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TECHNICAL REPORT ARCCB-TR-99012

**ANALYSIS OF ENGRAVING AND WEAR  
IN A PROJECTILE ROTATING BAND**

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JULY 1999

	<p><b>US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER CLOSE COMBAT ARMAMENTS CENTER BENÉT LABORATORIES WATERVLIET, N.Y. 12189-4050</b></p>	
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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE July 1999	3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE  ANALYSIS OF ENGRAVING AND WEAR IN A PROJECTILE ROTATING BAND		5. FUNDING NUMBERS  AMCMS No. 6226.24.H191.1	
6. AUTHOR(S) Peter C.T. Chen		8. PERFORMING ORGANIZATION REPORT NUMBER  ARCCB-TR-99012	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  U.S. Army ARDEC Benet Laboratories, AMSTA-AR-CCB-O Watervliet, NY 12189-4050			
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)  U.S. Army ARDEC Close Combat Armaments Center Picatinny Arsenal, NJ 07806-5000		10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Presented at the 9 <sup>th</sup> U.S. Army Gun Dynamics Symposium, McLean, VA, 17-19 November 1998. Published in proceedings of the symposium			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  A large deformation analysis of the engraving process and wear in a projectile rotating band is considered by using the finite element program ABAQUS. The tube and the projectile are assumed to be rigid, and the bore of the tube is assumed to be smooth and axisymmetric. An elastic-plastic material model is chosen for the copper band, which remains attached to the projectile, and an appropriate coefficient of sliding friction is chosen. The magnitude and distribution of the contact pressure between the band and the tube are obtained during engraving. The band pressure is large with severe plastic deformation occurring in the band.			
14. SUBJECT TERMS Engraving, Wear, Projectile, Rotating Band, Plastic Deformation			15. NUMBER OF PAGES 16
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT  UL

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## ACKNOWLEDGEMENTS

The author appreciates the valuable assistance provided by his colleagues, Dr. J.M. Coyle, J. Higgins, and M. Leach.

## INTRODUCTION

It has been postulated that due to today's higher energy propellants and heavier projectiles, the rotating band deforms so severely that it loses the ability to properly support the projectile resulting in unanticipated wear at the muzzle end. Earlier research has indicated it is probable that all cases of rotating band failure can be attributed to excessive wear in the initial portion of the projectile's travel, even when the failure does not occur until well down the tube (refs 1,2). When the projectile enters the barrel of the gun, the rotating band passes through a forcing cone that places it under compressive interference stresses. Thus, large plastic deformation occurs along the driving edges of the forcing cone. The radial pressure between the projectile band and bore produces friction and an abrasive action on the bore surface. Approximate theoretical estimates of radial band pressure have been obtained by using the rigid-plastic flow theory and assuming uniform distribution (refs 3,4). A satisfactory stress analysis of the engraving process and wear has never been reported.

This report includes a large deformation analysis of the engraving process in a projectile rotating band by using the finite element program ABAQUS (ref 5). The calculations are obtained by assuming the bore of the tube as smooth and axially symmetric. Furthermore, the tube and the projectile are assumed to be rigid and the copper band is considered as elastic-plastic. The copper band, which remains attached to the projectile, will slide against the bore when the projectile enters the barrel of the gun. Appropriate coefficient of sliding friction is also chosen. The magnitude and distribution of the contact pressure between the band and the tube are obtained during different stages of engraving. The deformations, strains, and stresses are also obtained. The magnitude of the band pressure is large with severe plastic deformation occurring in the band. As such, wear in the band is discussed.

## MODELING

### Geometry

The rotating band chosen for this study is of axial length  $L_o = 37.084$ -mm and radial thickness  $B_o = 2.3114$ -mm. A simple mesh of the band is constructed of 281 nodes and 250 four-node bilinear elements. The radius of the projectile is  $R_p = 76.581$ -mm and the band is attached to the projectile. The radius of the bore behind the forcing cone is  $R_o = 79.38$ -mm with the length of the forcing cone at  $L_c = 40.54$ -mm. The radii of the bore after the forcing cone through the groove and land are  $R_g = 78.74$ -mm and  $R_l = 77.485$ -mm, respectively. Therefore, the reductions in thickness through the groove and land are 6.6% and 60.9%, respectively.

