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Research Article

INVESTIGATION OF CLUTCH HUB STRENGTH WITH VARIOUS GEOMETRIES UNDER VARIABLE TORQUE CONDITIONS

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ABSTRACT

The clutch is a component that performs the duty of transmitting the torque generated by the internal combustion engines to the powertrain. The hub component on disc assembly is one of the most important components in this transmission process. During operation under torque conditions, a hub is supposed to withstand the radial loads. For this purpose, the structural strength analysis of the hub is of importance. In this study, the hub component of the clutch disc assembly is analyzed to simulate real driving conditions. In this analysis, analytical calculations and finite element calculations were made for different hub structures. By comparing the two calculations, the precision of the design and the reasons of failures were determined. According to FEA results, the maxımum principal stress occurs in the contact regions where the pressure is applied. With respect to these results, the damage locations are compared to the parts which have been subjected to real bench test, and cracks/breaks occurred. After the tests, damage analysis was performed for fractures. This study enables the assumptions of the hub resistance under the various dynamic conditions with different hub geometry. Furthermore, this novel study provides the cost and time-saving in terms of the design phase in automotive engineering.
Keywords: Hub, FEA, powertrain system, clutch disc, overtorque, automotive engineering.

1. INTRODUCTION

The clutch is a component that performs the duty of transmitting the torque generated by the internal combustion engines to the powertrain. Transmission is done by friction torque between the disc and the flywheel. There is a drive plate that comes in contact with the hub on the disc assembly, with pre-dampers and main dampers to smooth sudden torques and vibrations in internal combustion engines. Thanks to the springs in the structure of the clutch disc, high torque, and the reduced vibrations are transmitted to the hub. The hub is subjected to axial and radial loads under operational conditions, so that, it must have high mechanical properties. In both the analytical calculations model and finite element method, these scenarios were transferred to the simulation environment and the real situation is observed in this study. In the clutch disc fatigue

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tests, the clutch disc assembly is tested with 2.3 times of the engine torque to simulate the worst case of the real driving conditions. In order to provide driving comfort, it must be ensured that there is no misalignment between the shaft and hub. In addition, no angular misalignment between the engine and the gearbox should exist. C40 steel was selected for the hub component analysis in this study.

In the literature, some studies have performed to observe the behavior of the clutch hub. This study is novel for the design of the experiment to see the behavior of different geometries in the clutch system. Jeyakarthikeyan and Hemesh observed the effect of mesh size on the tensile results of the hub of the clutch system. They examined the accuracy and change of strain ratios with mesh dimensions. Because of the accuracy of the result in the finite element method is directly related to the shape and size of the mesh [1]. Xintian et al. have performed five different FEA and test for structural strength of the clutch hub. Consequently, they observed that the failure in the welding regions [2]. Liu et al. analyzed the structural strength of the hub in ABAQUS and INDEED and observed that the results were relatively close to each other [3]. Gül et al. investigated the resistance of the clutch disc hub by performing an experimental Charpy test. They found the correlations between the FEA and the experimental Charpy test for defined clutch hub disc geometry [4]. Figure 1 shows the disc mounting elements of the hub.

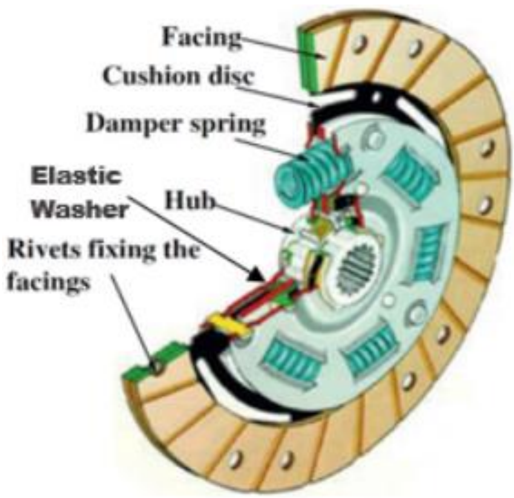

Figure 1. Clutch disc components [5]

This study has newness for the clutch system in terms of the design approach of the clutch disc hub. In the study, the robustness of the clutch disc hub is investigated with respect to FEA, torque and analytical pressure calculation to provide durability assumption in real driving condition. Furthermore, the cost and time-saving are obtained in terms of the design phase in automotive engineering.

