

Using the remote diagnostic systems based on virtual environment and digital twins to lifetime assessment of power equipment

Jerzy Trzecznyński, Marcin Hatłas, Wojciech Murzynowski and Radosław Stanek

Introduction

The Polish energy system, despite investments in renewable sources, still relies predominantly on coal-fired power plants, with the largest group being the 200 MW class units. Many of these units have operated for over 200,000 hours, exceeding their designed operational lifespan. Some are nearing 300,000 hours of operation. However, these units have undergone numerous repairs and modernizations to extend their

operational lifetime, enhance efficiency, and align with current emission limits.

These actions necessitate an individualized approach when assessing the technical condition of each specific unit. This evaluation should consider its operational history, conditions, retrospective researches, the scope of modernizations, quality of repairs, and information regarding past failures.

To successfully perform diagnostics and ensure availability of such devices, virtual (digital) diagnostic environments based on expert algorithms and digital twins can be effectively utilized. These systems enable the prediction of safe operation by conducting simulations on the depletion of durability reserves under the assumption of the most probable future operating scenarios.

Over the last 20 years, Pro Novum has been introducing solutions related to remote diagnostics. Starting with the Life Management System PRO+[®], service, which made it possible to manage the maintenance of the technical condition of equipment in power plants. Along with the increase in possibili-

ties related to digitization, new versions of products containing much more advanced algorithms were developed (Figure 1), e.g. automated analysis of operating conditions (including base load and flexibility load – regulatory work), admitting elements to conditional work, risk assessment according to the RBM (risk based maintenance) strategy, etc. The latest version Virtual Diagnostic System (VDS), which is still being developed, already enabled diagnostics of power devices based on digital twins and about the AI algorithm.

The article introduces the concept of Pro Novum Virtual Diagnostic System, parametric digital twin and highlights the benefits derived from its application in diagnosing critical components of long-operating thermal-mechanical devices.

Virtual Diagnostic System

VDS is based on the digitization of processes and objects being the subject of diagnostics and communication between the real object and the Diagnostic Testing Environment

Authors

Jerzy Trzecznyński
Marcin Hatłas
Wojciech Murzynowski
Radosław Stanek

Przedsiębiorstwo Usług Naukowo-Technicznych
PRO NOVUM SP. Z O.O.
Katowice, Poland

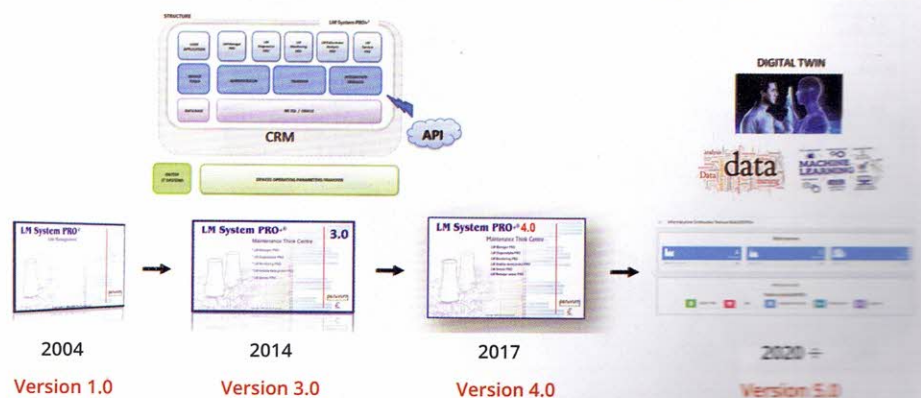


Fig. 1. Development of Pro Novum life management systems (LM System PRO+[®]).

