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AUTOMOTIVE TRANSMISSION SYSTEM DESIGN BASED ON RELIABILITY PARAMETERS

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Abstract

Failure of any component or product or system before its time period is always unacceptable and hence in the engineering design the safety and reliability of any system is invariably the principal technical objective. The level of design, control and manufacturing of automobiles transmission system has always been critical in terms of reliability and safety. This paper describes the work done by the Author(s) for the reliability based design of automobiles transmission system based on its failure criteria at subsystem and system level in order to improve the reliability of whole transmission system and henceforth the safety and it has also shown with the results that while designing such system based on reliability parameters, the reliability has always improved with the improved factor of safety values.

Key Words: Automotive Transmission System, Reliability, Safety, Factor of Safety, Failure Analysis.

1. Introduction

The transmission system of the vehicle is an elaborate assembly of gears, shafts, bearings and other parts that transfers selected amount of power to the vehicles wheels [1]. The transmission enables the vehicle to accelerate forward or backward or to maintain high cruising speeds-all while the engine operates at efficient speeds and within safety limits. In the development of cars, transmission evolution veered the vehicle towards comfort and convenience.

The research work presented in this paper, to design automotive transmission system based on reliability parameters is the advanced and completely new methodology developed by considering the work done by S.S Rao and M Tjandra [2]. In this work the following main components for modeling and reliability based design of the transmission system at system level, considering the main failures that could occur with their respective components [3, 4] is done.

1) Gear Pairs. 2) Shafts and 3) Bearings.

1.1 Gear-pairs

In the transmission system case, the failure of the gear train is characterized by either of the two modes of failure [5, 6].

1) Bending and
2) Surface wear.

The layout, speeds and the interconnection of the various gear pairs of the gear train are considered to be known. The power transmitted by all the gear pairs is assumed to be the same. The design parameters are the face widths of the gear pairs for variable data.

1.2 Shafts

The three shafts as mentioned below in the transmission system is considered for designing.

1) Input shaft (clutch shaft)
2) Lay shaft (counter shaft)
3) Output shaft (main shaft)

The transmission shafts are subject to combined bending and torsion. It would seem reasonable to use maximum shear stress for the case of ductile components under combined stress. So for the case of a rotating shaft, it can be designed with respect to failure mode of Fatigue failure due to its maximum shaft diameter.

1.3 Bearings

There are five bearings which has been considered for design

1) Input shaft bearing.
2) Lay shaft front bearing.
3) Lay shaft rear bearing.
4) Main shaft front bearing.
5) Main shaft rear bearing.

All bearing are cylindrical roller bearings. The roller bearings have a higher radial load capacity compared to ball bearings. Furthermore, most modern automobile transmission systems use plain or tapered roller bearings to support the shafts. In calculating the forces acting on the bearings, the bearings are modeled as simple supports for the shaft. The design parameter is the length of the roller bearing.

2. Formulation of Automatic Transmission System Design

Design of the automotive transmission system involves the Reliability based design of gear-pairs, shafts and bearings taking the parameters i.e., face width of gears, diameter of shafts and length of roller of bearings with respect to the variable factor of safety values. The methodology and the necessary procedural frame work to do the safe design of the transmission system is analyzed and derived by Author(s) and is verified and implemented in collaboration with IIT Bombay and General Motors, Bangalore. The concepts below explain the strategy for safe design of the transmission system considering reliability parameters, in order to improve the reliability of the whole system and as well as at component level (refer Appendix A for understanding)

2.1 Reliability Based Design of Gear-pairs

Calculating face width of gear

1. Calculate Tangential Load F_t

$$F_t = \frac{P \times K_t \times K_w}{V_p} \tag{1}$$

Where P – Power, HP
K_t – Load Factor
K_w – Wear Factor
V_p – Pitch line Velocity m/sec^2

Bending Criteria:

2. Calculate beam strength F_b

$$F_b = S_0.C_v.b.Y.m_n \tag{2}$$

3. Calculate Face width b by equating $F_b = F_t$

Surface wear criteria

4. Calculate Dynamic load F_d

$$F_d = F_t + \frac{2W_p(C.e.b.\cos^2\psi + F_t)}{2W_p + \sqrt{C.e.b.\cos^2\psi + F_t}} \tag{3}$$

5. Calculate Wear Strength F_w

$$F_w = \frac{m_n.T_p.b.K.Q}{\cos^2\psi} \tag{4}$$

6. Calculate Face width b by equating $F_w = F_d$

Take maximum value of face width to make gear safe both from bending and surface wear.

