MAN Diesel & Turbo

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Exhaust valve spindles for marine diesel engines manufactured by hot isostatic pressing

Alberto Lapina, Harro Andreas Hoeg, Jakob Knudsen *MAN Diesel & Turbo*

Tomas Berglund *Sandvik Powder Solutions*

Rune Møller, Jesper Henri Hattel *Technical University of Denmark*

Challenge nr. 1

- **How do you power the world trade to feed and cloth 7+ billions people?**

- You need 50000+ ships
  - Container ships
  - Oil tankers
  - Iron ore carriers
  - Fruit juice tankers (yes, there is such a thing!)
  - Etc. Etc.

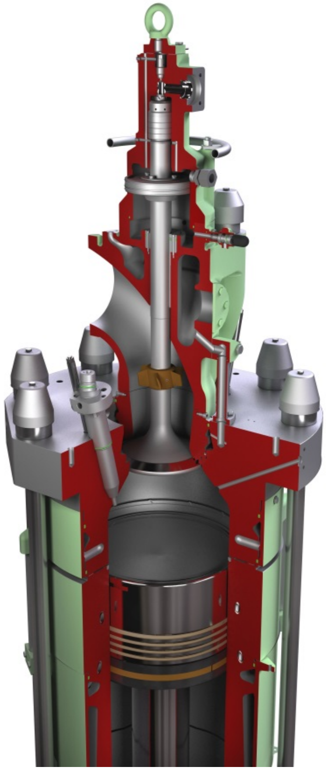
- You need a power technology which is cheap, efficient and reliable

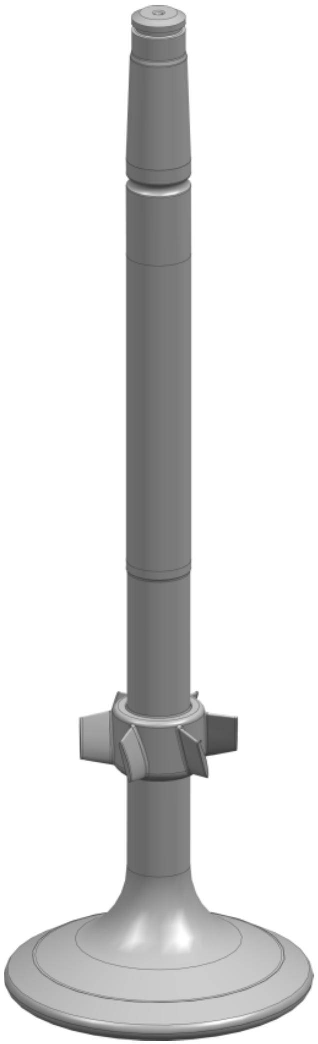
The solution to challenge nr. 1: the two-stroke diesel engine

- Well-proven technology
- High efficiency
- Wide range of possible fuels (heavy fuel oil, diesel oil, natural gas, ethane, methanol, etc.)
- 3-80 MW power range depending on engine model

Challenge nr. 2

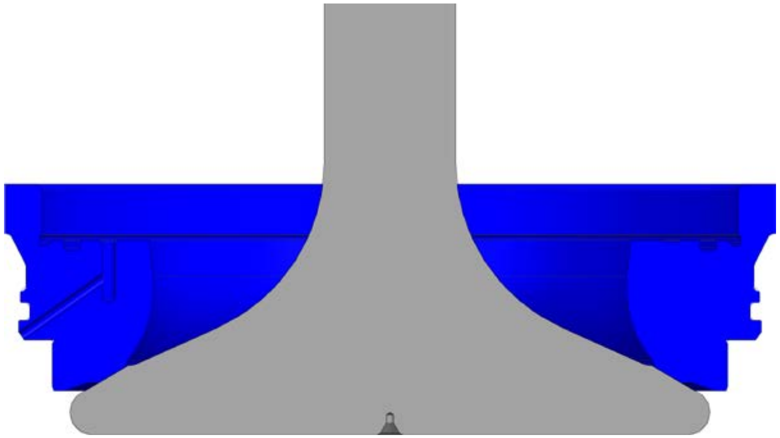
- Fuel efficiency must increase to reduce costs & environmental regulations are getting more and more stringent
- The maximum pressure in the combustion chamber has doubled over the last 30 years
- The thermal loads have increased
- The exhaust valve spindle is experiencing high temperatures, since it has no active cooling!!
- **Result: high hot corrosion rates of the spindle bottom.**





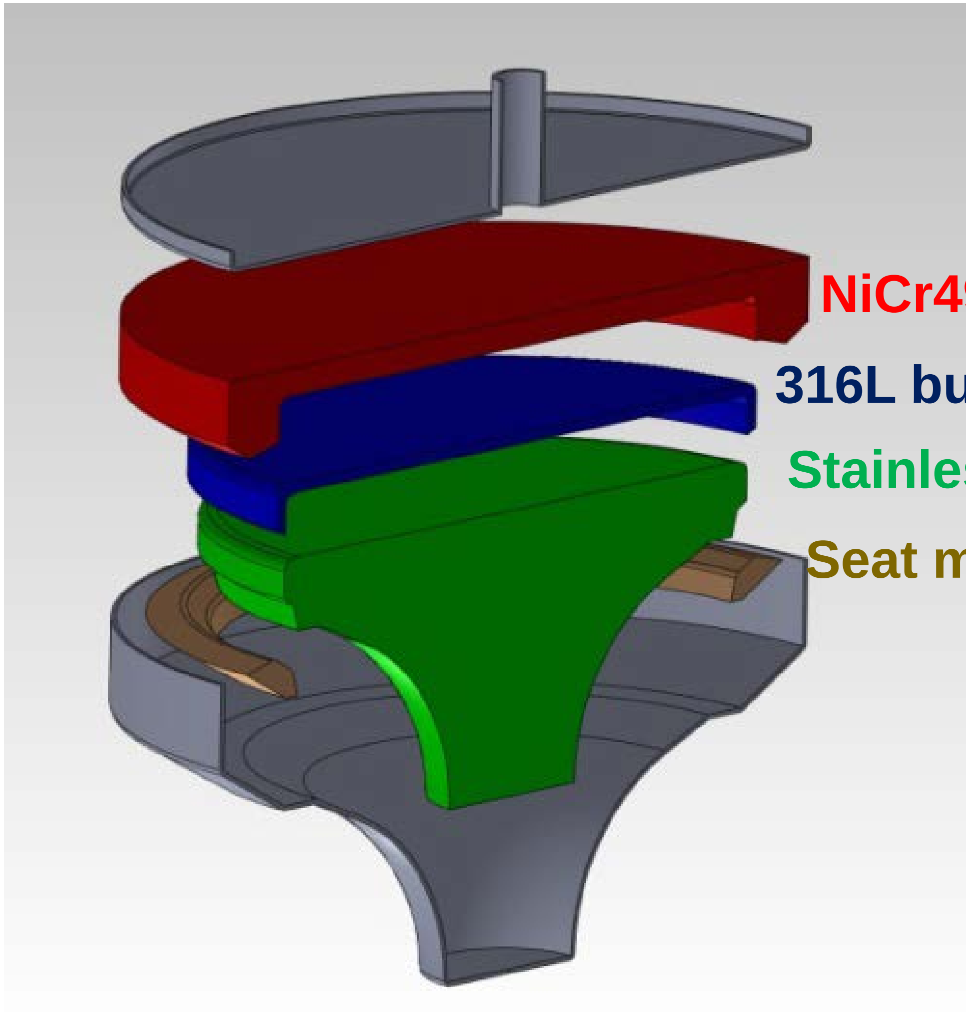
The current solution to problem 2: the Duraspindle™