2. MATERIAL and METHOD

2.1. ANALYTICAL CALCULATIONS

The hub materials used in the analysis and their properties are shown in the table below (Table 1). Also, Fig. 2 explains the Stress-Strain graph of the related material.

Table 1. Clutch hub material properties

Material Definition	Young Modulus	Poisson's Ratio	Tensile Strength
Structural Steel (C45)	200000	0,29	630 MPa

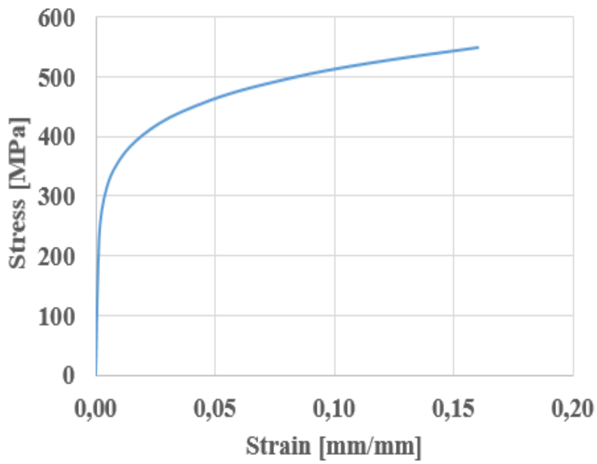

Figure 2. Stress – Strain graph of hub

Pressure value on internal spline simply calculated by applied torque divided into the total contact area. The total contact area between the input shaft depends on X spline length, the number of inner spline teeth, the mean diameter of contact, min holding tooth height and length of contact.

Parameters for design and analytical calculations are explained in Fig. 3. Also, Fig. 4 illustrates the outer geometry of the representative calculated hub.

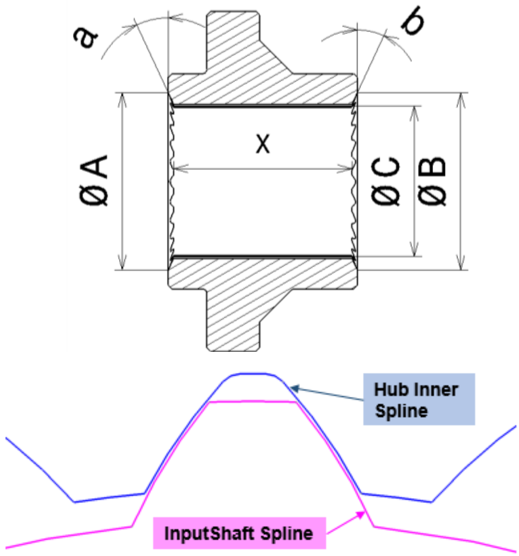

Figure 3. Clutch hub disc geometry with calculation parameters for pressure calculation on inner spline

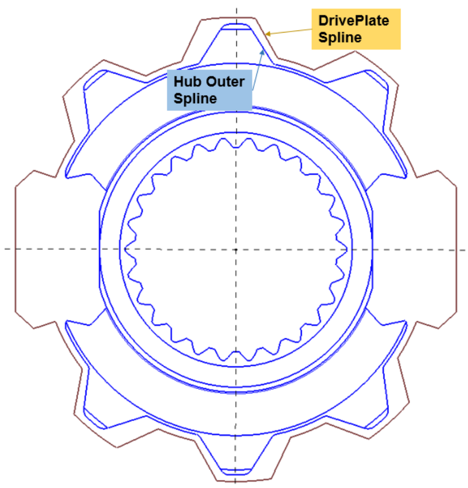

Figure 4. Clutch hub disc geometry for torque calculation on outer spline

Depending on the torque of the engine, there is a force in the contact area at the outer spline as well. The force value obtained is divided by the area in the contact area and the pressure values in that region are found. These pressure values will be used in the boundary conditions for FEA. Contact surface area and average contact radius can be explained with Equation 1 and Equation 2. In these equations, the drive plate inner diameter is represented with X, clutch disc hub outer diameter is represented with Y, and the thickness of the hub is T.