## Material

The tube and projectile are assumed to be rigid, and the copper band is considered as elastic-plastic. The values of Young's modulus and Poisson's ratio for the copper are 110 GPa and 0.33, respectively (ref 6). The initial yield stresses in compression and shear are 314 MPa and 181 MPa, respectively. Additionally, the dependence of the yield stress upon the plastic strain in the plastic range is piece-wisely defined by the data points (314 MPa, 0.0), (620 MPa, 0.126), and (620 MPa, 10.0).

## Boundary Conditions

There is no separation between the band and the projectile because the band is welded to the projectile. In addition to sliding contact between the band and the tube in the forcing cone, the band may be deformed to slide axially in either direction against the projectile faces. Therefore, there are four contact pairs and the coefficients of sliding friction are assumed to be 0.01 for the band/tube pair and 0.10 for the band/projectile pairs.

## Force/Displacement

Initially, the back face of the band is only 40.0-mm behind the entrance of the forcing cone, whose length is 40.54-mm. Therefore, when the projectile travels 80.54-mm, the band will have passed the forcing cone and the engraving process will be considered complete. The prescribed displacement used in this nonlinear analysis is 100-mm.

## **ENGRAVING THROUGH GROOVE**

The initial thickness of the band is  $B_0 = 2.3114$ -mm, and the final thickness of the band after passing through the groove will be  $B_g = R_g - R_p = 78.74$ -mm -  $76.581$ -mm =  $2.159$ -mm. Therefore, the reduction in thickness through the groove is  $(1 - B_g/B_0) \times 100\% = 6.6\%$ . It takes 49 increments to complete the analysis. Figure 1 shows the initial and final position of the band after traveling 100-mm through the groove. Figure 2 shows the enlarged original and deformed mesh after traveling 100-mm. Larger plastic deformation occurs at the front and back ends near the band/projectile interface. The contour plots of the Mises' stress and equivalent plastic strain in the final stage are shown in Figures 3 and 4, respectively. The size of the plastic zone can be seen in Figure 3; the maximum equivalent plastic strain is 2.233 at the back end close to the band/projectile interface. Figures 5 through 8 depict the distributions of contact pressure between the tube and the band at different stages of traveling through the groove. The maximum value of contact pressure is 3548 MPa, as shown in Figure 5. If the coefficient of sliding friction were less than 5%, then this value of contact pressure would generate a maximum shear stress of 177 MPa, which is smaller than the shear yield stress of 181 MPa of the copper band. Accordingly, it seems engraving through the groove can be completed without causing damage to the band or tube.

## ENGRAVING THROUGH LAND

The initial thickness of the band is  $B_0 = 2.3114$ -mm, and the final thickness of the band after passing through the land will be  $B_1 = R_1 - R_p = 77.485$ -mm -  $76.581$ -mm =  $0.904$ -mm. Therefore, the reduction in thickness through the land is  $(1 - B_1/B_0) \times 100\% = 60.9\%$ . It takes 227 increments to travel 49.7-mm, then the analysis ends because the time increments required are less than the minimum (0.001-mm) specified. Figure 9 shows the initial and final position of the band after traveling 48.4-mm through the land. Figures 10a through 10c show the enlarged deformed meshes at the front, middle, and back of the band. Plastic deformations are very large with severe distortions occurring especially at the front and back ends near the band/projectile interface. The distortions are so severe that computation stops. The contour plots of the Mises' stress and equivalent plastic strain in the final stage are shown in Figures 11 and 12, respectively. The size of the plastic zone can be seen in Figure 11; the maximum equivalent plastic strain is 57.58 at the front end. This value of plastic strain is so large that some failure criterion has to be introduced. Figures 13 through 16 illustrate the distributions of contact pressure between the tube and the band at different stages of traveling through groove. The maximum value of contact pressure is 6991 MPa, as shown in Figure 13. If the coefficient of sliding friction were more than 2.59%, then this value of contact pressure would generate a shear stress larger than the shear yield stress of 181 MPa of the copper band. Accordingly, it seems engraving through the land cannot be completed without causing damage to the band. The contact pressure between the band and tube is so large that together with friction, it would be likely to cause an abrasive action on the bore surface.

