FVV PRIMEMOVERS. TECHNOLOGIES.

1970 - 2025 | W10 | FVWHT + FVV

High-temperature behaviour of creep-resistant steels

Applied materials research for the energy industry

Science for a
moving society

Science for a
moving society

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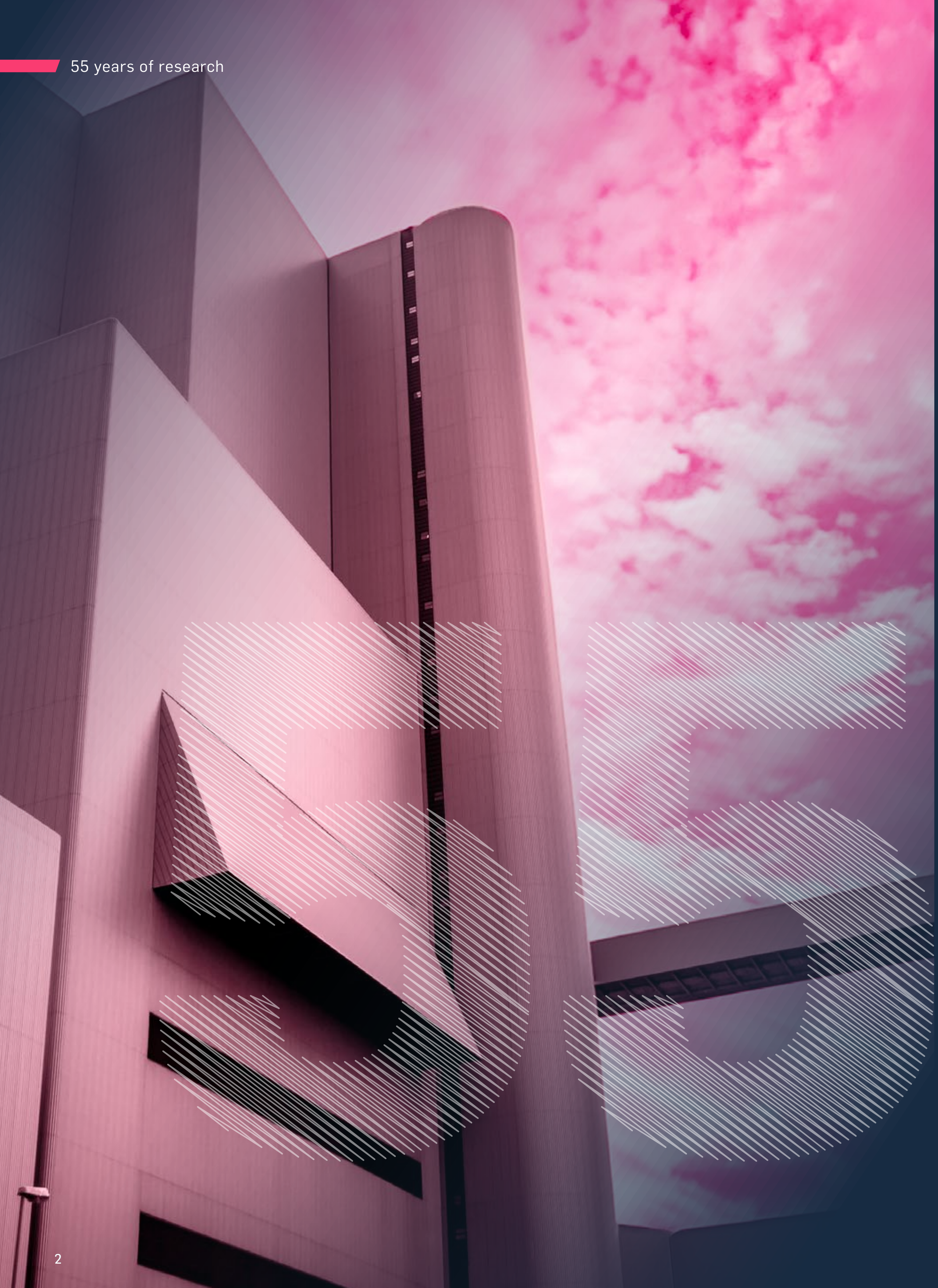


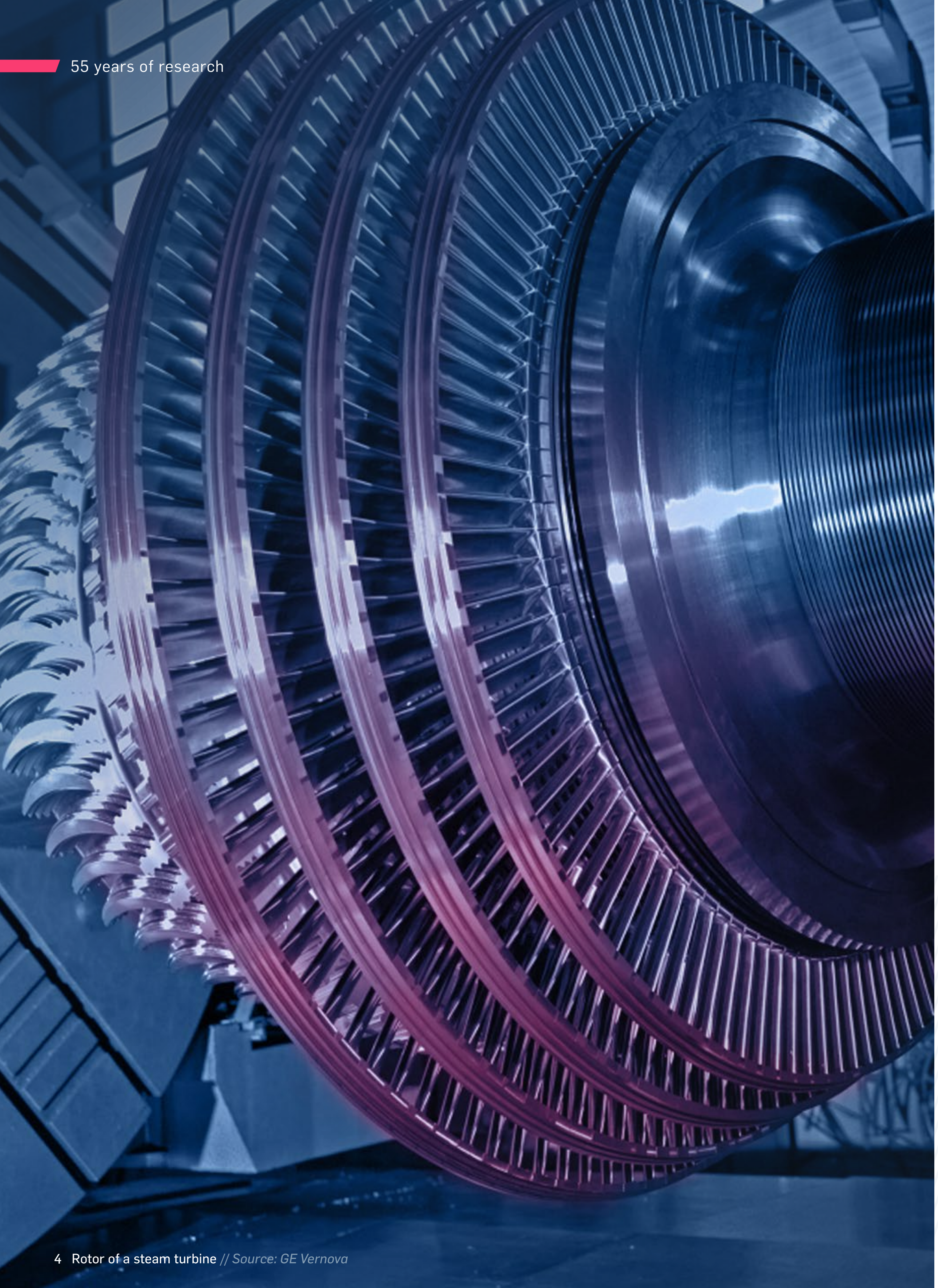
55 years of research into the high-temperature behaviour of creep-resistant steels