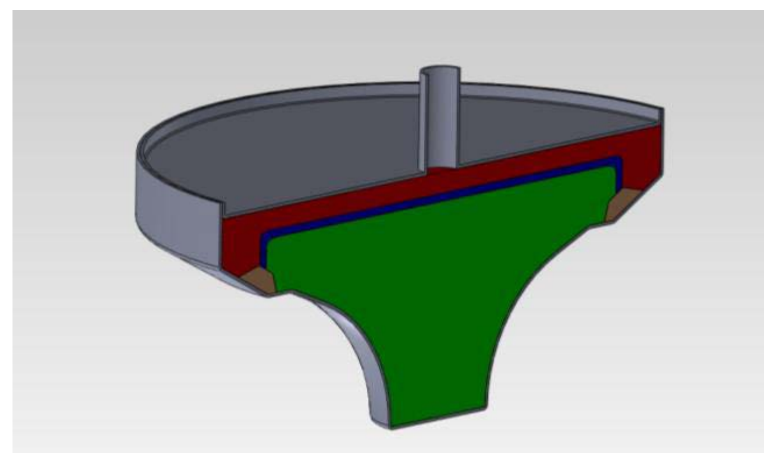
- Stainless steel substrate
- Inconel 718 seat: high hardness after aging and cold deformation ➔ good wear resistance
- Inconel 625 bottom coating: high hot corrosion resistance
- Max allowed corrosion rate: 0. 4 mm/ 1000 hrs



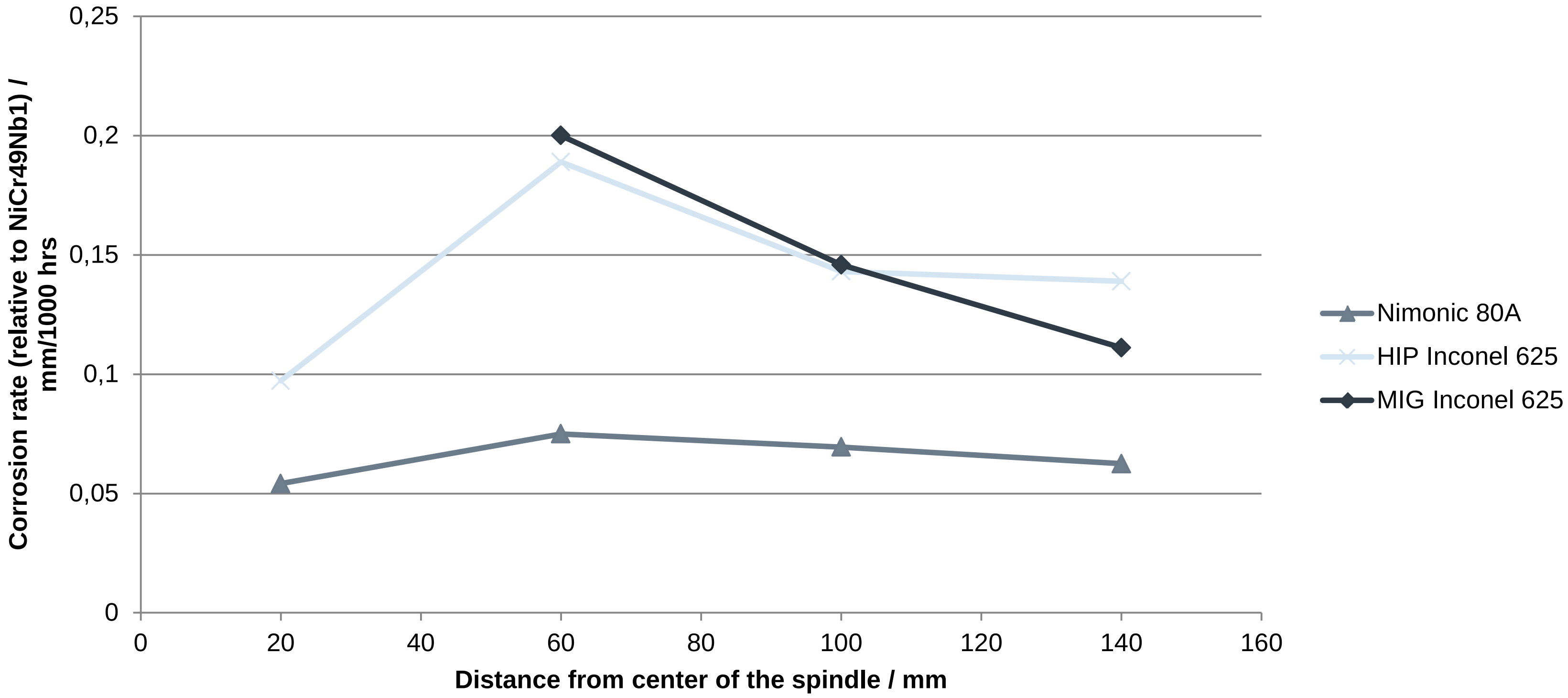
A possible new solution to problem nr. 2
The HIP spindle

- To be tested in service onboard ships up to 18000 hours (~ 3 years)