## DISCUSSION

This report, based on a simple band, is the first one on this subject. We have tried different types of elements and different boundary conditions. The constraints on the band by the projectile play an important role in the computation. If the band were allowed to slide between the tube and projectile, then the computation through the land could be completed without difficulty as an extrusion process. The requirement of no separation at the band/projectile interface causes the computation to stop sooner because more severe distortions have occurred at the front and back ends.

We have also completed the computation for a two-dimensional model of the refined band, including the cannellure. These results will be reported later. In addition, we have generated a two-dimensional rigid surface model of the tube and a three-dimensional solid model of the rotating band, but the three-dimensional simulations are computationally expensive and the results are not accurate.

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5. *ABAQUS/Standard User's Manual*, Version 5.7, Hibbitt, Karlsson, and Sorensen, Inc., 1998.
6. Boyer, H.E. (Ed.), *Atlas of Stress-Strain Curves*, ASM International, Metals Park, OH, 1987.

ENGRAVING OF COPPER BAND

100 mm through GROOVE

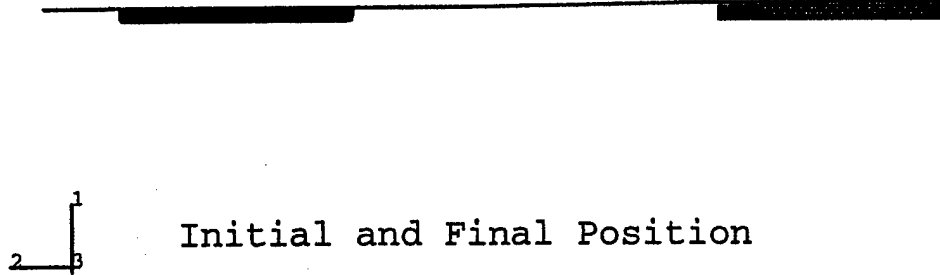


Figure 1. Initial and final position of band after traveling 100-mm through groove.

DEFORMED MESH



UNDEFORMED MESH

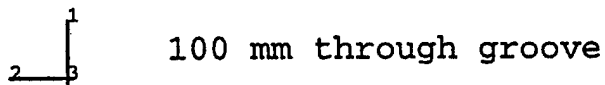
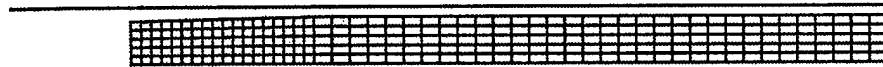


Figure 2. Original and deformed mesh after traveling 100-mm through groove.

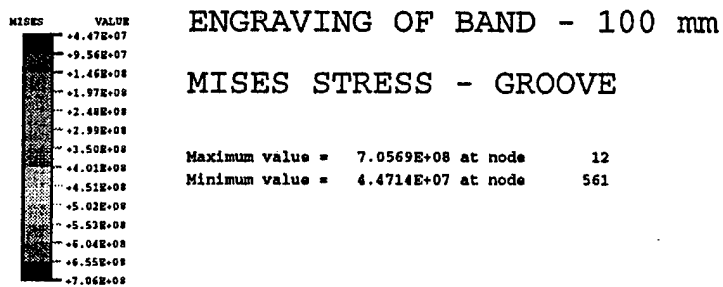


Figure 3. Contour of Mises' stress in band after traveling 100-mm through groove.

