Reliability Prediction And DFMEA of PTO Gearbox of ARRV

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Abstract*- This paper presents Reliability analysis model of PTO Gearbox by developing generic gearbox configuration and modules structure. It encapsulates all the Reliability critical components with the Gearbox in drive engine. Here find out the system reliability of PTO Gearbox of ARRV. DFMEA is carried out systematically by brainstorming team to identify the potential failure modes and its effects of a product and process. This will be Optimize the design parameters of PTO Gearbox by using Reliability prediction and DFMEA calculation and divide the failure modes by using RPN value.*

Keywords- Reliability prediction, RPN, DFMEA, Failure modes.

NOMENCLATURE:
DFMEA = design failure mode and effect analysis
PTO = Power take off
RPN = Risk Priority number
A_E= Misalignment Factor
λ_G = Total failure rate of gears
$\lambda_{G,B}$ = Base failure rate of component.
C_{GS} = Speed factor
C_{GL} = Lubrication factor
C_{GP} = Actual loading
C_P = Pressure factor
H_1 = Helical gear one
H_2 = Helical gear two

I. INTRODUCTION

MizraHyder et al. [1], Reliability prediction describes the process which is used to estimate the constant failure rate during the useful life of a product. Reliability prediction is one of the important criteria in the new product development process. Carderock div et al. [2], farav J.et arom this paper carried out the Failure rate and Failure modes of Mechanical components. Robin. MC Dermott et al. [8], basic concepts of FMEA and RPN value of components. By using of this FMEA analyze the failure modes of individual components of system and give the particular RPN value to the each and every component. DFMEA is an analytical technique used during design phase of a product development. Gaurav J. Pawar et al. [10], DFMEA helps the engineer to design reliable and safe product by mitigating the anticipated failure modes. DFMEA can be conducted

- New system, products or process are being designed.
- Existing design are being changed.

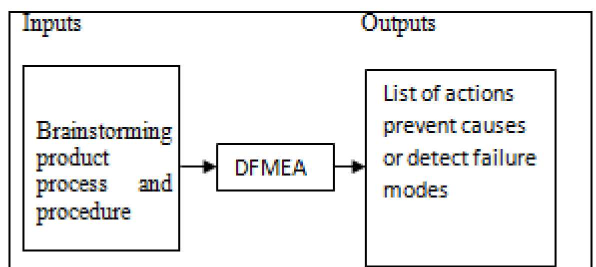


Fig.1: DFMEA Concept

This fig.1 shows a simplified concept of DFMEA indicating required inputs and desired output.

1.1 CVRDE:

Combat Vehicles Research and Development Establishment has its origin as chief inspectorate of mechanical transport establishment in CHAKLALA CVRDE is involved in development of recovery vehicles equipment operated by hydraulic power. This project of result is carried out from the CVRDE. The required hydraulic power is generated from hydraulic pumps which run at range of specified speed and consume torque depending on the load on pumps. The power take off gearbox receives drive from damper end of engine and provides drive to hydraulic pumps with reduction ratio of 1.1. CVRDE has the design and the development is in progress.