$$S = \frac{X - Y}{2} \times T \quad (1)$$

$$R_m = \frac{X + Y}{2} \quad (2)$$

Equations 1 and 2 are used to define pressure on the clutch disc hub. Fn, which is the normal load that comes through the hub, can be found with the equation 1. In Equation 3, Sf is the safety factor that is selected according to the risk factor of the clutch design. Cm represents the engine torque of the vehicle. n expresses the number of the teeth belongs to the clutch disc hub, Rm is the average contact radius between the clutch disc hub and input shaft. Equation 4 explains the Pressure formula on the clutch disc hub. Fn is the normal load that comes from Equation 3, S is the contact surface area between the clutch disc hub and input shaft.

$$Fn = \frac{Sf \times C_m}{n \times R_m} \quad (3)$$

$$P = \frac{Fn}{S} \quad (4)$$

2.2. FEA METHODOLOGY

During the driving condition, the torque coming from the engine is transmitted to Flywheel and PPCA, then the torque is transmitted to Clutch Disc by clamping starting from the outer diameter. After, the torque flows retainer plate, damper spring and clutch disc hub. After all, the torque is transmitted clutch disc hub to the input shaft of the gearbox. In parallel to real conditions in the FE model, the calculated pressure values are entered into the contact zone. For example, the pressure of 307,83 MPa is applied to the outer splines of the hub by eq.1 and eq.2. Axial displacement is fixed on the hub. Except for rotation on the Z-axis, other DOFs are restricted. The gearbox input shaft is also limited to 6 DOF.

The distributed load has been applied to the area in the FE model. The solution method is selected as Non-Linear due to the material properties. These boundary conditions are shown in Figure 5.

The mesh structure is created more frequently in the areas where stresses are thought to be more. The inner and outer splines have a mesh size of 0,5 mm. The hub and gearbox have a mesh size of 0,8 mm. The following table has shown the mesh structure (Table 2). In addition, Figure 6 shows the mesh structure of the representative calculated hub. The accuracy of FE results has been confirmed with the bench tests.

Table 2. The mesh structure of the hub component

	Hub	Gearbox Input Shaft
Method	Tetrahedrons	Triangles
Body Sizing	0,8 mm	0,8 mm
Face Sizing	0,5 mm	0,5 mm

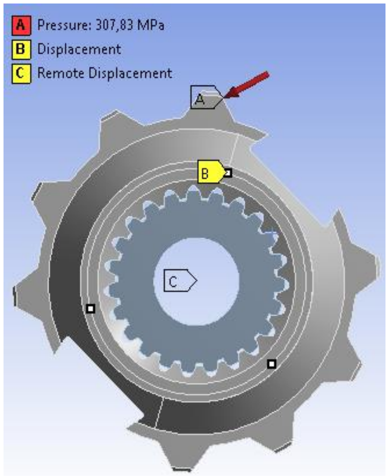

Figure 5. Hub FEA boundary conditions

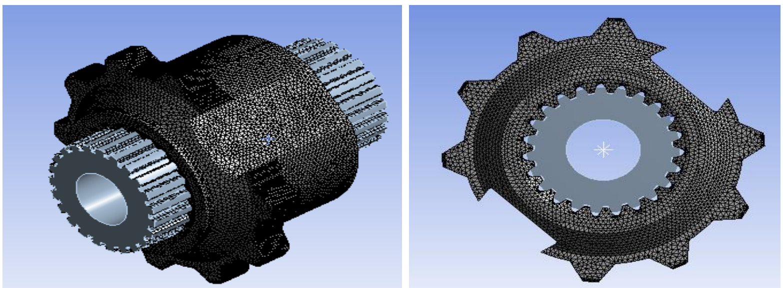

Figure 6. Mesh assigned hub structure

The test is carried out at ambient temperature. The hub is forced to about 2,3 times the engine torque. Then the location of the failure and causes of damage are determined for a defined fatigue limit. Figure 7 is the operation positions of the clutch disc assembly under the fatigue test. Torsional endurance test (Overtorque test) simulates the worst condition on the automobile with representing the endurance of the clutch disc components against torque oscillations generated in the engine. Many factors have high effects on the torque oscillations of the automobile such as driver profile, air condition on/off, lightening on/off, fuel type gasoline/diesel, fuel quality, engine maintenance quality, abusive usage, etc. 2 million cycles conducted to the samples in this study.