Steps for calculating Reliability of a gear
Take face width as calculated above.

Surface criteria:

- Calculate mean value of Tangential load $\overline{F}_t$

$$\overline{F}_t = \frac{\overline{P} \times \overline{K_t} \times \overline{K_w}}{\overline{\overline{V}}_p} \tag{5}$$

- Calculate standard deviation of Tangential load σ_{F_t}

$$\sigma_{F_t} = \overline{F_t} \times \left(\gamma_p^2 + \gamma_{K_t}^2 + \gamma_{Kw}^2 + \gamma_{v_p}^2 \right)^{\frac{1}{2}} \tag{6}$$

Bending criteria:

- Calculate mean value of Beam Strength $\overline{F}_b$

$$\overline{F}_b = \overline{S_0}.\overline{C_v}.\overline{b}.\overline{Y}.\overline{m_n} \tag{7}$$

- Calculate standard deviation of Beam strength σ_{F_b}

$$\sigma_{F_b} = \overline{F_b} \times \left(\gamma_{S_0}^2 + \gamma_{C_v}^2 + \gamma_b^2 + \gamma_{y'}^2 + \gamma_{m_n}^2 \right)^{\frac{1}{2}} \tag{8}$$

- Calculate reliability index β

$$\beta = \frac{\overline{F}_b - \overline{F}_t}{\sqrt{\sigma_{F_b}{}^2 + \sigma_{F_t}{}^2}} \tag{9}$$

- Calculate Reliability, using Normal standard R= φ(β)

Surface wear criteria:

- Calculate mean value of Dynamic load $\overline{F_d}$

$$\overline{F_d} = \overline{F}_t + \frac{2\overline{W_p}(C.e.\overline{b}.\cos^2\overline{\psi} + \overline{F_t})}{2\overline{W_p} + \sqrt{C.e.\overline{b}.\cos^2\overline{\psi} + \overline{F}_t}} \tag{10}$$

- Calculate standard deviation of Dynamic load σ_{F_d}

$$\sigma_{F_d} = \left(\sigma_{F_t}^2 + \sigma_{X_5}^2\right)^{\frac{1}{2}} \tag{11}$$

- Calculate mean value of wear strength $\overline{F_w}$

$$\overline{F_w} = \frac{\overline{m_n}.\overline{T}_p.\overline{b}.\overline{K}.Q}{\cos^2\overline{\psi}} \tag{12}$$

- Calculate standard deviation of wear strength σ_{F_w}

$$\sigma_{F_w} = \overline{F_w} \times \left(\gamma_{m_n}^2 + \gamma_b^2 + \gamma_k^2 + \gamma_Q^2 + \left(3\tan\overline{\psi}\right)^2.\sigma_\psi^2\right)^{\frac{1}{2}} \tag{13}$$

- Calculate reliability index β

$$\beta = \frac{\overline{F}_w - \overline{F}_d}{\sqrt{\sigma_{F_w}{}^2 + \sigma_{F_d}{}^2}} \tag{14}$$

- Calculate Reliability, using Normal standard table

R= φ(β)

2.2 Reliability Based Design of Shafts

The loading on Transmission Shaft is the Torque (T) and Bending (M). They produce shear stress and bending stress respectively in it. The shear and bending stress are

$$s_{shr} = \frac{16T}{\Pi d^3} \quad \text{(Due to torsion)} \tag{15}$$

$$s_b = \frac{32M}{\Pi d^3} \quad \text{(Due to bending moment)} \tag{16}$$

Where,

s_{shr} =Shear stress (N/mm^2)

S_b= bending stress (N/mm^2)

d= diameter of shaft (mm)

T=torsion= $\frac{60P*k_l*k_w}{2\Pi N_{input}}*10^3$ (N-mm)

K_l=load factor

K_w=wear factor

M= bending moment (in N-mm) which can be obtain from a Bending Moment Diagram (BMD) of the shaft.

