Investigating the Behavior of Ball Joint Sealing Boots Using a 3D Finite Element Model

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Abstract

One of the reason causing ball joint failure in practice is the sealing boot failing to seal the joint under the dynamic working conditions. In order to improve sealing boot design, we created a 3D finite element model to investigate the dynamic behavior of sealing boots using MSC.Marc software. In this paper, some of the modeling aspects were discussed. The obtained FEA results were compared with real sealing boots.

Introduction

In design of ball joints for automotive applications, the major design concern is to prevent their sealing boots from leaking, because most failure of ball joints are corrosion, contamination and dirt getting into ball joint causing excessive wear. Figures 1a and 1b show some typical ball joint failure modes. In practice the stud of a ball joint is subjected to axial, oscillation and rotation loads. Currently most designs of sealing boots are based on design engineer's experience, experimental tests, and/or much more simplified FEA models. In this paper, we present a three-dimensional finite element model to investigate the contact behavior of ball joint sealing boot, especially for the sealing behavior under the stud oscillation. Also modeling aspects and comparison are presented in the paper. Using the 3D finite element model, design engineers can not only make design decisions based on the obtained insight information of the contact behavior, but also evaluate the boot age-effects on the sealing effectiveness for high mileage related concerns.

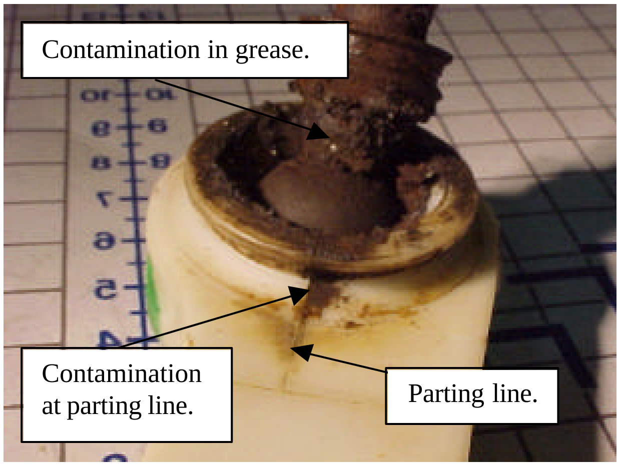


Fig. 1a Ball joint failure: corrosion and contamination in grease.

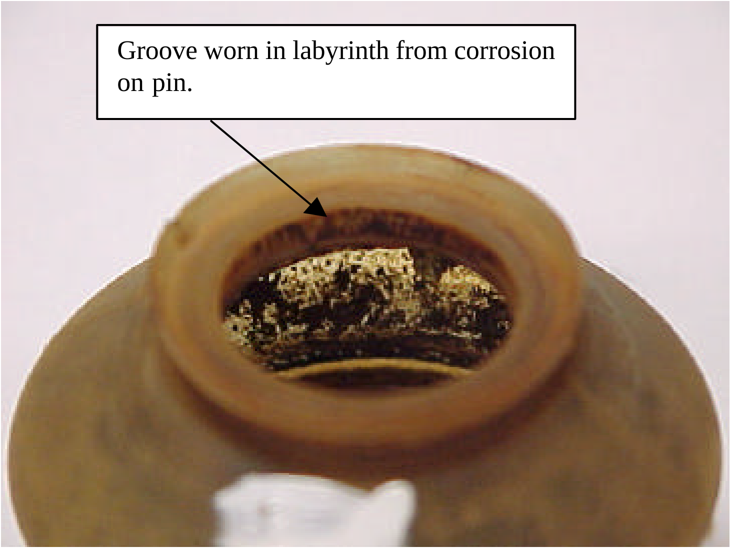


Fig. 1b Ball joint sealing boot failure: excessive wear in labyrinth.

Finite Element Model of the Ball Joint Sealing Boot

Using Finite Element software to investigate the contact behavior of sealing boot involves in simulating the assembly process and ball joint working conditions. In this paper, we only demonstrate the assembly process and the ball stud oscillation.

The finite element model of the sealing boot contains the following components:

- sealing boot
- ball stud
- housing
- knuckle
- clamping ring on the housing side
- clamping ring on the stud side

Since the stiffness of the housing, ball stud, and the knuckle is much higher than the rubber sealing boot, they were modeled with rigid body in the FEA model. The rubber-sealing boot was modeled using Neo-Hookinian material model. The used Neo-Hookinian model has been demonstrated good overall behavior in comparison to the real components. The two steel clamping rings were simplified by using circular rings. The mechanical properties of the clamping rings were adjusted accordingly.

