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A Comparative Study on Improving the Durability due to the Design of Automotive Torque Sensor Disk According to the Number of Holes

Kye-Kwang Choi, Jae-Ung Cho

Abstract*: *In this study, the durability of the torque sensor disk of a car was designed according to the number of holes and simulation analysis was carried out. In this study, the torque sensor disk was designed using CATIA, a 3D modeling program, and analyzed using ANSYS. The design variable of torque sensor disk is the number of holes. The number of holes at models 1, 2 and 3 are 31, 26 and 21 respectively. The analyses of fatigue lives and damages at three models are carried under the loads of SAE bracket history, SAE transmission and Sample history. As this study result obtained by carrying out the structural and fatigue analyses, the equivalent stress and deformation of model 3 are shown to be smallest among three models. So, it is estimated that model 3 with the smallest numbers of grooves among three models has the best strength and durability. As the number of holes is the least on design, the disk is estimated to endure for long time against the external force. When the external load is applied, the stress is concentrated at the part near the edge of torque disk. On the contrary, the magnitude of stress becomes low as the number of holes becomes small. The maximum fatigue damages under the loads of SAE bracket history, SAE transmission and sample history are the lowest in model 3 with the lowest number of holes among three models. At the design of torque sensor disk, the number of holes must be decreased to the maximum. But the original function should be maintained at the torque sensor disk. This study result is thought to be useful data for applying to the design of advanced disk by preventing the disk from of fracture and improving the durability.

Index Terms*: *Torque sensor, Equivalent stress, Fatigue damage, Durability, Fatigue life.

I. INTRODUCTION

Steering device enables the driver to manipulate the direction of moving automobile in the desired direction. At the time of manipulation of the handle by driver, the torque sensor is the device that delivers the necessary driving force for steering by operating the electric motor through sensing of the rotational direction and speed. Due to the assistance provided by this device, the driver is able to manipulate the vehicle with the minimum force. Torque sensor that detects the steering intention and power of the driver is an important component that determines the characteristics and performances of MDPS. Force is exerted to the torsion bar between the input disk and output disk of torque sensor at the time of steering. At this time, the status of the input and output disks changes in accordance with the extent of the twisting of torsion bar. In addition, at the manipulation time of steering handle, the displacement of prescribed angles between input and output disk occurs as the torsion bar is deformed. Accordingly, the structural and fatigue analyses was carried by using ANSYS program after having modeled three kinds of configurations by using CATIA program in this study. Then, the durability against the force exerted onto the model was deduced by computing the equivalent stress and extent of deformation by using this analysis. In addition, the fatigue life and damages were computed through the fatigue analysis. It is deemed that this study would provide the substantial assistance in manufacturing high-performance torque sensor disk[1]-[6].

II. ANALYSIS MODEL AND CONDITION

A.Analysis model

In this study, the structural changes in the torque sensor disk which is an important component that determines the performances of MDPS, are examined by imparting the moment by using models. Models were designed by making reference to the actual torque sensor disk. As the common aspect of each of the models, the torque sensor disk was composed of one steering handle input axis, one output axis motor and rack, one input axis disk and one output axis disk, while the number of grooves in the disk was used as the variable by reducing the number by five in designing the models. Fig. 1 shows three kinds of torque sensor disk models. Model 1 has configuration that is most similar to the actual torque sensor disk while model 2 and model 3 were designed by reducing the difference in the grooves. Accordingly, model 1 has 31 grooves while models 2 and 3 have 26 and 21 grooves, respectively, at the torque sensor disk. The material for the torque sensor disk was presumed to be the generally

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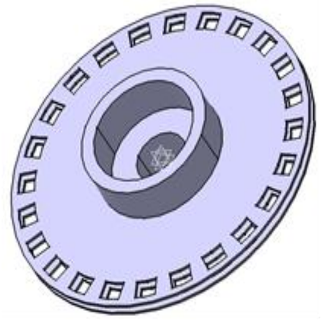
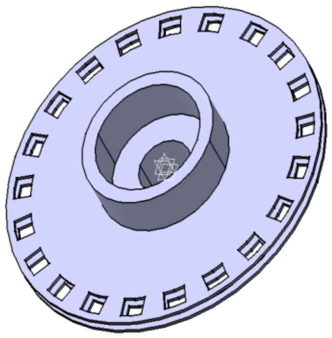
used structural steel and finite element analysis was carried out through mesh work.

