Experimental Analysis Through Design Optimization for DFM and weight Reduction of Gear shifter Diff-Lock Fork of Transmission System of Commercial Vehicles

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Abstract

During the process of Milling for v cut Slot minor Cracks are generated in fork Surface, which during induction hardening process converts in to deep cracks and can only be detected during the non-destructive testing like MPI. This leads to higher rejection ratio and incur financial and material losses. The existing design of fork is heavy and not compact which leads to problems during assembly and leads to bending in rails. This necessitates a new design of fork is compact and light weight. The aim of this research is to determine the contribution of v cut slot in forks. The second design is modelled without v slot and analysed under the same boundary conditions. The experimental tests using driveline rig is also performed and on Road Vehicle Testing is verified with simulation results.

Keywords

V slot, Gear shifter fork, Structural Analysis, Driveline Rig Test

I. INTRODUCTION

The fork of the car is one of the key parts of the car speed shifting system playing an important role in shifting the speed and changing the direction. The fork could move the ring gear of synchronizer to separate and unite thus the speed shifting is achieved. As a part of the car the fork has a bearing on the safety of the car and person. The clear speed gear and the smooth transition have always been the objective of the transmission control facility design and important index for evaluation of good transmission. The ingenious and flexible control facility could not only improve the comprehensive function of the transmission but also promote the comfortable feeling of driving and riding.

Figure 1: Fork

The property of the speed shifting of the transmission has a direct bearing on the technological level and performance of the car. As an important part of transmission, the fork should not only have high stiffness and strength but also have good reliability. According to statistics a 80% of the mechanical damage belongs to fatigue damage.

II. LITERATURE REVIEW

Dogan [1] have investigated the cause of rattling and clattering noise and concluded that torsional vibration is the main reason of vibration. For this analysis, Dogan has used simple gearbox geometry. This geometry consist of only transmission casing. The main advantage of Dogan study is that he has start simulating such a complex geometry of transmission gearbox. He has used EKM simulating program. Abouel has performed similar study on car gearbox.

Abouel Seoud et al. [3] have used vibration response analysis method for the analytical analysis of car gearbox system. He has performed analytical and experimental analysis of a car transmission system. By using physical properties, he has calculated the radiation efficiency, and the vibration response was measured.

Vandi et al. [4] have presented the implementation of a simplified engine-driveline model to complete an existing vehicle dynamic model. The engine model is based on maps which are expressed as function of engine speed and load.

Nacib et al. [5] have performed the failure analysis of heavy gearbox of helicopters. To prevent break down and accident in helicopters gear fault detection is important. Spectrum analysis and Cepstrum analysis method is used to identify damage gear.

Gordon et al.[6] have studied the source of vibration. A Sports Utility Vehicle with sensor and data acquisition system is used to find the vibration source. This study was focused on vehicle vibration response from road surface features.

kar et al. [7] have used motor current signature analysis (MCSA) and discrete wavelet transform (DWT) for studying the gear vibration. Transmission errors and internal excitation causes vibration and noise problem.

Czech [8] has described the vibroacoustic diagnostics of high-power toothed gears. The presented analysis is a experimental work done in a steel plant.

Singh [9] has done two case studies for the vibro-acoustic analysis of automotive structures. Analytical and experimental results are presented for brief description. In first case passive and adaptive hydraulic engine mounts and in second case welded joints and adhesives in vehicle bodies were considered

