

Establishment of Prediction Technology of Fatigue Strength in Roots of Internal Thread for Crankcase Assembly and Clarification of Cracking Mechanism in Roots of Internal Thread

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ABSTRACT

In motorcycle engines with aluminum crankcases, fatigue fractures at the roots of the internal threads of the fastening bolts used for the cylinder head and crankshaft main bearing often occurs during the durability tests at the prototype stage. A technology that evaluates the fatigue strength of the entire crankcase including the roots of internal threads using a large-scale and nonlinear finite element method (FEM) analysis is established by this research. Parallel process computation by a cluster server enables the evaluation of the fatigue strength of the crankcase in a short time suitable for the development process even when using a model that faithfully reproduces the shape, the contact property, and the elasto-plastic material characteristic of the threads. This technology enables the efficient design of crankcases that are light and durable. Moreover, the mechanism of fatigue fracture at the root of the internal thread is clarified because a quantitative evaluation of thread root stress is possible.

INTRODUCTION

To save weight, aluminum crankcases are generally used for motorcycles. For these engines, fatigue fracture at the root of the internal threads fastened by bolts using high axial force (i.e., clamping bolts used for the cylinder head and crankshaft main bearing) often occurs during the durability test at the prototype stage. When both the internal and external threads are steel, the fatigue fracture at the fastening area generally occurs at the under-neck round part of the flange of a bolt or the non-engaging area of the external thread. In contrast, when steel external threads are fastened to an aluminum

crankcase that has a lower material strength than steel, the fatigue fracture frequently occurs in the internal threads of the crankcase. [Figure 1](#) shows the area in which fatigue fractures from the root of internal threads occur. The starting point of the cracks is the root of the internal threads at the end of the external thread engagement, and a fracture surface occurs as a fatigue fracture surface.

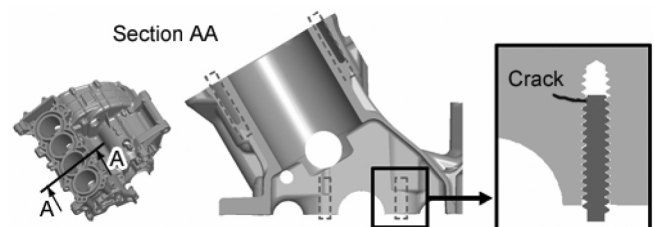


Fig. 1. Location of starting point of fatigue fracture at the internal thread

Durability analysis of products by FEM analysis in the prototype stage is popular in the industrial world. Bolt fastening areas are, however, sometimes exempted from an evaluation of strength analysis because of the difficulty of faithful modeling due to the complex contact conditions and minute form relative to the overall size of the analyzed part. Furthermore, as the starting point of the cracking is inside the fastening area, stress measurement on actual engines is extremely difficult. Thus, strength evaluation of such locations had to depend on durability tests with actual engines. In recent years, some research results of nonlinear FEM stress analysis at the fastening area have been reported.

However, most of such research has been on simple components such as bolts and nuts [1] [2]. Even if they are identified for products, important characteristic such as contact conditions and the elasto-plastic behavior of materials at the fastening area are analyzed in a simplified way, and there have not been any reports that carried out a stress analysis for overall industrial products with faithful modeling for the fastening area [3]. Moreover, much conventional research performed calculations only, and there have been few instances of verification of correlation with actual measurements.

In this research, stress analysis technologies were established for the evaluation of the fatigue strength of a whole crankcase including the root of the internal threads of the cylinder head fastening bolts and crankshaft main bearing fastening bolts. Parallel process computation by a cluster server enabled the stress analysis to be completed in short times suitable for the development process using a model that accurately reproduced the shape of the threads, the contact properties, and the elasto-plastic material characteristics. Furthermore, it is possible to evaluate the fatigue strength of the whole of crankcase including the roots of internal threads by executing a stress analysis for multiple load conditions using the proposed analysis method and fatigue processing.

This paper describes the modeling method, the results of model validity verification, and examples of application to engine development. It also describes the mechanism of fatigue fracture at the root of internal threads.

ESTABLISHMENT AND VERIFICATION OF FATIGUE STRENGTH EVALUATION METHOD FOR CRANKCASE INCLUDING THE BOLT FASTENING AREA

The proposed technology has been established through the following three processes.

STEP 1: Establishment of a FEM stress analysis model for bolt fastening area

Measurements of the strain at the root of the internal threads and their external surfaces in a test piece and FEM strain analysis that simulate the measurements were carried out, and the modeling method was verified by correlating between those results.

STEP 2: Establishment of FEM stress analysis model for the whole crankcase

A crankcase stress analysis model that incorporates the fastening area analysis model was built. Then, measurement

of the strain on an actual engine was carried out, verifying the validity of the crankcase stress analysis model.

STEP 3: Establishment of technology to calculate safety factor for the whole crankcase.

Technology to calculate a safety factor for all the nodes of the crankcase FEM model using the stress analysis results at some crank angle and a fatigue limit diagram of the material of the crankcase.

ESTABLISHMENT OF FEM STRESS ANALYSIS MODEL FOR BOLT FASTENING AREA

Direct measurement of strain at the root of internal thread

Figure 2 shows the form of the test piece for the measurement of the roots of the internal threads and the procedure for measuring strain. M6 to M12 bolts are often used as the major bolts for motorcycles. To allow attachment of strain gauges to the roots of internal threads, the nominal thread diameter of a test piece was set to 64. Moreover, an axisymmetric form model for the thread was adopted in this research. Therefore, it is assumed that the lead directional force that is generated by contact between the internal and external threads is sufficiently small compared with axial directional force, and the lead directional force has little effect for the fatigue strength of the internal thread. The bolt has one external thread, and the base body has seven internal threads. The strain gauge was first attached to the internal threads of the disassembled base bodies. Then, a bolt with one external thread was inserted into the fourth internal thread from the top of the internal thread, and the base bodies were assembled. Finally, an axial force was loaded on the bolt by fastening the nut, and the strain of the internal thread and the bolt axial force were measured.

