24th International Conference on Renewable Energies and Power Quality (ICREPQ'26)
Santander (Spain), 10th to 12th June 2026 №310-26

Electromagnetic Forces and Mechanical Stresses in the Outer Segments of Turbine Generator Stator

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INTRODUCTION

During operation of high-power turbine generators (Fig.1) in renewable energy grids, especially in underexcitation conditions, segments of the outer stator packages can gradually fail. Breaking off particles of electrical steel exposed to magnetic fields can damage the insulation of the turbo generator stator winding. Current technical solution do not completely eliminate the problem.

The objective of this study is to determine the electromagnetic forces, bending moments and mechanical stresses in the segments of the outer stator core packages and to establish criteria for fatigue failure of stator core segments.

ELECTROMAGNETIC FORCES DENSITY

The force waves act in opposite directions on the outer and inner surfaces of the segment, creating force wave.

$$p_z = (b_{z1}^2 - b_{z2}^2)/(2\mu_0) = 0.2\, B_e^2(y)\, cos[2\omega t - 2\alpha x - 2\phi],\ MPa \qquad (1)$$

The equivalent force increases as the segment detaches from the stator stack. The force wave density is concentrated at the edges of the teeth. This enabled the use of an equivalent concentrated force in computation.

BENDING MOMENTS IN RADIAL AND TANGENTIAL RESTRAINT

When moments calculation the Saint-Venant's principle was applied.

$$m_x = 0.2 l \Delta D B_{em}^2 cos(2\omega t - \alpha D - 2\phi),\ MHм \qquad (2)$$

The bending moment relative to the radial restraint (Fig. 2a) is similar to the moment of a cantilevered beam and is proportional to the equivalent force at the edge of the tooth and the arm of this force from its application up to the restraint line.

$$m_y = 0.1 \Delta d^2 B_{em}^2 \cos(2\omega t - \alpha d - 2\phi),\ MHм \qquad (3)$$

The bending moment relative to the tangential restraint (Fig.2b) is equal to the product of the equivalent force concentrated on the radial edge of the tooth in the center between the tangential edge of the segment and the restraint, and the arm of this force up to the restraint line.

COMPARISON OF STRESSES

The difference (Fig. 3, 4) is that the tangential restraint is not subject to an impact averaged over the width of the tooth, but to a direct impact of the maximum values of the force wave. Therefore, one can expect the onset of segment failure from a rupture along the tangential restraint line from the edge of the tooth. Thus, delaminations with tangential restraint are more dangerous.

As can be seen, for example, from Fig. 4, with an axial induction exceeding 1 T and delamination from the tangential restraint by 10 mm or more, the bending stresses in the restraint exceed the fatigue strength limit of segment.

CONCLUSION

1. In low and medium power turbine generators up to 300 MVA with end area axial induction of less than 1 T, bending stresses, as a rule, do not exceed permissible values.

2. In turbine generators with a capacity of over 300 MVA, electromagnetic loads, including axial induction, increase in the end area, and special design solutions are required to prevent delamination of the outer segments and limit bending stresses

3. A widely used technical solution for limiting the impact of axial stator winding leakage fields on the main core stacks is the use of outer stepped beveled stacks in the form of magnetic shunts.

4. To improve the mechanical strength of the outer segments, it is recommended to make them from isotropic electrical steel.

5. Delamination of segments with tangential restraint leads to dangerous stresses at distances an order of magnitude smaller than for radial restraint of the segment. If admissible stresses are exceeded, the initial rupture of the segments may occur along the tangential restraint in the radial direction.

6. It is recommended to place the tangential restraint (tooth support or vent finger) at a distance of less than 10 mm from the lateral edge of the segment and to structurally secure the segment edges to prevent delamination.

