TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
ELECTRICAL ENGINEERING | ELEKTROTECHNIKA

1-E/2015

ANDRZEJ BYTNAR*, SŁAWOMIR WRÓBLEWSKI**

ONLINE DIAGNOSTICS OF THE TECHNICAL CONDITION OF THE TURBOGENERATOR STATOR CORE SUSPENSION

DIAGNOSTYKA ONLINE STANU TECHNICZNEGO ZAWIESZENIA RDZENIA W KORPUSIE STOJANA TURBOGENERATORA

A b s t r a c t

This paper presents a method for the continuous technical diagnostic of the core suspensions at selected measurement points of the turbogenerator stator. The method extends diagnostic capabilities of a turbogenerator vibration monitoring system which has been designed with the participation of the authors of this paper and applied within the Polish power industry. This method uses two indicators (suppression and vibration harmonic contribution in suspension nodes) whose values are calculated from acquired and processed data in a given turbogenerator operation period. There has been four value ranges proposed for the indicators. The ranges define a technical condition of a stator suspension (very good, good, acceptable, bad) including two alarm ranges. Each technical condition is presented as a colourful area on an idle and active power plot. This enables the quick identification of machine operation areas, which reveals the weakened technical condition of a stator component.

Keywords: *turbogenerator*, *diagnostics*, *suspension*, *technical condition*

S t r e s z c z e n i e

W niniejszym artykule przedstawiono metodę ciągłej automatycznej wibracyjnej diagnostyki stanu technicznego elementu zwieszenia rdzenia stojana w wybranych punktach pomiarowych stojana turbogeneratora. Rozszerza ona możliwości diagnostyczne systemu monitoringu wibracji turbogeneratora, który został opracowany i wdrożony w energetyce polskiej przy współudziale autorów niniejszego artykułu [12]. W metodzie tej wykorzystano dwa wskaźniki oceny (tłumienia i udziału harmonicznych wibracji w węzłach zawieszenia), których wartości są wyznaczane w zadawanym okresie pracy turbogeneratora z przetworzonych i gromadzonych danych pomiarowych w systemie monitoringu. Dla wskaźników zaproponowano cztery przedziały wartości określające stan techniczny elementu zawieszenia rdzenia (bardzo dobry, dobry, przejściowo dopuszczalny, zły), w tym dwa stany alarmowe. Każdy stan techniczny przedstawiany jest w postaci innego barwnego obszaru na wykresie mocy czynnej i biernej turbogeneratora. Umożliwia to szybką identyfikację obszarów pracy maszyny, w których zachodzi znaczący proces pogarszania się stanu technicznego elementu zawieszenia rdzenia stojana.

Słowa kluczowe: *turbogenerator*, *diagnostyka*, *zawieszenie*, *stan techniczny*

DOI: 10.4467/2353737XCT.15.046.3846

* D.Sc. Ph.D. Eng. Andrzej Bytnar, The Institute of Power Engineering, Warszawa.
** Ph.D. Eng. Sławomir Wróblewski, Ericpol Sp. z o.o., Łódź.

1. Introduction

It is known that turbogenerator stator core elements are vulnerable to damage during operation with a variable load of active and reactive power. The damage is mainly caused by vibrations (Fig. 1) [5].

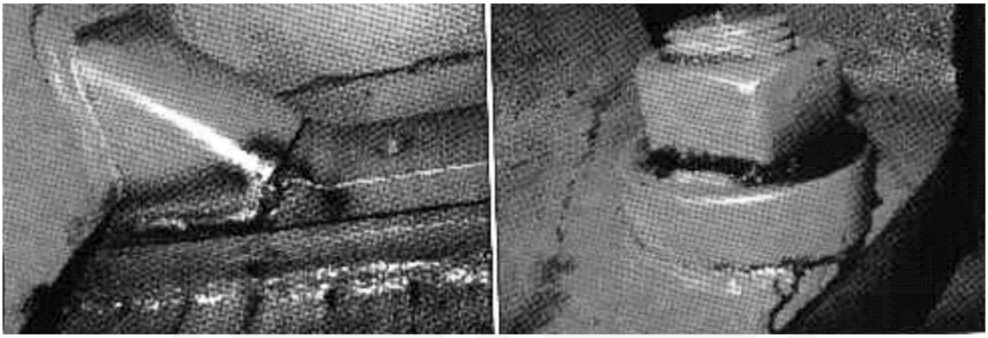

Fig. 1. Examples of suspension components' damage in the body of the stator core of a large turbogenerator