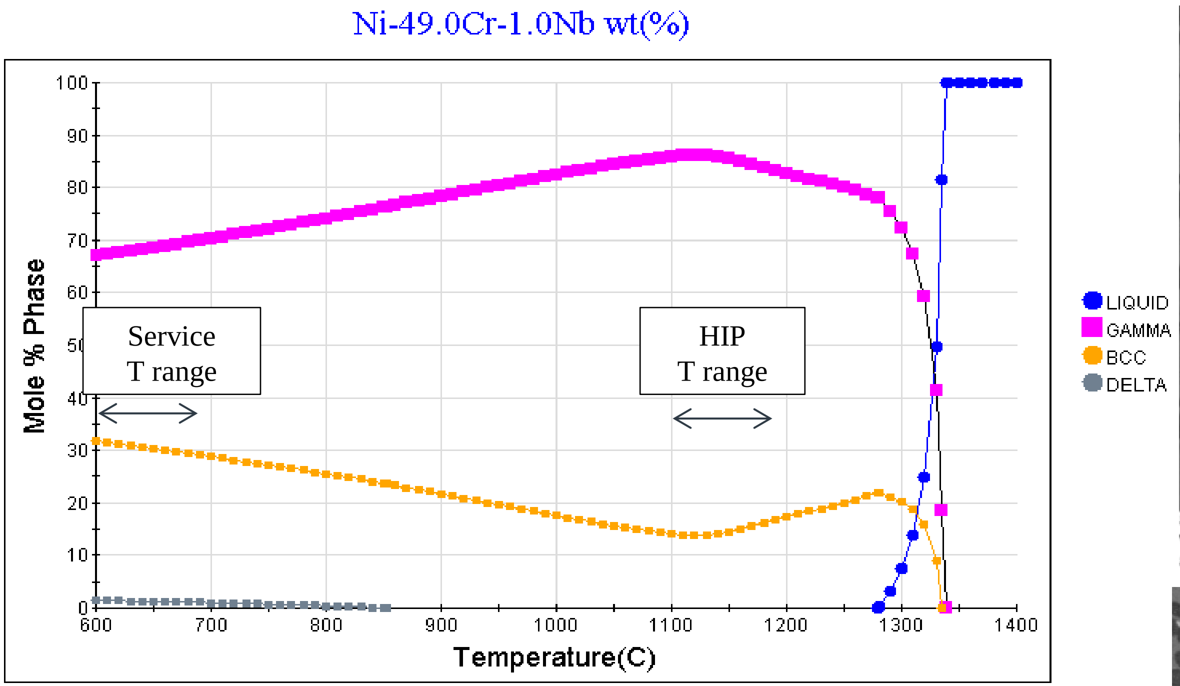


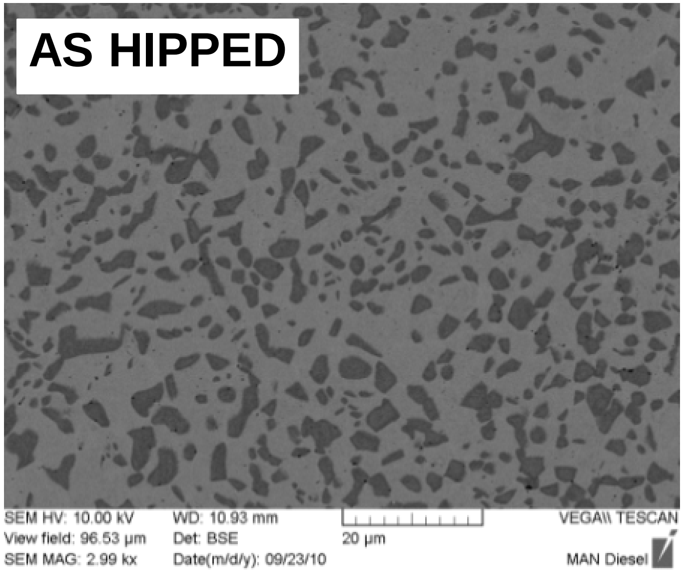
Corrosion rate: State-of-the-art materials vs NiCr49Nb1

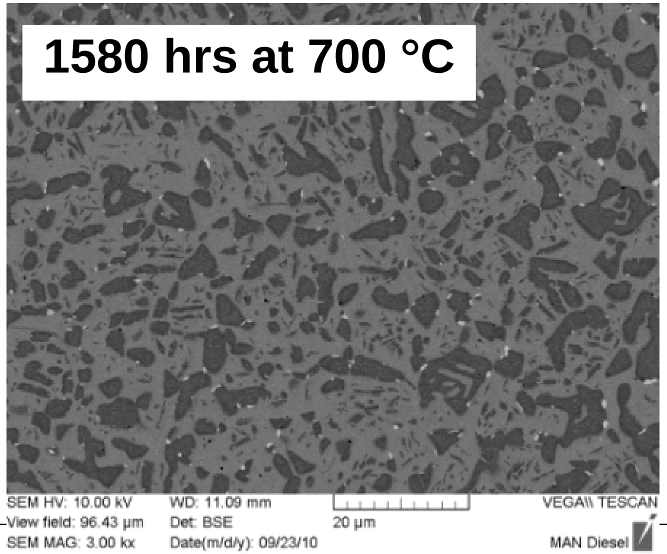


- In this test, the new material gives only a marginal improvement over the state-of-the-art materials, because of relatively low temperatures
- Previous tests show differences in corrosion rates 4-5 times higher, in engines with higher temperatures.