(a) Torque sensor disk (31 grooves) of model 1



(b) Torque sensor disk (26 grooves) of model 2

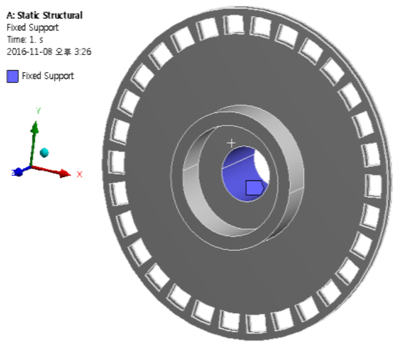


(c) Torque sensor disk (21 grooves) of model 3

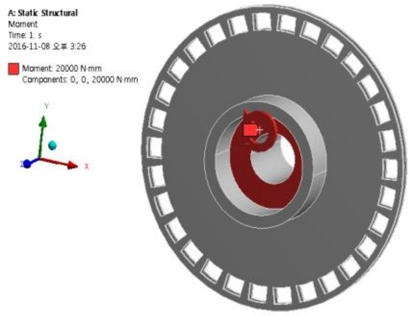
Fig. 1 Analysis models

B. Analysis condition

In this study, the following conditions of analyses were set to examine the durability by imparting force and moment to torque sensor disk. Fig. 2 illustrates that the conditions of fixation given to the part that comes in contact with the torque sensor disk surface. Moreover, the rotational moment was designated at 20000N·mm and imparted onto each of the disk models.



(a) Fixed support at model



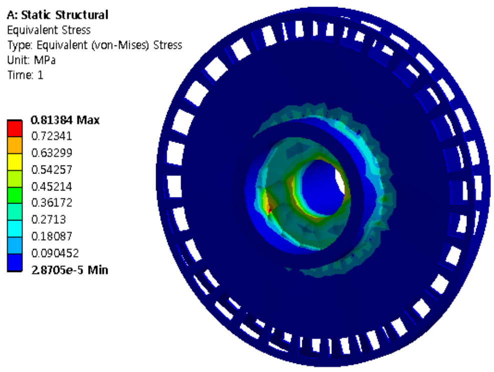
(b) Moment force at model

Fig. 2 Analysis condition of model

III. ANALYSIS RESULT

A. Structural analysis

Analysis results of the equivalent stress due to the moment exerted onto torque sensor disk were examined. Fig. 3 illustrates the contour of equivalent stress of the torque sensor disc, which is the analysis model. In case of model 1 with 31 grooves, the maximum equivalent stress was thought to be 0.81384MPa and appears to occur in the internal aspect of the disk axis. Model 2 with 25 grooves, which is 5 less than that of model 1, was found to have the maximum equivalent stress of 0.84947MPa and, similar to model 1, appears to occur in the internal aspect of the disk axis. Model 3 with the smallest number of grooves at 21 was found to have the maximum equivalent stress of 0.80238MPa and the part at which stress occurs was thought to be similar to those of the other two models. When the equivalent stresses of each of the torque sensor disks are compared and analyzed through the results of analysis, model 2 with the second smallest number of grooves showed the highest maximum equivalent stress, while model 3 with the least number of grooves showed the lowest maximum equivalent stress[7]-[10].