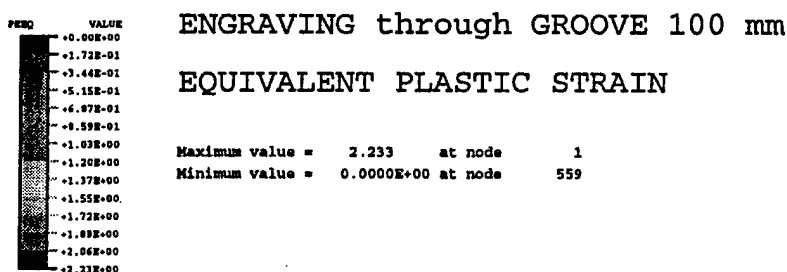


Figure 4. Contour of equivalent plastic strain after traveling 100-mm through groove.

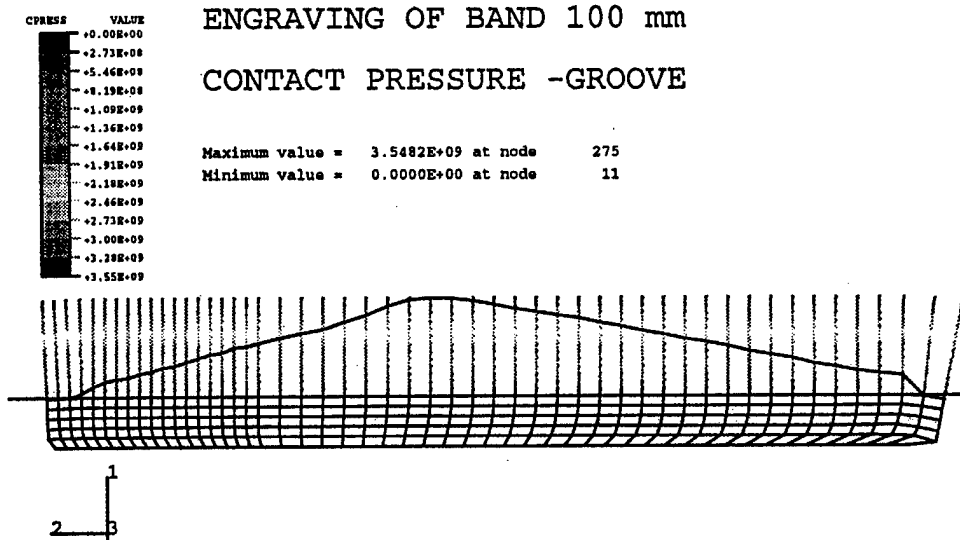


Figure 5. Contact pressure between band and tube after traveling 100-mm through groove.

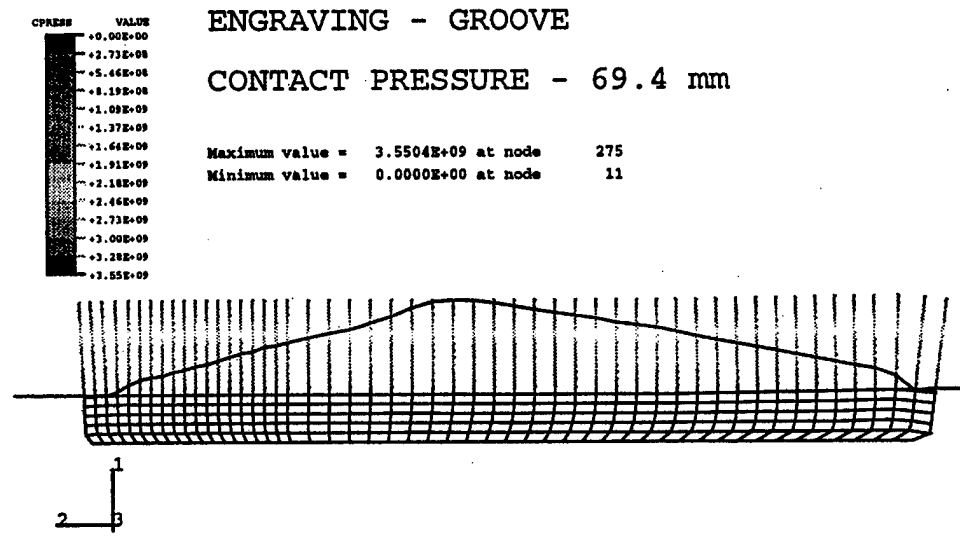


Figure 6. Contact pressure between band and tube after traveling 69.4-mm through groove.