III.MANUFACTURING PROCESS

Receiving of Raw material of Fork Diff lock 671 forging from Forger is done by store Department then Quality Gives Approval of Material to be used in manufacturing Process or not after ensuring the material by several tests. Checking these chemical Composition by Spector Analysis & Frequency of Checking is 1 Nos per Heat Code lot Checking Method Includes Supplier TC Verification, Mill Tc & outside Lab TC For Verification & Inhouse Testing of Material Chemical Composition. SPM Is a Special Purpose Milling Machine Specially Used for Fork Dill Lock of Part no. 671.In This Milling Machine Forged Part Is Rested Vertically for Milling Total Length of the Fork & Maintaining Other Dimension Like Boring of Día 20.056± .016.Milling Done on both the Faces of The Fork Front Face & Back Face of the Fork for Maintaining the Dimension of Total length of 59±0.2. For Maintaining This Dimension Part Is Rested On v Block for Mistake Proofing, Clamping & Resting of The Part Is Done on Both Pads & Part is Located from Both the Outer Curves of Pad. In SPM Machine Part Is Located from to side of the Forging For adjusting the load of the Whole Part. In This Method Boring of The Part is Done by Boring Bar & Dim 20±0.016 should be Maintain At Higher Side of Specification. Surface Finish of 1.6 RA &inside the Bore is Maintained By using Finish Reamer * 3.2 Ra Maintained on both Faces of Milling. OPN 30: - In This Operation Part Moved to VMC Machine for further Process, in this Part rested On Hydraulic Fixture by Horizontal y & Clamping on Both Pads from Top. In this Operation Part Located on Both Side of the curve of outer Side of the Pad & Maintaining Bellow Given dimensions. In This Operation Cross Hole 8.5 ± 0.2 Made by Using Drill. For Easy Process Hydraulic Fixture is Used With turret for Easy Rotating of Fixture in 90°. So that When Pad Milling Completed by End Mill the Fixture Will be rotated in Angle for Conducting Cross Hole of 8.5 mm by which Specifications can be Maintained Easily with les Effort of Introducing Separate Operation. Induction Hardening Done on both Pads of the Part, heat Treatment process Done on Pads for Maintaining 45 HRC Min at 1.5 to 3 Mm Depth Portion & 55 to 6 HRC Min. as Quenched. LH & RH both Side Pad Hardened Done For maintaining required Pattern. Tempering Should BE Done within 4 to 6 Hrs. Max. From Frist piece after Induction in Tempering Furnace. Lot No. Will be Generated for lot Tracing. During Induction Process if Power, off then Part Must be rejected & Kept in rejection Bin. Part fitted in Induction Fixture
& Heating Passed by using induction Coil made by Copper Tubes.

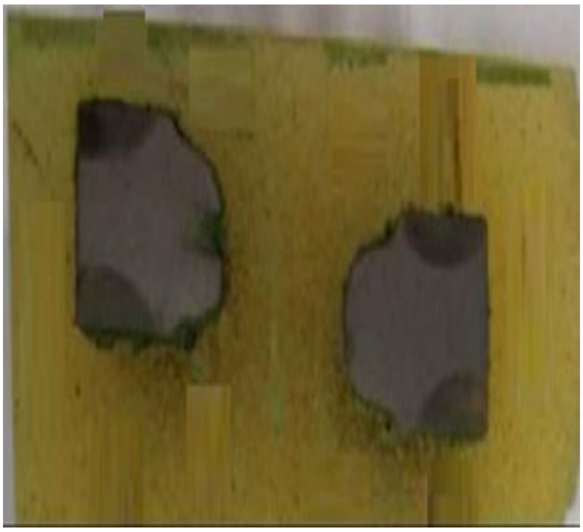


Figure 2: Pad Induction Case Depth

Figure 3: Fork Induction Coil

Figure 4: Induction Hardening Fixture

MPI Is Magnetic Particle Inspection Method in which, Magnetic Field is Generated on Part & then Checking the Stress Generated on the Part With the Help of ultra Violet Rays For Detecting Cracks Generated on the Part During The Process.100% Parts Should be Checked in MPI for Eliminating the Causes of Field Failure in Vehicle function.

Figure 5: Demagnetization of Fork

This Process Includes Cleanliness of the Fork as per the requirement of 0.040 M^2 of Total Part Area and Maximum Allowable contaminant is 17.76 mg. This Process Will be Achieved by TEC Chemical, Millipore Kit & Millipore Paper Size 5 Micron. After This method Part Should BE Clean in Visual Inspection As per the Assembly Requirement.

IV. EXPERIMENTAL TESTING

Experimental Testing of process done on Co-ordinate measuring machine, for Dimensional testing of part.

METALMAN AUTO PVT. LTD.