Phase evolution

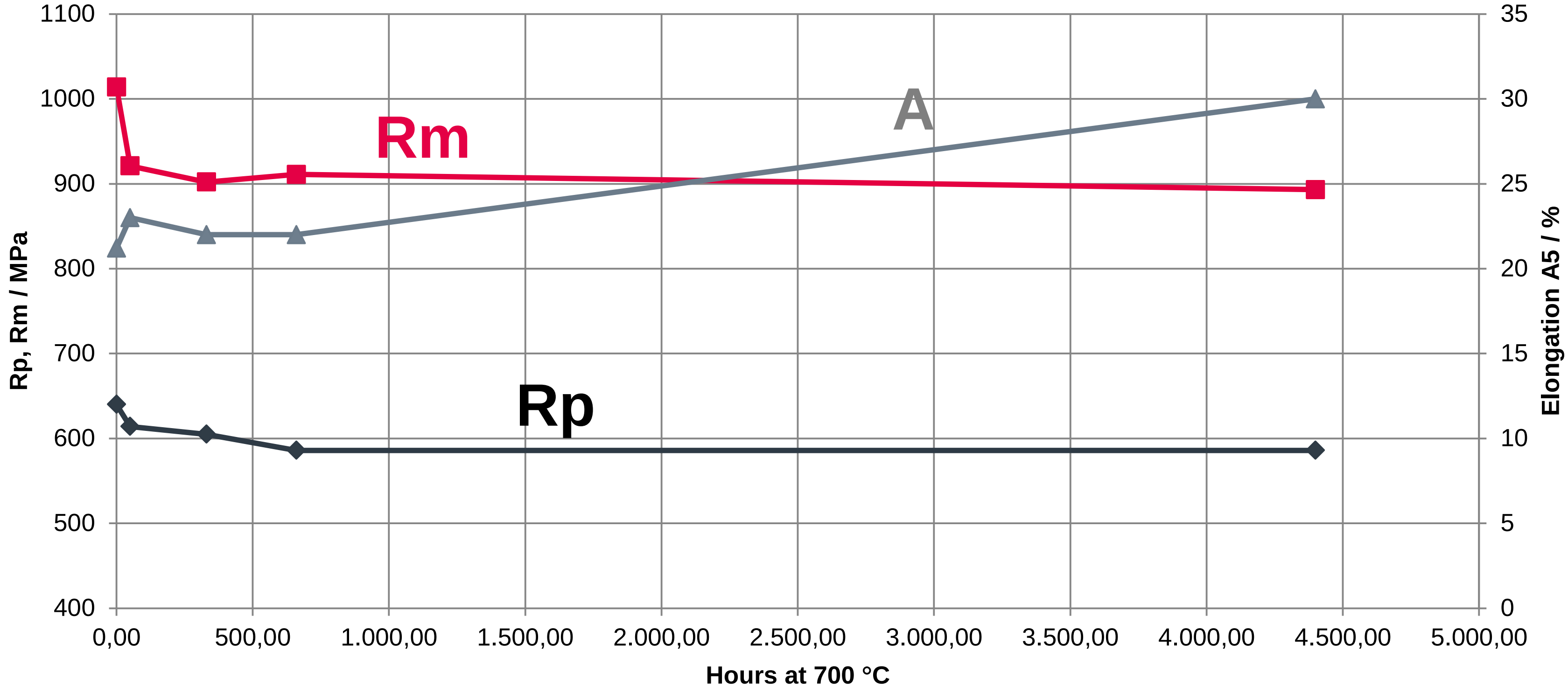






- The material microstructure evolves to a new equilibrium state at service temperature
- Increase of fraction of α-Cr and formation of Ni_3Nb particles

Evolution of mechanical properties



- Rp and Rm decrease over the first few hundred hours, then stabilise

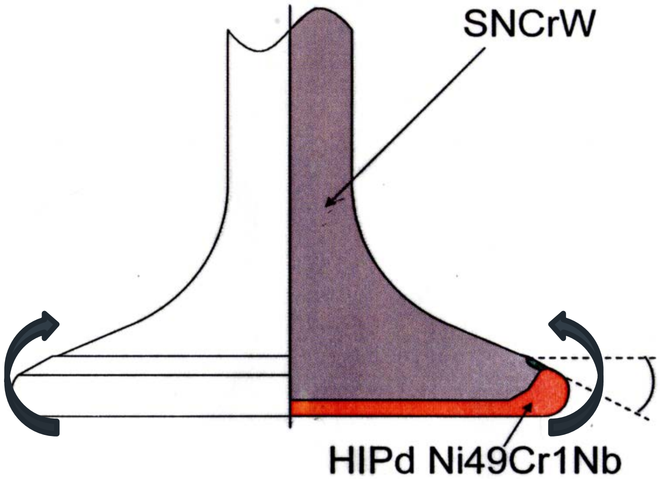
Performance of the new NiCr49Nb1 coating

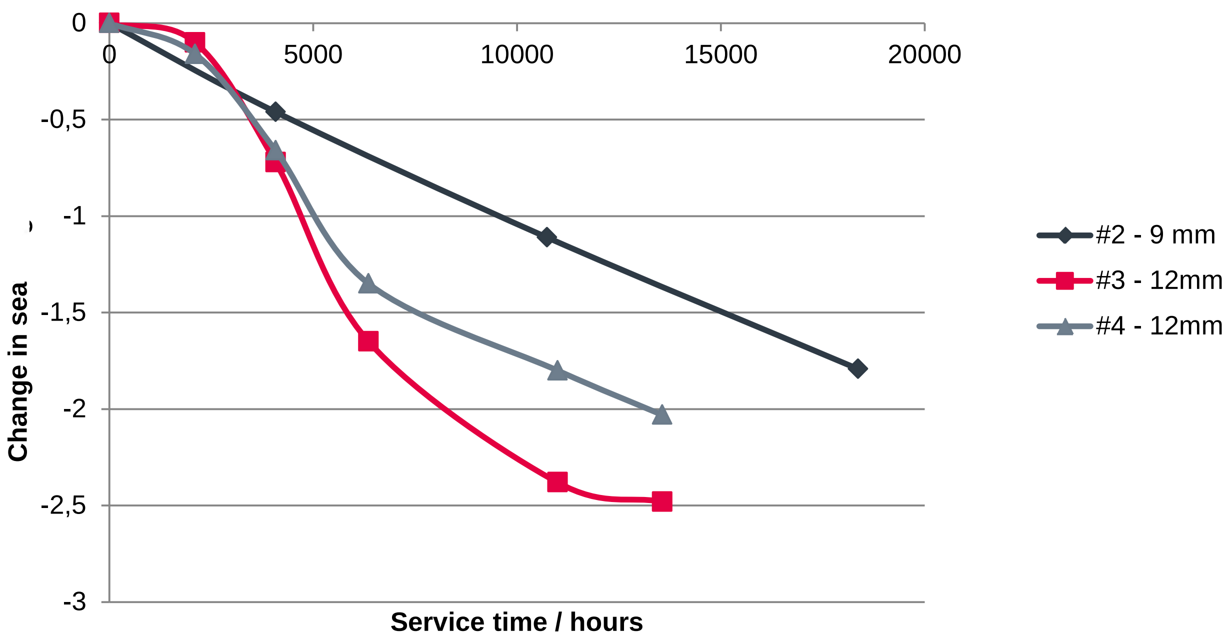
- Corrosion resistance is improved (level of improvement depends on the type of engine and specific running conditions)

- The strength of the material decreases in the first few hundred hours but then stabilises.

- **However there are two issues with this spindle design**.

