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RESEARCH OF NONLINEAR FINITE ELEMENT APPROACHES FOR SEAL COMPRESSION USING STATIC AND TRANSIENT ANALYSIS

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Abstract: This study compares static and transient structural analyses of two seals in ANSYS under identical modelling principles. Parameters such as stress, strain, contact pressure, reaction force, and computation time were evaluated for both configurations. Results showed minimal differences in mechanical response, with transient analysis offering significantly faster computation in both cases. Both approaches proved reliable for seal modelling. The findings assist in selecting the appropriate method for efficient and accurate simulation.

KEYWORDS: seal simulation, ANSYS Workbench, static analysis, transient analysis, hyperelastic material

1 Introduction

Seals are critical components in mechanical systems, ensuring the containment of fluids and gases [1, 2]. Due to their typical rubber composition, they exhibit nonlinear mechanical behaviour [3, 4], complicating their numerical simulation and often leading to convergence difficulties. This study focuses on simulating a seal in ANSYS Workbench using Static Structural and Transient Structural analysis [5, 6] under identical conditions. These include the same hyperelastic material model based on the Ogden 1st-order formulation [7, 8], consistent contact settings using the pure penalty method [9], and a mesh configuration refined for the seal and coarser for the housing. The two seal geometries were designed to accommodate two different grooves. To reflect realistic behaviour of sealings manufacturing tolerances, minimal and maximal compressions and groove filling ratio were considered [10]. A displacement of 1.62 mm and 2.67 mm was applied to the closing surface of Seal 1 and Seal 2, respectively, to achieve the calculated compression. The objective is to compare key output parameters in this case, reaction force, equivalent stress and strain, contact pressure and area, and computational time for both seal designs to assess the reliability and efficiency of each analysis method in simulating quasi-static seal behaviour.

2 Methodology

2.1 Model Setup

The seals were designed with realistic tolerances and compression limits, reflecting actual manufacturing and assembly scenarios. Additionally, operational temperature variations ranging from –40 °C to 130 °C were considered due to the thermal expansion behaviour of the materials. The sealings were first modelled in Creo Parametric, where the initial 3D geometry was created based on design requirements. After completing the modelling process, the geometry was exported into Design Modeler to make the necessary adjustments and simplifications for performing a 2D axisymmetric simulation.

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Table 1. Calculated parameters of Sealings for a groove:

	Groove width, mm	Groove depth, mm	Maximum compression, %	Minimum compression, %	Groove filling ratio, %
Seal 1	6	5	30.2	18.45	89
Seal 2	6	8	29.18	21.01	92

2.2 Material Definition

The material used for both seals is EPDM rubber with Shore hardness 85A [11, 12], chosen for its flexibility, chemical resistance, and thermal stability. The hyperelastic behaviour was defined using experimental data fitted to the Ogden 1st-order formulation [7, 8], capable of accurately capturing large deformations typical of rubber-like materials.

2.3 Contact Definition

Three frictional contacts were defined in both models with a friction coefficient of 0.15 using the pure penalty method [9]. Contact settings were configured with Adjust to Touch behaviour to enhance convergence during initialisation and contact detection. These settings are ideal for scenarios with small initial contact gaps and compressive loading [13, 14, 15].

2.4 Meshing Strategy

A refined mesh was applied to the sealing component, which was defined as the contact body. Linear quadrilateral-dominant elements with an element size of 0.1 mm were used. For the groove and housing (defined as the target surfaces), a coarser mesh with 0.2 mm element size was used (Fig.1), maintaining a balance between accuracy and computational efficiency [16, 17]. The total number of elements was 3271 for Seal 1 and 5205 for Seal 2.

