On-site test methodology for gas turbine rotor assessment and lifetime extension

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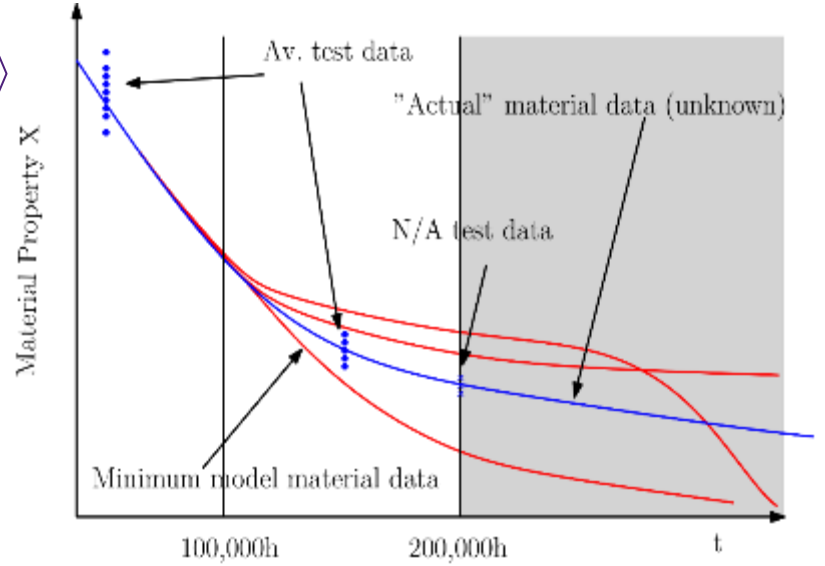
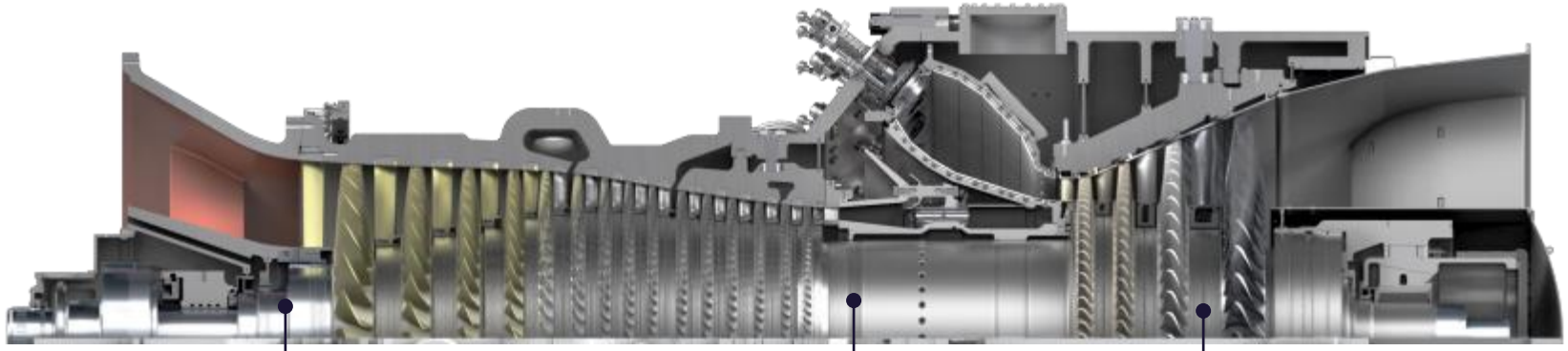
Long-term Material Behavior of Rotor Steels

Effect	Consequence	Action
As a result of long-term operation the rotor material properties will change, e.g. • Reduction of strength and / or ductility possible • Reduction of toughness possible • Microstructural degradation • Oxidation	If the material behavior has not been assessed beyond the targeted operation time, the operation must be restricted.	Validate material property modeling either generically for an entire fleet or for individual units.