P= power (W)

Fatigue Failure due to maximum shear stress theory

In case of combined bending and torsion of circular shafts, the maximum shear theory with Sodarberg's approach of fatigue failure yields induced shear stress as

$$s_{shr} = \frac{16T}{\Pi d^3} * \sqrt{\{[M_m + \frac{S_y}{S_e} * K_f * M_v]^2 + [T_w + \frac{S_{yshr}}{S_{eshr}} * K_f * T_v]^2\}} \tag{17}$$

The majority of Rotating shafts carry a steady torque and loads remain fixed in space in both direction and magnitude. Thus during each revolution every fiber on the surface of the shaft undergoes a complete reversal of stress due to bending moment. Therefore for the usual case when M_m=0, M_v=M, T_m=T, T_v=0, the above equation will become as

$$s_{shr} = \frac{16}{\Pi d^3} * \sqrt{[\frac{S_y}{S_e} * K_f * M]^2 + T^2} \tag{18}$$

Mean Value and Standard Deviation

Mean and Standard Deviation of induced shear stress is calculated using first order Taylor's Series expansion, so

$$\overline{s_{shr}} = \frac{16}{\Pi \overline{d}^3} * \sqrt{[\frac{\overline{S}_y}{\overline{S}_e} * \overline{K}_f * \overline{M}]^2 + \overline{T}^2} \tag{19}$$

Standard deviation is calculated in the following way

$$\overline{M_e} = \frac{\overline{S_y}}{\overline{S_e}} * \overline{K_f} * \overline{M}$$

$$\sigma_{M_e} = \overline{M_e}\sqrt{(\gamma_{S_y}{}^2 + \gamma_{K_f}{}^2 + \gamma_M{}^2 + \gamma_{S_e}{}^2)}$$

$$\overline{T_{eq}} = \sqrt{\overline{M_e{}^2} + \overline{T^2}}$$

$$\sigma_{T_{eq}} = \sqrt{\frac{\overline{M_e{}^2}}{\overline{M_e{}^2} + \overline{T^2}} * \sigma_{M_e}{}^2 + \frac{\overline{T^2}}{\overline{M_e{}^2} + \overline{T^2}} * \sigma_{M_e}{}^2}$$

$$\gamma_{T_{eq}} = \frac{\sigma_{T_{eq}}}{\overline{T_{eq}}}$$

$$\overline{s_{shr}} = \frac{16}{\Pi \overline{d}^3} * \overline{T_{eq}}$$

$$\sigma_{s_{shr}} = \overline{s_{shr}}\sqrt{\gamma_{T_{eq}}{}^2 + 9\gamma_d{}^2}$$

2.3 Reliability Based Design of Bearings:

The induced stress in a roller bearing, derived from the contact stress between two cylinders, can be expressed as

$$s_{bear} = 299.115\sqrt{\frac{P_o}{l_r d_r}} \tag{20}$$

Where,

P_o= radial load (N)
l_r = length of roller (mm)
d_r= diameter of roller (mm)

Mean Value and Standard Deviation:

Mean and Standard Deviation of induced contact stress is calculated using first order Taylor's series expansion, so

$$\overline{s_{bear}} = 299.115\sqrt{\frac{\overline{P_o}}{\overline{l_r}\,\overline{d_r}}} \tag{21}$$

$$\sigma_{s_{bear}} = \overline{s_{bear}}\sqrt{0.25({\gamma_{P_o}}^2 + {\gamma_{l_r}}^2 + {\gamma_{d_r}}^2)} \tag{22}$$

3. Results

The results are obtained using the procedure mentioned above for the variable data samples collected from Hindustan Motors and General Motors.

