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Research Paper

FAILURE ANALYSIS OF MOTORBIKE KICK SPLINED SHAFT AND KICKBOSS BY FINITE ELEMENT METHOD

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The kick boss and shaft assembly of a typical commercial motorcycle is a commonly encountered failure. The typical observation, kick boss becomes loose on spline and rotates freely on the shaft, as all teeth of splines are worned off. The kick slips over the kick shaft not generating the sufficient torque to start the, engine. Most common reason is the kick boss splines worn out decrease the depth of splines and/or the splines of the shaft worn out. The oblivious reason for this failure is the high shear stresses at contact zone. The work include, studying the geometrical feature of kick boss and shaft. Creating the CAD model of the kickboss and kick splines shaft assembly with various position of kick boss bolt so as to represented the actual possible engagement scenario between kick shaft and kick boss. Each of these CAD model is converted to FE model and is analyzed using commercial analyzing software. The empirical relations for the shear stress on spline were theoretically calculated using machine design handbook. The empirical relation shows as the contact coefficient as one of the important coefficient for finding the shear stresses. For a good spline with ideal contact it is four and may varied up to six as the spline are becomes misaligned/separated. The shear stresses varying values of contact coefficient were calculated and found to have increase as the coefficient increases. The finite element model were created for the various contact condition which were the analyze using FE for the above referred contact variation. The results are convergent with the prediction that the prime reason for failure is decreasing of contact with the loosening in use. The report describes the details of theoretical as well as FE analysis carried out to reach above conclusion.

Keywords: Failure analysis, Kickboss, Kick splined shaft, Finite element method

INTRODUCTION

Among various mechanical components used for transmitting the torque between two shaft especially for temporary transmission, splined shaft are commonly used component. These splined shafts are subjected to wear. The

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geometric alignment of the splined in the coupling is a important feature along with the mechanical and metallurgical properties of the coupling element.

Unlike gear these splined are often known to have the lateral movement along the shaft axis and hence these demands high clearance among the matting element of the coupling hence there is scope for optimization of the clearance usages and this optimization process demands an additional study on the type and amount of stresses in the coupling especially in teeth of the mating splined.

A typical splined shaft arrangement used in two wheeler motorbike kick often fails. The failure is usually of the kick boss. The common remedial action is to tighten the kick boss bolt which extends its life but the failure is imminent. Hence it is proposed to analyze the kick assembly for various bolt position.

FEM being most practice method to analyze various mechanical component for various load condition. It is proposed to analyze the referred problem using FEM.

Figure 1: Location of Kickboss

Figure 2: Kickboss Dimension

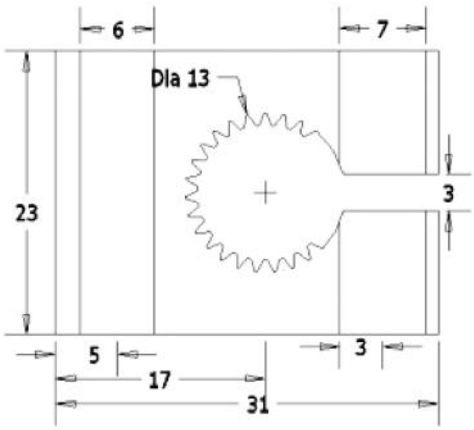
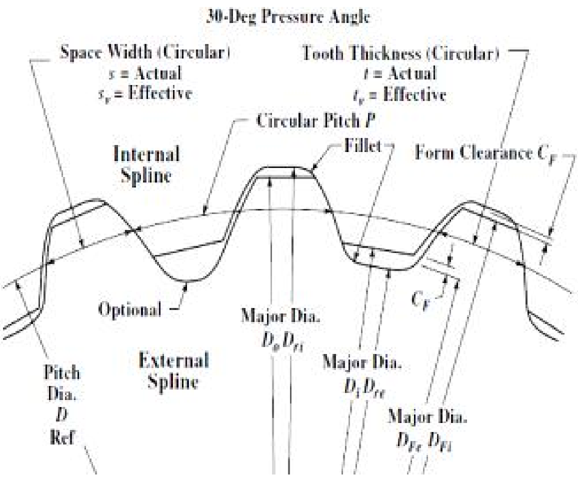


