American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-6, pp-174-178
www.ajer.org
Research Paper Open Access

Problem Prevention Method for Product Designs Based on Predictive Technical Evaluation: A Study of Bolt-loosening Mechanisms in Automobiles

Ryota Nomura[1], Kimihiro Hori[2], Kakuro Amasaka[3]
[1]*(Graduate School of Science and Engineering/ Aoyama Gakuin University, Japan)*
[2]*(Graduate School of Science and Engineering/ Aoyama Gakuin University, Japan)*
[3]*(School of Science and Engineering/ Aoyama Gakuin University, Japan)*

ABSTRACT : *This research investigates the mechanisms that cause bolt loosening, which is a concern for automobile manufacturers. Specifically, experimental analysis is conducted in order to ascertain stress distribution patterns when bolts loosen under vibration testing conditions. The insights gained from this analysis are then used to reproduce actual machine tests in a simulator based on a technical element model for highly accurate CAE analysis. Looking at pressure distribution on the nut seating surface (the trigger for thread loosening), the authors were able to clearly and rationally clarify the degree to which this pressure distribution impacted the contact points between nut and bolt threads. The results can contribute to the formulation of problem prevention methods for product design based on a predictive technical evaluation process that does not rely on actual machine testing.*

Keywords -*CAE, bolt-loosening, thread portions of nuts and bolts*

I. INTRODUCTION

In recent years, the authors have been conducting research on the establishment of highly accurate Computer Aided Engineering (CAE), which improves the reliability of product development and design. This research investigates the mechanisms that cause nut loosening in solid axle rear suspension, which is a matter of concern for automobile manufacturers around the world. Ultimately, actual machine tests revealed that that the primary cause of loosening was due to uneven surface pressure distribution between the chassis nuts and the welded base (at the point where surface pressure was the weakest). Next, the authors used CAE Finite Element Modeling (which incorporates actual phenomena, modeling, algorithms, theory, and computers) to come up with a highly accurate numerical simulation that was then reproduced through actual machine tests. This made it possible to identify the key factors that cause loosening which were difficult to observe (visually confirm) through experimentation. Specifically, the causal relationship between (1) stress distribution (dynamic behavior) at the engaged thread portions of nuts and bolts, and (2) surface pressure distribution (dynamic behavior) at the contact point between the seating surface of the nut and the welded base, which directly contacts the area described in (1). The insights gained from these investigations were then successfully used to improve product development and design through highly accurate numerical simulations that do not rely on real-world testing.

II. THE TECHNICAL ELEMENT MODEL

1.1 A Highly Reliable CAE Analysis

Highly reliable CAE analysis refers to CAE analysis that produces results that do not deviate from those obtained during actual machine testing. Accuracy is further improved by taking the mechanisms discovered during actual machine testing and entering them into the CAE software. This helps achieve intelligent development design as well as shorter development times.

1.2 The Technical Element Model

This section focuses on bolt loosening. In order to more accurately reproduce actual machine test results with the aim of setting up a highly reliable CAE analysis, the authors developed the technical element model in figure 1 based on six principal factors. This model addresses the failure mechanism through steps (1.2.1) to (1.2.6) below.

1.2.1 Phenomenon

Based on the insights obtained through previous research, it was critical to logically identify the mechanism triggering the bolt-loosening phenomenon in bolted parts and to identify a physical phenomenon that could be numerically simulated.

1.2.2 Problem

Prior research on “the mechanism that loosens threads” indicates that uneven pressure on the nut seating surface has a major impact on the loosening of bolted parts. As a point for further research, note that it has not yet been determined how the fit between male and female threads, which is a source of stress, influences fluctuations in seating surface pressure values. For this reason, the authors chose to define the problem here as clearly determine the impact of stress generated from thread contact areas identified during actual machine testing. In order to research the problem, the authors visually represented the dynamic behavior of thread loosening and its mechanisms by assigning, the authors assigned actual measured values for parameters like thread dimensions, coefficient of friction for thread contact points, and load torque.