Figure 8 shows the samples of the failed clutch disc hub at the overtorque test. This figure illustrates the possible failure locations on the hub component. Failures occur on the inner spline and external spline in reality as well. For this reason, our first approach to estimate our hub design's endurance level can be evaluated by pressure estimation. Then FEA can be carried out in order to verify our design is ok or not.

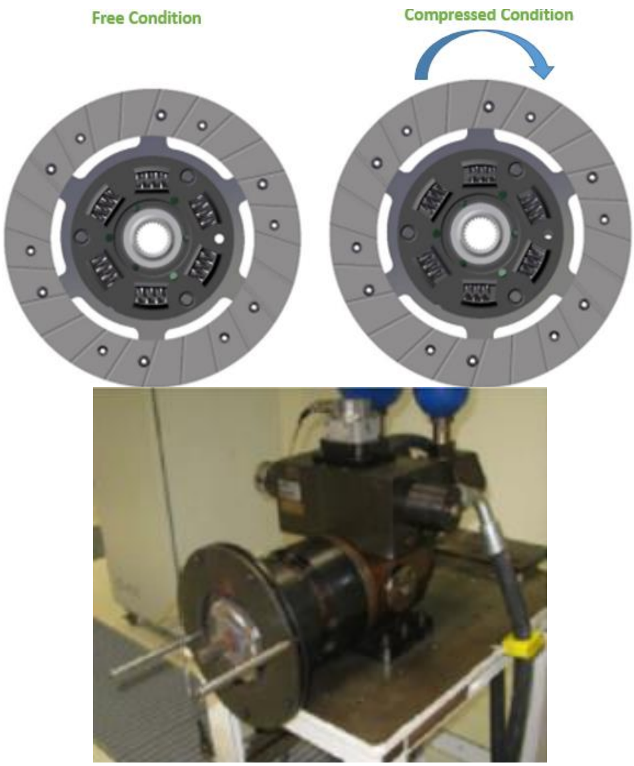

Figure 7. Clutch disc under 'Overtorque test' condition [5]

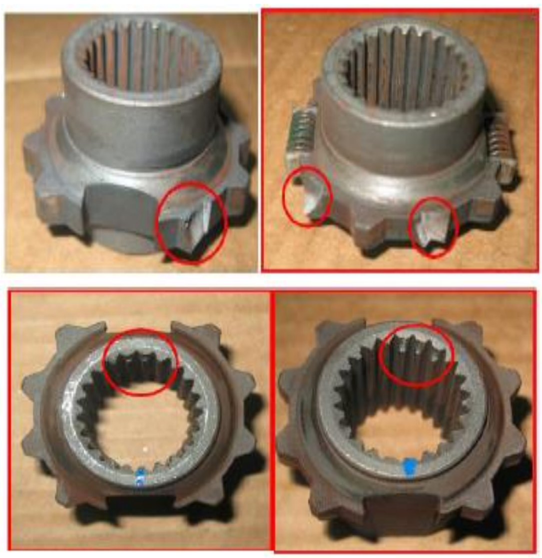

Figure 8. Damaged hub samples under real bench test conditions [5]

3. RESULTS AND DISCUSSIONS

This section investigates and evaluates the results of calculation and FEA for defined geometries. Fig. 9 shows one of the FE analysis in 14 studies. In this analysis, the outer and inner hub is observed to determine the critical location which attempts to crack or break under worst-case driving conditions. These critical locations on the hub are needed to investigate in detail to avoid any failure which causes time and cost consuming for the production in serial conditions.