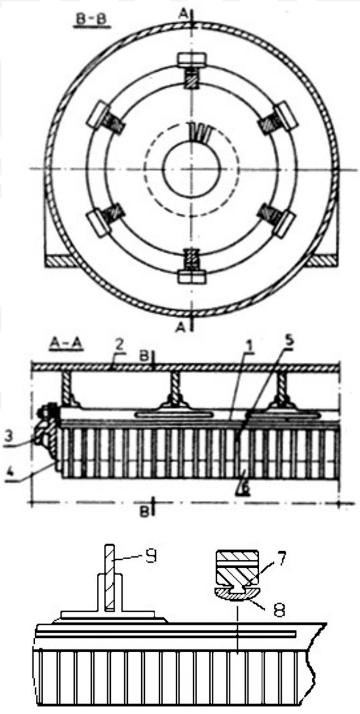

Fig. 2. Elastic suspension in the turbogenerator stator core [1]: 1 – a bar pulling elastic suspension elements of the core; 2 – core; 3 – retaining ring; 4 – platen; 5 – radial ventilation duct; 6 – stator lamination stack; 7 – a fragment of the pulling bar; 8 – notch in the plates of the yoke core; 9 – lateral wall (a rib) of the stator

High vibration levels are very often present in the turbogenerator stator core, especially in its active part. The vibrations are mainly caused by the meaningfully lowered pressure of the stator lamination stack. They can penetrate into a stator housing, its foundation and the building foundation – this is considered to be a serious threat.

The core is elastically suspended in the stator frame in modern constructions of large two-pole turbogenerators. This suspension type is used to suppress the vibrations in the stator core and in the foundations. There is a wide array of suspension types used in turbogenerators [1, 2, 11, 12] (Fig. 2). The core suspension damage caused by vibration phenomena appears very often during turbogenerator exploitation and there are a number of pieces of research dedicated to that phenomena [3–7, 13].

2. Turbogenerator Suspension Design Guidelines

The elastic suspension is so designed that vibrations between the stator core and the housing, caused by the basic harmonic of 100 Hz, are suppressed at least three times (9.5 dB).

The highest admissible vibration level is specified by recommendations – construction standards for turbogenerators [8] and indirectly by vibration standards for non-rotating machine parts [9].

On the basis of vibration phenomena analysis and visualization of particular stator suspension parts in the stator core of large turbogenerators, a new method of continuous automatic vibration diagnostics of the stator core technical condition has been designed.

3. Analysis of Vibrations Transferred through the Core Suspension

Analysis of electromagnetic phenomena and vibration measurements of turbogenerators shows that the rms value of the vibration of the stator components in the low frequency band of approx. 10 to 1 kHz (in accordance with the standard parameters for the assessment of the turbogenerator bearing technical condition) depend mainly on: active induction in the rotor gap; coupling induction of a stator; rotor end winding dissipation; the stiffness of vibrating elements.

The values of the vibration excitation forces depend on the value and type of electrical load *P*; *Q* of the turbogenerator (induction dissipation is considerably increased in the area of underexcitation). Also, the rigidity of the structural elements in the nodes (associated with excessive clearances, microcracks, etc.) may change in the existing real power load area as a result of the action of the synchronous torque. A mechanical shock (the measured vibration harmonics) appears in damaging components. The shock frequency in ‘clocked’ with a main force of 100 Hz making turbogenerator vibrations.

Pairs of accelerometers placed on the outer planes of the stator core and on the housing in the same cross-sections (described by a clock scale) (Fig. 3) allow the identification and analysis of the vibration signal transferred between the pairs. Inner sensors are mounted with screws anchored in the core radial channels and outer ones are mounted with neodymium magnet holders with a lifting strength of 30 kG.

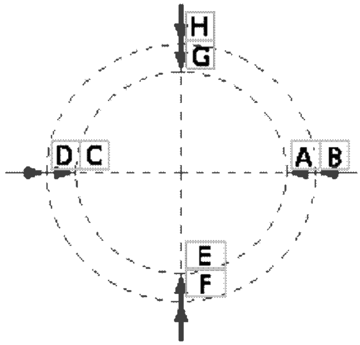

Fig. 3. Distribution of vibration sensors on the outer surface of the stator yoke and on the body in the cross-section of the stator: A, E, C, G – sensors on the yoke core; B, F, D, H – sensors on the housing

Such a distribution of accelerometers allows calculating a new suspension technical condition state indicator from the vibration signals.

It has been found that when the suspension is operating correctly, the core vibrations are transmitted into the stator housing almost without distortion. However, when weakening of the mounting in the structural nodes appears, higher harmonic velocity vibrations are generated and their parameters can be used in the diagnostics (Fig. 4).