The assembly process is first to put the sealing boot onto the housing and the ball stud, and then put the clamping ring onto the sealing boot at both housing and stud side, and finally, compress the knuckle down to engage the ball joint assembly into the design position. An axisymmetric FEA model can simulate this assembly process. In this axisymmetric model, initially the inner diameter of the boot is smaller than the one of the housing and the stud. Also the inner diameters of the two clamping rings are smaller than the ones of sealing boot. By specifying the final position of the ball stud, the housing, and the knuckle the final assembly of the ball joint can be simulated as shown in Fig. 2. In the figure 2 the contact normal force is also shown.

To simulate the oscillation of the ball joint, a 3D FEA model has to be used since the axisymmetric condition does not exist any more. Using a 3D FEA model to repeat the above assembly process is extremely difficult if it is not technically possible. In the new MSC.Marc 2000, there is a new feature called “AXITO3D”, which is to transfer the results from the axisymmetric model into a fully 3D analysis. For this analysis, we transferred the state of stress and strain for the ball joint assembly obtained from the axisymmetric analysis to our 3D FEA model. The transferred stress and strain were treated as initial condition. The 3D FEA model was created by revolving the axisymmetric model 180^o about the symmetry axis, since only half of the ball joint assembly is needed for simulating the oscillation. The 3D FEA model and its contact body definition are shown in Fig. 3. The transferred contact normal force from the axisymmetric analysis of the sealing boot at the beginning of the oscillation is plotted in Fig. 4. There are three types of contacts involved in the analysis, namely, deformable body to deformable body, rigid body to deformable body, and deformable body self contact. To effectively utilize the computer resource, corresponding contact pairs were defined in a contact table using MSC.Mentat and the symmetry boundary condition was imposed on the central plane. In the analysis, the ball stud and the knuckle were oscillated within the range of 19^o.