W10 ›High-temperature Behaviour of Materials under Changing Loads‹ - a joint working group of FVWHT and FVV

To design high-temperature components reliably, for example for use in steam turbines for the power plant industry, and assess their service life accurately, the properties of the materials used must be known under conditions close to the application.

For five decades now, the **Research Association for Creep-resistant Steels and High-temperature Materials (Forschungsvereinigung Warmfeste Stähle und Hochtemperaturwerkstoffe FVWHT)** has been coordinating projects to research the behaviour of materials under alternating loads.

The activities are bundled in the project group W10 ›High-temperature Behaviour of Materials under Changing Loads‹, in which the FVWHT, together with the FVV, conducts practice-oriented research into metallic materials for the energy industry.



Rotor of a steam turbine // *Source: GE Vernova*

»The greater the share of renewable energies in the electricity mix, the more challenges arise for the security of power supply throughout Germany.«

More and more energy from solar and wind power, less and less of the electricity mix from traditional fossil-fuelled power plants: The energy transition in Germany continues to gather pace; in 2023, more than half of total electricity consumption was covered by renewable sources for the first time, and in the long term, power generation should even be completely greenhouse gas-neutral.

However, the greater the share of renewable energies in the electricity mix, the more challenges arise for the security of power supply throughout Germany. This is because the demand from households and companies must also be covered during so-called dark doldrums, i.e. when solar plants are not producing electricity and wind turbines are at a standstill due to a lull. In this case, thermal power plants have to step in and supplement energy generation.

With their new status as grid reserve capacity, the technical requirements for thermal power plants and their turbines are changing, too. In continuous load operation, which was still characteristic of the design, the turbines were brought up to temperature for their entire service life and then ran permanently. In future, they will be operated much more dynamically to cover the residual load; they will have to start up quickly from a standstill and generate energy rapidly.

»The superposition of centrifugal stress and alternating thermal stress in the surface notches of the rotor that occurs during start-up and shutdown limits the service life of the turbine and defines the minimum start-up times,« explains Henning Almstedt from Siemens Energy. He is a long-standing member of the joint FVWHT and FVV project group. The modified load profile of the turbine therefore has a direct impact on the materials used for the rotor and housing.

»The main challenge is the large temperature gradients due to the steep run-up ramps of the turbine. The temperature differences in the material create stresses that can lead to cracks,« says Dr Martin Reigl from GE Vernova. He is the coordinator of the W10 project group, which is researching the behaviour of materials for turbines that can be used, for example, to better implement the changed requirements for thermal power plants as part of the energy transition.

High-temperature materials research can look back on a long tradition: The first FVWHT project was launched in 1970 to experimentally simulate the variable operational loads on real components in the laboratory.

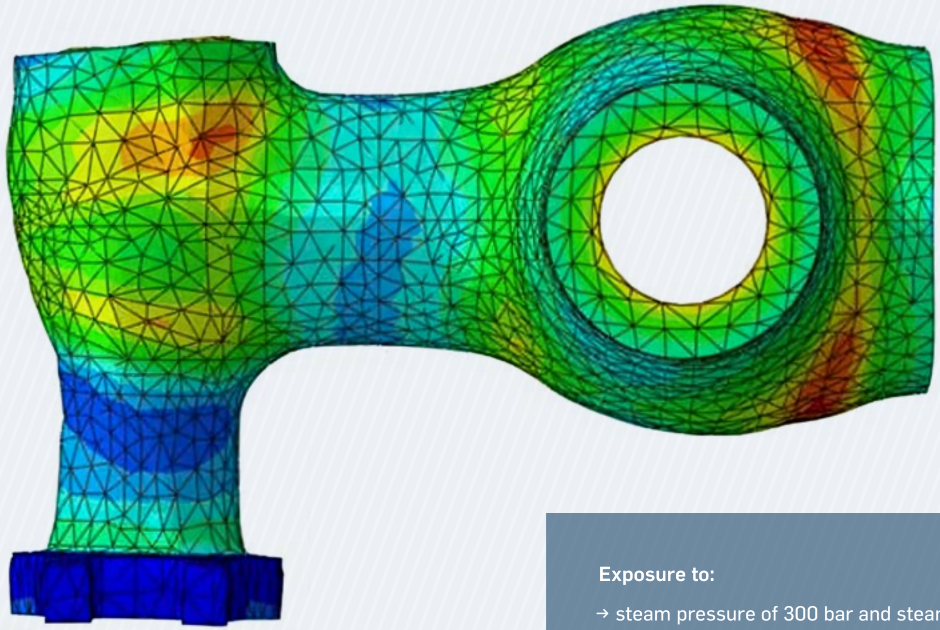
The accompanying committee of industry representatives set up at that time has been supervising projects on variable creep-fatigue loading (AiF Research Task IV.1) and on combined creep an cyclic loading (AiF Research Task IV.2) ever since - without interruption to this day.