(a) Model 1

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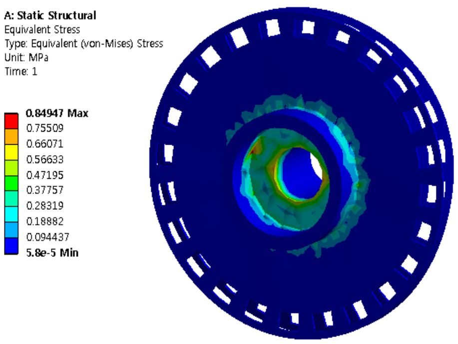
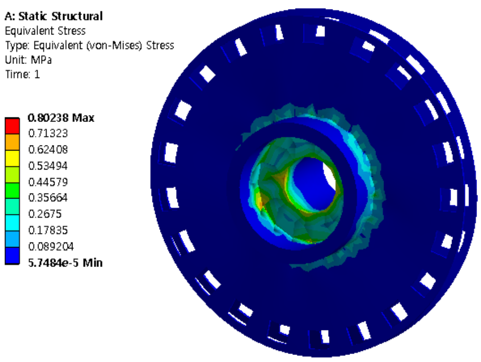


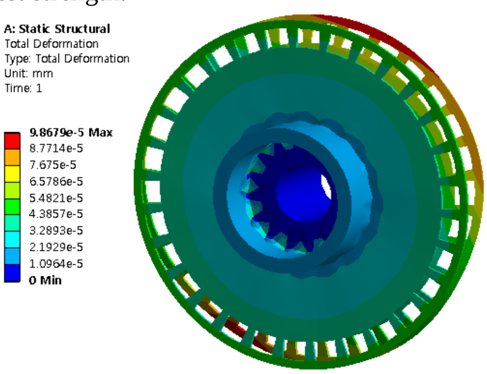
(b) Model 2



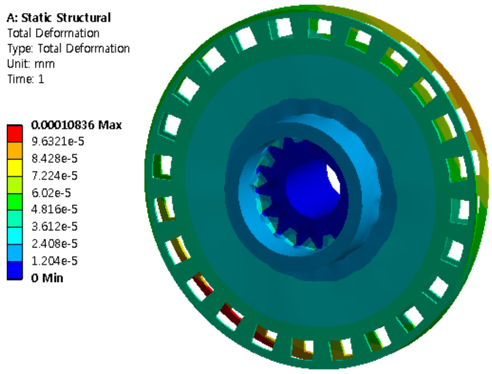
(c) Model 3

Fig. 3 Equivalent stresses of three models

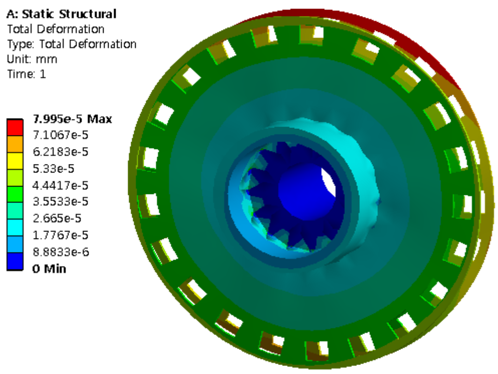
Fig. 4 illustrates the results of the overall contour of deformation due to moment exerted onto the torque sensor disk. When the extent of deformation is investigated in accordance with the number of grooves, model 1 with the largest number of grooves as 31 showed the maximum deformation of 0.068676mm, while model 2 with five grooves less than model 1 showed the maximum deformation of 0.10836mm and model 3 with the smallest number of grooves showed the maximum deformation of 0.07995mm. Based on the analysis results, the deformation of torque sensor disk occurred at the same location in all the models with the model 2 showing the greatest deformation and model 3 showing the least deformation. Accordingly, it can be determined that model 3 with the least deformation has the highest strength.