SGT5-4000F

Moderate Metal Temperature

Highest Metal Temperature

Medium Metal Temperature

Evaluation strategies for long-term material properties

Established Approach

To determine material properties on operated rotating components we use an established approach with

Furnace testing

Advantages
- All material properties testable
- Ageing under controlled conditions

Disadvantages
- Expensive to purchase material
- Duration and cost of test program (>10 years)
- Stress impact might not be covered as under service conditions

Scope
- Fleet Data Generation

&

Destructive testing service exposed components

Advantages
- All material properties testable
- Cheap purchase of scrap parts
- Stress, temperature and environment influence covered

Disadvantages
- Not all properties and temperatures measurable
- Quantitative assessment and interpretation not trivial

Scope
- Fleet Data Generation

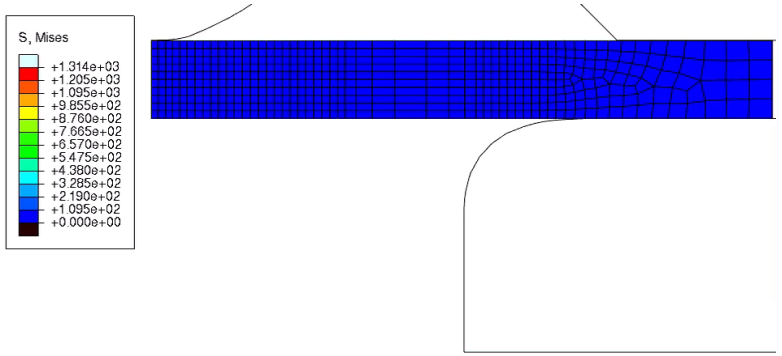
Small Punch Testing

General motivation for Small Punch Tests on turbine components

Abilities of the Small Punch Technique

- Evaluation of service exposed microstructure (thermal and mechanical load) by determination of material properties
- Minimal specimen size without effecting the component's functionality and integrity
- SPT testing is suitable to describe material properties usually determined with standard specimens and tests

- Assessment of the current material condition after service exposure
- Small punch tests allow the approximation of required tensile as well as fracture mechanical properties to ensure:
- **Lifetime extension of components e.g. rotor parts**



Small punch specimen (right) compared to tensile and CT-specimen

Micro Sampling Device – MSD
Overview

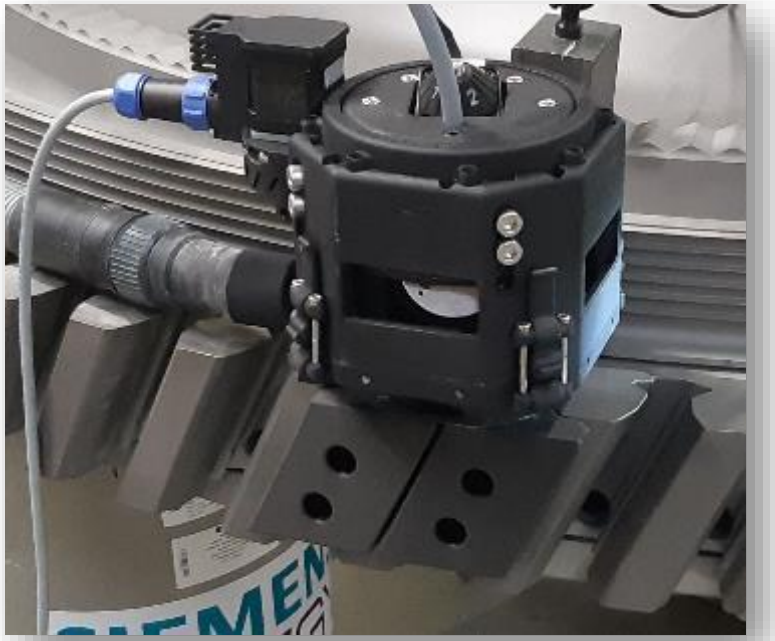
Features

The **patented** Micro Sampling Device was developed to:

- extract very small material samples
- from any component without destroying and rework
- extraction of the material samples take approximately 1 hour
- Low heat input in the material sample

Individual solutions

In order to ensure the exact positioning of the MSD on complex structures, molded parts can be adapted to the device by additive manufacturing shortly.