Gear-pairs Results: For Gear-pairs face width is calculated considering bending or surface wear only and considering both bending and surface wear. To make gear pair safe both from bending and surface wear the maximum value of face width is used for designing obtained from the various data samples with variable coefficient of factor of safety.

Results show that the reliability of gear-pair system at factor of safety 1.0 is 0.125 which is very-very less and from the probabilistic point of view the chance of system failure is extremely high. Further if factor of safety is increased from 1 to 2.0 the reliability increases considerably 0.9798. Also if factor of safety is increased to 2.2 the reliability increases to 0.9919 which shows that the design is completely safe.

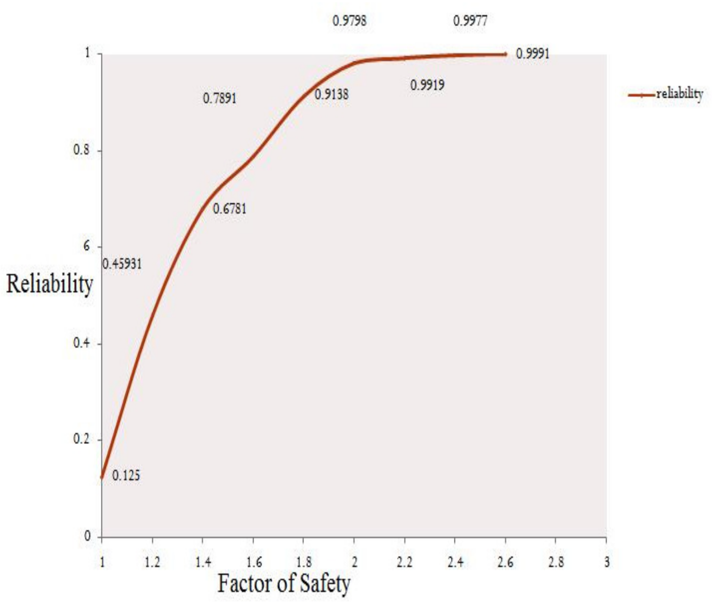

Fig.1: Reliability of Gear pair system Vs factor of safety

The face width values calculated at different values of factor of safety is considered, where both the bending and surface wear criteria is considered and the graph shows that the reliability increases as the value of face width of gear increases. It is to be presumed that to make the gear train design safe from both failures, the higher face width values has to be considered.

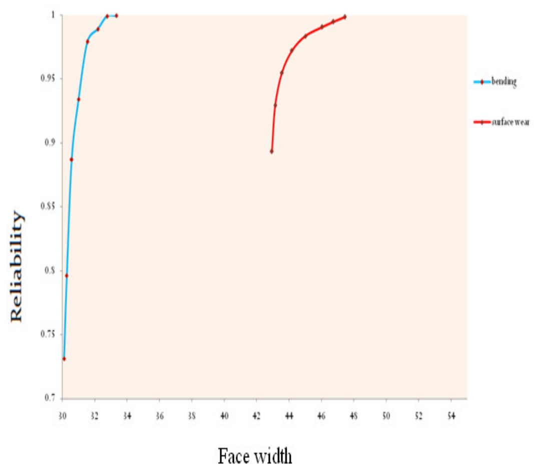

Fig.2: Reliability of Gear pair system Vs face width of gear

Shafts Results:

For shafts diameter is calculated considering fatigue failure with maximum shear stress theory.

