Preload Release in a Steel Band under Dynamic Loading

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Abstract

A steel band is tightened around a thin walled steel cylinder. The assembly is exposed to different dynamic loadings including shock and vibration. While tightening, the circumferential stresses developed in the band, decrease as a function of the distance from the bolts and the value of the coefficient of friction between the band and the cylinder. Experiments show that dynamic loadings, such as shock and vibrations, release the initial preload of the tightening bolts. The extent of the change in the internal forces distribution depends on the level of the dynamic loading. The maximum possible release of the initial internal forces in the band, as a function of the friction coefficient between the cylinder and band, and the rigidity of the cylinder, was determined using LS-DYNA® explicit simulation. This method can be used to determine the initial tightening force of any assembly, and to assure that it stands dynamic environmental conditions.

Introduction

Steel bands are often used to attach equipment on round cylinders, where no interference to the cylinder is required. The amount of preload release in the bands under dynamic loading, such as shock and vibration, strongly depends on the coefficient of friction, and on the cylinder's rigidity. This assembly method includes a mounting which is tightened with bolts to the steel band. The functionality of the band is to hold the mounting attached to the cylindrical part. This can be achieved by preload supplied by the bolts.

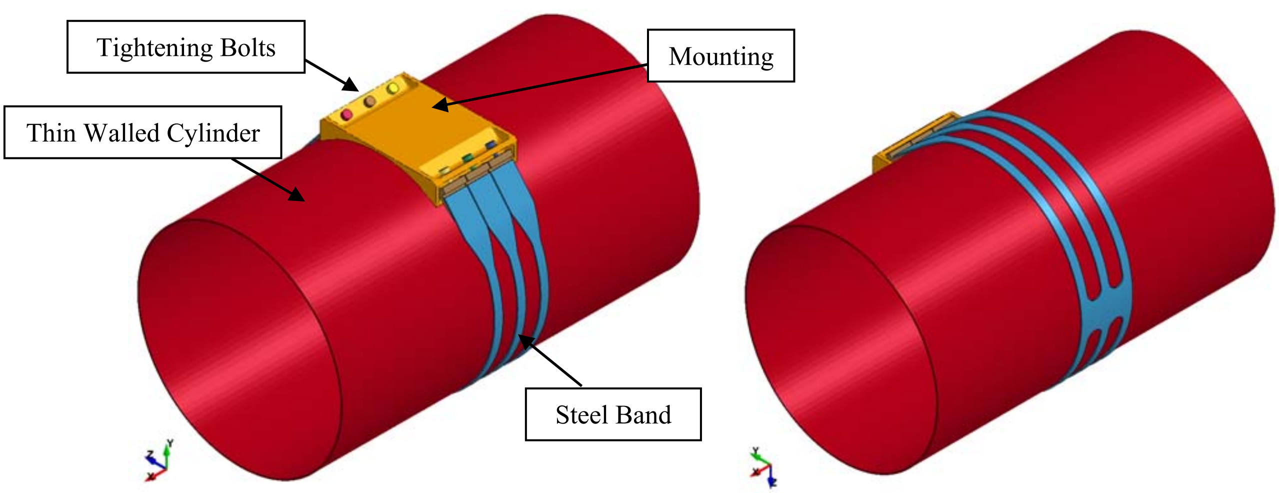


Figure 1: Band clamp assembly model

The only indication for the preload force in the band during installation is the level of the bolt's tightening torque. This is actually an indication for the maximal internal tension force in the band, because the internal tension forces developed in the band, decrease as the distance from the bolts increases. The level of the actual preload force is a function of the specific assembly, as well as the coefficient of friction between the bands and the cylinder.

This paper presents a work done using LS-DYNA explicit simulations, in order to find the distribution of forces in the band, the influence of the geometry, the cylinder's rigidity, and the friction on the internal forces release in the band, and finally, the maximum possible release in preload due to dynamic possible loads. Taking all these findings into account will result a recommended initial tightening force of the bolts.

Motivation

Tightening of a uniform cross sectioned band around a rigid cylinder introduces tension internal forces that decrease exponentially as a function of the coefficient of friction, and the distance from the tightening edge, expressed by the angle θ:

$$\frac{F}{F_0} = e^{-\mu\cdot\theta} \qquad (1)$$

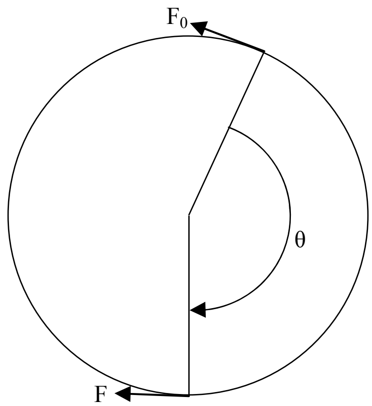


Figure 2: Band clamp sketch

Figure 3 shows the theoretical calculation (by Eq-1) for decreasing internal forces along the band, for various values of the coefficients of friction between the band and a rigid cylinder:

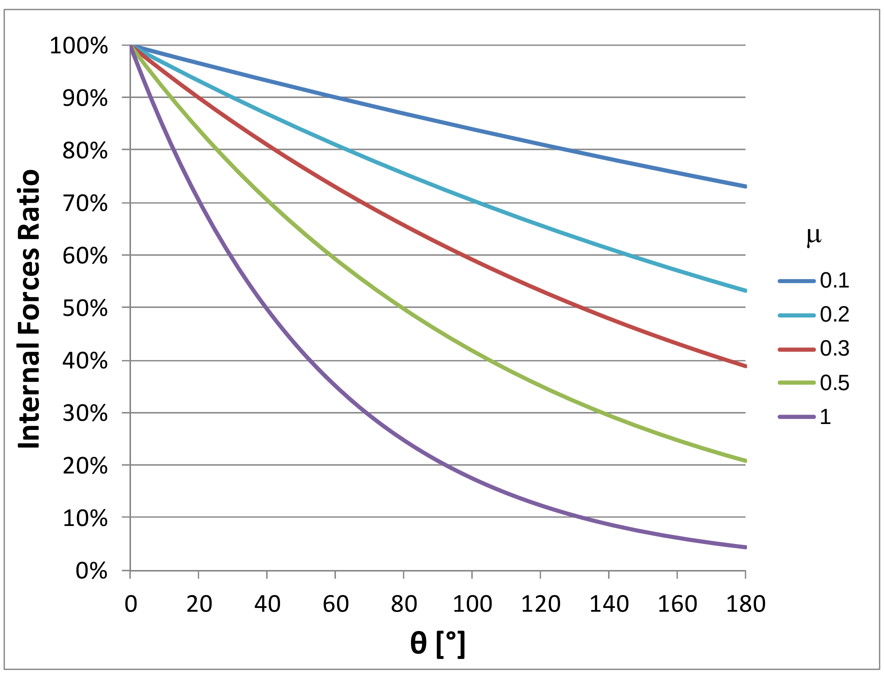


Figure 3: Theoretical force decrease along the band for various coefficients of friction

In order to average the distribution of the internal tension forces in band assemblies, a common practice is a gradual tightening of the band using hammer in between the stages. The hammer introduce series of shocks to the assembly, that release the distribution in the internal tension forces, resulting from the friction affect described above. The effect of averaging the force means an increase of internal tension forces in the lower part of the band (far from the bolts), and decrease in the internal tension forces at the upper part of the band, closer to the bolts. An additional torque is required in order to get the bolts to the desired level of tension force.

Figure 5 shows experimental measurements of a process of gradual tightening with hammering. The bolts were tightened with an increasing preload of 22.6 [N·m] to 48.6 [N·m]. The last preload was repeated ten times. Hammer stages were executed on the band between tightening stages. The tension forces of the bolts were measured by strain gage bolts, and the circumferential stresses of the band were measured using strain gages on the outer surface of the band, as can be seen in Figure 4. The thin-walled band is under pure tension; hence the internal tension force in the band can be approximated by multiplying the cross section area with the circumferential stress, measured on the outer surface of the band: $F = A \cdot E \cdot \varepsilon$ (2)

