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Unique Method for Simulation of Bolt Pre-Load

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***Abstract:-* This paper describes the modeling approach for simulating bolt pre-loads when there is interference in the bolt-nut CAD or in the FE model. In general, the Bolt and Nut will have interferences in the CAD at the thread region during the CAD modeling. When it comes to simulation, either interference regions are de-featured or ignored. There will always be a question on the validity of results when assumptions like beams with rigid elements or bonded contacts are used for simulating the bolts with preloads. The proposed beam with thermal expansion (BTE) has the advantage of using the actual 3d bolt and nut geomentry even when there is CAD interference. The method ensures that the contact area and the relative movements between the components are captured as-it-is in the actual scenario. It is specifically very useful in the bolt overload clamping simulations. BTE method can also be used in various other load cases scenarios like Load by Force, displacement and Moment. This method is successfully followed in various automotive projects and has shown good co-relation between the test results and the simulation results.**

Keywords—Bolts, Finite Element Analysis, Pre-Load, Clamping, Ls-Dyna

I. INTRODUCTION

Most bolting systems involve a bolt preload. In the real world this is applied by torqueing the bolt against the nut and pre-stressing the shank. In an FEA simulation, it would be unusual to model the full thread engagement between the bolt and the nut. When simulating these clamping processes usually a lot of assumptions or model simplifications are made, which might cause a difference in results from the actual scenario. The simulations are really challenging when an over clamping or misuse load analysis is performed, where the bolt contact surface may slide over the mating component. When we use bonded contact this sliding behavior may not be captured. The proposed BTE approach/modeling technique covered in this paper overcomes the above mentioned limitation and provides more realistic bolt behavior.

II. PROBLEM DEFINITION

Fastener joints can be difficult to analyze due to the many parameters and complex phenomena involved in the behavior of the joints such as:

- Friction
- Sliding
- Bolt hole deformation
- Contact
- High local stresses
- Fastener bending and tilting
- Plate bending
- Bolt hole clearance
- Pre-tension

To include all parameters in a structural analysis of a general fastener joint may transform the problem to a complex one. It is therefore necessary to reduce the problem to a manageable size by reasonable assumptions and proper modeling rules.

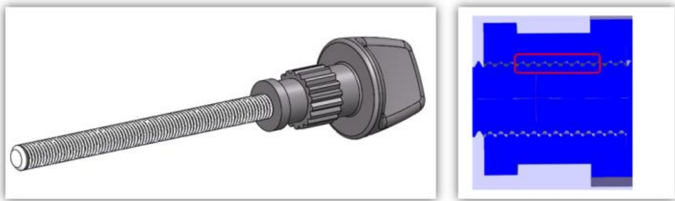

Fig.1- Interference in CAD at Thread

Modeling of bolted joints needs careful consideration of the analysis objective. It needs to be studied if the bolts critical members and need individual modeling or can the load transfer path be adequately represented by 1D idealization.

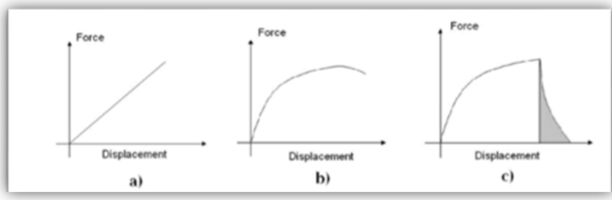

Fig.2- Different behaviours of the fastener joints a) linear Elastic behaviour, b) Non-linear Elasto-plastic behaviour , C) damage Behaviour

Since bolts are sliding contact thread devices, most of the energy spent tightening them is dissipated by friction. In general, about 50% of the energy goes to friction under the bolt head, 40% goes to friction in the threads, and only about 10% goes to creating tension in the threads. Fortunately, rotation of the bolt head relative to the parts being bolted together is a good measure of the tension in the bolt.

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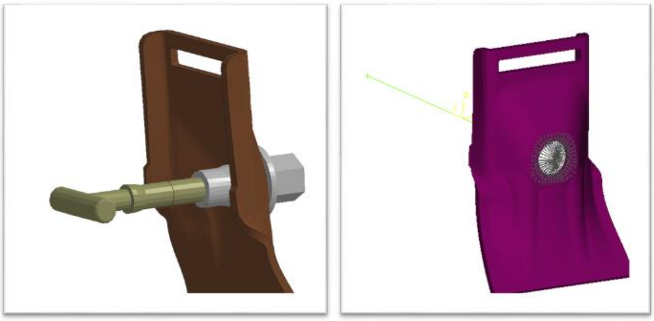

Fig.3- Typical Bolt Nut Interface with 1D beam and rigids

III. PROBLEM SOLUTION

In the proposed BTE approach, a negative thermal expansion co-efficient is defined on the 1-D beam element. This creates thermal strains which are used to simulate mechanical strains present in a preload. The expansion co-efficient value is tuned to accurately match the required preload value.

A. Linear Thermal expansion

From the mathematical point of view, thermal expansion can be described as linear (one direction 1-D), areal (two directions 2-D) and volumetric (three directions, 3-D). The linear and areal thermal expansion applies to solids.