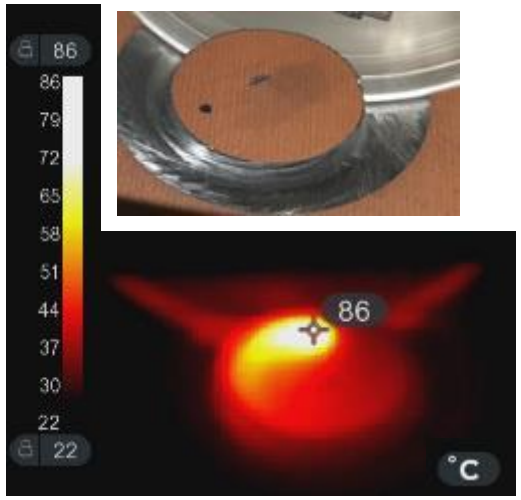
Extraction position

Component and position with its corresponding extraction depth must be defined by engineering with consideration of:

- Heat-affected zones
- Material degradation

Casing of the MSD:

- Universal mounting (via magnet, attachments, ribbons etc.)
- Depth adjustment
- Contact protection
- Suction lead

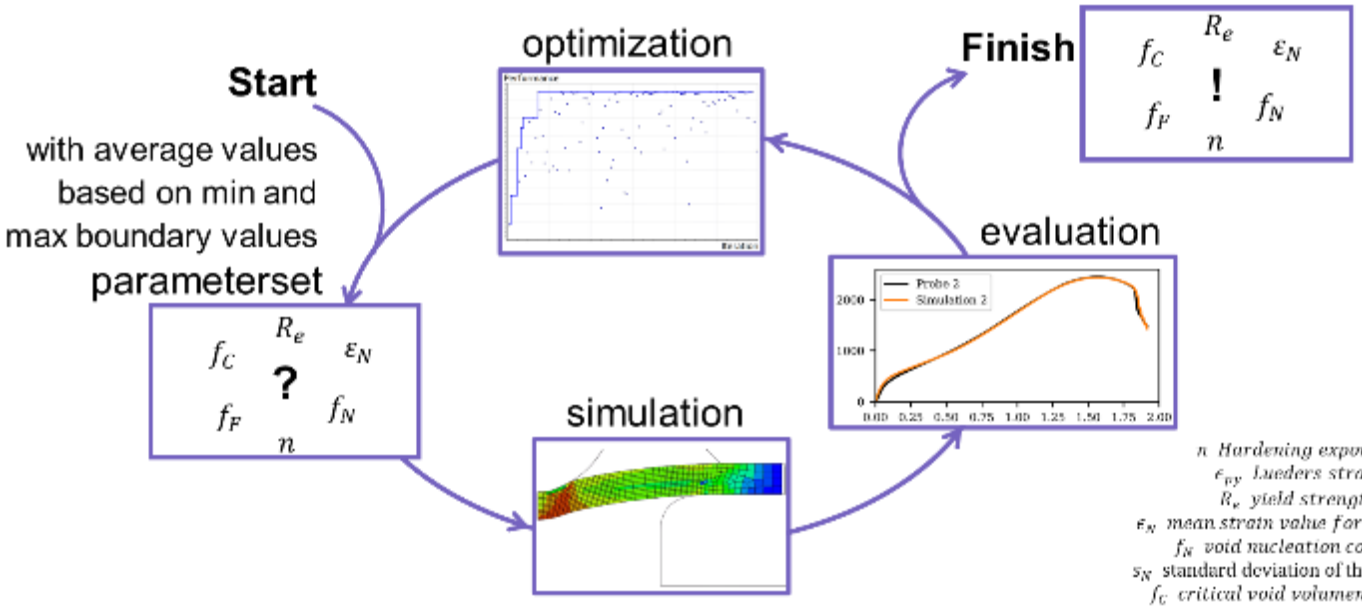


Small Punch Testing

Property optimization process chain

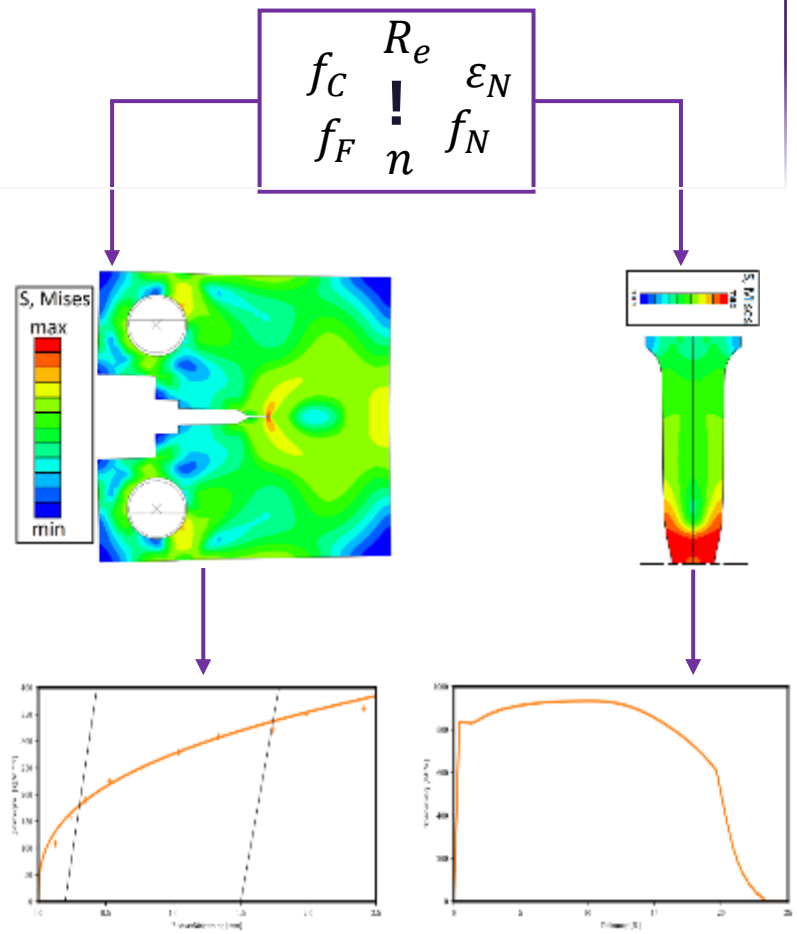
Calibration of the material model via inverse FEM

- Optimization process for the determination of the damage model Gurson-Tvergaard-Needleman (GTN) and the hardening model of Ramberg-Osgood
- Target for the optimization is the difference between simulation and experimental curve of the small punch test; derived parameter are then used to calculate standard test results.



n Hardening exponent
ϵ_{uy} Lueders strain
R_e yield strength
ε_N mean strain value for nucleation
f_N void nucleation constant
s_N standard deviation of the nucleation
f_C critical void volumen fraction
f_F void volume fraction at material failure

