Creep Deformation Behavior of Heating Filaments in High Temperature Applications

Bernhard Valentini[1]
1. Plansee SE, Innovation Services, Metallwerk-Plansee-Straße 71, Reutte, Austria.

Introduction: In high temperature applications above 2000° C, e.g., in furnaces for growing single crystals, resistive heating filaments made of refractory metals are widely-used. The lifetime of such filaments is often limited by creep deformations which can in the worst case lead to a short circuit between filaments and other furnace components. To this end predicting the time-dependent creep deformation due to thermally induced stresses and electromagnetically induced Lorentz forces is an important part already during the development of new heaters.

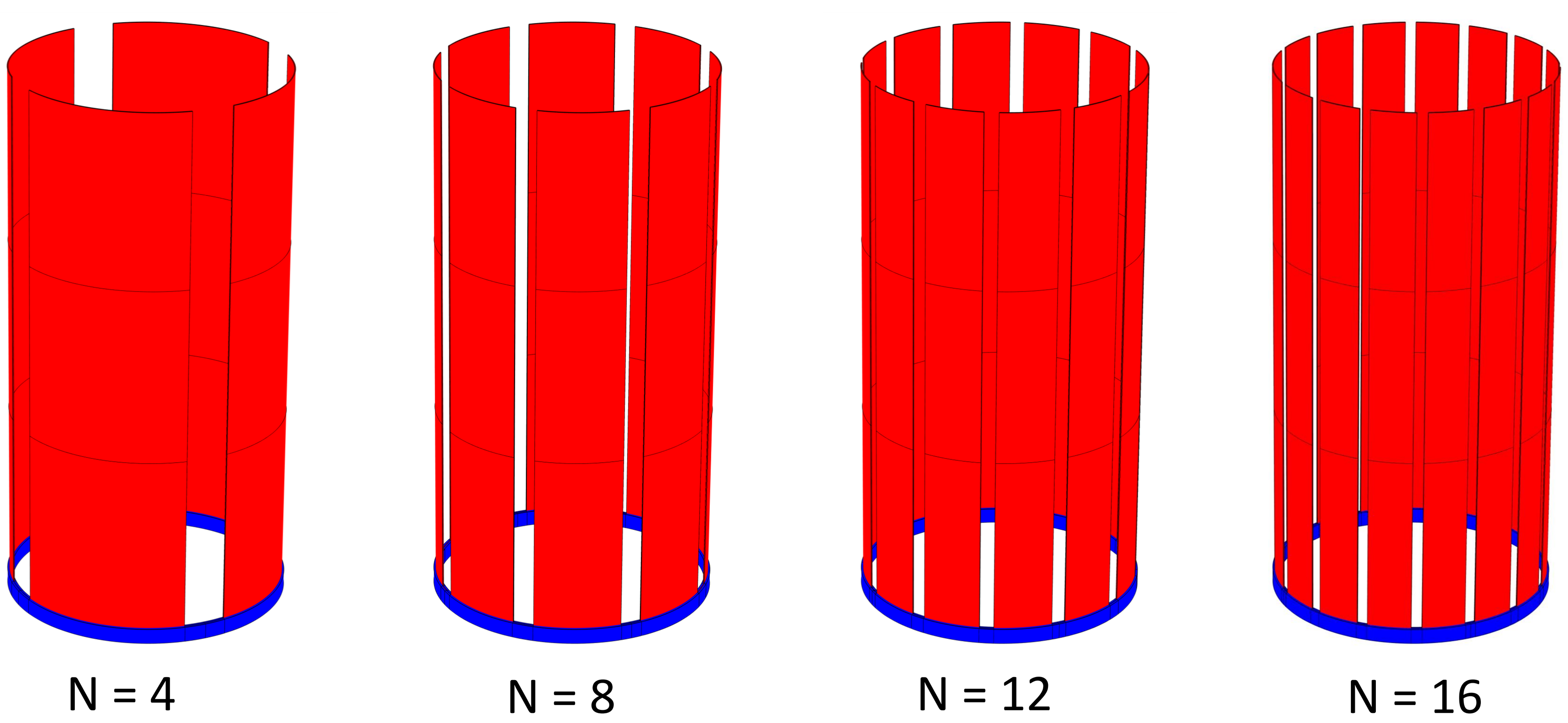

Figure 1. Heater assembly designs with N = {4, 8, 12, 16} heating filaments and a short circuit ring without anode and cathode