Since 1978, the working group with its two main areas of research has been known as project group W9 (IV.1) and W10 (IV.2), since 2000 only under the name W10.

The cooperation between the research and technology performers involved - the Materials Testing Institute (MPA) at the University of Stuttgart and the Institute of Materials Science (IfW) at the Technical University of Darmstadt, among others, have been continuously involved - and industry [→ p. 28] has resulted in a broad basis of materials data and calculation methods over the past 50 years.

FIGURE 1

FEM simulation of a high-pressure USC valve housing *// source: GE Vernova*



Exposure to:

→ steam pressure of 300 bar and steam temperature of 600 °C over 300,000 operating hours

→ thermal cycling due to cold, warm and hot starts, load changes and shutdowns

Applied materials research

The content and tasks of FVWHT's high-temperature research have always been orientated towards the needs of the energy industry. »Research has generally focussed on materials for higher turbine efficiency so that base load could be covered even more cost-effectively. In the 1970s, the increasing use of nuclear power plants was responsible for the fact that conventional power plants needed to be operated more and more variably, and today it is to an even greater extent the expansion of renewable energies,« says Almstedt.

Although the results of the W10 project group can in principle be applied to all appliances and machines subject to alternating thermal loads, the activities are traditionally focussed on applications in steam turbine construction.

This can be seen, among other things, in the selection of materials and the loads in the test, which up to now has mainly been carried out with regard to the rotor as the component with the longest service life. It is only in recent years that the solid turbine housing has also been taken into account. »The progress we have made in determining the service life and design of the rotor has meant that the housing could now also become a limiting factor for the start-up time as a result of thermal cycling. We are therefore trying to transfer the methods developed for the rotor materials to the housing materials,« says Reigl. The methods developed by the W10 project group can be used in the design of new power plant turbines, but they also help to determine the residual service life of older turbines more accurately.

In contrast to new builds, the actual operating conditions of an existing system, which can differ significantly from the operating conditions assumed in the design, are known. »Thanks to the research results of the W10 project group, the operating life can often be extended beyond the originally planned service life, possibly by replacing individual components that have reached the end of their calculated life,« explains Almstedt. In addition to the evaluation of structural specimen impressions or deformation measurements of the components, theoretical analyses using calculation and simulation play a key role.

The research of the W10 project group thus ensures high efficiency in energy generation through robust, durable turbines in new and existing power plants and also creates the basis for a high level of security of supply in sustainable electricity generation.

Three questions for Dr Stefanie Brockmann

// Executive Member of the Managing Board VDEh Steel Institute

1. How did the FVWHT come about and what is the organisational connection with the VDEh Steel Institute?

The foundation of the FVWHT dates back to 1949. At the suggestion of the German Association of Large Boiler Owners (today: vgbe energy), the working group ›Collaborative Fatigue Tests‹ was founded that year by a number of tube and pipe manufacturers, foundries and forging producers, later joined by steel users. This was the birth of the German Creep Committee on Creep-resistant Steels (AGWS).

The German Creep Committee on High-temperature Alloys (AGHT) was founded in 1957 for materials for gas turbines and aircraft engines, which have to withstand temperatures of well over 800 °C. Over the years, the work of AGWS and AGHT was increasingly organised collectively, which led to the merger of the two cooperation bodies into the Research Association for Creep-resistant Steels and High-temperature Materials (FVWHT) in 2015, which is now an independent association.

The VDEh Steel Institute, based in Düsseldorf, acts as the management of the FVWHT. VDEh itself emerged from the Association of German Steel Manufacturers and has been dedicated to technical and scientific issues in the steel industry since 1860. In addition to steel manufacturers, both plant manufacturers and other suppliers to the steel industry are represented in the VDEh.

2. How is the W10 project group integrated into the FVWHT?

The research projects supervised by the FVWHT are divided into two groups: Research projects (usually testing tasks) that are financed exclusively by FVWHT membership fees and publicly funded, pre-competitive research projects. These include the W10 research projects funded by AVIF (German Steel Application Research Foundation) and the IGF (Industrial Collective Research) programme. The W10 projects are supervised by the FVV and therefore only indirectly by the FVWHT.

The work of all project groups, including the W10 project group, is coordinated by the steering committee, which jointly initiates new research topics and assigns them to qualified test centres. The transfer of results takes place within the FVWHT (at the meetings of the W10 project group) and for the public at the FVWHT's annual lecture event.

3. Are there other co-operation partners of the FVWHT besides the FVV??

The FVWHT is supported by a total of five organisations: the VDEh Steel Institute, the Federal Association of the German Foundry Industry (BDG), the Association for Plant Engineering and Industrial Services (FDBR/VAIS), vgbe energy and the FVV. The FVV occupies a special position in this structure due to its orientation as initiator and coordinator of research projects in operational work.

The management of the FVWHT provides organisational support for industry projects and covers the entire field of materials manufacturers and users via its cooperating sponsoring associations. The research institutes and testing centres with which the FVWHT works on an ongoing basis should also be regarded as cooperation partners.

Three questions for Dirk Bösel

// Project Manager of the FVV

1. Why is the FVV involved in research into high-strength steels under high-temperature exposure?

Materials science is a key component in the development of sustainable, climate-neutral technology solutions in the field of energy generation and conversion. Especially for the development of gas and steam turbines, there is a high demand for new high-temperature-resistant steels that can be used to fulfil requirements such as higher efficiency, shorter ramp-up times and longer service lives.

The research results of the W10 project group create the basis for efficient development at our member companies at a pre-competitive level and thus for the rapid market launch of turbomachinery and components. With our research tasks, we are addressing current issues arising from the increasingly flexible use of grid reserve power plants and are making a direct contribution to environmental and climate protection with our investigations into material qualification.

2. What are the advantages of the co-operation between the FVV and the FVWHT?

By cooperating with the Research Association for Creep-resistant Steels and High-temperature Materials FVWHT, we are building a bridge from production to the subsequent use of materials and components in power plants. In FVV and FVWHT, material producers, material users and the manufacturers of power generation plants work closely together on collectively defined research tasks.