Figure 3: Involute Spline Profile



ANALYTICAL SHEAR STRESS CALCULATION OF KICKBOSS ASSEMBLY

Specification of the Kickboss

The kickboss and kickshaft assembly is attached to kick arm of the motorbike through pin. The location of the kick boss is shown in Figure 1. The dimensions of kickboss are shown in Figure 2 and involute spline profile is shown in Figure 3. The dimension and technical specifications of kickboss assembly are given in Table 1. The overall load (force) of about 200 to 250 N. required for kicking to start

Table 1: Dimension of Kick Boss and Kick Shaft of Bajaj 4S Motorbike

Part Name	N	P_i	¨ 0^0	D_{mmm}	D_{pi} mm	D_{ri} mm	D_{fi} mm	D_{ri} mm	S mm	S_v mm	t mm	L mm
(Kick Boss)	27 (21 Effective)	2.25	30	10.4	12	12.6	12.44	11.55	0.698	0.698	0.698	14
(Kick Shaft)	27	2.25	30	10.4	12	12.44	11.55	11.4	0.698	0.698	0.698	14

the engine. This load is then distributed by the kickboss over each teeth of the kickboss and kick shaft.

Shear Stress Calculation

Stress calculation has been carried out for kickboss using the technical specifications mentioned above and with following assumptions as listed with the calculations.

Assumptions

- Kickboss and kick splined shaft assembly is a perfectly splined coupling arrangement, where kickboss is a internal involutes splined and kick shaft is a external involutes splined.
- The joints are perfect and there are no geometrical irregularities.
- Average force 'F' required on kick paddle to start the engine is 200 N.
- Splined application factor Ka = 2.4 for intermittent shock load.
- Load distribution factor Km = 1 for fixed spline.
- Fatigue life factor Kf = 0.5 for 100000 cycle, torque cycle consist of one start and one stop, not the number of revolution.
- All kinds of loads other than those mentioned in calculations are neglected.
- Above assumption are on the basis of manufacturer specification and Machinery's Handbook 27th Edition, Industrial press New York.

Shear stress at the pitch diameter of teeth

$$S_s = 4\, T\, K_a\, K_m / D_p\, N\, L_e\, t\, K_f \text{ N/mm}^2$$

where,

T = Torque. = 40000 N-mm (specified)

K_a = Spline application factor.

K_m = Load distribution factor.

D_p = Pitch diameter in mm.

N = Number of teeth in contact.

L_e = Length of spline in mm.

t = Circular tooth thickness in mm.

K_f = Fatigue life factor.

As per machinery's handbook reference, factor 4 assumes that only half the teeth will carry the load when full tightening of bolt because of spacing errors. This multiplying factor varies from 4 equivalent to 100% or full tight of kick bolt and increases up to 6 equivalent to 60% looseness of kick bolt.

The maximum shear stresses calculations at various bolt position are presented tabulated form in following section.

Case I: Maximum Shear Stress Calculation Considering Specified Torque

Maximum shear stress calculation when average force applied by user is 200 N. Assume that spline becomes misaligned/ separated and kick bolt loosed in step. Table 2 shows calculation of maximum shear stresses at various position of kick bolt.

Table 2: Calculation of Max Shear Stresses for Case I

S. No.	Recommended Torque T (N-mm)	Equivalent % Contact on the Basis of Position of Kick Bolt	Equivalent Multiplying Factor for Calculating Shear Stress at Various Position of Bolt/Contact of Spline	Maximum Shear Stress at the Pitch Diameter of Teeth N/mm^2 or Mpa $S_s = T K_a K_m / N D_p L_e t K_f$
1.	40000	100	4.0	312
2.	40000	90	4.5	350
3.	40000	80	5.0	390
4.	40000	70	5.5	429
5.	40000	60	6.0	467

Case II: Maximum Shear Stress Calculation Considering 100% Tight of Kick Bolt and 25 to 35% Excess Torque is Applied

Maximum shear stress calculation when force applied by user is changes depends upon the different user. In practice some people push it hard. Taking excess torque 25 to 35% more and consider that 100% tight of kick bolt. Therefore torque varies from 40000 to 65000 N-mm. Table 3 shows calculation of maximum shear stresses at full tight of kick bolt.

Case III: Maximum Shear Stresses Calculation Considering 25% Excess Torque and % Contact of Spline Reduces in Step Due to Loosening of Kick Bolt

Maximum shear stresses considering torque is 50000 N-mm. and percentage tightening of bolt reduces instep. Table 4 shows calculation of maximum shear stresses at full contact of kick bolt.

