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Application of the Finite Element Method for the Analysis of Damage in Compensating Elements of Pipelines Operated at High Temperatures

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ABSTRACT: The paper presents a modelling method for process installations operated at high temperatures, which must account for thermal expansion. The prevalent computational models encounter difficulties in selecting compensators for highly complex multi-circuit installations. The proposed numerical analysis using finite element method at the entire installation level, as well as at the level of a single compensator and a selected fragment thereof, enables a more precise analysis of the installation elements' stress. The models at different levels integrate the introduced substitute compensator, which takes into account linear stiffness, angular stiffness, and stiffness related to loss of rotary motion. The presented approach was applied to a process installation where issues had arisen. Based on the results, the type of compensators was changed and a technical problem was solved.

KEY WORDS: finite element method, coupling thermal-stress analysis, thermal compensator

1. Intorduction

Industrial process installations operate under challenging conditions due to the demands of the chemical reactions involved, including high temperature, pressure, and the chemical aggressiveness of the environment. Often, the products of these processes pose a threat to the environment, necessitating the maintenance of tightness and ensuring reliable operation [1-3].

Due to the effects of high temperature and the phenomenon of thermal expansion, significant changes in the linear dimensions of installation components occur. This phenomenon must be compensated for by using appropriate flexible elements, such as compensators and highly flexible supports. In large installations, the selection of such elements is made using simplified numerical models, where wireframe finite elements are applied. In simple structural cases, this is effective. However, in complex, multi-circuit process installations with large pipe diameters, solving the problem requires consideration not only of significant deformations along the length of the components but also those related to bending and the loss of the circular cross-section of the pipes. For this purpose, it is necessary to use more accurate numerical models based on surface and even volumetric geometry. However, this introduces the challenge of the computational model size that can be solved, especially since the calculations involve thermomechanical analysis with geometric nonlinearity considerations[4-6].

2. Substitute Models of Compensators

The primary compensating elements are disc compensators with high transverse stiffness. In typical wireframe geometry models, it is generally assumed that disc compensators lack transverse and bending flexibility, which is a significant simplification but allows for calculations using wireframe geometry. In complex systems, there is a need to use shell models; however, this type of finite element is not suited for compensating elements. This poses a significant problem, as compensators are the components that mainly suffer damage.

The proposed solution is to conduct numerical analysis at several levels:

a) Volumetric model of the compensator – to determine notch factors and assess residual stresses related to the manufacturing process of the compensator.

b) Shell model of the compensator – to determine the load-stiffness characteristics under various loading conditions.

c) Shell model of the process installation using substitute elements with previously determined stiffness.

The procedure is illustrated in Figure 1. The substitute characteristics are nonlinear, taking into account axial, transverse, bending, and torsional flexibility, as well as flexibility related to the loss of roundness. Figure 2 shows an example of a shell model of a three-lens compensator under bending conditions, and Figure 3 presents the compressive force-deflection characteristic. Based on these, the stiffness matrix of the substitute element is introduced in the Figure 4.

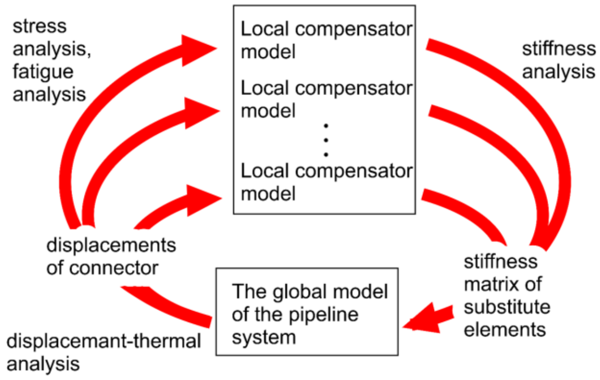

Fig. 1. Calculation scheme

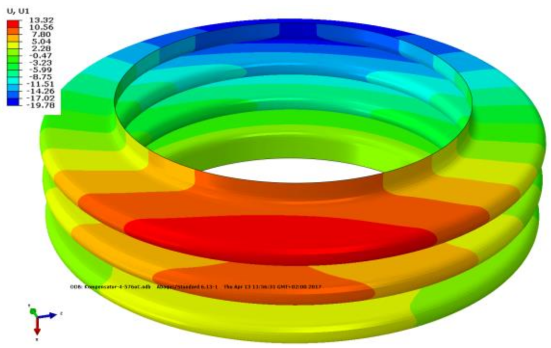

Fig. 2. Three -lens compensator - displacement field

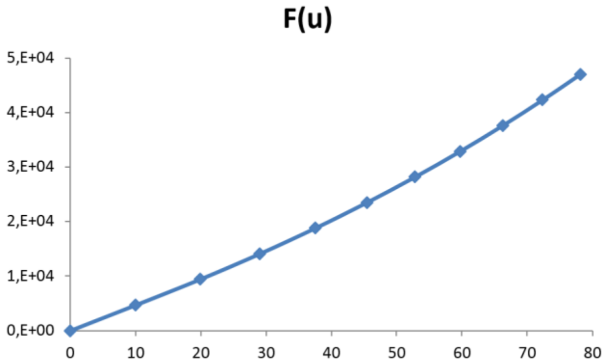

Fig 3. Characteristics Compressive force - deflection of the compensator

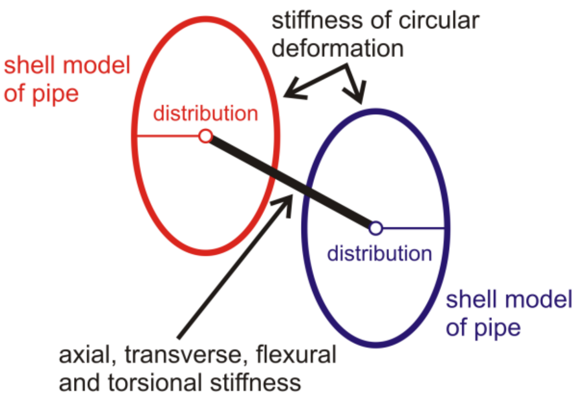

Fig 4. Schematic of the substitute element application

3. Calculation results

The research object was a process installation, the components of which were operated in the temperature range 450°C - 560°C. The temperature ranges were determined on the basis of runs from two months of operation. From the calculations carried out on the installation model, the components of the forces and moments loading the individual compensators were determined and applied to the local model of the compensators. A stress field was obtained in this way and shown in the Figure 5.

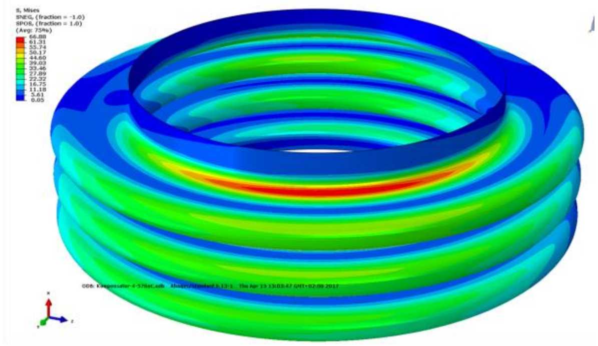

Fig. 5. Three -lens compensator - Huber-Mises stress field

4. Summary

The analysis carried out showed insufficient lateral compliance of the compensators used, resulting in high strain on them. The use of a different type of compensator was proposed and thus effectively solved the technical problem.

The developed method of analyzing process installations using a substitute element proved to be effective

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