Through these joint projects, FVV and FVWHT pool their efforts and realise synergies, as the research results are made directly accessible to all relevant industrial circles, thus enabling rapid implementation in practice.

For me, the collaboration with the FVWHT is an example of the potential that pre-competitive collective research offers for companies and society.

3. How long has the cooperation with the FVWHT existed?

The FVV has always maintained close contact with the FVWHT and its predecessor organisations. The cooperation in research into the long-term behaviour of metallic high-temperature materials in its current form has existed since the early 1980s.

During this time, we have been able to investigate and characterise a large number of materials in the projects. Gas and steam turbines are technologically highly complex systems whose design requires the interaction of many disciplines.

The collaboration with the FVWHT is a valuable component of our cooperation network for industrial research on power generation plants, which we use to promote the transfer of knowledge and technologies.

> »The collaboration with the FVWHT is a valuable component of our cooperation network, which we use to promote the transfer of knowledge and technologies.« // Dirk Bösel

High-strength steels throughout time

The potential for optimisation in power plant technology is directly linked to the properties of the materials used to manufacture key components such as the rotor, as well as the housing and piping. The goal of ever higher turbine efficiencies requires increasing steam temperatures and pressures, which in turn can only be realised using steels with higher creep rupture strength.

Until the early 1980s, the maximum steam temperature of turbines for power plants was 540 °C due to the low-alloy chromium steels used. The leap to high-alloy steels such as X12CrMoWVNbN10-1-1 for the rotor and cast materials such as GX12CrMoWV10-1 or GX12CrMoVNbN 9-1 (C91) for the housing enabled steam temperatures of up to around 600 °C and therefore significantly higher system efficiency without compromising on service life. **High-temperature-resistant steels such as X13CrMoCoVNbNB9-2-1 (FB2) and G-X13 CrMoCoVNbN 9-2-1 (CB2), which can be used to achieve steam temperatures of up to around 620 °C and steam pressures of up to around 300 bar, are the current state of the art.** **[→ Tab. 1]**

MarBN steels, which offer further improved long-term stability of the microstructure through the addition of boron and nitrogen, are being discussed as a future alternative for even higher temperatures.

As performance has increased, the development and production of high-strength steels has also become more complex. For example, the permissible temperature windows for heat treatment have become ever narrower and the alloy components must be dosed ever more precisely in order to reliably achieve the desired microstructure.

The fact that these new materials can be used in power plant technology is also thanks to the W10 project group. Their research is orientated towards the changing requirements so that the industry always has the right data and models to describe the materials for the further development of turbine technology.

»In large parts of power plant technology, no DIN, EN or ISO standards apply, so the manufacturers and operators of the plants have to rely on their own experience when it comes to design. Through our pre-competitive research, we answer the question of which materials are suitable for which applications and thus provide the framework for industrial research and development«, says Reigl. The material samples analysed in the W10 projects are supplied by the industrial partners and usually come directly from component production, so that investigations and tests with these samples can provide representative results. In the case of cast materials, for example, this ensures that the microstructure composition is identical to the components used in the power plant.

In the W10 projects, all materials undergo a detailed initial test in which an initial characterisation of the cast with regard to chemical composition, heat treatment and mechanical properties is carried out and documented in a preliminary meta data test certificate before the long-term tests are carried out. **With this 'delivery certificate', which the W10 has produced for all steels analysed since it was founded, it is a pioneer of consolidated data management, as the German Research Foundation (DFG) has been demanding for some time as a collection of meta information (FAIR data).** The acronym FAIR stands for 'Findable', 'Accessible', 'Interoperable' and 'Reusable'.

Damage to steels in the high-temperature range is mainly due to creep and fatigue or a combination of both. The damage patterns change over time. Initially, transcrystalline cracks occur, i.e. cracking within the grains of the microstructure; later, intercrystalline cracks along the grain boundaries dominate. **In long-term tests, the W10 project group is investigating microstructural mechanisms in steels under creep, fatigue and combined creep-fatigue loading under isothermal, anisothermal and service-like conditions.** Changes in subgrain size, dislocation structure, pore density and precipitation structure are analysed.

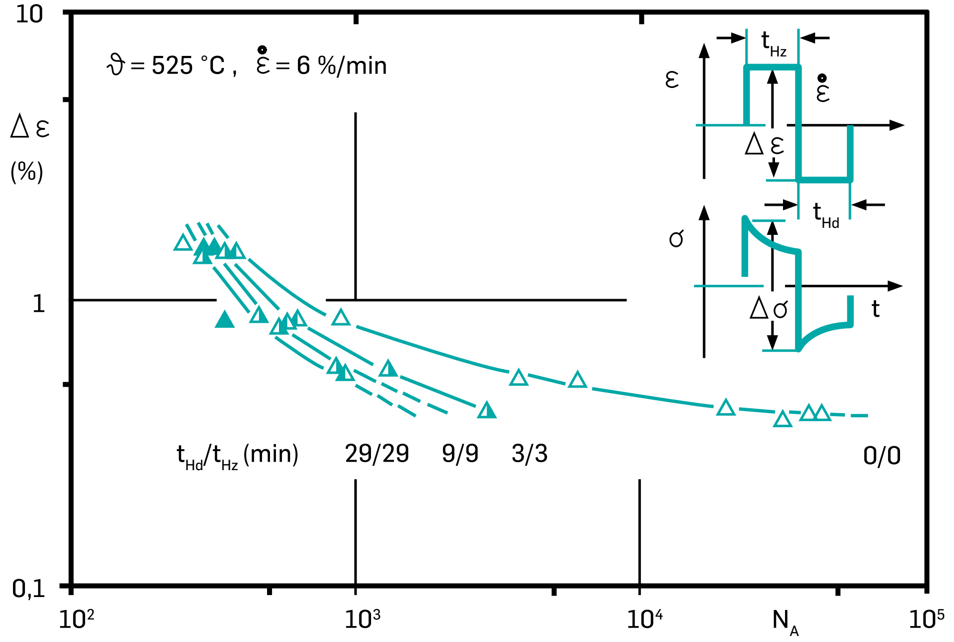
»Under creep- fatigue loading, considerable deformations occur at the microstructural level after a relatively short period of time. This is mainly due to cyclic softening, which is associated with the dissolution of the initial lath and subgrain boundaries, the coarsening of the subgrains and the reduction of the dislocation density. When comparing creep and creep-fatigue loading, it also becomes apparent that the decrease in dislocation density and the increase in subgrain size occur much faster under superimposed loading than in the case of pure creep,« says Reigl about the results of an exemplary W10 research project, in which investigations were carried out for the first time to quantify the change in dislocation and subgrain structure under complex high-temperature loading of 9 % Cr martensitic materials.