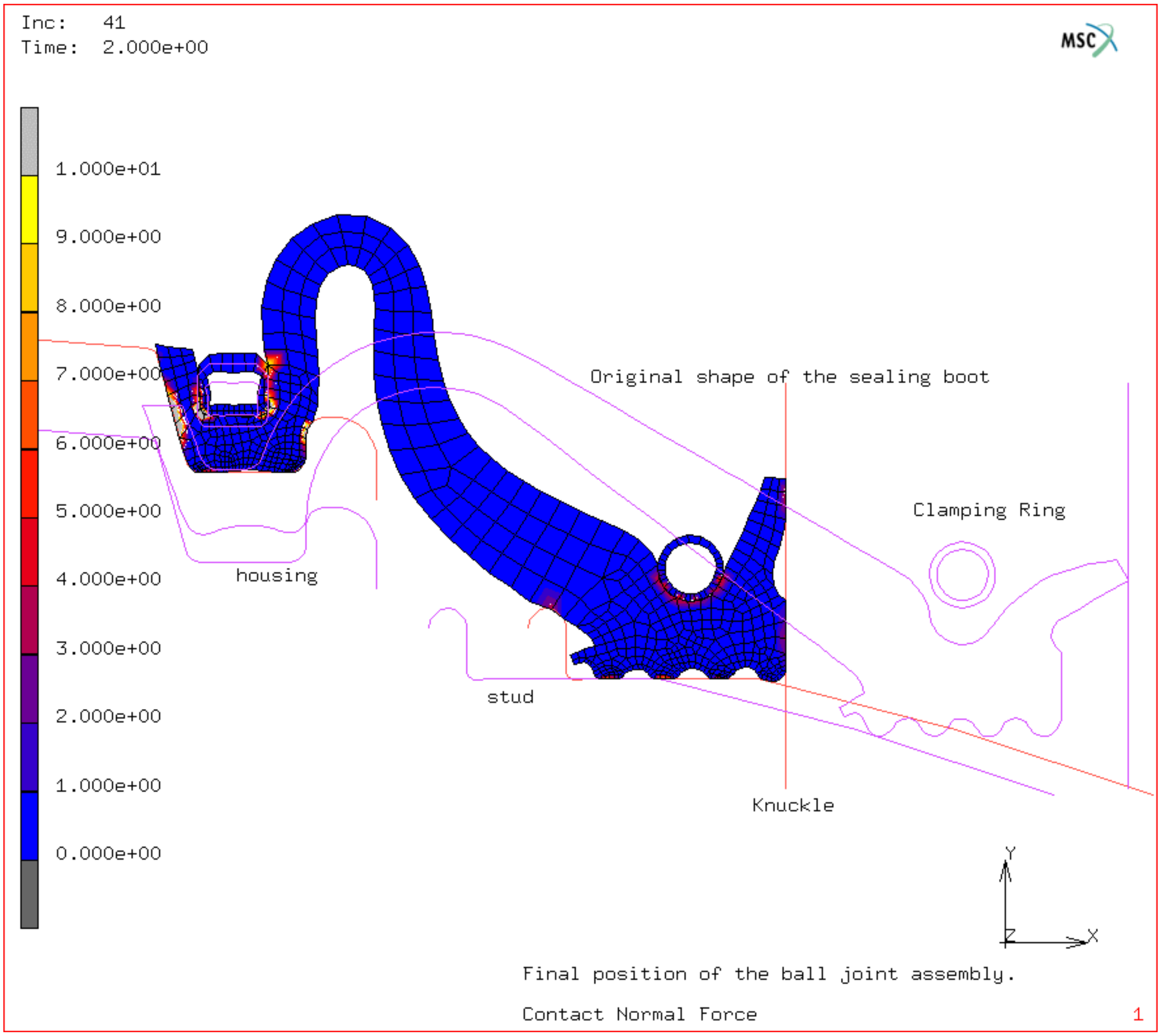


Fig. 2. Final position of the ball joint assembly by using the axisymmetric FEA model.