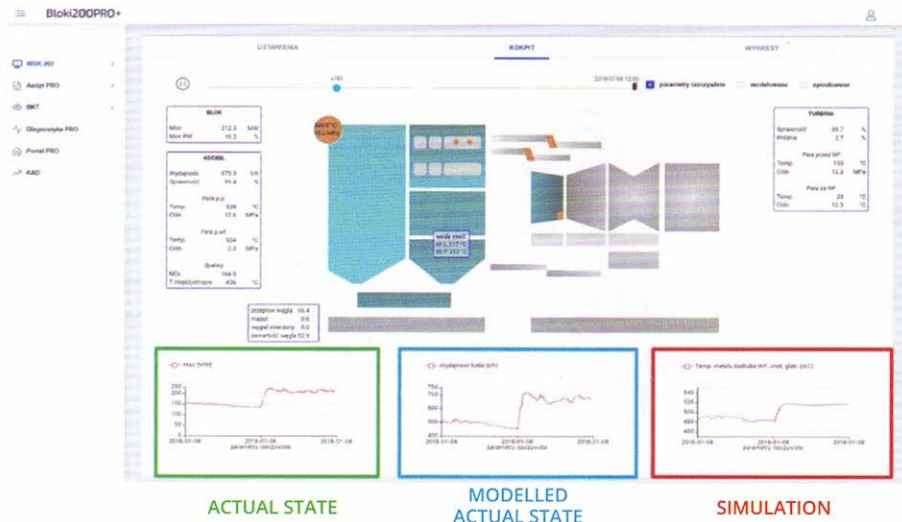
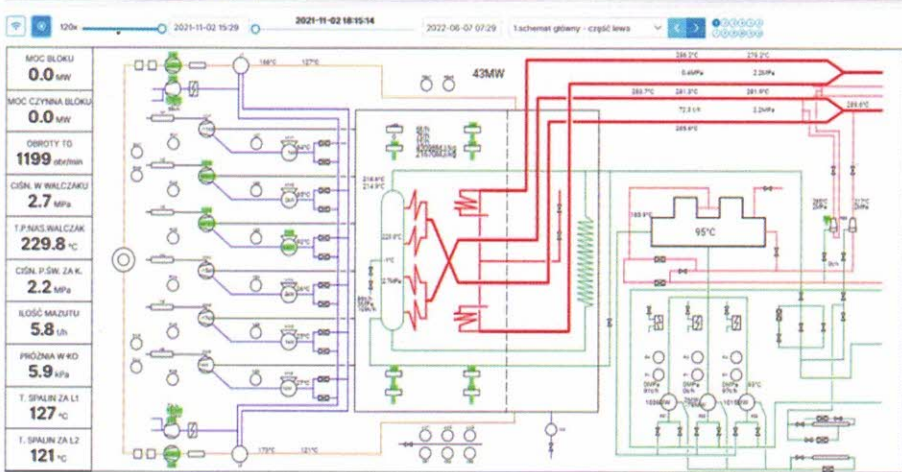


Fig. 2. Virtual power unit 200 MW class in Virtual Diagnostic System, enabling the display of current process data, modeled data and simulations.

(Figure 2). It is a universal technology, giving obvious advantages on older units as well as on new ones. The basis of VDS operation is communication between the systems located in the power plant (measurement systems, DCS, etc.) and the Pro Novum expert system in which diagnostic algorithms are implemented. In the Pro Novum environment, tests and calibrations of algo-

rithms are performed, which are finally installed at engineering stations in the power plant – in order to increase the security of the infrastructure. Thanks to this, Pro Novum algorithms can be also a part of the unit control system (stored in operator logics) The VDS system allows communication between power plant experts and Pro Novum experts (Figure 3). Thanks to the created