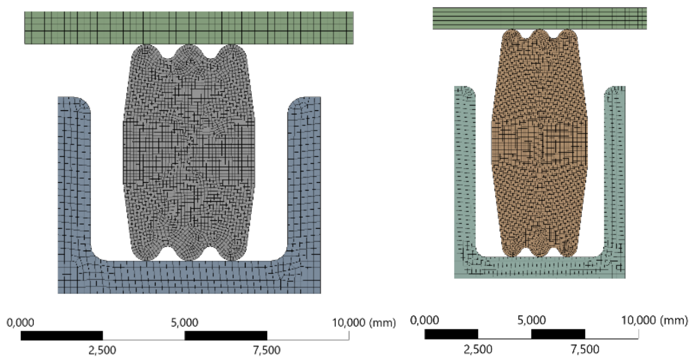

Fig. 1 Meshed models for Seal 1 (left) and Seal 2 (Right)

2.5 Boundary Conditions

The groove body (housing) was fully constrained using Fixed Support. Displacement was applied to the upper (closing) surface to compress the seal vertically: Seal 1 – 1.62 mm, Seal 2 – 2.67 mm.

All lateral and rotational motions were restricted to enforce axial symmetry. The Large Deflection option was enabled to capture the geometric nonlinearities associated with hyperelastic deformation. Each simulation was divided into three load steps to support convergence in the nonlinear simulation [13].

3 Results and Discussion

The numerical simulations carried out using both static and transient structural analysis in ANSYS yielded closely aligned results across all evaluated parameters. However, subtle differences were observed, which are discussed in the following subsections.).

Table. 2 Seal 1 and Seal 2 results

Physical Quantity	Static Structural		Transient		Percentual diff [%]	
	Seal 1	Seal 2	Seal 1	Seal 2	Seal 1	Seal 2
Force reaction [N]	1132.5	1328.3	1120.4	1328.5	1.08	0.02
Equivalent Strain [%]	0.54	0.65	0.54	0.65	0.00	0.00
Contact Pressure [MPa]	2.15	2.38	2.13	2.38	0.94	0.00
Equivalent Stress [MPa]	1.48	1.83	1.47	1.83	0.68	0.00
Contact Area - Groove [mm²]	696.22	735.17	695.86	734.85	0.05	0.04
Contact Area - Housing [mm²]	695.14	733.68	694.86	732.51	0.04	0.16
Time to compute [s]	115	261	71	137	38.26	47.51

Despite almost no differences in mechanical results, the Transient analysis required 38.26% less computation time than the Static Structural analysis. This confirms the improved efficiency of the solver when dealing with nonlinear problems. It also shows that Transient analysis can be a more practical choice when time and resources are limited.

For Seal 2, both Static Structural and Transient simulations produced almost identical mechanical results. However, the transient simulation was significantly faster, it required 47.51% less computation time. This confirms the earlier trend and shows that the transient approach can save time even for larger models, without losing accuracy.

CONCLUSION

This study presented a comparative analysis of static and transient structural simulations of a sealing in ANSYS Workbench under identical boundary conditions, contact definitions, material models, and mesh configurations. The objective was to evaluate the differences in key output parameters, including reaction force, equivalent stress and strain, contact pressure, contact area, and computational time.

The results showed that both simulation types produced nearly identical outcomes for the two tested seals in terms of mechanical response. The differences in stress, strain, contact pressure, and contact area remained below 1,1%, indicating that either method can be effectively used for modelling hyperelastic seals under quasi-static loading conditions.

However, a notable difference was found in the computation time. Contrary to expectations, the Transient simulation was significantly faster by 38.26% for Seal 1 and 47.51% for Seal 2 than the Static Structural simulation. This may be attributed to improved numerical stability and convergence behaviour in the Transient solver when dealing with nonlinear material properties and contact conditions.

In conclusion, both Static Structural and Transient analyses are suitable for evaluating seal performance. For applications prioritizing speed and numerical stability, the transient approach may offer a practical advantage. Nonetheless, the choice between methods should be guided by the specific requirements of the simulation task, including complexity, load history, and acceptable levels of approximation.

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