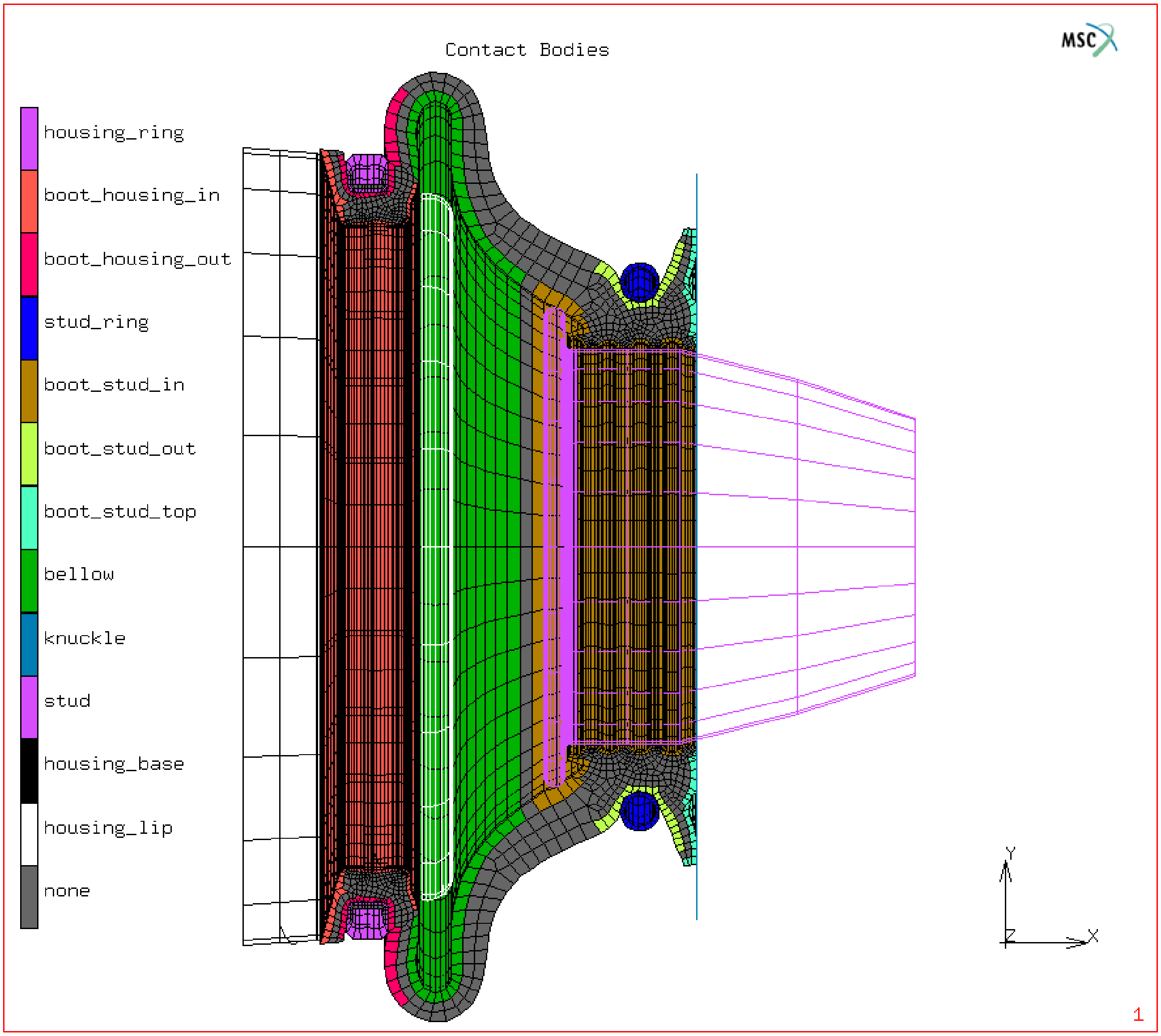


Fig. 3 The 3D FEA model of ball joint assembly created by revolving the corresponding axisymmetric FEA model and the definitions of contact bodies.

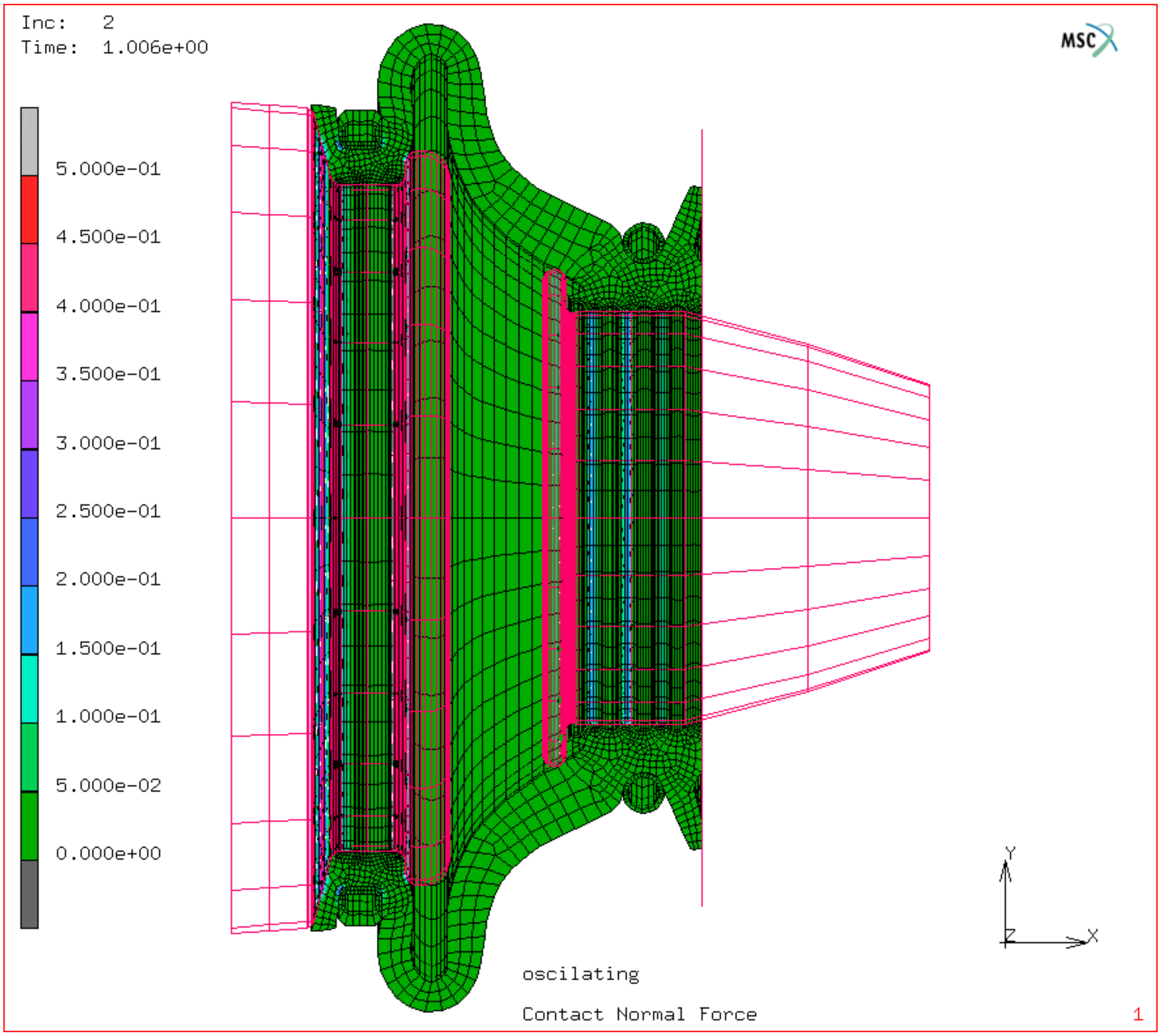


Fig. 4 Contact normal force of the ball joint sealing boot at the start of the oscillation.