(a) Model 1



(b) Model 2

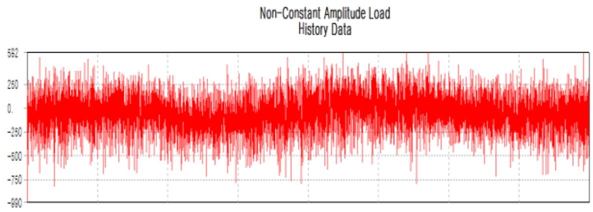


(c) Model 3

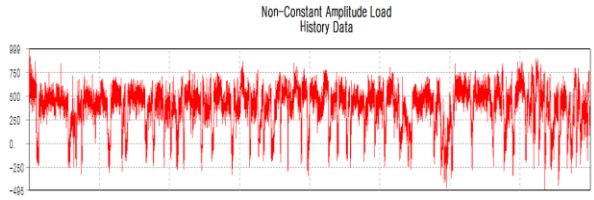
Fig. 4 Total deformations of three models

B. Fatigue analysis

Fatigue lives and damages due to the fatigue load exerted on the torque sensor disk were analyzed. As illustrated in Fig. 5, the loads of SAE bracket history, SAE transmission, Sample history with the stress amplitude on one cycle being progressed and the fatigue load, which was the average stress, were applied to three models. As it can be seen in the figure, SAE bracket history was the fatigue load condition applied in locations such as mountainous regions while the case of SAE transmission can generally be applied to non-paved road situations. In addition, sample history can be applied to well-paved road such as asphalt road.



(a) SAE bracket history



(b) SAE transmission

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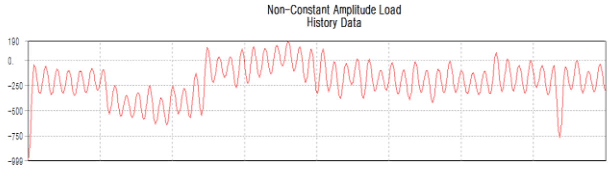
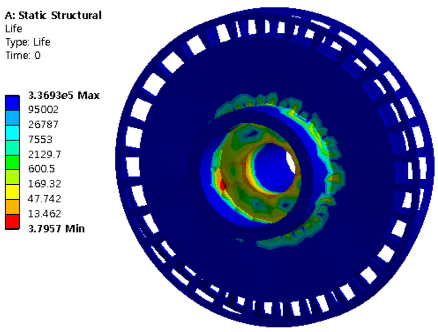


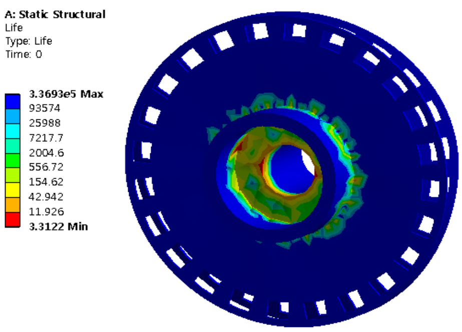
(c) Sample history

Fig. 5 Load histories at non-uniform fatigue loads

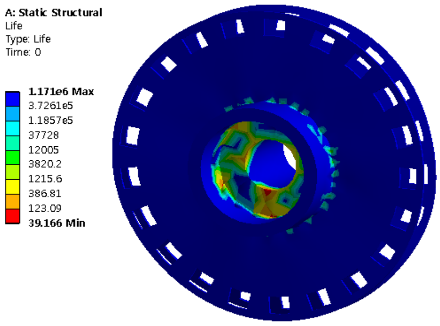
Figs. 6, 7 and 8 shows the contour plots on the fatigue lives in models 1, 2 and 3. When the results of the analysis results are examined, SAE bracket history at all three models has the shortest the maximum lifespan of 3.3693 x 105 Cycles, while Sample history with the most gradual changes in the load has the longest lifespan of approximately 2 x 107 Cycles. In addition, the lifespan of SAE transmission is 1.171 x 106 Cycles. Among three models, the maximum fatigue life in the case of Sample history was approximately 6 times longer than the maximum fatigue life of SAE bracket history and approximately 60 times longer than the maximum fatigue life of SAE bracket history. In case of SAE transmission, the maximum fatigue life is about 3.5 times longer than that of SAE bracket history. However, the minimum lifespan did not show the similar trend. In cases of models 1 and 2, the minimum lifespans under the load of SAE bracket history, SAE transmission and Sample history were 3.8, 0 and 863.52 for model 1 and 3.3, 0 and 750.15 for model 2, respectively. It can also be seen that model 3 has the values of 39.17, 22.46, and 5393.9, respectively. Although model 1 and model 2 show the similar trend, it can be seen that model 3 shows the fatigue lives that are substantially different from those of the models 1 and 2.