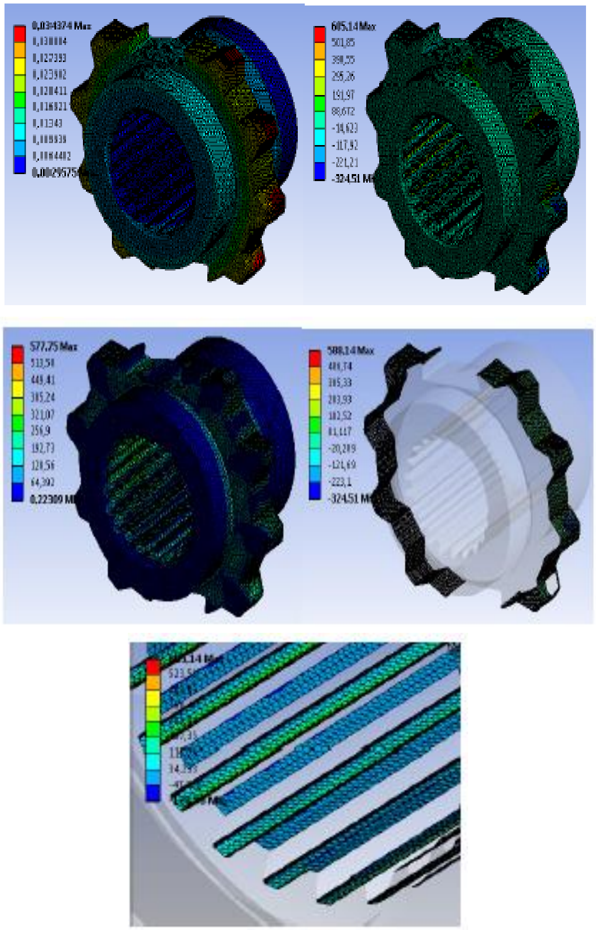

Figure 9. FEA results of the outer and inner hub

Table 3 indicates the general comparison between the various hub geometries, analytical pressure calculations, and FEA results to see stress level whether we are below our material tensile strength. In total, 14 different hub geometries have been investigated to see the effects of variations in the engineering design phase. The differences between the 14 hub designs are spline diameters and the number of hub teeth (Table 3). Results are shown that the consistency was provided between the analytical calculations and FEA outputs. These results prove the reliability of the analytical calculation which is currently used for the clutch engineering design.

Table 3. Comparison chart for analyzed hub geometries for Outer/Inner Teeth

	Outer Teeth						
Case	Number of Teeth	Axial Contact Length (mm)	Radial Contact Length (mm)	Total Area (mm2)	Applied Torque (Nm)	Calculated Pressure (MPa)	Stress @ FEA (MPa)
1	6,0	3,5	38,4	61,4	354	377	264
2	6,0	4,0	46,4	78,9	474	322	423
3	6,0	3,5	36,4	64,3	575	619	493
4	8,0	5,5	46,4	154,4	888	308	486
5	6,0	3,5	38,4	66,0	345	342	285
6	6,0	4,0	46,4	78,9	474	322	330
7	8,0	4,0	41,3	103,6	851	481	754
8	8,0	4,0	46,4	105,2	874	445	564
9	6,0	4,0	36,5	73,3	483	457	491
10	10,0	3,5	37,0	142,6	690	298	300
11	10,0	3,5	37,0	133,8	575	265	273
12	6,0	3,5	38,4	61,4	219	233	207
13	6,0	4,0	36,4	73,5	575	542	525
14	6,0	3,5	36,4	64,3	575	619	513

	Inner Teeth						
Case	Number of Teeth	Axial Contact Length (mm)	Radial Contact Length (mm)	Total Area (mm2)	Applied Torque (Nm)	Calculated Pressure (MPa)	Stress @ FEA (MPa)
1	18,0	20,9	0,83	311,8	354	119	352
2	20,0	18,9	1,03	311,8	474	115	301
3	23,0	18,5	1,09	386,7	575	102	314
4	23,0	31,2	1,09	464,6	888	93	353
5	26,0	22,8	0,64	783,5	345	87	298
6	20,0	19,0	1,03	388,7	474	115	310
7	20,0	24,4	1,03	501,0	851	160	466
8	20,0	27,3	1,03	558,8	874	147	605
9	20,0	23,9	1,03	489,7	483	93	300
10	21,0	32,0	0,56	373,4	690	167	328
11	18,0	26,1	0,77	359,2	575	168	320
12	26,0	22,8	0,64	380,1	219	55	169
13	28,0	23,5	0,58	378,0	575	145	243
14	18,0	23,6	0,94	399,1	575	150	320

Figures 10, 11, 12 and 13 explain the relationship between the stress, applied pressure and applied torque to outer teeth of the hub. This calculation gives data on stress variation depends on the applied pressure. The calculation gives the proportional polynomial rate between stress, pressure and applied torque.