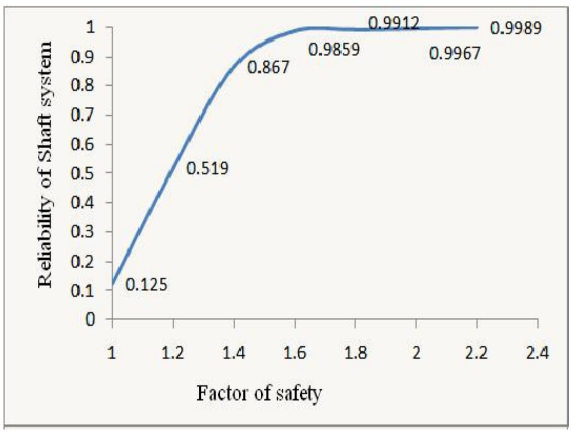

Fig.3: Reliability of shaft system Vs factor of safety

For the shafts the result shows that at factor of safety 1, the reliability is very-very less which is 0.125 and from probabilistic point of view there is extreme chance of failure and totally unacceptable design. On the other hand at factor of safety 1.6 the reliability is 0.9859 which is quite acceptable and it shows that the design is safe.

Bearing Results

For bearings length of the roller of bearings is calculated considering contact stress developed between two cylinders.

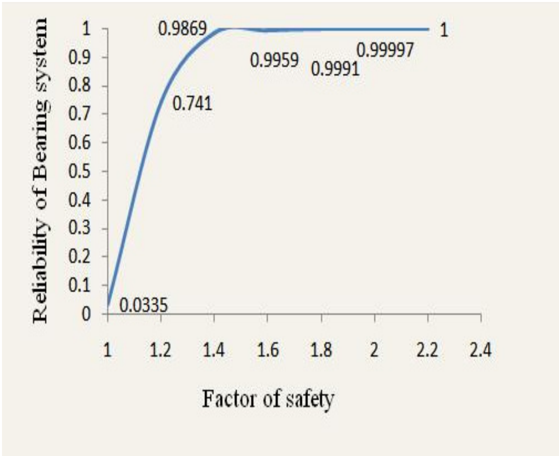

Fig.4: Reliability of bearing system Vs factor of safety

In the above fig the reliability of shaft system is taken on y-axis and factor of safety is taken on x-axis. From the graph we can clearly see that for the bearing system to get Reliability more than 98%, factor of safety should be greater than 1.4 (0.9869) and hence the design will be safe.

4. Results

The design of the of the Automotive Transmission System shows that reliability of gear pair system, shaft system and bearing system at factor of safety 1.0 is very less and hence there is a great risk of failure. For gear pairs face width is calculated considering bending or surface wear only and considering both bending and surface wear. The reliability of gear pairs at factor of safety 2 is 0.98 which is acceptable according to the manufacturing terms of General Motors. This shows that to make gear pair system reliable factor of safety should be kept greater than 2. Similar to gear pairs for the shafts, the diameter of shafts is calculated considering fatigue failure with maximum shear stress theory and to make the safe design of shaft system (i.e., reliability greater than 98%) the factor of safety value should be greater than 1.6 and similarly for bearings system length of roller bearing is calculated considering contact stress developed between two cylinders and to design the bearing system safely the factor of safety value for bearing system should be greater than 1.4. As all these components are connected in series and to make the safe design of entire system the factor of safety should be kept more than 2.5 for all gear pairs, shafts and bearings.

References

1. (1992). A study on automatic transmission control” London.
2. Agarwal, H. (2004). Doctoral Thesis (Reliability Based Design Optimization), University of Notre Dame.
3. Cruse, T.A. (1997). Reliability-based Mechanical Design, CRC Press; Har/Dskt edition.
4. He X. D. and Wen B. C. (2005). Reliability Sensitivity of Automobiles Components Switch Arbitrary Distribution Parameters, Journal of Automobile Engineering, 219, p. 165-182.
5. Rao, S.S. and Tjandra, M. (1994). Reliability based design of Automotive Transmission System, Journal of Reliability Engineering & System Safety, 46(2).
6. Sun, Z. and Hebbale, K. (2005). Challenges and Opportunities in Automotive Transmission Control, American Control Conference, June 8-10, 2005.
7. Tani, M., Yamada, K., Yoshida, H., Hayafune, K., Hatta, K. and Yoshida, S.
8. Wen, B. and Zhang Y. M. (2003). Practical Reliability Based Design of Gear Pairs, Journal of Mechanism and Machine Theory, 38, p. 1363-1370.
9. Yimin, Z. and Qiaoling, L. (2002). Reliability-based design of automobile components. Proceedings of the Institution of Mechanical Engineers Part D-Journal of Automobile Engineering, 216 (D6), p. 455–471
10. Zhang, Y.M. (2008). Reliability Based Design for Automobiles in China, Front. Mech. Eng. China, 3(4), p. 369–376.
11. Zhang, Y.M. and. Liu, Q.L (2002). Reliability based design of spur gears, Proceedings of the Institution of Mechanical Engineers Part C, Journal of Mechanical Engineering Science, 216 (C2), p. 179–182.