(a) Model 1

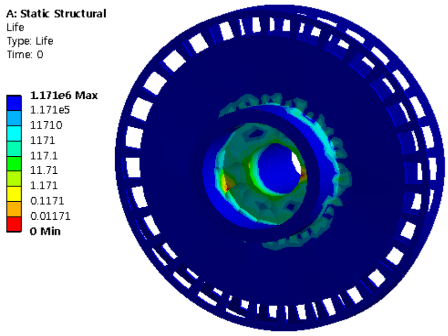


(b) Model 2

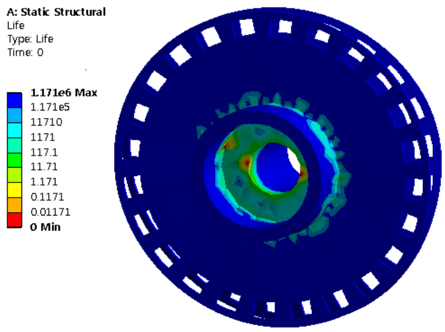


(c) Model 3

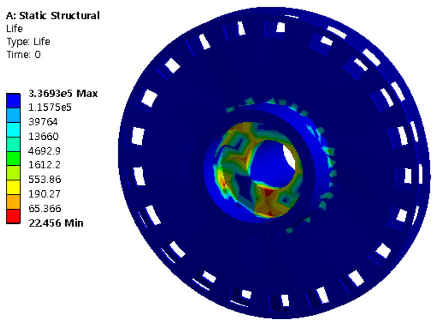
Fig. 6 Fatigue lives at SAE bracket history of three models



(a) Model 1



(b) Model 2



(c) Model 3

Fig. 7 Fatigue lives at SAE transmission of three models

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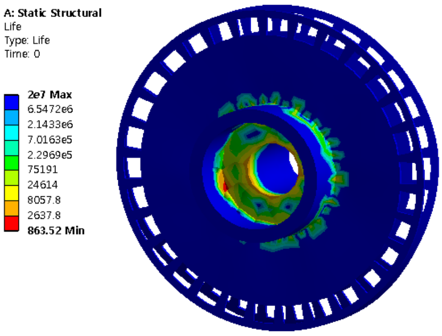
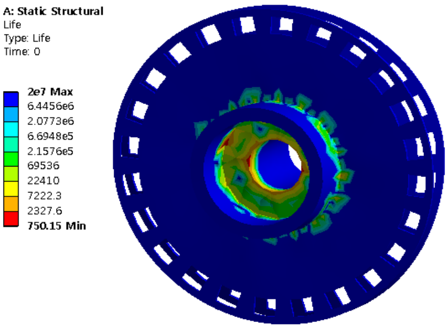
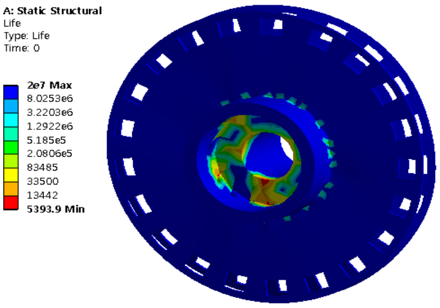