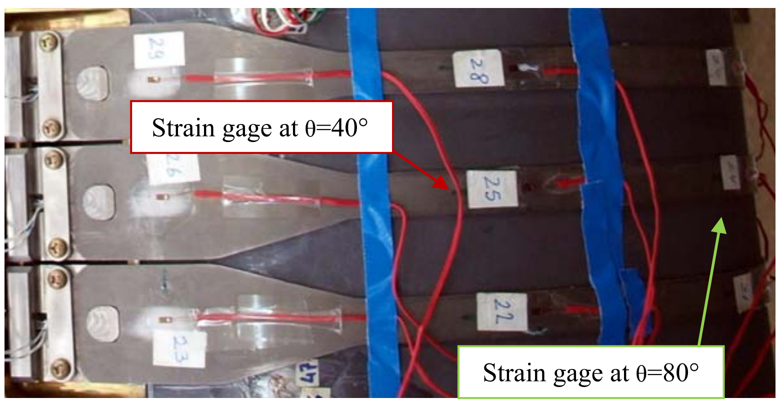


Figure 4: Strain gages attached to the band

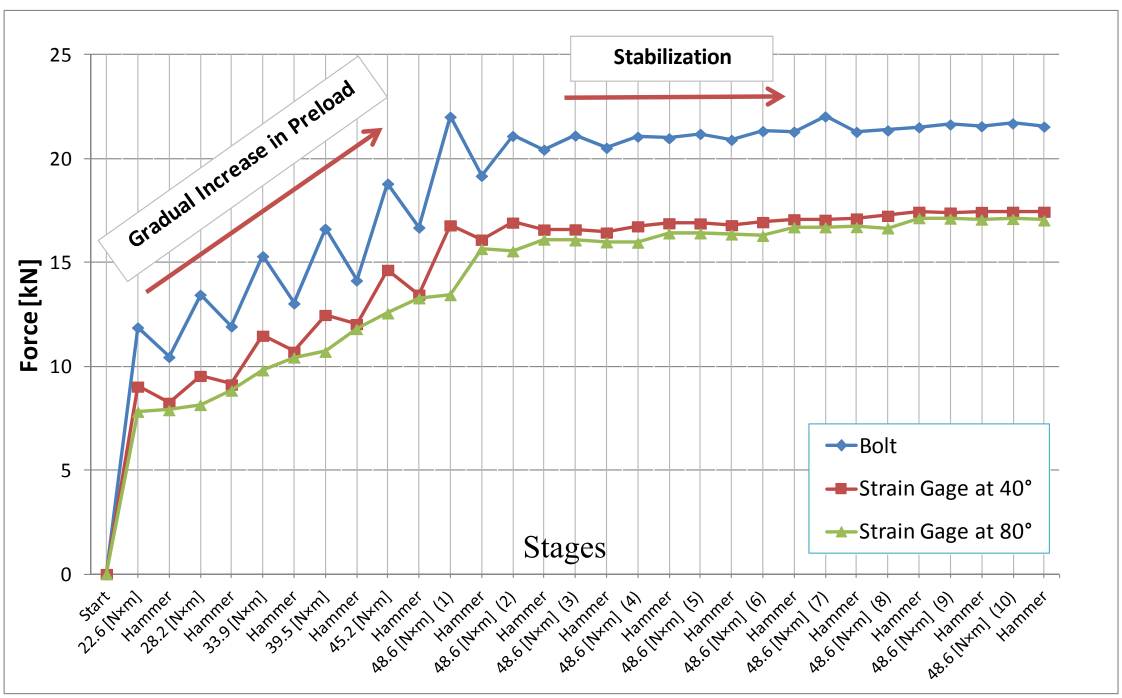


Figure 5: Experimental measurements for assembly process using stages of hammering

Figure 5 shows the decrease of the force, measured in the bolt, after every hammer, and the convergence to the final force at the end of the process. The distribution of the internal tension forces in the band can be seen as the difference in measurements between strain gages at θ=40° and θ=80°. The hammer mainly affects the upper part of the band, and reduces the distribution of the internal forces in the band.

The process of hammering is non-repeatable, depends on workmanship, and cannot assure the final uniform stresses in the band. Furthermore, the dynamic environmental conditions of the system are expected to change the distribution of the internal tension forces along the band. Hence the maximal decrease of the internal forces in the band is needed to be evaluated by FE simulation.

Distributed Internal Forces along the Band

As mentioned above, the internal tension forces distribution depends on the geometry of the assembly and on the stiffness of its components: cylinder, band and mounting.
The FE model described in Figure 6 is an example for this kind of specific assembly. The FE model contains shell elements for the thin-walled cylinder and for the thin-walled band, and solid elements for the mounting and 3 bolts. The problem was modeled as a half model with symmetry boundary conditions in the X-Y plane and fully constrained boundary conditions for both sides of the cylinder. All parts were modeled as elastic materials with stainless steel properties.

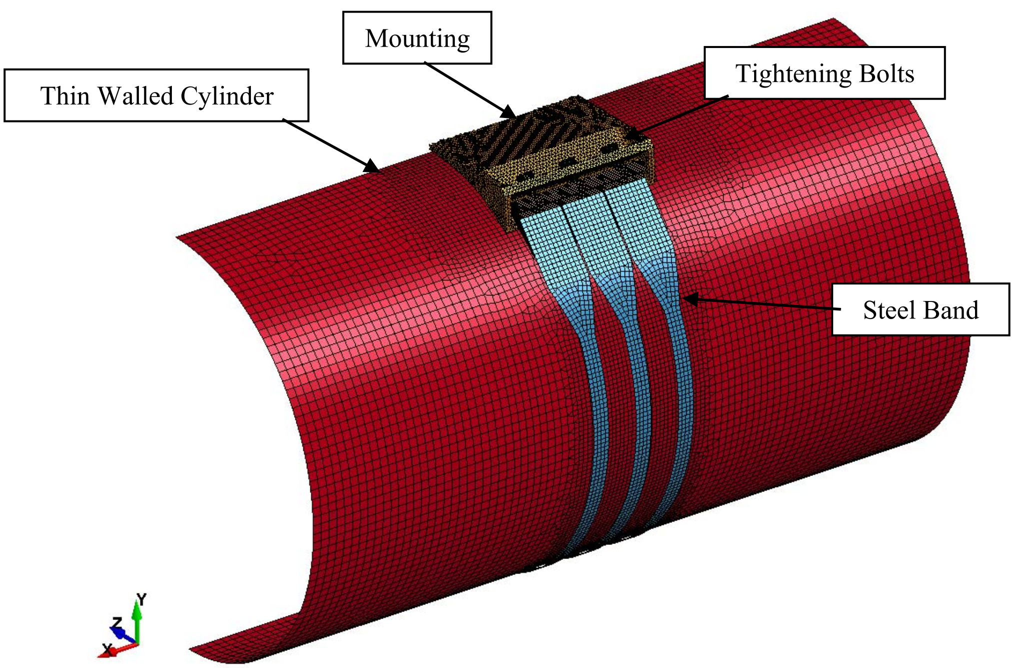


Figure 6: FE Model

Internal tension stresses are developed in the band when the bolts are subjected to torque loading. These stresses are modeled with *SECTION_FORCE keyword. The force applied to each bolt is 20 [KN], thus the total force is 60 [KN]. These internal stresses are not the same in different sections around the cylinder as can be seen in Figure 7. The same problem was solved for various values of the coefficient of friction, and the results are summarized in Figure 8.

The results show decrease in the internal tension stresses as function of the distance from the bolts, and the level of the coefficient of friction between the bands and the cylinder.

