DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

KURZVERÖFFENTLICHUNG

Virtual design of elastic knitted fabrics using process simulation

Authors: Hermann Finckh
Florian Fritz
Ivan Kirsten
Albrecht Dinkelmann

Research Center: DITF – Textil- und Verfahrenstechnik
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Abstract

The prevailing trend in technical knitted fabrics, particularly compression textiles, is the individualized, form-fitting production of products with precisely defined functional properties, most notably a controlled compression effect. The determination of suitable production parameters for manufacturing knitted fabrics with defined mechanical characteristics is still achievable only through trial-and-error procedures, which are both time- and cost-intensive. To overcome this limitation, knitting simulations and yarn models have been investigated to enable virtual testing of knitted structures and thus facilitate targeted product development.

Particular attention is directed toward elastane-covered yarns, whose structural complexity and highly elastic material behavior complicate predictions of loop dimensions and textile properties. Their multilayered construction, extensibility of several hundred percent, and pronounced nonlinear response render them especially challenging for numerical simulation.

The employed yarns and the produced compression textiles were characterized with respect to structure, using micro-computed tomography (µCT), and mechanical behavior. Simulation models were subsequently derived. For the knitting simulations, a Lawson circular knitting machine (10″, E20, single-system, 624 needles) was employed; the findings are, in principle, transferable to other machine types.

Results

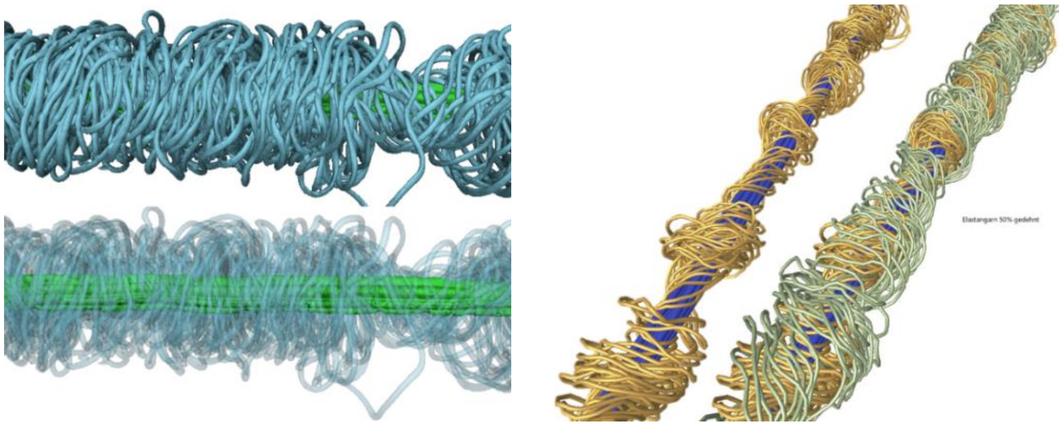
Investigations were conducted on an elastane-covered yarn supplied by Zimmermann (Ultraelastic 6172XX-9686, 442 dtex with a 130 dtex Lycra core and PA 6.6 covering).

Deutsche Institute für Textil- und Faserforschung Denkendorf
Körschtalstraße 26
73770 Denkendorf
www.ditf.de

Bibliothek
Bernd Janisch
bibliothek@ditf.de
T +49 (0)711 93 40-505 | F +49 (0)711 93 40-297

High-resolution µCT scans at elongation states of 0%, 10%, and 50% were performed, the individual components (elastane core, PA coverings 1 and 2) segmented, and corresponding three-dimensional models generated. For comparison, a pure polyamide yarn (PA 6.6 44f13x2) was also analyzed.