1.2.3 Model

In the modeling stage, the shape and dimensions of the target structure, Young’s modulus, the modulus of rigidity, and other material characteristic values were used to reproduce the phenomenon as a 3D model. In order to create a highly realistic reproduction during the analysis, the authors generated a fine mesh for the thread area, seating surface, and other critical contact points when applying the finite element method to break down the elements of the model. Since it was important to determine element size which convergence properties were taken into account for reason to prevent diversion of the output, the minimum element size for contact points in the model was set to 0.08 mm. Faithfully reproducing contact points between components also required that a valid contact force be defined for each contact surface. Augmented Lagrangian methods were implemented to avoid overlap with the model when element node loads for the fit between thread portions. Because the authors determined the properties and response phenomena of structures targeted by this modeling stage, numerical value settings and applied definitions could be precisely implemented—laying the groundwork for highly accurate CAE analysis.

1.2.4 Computer

Although computer technologies are largely reliant on the hardware and software used, it was necessary to select optimal settings from the perspective of the CAE model being employed in order to ensure analytical precision and realistic calculation times. The penalty method was used so that the non-linear analysis of bolted parts could be treated as a linear problem, while Augmented Lagrangian methods were employed in areas where generating highly accurate output was particularly important.

1.2.5 Theory

In order to accurately and faithfully replicate the identified phenomena in the numerical simulation, it was critical to logically identify the physical phenomena involved. The primary theoretical formulas used to assign selected actual measurement values as parameters were structural mechanics, the equation of equilibrium, and the coefficient of friction calculation method.

1.2.6 Algorithm

The finite element method is widely applicable, and was therefore used to analyze physical phenomena affecting complex structures. The thread contact portion between two screws has a complex shape, but the authors were able to calculate an accurate approximation by developing a model with minute element units and using it as the basis for their computations.

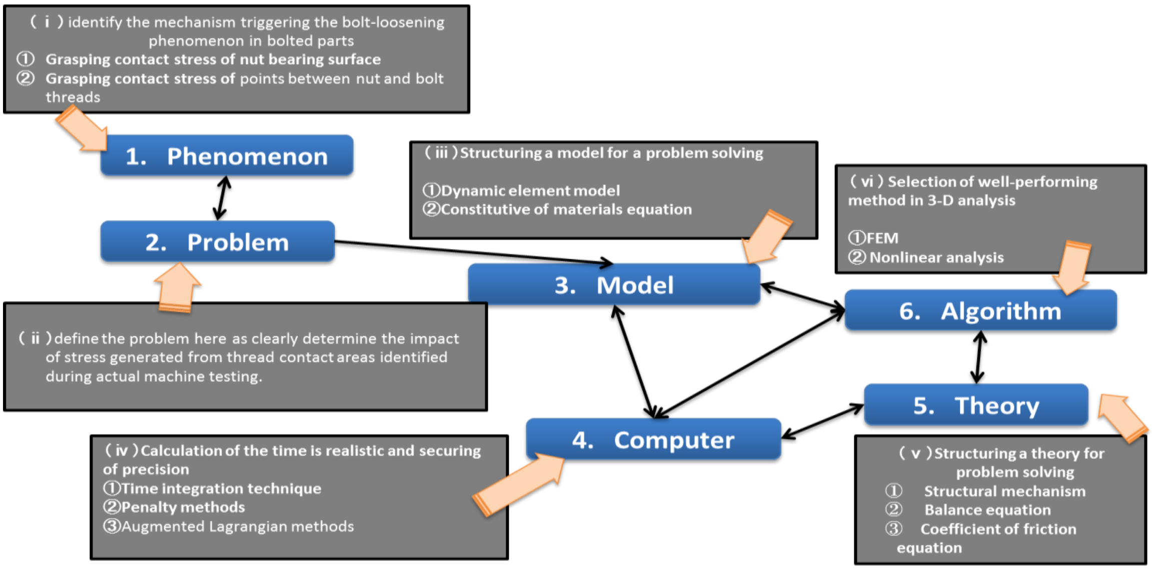


Fig.1The technical element model

III. SAMPLE APPLICATIONS : USING CAE TO ANALYZE THE LOOSENING MECHANISM FOR BOLTED PARTS IN AUTOMOBILES

The authors next applied their predictive technical evaluation model in order to analyze the mechanism triggering loosening between bolt-tightened automotive parts. Specifically, they used the knowledge gained from their previous study indicating that uneven stress on the nut seating surface causes structures fastened with a nut and bolt to loosen. This allowed them to focus the current study on the thread contact areas between the nut and bolt.

