SUMMARY

The statistics of the last decades shows the fact that the stator cores have become the main unit responsible for limited service lifetime and low reliability indices of large turbogenerators.

The most distributed defects are as follows:
- self-unscrewing of pressing rings fastening nuts,
- tears off of threaded tails of stacking ribs,
- loosening of the core radial connections with the stacking ribs in the stator top part, bends and tears off in cantilever sections of active sheet steel in the teeth zone,
- emerge of local overheating due to pressing down fingers insulation covering abrasion and fracture determination of glued end packages.

These defects in some cases caused heavy damages of the stator winding.

Due to decreasing of the stator unit operation reliability carrying out of expensive repairs in the plant conditions or the stator replacement at site of installation as soon as calculated service lifetime (or in the case of the stator core service ability) end.

There is misunderstanding in power processes in the stator cores. Despite the application of method of “short time replacement” of stator core-and-winding assembly by some of leading firms the main cause of the paradox remains unknown.

We have performed the analysis of the extensive statistical materials and, the most important thing is new measurements of axial vibration components and variable mechanical stresses in the stator core at mounting places of large turbogenerators. The last revealed that the main cause of the paradoxical situation is in misunderstanding of force processes in the stator core.

It was found that in the stator core the complex of internal forces of the same order as the forces of magnetic tension in air gap emerges. Therefore designing conceptions and maintenance of large turbogenerators shall be reviewed with allowance for those forces.

Those electromagnetic (“ponderomotoric”) forces emerge as a result of electric current interaction. According to the classic theories in the coreless coil with electric current such forces has axially pulling and radially pushing character. The same phenomena originate in
every part (tube) of magnetic flux in ferromagnetic volume by action of “tied” (Amper’s) currents.

As a result inner pressures emerge in the same direction inside ferromagnetics. Their value is proportional to the square of the flux tube induction.

The frequency of these pressures alternation is twice more than the frequency of alternating inductions value. Axial electric-mechanical forces influence harmfully to reliability of turbogenerator stators due to resonance phenomena, that originate in the operation period as a result of stacking pressure decreasing. These dangerous vibromechanical cases are the main cause of defects listed above.

For the most of the generators in operation the necessary innovations can be put into practice at the power plant during the process of rehabilitation works.

The paper represents a new approach to condition estimation, modernization and put in to practice of the new methods of further technical maintenance of large turbogenerators. Put in to practice of these innovations let greatly increase reliability indices and service life of powerful turbogenerators which are in operation now.

KEYWORDS

Turbogenerator, stator rehabilitation, innovation approach.
THE HISTORY OF THE PROBLEM

In the 50's during development of power plants in Ukraine and Russia in power units rated over 100 MW began showing the defects of the stator cores in two main areas of active part:

– in the zone of the yoke namely increased vibration and noise of the casing, insulation wearing out of the steel sheets;
– in the teeth zone namely deformation and fracture of the steel sheets.

In 60's SEP “Electrotyazhmash” spent a lot of money and time in order to rebuild the stator core of the turbogenerator rated 300 MW and 3000 rpm from the radial resonance frequency [1], then vibration activity of the yoke was abruptly reduced and the above mentioned defects have been eliminated.

In few years during routine inspections of the generator stators of TGV series rated 200 MW and 300 MW some cases of nuts unscrewing the pressing down flange, which preceded the destruction processes of latching parts were detected. Then some cases of rib endings rupture [2] were detected.

The character of damages is in fatigue fracture of the rib endings which as time progresses. In 2004 at turbogenerator of Trypolskaya TPP simultaneously several rib endings had raptured. Analogous fatigue fractures of the tails of the studs were observed in the stators of hydrogenerators [1].

The analysis of considered statistic data, reports of damages investigation and also additional information from some sources let mark the following the most significant moments which characterize emerge of defects in fastening units of the pressing down flanges.