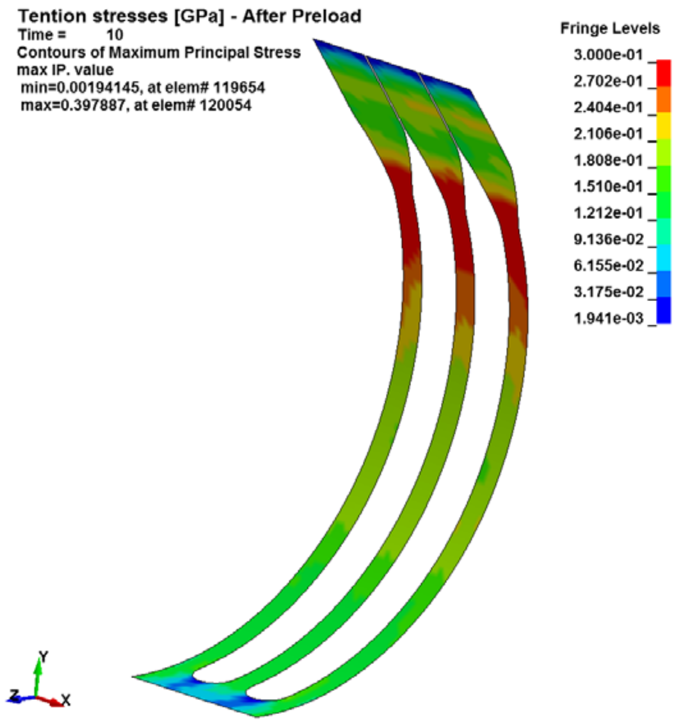


Figure 7: Stress distribution along the band after preload for μ=1

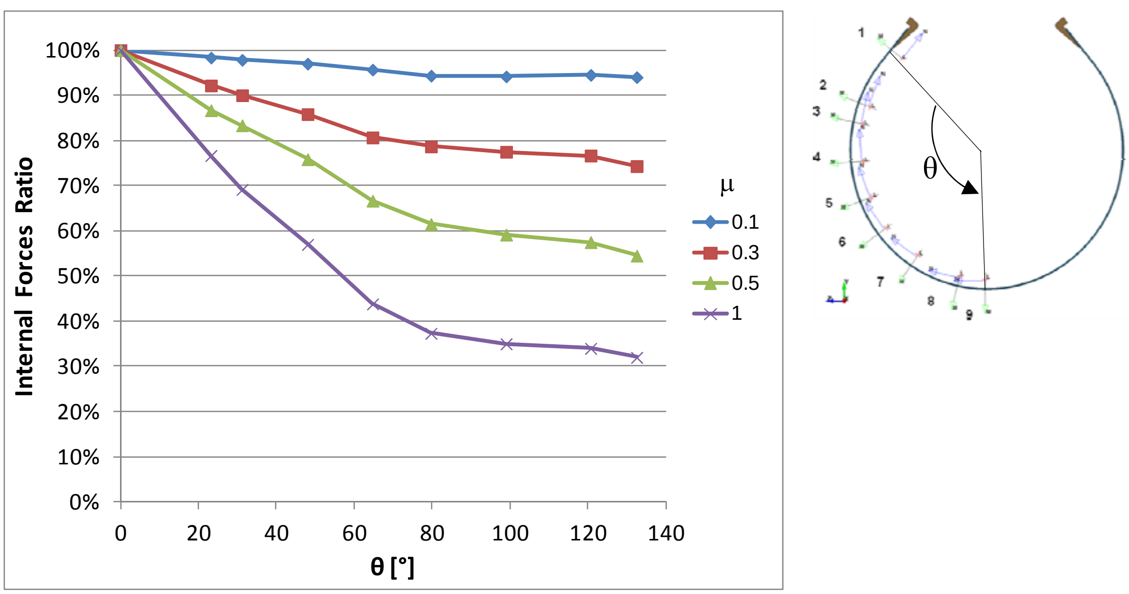


Figure 8: Force decrease at different angles

A comparison between a rigid cylinder and a thin walled (2.5 mm) elastic cylinder can be seen in Figure 9, showing that the elasticity of the cylinder affects the amount of force decrease in the band. Using a band over a rigid cylinder will result in a maximal distribution of internal tension forces in the band. Changing the rigidity of the cylinder in the FE model to a rigid cylinder result with force distribution correlating to the theoretical calculation as can be seen in Figure 10.