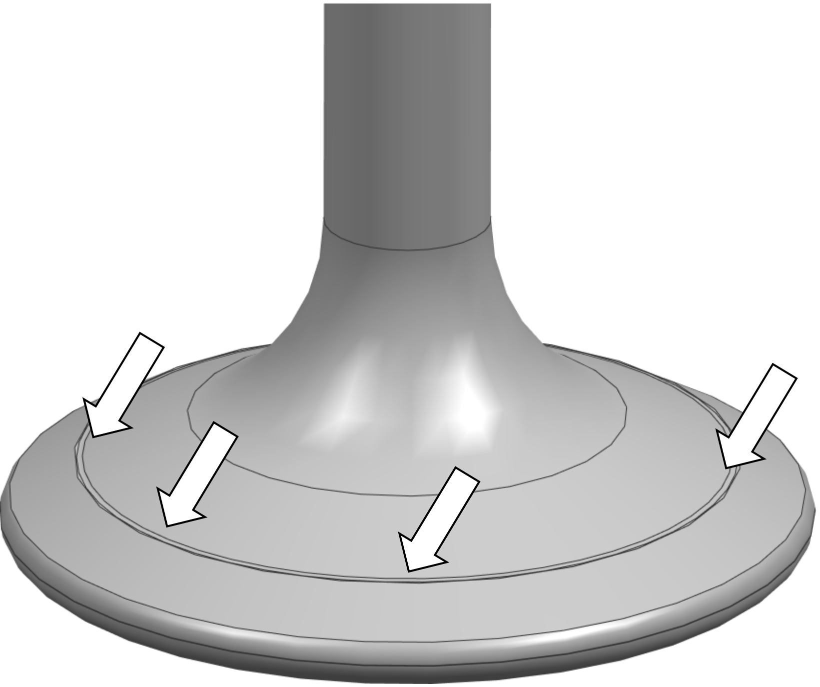
Issue 1: Bending of the spindle

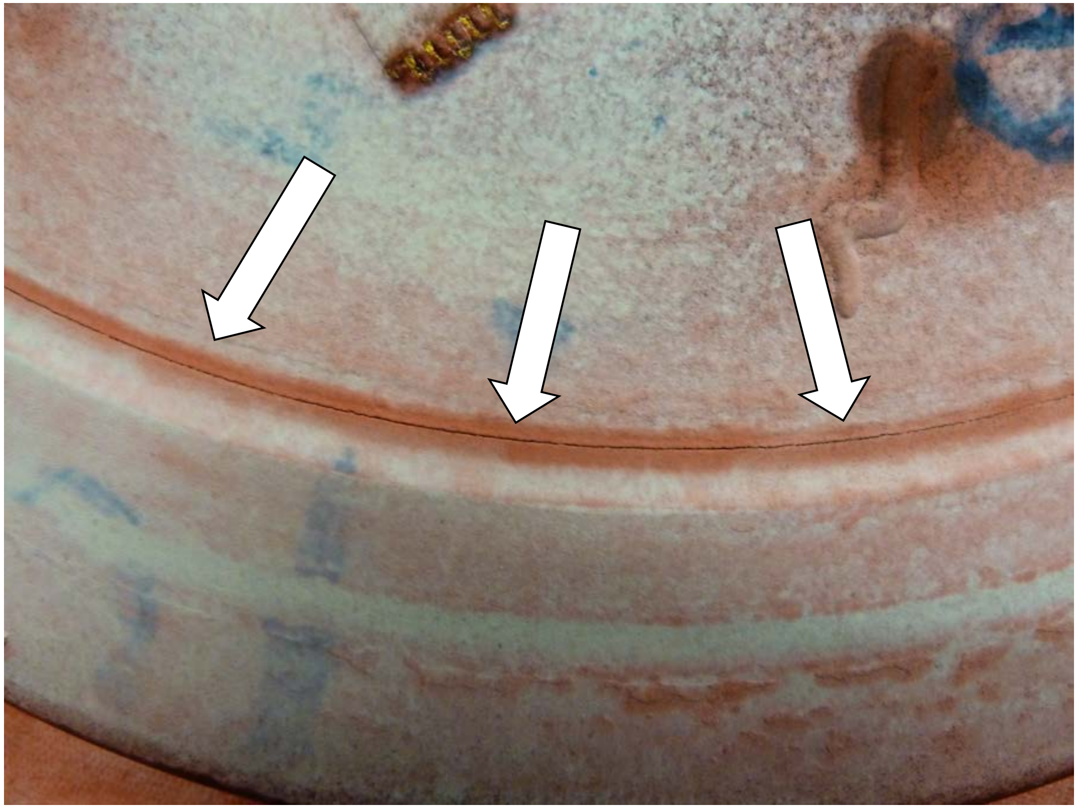




- The spindle bends upwards during service
- This occurs continuously over thousands of hours in service

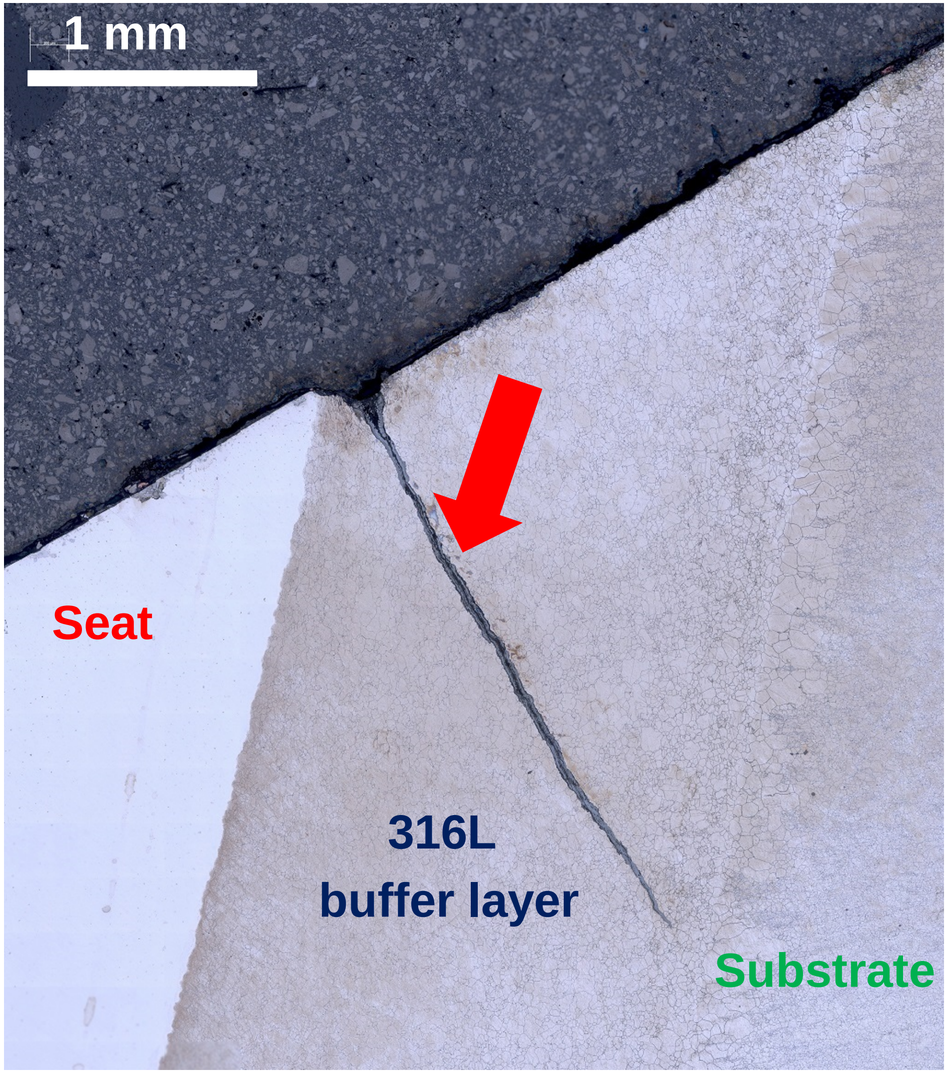
Issue 2: crack at inner seat circumference