ACCURATE

Customer Name:	VECV	Date:	14-04-2018
Part Name:	Fork	Time:	17:05:19
Inspected By:	Pradeep Kumar Jha	Part No. :	R140671
Approved By:	Ashok Mansare	CMM INSPECTION REPORT	

	A	N	D / B	LT	UT / T	OOT
POSITION_OF_HOLE_20.056 [CYL_2] [POS]						
Pos	0.1612		0.0000		0.2000	
CD_188.80 [CYL_1 - CYL_2] [DISTB]						
Dst	188.8806	188.8000	0.0806	-0.1500	0.1500	
PARPENDICULARITY_0.1 [CYL_2] [PERP]						
Per	0.0226		0.0000		0.1000	
ANGLE_60 [PLA_6 - PLA_7] [ANGLB]						
Dst	60.2765	60.0000	0.2765	-2.0000	2.0000	
ANGLE_39.9 [PLA_8 - LIN_1] [ANGLB]						
Dst	39.9524	39.9000	0.0524	-0.5000	0.5000	
ANGLE_29.9 [PLA_12 - LIN_2] [ANGLB]						
Dst	29.8925	29.9000	-0.0075	-0.5000	0.5000	
ANGULARITY_0.6 [PLA_8] [ANGLR]						
Ang	0.0274		0.0000		0.6000	
CYL_1 [CYLNDR/INNER]						
Dia	98.3805	98.3805	0.0000	-0.1500	0.1500	

Figure 6 : CMM Testing Report

Another test of new fork diff lock shifter is done on driveline test rig. In driveline test rig fork is assembled on driveline and different types of stresses and forces are applied on fork for knowing failure mode of fork. In experimental testing 4 sample forks are arranged and assembled in commercial vehicles. These vehicles run 2 lac kilometres in static conditions and abnormal conditions also for testing fork practicality and knowing deformation in fork.

METALMAN AUTO PVT. LTD. Forging Report		Form No.	MAPL/F/PROD/51
		Issue:	01
		Sheet No.	1/1

Report No.	3023	Date	20/01/2018
Part Name.	Fork Diff. Lock	Raw Material	SAE 1541
Part No.	671	Raw Material Used	SAE 1541
Material TC	Recieved	Heat No./Heat code	17B2370/17L11
Suppler Name	Harpreet Forgings	Qty	100 Nos

Chemistry (as per Std.) (Test Method – ASTM E415)

Composition	%C	%Mn	%Si	%P	%S	%Cu	%Cr	%Mo	%Ni	%Cr+Mo+Ni	%Ca
Specified Min.	0.36	1.35	0.15	-	-	-	-	-	-	-	-
Specified Max.	0.44	1.65	0.35	0.040	0.040	0.30	0.20	0.06	0.12	0.25	
Obs. Value T.C	0.40	1.46	0.23	0.020	0.021	0.006	0.090	0.001	0.005	0.096	-
Inhouse Spectro	0.38	1.36	0.27	0.019	0.010	0.004	0.18	0.050	0.008	0.23	0.09

Inclusion Rating at 100X (as per Std.)

Type	(A) Sulphide		(B) Alumina		(C) Silicate		(D) Oxide	
	Thin	Heavy (Thik)	Thin	Heavy (Thik)	Thin	Heavy (Thik)	Thin	Heavy (Thik)
Specified	4	3	4	3	3	2	2	2
Observed Supplier T.C	1.5	-	1.0	-	1.0	-	1.5	-

Metallographic Observation:

Test	Specification	Observation	Remark
Core Microstructure	Pearlite + Ferrite	Pearlite / Ferrite	OK
Grain	5 – 8	7	OK
Macro Test (T.C)	C2, R2, S2 Max	C2, R2, S2	OK
Hardness	241 BHN Max	179 - 183 BHN	OK
Remark:- OK			

Figure 7: Forging Testing Report

As per forging material testing report it has been found that requirement of core microstructure that is pearlite and ferrite combination observed in testing as required grain size of particle required in 5 to 8mm observed 7 and hardness of 241BHN maximum observed 179 to 183BHN found ok as given in above report.