II. PROCEDURE AND SETUP

2.1 PTO Gearbox:

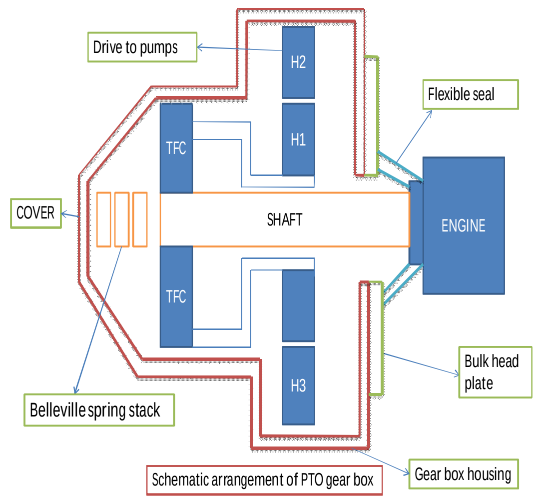


Fig. 2: PTO Gearbox structure

Fig shows that PTO means that power take off, it is takes power from engine and provides drive to load, in this case load is hydraulic pump. Gearbox is designed as one input and two output gearbox. The gearbox is proposed to be mounted separately for from engine. Due to manufacturing and assembly tolerances and due to dynamic and static deflection of large misalignments are expected. The design takes care of this aspect by suitable design of shaft. When the shaft is running in the misaligned condition it is likely to move in axial direction. The Gearbox needs to be seal from engine in all operational conditions. Helical gears are used to reduced noise and vibrations. In this gearbox power flow takes place from engine to pump through a torsional flexible coupling.

2.2 RELIABILITY PREDICTION:

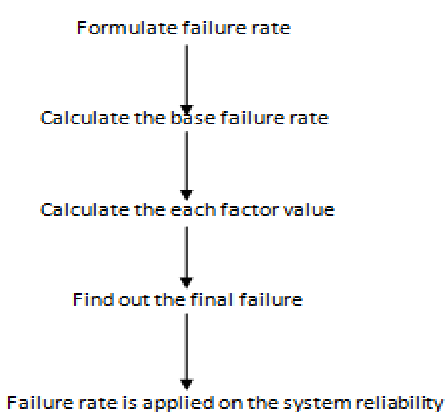


Fig.3: Reliability prediction steps

The above flow chart explains about steps are involved in Reliability calculations. In First step, find out the failures then calculate base rate, it depends on the component multiplying factor. Then find out the total failure rate, then finally calculated Reliability of components.

2.3 RELIABILITY OF INDIVIDUAL COMPONENT: GEARS:

The gears are designed by incorporating involute gear profile which is the most commonly used system for gearing. Bearing strength, contact durability is the main criterion for gear design. In PTO Gearbox helical gears are used for power transmission to the torsional flexible coupling.

HELICAL GEARS:

Helical gears have teeth inclined to the axis of rotation. Helical gears are used for the same application as spur gears. There is no any noise disturbance because of the helical gears having more gradual engagement of the teeth during meshing.. H1 gears drivesH2 and H2 gears.

RELIABILITY PREDICATION OF GEARS:

Here used manufactures specification for each gear as the base failure rate.

$$\lambda_G = \lambda_{G,B} \cdot C_{GS} \cdot C_{GP} \cdot C_{GA} \cdot C_{GL} \cdot C_{GT} \cdot C_{GV}$$

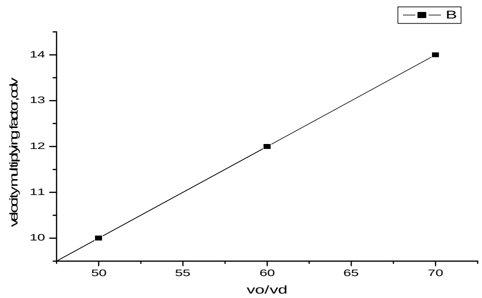
The above all multiplying factors are evaluated by using NSWC -2011 book for find out the total failure rate of Gear in PTO gearbox. Then calculated the Reliability of Gear at 10000 hrs.

In this project using two helical gear 1. Input gear 2.output gear

$\lambda_{g,b}$= base failure rate in failures per million hrs
$\lambda_{g,b}$= (RPM*60)/(design life) failures per million hrs

SPEED FACTOR C_{GS}:

$$C_{GS} = 1.0 + \left(\frac{V_O}{V_d}\right)^{0.7}$$



Graph. 2.2.1: Speed velocity factor

$C_V = (V_O/V_L)^{0.54}$
V_O = Viscosity of specification lubricant, lb-min/in^2
V_L = Viscosity of lubricant used, lb-min/in^2

An important in the design of gears is the speed velocity co efficient factor. This factor is mainly used for Reliability when compared to the manufactures limit.