Geometry: The heater assembly consists of a short circuit ring at the bottom, two fixed half rings representing the anode and cathode at the top and N = {4, 8, 12, 16} tungsten heating filaments (**Figure 1**). The heating filaments have a length of 700 mm, a thickness of 1 mm and are arranged in a circular pattern at a cylinder with a diameter of 361 mm. The tungsten short circuit ring has a thickness of 6 mm and a height of 20 mm. Because of the twofold plane symmetry of the investigated problem only one quarter is modelled.

Loading and boundary conditions: One heating process cycle is assumed to take nine days. The electrical current flowing down on one half of the filaments and up on the other half is ramped up from zero to a maximum current of 4300 A in half a day, kept constant for eight days and then ramped down to zero in half a day. The associated predefined temperature distribution is shown in **Figure 2**. The creep behavior is considered by a material model for secondary creep.

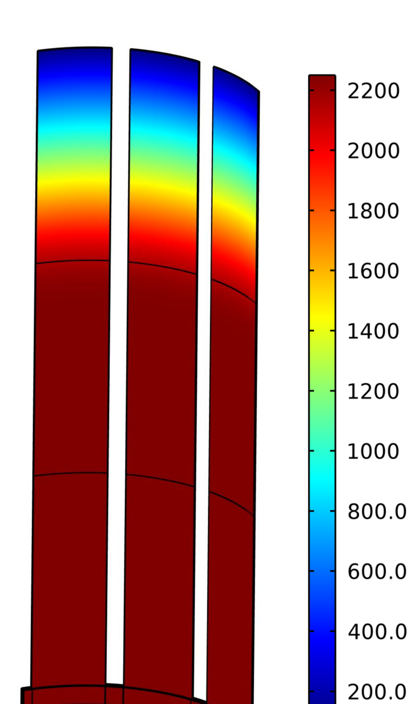

Figure 2. Temperature distribution [degC] of the heating assembly with N = 12

Electromagnetic results: The radial component of the Lorentz forces is increasing with increasing distance from the plane of symmetry at the bottom and is not constant along the arc length of each heating filament (**Figure 3** and **Figure 4**).