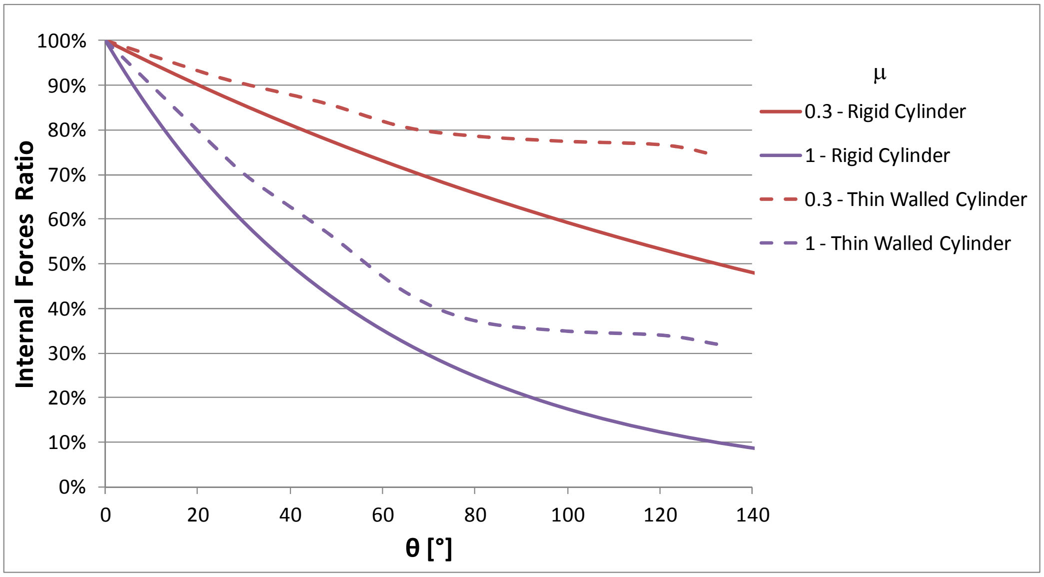


Figure 9: A comparison between a rigid cylinder and a thin walled elastic cylinder

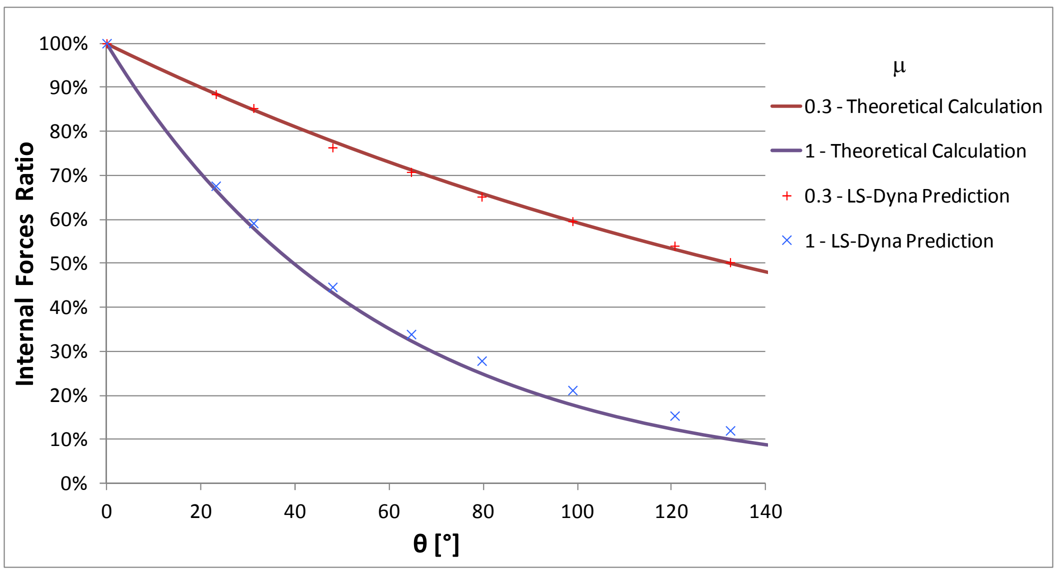


Figure 10: A comparison between theoretical calculation and LS-DYNA Prediction for a rigid cylinder

Preload Release during Dynamic Loading

The preloaded assembly is exposed to various levels of shock and vibrations during its life-cycle. These dynamic loadings can change the internal forces distribution in the band, which can be wrongly interpreted as a decrease in band tightening.

The extent of the change in the internal forces distribution depends on the level of the dynamic loadings. While the motivation of the work was to find the maximal decrease of the tightening force, a severe shock was chosen to demonstrate this phenomenon. This shock was achieved by pulling the mounting to a displacement of 2 mm, while stretching the elastic band, and releasing it abruptly. The shock created from the collision of the mounting and the cylinder is a relatively high and non-realistic shock for this kind of assembly, but it released all stress distributions along the band.

Figure 11 shows the stress distribution created along the band after the preload on the left, and a uniform stress distribution along the band as a result of the severe shock that was applied to the model, on the right.