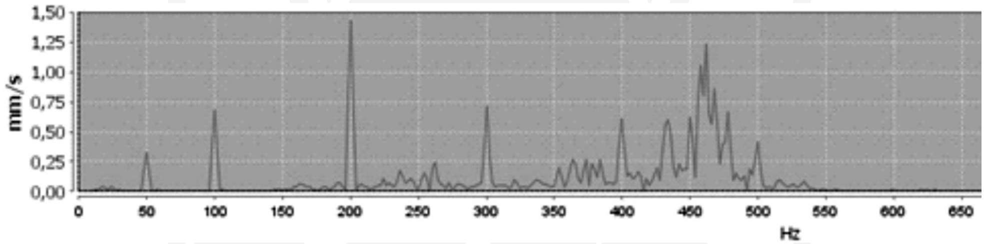

Fig. 4. Velocity vibration harmonics in the lower frequency band on the housing; $P \approx 211$ MW and $Q \approx 36$ MVar 230 MW turbogenerator

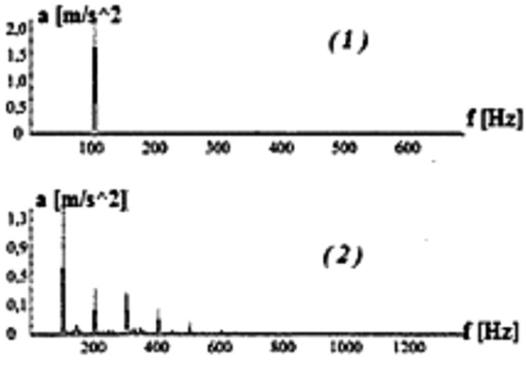

Fig. 5. Acceleration vibration plots of the stator suspension at turbogenerator rated duty (1) – correctly operating core suspension, (2) – weakness in the nodes of the suspension mounting

The research results of vibrations on the stator housing surface (Fig. 5, [2]) confirm that phenomena.

4. Estimation of the Technical Condition of Suspension Components

So far, however, there is no method of evaluating the technical condition of the core suspension while the turbogenerator is operating. The authors have therefore attempted to create it on the basis of numerous vibration studies of the core yoke, the stator body, the stator frame and the suspension inspection during repairs of various turbogenerators.

Attenuation rate and vibration harmonics transfer indicators (between described reference points, e. g. A and B; H and G Fig. 2) have been introduced to estimate the technical condition of i-th element of stator suspensions:

- **τ(i)** (a basic indicator, formula (1)), attenuation rate indicator taking into account the frequency band 10–1000 Hz [13],
- **λ(i)** (a supplemental indicator, determining the harmonic contribution; formula (2)) taking into account the frequency band 10–1000 Hz without 100 Hz component.

$$\tau_{(i)} = \sqrt{\sum_{\mathrm{k=10Hz}}^{\mathrm{1000Hz}} \left(v_{(i)\mathrm{inner}(k)} / v_{(i)\mathrm{outer}(k)} \right)^2} \tag{1}$$

Where:
$v(i)$outer(k) – k-th harmonic velocity on the stator housing (e.g. sensor A),
$v(i)$inner(k) – k-th harmonic velocity on the stator core (e.g. sensor B),
k – k-th harmonic.

$$\lambda_{(i)} = \frac{\sqrt{\left(\sum_{\mathrm{k=10Hz}}^{\mathrm{1000Hz}} v^2_{(i)\mathrm{inner}(k)}\right) - v^2_{(i)\mathrm{inner(100Hz)}}}}{\sqrt{\left(\sum_{\mathrm{k=10Hz}}^{\mathrm{1000Hz}} v^2_{(i)\mathrm{outer}(k)}\right) - v^2_{(i)\mathrm{outer(100Hz)}}}} \tag{2}$$

where numerator and denominator – geometric sum of k-th harmonic values without 100 Hz respectively on the stator housing and core.

Attenuation rate **τ(i)** and vibration harmonics transfer **λ(i)** indicators have been determined on the basis of vibration and visualizing the survey of turbogenerator components (Table 1).

The values of **λ(i)** are similar to those used in Russia [4].

At the given P; Q load of the turbogenerator, technical condition of the i-th suspension component is estimated by comparing the value **τ(i)** (calculated using the formula (1)) to the criteria values (Table 1), completed with +/– signs: ‘1+’; ‘2+’; ‘3+’ or ‘1-’; ‘2-’; ‘3-’ in cases when value ***λ(i)p*** (calculated using the formula (2)) is in a different range of the approved grading scale.