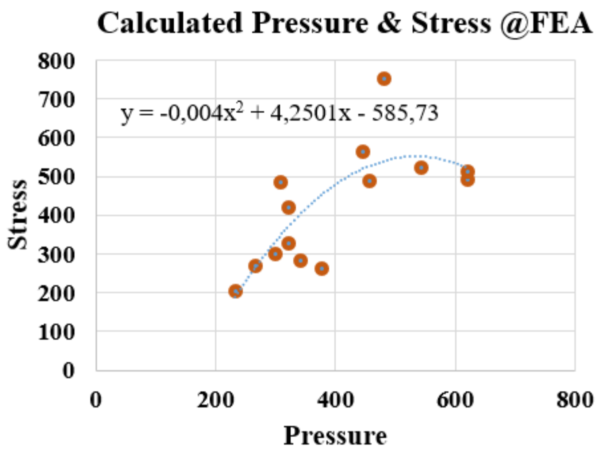

Figure 10. Pressure & Stress Results for Outer Teeth

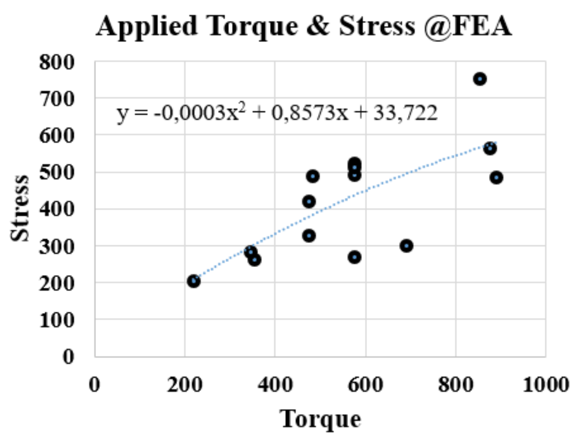

Figure 11. Torque & Stress Results for Outer Teeth

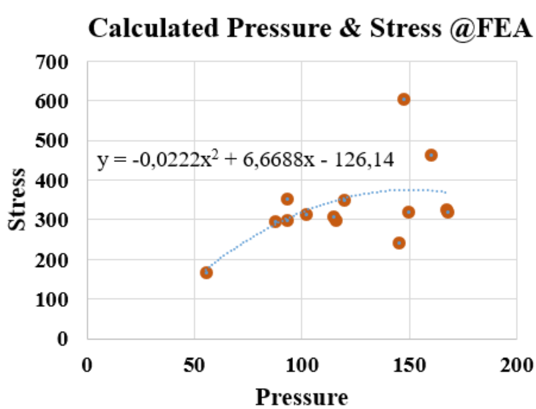

Figure 12. Pressure & Stress Results for Inner Teeth

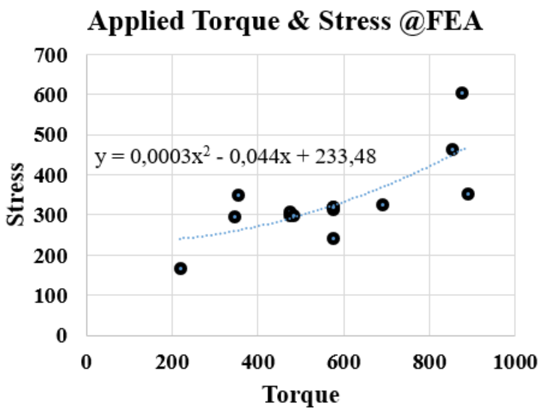

Figure 13. Torque & Stress Results For Inner Teeth

Stress function by applied torque and calculated pressure is shown in Equation 5;

Stress@outerspline/innerspline = f (Applied Torque (Nm), Calculated Pressure (P))   (5)

The equation is created by regression analysis in order to create a common approach to stress definition with pressure and torque.