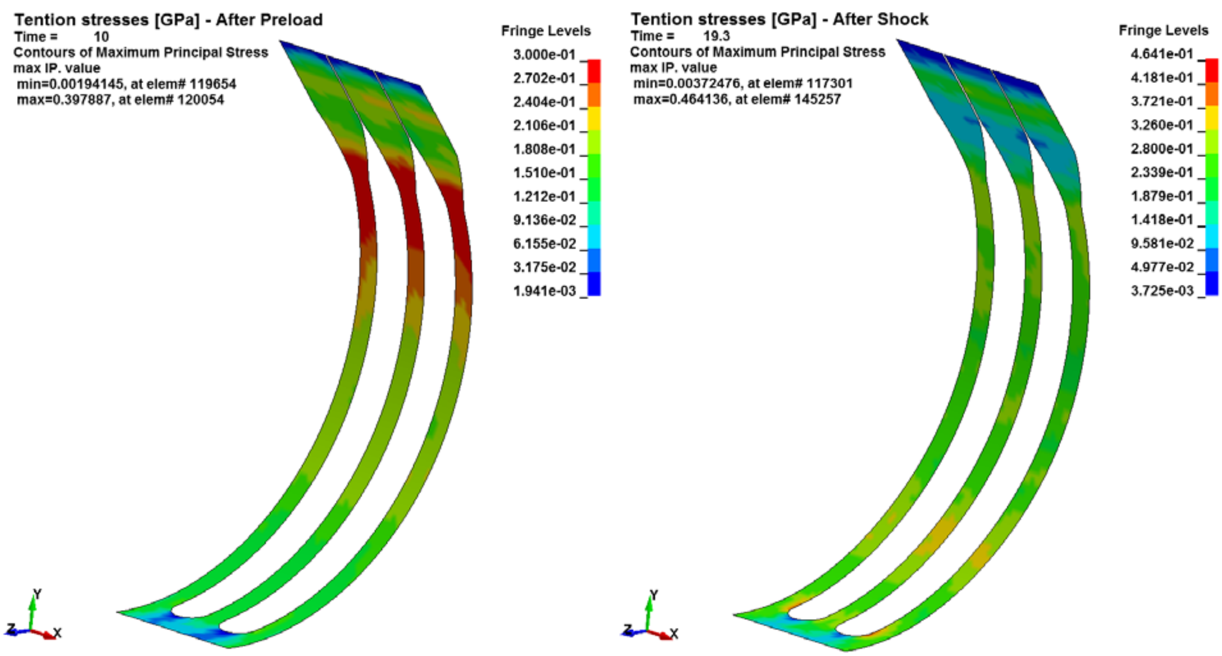


Figure 11: Stress distribution in the band for μ=1 after preload stage (left) and after the shock (right)

Figure 12 and Figure 13 show the internal tension forces in various cross sections of the band, for μ=0.3 and μ=1, when the band is exposed to the shock created by the mounting pull and release. The difference in the stress distribution after preload stage (at 10 [ms]) is explained by the difference in the coefficient of friction, as was described above in Figure 8.
After the mounting was released at 15 [ms], the internal tension forces at different cross sections converged to the same final uniform force. The level of this final force varies, depending on the coefficient of friction.

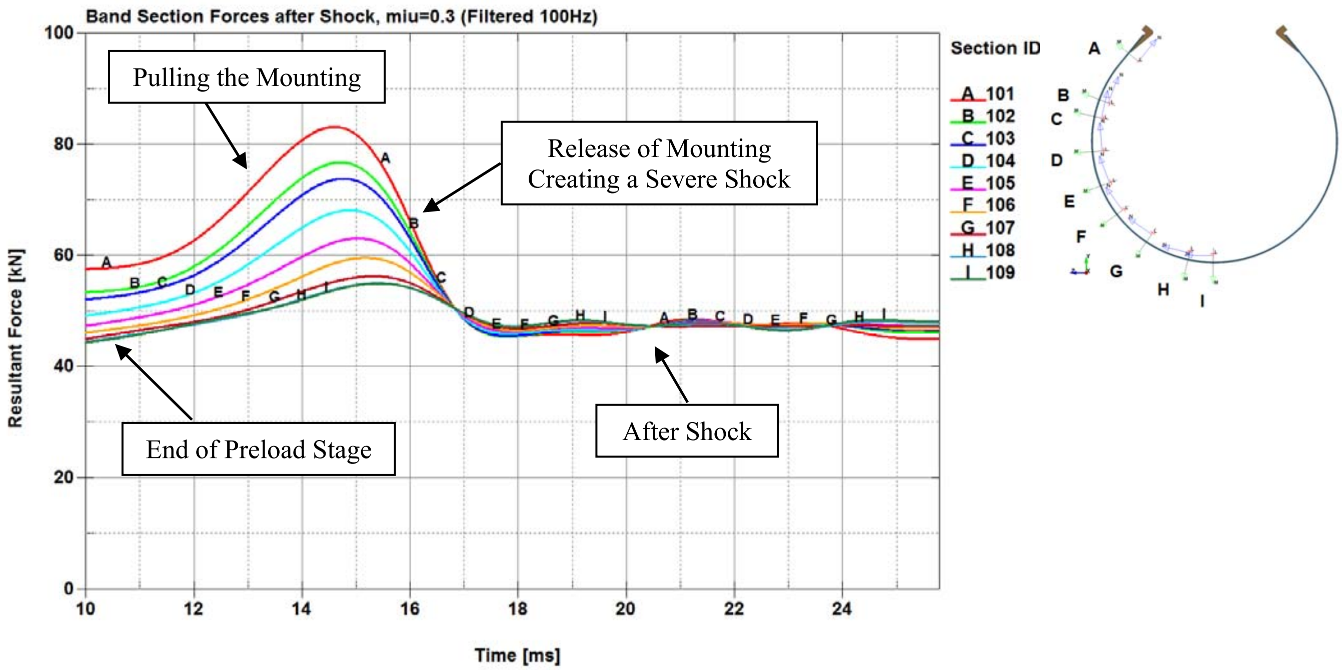


Figure 12: Internal tension forces in the band subjected to severe shock with μ=0.3