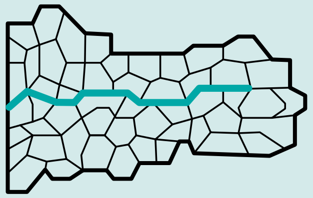
Commissioning of the turbines	Typical max. vapour temperature	Materials for rotors	Materials for housings
since the 1950s	530 bis 540 °C	1CrMoV	1CrMoV
approx. since 1990	565 °C	1CrMoV, 2CrMoWV	1CrMoV
approx. since 1997	580 °C	10CrMoWVNbN	9CrMoWVNbN 9CrMoVNbN (C91)
approx. since 2002	610 °C	9Cr-2Mo-1Co-VNbNB (FB2)	9Cr-2Mo-1Co-VNbNB (CB2)
approx. since 2012	620 °C		

TABLE 1
Development of steam temperatures of steam turbines for electricity supply (reference values)
// Source: Project Group W10

FIGURE 2

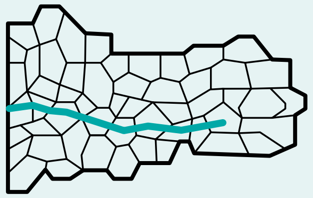
Early work on creep-fatigue interaction performed by the working group W10 *// Source: IfW | TU Darmstadt*





Intergranular crack:

- → High temperature
- → Long hold time
- → Low strain rate



Transgranular crack:

- → Low temperature
- → Short hold time
- → High strain rate

Another relavant and time-dependent mechanism of the long-term deformation in the properties of high-alloy steels as a result of high vapour temperatures is the precipitation state of the alloy components in the material structure at an atomic level Depending on the composition, these include chromium, vanadium and molybdenum (CrVMo steel). »We also map the development of such mechanisms in the long-term tests performed by W10 and make them visible using modern methods of material analysis, for example with the help of energy dispersive X-ray spectroscopy (EDS) and electron microscopy (SEM, TEM)«, explains Dr Min Huang from the MPA at the University of Stuttgart. [→ Fig. 3]

Cast materials that are used for turbine housings, for example, pose a particular challenge in terms of production and service life assessment. Due to the casting and solidification process, impurities and undesirable cavities, so-called blowholes, in the material are almost unavoidable. These inhomogeneities in the microstructure are weak points that can lead to a reduced creep rupture strength of the component. When analysing cast materials, the samples for the creep rupture tests are therefore systematically taken from the outermost layer and the core area of the cast steel so that the tests cover all areas of the cast component.

The W10 project group thus provides research results for the entire range of high-strength steel materials used in power plant construction.

initial state

600 - 200 °C, 840 cycles
t_H = 3.2 h, 2,688 h

600 - 300 °C, 510 cycles
t_H = 3.2 h, 856 h

600 - 300 °C, 462 cycles
t_H = 3.2 h, 1,728 h
plateau 0.0006 % / min

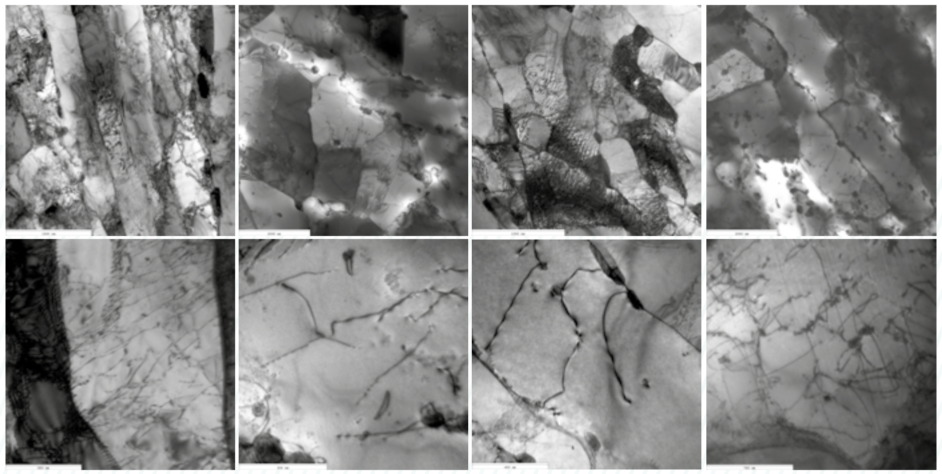


FIGURE 3

TEM bright-field images of samples from service-like anisothermal creep-fatigue tests *// Source: MPA Stuttgart*

Laboratory tests verify service life models

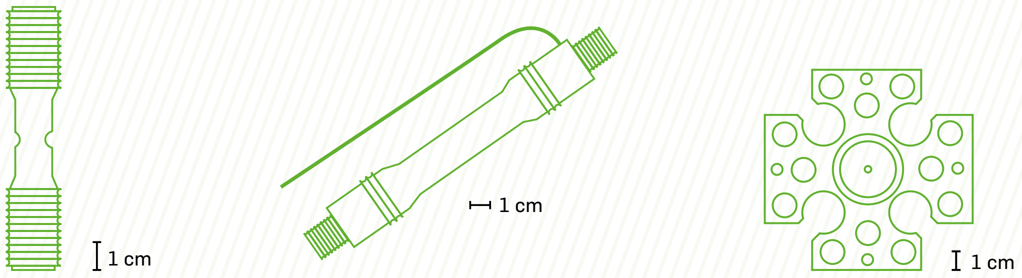
The materials tests carried out in the W10 group's research projects are primarily aimed at improving the predictive accuracy of the service life models for the heat-resistant steels used in steam turbines. These models and their validation enable manufacturers and operators of power plants to optimally utilise the scope of the individual materials with regard to longer operating times and higher loads.

To this end, the test set-up is closely modelled on the real-world conditions in turbines. **The influence of temperature on the performance of the high-temperature steels is modelled using test temperatures of up to over 600 °C. The necessary test duration is a challenge.** »To realistically reproduce the behaviour of the steels tested, some of the samples in the creep-fatigue test were tested for 15,000 hours, or in other words more than two years, in a row. During this time, the test rig is occupied with this test and cannot be used for any other purpose,« says Dr Christian Kontermann from the IfW. This explains why the W10's long-term projects generally only look at two to three different materials, which are then comprehensively examined and characterised.