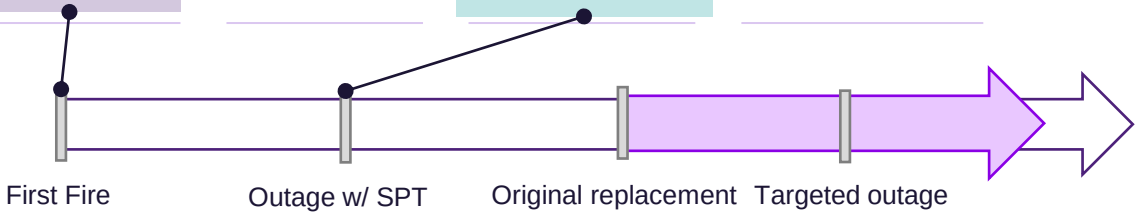
Digital Twin of Specimens



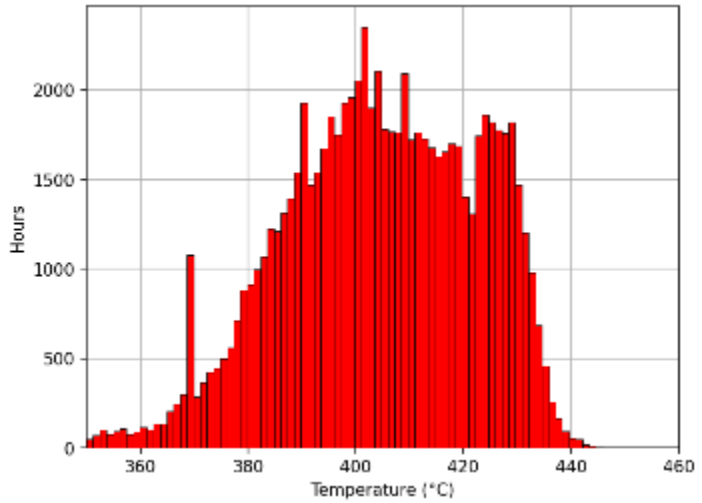
Small Punch Testing

Interpretation at the example of single rotor

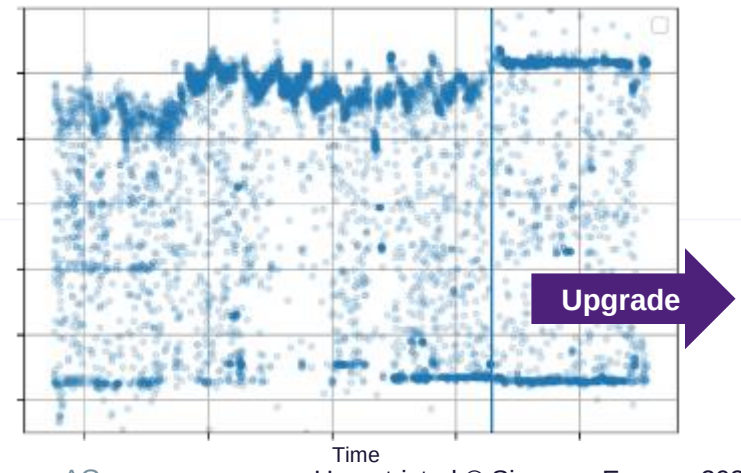
Material Property	As delivered	Trend	From SPT	Design Data
Duration	0 kOH		120 kOH	e.g. ~200kOH
Yield Strength	121%	→	115%	100%
Ultimate Tensile Strength	119%	→	108%	100%
Fracture Toughness	123%	→	121%	100%



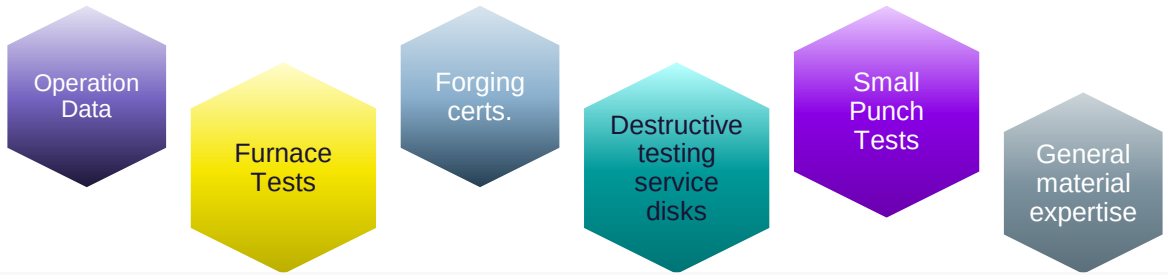
Histogram of historic metal temperature at component



Historic power output



Combination of various inputs allow unit specific recommendation

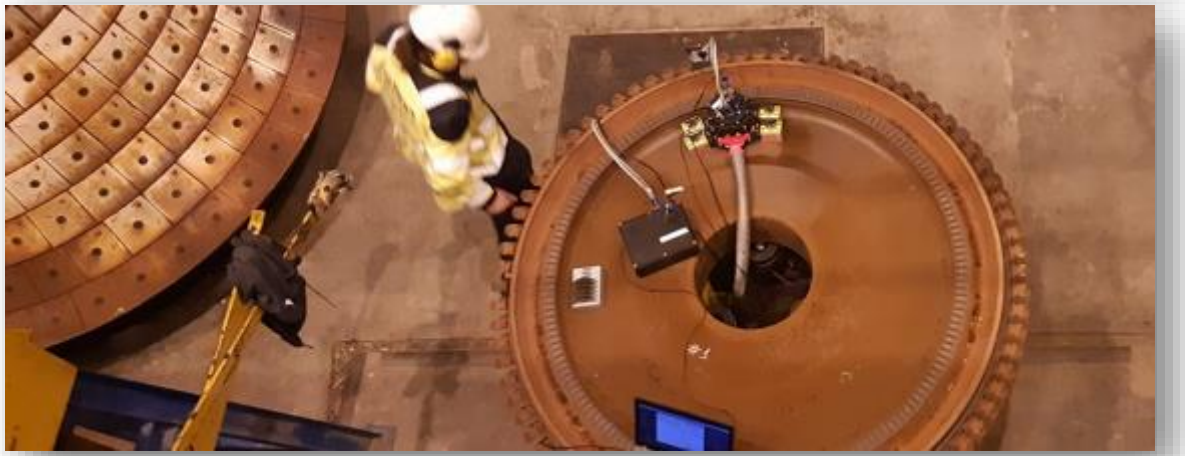


Conclusion

We have presented the first time-application of **Small Punch Testing** (SPT) to Siemens Energy Large Gas Turbine rotors.