Appendix A

Reliability Based Design and calculation of Reliability of an Automatic Transmission System.

The initial data available for the five speed manual transmission system (Hindustan Motors, 1800 ISZ MPFI) is given below

ENGINE:

Type	MPFI with 4 cylinder OHC
Fuel	Petrol
Max power (P):	74HP at 5000rpm

TRANSMISSION SYSTEM:

Gear Box:	5 speed overdrive gear box
Gear Ratio:	

Gear	**Gear Ratio**
1st	3.737 : 1
2nd	1.963 : 1
3rd	1.364 : 1
4th	1.000 : 1
5th	0.776 : 1
Reverse	3.402 : 1

Primary Reduction ratio: 1.8 : 1

GEARS:

Type	standard 200 involute
Material :	SAE 1045 heat treated (carbon steel)
Max. Allowable Bending stress :	Sb = 245.24 N/ mm^2
Allowable Surface Wear Stress :	Sw = 1717.75 N/mm^2
Young's Modulus :	E = 2.10915 * 105 N/ mm^2
Deformation factor :	C = 12300
Error in profile:	e = 0.25
Load Factor	Kl = 1.25
Lubrication factor:	Kw = 1.15

Number of teeth on Gear Pairs

Gear Pair	Number of Teeth	Transmission Ratio
1st speed gear pair	T1 = 25, T2 = 45	1.800 : 1
2nd speed gear pair	T5 = 23, T11 = 47	3.678 : 1
3rd speed gear pair	T4 = 34, T10 = 36	1.906 : 1
4th speed gear pair	T3 = 40, T9 = 30	1.350 : 1
5th speed gear pair	T3 = 49, T9= 21	0.771 : 1
Reverse Speed	T6=15, T8=15, T12=28	3.360 : 1

Module: mn = mt =3mm

Helix angle: ψ = 16.50

Center distance: A = 109.5mm

SHAFTS:

Material C55Nn1,forged:hardened and tempered

Yield Strength (S_y) 460 N/mm^2

Shear Yield Strength (S_{y-shr}) yield strength/2 = 230 N/mm^2

Ultimate Strength (S_{ut}) 775 N/mm^2

Endurance Limit (S_e) 0.46 S_{ut} N/mm^2

Fatigue Stress concentration factor (K_f) 1.5

BEARINGS:

Type Cylindrical roller bearing

Roller diameter (d_r) (for each bearing) 10mm

Maximum allowable strength (S_a) 3433.5 N/mm^2

γp = 0.1, γkw=0.033, γm=0.005, γw=0.005, γN=0.1, γb=0.005, γso=0.1, γSw=0.1, γE=0.5, γSy=0.1, γSut=0.1, γkf=0.01, γL_shaft=0.005, γd_shaft=0.005, γd_gear=0.005, γSa=0.1, γdr_bearing=0.005, γlr_bearing=0.005