The yarns and compression textiles were further examined with respect to tensile, compressive, and frictional properties. By employing different µCT analysis software tools (VGStudioMax, AVIZO, GeoDict), precise three-dimensional models with yarn centerlines and cross-sections were extracted from the µCT data. Figure 1 illustrates the architecture of the elastane yarn in both unloaded and strained states.



a) Unloaded *b) 50% elongation (one of the two outer windings is hidden on the left)*

Figure 1: µCT analysis of Ultraelastic 6172XX-9686 elastane textured yarn, 442 dtex

A Python-based software tool was developed to generate yarn models for knitting and load simulations. These models are applicable not only to knitted fabrics but also to woven fabrics, braids, and non-crimp fabrics. The initial focus was placed on multifilament simulation models. The multifilament beam model reproduced the tensile behavior of the elastane-covered yarn with good qualitative agreement. Constriction of the covering filaments was computed and verified against µCT scans of specimens at different strain levels. Figure 2 presents four elongation states of the yarn simulation with increasing filament constriction (left) alongside qualitative comparisons to µCT filament paths (right).

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73770 Denkendorf
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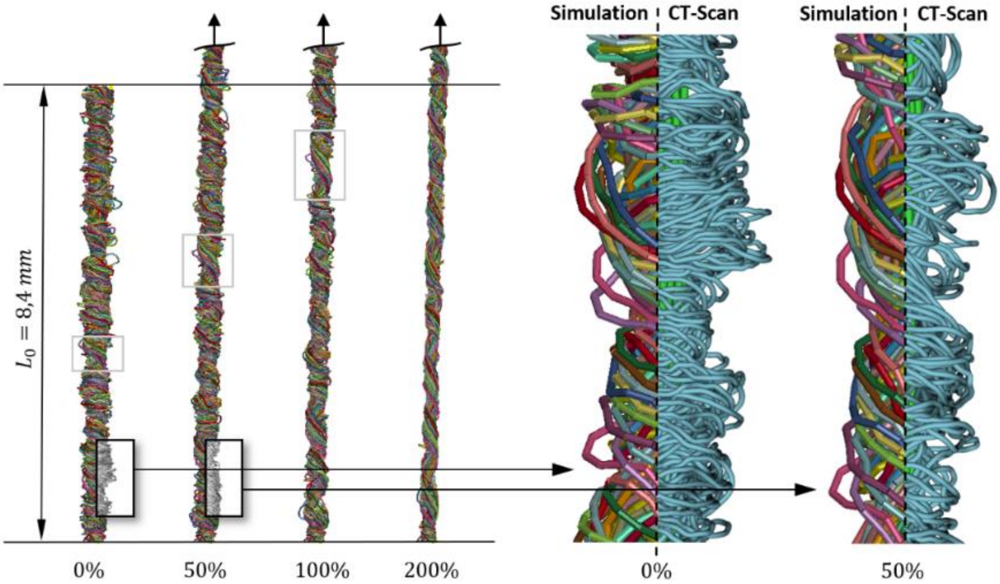

Figure 2: Verification of the material behaviour of the multifilament beam model using µCT scans of different strains

The force–elongation response of the developed models reproduced the tensile behavior of the elastane-covered yarn with high accuracy. Figure 3 shows the force–elongation curves obtained from the monofilament and multifilament beam models compared to the mean experimental curve.

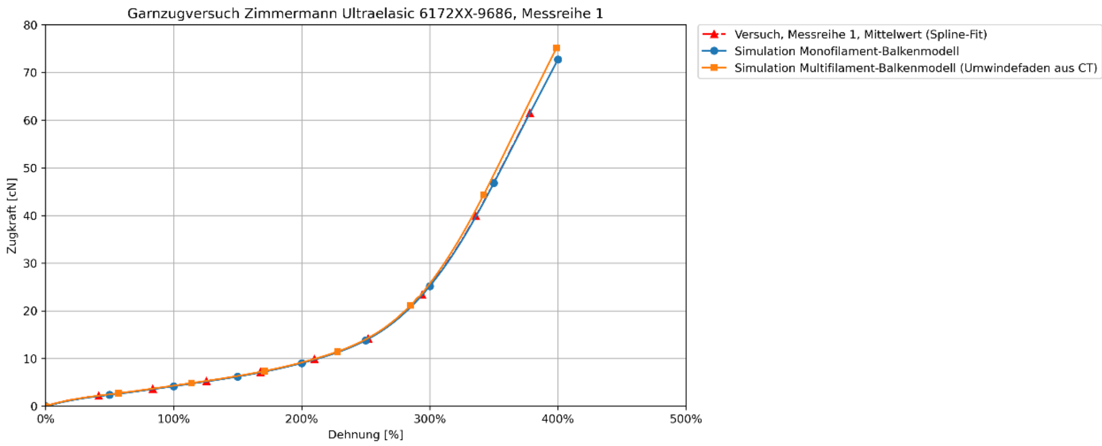

Figure 3: Force-strain diagram of the yarn tensile simulation with the monofilament and the detailed multifilament beam model compared with the measured values from the experimental tensile test.