MODELING AND FE ANALYSIS OF KICKBOSS ASSEMBLY

Three dimensional modeling is the process of developing a mathematical representation of any three-dimensional surface of object (either inanimate or living) via specialized

Table 3: Calculation of Max Shear Stresses for Case II

S. No.	Torque T (N-mm)	Equivalent % Contact on the Basis of Tightening of Kick Bolt	Equivalent Multiplying Factor for Calculating Shear Stress at Various Position of Bolt/Contact of Spline	Maximum Shear Stress at the Pitch Diameter of Teeth N/mm^2 or Mpa $S_s = 4T K_a K_m / N D_p L_e t K_f$
1.	40000	100	4	312
2.	45000	100	4	350
3.	50000	100	4	389
4.	55000	100	4	429
5.	60000	100	4	467
6.	65000	100	4	507

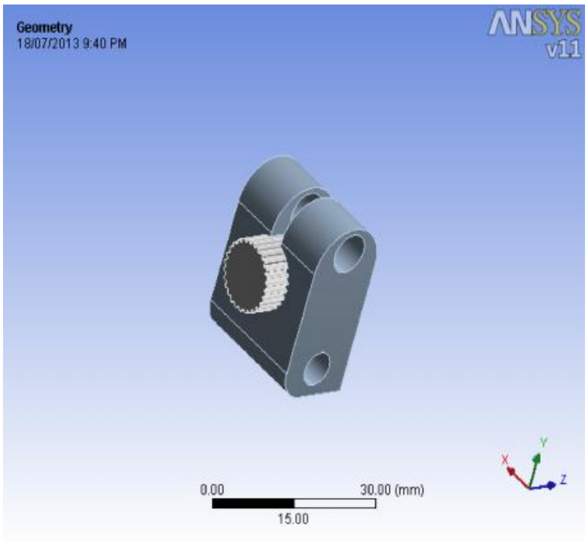
Table 4: Calculation of Max Shear Stresses for Case III

S. No.	Torque T (N-mm)	Equivalent % Contact on the Basis of Tightening of Kick Bolt	Equivalent Multiplying Factor for Calculating Shear Stress at Various Position of Bolt/Contact of Spline	Maximum Shear Stress at the Pitch Diameter of Teeth N/mm² or Mpa $S_s = T K_a K_m / N D_p L_e t K_f$
1.	50000	100	4	389
2.	50000	90	4.5	437
3.	50000	80	5	487
4.	50000	70	5.5	536

software. These models represent a 3D object using a collection of points in 3D space, connected by various geometric entities such as triangles, lines, curved surfaces, etc. Here commercial software is used to model the kickboss and kick shaft and included the part modeling environment in which the extrude command is used for the modeling of the same. The parameters required for the modeling of kickboss and kick splined shaft are contour dimensions height, length, width, Internal and External Teeth of kickboss and kick splined shaft, hole diameter. The 3D SOLID is prepared by thickness in the third dimension provided after selecting the 2D shell element. Figure 4 represents the CAD model of a basic kick boss assembly for 300 pressure angle prepared in commercial software.

In design simulation mesh element is used for meshing of kickboss assembly. Equivalence of the nodes is executed for this element. The material properties like modulus of elasticity and poisons ratio is assigned to the kickboss and kick splined shaft in materials list in software. The modulus of elasticity and poisson's ratio for the structural steel material is 200 x 10^3 N/mm^2 and 0.3.

Figure 4: Basic Model of Kickboss Assembly



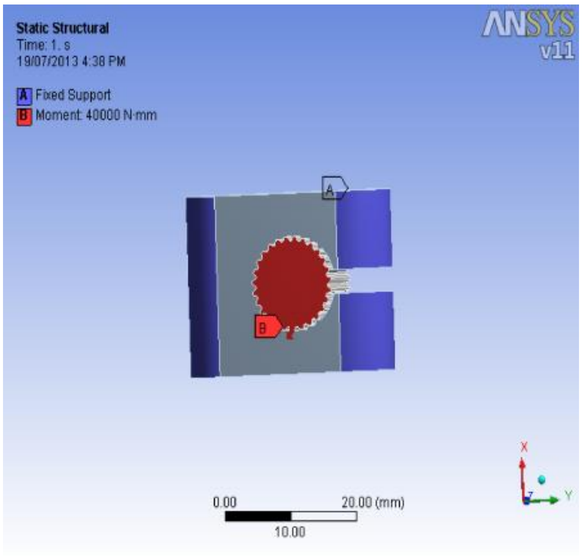
Maximum Shear Stress Analysis Considering Original Kickboss Assembly with 300 Pressure Angle

Using the technical specification of kickboss assembly the FE analysis has been carried out in commercial software a higher order 3-D FEM package. The analysis was carried out for the for the torque calculated. At first the kickboss assembly is analyzed by considering the maximum shear stress calculated earlier. The maximum shear stresses are obtained which gives comparative results for failure analysis of kick boss.