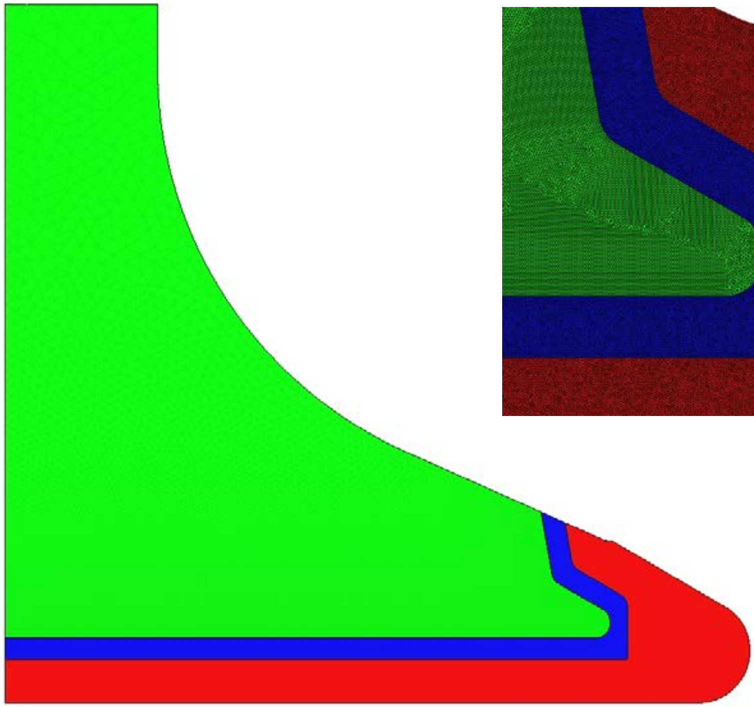
Issue 2: crack at inner seat circumference

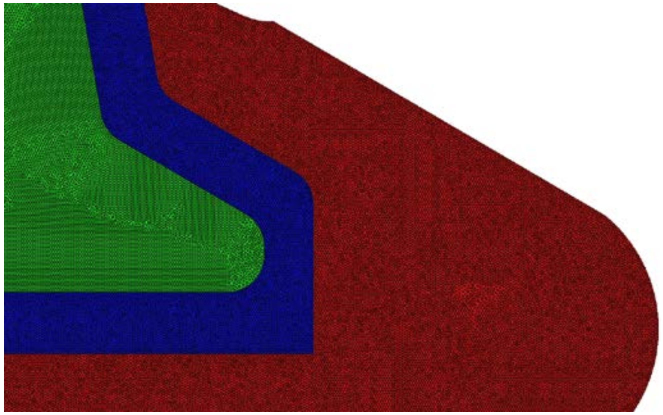
- The step at the seat-316L is due to different corrosion rates of the two materials
- The step acts as a stress concentrator
- The bending of the spindle moves the contact point with the bottom piece toward the outer part of the seat area
- This increases the bending moment and so the stresses in the inner seat area.
- The bending induces the crack

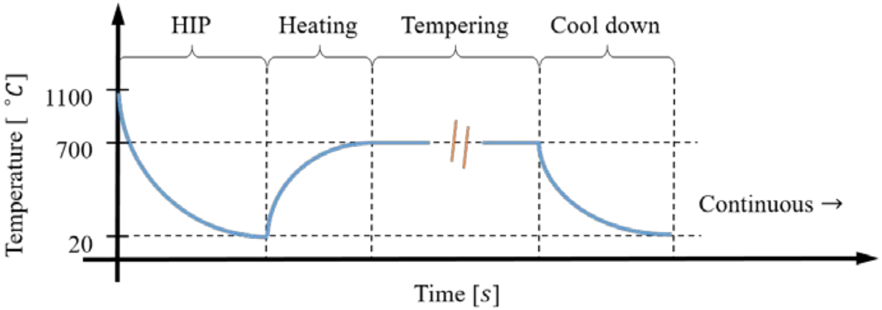


FE modelling: understanding the bending

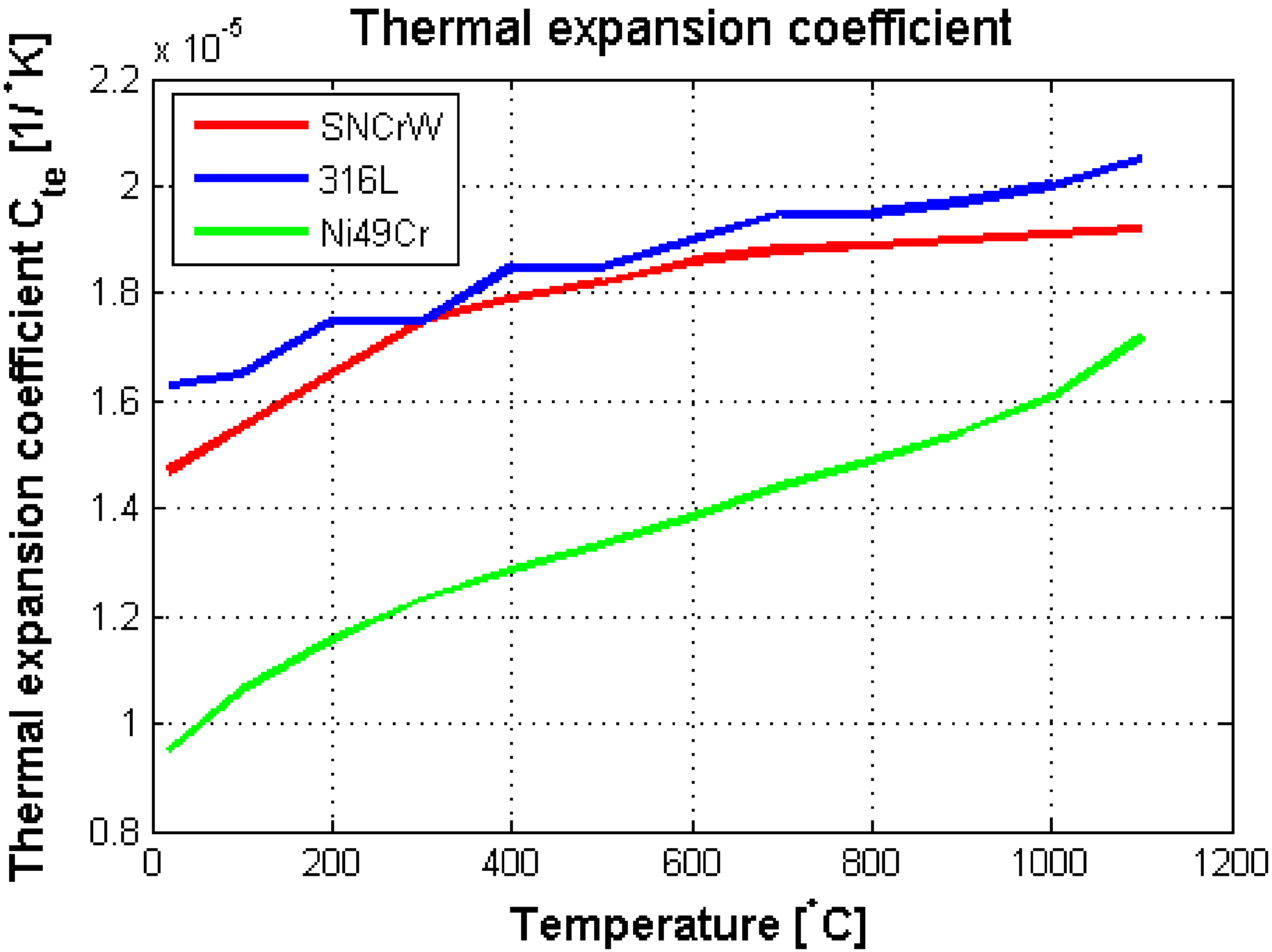
- High cycle thermal fatigue is excluded as a possible mechanism
- Low cycle thermal fatigue (start-stop cycles of the engines) is modelled
- Significant TEC mismatch between 316L and NiCr49Nb1
- Main approximations:
  - Seat in NiCr49Nb1
  - Uniform temperature field





