A Study of Durability Improvement of Balance Shaft Module

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Abstract: The balance shaft clamping bolts in the recent engines tend to have the loosening problem by increased engine power. In this paper, a CAE procedure is introduced to predict loosening angle of bolts, wear, durability of the drive shaft. The procedure is performed through two analysis steps. In the first step, the multi-body dynamic simulation is used to obtain more accurate loading boundary conditions applied to the finite element model for the following step. Next, the finite element analysis is performed to predict the durability of the drive shaft through the calculation of the safety factor. Through this CAE procedure, design guidelines leading up to good BSM reliability has been obtained as a result of this activity.

Keywords: Engine, Achard Equation, High-cycle fatigue, Bolt-loosening, FEA.

1. Introduction

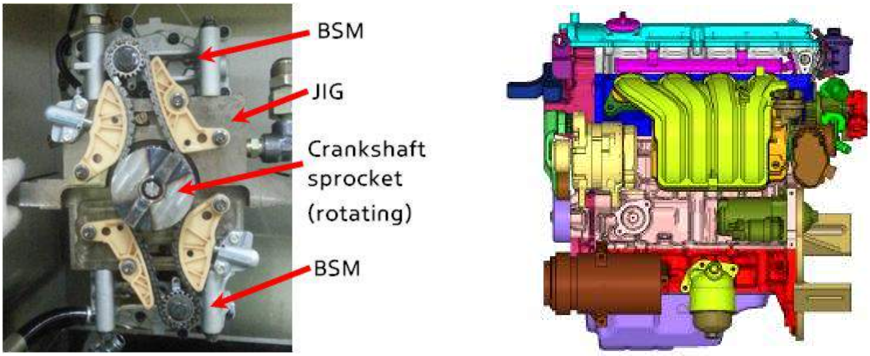
BSM(Balance Shaft Module) is an engine part developed by the module about balance shaft and engine oil pump. The role of the balance shaft is to reduce the vibration generated by the secondary inertia force.

In the recent engines, the main parts of the engine were operating heavy load by increased engine power. In addition, we are reducing the weight of the engine parts to improve fuel efficiency. So, it is important to optimize shape of engine parts.

The purpose of this study is to derive the optimal structure of BSM considering wear, fatigue endurance and stability about bolt loosening.

2. Experimental testing

When developing engines, we conduct an experiment about part level and engine level conditions. Although it has no problem under part level, it may have a problem under engine level. So, when developing engines, it is very important to know interactions of engine parts. The following figure shows the setup created to conduct these experiments.



(a) Part level condition **(b) Engine level condition**

Figure 1. Comparison of test level (a) Part level condition (b) Engine level condition

To produce a clearer measure of the bolt tension, as the engine is running, we attach a gauge to a bolt.

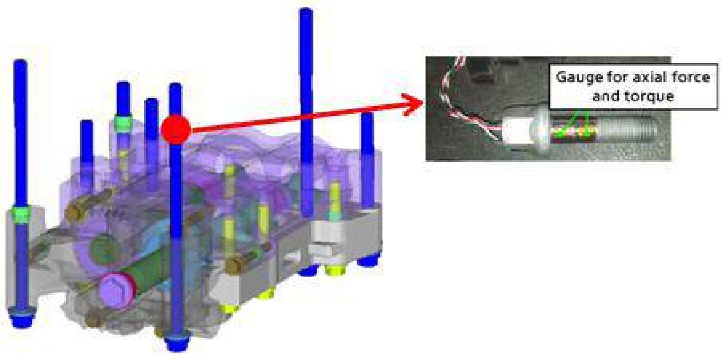


Figure 2. A gauge attached to BSM bolt

3. FEM Model Description and analysis procedure

To review durability under the engine level conditions, the model range is equal to fig1.
The BSM is driven by a chain system and is bolted to the engine.