Stress value of outer spline = -79.2 + 0.436 x Nm + 0.628 x P   (6)

Regression parameters; R square = 0.7732, P<0.05, F=18.7512
Stress value of inner spline = 104.6 + 0.334 x Nm + 0.323 x P   (7)

R square=0.5473, P<0.05, F=6.6517

Stress functions (Eq.6 and Eq.7) comply with the conditions of the regression model. The R squared is an interaction indicator between different variations to show the strength of the relationship between variables. In this study, Stress, calculated pressure and applied torque have a relationship since R squared is more than 0.3 statistical measures. The P-value defines our results significance level as the statistical measure, smaller P-value indicates the more significant results. Applied torque and calculated pressure have importance on the stress of hub since the P-value is less than 0.5. F value gives information about how the groups spread out than the variability of the data within groups. Stresses created by applied torque and calculated pressure on inner spline distributed tighter than applied torque and calculated pressure of outer spline.

4. CONCLUSION

This study investigates the robustness of the clutch disc hub with respect to FEA, torque and analytical pressure calculation to provide durability assumption in real driving condition. Clutch disc hub has major importance in terms of engineering design because the generated torque coming from the engine is directly transmitted by means of a clutch disc hub. Therefore, the product life of the hub should be at the desired level. In this study, 14 different clutch disc hubs, which have different numbers of teeth and spline diameter, are investigated according to safety design and robustness. Results show the regression analysis approach provides examining the relationship between different outputs for the clutch. It increases the robustness of the reliability level of Hub Design. We can check stress level by adjusting applied torque and pressure subjected to contact area on outer teeth and inner teeth. Some additional outputs can be inferred from the results of the study;

- A more applied torque is on outer teeth and inner teeth, the higher stress occurs on the hub.
- Applied torque has more impact on stress value than applied pressure on teeth.
- A number of teeth, mean radius of applied torque and contact length of the hub are of importance on the stress value of hub.

Acknowledgement

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REFERENCES

[1] Patil, H., Jeyakarthikeyan, P. V. 2018. Mesh convergence study and estimation of discretization error of hub in a clutch disc with the integration of ANSYS, 2nd International Conference on Advances in Mechanical Engineering.

[2] Xintian, L., Yansong, W., Lihui, Z., Yanfeng, X., Hui, G. 2013. The analysis of structural strength of UD clutch hub assembly, Applied Mechanics and Materials Vols. 303-306, pp 2754-2757

[3] Liu, C., Liu, X., Huang, H., Zhao, L. 2009. 'Simulation Research on Structural Strength of the Hub Plate', Proceedings of the 2008 IEEE International Conference on Robotics and Biomimetics Bangkok, Thailand, February 21 – 26.

[4] Gul, C., Genc, M.O., Durmus, A. 2019. Shock strength investigation of sintered clutch disc hub experimentally with a modified Charpy test bench. International Conference on Artificial Intelligence and Applied Mathematics in Engineering, Antalya, Turkey

[5] Valeo Automotive Systems, "Technical Documentation" 2016, Bursa, Turkey

[6] H. Serizawa, Z. Wu, H. Murakawa. 2001. Computational Analysis of Charpy Impact Tests Using Interface Elements, Transactions of JWRI, Vol. 30, pp 97-102.

[7] K. M. Kumar, M.R. Devaraj, H.V. LakshmiNarayana. 2012. Finite Element Modelling for Numerical Simulation of Charpy Impact Test on Materials.'' International 10 Conference on Challenges and Opportunities in Mechanical Engineering, Industrial Engineering and Management Studies, pp 32-36.

[8] A, Emamian. 2012. A Study on Wear Resistance, Hardness and Impact Behaviour of Carburized Fe-Based Powder Metallurgy Parts for Automotive Applications, Materials Sciences and Applications, Vol.3, pp 519-522.

[9] Gul, C., Genc, M.O., Durmus, A. 2017. Numerical estimating the shock strength of automobile clutch disc hub, 6th International Conference on Advances in Mechanical and Robotics Engineering, pp.16-19, Roma, Italy.