Table 1

Criteria values of attenuation rate indicator $\tau_{(i)}$ and vibration harmonics transfer $\lambda_{(i)}$

Values of the indicators	Technical condition of the suspension
$\tau_{(i)} > 3$	Very good
$\lambda_{(i)} < 1$	
$3 \geq \tau_{(i)} > 1.5$	good
$1 \leq \lambda_{(i)p} < 1.5$	
$1.5 \geq \tau_{(i)} > 0.5$	temporarily permissible
$1.5 \leq \lambda_{(i)} \leq 3$	(alarm I)
$\tau_{(i)} \leq 0.5$	bad
$\lambda_{(i)p} \geq 3$	(alarm II)

When the technical condition of *i*-th element of the suspension is mapped into four colours in the permissible load plot, the mentioned signs increment or decrement the calculated value of **τ(i)** by 10% of the average value of the lower and upper range (good and temporarily permissible) or of the minimal lower value (very good and bad) of the given criteria range for every sign value of the supplemental number. In extreme cases, evaluation of the technical condition can be changed, for example, from 'temporarily permissible' to good.

Values of criteria indicators will be verified on the basis of future complex turbogenerator research.

5. Continuous Automatic Evaluation of the Technical State of Suspension in the Body of the Stator Core

For the purposes of the existing vibration monitoring system for turbogenerators [12], algorithms for the automatic determination of the values of the indicators (attenuation and harmonic transfer) and creating the technical condition of *i*-th element maps have been developed. These have been applied in the form of a computer programme.

Suspension *i*-th element points in the cross-section are automatically identified (Fig. 3) thanks to the machine model which was previously saved in a database.

The values of the indicators are calculated according to formula (1) and (2) for each pair of adjacent points lying in the same stator cross-section. For example, for points A, B, C, and D in Fig. 2. The technical condition of *i*-th stator elements are presented as coloured areas (rectangles) on the turbogenerator load plot (*P*-*Q* plane). The size of each area is defined when defining the parameters of the map.

Depending on the predefined machine type, each area contains a resulting indicator value in the given range of active and reactive power. For example, the areas can be sized to 3 MVar/3 MW and presenting the worst value or the last value for the defined time span (Fig. 6). The areas can be zoomed in on to look closer into the surrounding.