Informatyczne Środowisko Testowe Bloki200PRO+



Informatyczne Środowisko Testowe Bloki200PRO+

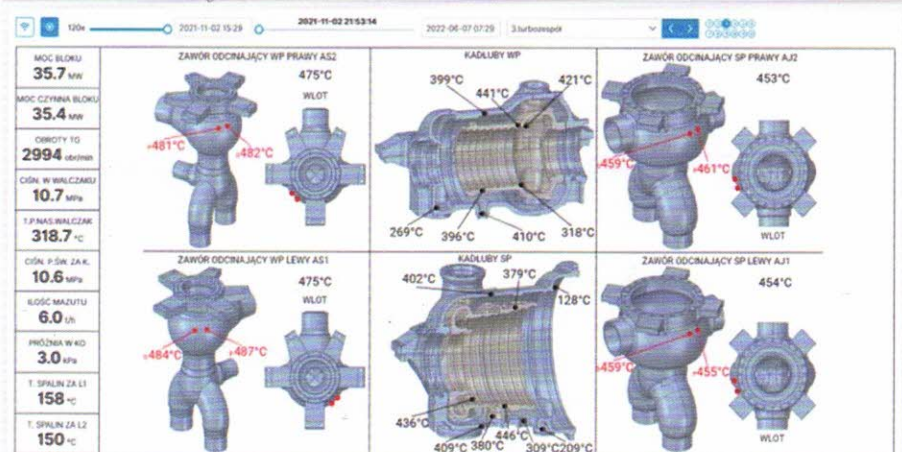


Fig. 3. Remote communication between DCS power unit and Virtual Diagnostic System Pro Novum via Pro Novum Engineering Station [6].

application, authorized persons have access to appropriate dashboards, where they are provided with information about the current condition of devices and installations and (e.g. in the case of property maintenance specialists) prognosed changes of their durability, along with recommendations for the range of testing and overhaul activities.

Parametric digital twins

For these purposes, digital twins of devices are implemented in the VDS, allowing for modelling and simulation of the behaviour of various structural nodes and its components under actual and changed unit operating conditions (e.g., accelerated startups, reduced technical minimums, etc.).

Digital twins, representing real components of a units or installations, enable the simulation of the behaviour of these objects and provide information about them that couldn't be obtained through measurement methods or would be economically unjustified. Examples of such data include information about displacements, thermal conditions, stresses, and forces acting on interacting elements. Understanding the stress state of an element during its operation allows for an accurate determination of the reduction in its durability resulting from actual working conditions. Additionally, having this data allows for real-time comparison between the actual object and its digital model, enabling the identification of any irregularities in its operation.

Pro Novum's digital twins are created as reduced parametric models. The creation of such a twin starts with generating a numerical model of the device (Figure 4). The numerical model is based on the real geometry of the structure, determined from technical documentation and on-site inspections. The geometric model undergoes discretization (Figure 5) into finite elements (FEM), after which material data are introduced, boundary conditions are set, based on supports, interaction with collaborating devices, and operating conditions (pressure, temperature, and flow of the working medium). Such a model can be reduced to a matrix system allowing real-time calculations and can be controlled using external parameters. These parameters influence the fidelity of the model's behaviour in comparison to the real model.

When creating twins of long-operating devices or installations, it's crucial for the numerical model to incorporate the actual and current characteristics of the device, such as material data that might have changed due to operation. It's equally important to consider any structural modifications resulting from upgrades and repairs. Such a prepared twin enables the determination of stresses in potential damage zones and identification of actual damage zones resulting from improper operation or changes in conditions, especially due to operating in regulatory mode.