3.1 Actual Machine testing

Actual machine testing involved subjecting threads of different pitches to vibrational tests under the same conditions to see whether different thread specifications had an impact on the loosening of bolted parts.

To start, a six-sided nut and bolt with a flange were manufactured at the smallest (1.75 mm, figure 2) and largest (0.50 mm, figure 3) pitches and vibrational testing was conducted.

A strain gauge was first attached to the bolt axis and the test piece was tightened to a load of 80 N m. To estimate the amount of load to use during the vibration test, the authors applied static external force at a right angle to the axis and measured the load at which slippage occurred on the seating surface.

Fig.21.75mm pitch

Fig.3 0.50mm pitch

Next, a vibration load equivalent to ±90% of the static extraction load was applied at a right angle to the axis, which is the primary trigger for loosening. The authors identified the phenomenon that triggered bolt loosening and measured the displacement trends in the bolt axial force relative to vibration time. Figures 4 and 5 below show the results of these tests. The figures indicate that the 1.75-mm pitch test bolts showed a loss of axial force at fewer repetitions than the 0.50-mm pitch test bolts. In other words, the length of the thread pitch impacts the way seating surface slippage is triggered, and was demonstrated to be a factor in the reduction of axial force.

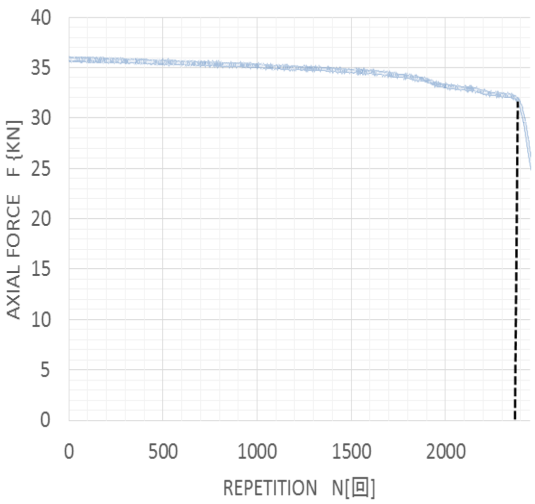


Fig.4 1.75mm pitch

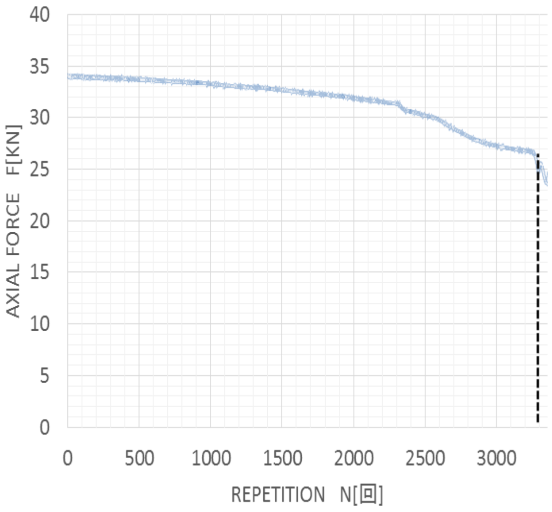


Fig.5 0.50mm pitch

3.2 Numerical Testing

Here, numerical testing were carried out under the same conditions as actual machine testing applying the technical element model in the last section. The analysis procedure had three steps. First, the fastened objects (two base plates) were placed between the nut and bolt. Second, the test pieces were subjected to the same loads during the test. Third, a vibration load equivalent to ±90% of the static extraction load was applied at a right angle to the bolt axis. In this way, factors that could not be seen during actual machine testing (nut surface pressure distribution and distribution of stress on thread contact areas) could be ascertained.