(a) Model 1



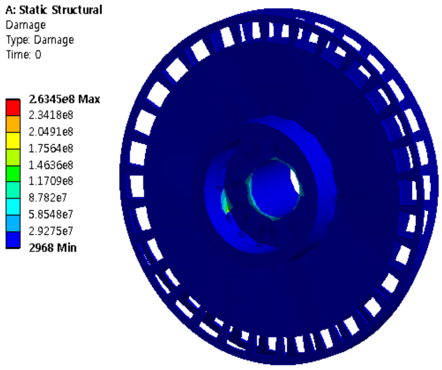
(b) Model 2



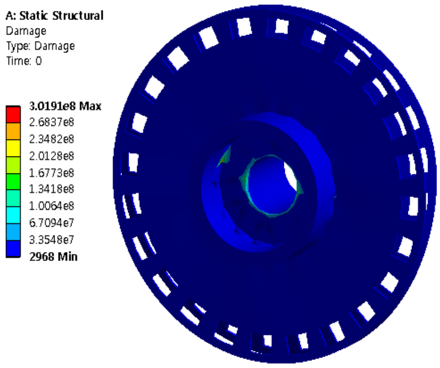
(c) Model 3

Fig. 8 Fatigue lives at Sample history of three models

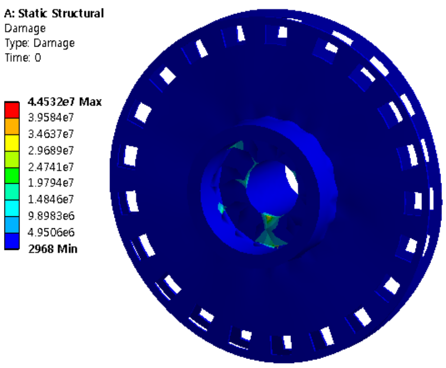
Figs. 9, 10 and 11 show the contour plots of fatigue damages in three models for comparison of the fatigue damages in three models. In can be seen that the damage is greatest for SAE bracket history with the value of 2968 while Sample history with gradual changes in load has the lowest value of fatigue damage at 50. Therefore, among the irregular fatigue loads, 'SAE bracket history with the severest fluctuation in the load generally shows the most unstable trend while 'Sample history' with relatively gradual changes in the loads shows greatest stability. Although SAE bracket history, SAE transmission and Sample history show the minimum damages of 2968, 854 and 50, respectively for loads of each of three models, the maximum damages were found to be 263450000, 1 × 1032 and 1158100, respectively in model 1, and 301910000, 1 × 1032 and 1333100, respectively in model 2. The maximum damages are 44532000, 25532000 and 185400, respectively in model 3. That is, SAE bracket history shows the greatest damage in model 2 while the damages are the same in models 1 and 2 but with the lowest damage in model 3 in the case of SAE transmission. Sample history shows the greatest damage in model 2.