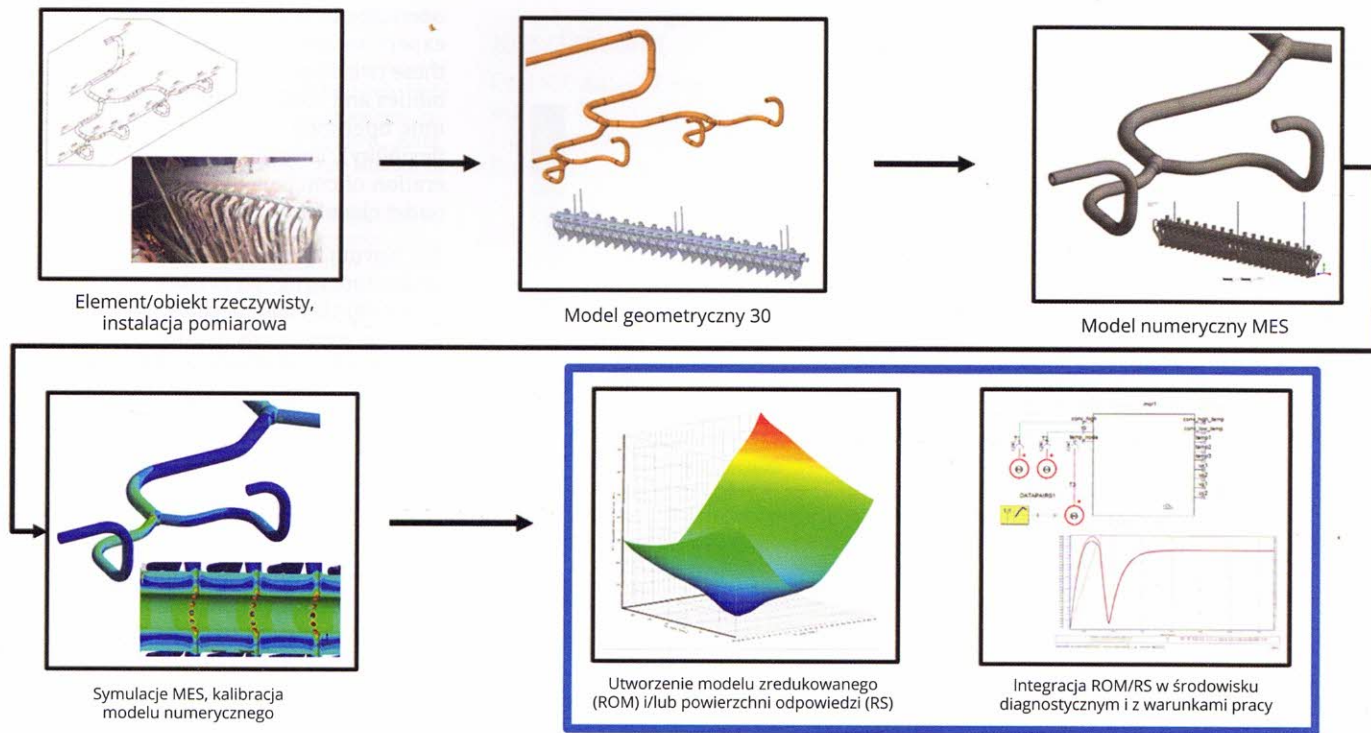


Fig. 4. The process of creating a parametric digital twin of an element or installation.

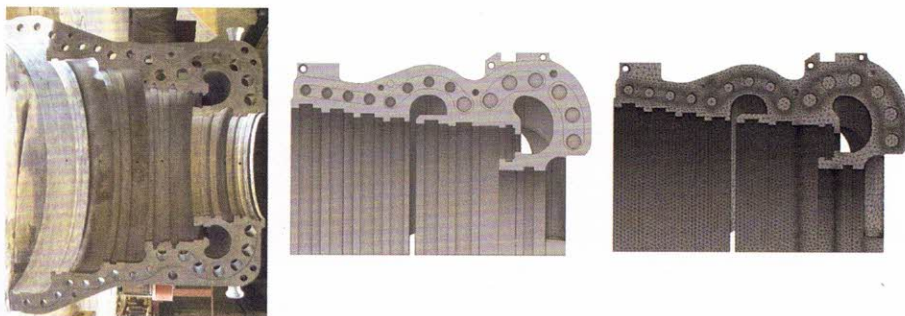


Fig. 5. Real element (turbine casing), geometric model, discretized model.

ment durability under different unit operating scenarios. This approach helps identify the actual reserve of durability within a specific element, which can be safely utilized, creating conditions for more flexible unit operation (Figure 7). Perhaps the most appealing feature of parametric digital twins is their capability to simulate practically any equipment and component operating scenarios. This minimizes the need for costly tests on the actual unit, allows forecasting based on assumed future operation scenarios, and supervises the safe utilization of the

Benefits of using parametric digital twins

Advanced Pro Novum expert systems supplied by data from digital twins can be utilized for various diagnostic tasks. Through numerical methods, one can more accurately replicate the effects of variable loads compared to using analytical formulas available, for instance, in standards [7].