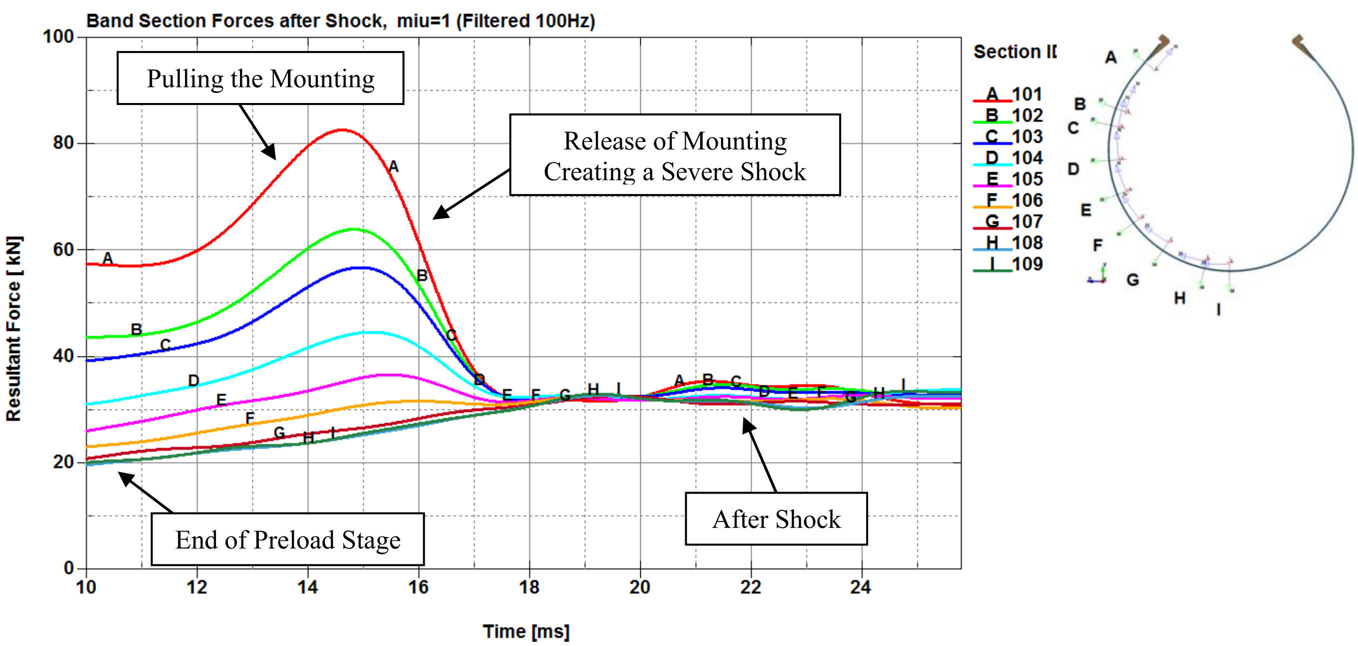


Figure 13: Internal tension forces in the band subjected to severe shock with μ=1

By this method, the maximal decrease of the initial preload force can be calculated for different values of the coefficient of friction. The results summarized in Figure 14, present the maximal decrease of initial internal tension force in the band as a function of the coefficient of friction. The maximal decrease of the initial preload force presented in terms of forces ratio between the final uniform tension force (after the severe shock), and the initial tightening force of the bolt.

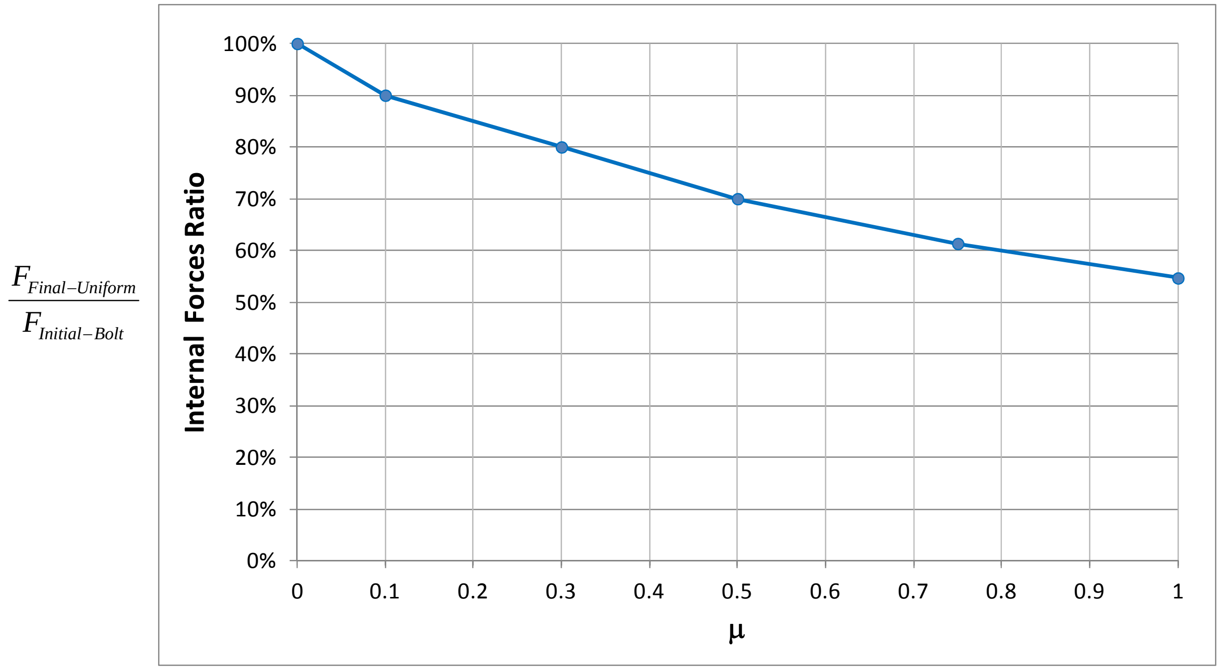
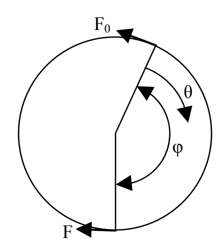
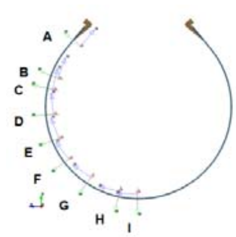