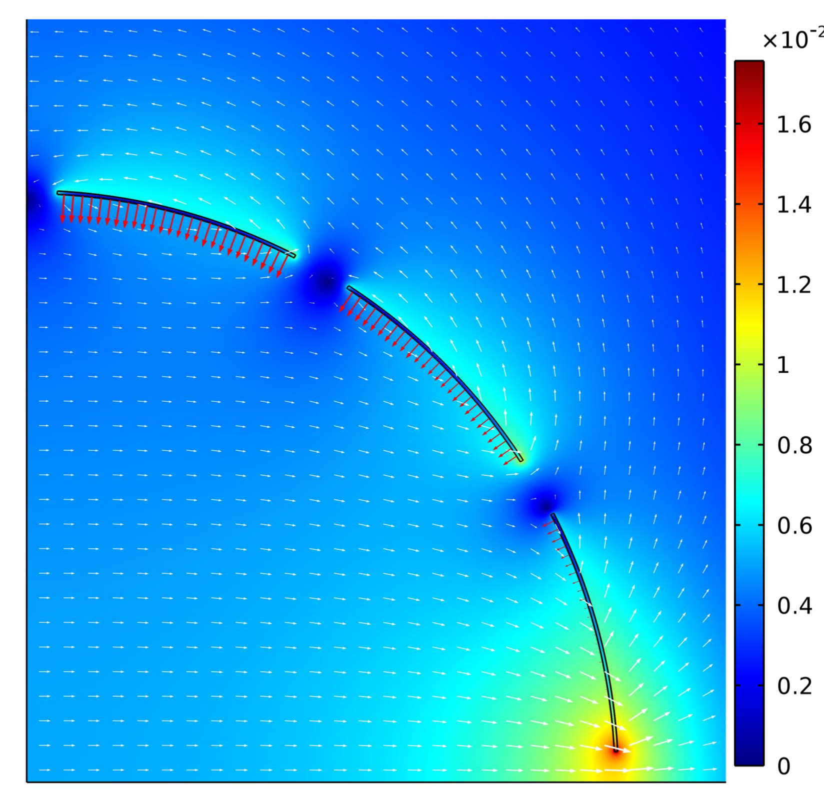

Figure 3. Magnetic flux density norm [T] (contour and white arrows) and radial component of the Lorentz forces (red arrows) for the heating assembly with N = 12

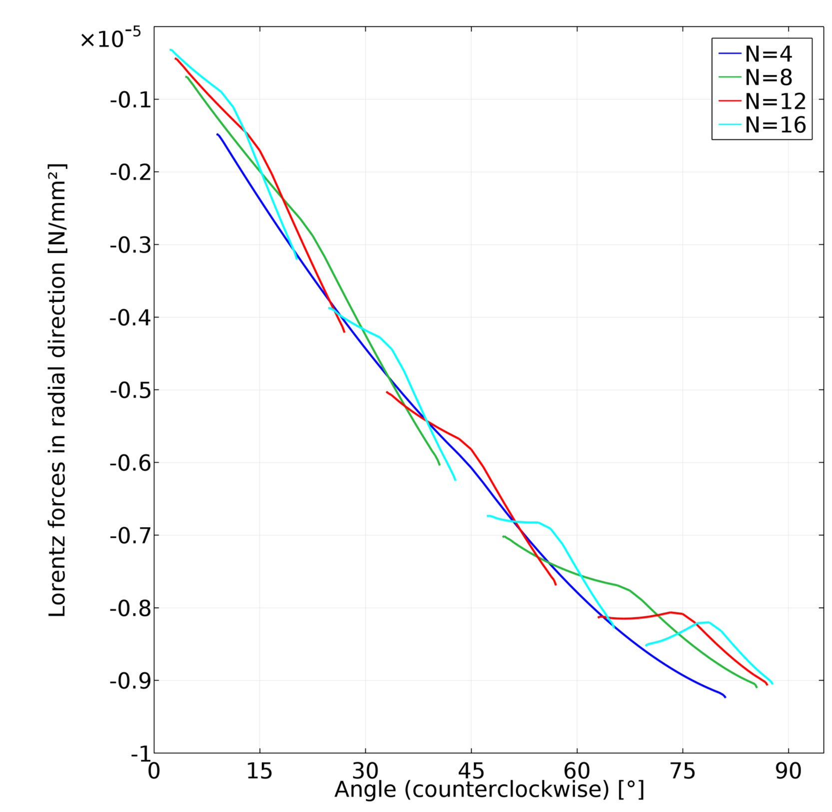

Figure 4. Radial component of the Lorentz forces over the angle in counterclockwise direction for all variants

Structural results: The variants with 12 and 16 heating filaments show significantly larger creep deformations than the variants with 4 and 8 filaments (**Figure 5**). The influence of the Lorentz forces to the creep deformations can be derived by the comparing the similarity of the deformation pattern of the individual heating filaments for each variant.