One of the primary tasks of digital twins is to generate stress data, allowing real-time monitoring of device safety. This data is also used to determine fatigue cycles affecting the remaining life. Such a system has been repeatedly employed, for instance, for diagnostic monitoring of main steam pipelines in a supercritical parameter unit and for remaining life assessment (RLA) for drums (Figure 6). A digital twin can be effectively utilized, especially when the element undergoes frequent upgrades and/or repairs that involve local shape changes.

The ability to accurately perform the RLA in various areas of elements, devices, and installations allows for determining durability reserves. As highlighted in article [2], this enables a more realistic forecast of compo-

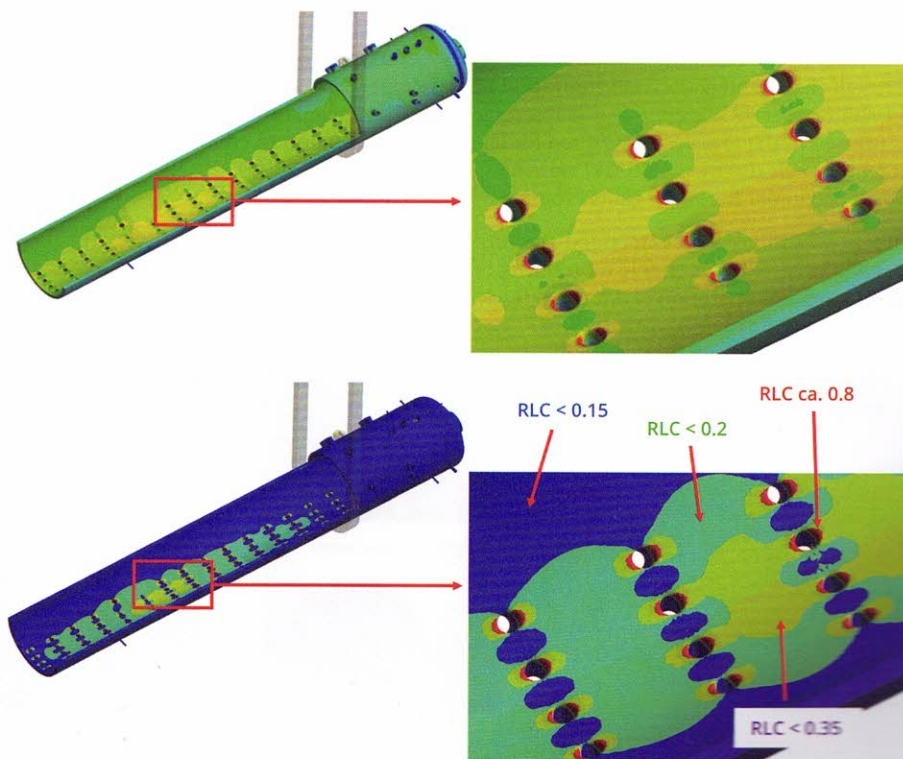


Bild 6. Stress distribution and remaining life coefficient (RLC).