Analysis results indicating the stress distribution on bolted parts are shown in figures 6 through 9 below. The test piece with a pitch of 1.75 mm caused surface pressure on the outside nut seating surface to drop significantly, and stress was found to be locally concentrated at the starting point of the thread. The piece with a 0.50-mm pitch (shallower thread angle) showed a stronger distribution of thread stress along the inside of the seating surface, but stress deviation was not particularly pronounced.

When we focus on the results of analyzing the thread contact surface, we see that the larger thread dimensions (the 1.75-mm piece instead of the 0.50-mm piece) experiences greater stress on each thread, and also shows a wider deviation in stress values along the seating surface. Using this information, the authors were able to clearly and rationally determine that different thread angles and thread dimensions were a factor in triggering uneven stress on the nut seating surface.

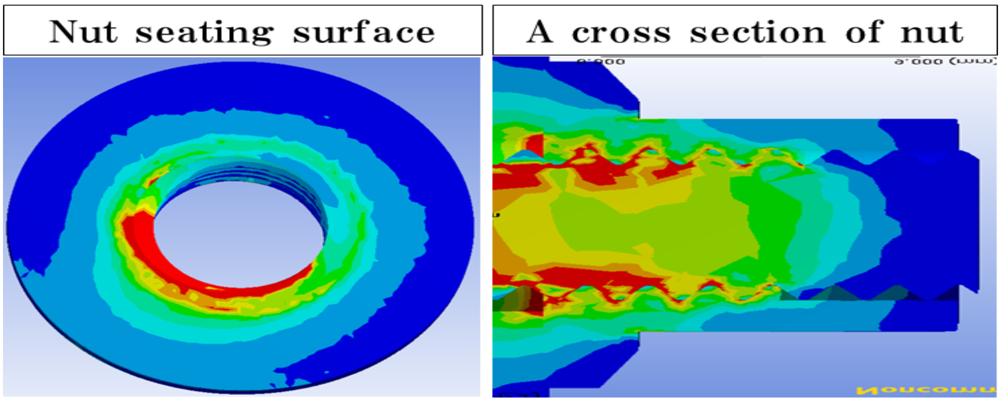


Fig.6 An analysis results: 1.75mm pitch

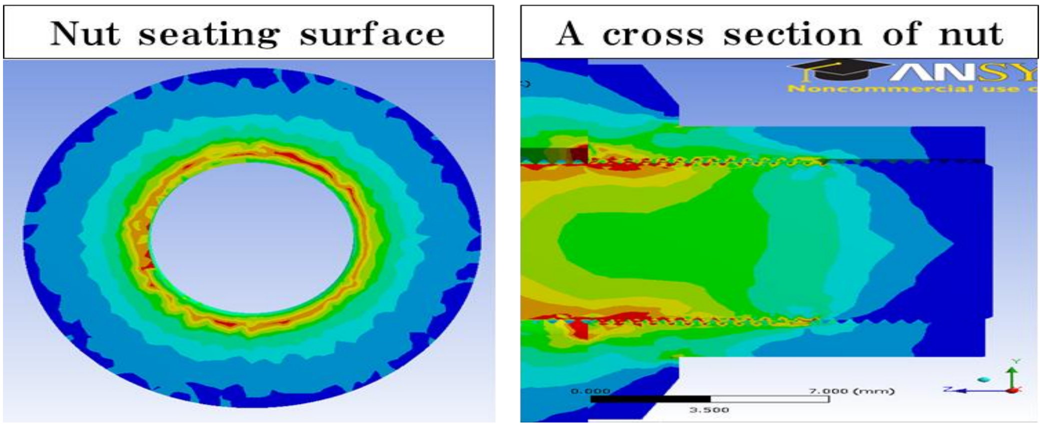
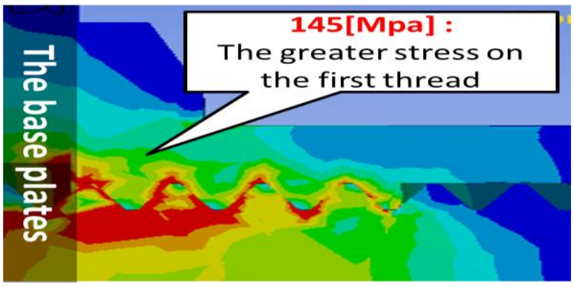