To generate realistic models of covered yarns without relying on µCT-derived filament paths, a stochastic method for producing covering filaments was implemented. This approach also reproduced the force–elongation curve. For fabric property simulations,

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T +49 (0)711 93 40-505 | F +49 (0)711 93 40-297

models with intermeshing loops are required. Accordingly, a prototype software was developed to transform yarn models into arbitrary paths, such as loop geometries. Input parameters include an undeformed path and yarn model, as well as the target path for transformation (Figure 4).

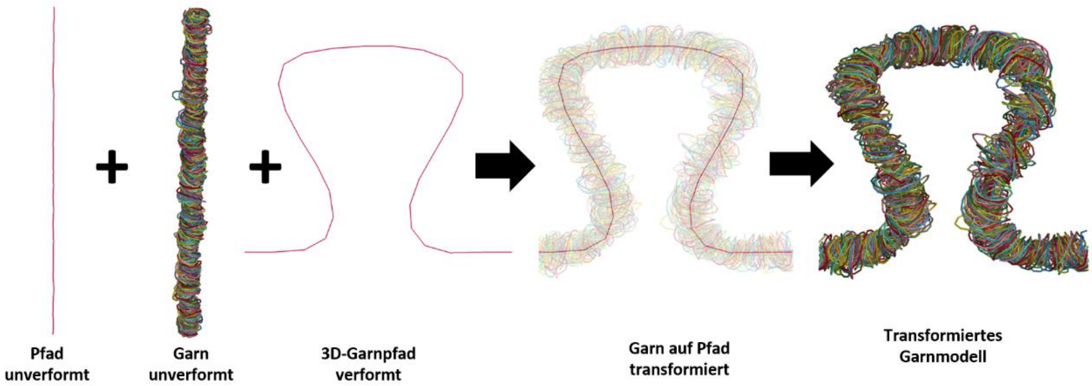

Figure 4: Principle of operation of the transformation software

With this software, large-scale models with complex yarn paths, such as those found in knitted fabrics, can be rapidly generated from existing yarn models (Figure 5).

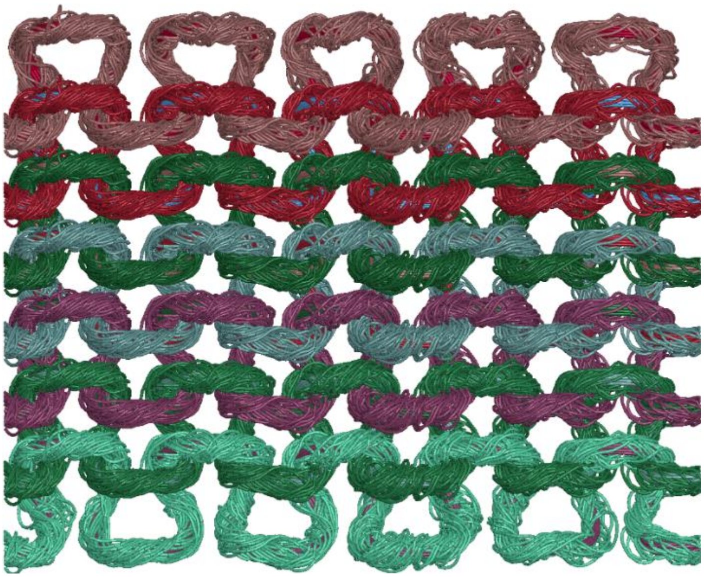

Figure 5: Knitted fabric consisting of 7x5 stitches; multifilament beam model, single yarns produced by transformation

To address computational expense and contact instabilities in knitting simulations, a universal yarn model was developed. The model combines shell and beam elements and

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Bibliothek
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T +49 (0)711 93 40-505 | F +49 (0)711 93 40-297

incorporates an elastically deformable sheath to represent the yarn surface. Under transverse loading, as encountered in yarn-to-yarn contacts, the yarn cross-section deforms accordingly.