1. Rapture of rib endings and wearing out of their threaded part uniquely has fatigue character.
2. The most frequent group damages of the rib endings (3 and more) marked in 10 cases of 14 considered ones.
3. Group damages of ribs were concentrated in the top half of the stator core.

Marked above “symptoms” uniquely lead to the following conclusions on causes of emerge of considered defects.

First, the nature of the break indicates that in addition to the static pressure from the pressed core on the pressing down flange alternating forces are also act. In domestic and international practices of turbogenerators [5] designing determining and taking in to consideration influence of such alternating loads never took place. And as a result axial vibration of the pressing down flanges up to the latest past years also not systematically measured.

First availability of such vibration “Electrosila” noticed during the process of finishing of turbogenerators TVV-1000-2 rated 1000 MW.

At first the cause of such defects was considered to be a violation of pressing tightness of stacked up cores, which in the 70's - 80's were devoted dozens of articles and patents.

It is undeniable that disturbance of pressing tightness is a violation of one of the accompanying factors, but according to the canons of classical mechanics of solid fatigue fractures can occur only as a result of sufficiently powerful axial alternating forces.

In recent years, increased the urgency of the problem of reliability of the stator cores due to three factors [3]:

– a growing number of turbogenerators has service life close to the established specifications for them, or exceed it;
– many of turbogenerators due to mode conditions are operated at increased voltage and (or) with high power factor and (or) in modes of the reactive power consumption;
– decreased quality of maintenance and repair.
These factors facilitate to a weakening of pressing tightness of the face end zones of the core giving rise to defects. Most often, these defects are detected during testing and diagnostic procedures or inspections during scheduled repairs. Weakening teeth pressing and fluff in the face end zone leads to vibration of active steel sheets under the influence of alternating axial electrodynamic forces and fatigue damage, followed by chipping fragments, which is very dangerous and restricts operation of turbogenerator.

Most often severe destruction of these areas, often leading to emergency outages occur in turbogenerator rated 165-300 MW, manufacturing up to 1975 with not baked utmost packages of cores [4].

At designing of turbogenerators with baked utmost packages of the stator cores expressed hope that such damages shall not occur. However, the subsequent operation and inspection of turbogenerators have shown that they have the utmost package teeth damages, although much less frequently, than in turbogenerators with not baked packages. At few turbogenerators due to that cause emergency switchings off were taken place.

The greatest danger is chipping in the area of ventilation ducts, which as a rule usually begin with mechanical damage delaminated vibrating sheets of active steel on ventilation spacers and further developed by rapture of sheets along ventilation spacers and their fracture in teeth depth. Destructions distributed to a considerable depth of the teeth, as well as the speed of development of active steel damages increases. Characteristic feature of the considered stage of defect is wearing out of ventilation spacers and pressing down fingers. In some cases ventilation spacers are completely destroyed to a depth of 50 mm, and are worn out per 1-3 mm of the spacer thickness to a depth of 150 mm or more from the surface of the stator bore.

It is considered that one of the most effective decisions of this problem is development and introduction of new methods of technical diagnostics, which allows a reliable estimation of the technical state of equipment to develop a set of recommendations for maintenance and operation, prolong service life and optimize the cost of repairs and upgrades through timely detection of defects and most worn out units of generators.

However, excessively high repeatability of similar defects in the vast park of turbogenerators of various designs suggests that damage to the teeth zone of the stator core is a consequence of the deeper reasons than those listed in [3,4].

Diagnostics, as well as in medicine, the ill or aging system needs, and here we are clearly dealing with a kind of pathology, laid in at developing of machines.

In order to clarify the causes of axial vibration emerge plant “Electrotyazhmash” carried out a very important experiment namely at turbogenerator rated 320 MW at testing at the stand static and dynamic components of the tensile stresses (8 strain gauges) were measured. At no load running duty with rated voltage the dynamic component (double amplitude at frequency of 100 Hz) was 51% (!) from the static one (at pressing pressure of 1.2 MPa). Action of external forces in that mode was insignificant.