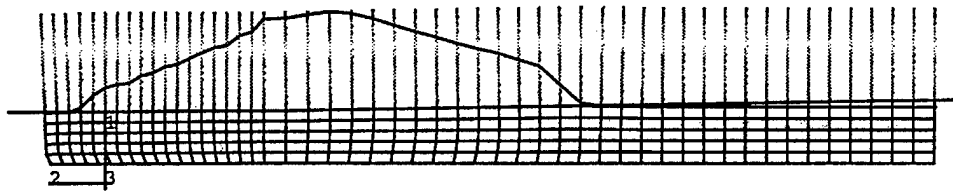
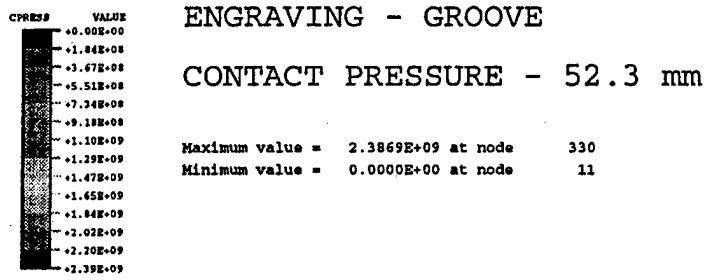


Figure 7. Contact pressure between band and tube after traveling 52.3-mm through groove.

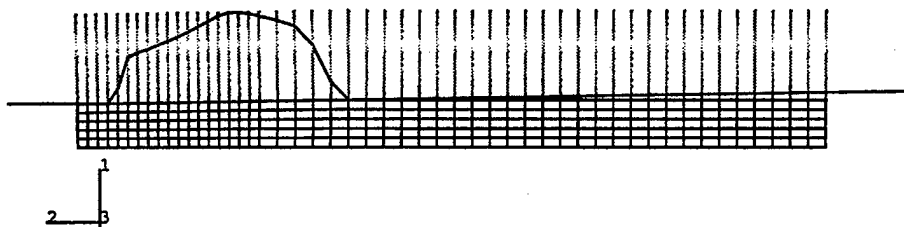
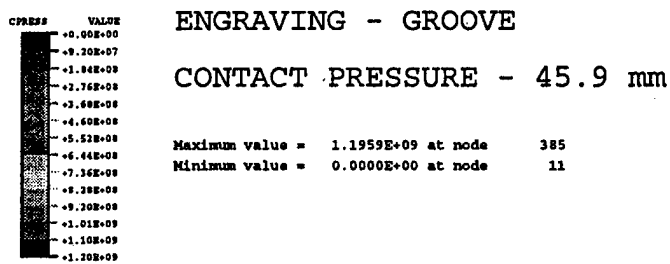


Figure 8. Contact pressure between band and tube after traveling 45.9-mm through groove.

# ENGRAVING OF COPPER BAND

48.4 MM THROUGH LAND



initial and final position



Figure 9. Initial and final position of band after traveling 48.4-mm through land.