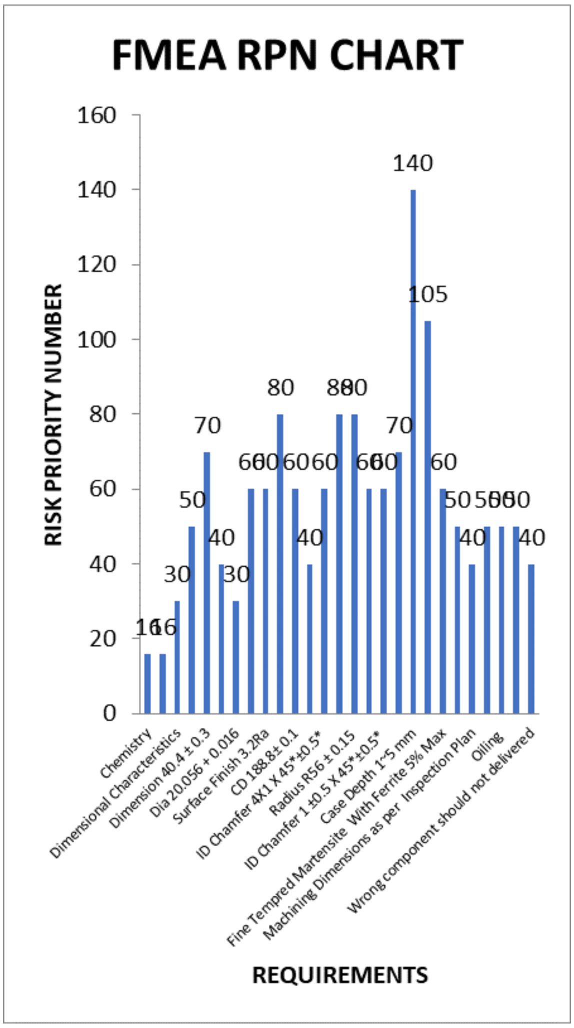


Figure 8: RPN Chart

Process failure mode effective analysis doe on various parameters for knowing risk priority number obtained from severity of specifications occurrence of failures and detection of dimensions in various operations.

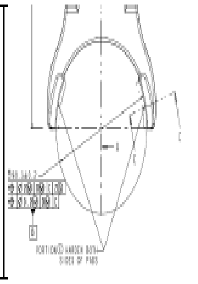
Risk priority number = severity x occurrence x detection

As we can see the graph between requirements and risk priority number maximum risk in fork is to maintain the case depth of 125mm and achieving hardness in induction process

METALMAN AUTO PVT. LTD. Material Test Report	Form No.	MAPL/F/PROD/51
	Issue:	01
	Sheet No.	1/1

Report No.	18030018	Date	15/04/2018
Part Name.	FORK, DIFF LOCK SHIFTER	Raw Material	SAE 1541
Part No./ Rev. No.	R140671(218384RE/B)20010302	Raw Material Used	SAE 1541
Material TC	Received Ok	Heat No.	B239(5567)
Heat Treatment Process	Induction Hard. & Temp. (HT30T)	Quantity	10 Nos.
Induction Hardening Batch, done & date	K22C18	Chemical Composition Report No. & Date	
	14/04/2018		

Component Sketch



Induction Heat Treatment Process Parameters (as per Std.)

Machine no.	2	KW	100 KW	
Location	X	Location	X	OK
Power (kW)%	18 %	Rotation	no	
Start Heating Time	After2 secs	Frequency KHZ	30 khz	
Heat Dwell Time	1.65 Sec	Polymer% (Without factor)	2%	
Scan Speed (Feed)	150 mm/min	Total Cycle Time	14 Sec	
Total Heating Time	2 sec	Quenching Bath Temp.	27 °C	
Total Quenching Time	8 secs	Tempering Temp.	160°C @ 90 min.	

Figure 8: Pattern Testing Report

Quality requirements for induction hardening for 'X' (as per std.)