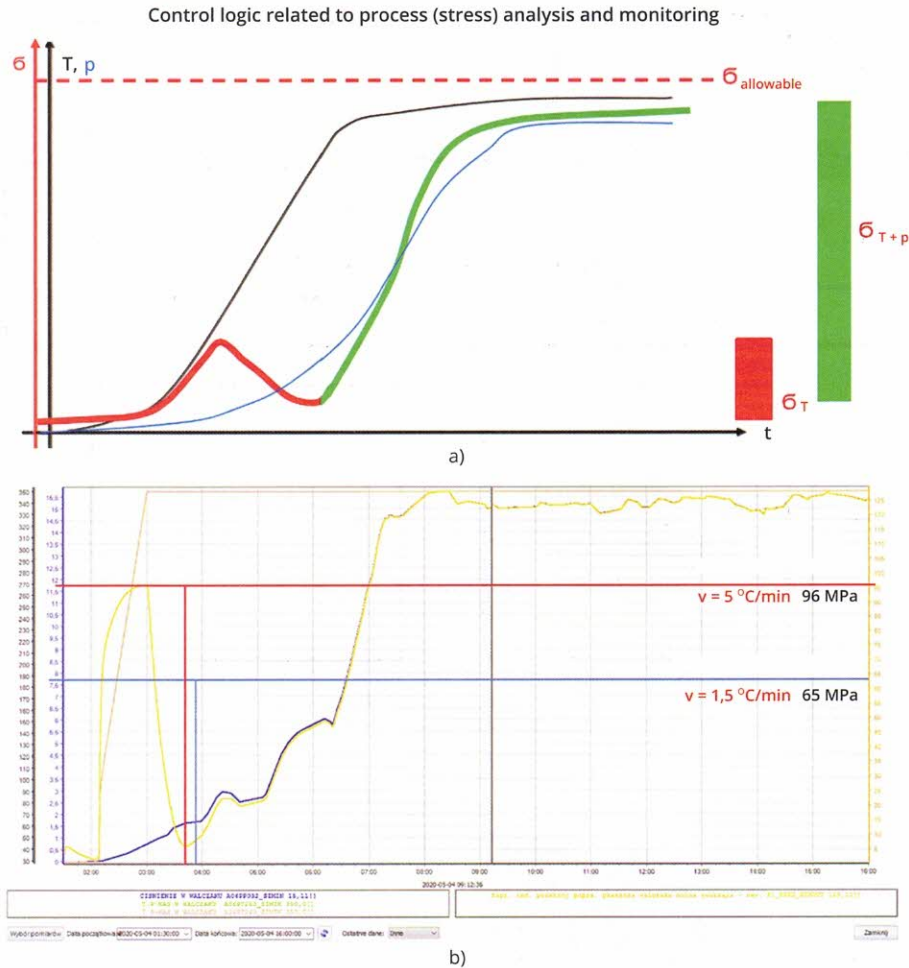


Fig. 7. Variable load simulation based on digital twins of critical equipment: a) share of thermal (σ_T) and thermo-mechanical stresses (σ_{T+p}) in the pressure element during unit startup; b) simulation of rapid saturation temperature rise in the boiler; thermal stresses (σ_T) vs. thermo-mechanical stresses (σ_{T+p}).

durability reserve, particularly associated with crack initiation and propagation [8]. This sets the stage for enhancing flexibility, especially in the case of 200 MW class units, through the identification and utilization of durability reserves and control-side reserves, as utilized in the Pro Novum Method for improving the flexibility of 200 MW class units developed under the 200+ Units Program.

Expert programs with embedded fracture mechanics algorithms enable monitoring of the conditional operation of damaged thick-

walled components. In these programs, digital twins allow for the utilization of durability reserves within elements exhibiting operational-type cracks, both during the initial safety assessment phase and during controlled propagation, following the principles and criteria described in the BS 9710 standard [8] (Figure 8).

Summary

Pro Novum has implemented and integrated over 30 digital twins of critical components

operating in 200 MW class units within its expert systems. A significant portion of these twins has been created to assess capabilities and monitor safety after changes in unit operation regimes (increasing their flexibility). They oversee the conditional operation of components such as coolers and outlet chambers of steam superheaters.

Pro Novum's digital twins serve as modern tools supporting the availability and safety of critical thermal-mechanical device components, particularly in 200 MW class units, during the extension of their operation in new, regulatory operating modes. Based on numerical models of real objects, these twins can be developed for individual components as well as entire installations and implemented in VDS.