Fig.7 An analysis results: 0.50mm pitch



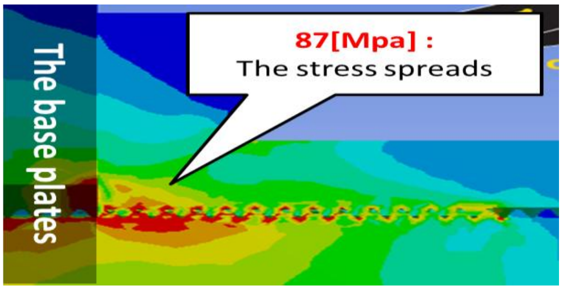


Fig.8 An enlarged drawing: 1.75mm pitch

Fig.9 An enlarged drawing: 0.50mm pitch

IV. CONCLUSION

In prior research, the authors clearly and rationally identified the mechanism that loosens bolts, and were able to visually represent a phenomenon that is difficult to observe in actual machine testing; namely, stress distribution along the nut seating surface. Here, the authors take the next step and visually represent the dynamic behavior of the thread contact points that generate stress during tightening, clarifying the causal relationship that determines how much impact the starting point of the thread affects stress distribution along the nut seating surface. The given results can be used to help establish product designs based on predictive technical evaluation.

REFERENCES

[1] K. Amasaka, Proposal and Effectiveness of a High Quality Assurance CAE Analysis Model: Innovation of Design and Development in Automotive Industry, Current Development in Theory and Applications of Computer Science, *Engineering and Technoogy, 2(1/2)*, 2010, 23-48.

[2] K. Amasaka and M. Yamaji, CAE Analysis Technology for Development Design Utilizing Statistical Sciences, *The Open Industrial and Manufacturing Engineering Journal, 1,* 2008, 1-8.

[3] K. Amasaka and T. Onodera, Developing a Higher-cycled Product Design CAE Model: The Evolution of Automotive Product Design and CAE, *International Journal of Technical Research and Applications, 2(1)*, 2012, 17-28.

[4] K. Hashimoto and K. Amasaka, Researching Technical Prevention Measures for Development and Design Utilizing Highly-Accurate CAE Analysis: Automotive Nut loosening Mechanism, *IOSR Journal of Mechanical and Civil Engineering, 11(4)*, 2013, 24-27.

[5] T. Onodera and K. Amasaka,Automotive Bolts Tightening Analysis using Contact Stress Simulation: Developing An Optimal CAE Design Approach Model, *Journal ofBusiness Research Mechanical, 10(7)*, 2012, 435-442.

[6] T. Onodera T. Kozaki ,and K. Amasaka, Applying a Highly Precise CAE Technology Component Model: Automotive Bolt-Loosening Mechanism, *China-USA Business Review, 12(6)*, 2013, 597-607.

[7] T. Ueno, M. Yamaji, H. Tsubaki, andK. Amasaka, Establishment of Bolt Tightening Simulation System for Automotive Industry Application of the Highly Reliable CAE Model, *International Business & Economics Research Journal, 8(5)*, 2009, 57-67.

[8] H. Yamada and K.Amasaka, Highly-Reliable CAE Analysis Approach-Application in Automotive Bolt Analysis, *China-USA Business Review, 10(3)*, 2011, 199-205.

[9] S. Kasei, W. Yoshida, H. Ishibashi, and M. Okada, Bearing Surface Slip and Self-loosening of Threaded Fasteners, *Proc. JSME Annual Meeting*, Japan, 2003(4), 67-68.

[10] M. Zhang and Y. Jiang, Finite Element Modeling of Self-Loosening of Bolted Joints, Analysis of Bolted Joints, *ASME Journals of Mechanical Design, 478*, 2004, 19-27.

[11] E. Alba, *A New Class of Algorithms*(Parallel Metaheuristics, London: Addison Wihey, 2005).

[12] R. C. Whaley, A. Petitet, and J.J. Dongarra, Automated Empirical Optimization of Software and the ATLAS Project, *Parallel Computing, 27(1-2)*, 2001, 3-7.