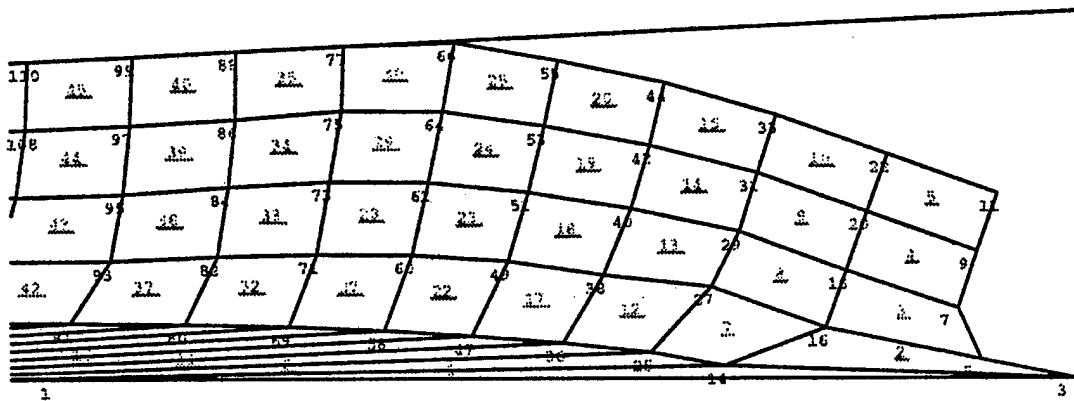


Figure 10a. Deformed mesh at the back end of band after traveling 48.4-mm through land.

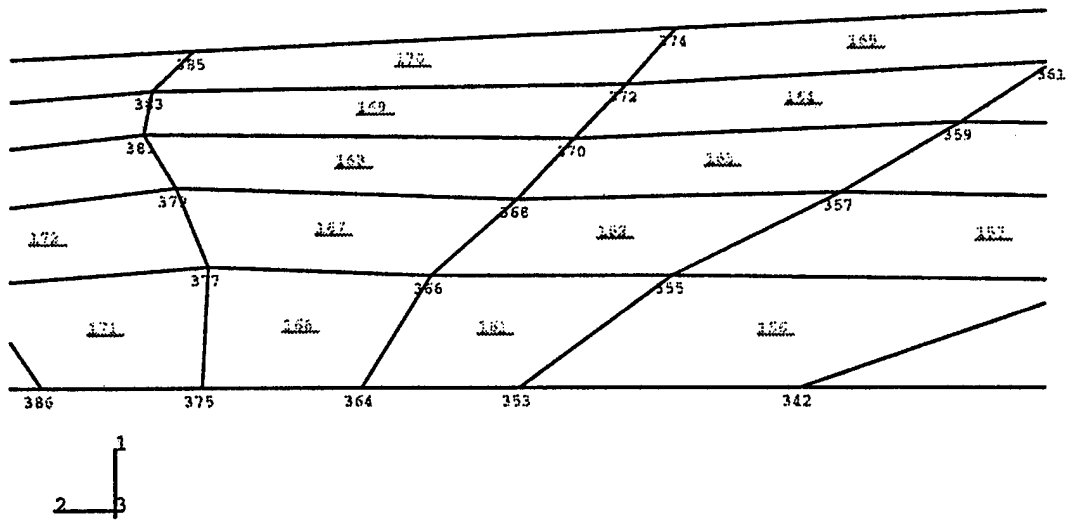


Figure 10b. Deformed mesh near the middle of band after traveling 48.4-mm through land.

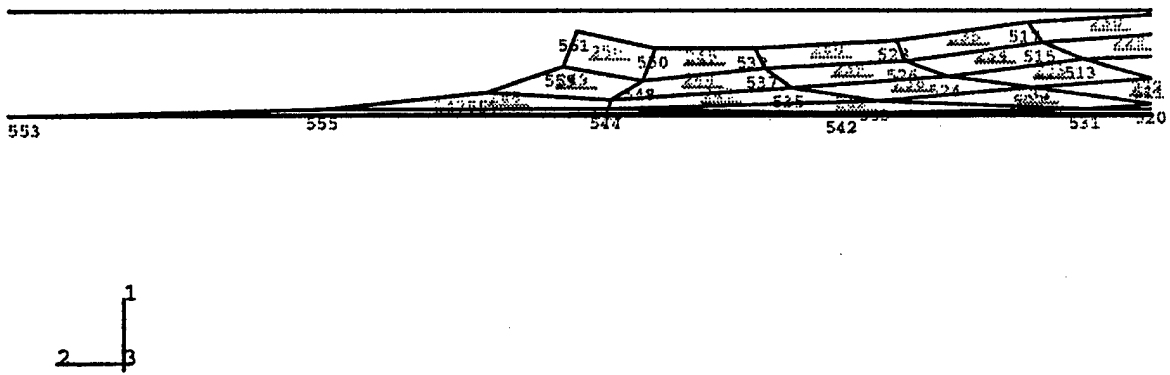
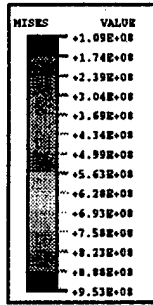