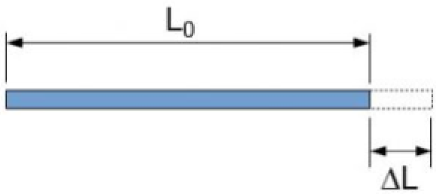

Fig.4- Linear Thermal Expansion

Knowing the initial length L_o(m) of a given solid the temperature difference ΔT (ºC) and the coefficient of linear expansion of the solid α (1/ºC), the change in length ΔT (m) of the solid can be calculated as in (1):

$$\Delta L=\alpha \cdot L_0 \cdot \Delta T \quad (1)$$

The change in length is directly proportional with the change in temperature. The higher the temperature difference the higher the increase in length of the material. If these thermal expansions / contractions are resisted by some means, then "thermal stresses" can arise. The total strain of a material is the sum of the mechanical strain and the thermal strain.

B. FE Modeling:

1) ANSA tool was used in this case for the FE modeling. The bolt and Nut are modeled with higher order Tetrahedron elements.

2) Local surface skin is extracted from the volume for the bolt and nut solid models. Extra nodes are created for both the surfaces separately as shown below,

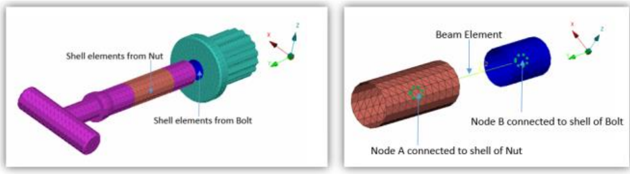

Fig.5- Bolt Modelling

3) 1D beam element created connecting the two extra nodes.
4) MAT_ADD_THERMAL_EXPANSION card (table A in Fig 4) defined for the beam element. Negative value defined on the MULT card to enable compression of the beam. Rather than obtaining the compression of beam with temperature differentials here (Ls-Dyna) it is established by defining a scale factor which makes the process simplified.
5) LOAD_THERMAL_VARIABLE card (table B in Fig 4) is defined for the nodes of the beam element by creating a set for the nodes. A load curve with desired load step is defined.
6) Create a cylindrical joint between the Bolt and Nut which makes sure that both the components are always in line even if there is a relative movement during the analysis.

C. Contact:

Surface to surface sliding contacts defined between the bolt, nut and their connected parts. This makes sure that the area of the bolt head is effectively captured and the sliding effect if-any is also simulated. Note that there is no contact defined between the Bolt and Nut as there is interference in CAD. The link between bolt and the nut is the beam element connected to the shells of Bolt and Nut as explained in point 2 of Section A. The cylindrical joint created between the bolt and nut ensures the relative movement between the two parts.

D. Results:

The method is explained in a typical clamping scenario where it involves in clamping of an automotive roof rack assembly to rail. First load step to its operating load, followed by an over clamping load. Also, an external load is applied additionally to the assembly, which is expected to act against the axial load of the bolt and create behaviors like bolt sliding over the bracket. If this condition is modelled using beams with rigid elements to the bolt face or with bonded contact, the sliding behaviour of the bolt cannot be simulated. But with the thermal expansion method the

The actual behaviour of sliding was successfully captured (higlighted in red on Fig. 5) in the simulation and the same is observed during the test as well.

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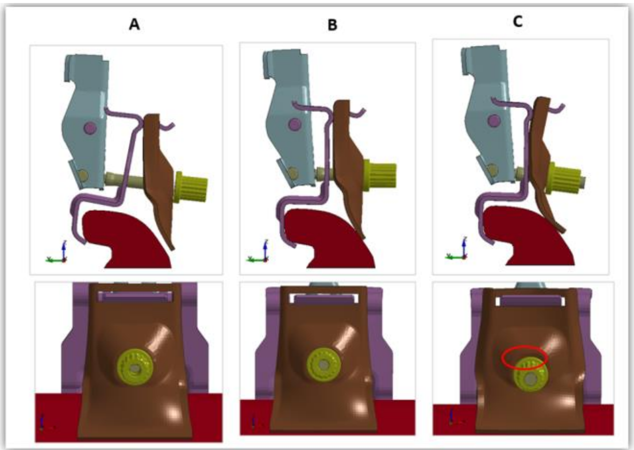

Fig.5- Position of bolt and Nut at A) Initial , B) Operating Load, C) Misuse clamp loading conditions.

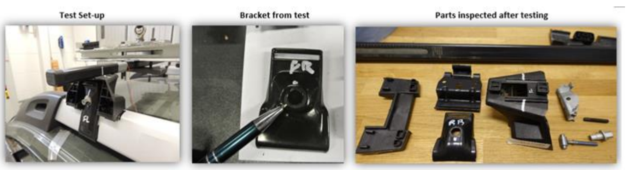

Fig. 6 - Clamping Test setup and results-Operating Load

The below plot shows the axial force vs displacement between the general practice method with rigids (GP 2) and proposed beam with thermal expansion method (BTE) .The simulation results and the failure predictions were matching close with the test results for the BTE method.