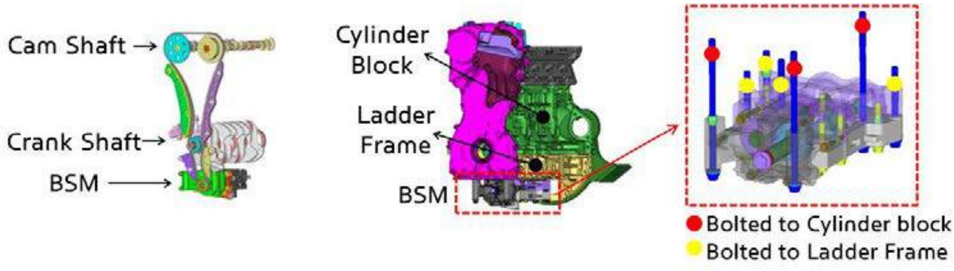


Figure 3. BSM layout

3.1 Calculation load by crank-train

The load applied to the main bearing was calculated through the dynamic analysis of the crank-train. The components used in the dynamic analysis are :

1) Crank-train
2) Connecting-rod
3) Piston
4) Crank case : Cylinder block, head, oil pan, main bearing cap

The following figure shows the engine's dynamic analysis model created to conduct this analysis.

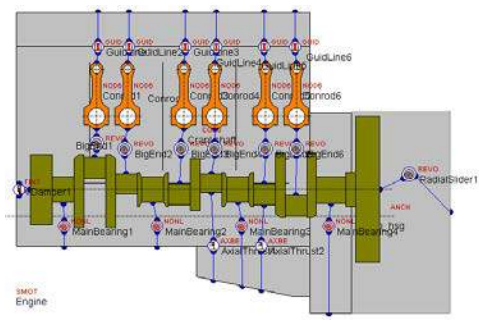


Figure 4. Dynamic analysis model

3.2 Finite element analysis (FEA)

FEA model is equal to Fig.1. The components used in the FEA are :

1) Cylinder block/head, main bearing cap
2) Engine support bracket
3) BSM

The load conditions about main bearing and piston side utilized the results of the dynamic analysis.

One purpose of this study is to calculate the wear of the contact between the shaft and the journal. So, FEA model contains a balance shaft. (Fig.1)

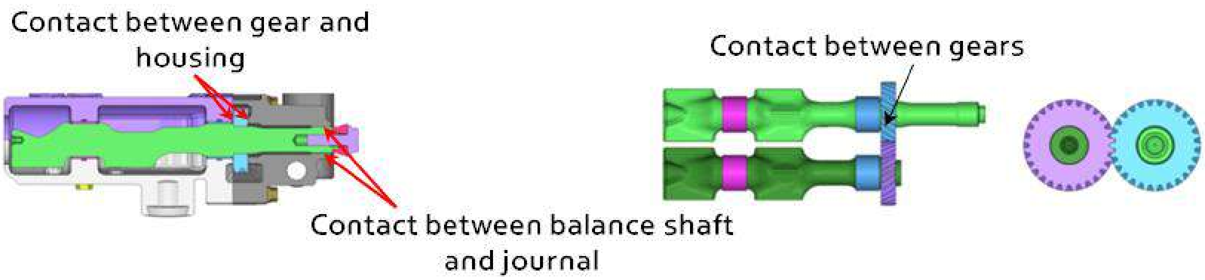


Figure 5. Balance shaft model conditions

Another purpose of this study is to calculate loosening angle of bolts. Recently, it tends to include thread models when analysis of loosening bolts. But, this method takes a long analysis time. In this study, I calculate the loosening angle of bolt using connectors. (Fig.1)

