жүктеме факторы болып табылады. Осыған байланысты, жоғары және өте жоғары кернеу классты трансформаторлы-реакторлық қондырғылардың шу мен діріл деңгейін төмендету бойынша тиімді шараларды зерттеу өзекті міндет болып табылады. Шу мен дірілдің пайда болу себептері және трансформаторлы-реакторлық жабдықтардың магниттік тізбегінде болатын негізгі физикалық процесстер, шу деңгейін төмендету әдістері қарастырылады.*

***Кілт сөздер:** трансформаторлы-реакторлық қондырғы, шу, діріл, шудан ластану, магнитострикция, магниттік тізбек, электрмагниттік күш, электртехникалық болат.*

Источники вибрации и шума трансформаторно-реакторного оборудования высокого напряжения

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***Аннотация.** В статье приведен обзор об источниках и характере возникновения вибрации и шума трансформаторно-реакторного оборудования. В процессе эксплуатации на энергетических объектах трансформаторно-реакторное оборудование производит шум, неблагоприятно воздействующий на окружающую среду, за счет вибрации активной части оборудования. Вибрация влияет на механическую прочность конструкции, приводя к снижению срока службы и повышая вероятность возникновения внутренних повреждений. Следовательно, повышенные и длительные шумовые воздействия являются неблагоприятным фактором нагрузки на экологию. В этой связи исследование результативных мер по снижению уровня шума и вибрации трансформаторно-реакторного оборудования высокого и сверхвысокого класса напряжения является актуальной задачей. Рассмотрены причины возникновения шума и вибрации, основные физические процессы протекающие в магнитопроводе трансформаторно-реакторного оборудования и способы снижения уровня шума.*

***Ключевые слова:** трансформаторно-реакторное оборудование, шум, вибрация, шумовое загрязнение, магнитострикция, магнитопровод, электромагнитная сила, электротехническая сталь.*

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