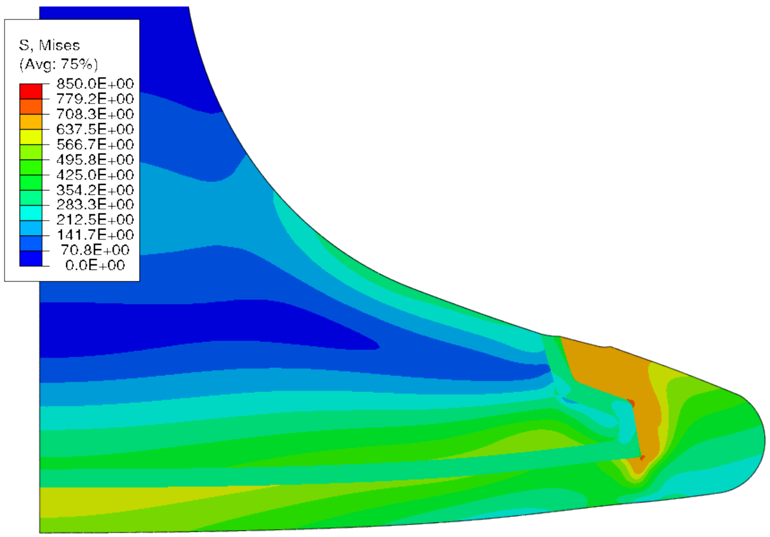


Thermal expansion coefficient mismatch

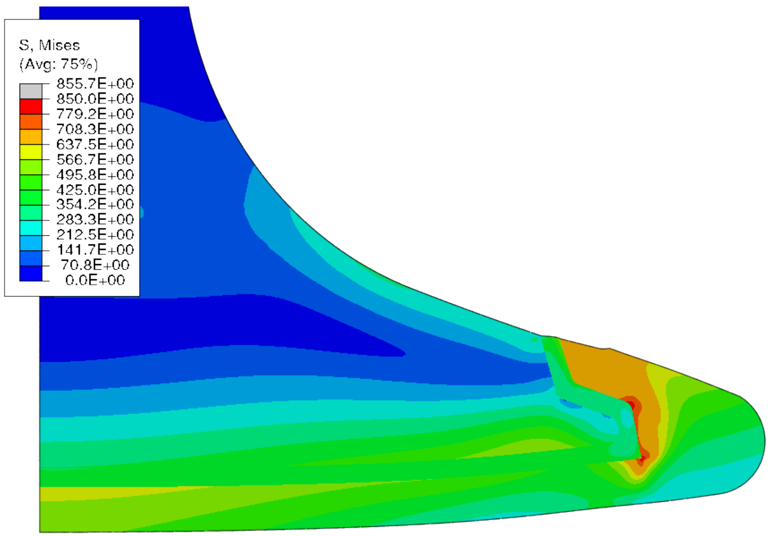


Von Mises stresses at room T

After 1st service cycle



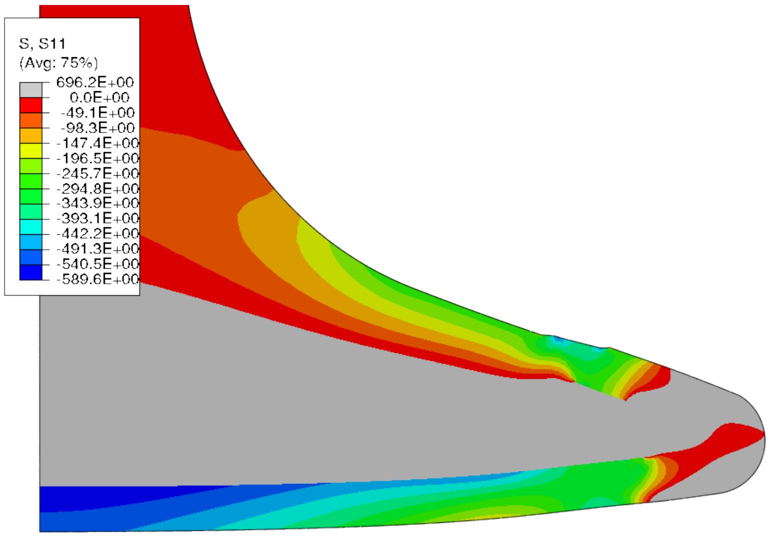
After 5th service cycle



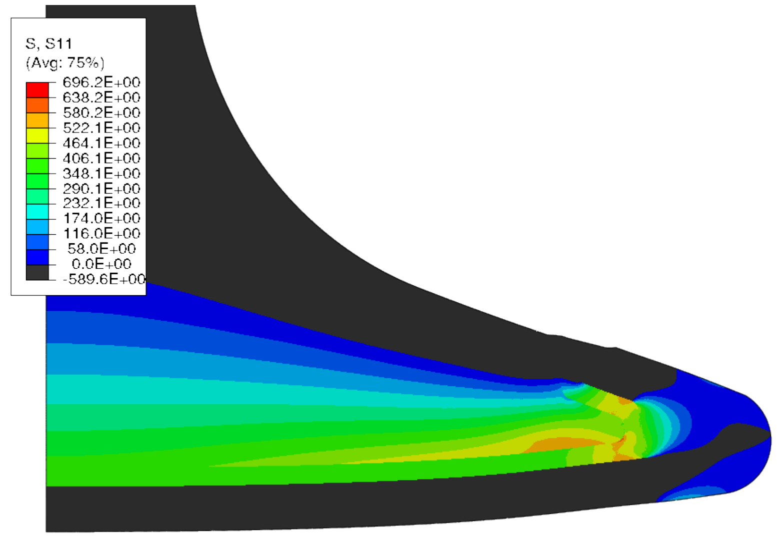
- Von Mises stresses increase slowly with the number of cycles