Boundary Condition, Constraints and Torque on the Kickboss Assembly

The constraint conditions and FE results in ANSYS for kickboss assembly are presented here. For static structure apply fixed support on all faces of kickboss excluding assembly contact faces shown in gray color in Figure 5 and torque is applied on the kick shaft 'B' at both the ends. The static structure and moment on kickboss assembly is shown in Figure 5 which shows fixed support 'A' in blue color.

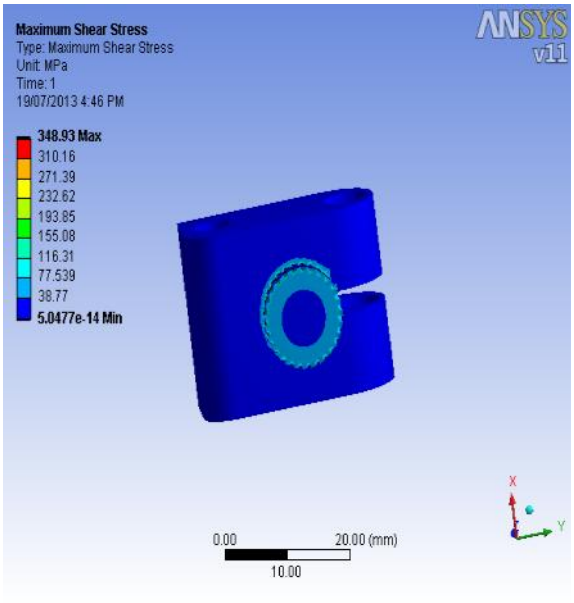
Figure 5: Boundary Condition, Constraints and Torque on the Kickboss Assembly



Case 1 of I: Maximum Shear Stress Analysis Considering Specified Torque

For the FE analysis of kickboss assembly when considering specofied torque and assuming full tightening of bolt equivalent to 100% teeth contact, the average torque of 40000 N-mm is applied on the outer edge of the kick splined shaft as calculated in earlier and fixed at the all faces of the kickboss, which, is assembled to the kick splined shaft. The model is shown in Figure 5. The mesh has 47068 elements and 86134 nodes. The results obtained for maximum shear stress are shown in the form of contours in Figure 6. It is seen that, the maximum shear stress is 348.93 MPa. The max stress is present at the periphery of mating teeth of the assembly and it is lower than the ultimate shear stress.

Figure 6: Maximum Shear Stress Analysis by FEM for Case 1 of I



Comparison of Result of Various Cases

Table 5 shows the comparison of results which are calculated therotical and FE analysis for 300 and 37.50 pressure angle.

RESULTS AND DISCUSSION

It is observed that there is zone of high ultimate shear stresses above 460 Mpa and thus there is shear failure at top and bottom portion of the kickboss, at tip of the teeth. For the case 5 of I for the torque of 40000 N-mm. When the teeth contact is reduced to 60% due to loosened of bolt. The maximum shear stress

Table 5: Comparison of Result for Various Cases

Case No.	Description Torque N-mm	Therotical % Contact of Spline w.r.t. Tight of Bolt	Therotical Calculation of Max Shear Stress MPa	FEM Analysis 300 Pressure Angle	FEM Analysis 37.50 Pressure Angle
1 of I	40000 (Recommended)	100 (Full Tight of Kick Bolt)	312	348	267
5 of I	40000 (Recommended)	60 (More Loose Contact)	467	492	411
5 of II	60000 (50% Excess)	100 (Full Tight of Kick Bolt)	467	497	408
3 of III	50000 (25% Excess)	80 (Loose Contact)	487	530	455
	70000 (60% Excess)	60 (More Loose Contact)	818	900	494

Table 6: Comparison of Result for Different Failure Cases

Case No.	Description Torque N-mm	Therotical % Contact of Spline w.r.t. Tight of Bolt	Therotical Calculation of Max Shear Stress MPa	FEM Analysis Max Shear Stress Mpa for 300 Pressure Angle	FEM Analysis Max Shear Stress Mpa for 37.50 Pressure Angle
Case I					
5 of I	40000 (Recommended)	60 (More Loose contact)	467	492	411
Case II					
5 of II	60000 (50% excess)	100 (Full tight of kick bolt)	467	497	408
Case III					
3 of III	50000 (25% excess)	80 (Loose contact)	487	530	455
Case IV					
	70000 (60% excess)	60 (More Loose contact)	818	900	494

is 492 Mpa which lead to the failure at top and bottom portion of the kickboss,at the tip of the teeth.