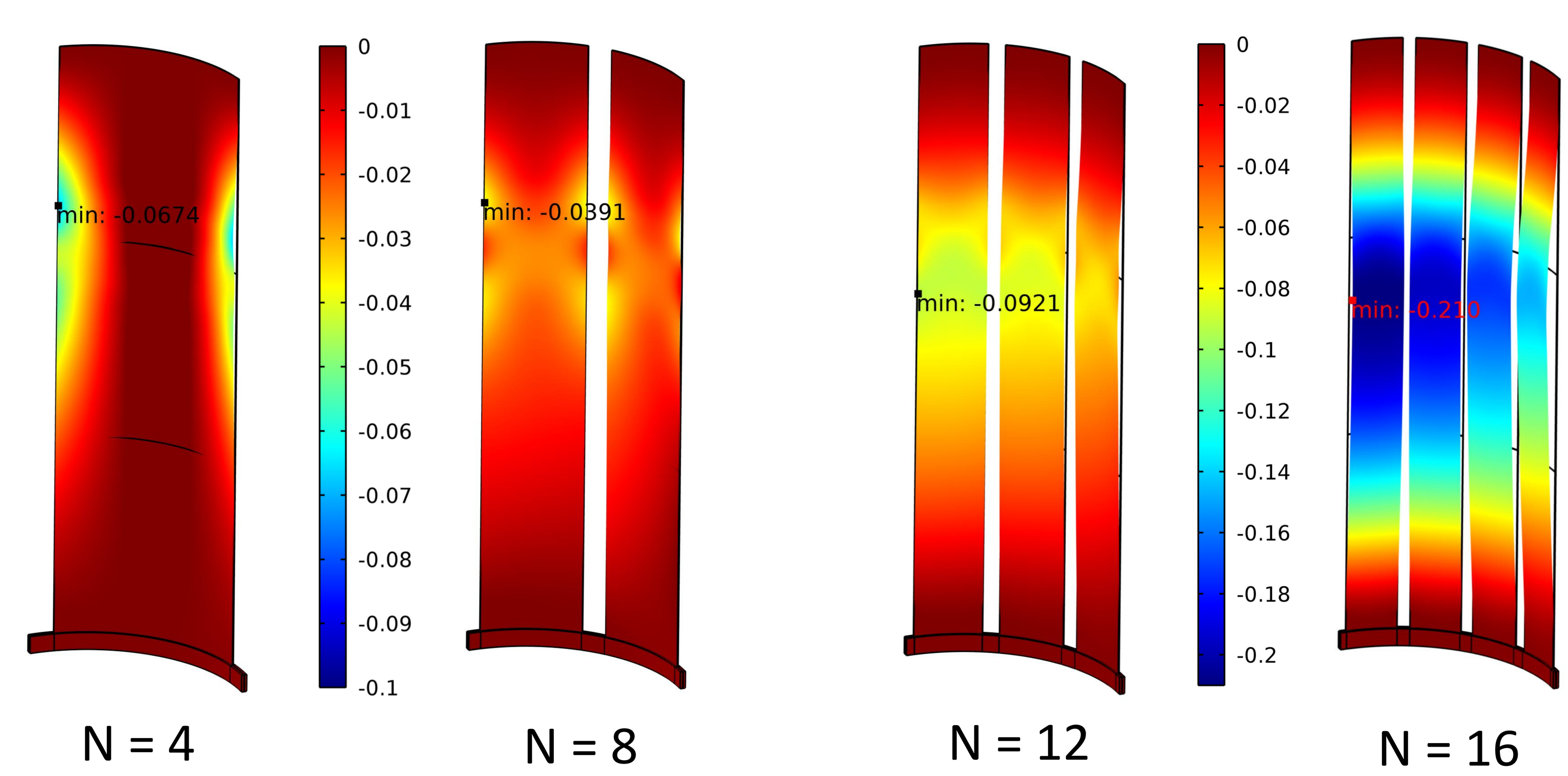

Figure 5. Radial displacements [mm] at the end of the process cycle after nine days: deformations 100 fold magnified.

Conclusions: Depending on the number of heating filaments creep deformations are not only a result of thermally induced stresses but also a result of electromagnetically induced Lorentz forces. In the presented study neglecting the Lorentz forces in cases with eight and more filaments would lead to a significant underestimation of the predicted creep deformations.

Excerpt from the proceedings of the 2015 COMSOL Conference in Grenoble