Tests with a standard load cycle in triangular form, i.e. with linear ramps, are generally used in materials engineering. »This approach does not provide sufficiently accurate results for the needs of the power plant industry. We have therefore developed our own test sample that comes close to the real-world operating mode in a power plant turbine,« explains Kontermann. An example of a representative test cycle includes a cold start, three warm starts and 16 hot starts and maps the temperature loads during turbine start-up (heating), during the holding time at operating temperature (constant load or relaxation) and during shutdown (cooling). [→ Fig. 5] This standardised procedure was established at the IfW back in the 1970s and is still valid today.

»The advantage is the comparability of all the results that our materials research has brought to light since then. We can still understand today what properties these materials had and compare them with our modern samples,« says Kontermann. This also helps to validate the calculation and design models, as more test data is available for comparing the results.

In some cases, special solutions are likewise required for the test specimens due to the specific demands of turbine construction. On the one hand, the familiar round specimens with and without notches are used for this purpose, while on the other hand, test series with cruciform specimens and hollow bodies are also carried out. In addition to load- and strain-controlled tests, tests with cycles with and without hold times, service-relevant load profiles and investigations of alternative casts have been carried out with the round specimens over the course of time. Cross-matching tests allow measurements of the influence of multi-dimensional loading due to the biaxial load application. This multiaxiality also arises in some turbine components, for example at wall transitions and notches in housings. Tests with hollow cylinders at the MPA also address this type of loading.



Round bar with notch

Hollow cylinder with/without notch

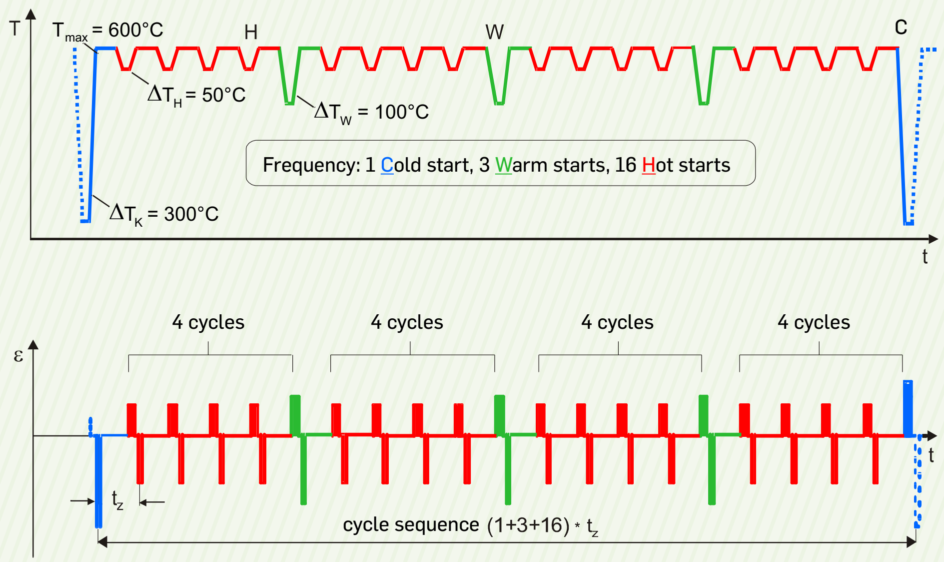
Cruciform specimen with hole

FIGURE 4

Specimen moulds for addressing component-like load situations *// Source: MPA | IfW*