Radial stresses at room T

After 5th service cycle
Compressive stresses



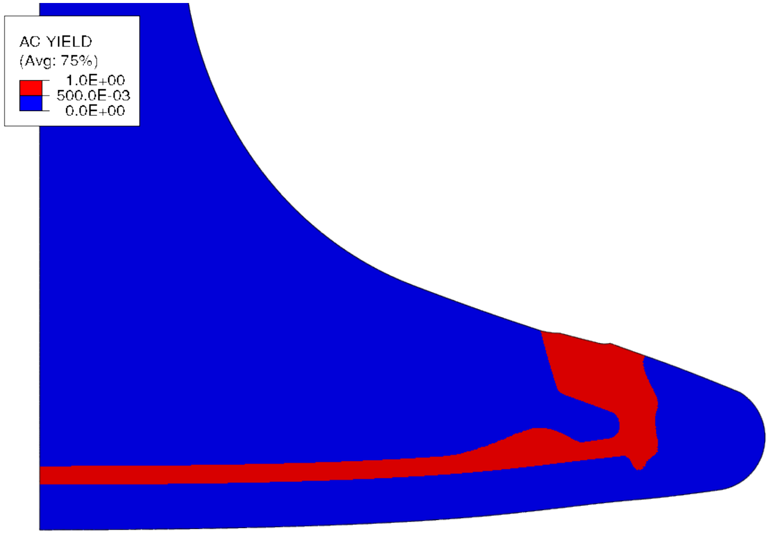
After 5th service cycle
Tensile stresses



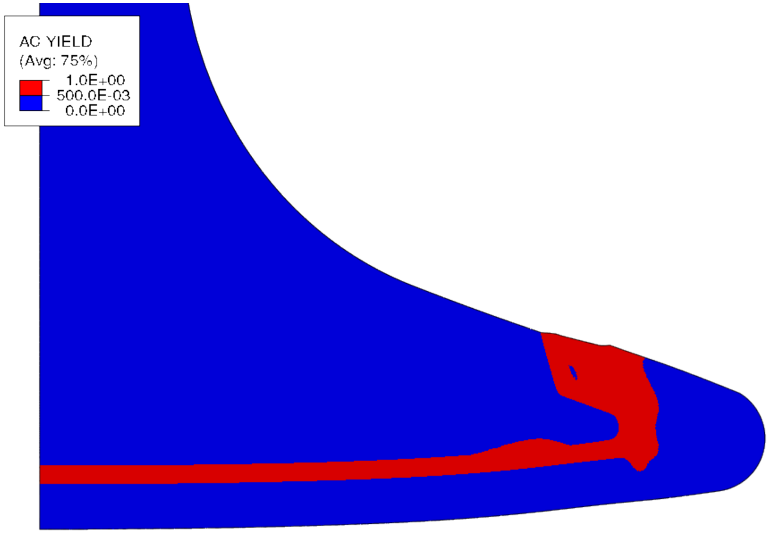
- The NiCr49Nb1 is in compression at the center of the spindle
- The 316L buffer layer is experiencing tensile stresses
- Cmpressive stresses in the seat area are so high the material would experience yielding

Yielding

After 1st service cycle

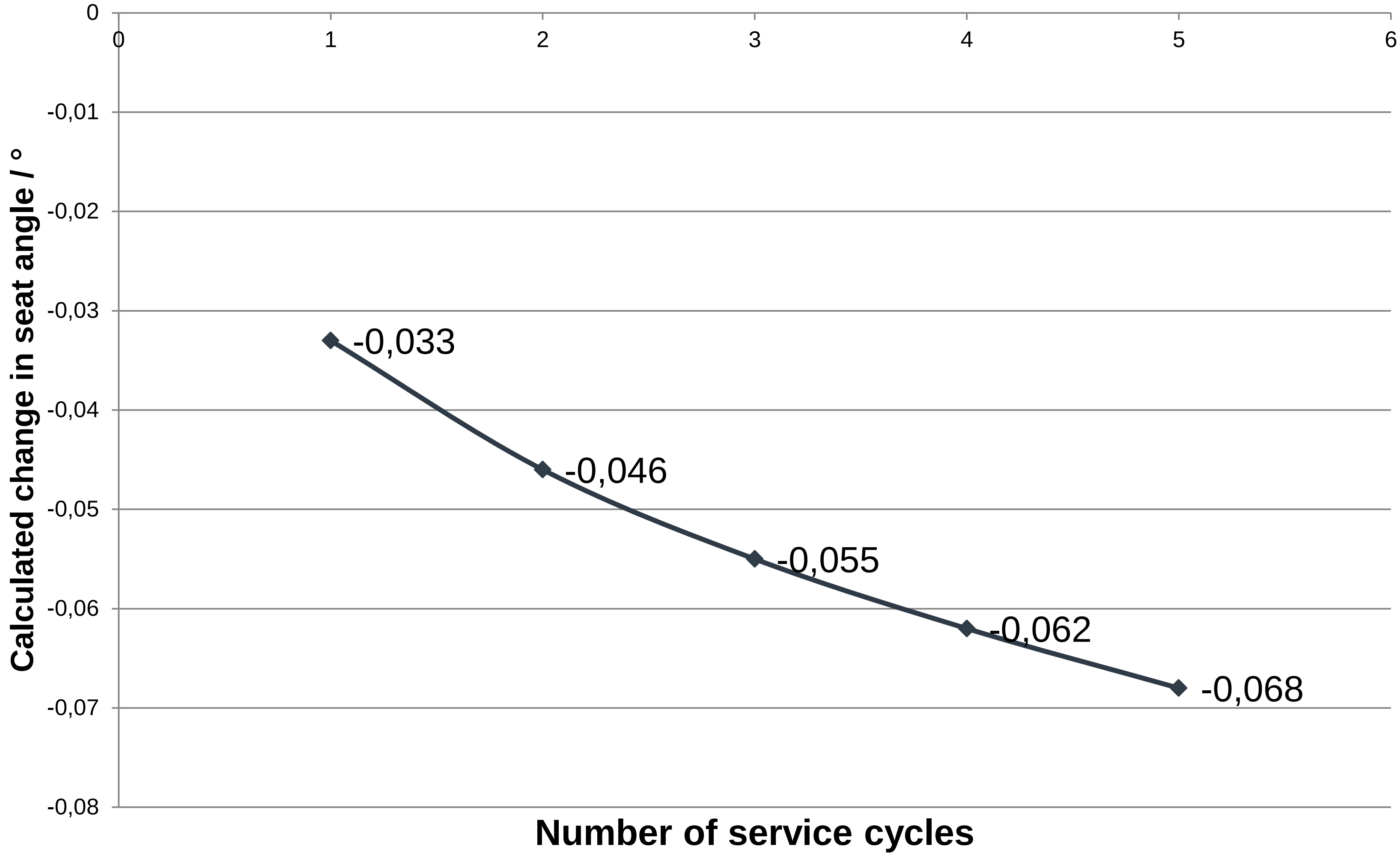


After 5th service cycle



- The 316L layer (and the seat area) are yielding

Calculated change in seat angle vs number of service cycles (up to 5 cycles)



Conclusions

- A hipped spindle with NiCr49Nb1 coating can operate successfully for thousands of hours
- The major challenges are the formation of cracks at the inner seat circumference and the bending of the spindle.
- A change in the design of the buffer layer (e.g. reduced thickness, change in shape) is currently considered, and other materials are under testing.
- Future simulation work will include temperature field in the spindle, and once experimental creep data for the materials involved are available, they will be implemented in the FE model.

Acknowledgments

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Disclaimer

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