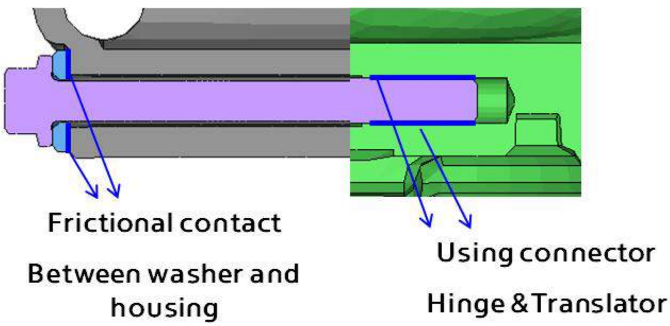


Figure 6. FEM model of loosening analysis

Table.1 shows analysis steps and Fig.1 shows temperature distribution of the engine.

STEP	Method	Event
1	STATIC	Clamping bolt
2	STATIC	Thermal load
3	Direct-Dynamic Transient	-Apply moving system force (crankshaft, piston) -Apply chain force and rotating balance shaft

Table 1. Analysis Step

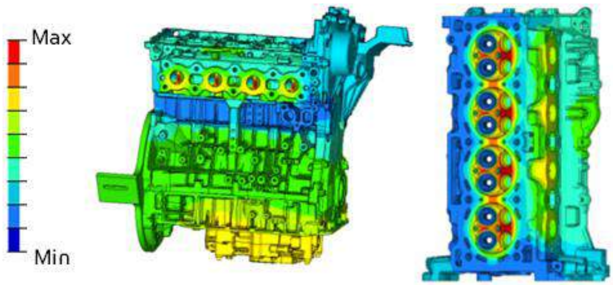


Figure 7. Analysis results about temperature

3.3 Calculation about wear amount, safety factor

In this study, I used Achard equation (Equation.1) as a wear amount index. This equation is based on frictional-energy concept.

$$\Delta h = \frac{k}{H} p \times \Delta u \times \Delta t \,, \quad \sum_i \Delta h = h \quad \textbf{-- Equation.1}$$

Here, Δh =amount of wear, k =wear coefficient, H =Hardness, p =contact pressure

Δu =slip velocity, Δt =time interval

The contact pressure and slip velocity was calculated using FEA results.

High-cycle fatigue safety factor was calculated using Haigh-diagram.

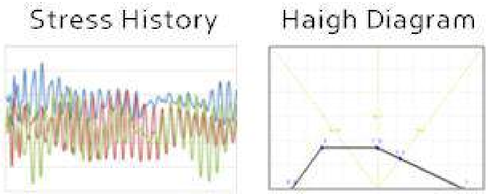


Figure 8. Stress History and Haigh-Diagram

4. Result and discussion

On this section, we will discuss the results found on the finite element analysis and how its output solution relate to the phenomena of the wear and loosening bolts which was found in the experiment.

4.1 FEA Results

4.1.1 The slope of the loosening angle

The following figures show the slope of the loosening angle for each location.

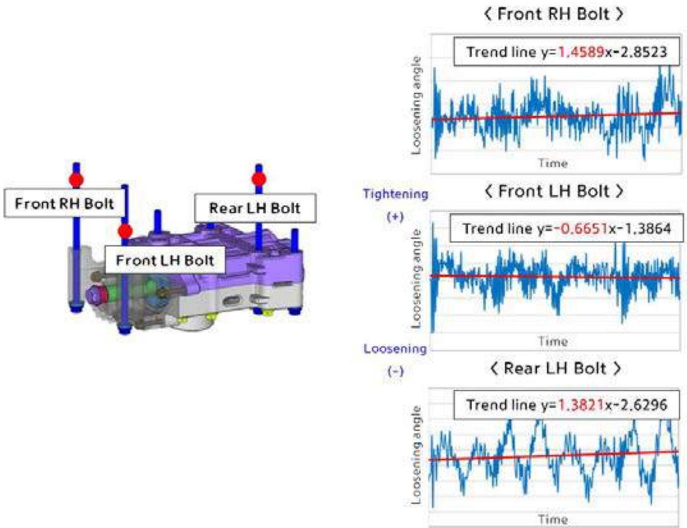


Figure 9. Analysis results about loosening angle

The reason why the Front LH bolt is most disadvantaged is because of their layout.