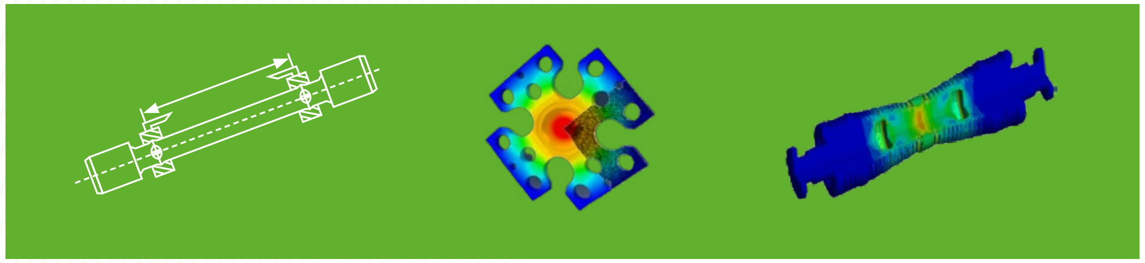
FIGURE 5

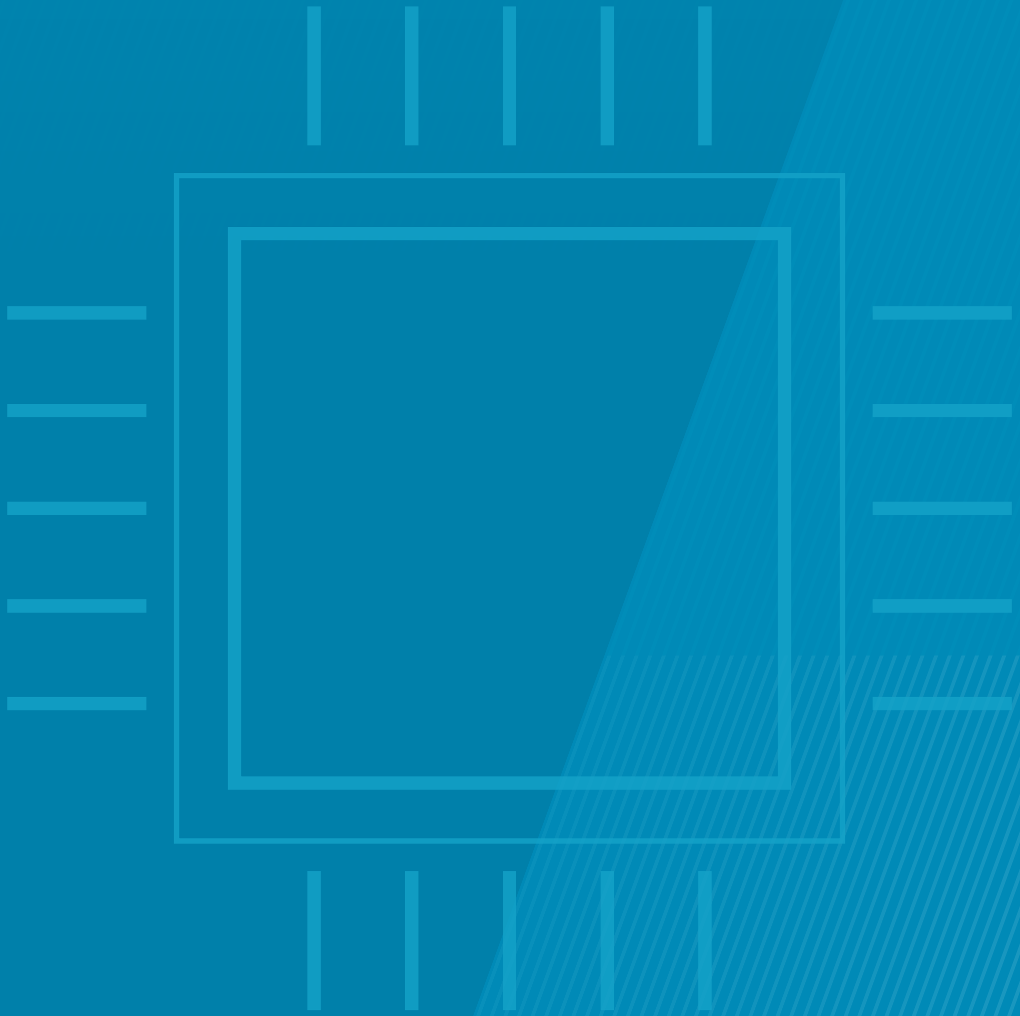
Exemplary cycles and test strategies for describing service-type loading scenarios *// Source: IfW | TU Darmstadt*



»Inside the test specimen, we can generate a gas pressure of up to 400 bar and a temperature of up to 600 °C and thus simulate the loads caused by vapour pressure as they occur in reality,« says Huang.

Recent research projects have broadened the horizon of observation. A new criterion is the development of small cracks in component notches that occur in the structure and continue to grow over time. **While in the past, safety factors in the sense of a conservative design ensured the necessary long-term durability, new research results can help to take real crack growth into account more precisely and thus better transfer it into the models.**





The more precise the models, the more scope for development

Due to the high time and cost involved in long-term material testing, the design of turbine components cannot be fully validated by laboratory tests. Instead, calculation and simulation models must be found that can be used to precisely predict the processes in the material and the resulting service life. One of the greatest challenges here are the high loads during the start-up of a turbine, caused by the large temperature gradients of the usually very thick and heavy components.

NASA employee S. S. Manson provided the first calculation approaches around 60 years ago. He simplified the specific operating cycle in the power plant using a factor. The rule of thumb was that operation under creep conditions accounts for 90 % of the cyclical service life.

A much more precise method can be traced back to the former head of high-temperature research at the IfW, Dr. Alfred Scholz. As part of his dissertation in the 1980s, he developed the post-processor method SARA (SchadensAkkumulation zur RechnerAnwendung, the German acronym meaning damage accumulation for computer application). The results of structural-mechanical calculations of the component serve as input variables. **SARA derives a damage accumulation from the FEM results within a few minutes. Cycles similar to the start-up, holding and shutdown phases for cold, warm and hot starts are specified and combined in different numbers depending on the operation.** The accuracy depends on the modelled cycle - the closer it is to the real-world cycle, the more accurate the results generated by SARA. »The findings of the W10 are implemented in the companies in internal design rules and have proven themselves in countless applications,« says Almstedt.

So-called unified models provide even more precise results. They can be applied using probalistic methods and provide precise information about where damage can occur, how likely it is and what damage propagation can be expected. When transferring the results to industrial research and development, however, Almstedt draws attention to a key point with unified models: »Sophisticated analyses can only be carried out with precise knowledge of all input values such as load regimes, geometries and material information. If this information is only approximately known during component development, a rough calculation using SARA is completely sufficient.« The disadvantages of unified models are the long calculation times of several weeks and the occasional lack of calculation stability.

»The W10 is therefore working hard on ways to further increase the accuracy of SARA on the one hand and to reduce the computing time of the unified models and improve their robustness on the other,« explains Almstedt. To this end, the potential of various players using unified models is to be pooled in future. On the initiative of the W10, a joint project funded by the Federal Ministry of Education and Research was launched as part of the ›Material-Digital‹ initiative. The aim is to establish standardised input and output interfaces for unified models.

Pre-competitive collective research could then benefit from easier handling and better comparability of the calculation results.