Stress analysis for the root of internal thread

Figure 3 shows an overview of the FEM model that simulates testing on the test piece. To recreate the rigidity characteristics of the test piece, the form and material characteristics of the individual components were measured and input into the FEM model parameters. To recreate the contact condition between the internal and external threads, a limit-sliding model with a coefficient of friction was defined in areas where the components contact each other. This contact model can represent the sliding behavior, frictional force, and normal force between the external and internal threads.

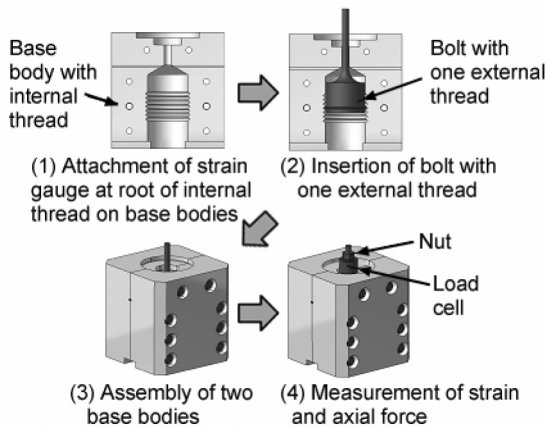


Fig. 2. Measurement sequence of strain at the root of internal thread

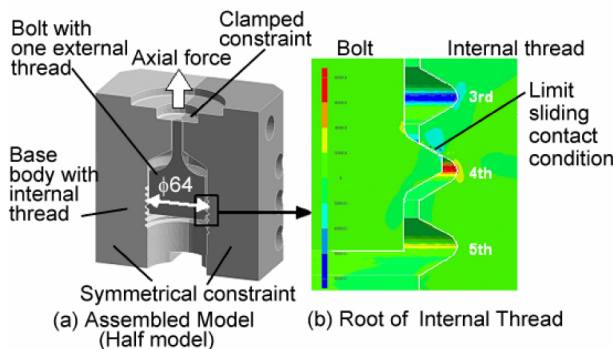


Fig. 3. FEM model for strain analysis at the root of internal thread

Verification of stress analysis model for the root of internal thread

Figure 4 shows the positions for the strain measurement. The strain gauges were put on the root of the internal thread where the external thread is engaged and on the above and below threads in the bolt axial direction, and also on three phase locations around the circumference. The strain is measured along the radius of the root of internal thread in the test and in the FEM analysis. Figure 5 shows a comparison of the strain values for the roots of the internal threads from the results of the analysis and the actual measurements. From the results of the actual measurement, it is seen that high tensile strain is generated at the roots of the internal thread where the bolt external thread is engaged. Furthermore, high compressive strain is generated at the roots of the upper thread adjacent to the thread where the bolt is engaged, and a little tensile strain is generated at the roots of the lower thread adjacent to the thread where the bolt is engaged. The analysis results correspond well to the actual measurement results and this indicates the validity of the proposed model.

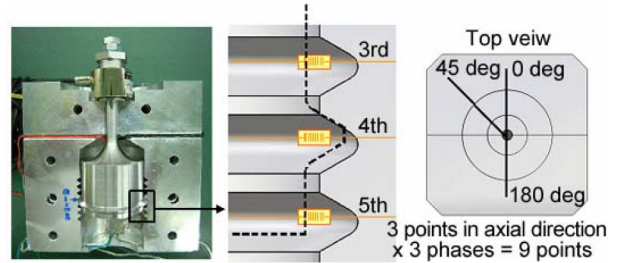


Fig. 4. Measurement points of strain at the root of internal thread

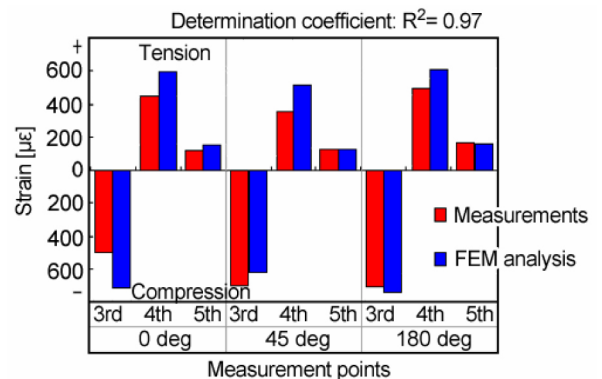


Fig. 5. Strain at the root of internal threads: Measurement vs. FEM analysis

Measurement of strain at outside surface of bolt fastening area

To evaluate the fatigue strength of the crankcase, it is also necessary to simulate the stress distribution on the external surface of the bolt engaging area. Therefore, the correlation between measurements and analysis was studied for this area. Figure 6 shows the test piece to measure the strain of the external surface of the bolt engaging area. The test piece has three columns. An internal thread is formed on the center cylindrical column, and strain gauges are attached to the external surface of the column synchronized with the thread pitch. Bolt engaging area strain can be measured by inserting a spacer to the test piece and applying an axial force using a bolt.

Stress correlation inspection at the external surface of bolt fastening area

Figure 7 shows an overview of an FEM model that simulates testing. The modeling method is the same as the internal thread stress analysis model, and the shape and material characteristics of each component, and the conditions of contact between them are faithfully recreated.