- ✓ SPT is an established, normed technology that allows us **to determine material properties** from extracted specimens.
- ✓ SPT uniquely offers the opportunity for material validation concepts to extend **individual component lifetime** beyond the operating time limit.
- ✓ Material extraction can be integrated into existing outage process small impact on outage duration and costs.
- ✓ Applicable if operation data history is limited or unknown.

Improve the attractivity of existing and future service contracts in terms of cost, upgradability, environmental impact and product safety.



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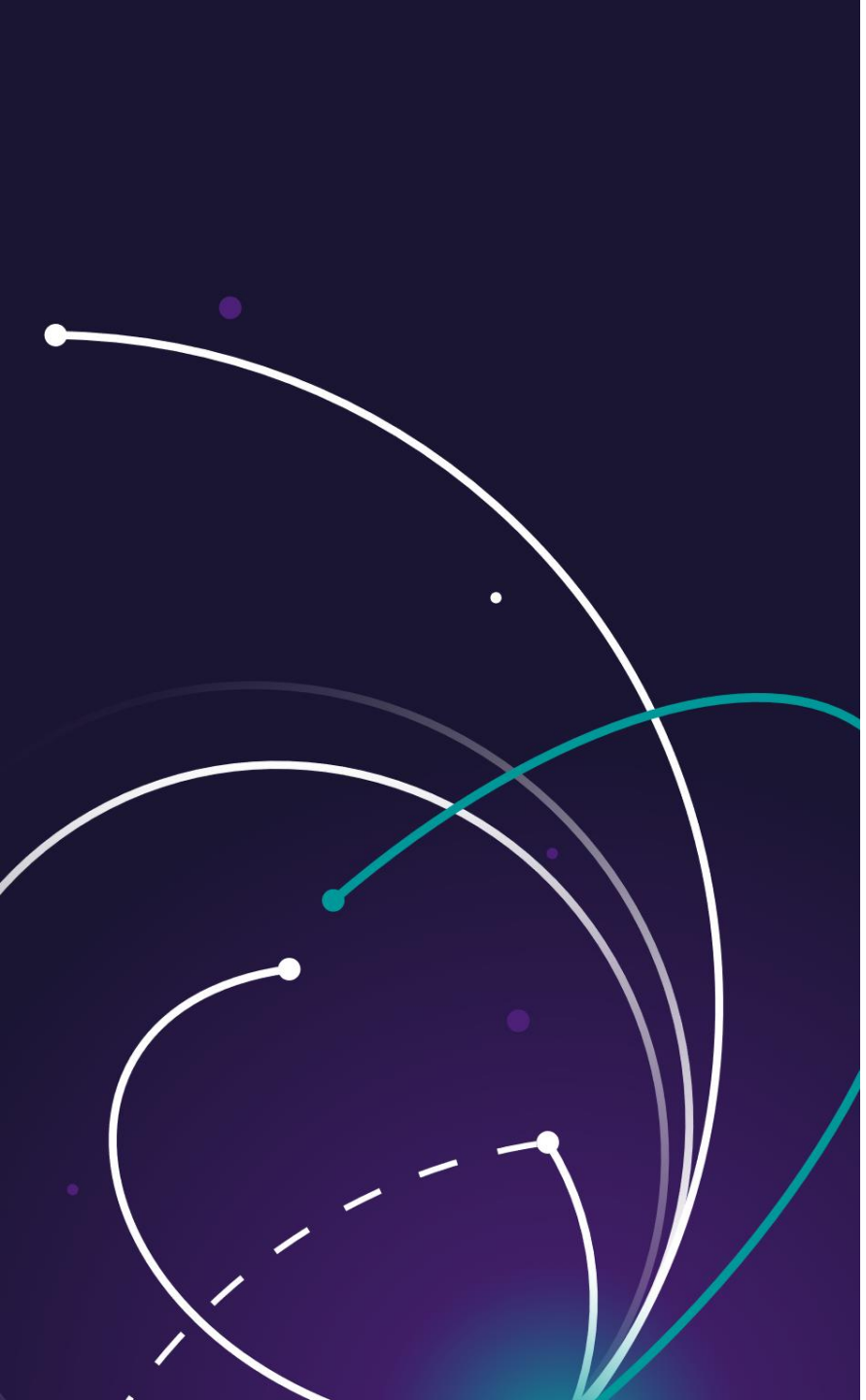

Contact page

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