Figure 10c. Deformed mesh at the front end of band after traveling 48.4-mm through land.



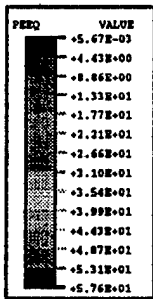
ENGRAVING OF BAND 48.4 MM

MISES STRESS - LAND

Maximum value = 9.5269E+08 at node 561  
 Minimum value = 1.0924E+08 at node 416



Figure 11. Mises' stress contour after traveling 48.4-mm through the land.



ENGRAVING OF BAND 48.4 MM

EQUIVALENT PLASTIC STRAIN

Maximum value = 57.58 at node 551  
 Minimum value = 5.6706E-03 at node 11

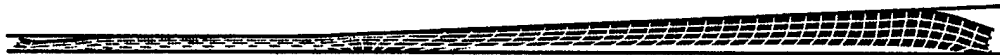


Figure 12. Equivalent plastic strain contour after traveling 48.4-mm through the land.

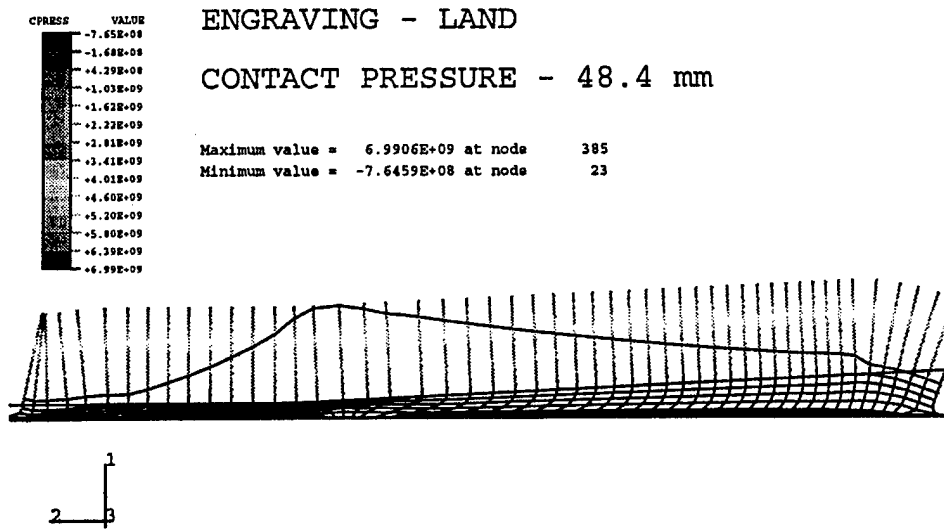


Figure 13. Contact pressure between band and tube after traveling 48.4-mm through the land.