Figure 7 illustrates the structure of the yarn model in three parts: (1) the yarn shell (red) on the left is primarily responsible for transverse deformation and contact detection; (2) the connecting elements between sheath and yarn axis (green) in the center is responsible for compression and coupling of the shell to the axis; (3) the yarn axis (yellow, blue) on the right is governing tensile behavior and contact detection.

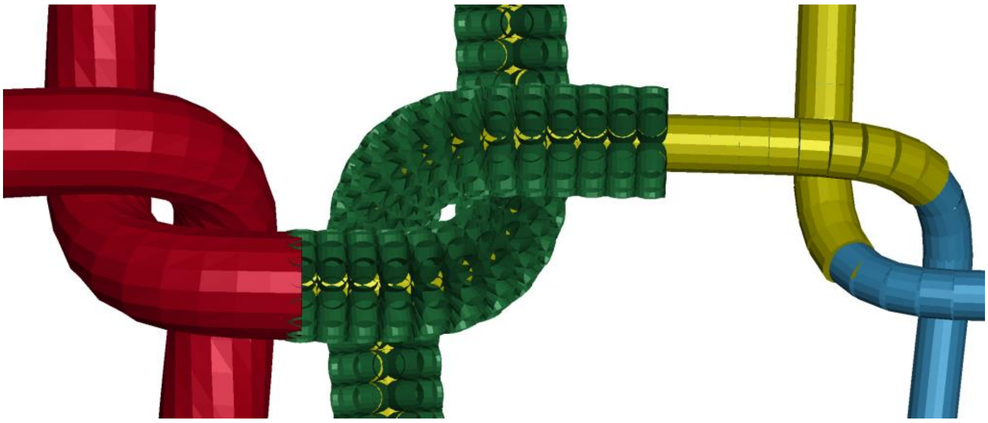

Figure 6: Universal shell-beam model (left: all components, centre: without shell, right: without shell and connecting elements)

Although the universal yarn model comprises multiple components, the computational time can be reduced by an order of magnitude compared to detailed multifilament simulation models. The tensile properties of the elastane-covered yarn were also accurately reproduced. By representing yarn surfaces with shell elements, transport phenomena such as electrical conductivity or thermodynamic effects can now be simulated, thereby enabling a wide range of additional applications in simulation-driven product development and optimization.

Tensile simulations of knitted fabrics demonstrated that the experimentally observed tensile behavior cannot be reproduced in simulation models with correct loop geometry (e.g., derived from µCT scans) without accounting for the production-induced residual stress state.

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T +49 (0)711 93 40-505 | F +49 (0)711 93 40-297

Although the yarn models accurately reproduce yarn behavior, knitted fabric models based on µCT analyses and the yarn models exhibited a delayed force increase in the stress–strain diagram compared to experimental tensile tests. This underscores the importance of knitting simulations with highly elastic yarns, in which the resulting loop model incorporates the residual stress state.