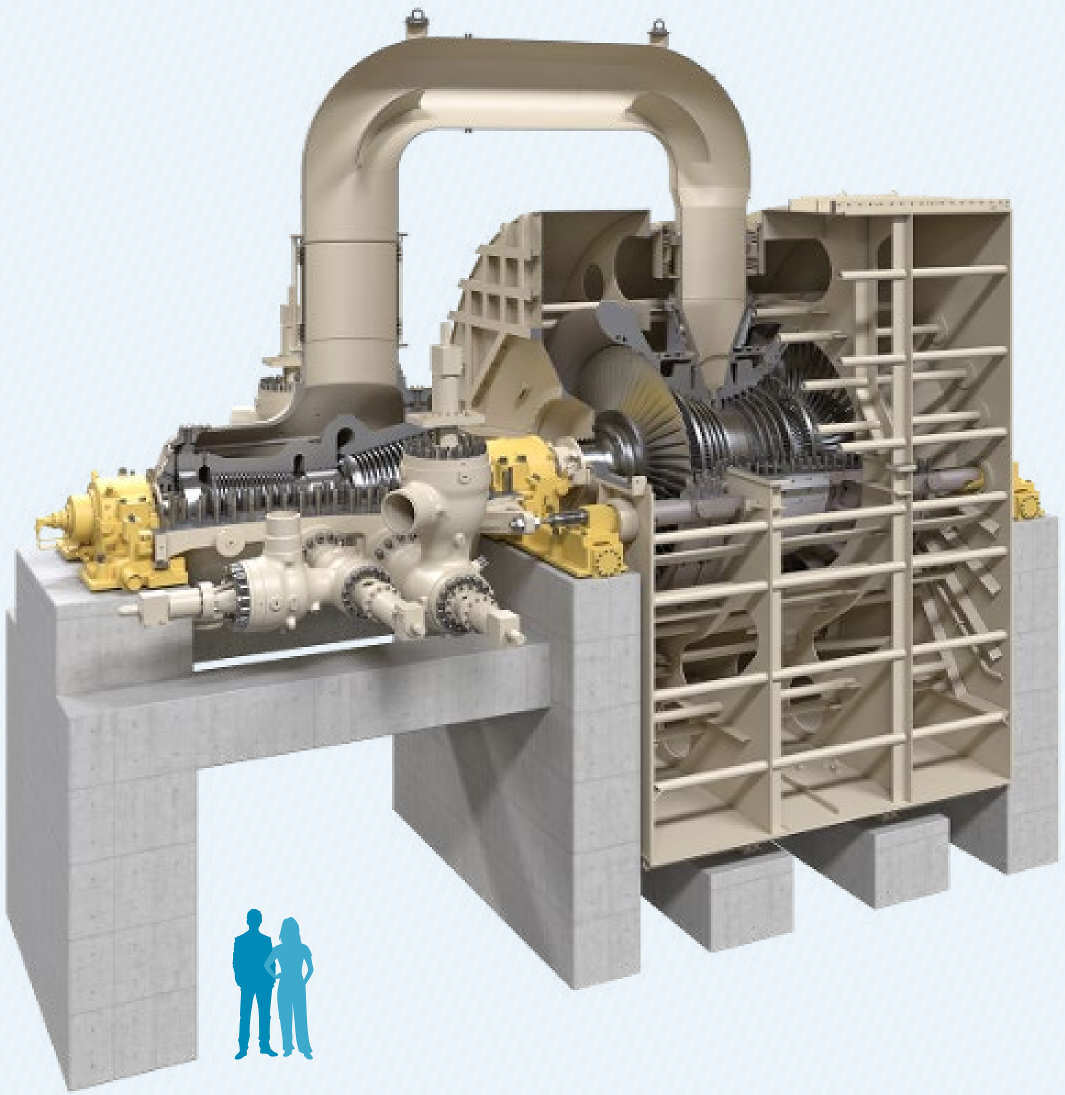


FIGURE 6

Steam turbine: design and size comparison // Source: Siemens Energy

Rotor of a steam turbine *// Source: GE Vernova*

PROJECT-NUMBER	TITLE // DURATION	RESEARCH-FOCUS	FUNDING ORGANISATION	RTD PERFORMERS	PROJECT COORDINATION
904	Fast Turbine Startup: deformation / damage propagation on heavy high-temperature turbine components during fast start-up processes // 01-07-2006 to 31-12-2010	Materials	AVIF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW)	GE Vernova
925	Optimisation of Material Model Parameters: advanced methods for parameter identification and sequential extrapolation by the application of constitutive material models for creep and creep fatigue loading // 01-01-2007 to 31-03-2010	Development tools	AVIF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW)	Siemens Energy Global
106	Wall Thickness of Turbine Housings: damage propagation for castings of modern thermal plants and machinery under multiaxial and thermomechanical loading // 01-01-2011 to 31-03-2015	Materials	AVIF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW)	GE Vernova
113	Creep Fatigue Support Effects: influence of support effects on the long-term creep-fatigue behaviour of power plant components at high load change rates // 01-01-2013 to 30-06-2016	Materials	AVIF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW) University of Stuttgart / Institute for Materials Testing (MPA)	Siemens Energy Global
1181	Creep Fatigue Probabilistic Methods: probabilistic lifetime assessment of high temperature components under creep-fatigue loading // 01-01-2015 to 30-06-2018	Materials	AVIF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW)	Siemens Energy Global
1259	Wall Thickness of Turbine Housings II: lifetime assessment and damage mechanisms of thick-walled housing components made of modern cast steel operated at variable loads. The approaches for modelling the calculated service life and damage included both an accumulative calculation model (SARA) and a constitutive model. // 01-01-2017 to 31-12-2020	Development tools	AVIF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW) University of Stuttgart / Institute for Materials Testing, Materials Science and Strength of Materials (IMWF) University of Stuttgart / Institute for Materials Testing (MPA)	GE Vernova
1299	Notch Support Cast Steel: quantifcation of notch support effects for cast steel components against the background of a more flexible power plant operation // 01-01-2018 to 31-12-2020	Materials	AVIF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW) University of Stuttgart /Institute for Materials Testing, Materials Science and Strength of Materials (IMWF) University of Stuttgart / Institute for Materials Testing (MPA)	Siemens Energy Global
1380	Creep Fatigue - Probabilistic Lifetime Model Comparison: application and comparison of lifetime models for analysing high-temperature components under creep-fatigue loading by utilising sophisticated probabilstic methods // 01-01-2020 to 31-12-2023	Development tools	AVIF	University of Wuppertal / Applied Mathematics - Stochastics Technical University of Darmstadt / Center for Structural Materials (MPA-IfW)	Siemens Energy Global
1401	LPBF High-temperature Lifetime: development of concepts for the determination of characteristic values for the evaluation of additively manufactured components for high-temperature use // 01-05-2020 to 30-04-2024	Materials	BMWK/IGF	University of Stuttgart /Institute for Materials Testing, Materials Science and Strength of Materials (IMWF) University of Stuttgart / Institute for Materials Testing (MPA) Technical University of Darmstadt / Center for Structural Materials (MPA-IfW)	MAN Energy Solutions
1518	Integrated Creep Fatigue Assessment: generalisation, extension and verification of damage accumulation approaches for an integrated assessment of realistic operation loads within FEM programs // 01-03-2024 to 31-08-2026	Development tools	BMWK/IGF	Technical University of Darmstadt / Center for Structural Materials (MPA-IfW) Fraunhofer Institute for Mechanics of Materials (IWM) University of Stuttgart /Institute for Materials Testing, Materials Science and Strength of Materials (IMWF) University of Stuttgart / Institute for Materials Testing (MPA)	GE Vernova

Further information:
THEMIS | W10 project group:
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RTD PERFORMERS

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University of Stuttgart / Institute for Materials Testing, Materials Science and Strength of Materials (IMWF)

University of Stuttgart / Institute for Materials Testing (MPA)

Technical University of Darmstadt / Center for Structural Materials (MPA-IfW)

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