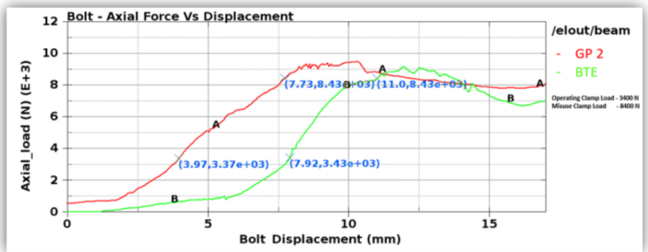

Fig. 7 - Results Comparison – GP 2 Vs BTE

BTE method also effectively captures the unclamping behaviour of the bolt. When there is external load which acts against the bolt axial load, the axial force is expected to decrease. A simulation was performed on an automotive roof rack assembly. The assembly is clamped for operating clamp load and when an external load was applied upwards the clmap load decreases slightly. The axial force values and the slipping of parts closely matched the test results.

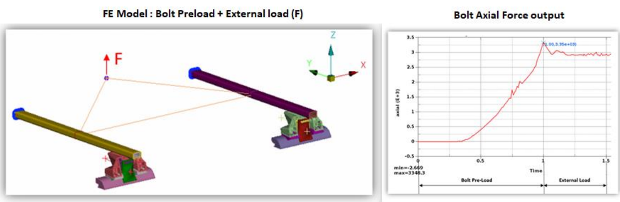

Fig. 10 - BTE method under external loads

IV. APPLICATION AND VALIDATION

The thermal beam method is versatile in its application and was tried in many other load setups as well. It works well and found to be very effective in load cases scenarios like,

- Load by Force
- Load by Displacement
- Load by Moment

A. Handle Lock:

Below is a typical example of handle lock where the simulation requirement is to calculate the failure load when the handle is locked and external load is applied. The model was initially simulated with force and displacement loads on the handle individually. It was found that the results were deviating when compared to the test result. This might be because the handle goes for a large displacement and but the load acts in the co-ordinate system direction defined.

The same assembly when simulated with the thermal beam method gave a good match with the test results. The permanent material deformation predicted on the cover very closely matched with the test results.

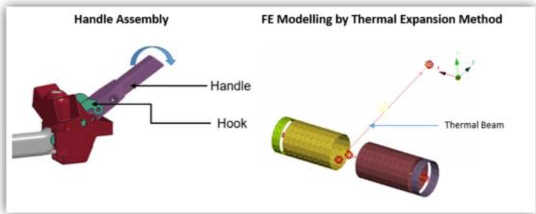

Fig. 11 - BTE method under external loads

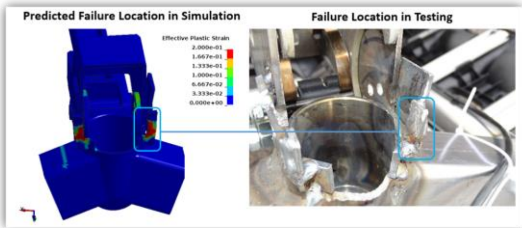

Fig. 12 - BTE method under external loads

V. ADVANTAGES AND CONCLUSION

The BTE method is found to effective in the application of bolt pre-loads with the advantage of geomentry taken into consideration for the simulation. The results are proven to be very much in line with the test results.

Table. 1 - BTE method under external loads

Practices on Bolt Modelling	***Prefix***	***Method***	***Advantages***	***Disadvantages***
Genreal Practices	GP1	Preload on bolt shank with bonded contact at bolt head	Modelling time is quick	1) Cannot be used in overload simulations where there will be a slip in bolt head and the part (bonded contact defined between bolt, nut and the mating parts,) 2) Need to remove interface in CAD to get convergence 3) High local stresses
	GP2	Beam with ends connecting to bolt Head by rigid elements + Preload applied on the parts holded together	Modelling time is quick	1) Cannot be used in overload simulations where there will be a slip in bolt head 2) High local stresses
Beam Thermal Expansion	BTE	Beam with Thermal Expansion method	1) No local stresses 2) Can be used in overload simulations 3) Quick post processing 4) Frictional contact can be defined between bolt, nut and the mating parts as in actual scenario 5) Can be used as an alternative to various loading scenarios like Load as force, dispalcement and moment.	Modelling time is slightly elaborate

- Very few assumptions in the bolt modeling compared to the conventional methods.
- Can be used in wide range of load applications like Load by displacement, by Force and by moment.
- As the method and its failure predictions matched closely with the test results for later concepts and other projects it saved significant reduction in testing and prototyping cost and efforts.
- Saves lot of time in Post processing as the load can be directly measured for the beam element by defining the ‘’LOAD HISTORY PLOT’’. No manual calculations or conversions required.
- Very much helpful in the product concept phase where lot of design iterations and failure predictions are expected to be simulated.

VI. FUTURE WORK

The simulations are mainly performed on the LS-Dyna tool. Scope identified to use the BTE method across all the common FEA tools available and come up with a generalized method.

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