# Modelling of liner behaviour using finite element analysis


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## Summary

A finite element model was developed to model the response of a liner to changes in liner material, geometry, tension and differential pressure. Liner tensile tests were used for preliminary validation of the results, which compared well with experiments.



***Key words****: Machine milking, finite element analysis, liner.*


## Introduction

Based on milk flow simulation data it is possible to predict the influence of various component dimensions on the teat end vacuum and liner differential pressure. However if a new liner is being developed it is not possible to predict the deformation or liner wall movement in response to a given differential pressure. It was proposed to develop a model based on finite element analysis (FEA), which could accurately model the liner wall movement profile for a number of discrete points on the surface of the liner.

Liner wall movement has elsewhere been indicated (O'Callaghan, 1997; Spencer and Jones, 1999). It has also been shown that poor liner wall movement as a consequence of pulsation failure can double the rate of new infection and also lead to an increase in petechial haemorrhaging of the teat. (Mein *et al*., 1983).

The objective was to model the liner response to an applied differential pressure using finite element analysis so that liner behaviour can be predicted based on *a priori* knowledge of the geometry and material characteristics.

## Material and methods

### Geometry and material characteristics

The liner material properties were measured for three similar liners by carrying out tensile tests on the materials in accordance with BS903:A2 (BSI, 1995).

The liner geometry was obtained from both part drawings and internal mould impressions. The internal mould impressions were taken using a surface impression compound, Technovit 3040, which was subsequently poured into the liner barrel. After a few hours when the compound had solidified the liner was split and the internal liner impression was removed. Dimensions were measured from the liner impression.

### Finite element analysis

A nonlinear finite element model was developed with 8 noded solid elements using Ansys 5.6 to model the collapse of the liner. The model geometry was defined parametrically in terms of upper barrel bore, lower barrel bore, barrel length, wall thickness, axial stretch and radial stretch. The elastic modulus for the material was also entered as a parameter. The Poisson's ratio was fixed at 0.49. A two dimensional section of half the liner was constructed by defining various keypoints and areas.

These areas were meshed with a special element (MESH200), which is intended for multi-step meshing operations that require a lower dimensionality mesh to be used for the creation of a higher dimensionality mesh, i.e. sweeping a 2-D mesh into a 3-D mesh. Model meshing was additionally parameterised which included the number of elements through the wall thickness, the element size and the number of elements in a 180° rotation.

This mesh was rotated about 180° and the mesh elements converted to solid 8 noded elements (SOLID45) used for 3-D models with materials obeying linear material constitutive laws. The materials were linear and isotropic in the strain area of interest. Despite the axisymmetric liner geometry it was necessary to model half the liner as the deformed model should only have one plane of symmetry. Specific groups of nodes were defined as components C1 to C5 within the geometry to simplify the application of loads and constraints.

Since the geometry and loading pattern are symmetrical the finite element model has no material imperfections and will not deform correctly when loaded. This is because the liner barrel will contract in the radial and circumferential directions and the material will compress therefore it was necessary to introduce an imperfection. Eigenvalue buckling analysis determined the initial buckling mode shape upon which miniature nodal offsets were applied to introduce the imperfection. The nodal offset was computed as 10% of the normalised buckling mode shape, i.e. a maximum offset of 0.1mm.

A solid plane was constructed so that deflections would not penetrate the plane of symmetry. The elements CONTA174 and TARGE170 were used to model contact between the internal liner barrel and the solid plane. The contact elements overlaid the solid elements describing the internal liner barrel.

Initial loading consisted of the radial and axial stretch when a liner is placed in the shell. Nonlinear geometry options were enabled due to the large deflections expected. Ansys solution control options were enabled. The model was then solved at the initial time step because loading may be path dependent and the principle of superposition would not apply. Differential pressures between 45kPa and –25kPa were placed across the liner barrel and the solution was obtained.

## Validation experiment

Three liner types were held in an Instron tensile testing machine and stretched to 50mm at a rate of 100mm / min. The load was then relaxed at the same rate. The load versus displacement curve was obtained and linear regression was carried out on these curves.

## Results and discussion

The measurements of the axial forces on the liner from experiments were compared with the F.E. model and are shown in figure 1. The comparison for the soft and medium material types are within result tolerances due to material properties, but the results for the hard material show a larger difference between the model and the tensile tests. During the tensile tests the hard material was stretched beyond its elastic limit and it deformed

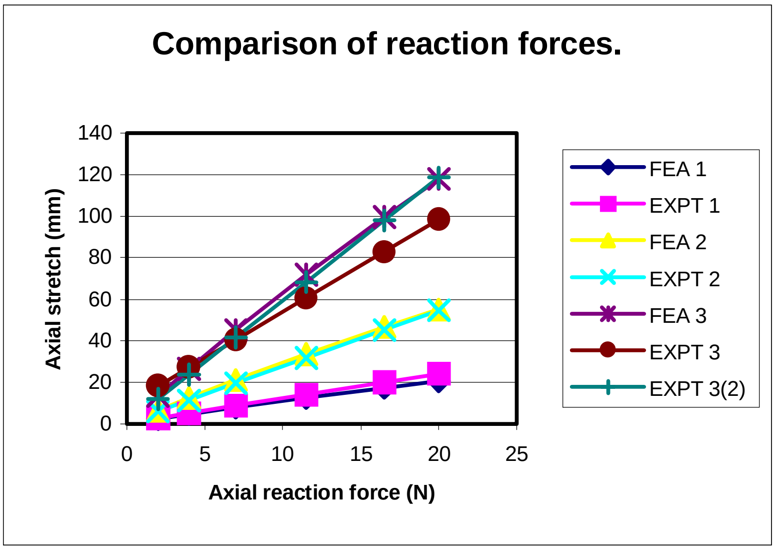


*Figure 1 Comparison of reaction forces.*

plastically. When linear regression was performed on the extension results with the regression line fixed through the Cartesian origin the comparison (FEA 3 vs. EXPT 3(2)) was better.

Displacement due to a differential pressure of 45kPa is shown in figure 2, although results can be viewed at any differential pressure.

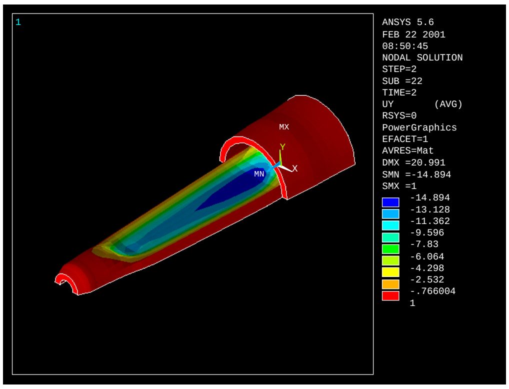


*Figure 2 Displacement due to a differential pressure of 45kPa.*

## Conclusion

Liner behaviour can be predicted for a range of geometries and material properties with excellent accuracy using FEA without the need for expensive prototyping processes.

## References

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