The use of digital twins in Pro Novum systems allows for monitoring the technical condition of thick-walled elements until the complete depletion of their durability and within the scope of safe crack propagation (as part of supervising the conditional operation of damaged elements that cannot be repaired or quickly replaced). Monitoring can occur in real-time or periodically. The ability to simulate various working conditions and their consequences enables the determination of durability forecasts for different future operating scenarios, subsequently verifying them continuously during the operation of an energy unit.

Bibliography

- [1] Hatłas M., Murzynowski W., Trzeszczyński J., Parametryczne bliźniaki cyfrowe źródłem informacji i wiedzy dla bezpiecznej eksploatacji urządzeń i instalacji energetycznych. „Energetyka” 2022, nr 12, Biuletyn Pro Novum 3/2022.
- [2] Trzeszczyński J., Murzynowski W., Określanie i monitorowanie zapasów trwałości elementów krytycznych na potrzeby przedłużonej eksploatacji bloków energetycznych w nowych reżimach prac, „Energetyka” 2023, nr.6, Biuletyn Pro Novum.
- [3] Trzeszczyński J., Hatłas M., Murzynowski W., Korzyści z zastąpienia kryteriów temperaturowych przez naprężeniowe dla zapewnienia bezpieczeństwa i dyspozycyjności bloków energetycznych eksploatowanych w trybie regulacyjnym oraz o zwiększonej ela-

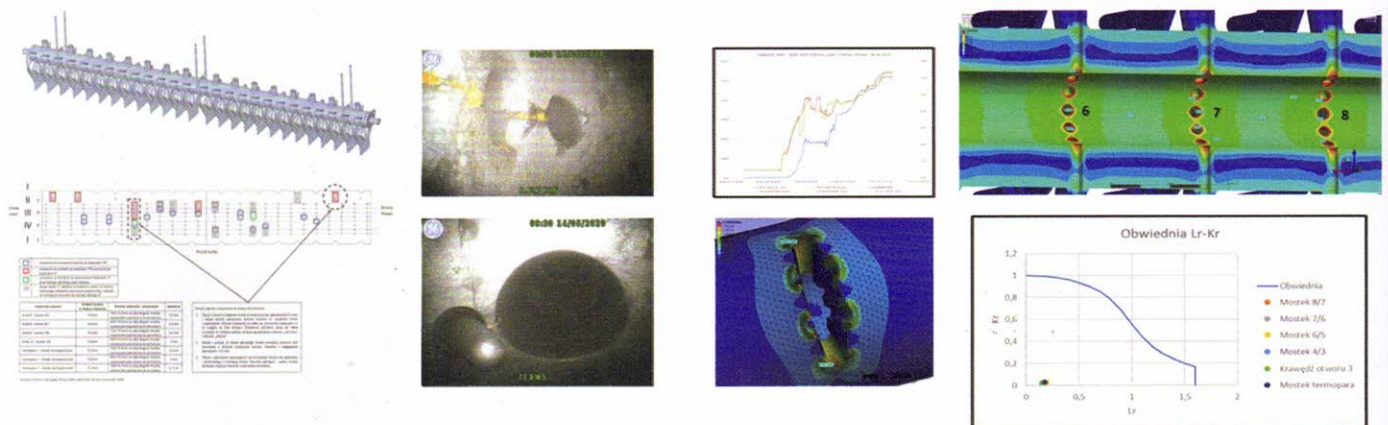


Fig. 8. Digital twins created for assessing the conditional exploitation of damaged equipment.

stycznosci, „Energetyka” 2022, nr 12, Biuletyn Pro Novum 2/2022.