(a) Model 1

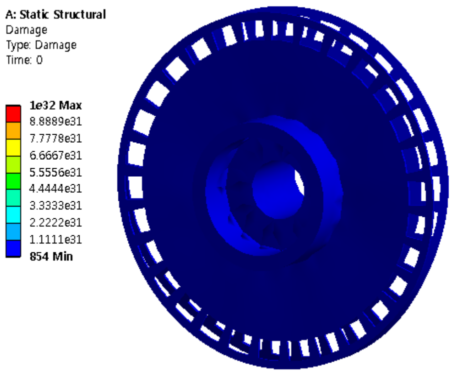


(b) Model 2



(c) Model 3

Fig. 9 Fatigue damages at SAE bracket history of three models



(a) Model 1

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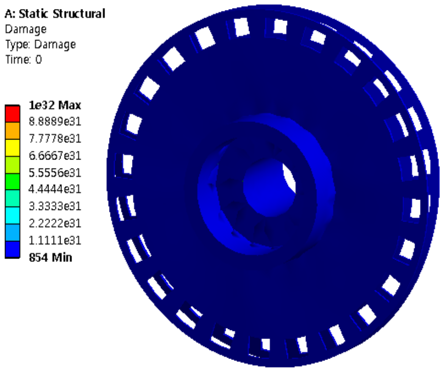
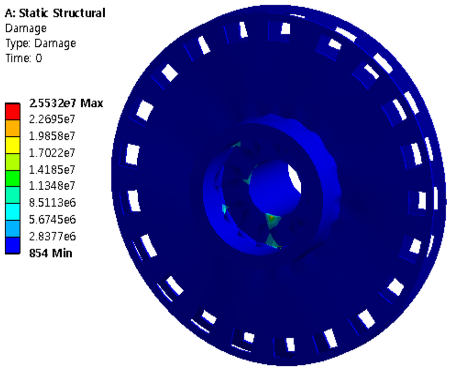
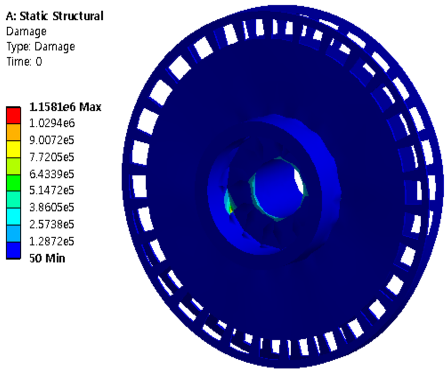


(b) Model 2

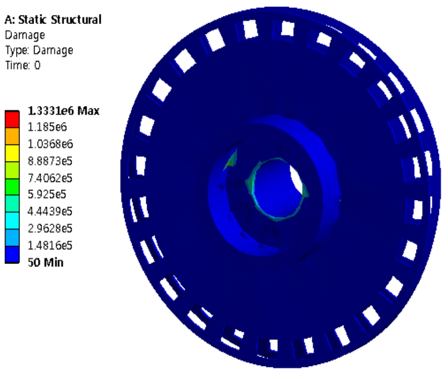


(c) Model 3

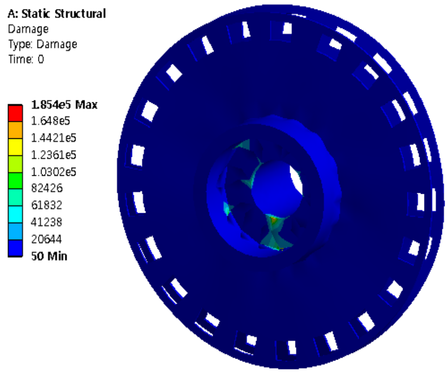
Fig. 10 Fatigue damages at SAE transmission of three models



(a) Model 1



(b) Model 2



(c) Model 3

Fig. 11 Fatigue damages at Sample history of three models

IV. CONCLUSION

In this study, the durability of torque sensor disk as a component part of electronically controlled steering device of automobile, was examined through the structural and fatigue analyses by using ANSYS program with three models with different number of grooves.

1. Through the structural analysis, it was confirmed that the model 2 had the highest equivalent stress, followed by model 1 and model 3. Therefore, it is deemed that model 3 would be able to withstand greater load in comparison to model 1 and model 2.

2. In three models, it was confirmed that the maximum fatigue life of Sample history was longer than that of SAE bracket history and the maximum fatigue life of SAE transmission was longer than SAE bracket history.

3. From the results of fatigue analysis, it can be seen that the maximum fatigue damages under the loads of SAE bracket history, SAE transmission and Sample history are the lowest in model 3 in comparison to those of model 1 and model 2. Accordingly, it is determined that model 3 with the smallest number of grooves among three models has the most outstanding durability.

4. It is thought that the results of this study can be applied usefully at designing the component of torque sensor in order to increase the durability by preventing it from fracture.

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12. AUTHORS PROFILE

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