Calculation of face width and Reliability Estimation of Gear-pairs

- This involves the designing of gear pairs and its reliability.
- To find out the reliability of the gear pairs, the face width of gear pairs is calculated considering the bending or surface wear.
- To make gear pair design safe from both bending and surface wear the maximum value of face width is used.
- The reliability of gear pair system at different values of factor of safety and face width of gear is found out and the graph has been plotted using those values.
- The Reliability Based Design of Gear pairs of Automatic Transmission System has done with an intention to obtain more than 98% Reliability of the gear-pair system and to obtain the same we observed that the factor of safety should be atleast 2.0
- To obtain this results the face width of the gear pairs is calculated considering bending and surface wear criteria and considering bending or surface wear criteria only and the graphs for this two conditions has been plotted for different values of face width and factor of safety obtained from the calculations by calculating the Reliability Values for all values.
- From the data given we will now proceed to calculate the face width and the reliability of a gear system.
- While designing, for making gear safe from bending, the beam strength (F_b) must be greater than tangential load (F_t) . i.e., ($F_b > F_t$) and
- From surface wear, wear strength (F_w) must be greater than dynamic load (F_d) . i.e., ($F_w > F_d$)

Calculating face width of a gear

1. Calculate Tangential Load F_t
2. Bending criteria:
   Calculate Beam Strength F_b
   Calculate Face width b by equating $F_b = F_t$
3. Surface wear criteria:
   Calculate Dynamic load F_d
   Calculate Wear Strength F_w
   Calculate Face width b by equating $F_w = F_d$

Take maximum value of Face width to make gear safe both from Bending and wear.

Calculating Reliability of a gear

Take face width as calculated above.

- Calculate mean value of Tangential load $\overline{F_t}$
- Calculate standard deviation of Tangential load σ_{F_t}

<u>Bending criteria:</u>

- Calculate mean value of Beam Strength $\overline{F}_b$
- Calculate standard deviation of Beam strength σ_{F_b}
- Calculate reliability index β
- Calculate Reliability, using Normal standard table
  R= φ(β)

<u>Surface wear criteria:</u>

- Calculate mean value of Dynamic load $\overline{F_d}$
- Calculate standard deviation of Dynamic load σ_{Fd}
- Calculate mean value of wear strength $\overline{F}_w$
- Calculate standard deviation of wear strength σ_{Fw}
- Calculate reliability index β
- Calculate Reliability, using Normal standard table
  R= φ (β)

As we know that the Automatic Transmission System is a combination of Gear-pairs, Shafts, bearings and other small parts we will further move to look ahead for the Reliability based design of shafts and bearings to complete the design of total Automatic Transmission System.

Now for the Reliability based design of shafts the diameter of a shaft is calculated at different values of factor of safety and the graph has been plotted. Similarly the Reliability based design of bearings has been done in which the length of the roller bearing is calculated for different values of factor of safety.

Calculation of Shaft diameter and Reliability Estimation of Shafts

While designing, to make shaft safe from fatigue failure the yield shear stress(Sy-shr) must be greater than the induced shear stress (Sshr) as obtained from the maximum shear stress theory i.e, Sy-shr > Sshr

Calculating diameter of a shaft

1. Calculate maximum bending moment (M) on the shaft using Bending moment diagram (BMD) technique.
2. Calculate maximum Torque (T) applied on shaft.
3. Calculate endurance limit (Se), using Se =0.46 Sut
4. Calculate induced shear stress (Sshr) using the equation given in formulae list.
5. Calculate design shear strength of material of shaft by dividing shear yield strength by Factor of Safety (FS). Sd-shr = Sy-shr /FS
6. Calculate diameter of shaft by equating induced shear stress and design shear strength of material of shaft i.e, Sd-shr = Sshr

Calculating Reliability of a shaft

1. Take diameter as calculated above in step 6.
2. Calculate mean value of induced shear stress Sshr from formulae list.
3. Calculate standard deviation of induced shear stress $\sigma_{s_{bear}}$
4. Calculate mean value of shear yield strength $\overline{S_{y-shr}}$ of material of shaft
5. Calculate Standard deviation of shear yield strength using $\sigma_{S_{y-shr}} = \overline{S_{y-shr}} * \gamma_{S_y}$
6. Calculate Reliability index β using $\beta = \dfrac{\overline{S_{y-shr}} - \overline{S_{shr}}}{\sqrt{\sigma_{S_{y-shr}}{}^2 + \sigma_{S_{shr}}{}^2}}$
7. Calculate Reliability, using Normal Standard table R= φ(β) strength of material of shaft i.e, Sd-shr = Sshr

In the Transmission System there are different shafts called input shaft, lay shaft and main shaft and if any one failure of this shaft will cause the failure of the whole Transmission System and hence this shafts should be arranged in a series.