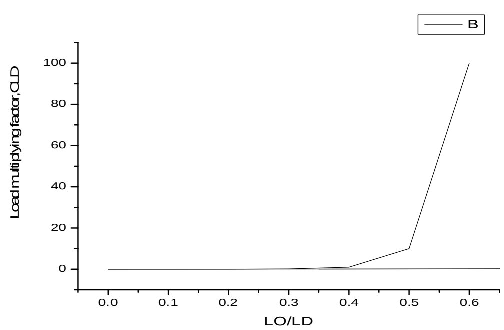
LOAD FACTOR C_{GP}:

$C_{GP} = (L_O/L_D*k)$^4.69
L_O = Operating load, lbs
L_D = Design load, lbs

MISALIGNMENT FACTOR C_{GA}:

The alignment of gears, bearings and shaft can be critical in the operation of a system.

$C_{GA} = (A_E/0.006)$^2.36



Graph. 2.2.2: Load multiplying graph

This graph explains about loads working condition on gears. The Gear multiplying factor C_{GL} has a lubricant and a fatigue impact.

LUBRICATION FACTOR C_V:

$C_V = (V_O/V_L)^{0.54}$
V_O = Viscosity of specification lubricant, lb-mim/in^2
V_L = Viscosity of lubricant used, lb-min/in^2

C_{GS}	C_{GP}	C_{GA}	C_{GL}	C_{GT}	C_{GV}
1.615	1	1	1.25	12.4	1.75

Table.3.2.1:Factors of Gears.

2.4 RELIABILITY PREDICTION OF SEAL:

Seal is device placed between two surface to prevent the flow of gears liquid from one region to other. In this project used three seals those are (1) Mechanical seal (2) Static seal (3) Dynamic seal.

Total failure rate of mechanical seal:

$$\lambda_{SE} = \lambda_{SE,B} \cdot C_Q \cdot C_F \cdot C_V \cdot C_T \cdot C_N \cdot C_{PV}$$

Base failure rate of mechanical seal carried out from NSWC handbook.

$\lambda_{SE,B}$ = 22.3 million per hours

Total failure rate of static Seal

$$\lambda_{SE} = \lambda_{SE,B} \cdot C_P \cdot C_Q \cdot C_{DL} \cdot C_H \cdot C_F \cdot C_T \cdot C_V \cdot C_T \cdot C_N$$

Base failure rate of 23.6 million per hours

Total failure rate of dynamic seal:

$$\lambda_{SE} = \lambda_{SE,B} \cdot C_P \cdot C_Q \cdot C_{DL} \cdot C_H \cdot C_F \cdot C_T \cdot C_V \cdot C_T \cdot C_N \cdot C_{PV}$$

Base failure rate of 22.3 million per hours

Seal diameter factor:

$C_{DL} = 1.1\ D_{SL}+0.32$
D_{SL} = inner diameter of seal
Contaminant factor C_N:
$C_N = (C_O/C_{10})$^3.FR.N_{10}
C_O = System filter size in microns
C_{10} = Standard filter size =10 microns
FR = Rated filter rate, GPM
N_{10} = Particle size factor
So here contaminant factor is 0.01
Allowable leakage factor C_Q:
For leakage > 0.03 in^3/ min, $C_Q = 0.055/Q_F$

Surface finishing factor:
F<15 micro inch C_F =0.25
F>15 micro inch $C_F = (F^{1.65}/353)$
Hardness factor C_H:
C_H = (M/C*0.55)^4.3
M = Mayer hardness, lbs/in^2
C = Contamination pressure, lbs/in^2

C_P	C_Q	C_{DL}	C_H	C_F	C_T	C_N	C_H	C_{PV}
0.25	3.5	3.07	1	0.25	1	0.017	1	1

Table.3.2.2; Factors of Seal.

2.5 RELIABILITY PREDICTION OF BEARING:

Bearing are used in mechanical design to achieve to a smooth, low friction rotary motion or sliding action between two surfaces. In PTO Gearbox four types of bearing are used for Reliability of PTO Gearbox.