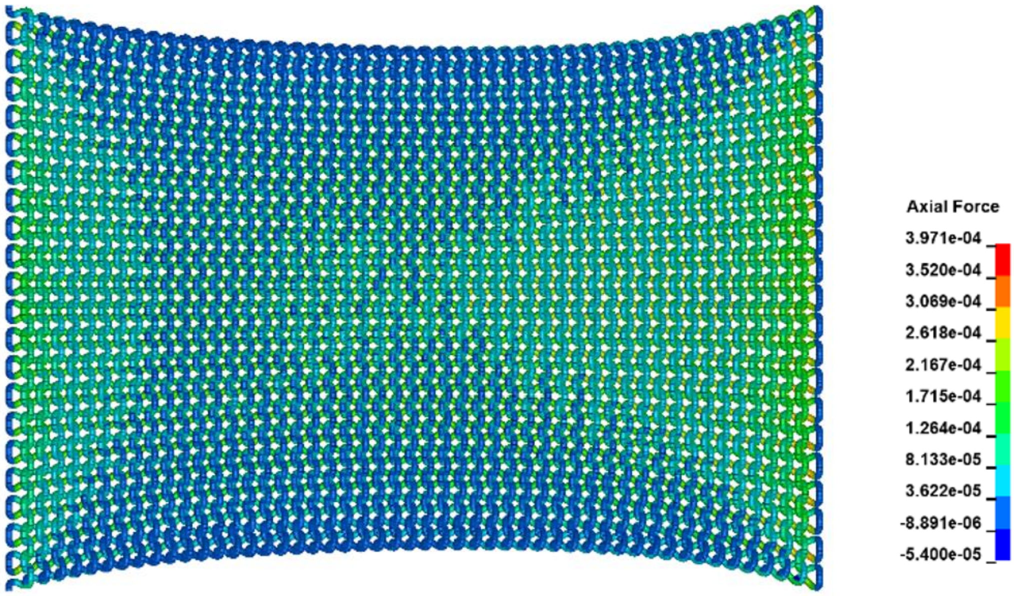

Figure 7: *Stress state of the knitted fabric tensile simulation with the monofilament beam model consisting of 21 stitches and 50 rows of stitches (axial force in the beam elements)*

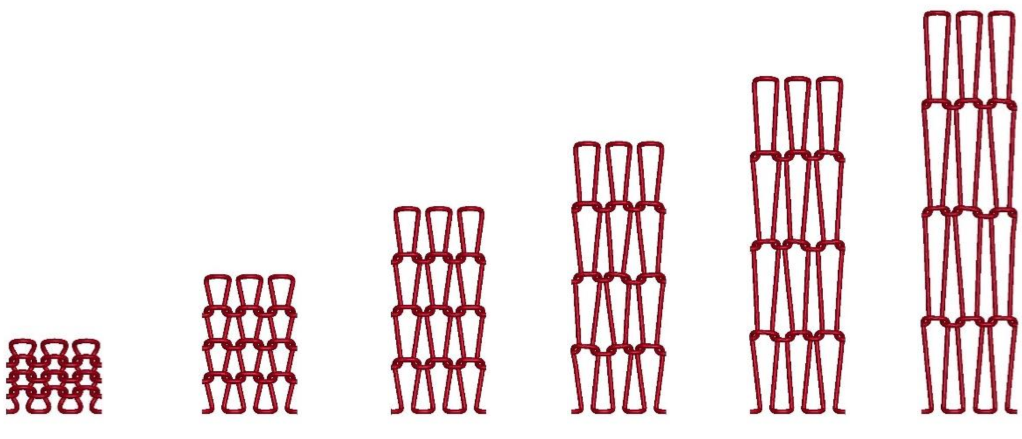

Abbildung 8: Simulation of tensile testing on knitted fabric using the universal shell-beam model

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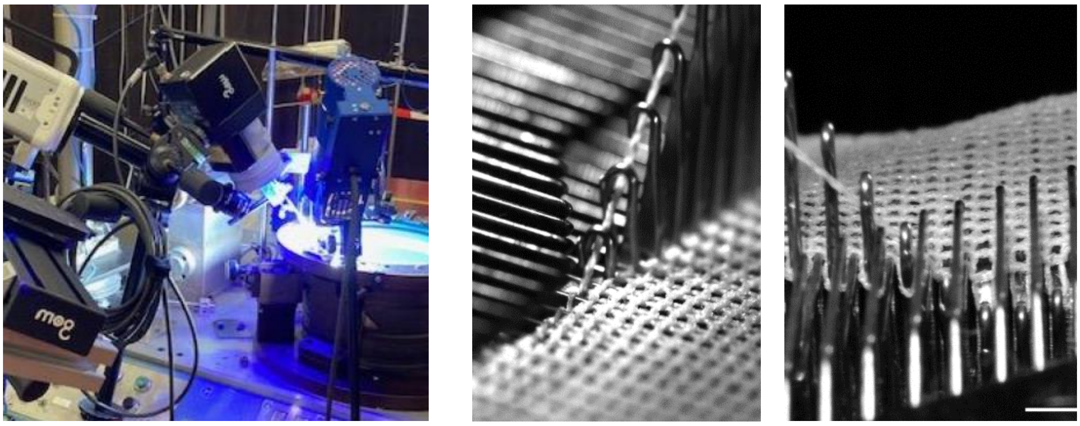
bibliothek@ditf.de
T +49 (0)711 93 40-505 | F +49 (0)711 93 40-297