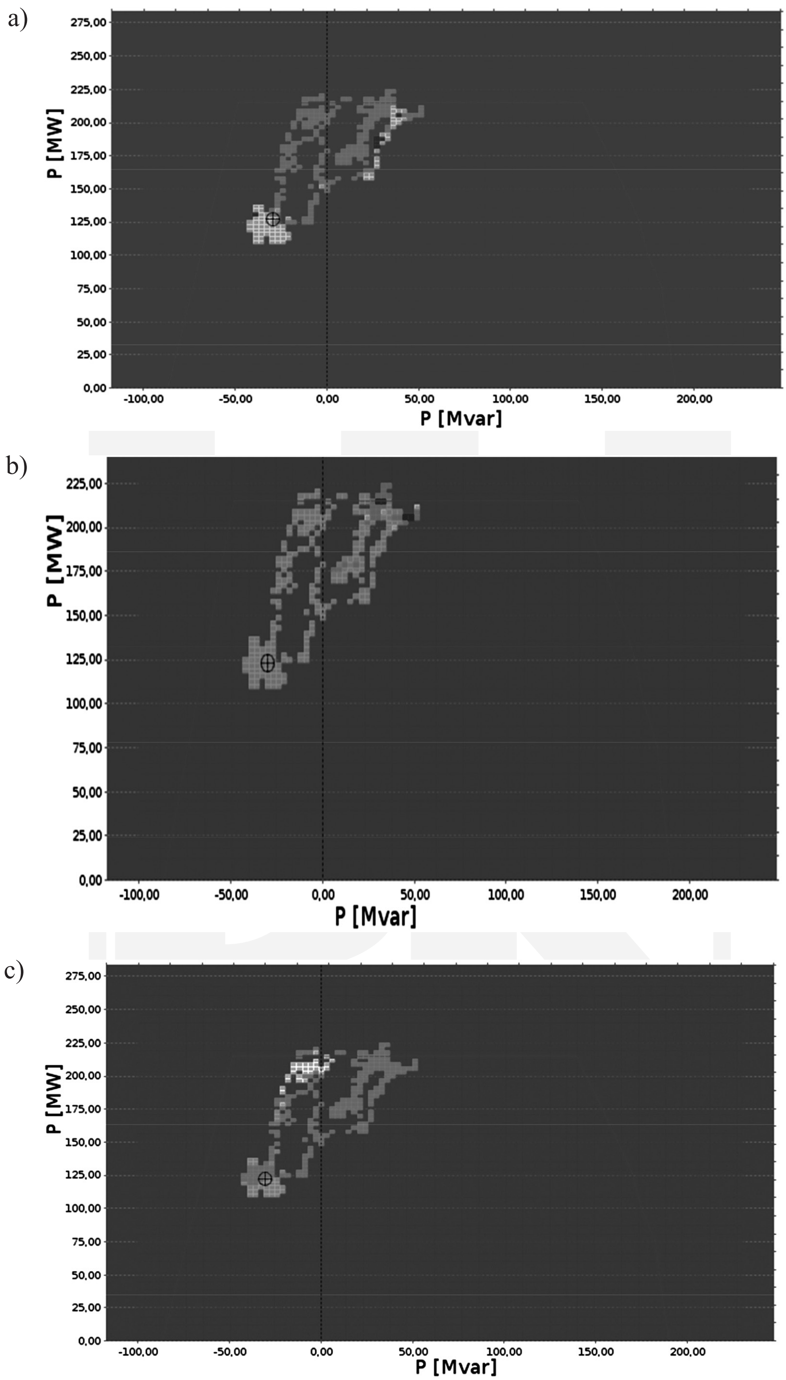

Fig. 6. Maps of the technical condition of three different suspension components in the body of the stator core turbogenerator of 230 MW, a) ring side; 9 o'clock, b) ring side; 3 o'clock, c) ring side; 12 o'clock, dark gray – very good, gray – good, light gray – temporarily permissible, very light gray – bad

Such a presentation allows pointing out the turbogenerator components with reduced technical quality and the areas on the *P*-*Q* plain which affect the stator condition in the most destructive way. Due to this, the first general analysis can be done in quickly.

6. Conclusions

1. The technical condition of turbogenerators operating in a diurnal cycle of variable loads should be continuously monitored during the turbogenerator exploitation to allow effective elimination of damage at a very early stage.
2. The presented method of automatic continuous assessment of the technical condition of the stator suspension expands the conventional turbogenerator diagnostics.
3. The next task is the design of complex computer software on the basis of the presented algorithms to support a modern turbogenerator diagnostic system.

References

[1] Bytnar A., *Wybrane zagadnienia z konstrukcji i eksploatacji turbogeneratorów*, Wydawnictwo Politechniki Warszawskiej, Warszawa 1983.
[2] Dement'ov V.I. et al., *Obnaruženie defektov statora turbogenertora po parametram vibroakustičeskih kolebanij ego stal'nyh konstrukcji*, Êlektričestvo, 2005, No. 12.
[3] Kumaraswamy S. et al., *Standardization of Absolute Vibration Lewel and Damage Factors for Machinery Health Monitoring*, Proceedings of Vetomac – 2, 16–18 December 2002.
[4] Kuznecov D.V., Šandyvin M.I., *Primenenie metodov vibrokomtrolja dla ocenki sostojanija uprugoj podveski serdečnika statora turbo-generatora*, Élektričeskie Stancii, 2007, No. 10.
[5] Kuznecov D.V. et al., *Vyjavlenie i ustranienie defektov podveski serdečnika statora mošnych turbogeneratorov*, Élektričeskie Stancii, 2012, No. 9.
[6] Maksimov L.V., *Vibrations of the stator of a turbogenerator with elastic suspension of the core using tangential rods*, Scientific-Research Institute of the LPÉO of the Élektrosila, Leningrad, Translated from Prikladnaya Mekhanika, January 1980, Vol. 16, No. 1, pp. 94–98.
[7] Nazolin A.L., Poljakov V.I., *Osobiennosti raboty uzlov kreplenija serdečnika statora turbo-generatora*, Élektričeskie Stancii, 2007, No. 6.
[8] Standard PN-80/B-03040.
[9] Standard ISO 10816-1(1995E).
[10] Patent PL 73909 B2.
[11] Patent PL 54535.
[12] Wróblewski S., Bytnar A., Pietrzak P., *Projektowanie systemów diagnostyki wibracyjnej turbogeneratora*, Wiadomości Elektrotechniczne, 2011, Vol. LXXIX, No. 11.
[13] Wróblewski S., Bytnar A., *Analiza stanu technicznego zawieszenia rdzenia w korpusie stojana turbogeneratora*, Zeszyty Problemowe – Maszyny Elektryczne, 2013, nr 100(4), BOBRME Komel.