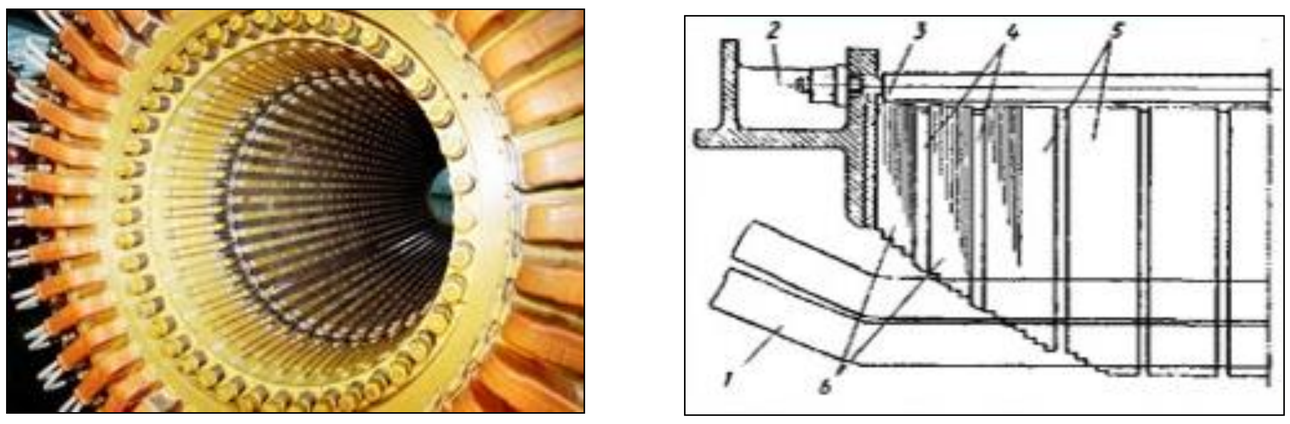

Fig. 1. The end part of power turbine generator stator. 1 – stator winding; 2 – pressure plate; 3 –electromagnetic shield; 4 – pressure fingers; 5, 6 – stator core packets

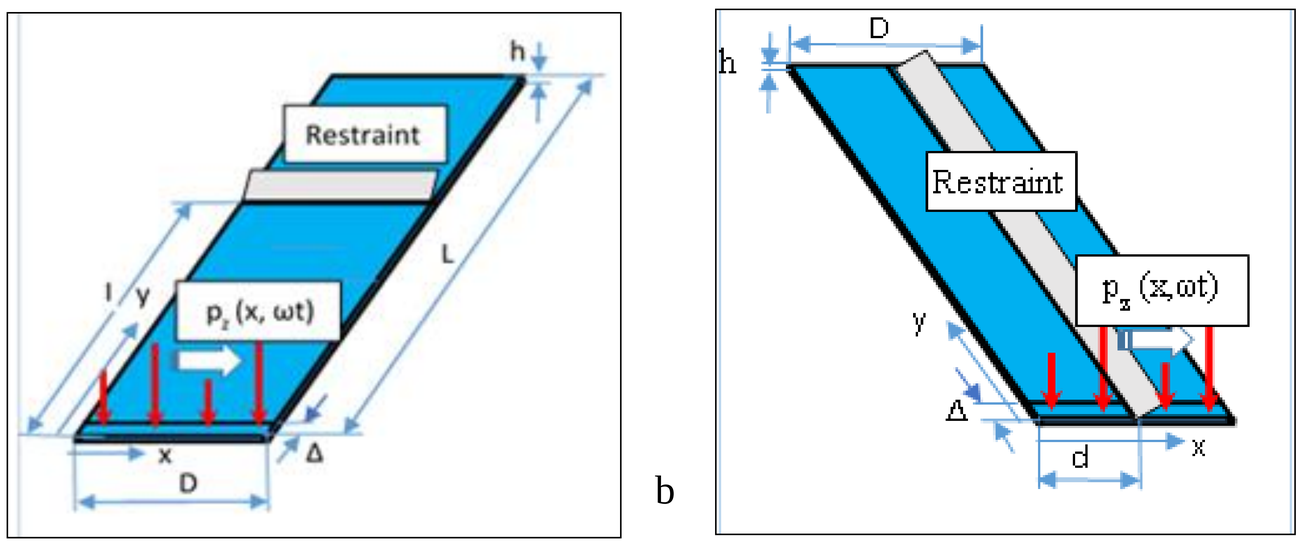

Fig. 2. Computational model of the tooth of outer stator segment with radial (a) and tangential (b) restraint