By varying the imposed internal stress state and iteratively matching the measured stress–strain behavior, the residual stress state present in the actual knitted fabric can be determined. This approach remains to be validated.

Development of knitting simulations:



a) Measurement setup on Lawson (E20) *b) Side view of needles (Photron SA 5)* *c) Front view of needles (Photron Nova S9)*

Figure 9: Knitting process analysis with two high-speed cameras

Detailed analysis and documentation of the knitting process using two synchronized high-speed cameras revealed the local mechanisms of loop formation and the influence of yarn tension (Figure 9). By analyzing the optical flow, yarn movements within and across multiple loops were tracked, enabling the determination of boundary conditions and providing key insights into yarn behavior during loop formation. The project results further demonstrate the potential for detailed process analysis of knitting.

A parameter-based, automated model generation approach for knitting simulations was developed, enabling the creation of complete models with the desired number of loop positions, needle beds, needle count, and needle configurations. Figure 10 illustrates loop formation in a knitting simulation with 78 needles and three active loop positions using the monofilament beam model.

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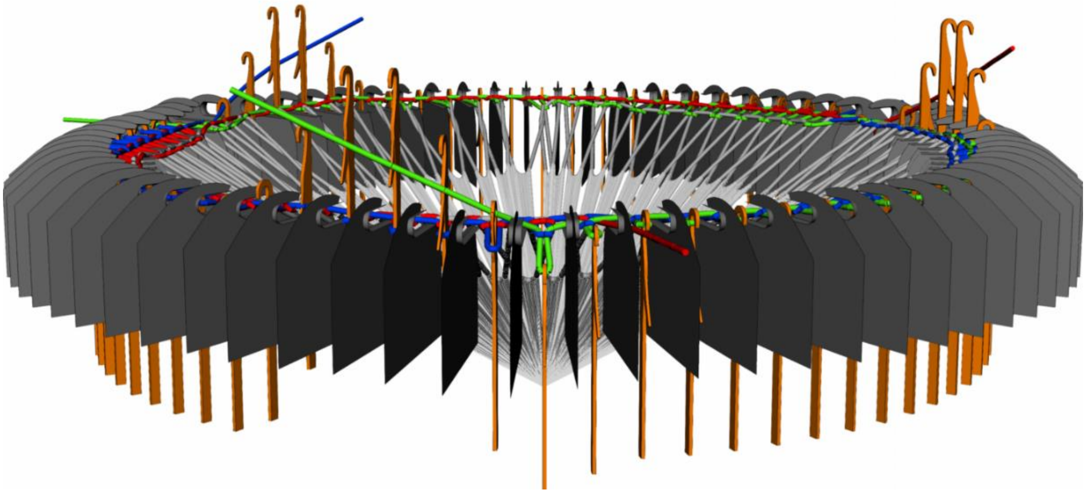

Figure 10: Knitting simulation with 78 needles and 3 active knitting points

Within the project It was not possible to perform knitting simulations using the newly optimized universal yarn model for the elastane yarn; this is planned for a subsequent study. The custom-developed software for yarn extraction, covering, transformation, network generation, and for the creation of simulation models—including knitting process, yarn, and fabric tensile simulations—remains available for further publicly funded projects.

The numerical calculations conducted within the publicly funded project were performed using LS-DYNA software (ANSYS, Inc.).

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The final report of the research project 01IF22228N is available from the German Institutes for Textile and Fiber Research Denkendorf (DITF)..

Contact person

Hermann Finckh, hermann.finckh@ditf.de

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Körschtalstraße 26
73770 Denkendorf
www.ditf.de

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