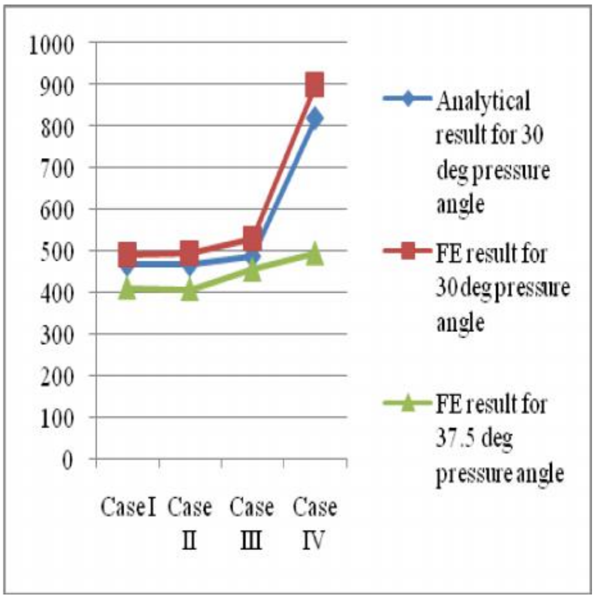
For the case 5 of II for the torque 60000 N-mm. When the torque increased the failure is observed at 100% contact with maximum shear stress is 497 Mpa which lead to the failure at top and bottom portion of the kickboss at the tip of the teeth.

For the case 3 of III for the torque 50000 N-mm. When the torque increased the contact is reduced due to loosened of bolt the failure is observed at about 80% contact with maximum shear stress 530 Mpa which lead to the failure at top and bottom portion of the kickboss at the tip of the teeth.

Effect of alteration of pressure angle for the case IV for 37.50 pressure angle, when torque increased 70000 N-mm and contact is reduced to 60% the failure is started with maximum shear stress is 492 Mpa which lead to the failure at top and bottom portion of the kickboss at the tip of the teeth.

From the above result it is evident that as the multiplying factor indicative of looseness kickboss over shaft, increases the shear

Figure 7: Variation of Shear Stress for Various Cases with Respect to Pressure Angle



stress increases. Up to 60% of the contact the shear stress for normal torque of 4000 N-mm the shear stress are safe. However these reaches the critical values beyond 60%. Further it should be noted that actual engagement of spline in the assembly will not be perfect and hence actual values of loading/contact would be adverse than considered for the calculation. The same observation for all the cases with constant torque and variation in contact hence it can be deduced that the looseness of kickboss should not be more than 60%, i.e., it should not loose beyond 30%. For the new splined assembly with 100% contact the shearing stress would be near the ultimate shear stress. When load of above 70000 N-mm is applied it must noted that in practice the kickboss assembly shall always be 10 to 20% loose and hence kicking with excessive torque should be avoided.

CONCLUSION

The commonly faced difficulties by the motorbike user is the failure of kickboss splined this typical problem is analyze theoretically as well as using FE approach. It is commonly known that splined transfer about 60% of design load due to inaccuracies in machining and allayment this leads to uneven shearing of torque by teeth making, some teeth vulnerable to shear this is further distributes the torque unevenly and the phenomenon continue till the failures occurs.

The theoretical analysis using empirical relation reviewed that for the prescribed torque the shear stress enters in the critical zone at about 60% of loosening. For higher torque this would occurs earlier hence it can be concluded that the bike users should be inform following working factors.

- Kicking with excessive force shall certainly reduced the life of kickboss hence it should be avoided.
- The life of kickboss is improved by frequently tightening it hence it should be avoided as a practice.
- Any axial misalignment shall be reduced the contact area under shear hence actual alignment should be maintained.

The above information should be incorporated in service manual by the manufacture.

The analysis also suggest that higher pressure angle of splined make the splined stronger hence this desirable change should be tested for validity and feasibility.

FUTURE SCOPE

- The experimental technique using in-situ measurement of shear stresses like making use of strain gauges shall give a better picture of stress involved.
- The kickboss thickness increased shall reduced the shear stresses and hence this may be tried as an optimization parameter.

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