If, moreover, considering that in the process of stators testing for an annular magnetization there are no external fields, and noise and vibration are very important, it becomes apparent that this is the result of internal forces arising in the laminated stator core.

**NATURE OF THE INTERNAL FORCES**

Although the modern theory of electrodynamics there is no information about the decision of this problem, it contains two fundamental principles upon which we have been able to find a solution.
First it is indicated that the magnetic interactions are always a consequence of all types
electric charges motion, i.e. electric currents of any nature - conduction, displacement, transit
including related the existence of which A. Amper predicted in the ferromagnet in 1820 (Ampere's theorem).
Second, in the “magnetostatics” – the use of associated currents is given as an alternative
description of the magnetic field in the ferromagnet when any tube of the field the value
of associated current $i$ is determined only by the value of induction in the section $B$
$$i = \frac{B}{\mu_0}.$$ (1)
Although A. Ampere formulated his theory as applied to the calculation of the field of
the permanent magnets, the ratio (1) can be used for “soft” ferromagnetic materials
(electrotechnical steel) with an error of not more than $(100/\mu)\%$.
We found that in the solenoid of length $L$ and cross-sectional radius $R$ on condition
that $L \gg R$ interaction of associated currents leads to the emergence of the internal radial
push pressure
$$p_i = 0.5\mu_0 i^2 \approx 0.4 B^2 \ [\text{MPa}].$$ (2)
A tube filled with ferromagnetic of the same dimensions experiences the same pressure.
Outside of such objects induction is zero, therefore they do not interact with each other
through empty space. This is possible to obtain only by a mechanical contact of such elements
(“threads” or “bars”) of ferromagnetic, regardless of the shape of their cross section. This
means for example that the pressure of the axial (cross-laminating) push pressure is developed
in each package of the stator core.
To include the effect of dynamic loads in strength calculations decided to use peak
values of pressures considering the dynamic coefficient $k_d$
$$p_d = k_d \cdot p_i = k_d \cdot 0.4 B_m^2,$$ (3)
where $k_d = \sqrt{1 - (2f/f_r)^2}$, $B_m$ – amplitude of induction changes with frequency $f$, $f_r$ – the
resonant frequency of the oscillating unit.
At the first stage of researches for finding the axial pressures diagram the "integral"
method was used. As per this method the pressure on (2) was calculated sector-wise on the
basis of integral parameters of the magnetic field in the stator core
– maximal induction value in the yoke $B_y$,
– design induction value in the tooth $B_{t13}$.
At estimation of stresses in the rib endings diagrams of average axial pressures per
sector were calculated on the assumption of a sinusoidal distribution of induction by sectors
(maximum induction in the yoke – on the axis $q$, and in the teeth – on the axis $d$).
For the idle mode of turbogenerator TGV-320-2P the results of evaluation as per this
method gave good agreement with the tensometry data from the experiments. The axial
pressure diagram is shown in Fig. 1 (solid line for the yoke, dashed for the teeth). Based on this
diagram the deformation of the units of stator ending zone was calculated using the 3D model.
Results are presented in Fig. 2.
Application of the integral method for the 320 MW turbogenerator with similar geometry
of the stator core ($Z_s = 60$) and in the same load modes gives the following relation
between static $p_0$ and dynamic (pulse or peak) $p_d$ pressure values $p_d \approx p_0$ for the yoke and
$p_d = 1.5 p_0$ for teeth.
Fig. 1 – The pressure diagram of the stator core

Fig. 2 – The dynamic stresses diagram of the stator rib endings
For the turbogenerators of TGV and TVV series as for all operated ones the calculation of the stator core strength in axial direction in the design of turbogenerators was carried out only at the basis of static pressures \( p_s \). Naturally the question arises namely why in TGV-300-2 only the tails of the ribs are treated and TVV-320-2 only teeth zone is damaged? It appeared that in TGV-300-2 the moment of resistance to banding of the pressing down fingers is in 3 times more and the strength margin of the tails of the ribs is three times lower than in TVV-320-2.