Test	Specification	Observation		Remark
Hardness	52 – 59 HRC	56 - 57 HRC		OK
Case Depth @ X Loc.	1.0 mm min. @ 440 HV1 (45 HRC)	Pad 1	A = 2.30 mm	OK
			B = 2.20 mm	
		Pad 2	A = 2.40 mm	
			B = 2.10 mm	
MPI	No Crack	No Crack Found		OK

Metallographic Observation:

Test	Specification	Observation		Remark
Case Microstructure	Fine Tempered Martensite at 400X	Fine Tempered Martensite		OK
	5% ITP depth at 100X	Paid 1	Paid 2	OK
		A- 1.3, B- 1.2 mm	A-1.4, B-1.3 mm	
	50 % Martensite Depth at 100X	A -1.9, B – 1.8 mm	A-1.8, B- 1.8 mm	OK
	HAZ at 100X	A-2.5, B – 2.3 mm	A -2.5, B -2.3 mm	OK
Core Microstructure	Pearlite + Ferrite	Ferrite / Pearlite		OK
Grain	5 – 8	7		OK

Case Depth @ Pad 1 Loc.

Dist. In mm	A	0.1	1.0	2.0	2.4		
Hard. In HV1		630	630	584	395		
Dist. In mm	B	0.1	1.0	2.0	2.3		
Hard. In HV1		623	627	500	260		

Case Depth @ Pad 2 Loc.

Dist. In mm	A	0.1	1.0	2.0	2.5		
Hard. In HV1		613	652	605	304		
Dist. In mm	B	0.1	1.0	2.0	2.2		
Hard. In HV1		664	675	522	271		

Pattern Photo

1	4.60 mm	L1	5.95 mm
2	5.25 mm	L2	5.81 mm
3	2.81 mm	L3	5.97 mm
4	8.15 mm	L4	5.31 mm

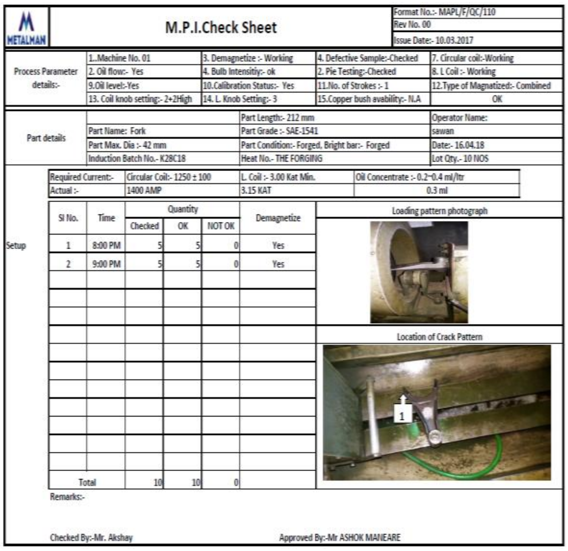
Remark:

Checked By: Jimmy

Approved By: Ashok Mansare

Figure 9: Case Depth Testing Report

In the above induction hardening report pattern we have performed the operation on location x of pad as given in report with 18% power consumption after 2 sec and with the scan speed of 150mm at quench speed of 8 sec found case depth on a pad is 2.4 mm and b pad is 2.3mm as per requirement found microstructure is fine tampered martensite, core microstructure of ferrite and perlite with grain size of 7mm and hardness of 56 to 57hrc.



M.P.I.Check Sheet

Format No.:- MAPL/F/QC/110
Rev No. 00
Issue Date:- 10.03.2017

Process Parameter details:-				
	1..Machine No. 01	3. Demagnetize :- Working	4. Defective Sample:-Checked	7. Circular coil:-Working
	2. Oil flow:- Yes	4. Bulb Intensitiy:- ok	2. Pie Testing:-Checked	8. L Coil :- Working
	9.Oil level:-Yes	10.Calibration Status:- Yes	11.No. of Strokes :- 1	12.Type of Magnatized:- Combined
	13. Coil knob setting:- 2+2High	14. L. Knob Setting:- 3	15.Copper bush avability:- N.A	OK

Part details			
		Part Length:- 212 mm	Operator Name:
	Part Name: Fork	Part Grade :- SAE-1541	sawan
	Part Max. Dia :- 42 mm	Part Condition:- Forged, Bright bar:- Forged	Date:- 16.04.18
	Induction Batch No.- K28C18	Heat No.- THE FORGING	Lot Qty.- 10 NOS

Setup

Required Current:-	Circular Coil:- 1250 ± 100	L. Coil :- 3.00 Kat Min.	Oil Concentrate :- 0.2~0.4 ml/ltr
Actual :-	1400 AMP	3.15 KAT	0.3 ml