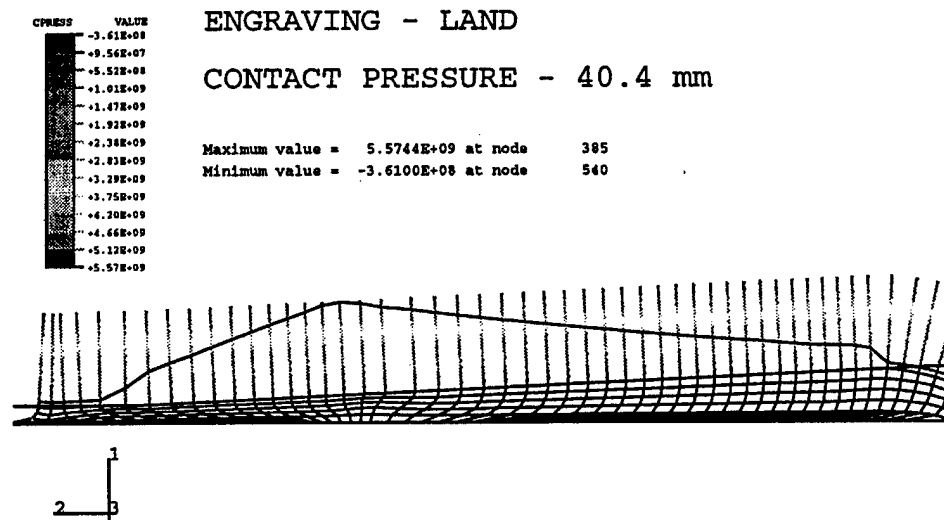


Figure 14. Contact pressure between band and tube after traveling 40.4-mm through the land.

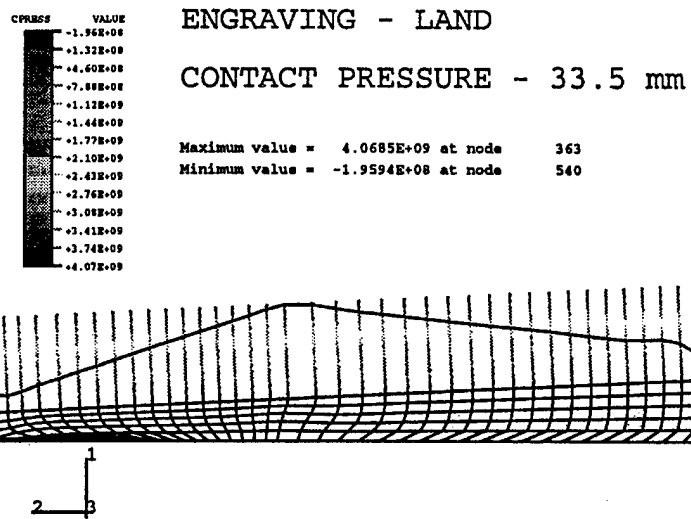


Figure 15. Contact pressure between band and tube after traveling 33.5-mm through the land.

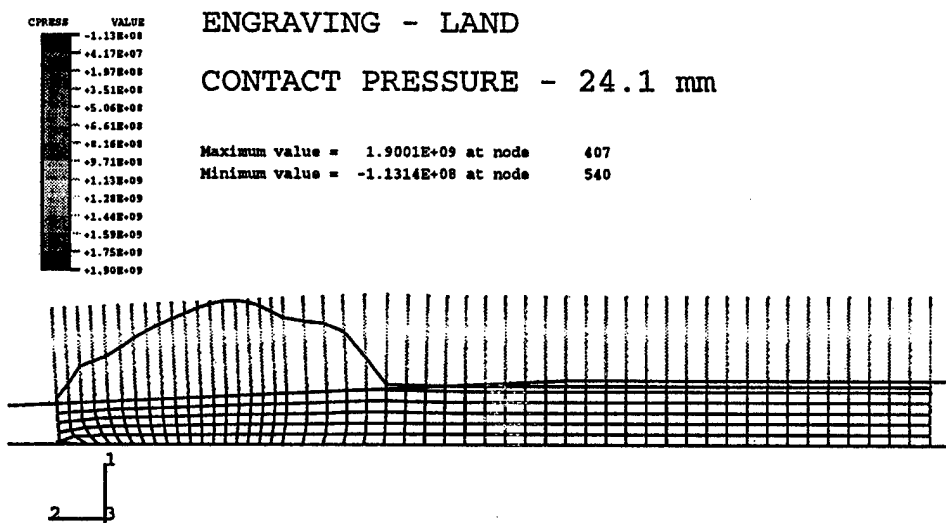


Figure 16. Contact pressure between band and tube after traveling 24.1-mm through the land.

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