In other words not mode peculiarities but flaws in predicting, manufacturing and maintenance are the basic cause of unreliability of the stators of modern turbogenerators.

On the background of 21-th century achievements actually paradoxical situation takes place at which the stator core as typical stationary unit with low mechanical electric and heat loads appeared the most weak unit decreasing reliability and service life of turbogenerators in the world energetics.

Its basic cause is that in the contrary to the laws of the classic electric dynamics power transfer in the stator core of turbogenerator takes place not from external part but inside the ferromagnetic material.

As a consequence, it is accompanied with significant internal power effects which emerge in all types of electric machines.

Basics of scientific, technical, organizational and production ensuring of the implementation of a new approach in order to increase the vibration resistance of the stator core of powerful turbo-generators can radically solve the problem of improvement of the reliability and service life.

The quickest and the most efficient way to perform these works is to carry them out at the plants-manufacturers [5]. Whereas it does not require any technical upgrading. And on the contrary – it is possible to refuse some useless processes like gluing sheets of steel or welding of them to the ribs – it would be enough to apply the classical core assembly segments made of lacquered steel.

Realization of these works in the rehabilitation of existing equipment is somewhat more complicated, but our experience [6-7] also provides grounds for organization of such works for the on-site installation of the turbogenerator. This can be performed on cores that do not have multiple damages of sheets insulation and places of “burning in steel” in the center part of the tooth area. Developed original technological devices allow to execute regenerative repair and modernization of the core with the removal of pressure flanges with no use of hydraulic presses.

Additionally, in the rehabilitation process innovations to expend the range of permissible loads, including the increase of active power by 10-20% can be implemented.

Complex of similar innovations can be offered either to provide vibration resistance of laminated magnet circuits or other types of large electrical machines and transformers [8].

**PROCEDURES ON ENHANCEMENT OF VIBRATION RESISTANCE OF STATOR CORE TO THE ACTIONS OF AXIAL FORCE**

Main stages of work performance on realization of new principles of designing and service maintenance of stator cores of turbogenerators summer down to the following.

1. The analysis of maintenance vast experience (mode, localization and frequency of defects occurrence).
2. The analysis of vibration resistance of original (basic) construction based on the calculation of assurance factors in core parts and units at the influence of static and dynamic
loads. Issuing of expert reports and preliminary suggestions as per elimination of production and maintenance demerits.

3. Supplemental inspection of one of the operating turbogenerators of “basic” construction after setting of axial vibration detectors.

4. Development of a set of measures to improve the vibration resistance and plan of organizational and technical work on their implementation.

5. Approbation (verification) of effective implementation of innovations in the course of a standard set of tests on the turbogenerator at the plant and (or) in operation.

6. Development of supplements to guidance materials for operation and repair regarding realization of vibration monitoring, diagnostics and preventive maintenance work in order to maintain a high level of vibration resistance of the stator core.

CONCLUSIONS

1. Internal electrodynamic forces occur in stator cores of turbogenerators in the amplification process of the magnetic field inside them. The axial components of these forces acting across the laminated arrays are the most dangerous.

2. Damages of fasteners and active steel of the cores are the direct result of the fact that until recently the dangerous action of the axial electrodynamic forces are not taken into account in the design process of stators.

3. New scientific and technical basic concepts and the organization of maintenance of turbogenerators were developed.

4. They should be used in the process of modernization of turbogenerators at the plant, and during rehabilitation at site.

5. Similar approaches to increase vibration resistance can be applied in practice and operation of hydrogenerators and power transformers.

BIBLIOGRAPHY


[8] Bondarenko Yu.N., Kuzmin V.V., Shpatenko T.V., Bondarenko Ya.Yu., Shpatenko V.S. New principals of designing and maintenance of stacked up magnetic conduits let many times increase resource of hydrogenerators and transformers at hydro power plant. (Hydro power of Ukraine, 2014. № 1)