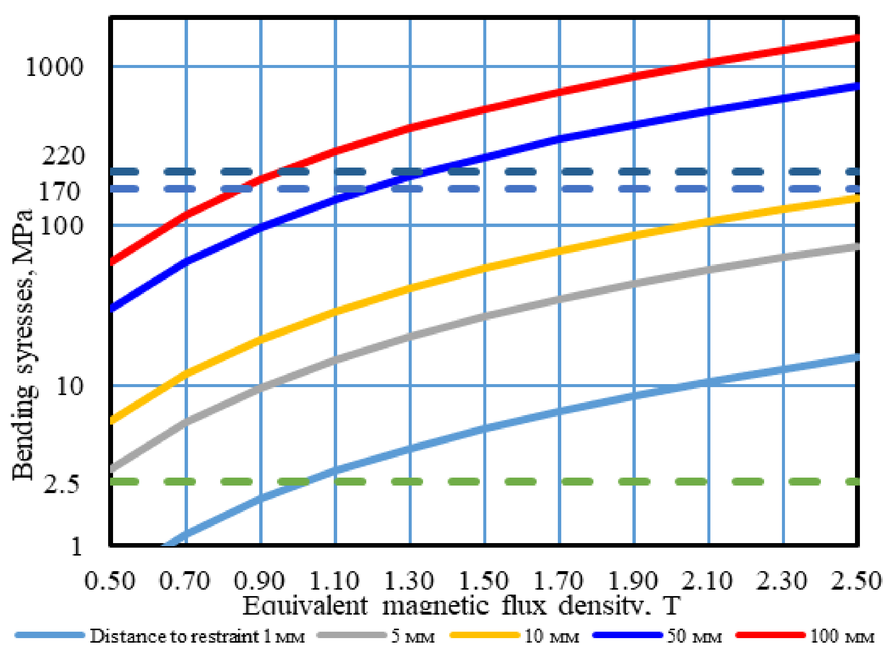

Fig. 3. Bending stresses in radial restraint

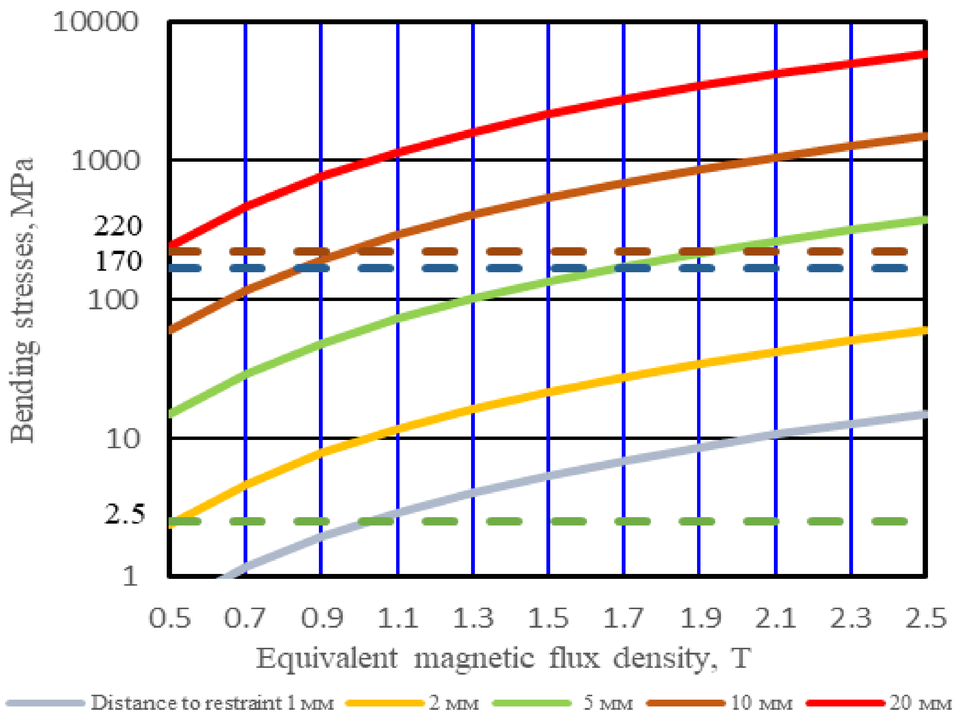

Fig. 4. Bending stresses in tangential restraint