Sl No.	Time	Quantity Checked	OK	NOT OK	Demagnetize
1	8:00 PM	5	5	0	Yes
2	9:00 PM	5	5	0	Yes
Total		10	10	0	

Loading pattern photograph

Location of Crack Pattern

Remarks:-

Checked By:-Mr. Akshay

Approved By:-Mr ASHOK MANEARE

Figure 10: MPI Result

This is non-destructive type of testing for detecting cracks on part by use of circular coil 1250 on 1400 ampere under 3.15kat and oil concentration of 0.3ml. Checking cracks by generating magnetic field on fork, applying oil flow and then visually detecting it in presence of uv rays.

V. RESULTS AND DISCUSSION

After Experimental testing we have found that the New fork is Compactable and having less weight as comparing with old existing fork .The new Fork also have good principal Stress , Satisfactory Von Mises Stress

Table 1:- Comparison of experimental Results

PARAMETERS	EXPERIMENTAL RESULTS	SOFTWARE RESULTS	PERCENTAGE DIFFERENCE
PRINCIPAL STRESS (Mpa)	104.2	103.05	1.7%
VON MISES STRESS (Mpa)	199.04	196.68	2.36 %
DEFLECTION (MM)	0.77	0.76	1.2%
WEIGHT (KG)	1.078 kg	1.075 kg	0.27 %

VI. CONCLUSIONS

The Driveline Test Rig is conducted on fork using obtained shows that fork without V slot and U slot performs better as compared with fork with U and V slots. Removal of U and V slots has also helped in weight reduction. Along with that the rejection rates which were higher in forks with slots is drastically reduced. Thus, the removal of slots has aided in reducing weight and high compactness is achieved which lead to better interference fit in assembly line and lower rejection rates during manufacturing. The experimental analysis is also conducted on Road by Assembled forks in four Commercial Vehicles which run 2 Lakh Kilometres and Found Results in close agreement with simulation results.

REFERENCES

[1] Dogan, S.N. (1999). Loose part vibration in vehicle transmissions Gear rattles. Transactions Journal of Engineering and Environmental Science, 23, 439-454.

[2] Wang, J.; Zheng, J.; and Yang, A. (2012). An Analytical Study of Bifurcation and Chaos in a Spur Gear Pair with Sliding Friction. Procedia Engineering, 31, 563-570.

[3] Abouel-Seoud, S.S.; Mohamed, E.S.; Abdel-Hamid, A.A.; and Abdallah, A.S. (2013). Analytical Technique for Predicting Passenger Car Gearbox Structure Noise Using Vibration Response Analysis. British Journal of Applied Science & Technology, 3(4), 860-883.

[4] Vandi, G.; Cavina, N.; Corti, E.; Mancini, G.; Moro, D.; Ponti, F.; and Ravaglioli, V. (2014). Development of software in the loop environment for automotive powertrain systems. Energy Procedia, 45, 789 – 798.

[5] Nacib, L.; Pekpe, K.M.; and Sakhara, S. (2013). Detecting gear tooth cracks using cepstral analysis in gearbox of helicopters. International Journal of Advances in Engineering & Technology, 5, 139-145.

[6] Gordon, T.J.; and Bareket, Z. (2007). Vibration Transmission from Road Surface Features– Vehicle Measurement and Detection. Technical Report for Nissan Technical Center North America, Inc. UMTRI-2007-4.

[7] Kar, C.; and Mohanty, A.R. (2006). Monitoring gear vibrations through motor current signature analysis and wavelet transform. Mechanical Systems and Signal Processing, 20, 158–187.

[8] Czech, P. (2012) Diagnosis of industrial gearboxes Condition by vibration and time frequency, Scale-frequency, frequency-frequency analysis. Metalurgija, 51, 521-524.

[9] Singh, R. (2000). Dynamic design of automotive systems-Engine mounts and structural joints. Dynamic design of automotive systems, 25, 319-330.

[10] Tuma, J. (2009). Gearbox Noise and Vibration Prediction and Control. International Journal of Acoustics and Vibration, 14, 1-11.