Figure 14: Maximal decrease of the initial preload force under dynamic loading conditions

Equation 3 shows an expression for the average internal tension force along the band, where F_θ is the local tension force in an infinitesimal segment of the band- $d\theta$, and φ is the total angle of the band in full contact with the cylinder: $\overline{F} = \frac{1}{\varphi}\int_0^{\varphi} F_\theta d\theta$ (3)



Discretization of Equation 3 results in: $\overline{F} = \frac{1}{n}\sum_{k=1}^{n} F_k \quad (F_n = F_A, F_B \ldots F_I)$ (4)



Calculating an average force (Equation 4), shows that the final uniform internal force is equal to the average of the distributed internal forces in the band at the end of the preload stage. This result can be demonstrated in **Figure 15** for μ=1.
Hence, the maximal decrease in preload force under dynamic loading can be calculated only from the preload stage, using FE model that includes preload only and regardless of the dynamic loading.
Since the dynamic load applied was an unrealistic severe shock (in order to find the maximal decrease of the internal forces in the band), a full dynamic simulation, including life-cycle dynamic loads, should be performed in order to find a realistic working point of a system.

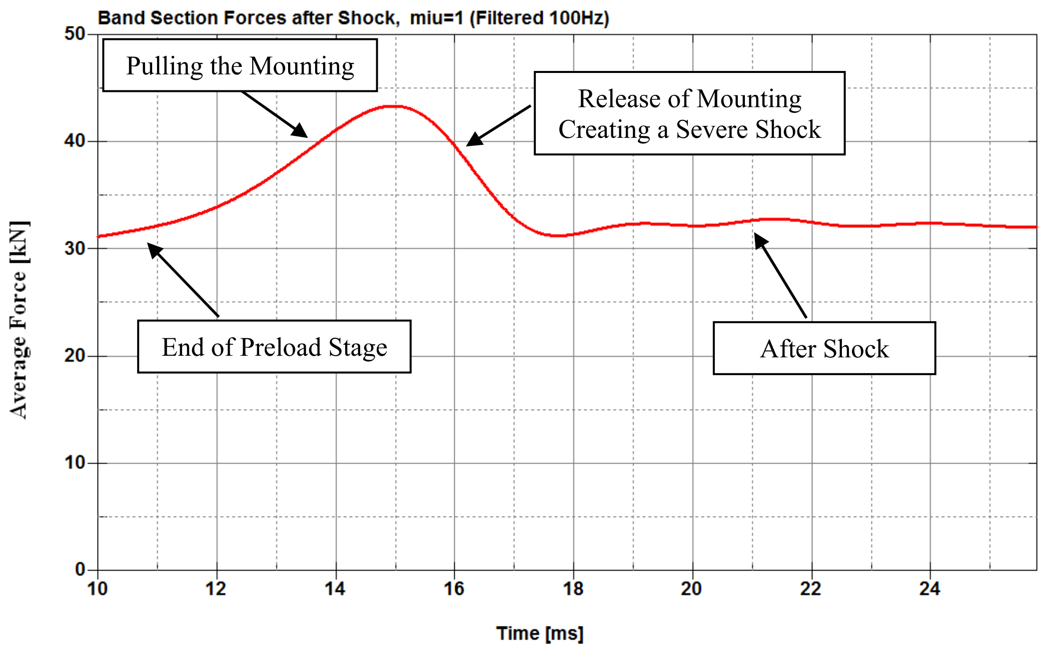


Figure 15: Average of the internal tension forces in the band for μ=1

Conclusions

This work was performed in order to find the maximal decrease in preload force of the band due to dynamic loadings. When the band is tightened, the circumferential stresses in the band translate into internal tension forces are distributed along the band's length. The distribution rises with the increase of the coefficient of friction between the cylinder and the band, as well as with the increase in the cylinder's rigidity. A uniform internal force in the band can be achieved after applying a severe shock on the assembly. This force is shown to be the average of the distributed internal forces in the band at the end of the preload stage (before applying the dynamic loading), and it presents the maximal decrease in preload force under dynamic loadings. Thus, a full dynamic simulation, including life-cycle loads, should be preformed, if a specific system's working-point is required.

References

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