Results and Comparisons

In this section, some of the numerical results obtained from the above 3D FEA model are presented. Figs. 5 and 6 show contact normal force distribution of the sealing boot at oscillation angle of 8.93 and 13.11 degree respectively. In these figures, the clamping rings were plotted for the sake of clarity. The bending moments required to oscillate the ball stud and knuckle are plotted in Fig. 7. The calculated deformed shape was compared with the real sealing boot at various oscillation angles as shown in Fig. 8. In the Fig. 8, the calculated deformed outline of the boot at center plane was mapped on top if the real boot. It is clear that the calculated boot outline matches the real boot well.

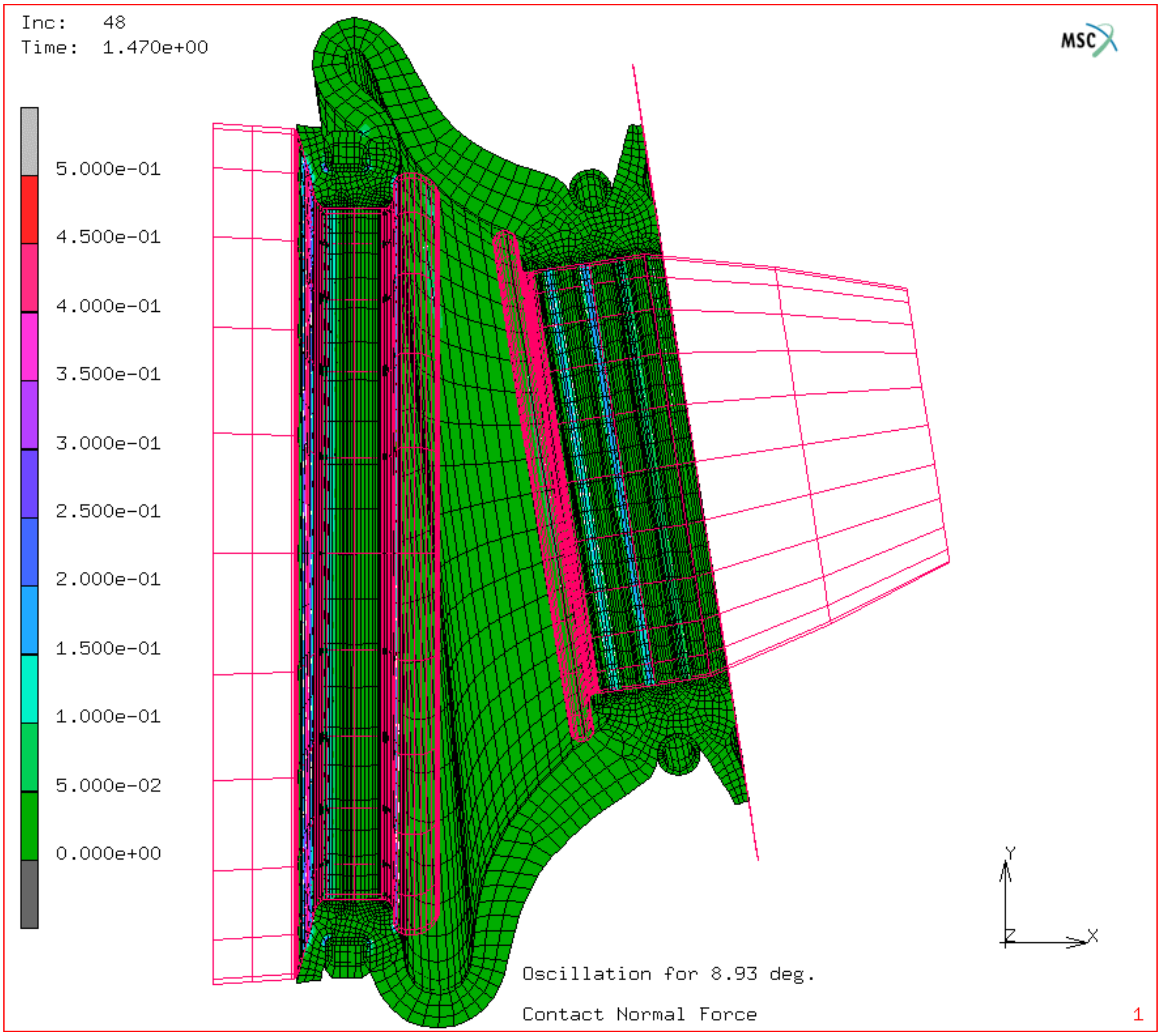


Fig. 5 Contact normal force at oscillation angle of 8.93 degree.

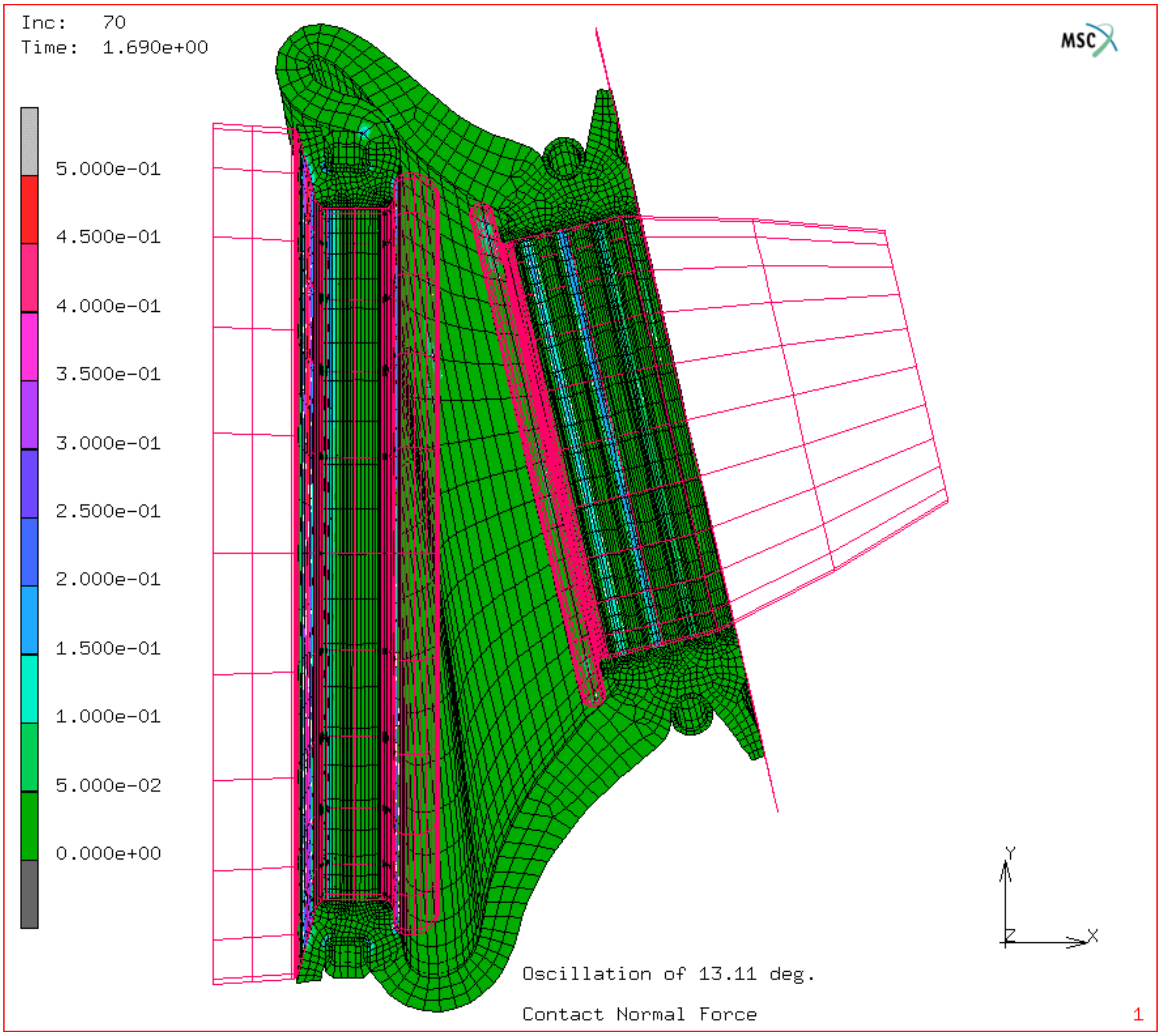


Fig. 6 Contact normal force at oscillation angle of 13.11 degree.