(1)Taper Roller Bearing 1(2) Taper Roller Bearing2
(3) Taper Roller Bearing 3 (4) Taper Roller Bearing 4

Total failure rate of bearings:

$$\lambda_{BE} = \lambda_{BE,B} \cdot C_Y \cdot C_R \cdot C_V \cdot C_{CW} \cdot C_T \cdot C_{SF} \cdot C_C \cdot 10^6$$

Here base failure rate of bearings is calculated by L_{10} life of bearing. L_{10} means 90% Reliability of bearings.

$$\lambda_{BE,B} = \frac{-\ln(r)}{L_{10}}$$ Failures per hrs.

Water contamination factor C_{CW}:

Generally in unused oil, water contamination level is zero percent. But maximum of 0.05% water contamination was observed in used oil. Therefore 0.05% of water content on the oil is considered.

C_{CW} =1.0+25.50(C_W)-(16.25) C_W^2

C_Y	C_R	C_V	C_{CW}	C_T	C_{SF}	C_C
1	3.01	1	1.3	1	1.4	1

Table.3.2.3:Factors of Bearings.

2.6 RELIABILITY PREDICTION OF SPRINGS:

Mechanical springs are used in machine design to exert force, provide flexibility and to store or absorb energy. In PTO gearbox compression spring is used for Reliability prediction calculation.

Total failure rate of spring:

$$\lambda_{sp} = \lambda_{sp,b} . C_G . C_{DW} . C_{DC} . C_N . C_Y . C_L . C_K . C_{CS} . C_R . C_M$$

base failure rate of spring:

$$\lambda_{SP,B} = 23.8 \textit{ failure per million hrs}$$

C_G	C_{DW}	C_{DC}	C_N	C_Y	C_L	C_K	C_{CS}	C_R
0.92	12.2	0.42	2.7	0.36	0.16	0.39	0.1	1

Table. 3.2.4:Factors of Springs.

2.7 RELIABILITY PREDICTION OF SHAFT:

Shaft is a rotating member, it is used to transmit power or motion to helical gear in PTO gearbox. Shaft are usually designed for an infinite life.

Failure rate of shaft:

$$\lambda_{SH} = \lambda_{SH,B} \cdot C_F \cdot C_T \cdot C_{DY} \cdot C_{SC}$$

C_F	C_T	C_{DY}	C_{SC}
0.89	1.11	1	2.92

Table.3.2.5:Factors of Shaft

2.8 RELIABILITY PREDICTION OF SPLINE:

Spline gears are used to transmit torque between shaft and flanges, gears and shaft and shafts.

Total failure rate of spline:

$$\lambda_{GS} = \lambda_{GS,B} \cdot C_{GS} \cdot C_{GL} \cdot C_{GT} \cdot C_{GV}$$

Base failure rate of spline:

$$\lambda_{S,B} = \frac{10^6}{\theta}$$

N= Operating speed
G_L= spline length
= 32 mm for

AGMA FACTOR C_{GV}:

This multiplying factor is used for determining inherent reliability and failure rate of gears, splines.

LUBRICANT FACTOR C_{GL}:

Lubricant factor is a function of viscosity of lubrication. It is Used for reducing corrosion.

C_{GL}	C_{GS}	C_{GT}	C_{GV}
1	1.71	1.15	1.5

Table. 3.2.6: Factors of Spline.

2.9 RELIABILITY PREDICTION OF SHEAR BOLT

Bolts are used as fasteners for tighting small components. Bolts, nuts are used as fasteners.

Total failure rate of fasteners:

$$\lambda_F = \lambda_{F,B} \cdot C_{SZ} \cdot C_L \cdot C_T \cdot C_I \cdot C_K$$

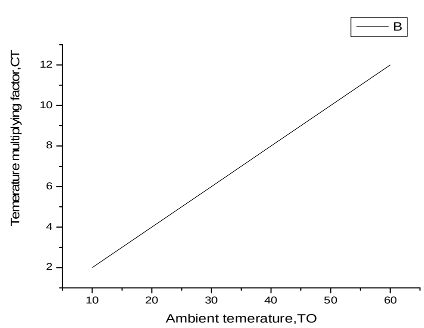
Base failure rate:

$\lambda_{f,b}$ = 0.072 failures per million hours.