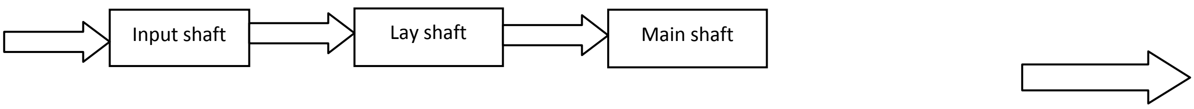

Fig.5: Reliability Block diagram of Shaft system

Reliability of this shaft system is given as

Rshaft-syst= Rinput-shaft * Rlay-shaft * Rmain-shaft

Calculation of length of roller bearing and Reliability Estimation of Bearings

While designing of bearing, maximum allowable strength (Sa) must be greater than the induced contact stress (s) i.e., Sa >s

Calculating of length of roller of a bearing

1. Calculate radial load (Po) acting on the bearing using equations of equilibrium of forces and moments on it.
2. Calculate induced contact stress(s) on the bearing using formulae list.
3. Calculate design strength (Sd)of material of roller of bearing by dividing maximum allowable strength (Sa) of roller of material by Factor of safety Sd= Sa /FS
4. Calculate length of roller (lr) of bearing by equating induced stress and design strength of material of roller of bearing Sd=s

Calculating of Reliability of bearing

1. Take length of roller as calculated above in step 4.
2. Calculate mean value of induced contact stress s using formulae list.
3. Calculate standard deviation of induced contact stress σs
4. Calculate mean value of maximum allowable strength of material of roller of bearing.
5. Calculate standard deviation of maximum allowable strength of material of roller of bearing using $\sigma_{S_a} = \overline{S_a} * \gamma_{S_a}$
6. Calculate Reliability index β, using $\beta = \dfrac{\overline{S_a} - \bar{s}}{\sqrt{\sigma_{S_a}^2 + \sigma_S^2}}$
7. Calculate Reliability, using Normal standard table R= φ(β)

In the Transmission System there are five different bearing and if any of the bearing i.e., input-shaft bearing, lay-shaft bearing, lay-shaft front bearing, lay-shaft rear bearing, main-shaft front bearing or main shaft rear bearing fails, the total system will get failed. So all the five bearings must be connected in series, while making the reliability block diagram for bearing system.

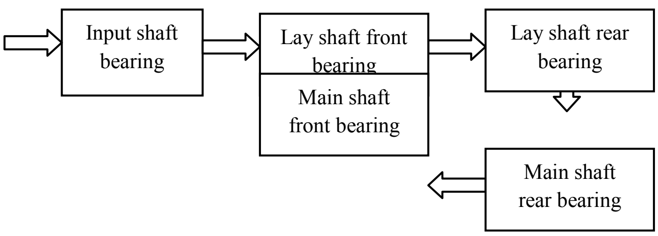

Fig.6: Reliability Block Diagram of bearing system.

Reliability of this Bearing system is given as
R(bear-syst)= Rinputshaft-bear *Rinputshaft-front-bear *Rlayshaft-rear-bear *Rmainshaft-front-bear *Rmainshaft-rear-bear

Reliability estimation of Automatic Transmission System

Reliability block diagram for the Transmission system will be as follows

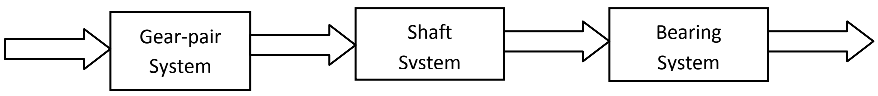

Fig.7: Reliability Block Diagram of Automatic Transmission System

Reliability of this system is given as [RTrans-syst= Rgearpair-syst * Rshaft-syst * Rbearing-syst]