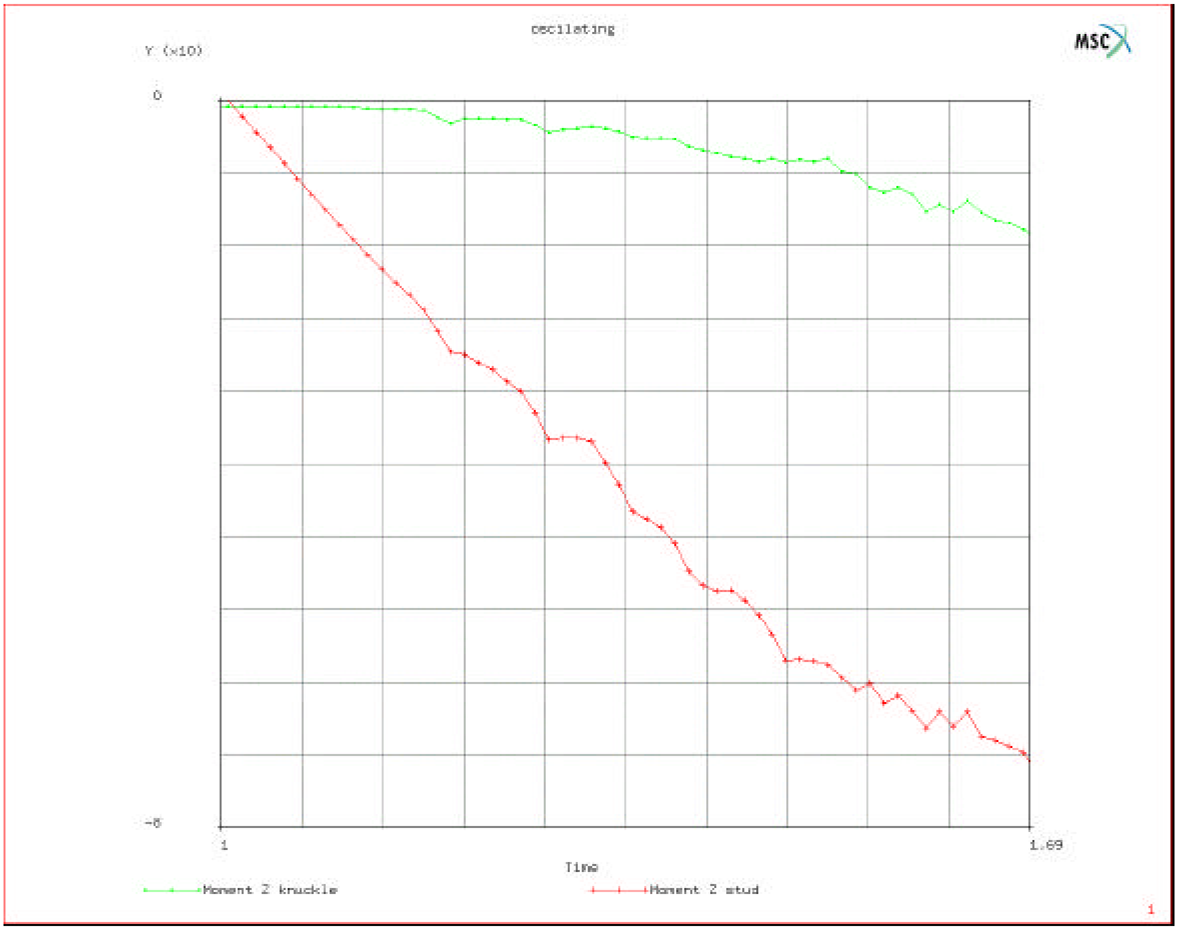
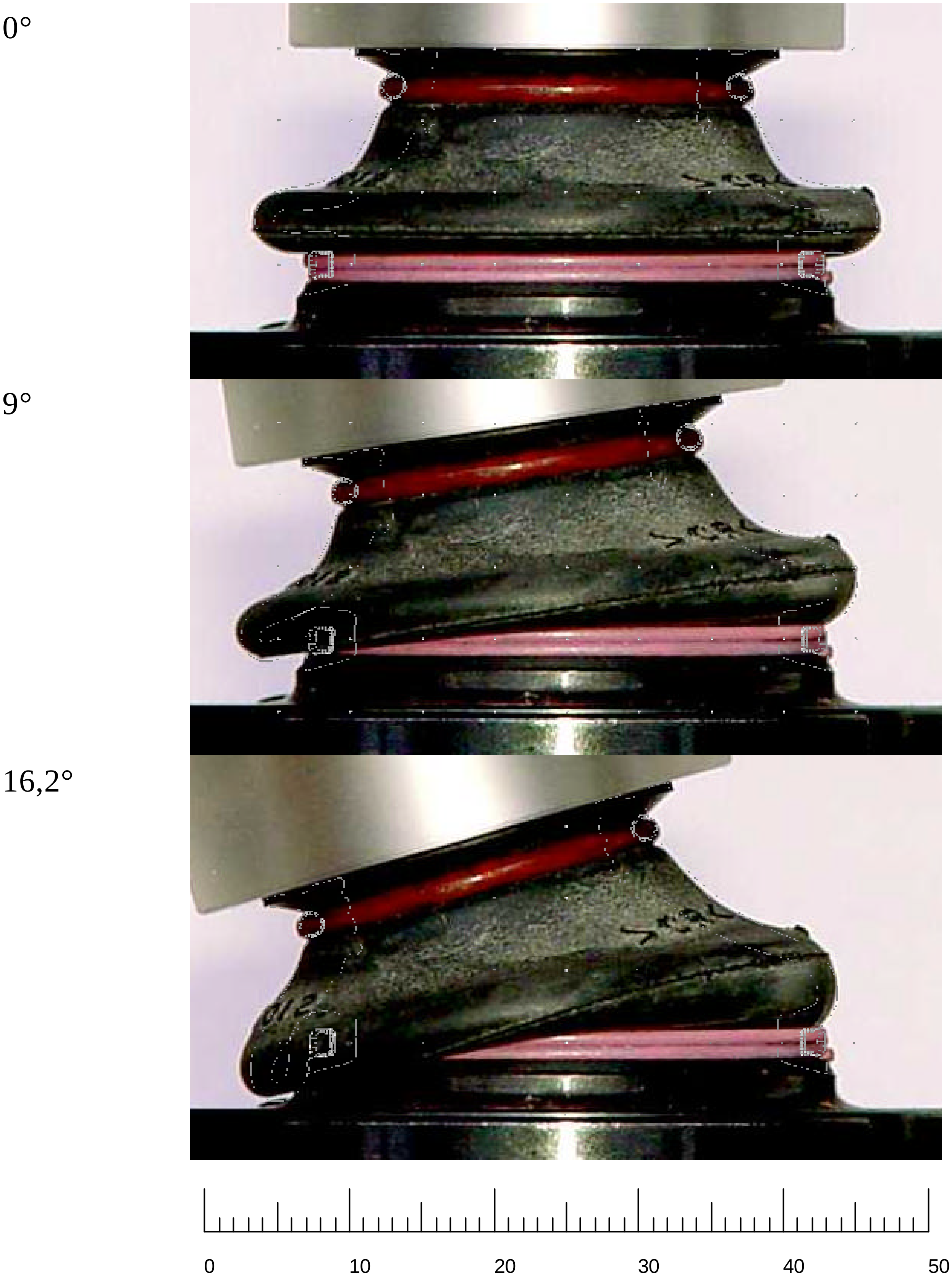


Fig. 7 Bending moment Z vs. oscillation angle.

Fig. 8 Comparison between the calculated deform shape (profile at the center plane drawn in white colored line) and the real sealing boot at various oscilation angles.



Concluding Remarks

In this paper, a 3D finite element model was presented to investigate the sealing behavior of ball joint sealing boot. The comparison between the numerical results and the real boot at various oscillation angle shows that the FEA model can predict the deformed boot shape well. More experimental tests are under going to further validate the other FEA results. The 3D finite element model may provide a very effective tool for design engineers to understand the sealing behavior under various dynamic working conditions. Also it can be very effective for engineers to evaluate the age-effects of the sealing boot. This is very important in answering high mileage related questions. The new feature of AXITO3D of MSC.Marc 2000 provides a vital tool to simulate the assembly process for the ball joint sealing boots. The output from the 3D finite element model provides important insight information on sealing mechanism for design engineers to improve their sealing boot design.

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