TEMPERATURE FACTOR:

$T_{at} = 248^0F\ (120^0C)$

Temperature Multiplying Factor



Graph.2.8.1: Temperature factor

This graph shows the temperature effect on bolt and fasteners. Typical rotating beam data are acquired at room temperature, fasteners are often called upon clamp equipment at higher temperature.

IMPACT LOADING FACTOR C_I:

C_I= 1.67 Normal vibrations

THREAD CORRECTION FACTOR C_K:

Ck = 3 for rolled threads

C_{SZ}	C_L	C_T	C_I	C_K
1	1.25	1.14	1.65	3

Table.2.2.7: Factors of Shear bolt.

The above tables are explained about multiplying factors of each individual component. These components are connected in PTO Gearbox in series system this relationship is find out from the power flow from engine to components through shaft.

All individual components of PTO Gearbox of Reliability is calculated at 10000 hours. Used multiplying factors as per NSWC hand book.

III. RESULTS AND DISCUSSION

Table.3.1: Reliability of Gears.

Gear type	Base failure rate	Total failure rate	Reliability
Input Gear	1.1889*10[illegible]	9.129*10[illegible]	0.999
Output Gear	0.0000026	7.546*10[illegible]	0.999

Seal Reliability:

Table . 3.2: Reliability of Seal.s

Type of Seal	Base failure rate	Total failure rate(mph)	Reliability
Static Seal	2.4	0.00191146	0.999
Mechanical Seal	22.8	0.02365978	0.999
Dynamic Seal	22.8	0.01815888	0.999

Bearings Reliability:

Table. 3.3: Reliability of Bearing

Bearing type	L10 (hours)life	Base failure rate	Total failure rate	Reliability
Taper Roller Bearing 1	10217	$1.031*10^{-5}$	$2.88*10^{-1}$	0.687
Taper Roller Bearing 2	17603.5	$5.985*10^{-6}$	$1.67*10^{-1}$	0.804
Taper Roller Bearing 3	10975	$9.600*10^{-6}$	$2.68*10^{-1}$	0.705
Taper Roller Bearing 4	19984.4	$5.272*10^{-6}$	$1.47*10^{-1}$	0.825

Shear bolt Reliability.
Spline Reliability

Table. 3.4: Reliability of Shear bolt

Spline name	Base failure rate (Failures per million hours)	Total Failure rate(Failures per million hours)	Reliability
1. Adaptor spline	$4.279*10^{-11}$	$1.262*10^{-10}$	0.9999
2. Spline between shaft and crown gear 1	$4.083*10^{-7}$	$1.381*10^{-6}$	0.9891
3. Spline between shaft and crown gear 2	$1.45624*10^{-7}$	$4.295*10^{-7}$	0.9995
4. Dog clutch spline input	$6.9706*10^{-8}$	$2.0561*10^{-7}$	0.9979
5. Dog clutch spline output	1.62*10^-14	4.790*10^-8	0.9995
6. Input gear splines	5.698*10^-14	1.680*10^-7	0.9983

Table.3.6 : Reliability of PTO Shaft.

Shaft type	Base failure rate	Total failure rate	Reliability
PTO shaft	0.00000288	$8.3078*10^{-6}$	0.9999

Table. 3.6: Spline Reliability

Type of bolt	Base failure rate	Total failure rate	Reliability
Shear bolt	0.072	0.5148	0.9948

Table. 3.7: Reliability of Spring:

Type of spring	Base failure rate	Total failure rate	Reliability
Compression spring	23.8	25926	0.9744

3.1DFMEA STRUCTURE:

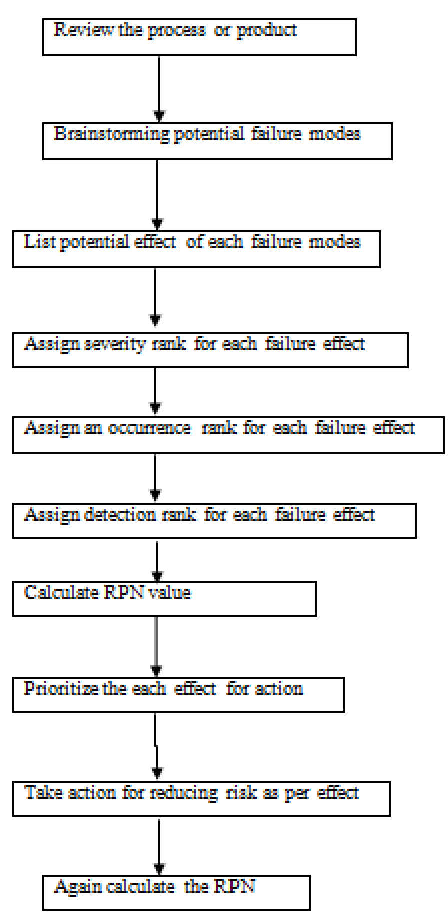


Fig. 3.1: DFMEA structure

3.2 CALCULATE THE RISK PRIORITY NUMBER:

The risk priority number is simply calculated by multiplying the severity ranking times the occurrence ranking times the detection ranking for each item.

3.2.1 SEVERITY NUMBER CALCULATION:

Severity is the assessment of the seriousness of the effect of potential failure of the system, subsystem or component severity is applicable only to effect of failure mode severity is rated by ranking. Severity rating can be defined using table given.

3.2.2 OCCURRENCE NUMBER CALCULATION:

The Occurrence is the probability that one of the specific mechanism of failure will occur. The best method for determining the occurrence ranking is to use actual data from the process. This may be in the form of failure logs or even process capability data. When actual data is not available, the team must estimate how often failure or effect of failure will occur.

3.2.3 DETECTION NUMBER CALCULATION:

The detection number is relative measure of difficulty of detecting the failure before the product is used by customer. This is step by identifying current control that may detect failure or effect of failure. If there are no current controls, the likelihood of detection of detection will be low and the item would receive a high ranking, such as a 9 or 10.

RPN = severity number*occurrence number*detection number.

3.3ANALYSIS OF RPN:

The total value of 25 Failure modes have been identified. The total RPN is 2632. It is observed that four failure modes contribute to 32% of RPN. Hence they are categorized as critical failure modes. These failures causes critical loss of PTO gearbox function and need to be attended during development with at most care

Top nine failure modes constitute 62% of total RPN. Hence the next five failure modes are classified as moderately critical failure modes and need to be taken care while testing. The remaining failure modes are not critical and regular testing will be able to detect the failure.

Accordingly critical failure modes are listed in the table. Also moderately critical failure modes are also listed in separate table.

IV. CONCLUSION

Based on component reliability and the reliability tree the overall system reliability is computed. The reliability so computed at 10000 hrs of required life is very low at 0.30884. based analysis of components contributing for reliability and their trend over life time, over hauling period policy was arrived. In this the bearings need to replaced at every 1000 hrs of operation. As is a practice, in similar applications, wherever bearings are changed Gaskets, Seals, also will be changed.

Based on this over hauling policy the reliability of PTO Gearbox is 0.85829 after 9th over hauling i.e. from 9000 hrs to10000. By used DFMEA meeting carried out the 25 failure modes and calculated the RPN for each failure mode. Failure modes classified as three types according to RPN value.

1. Critical failure modes. These modes having RPN value is 888 which is 32% of total RPN value
2. Moderate failure modes. These modes having RPN value is 1624 which is 62% of total RPN value
3. Not critical failure modes. These modes having 2632 and bottom 6% total RPN.

V. ACKNOWLEDGEMENT

In this paper, comparative studies of different controllers are studied and performance is evaluated according to time domain functions. It is observed that all controllers able to maintain the set point at the desired value but ZN-PID ,Fuzzy based controllers has slight overshoot, Model Reference Adaptive controller has no overshoot and settles quickly. So it conclude that Model Reference Adaptive Controller is the best controller then other controllers

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