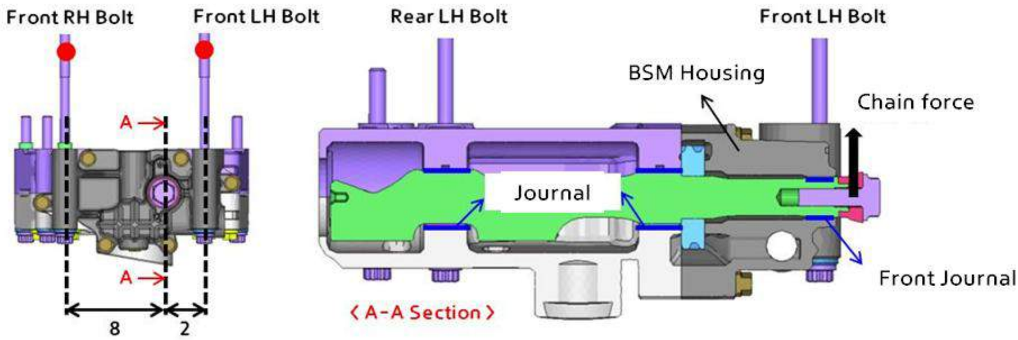
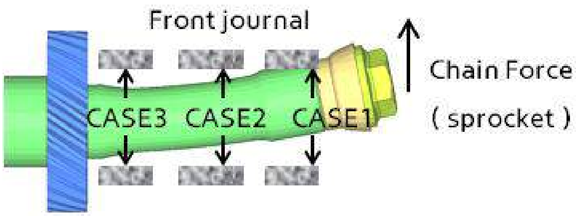


Figure 10. BSM layout

The mechanism of loosening the Front LH bolt is attributed to the contact between the drive shaft and the front journal, which causes the BSM case to condense, causing the axial force to deteriorate.

So, the plan for improvement is to prevent any contact with the journal in spite of the bending deformation of the driveshaft because of chain force. Specific improvement measures are as follows.



	Front Journal Position	Shaft Dia.
CASE1	-	100
CASE2	20mm Backward	108
CASE3	40mm Backward	

Figure 11. Improvement measures

4.1.2 Durability analysis results for each case

The loosening problem is improved when the journal is back in this system. When the journal is back, no contact interval increased. So, wear problem is improved, too.

Durability of drive shaft deteriorates because of increasing bending deformation. But, durability of drive shaft deteriorates because of increasing bending deformation. But, durability of case1 & case2 is same. This is effect of increasing shaft diameter. Durability of case3 is weaker than case1, and case3 doesn’t satisfy our guide lines. So we choose case2 as a result of optimal BSM.

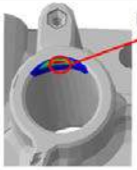
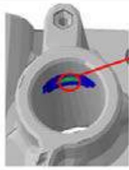
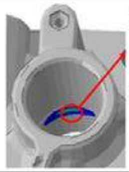
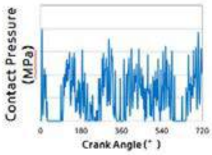
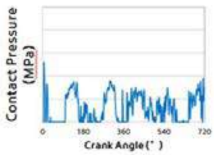
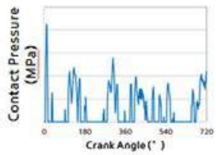
	CASE 1	CASE 2	CASE 3
The slope of Loosening angle	-0.665 (Base)	-0.476 (28% improved)	-0.294 (56% improved)
Contour Of Wear amount	 Max. wear 3.75 (BASE)	 Max. wear 2.16 (42% improved)	 Max. wear 1.99 (47% improved)
History of Contact pressure @ Max. wear			
No contact time	167°	213°	404°