- [4] Trzeczcyński J., Hatlas M., Murzynowski W., Wykorzystanie parametrycznych bliźniaków cyfrowych do analizy trwałości kładubów turbiny podczas uruchomień, „Energetyka” 2022, nr 6, Biuletyn Pro Novum nr 1/2022.
- [5] Trzeczcyński J., Murzynowski W., Białek S., Monitorowanie stanu technicznego urządzeń ciepłno-mechanicznych bloków energetycznych przy wykorzystaniu platformy informatycznej LM System PRO+®. „Dozór Techniczny” 2011, nr 5.
- [6] Trzeczcyński J., Hatlas M., Murzynowski W., Stanek R. Trzeczcyńska E., Adaptation of coal-fired units for further operation in the transitional period of transformation of the Polish energy sector. Vgbe Energy Journal, 12/2023.
- [7] Standard PN-EN 12952, Kotły wodnorurowe i urządzenia pomocnicze.
- [8] Standard BS 9710_2013, The British Standards Institution 2015.

Kurzfassung

Einsatz von Ferndiagnosesystemen auf der Grundlage einer virtuellen Umgebung und digitaler Zwillinge zur Bewertung der Lebensdauer von Energieanlagen

Das polnische Energiesystem stützt sich trotz Investitionen in erneuerbare Energiequellen immer noch überwiegend auf Kohlekraftwerke, wobei die größte Gruppe die Blöcke der 200-MW-Klasse sind. Viele dieser Blöcke sind seit mehr als 200.000 Stunden in Betrieb und haben damit ihre vorgesehene Betriebsdauer überschritten. Einige nähern sich 300.000 Betriebsstunden. Diese Blöcke wurden instandgehalten und Modernisierungen unterzogen, um ihre Lebensdauer zu verlängern, die Effizienz zu verbessern und die aktuellen Emissionsgrenzwerte einzuhalten. Diese Maßnahmen erfordern einen indi-

viduellen Ansatz bei der Bewertung des technischen Zustands jeder einzelnen Anlage. Um eine erfolgreiche Diagnose durchzuführen und die Verfügbarkeit der Anlagen zu gewährleisten, können virtuelle (digitale) Diagnoseumgebungen auf der Grundlage von Expertenalgorithmen und digitalen Zwillingen effektiv eingesetzt werden. Diese Systeme ermöglichen eine Prognose für sicheren Betrieb, indem sie Simulationen über die Erschöpfung der Lebensdauerreserven unter der Annahme der wahrscheinlichsten zukünftigen Betriebsszenarien durchführen.

Der Artikel stellt das Konzept des virtuellen Diagnosesystems Pro Novum, eines parametrischen digitalen Zwillinges, vor und beschreibt die Vorteile, die sich aus seiner Anwendung bei der Diagnose kritischer Komponenten von thermomechanischen Komponenten mit langer Betriebsdauer ergeben.



vgbe-Standard VGBE-S-010-00-2023-08-EN

Feed Water, Boiler Water and Steam Quality for Power Plants/Industrial Plants formerly VGB-S-010-T-00;2011-12.EN

154 S., 46 Abb., 24 Tab., vgbe energy e.V. & vgbe energy service GmbH, Essen, Deutschland (2023) print/e-book, English and German edition available

Price for vgbe-members* 240.- €, non-members 360.- €, + postage, package and VAT

vgbe energy e.V. hereby presents a revised version of the VGB-Standard VGB-S-010 for “Feed Water, Boiler Water and Steam Quality for Power Plants/Industrial Plants”. This vgbe-Standard replaces the edition 2011.

The present vgbe-Standard summarises the latest and updated experiences gained within water-steam chemistry worldwide and is the work of an international task group organized by the vgbe Technical Committee “Chemistry and Emission Control” (CEC).

This task group identified and agreed on more than 80 single topics to be revised, or to be rewritten for further precision or also to be integrated as new/additional information in order to deliver the most actual information, state of the art and recent technical developments.

It needs to be emphasized again, that this standard is also valid and applicable for any kind of industrial power plants with process steam production for all pressure ranges.

vgbe energy service GmbH | Deilbachtal 173 | 45257 Essen | Deutschland
Verlag technisch-wissenschaftlicher Schriften t +49 201 8128-200

i www.vgb.org/shop
e sales-media@vgbe.energy