Table 2. Analysis results about wear & loosening angle of bolt

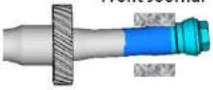
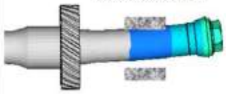
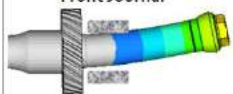
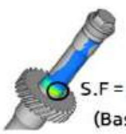
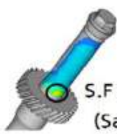
	CASE 1	CASE 2	CASE 3
Deformation	Front Journal 	Front Journal 	Front Journal 
High-cycle Fatigue Safety factor	 S.F = 100 (Base)	 S.F = 100 (Same)	 S.F = 83 (17% ↓)

Table 3. Analysis results about deformation & fatigue safety factor

4.2 Test results.

As a result of the test, a decrease in the axial bolt force about case 2 is 50% preferable to case 1. It is the same for the wear phenomena. This tends to be the same as the results of the FEM analysis.

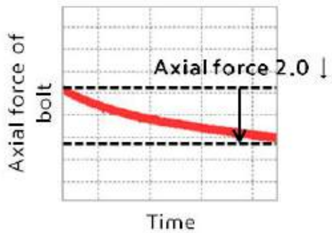
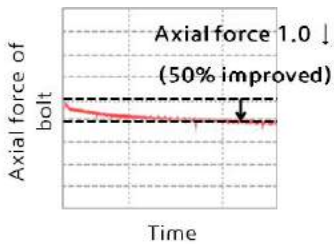
	History of Bolt axial force	Wear phenomena for journal	Test result
CASE1			Fail
CASE2			Pass

Table 4. Test results

5. Conclusion

The conclusions obtained through this study are as follows.

1) When apply external force at bolting system, I calculated loosening angle of bolt. Analysis time using the method in this study is shorter than the method using thread model.
2) We found the mechanism of loosening bolt and the loosening problem is improved. Also, we consider high cycle fatigue. Finally Optimized BSM system that satisfies loosening, wear, fatigue has been obtained as a result of this study.
3) In this study, developed the FE analysis procedure to predict the bolt loosening & wear. The FE analysis results verified with the real engine test.

6. References

1. D.K Killion, S. Chevalier, D. Tabbert, S.B.Joo, C.Y. Ha, “New Energy Efficient Balance Shaft/Oil Pump Module for Hyundai NF”, SAE 2006-01-0405, 2006.
2. H.W. Lee, M.R. Cho, J.W. Cho, M.S. Shin, W.T. Kim, G.S. Ko, “Development of a Compact Balance Shaft Module”, JSAE Annual Congress, Japan, 2009.
3. St. Huegen, G. Warren, R. Menne, J. Wolschendorf, M. Schwarderlapp, C. Schoenherr, “A New 2.3L DOHC Engine with Balance Shaft Housing – Steps of Refinement and Optimization”, SAE 970921, 1997.
4. D. Meek, M. Roberts, “Balance Shaft Conversion of a Four Cylinder Engine – The Challenges of Packaging and Mechanical Integration”, SAE 981084, 1998.
5. M. Prandstotter, H. Reiner, M. Steinbatz, “Simulation of an Engine Speed-Up Run: Intergation of MBS-FE-EHD-Fatigue”,ADAMS User Conference, 2002
6. HIBBIT, KARLSSON & SORENSON: ABAQUS/Standard, Users Manual Volume I-III.
7. G.Steinwender, C. Gaiger, B. Unger, “Improving the Life Time of Dynamically Loaded Components by Fatigue Simulation”, SAE 982220, 1998.
8. A. Carpinteri, A. Spagnoli, “Multiaxial high-cycle fatigue criterion for hard metals”, Int J. Fatigue, 23, pp.135-145, 2001